Atomic Layer Deposition

Fiji G2

Plasma Enhanced Atomic Layer Deposition System

Users Manual

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Notice

Veeco Instruments Inc. welcomes requests for information, comments and inquiries about its products.

Atomic Layer Deposition

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1 Introduction

Congratulations on your purchase of a Veeco Fiji G2 Plasma Enhanced Atomic Layer Deposition (PEALD) system. The Fiji G2 is a modular, high-vacuum system accommodating multiple deposition modes using flexible system architecture and multiple configurations of precursors and plasma gases. The standard configuration of the Fiji G2 enables deposition of a wide range of materials including oxides, nitrides, and metals. Features of the Fiji G2 include:

- Plasma Enhanced ALD with an integrated Inductively Coupled Plasma (ICP) source
- Conventional Thermal ALD
- Exposure Mode Thermal ALD for high aspect ratio substrates
- Temperature controlled substrate holder
  - 200mm up to 500°C standard
  - 100mm up to 800°C optional
- Heated precursor sources
  - 4 precursors standard
  - 6 precursors optional
- Reactor walls heated up to 300°C
- Individually controlled plasma gas source MFCs
  - 4 MFCs standard (Ar, N_2, O_2, H_2)
  - 6 MFCs optional (for additional gases)
- Main reactor turbo pump standard
- Optional load lock with optional turbo pump
- Integrated ALD Shield™ vapor trap
- Optional chamber ports for in situ process monitoring
  - Ellipsometry
  - QCM
  - Mass Spectrometry
  - Optical Emission Spectroscopy
- Compact footprint
- Intuitive software
- Maximum experimental flexibility

This manual will provide the user with a background in ALD theory as well as knowledge on the system hardware and operation and use of the Fiji G2 so that they can maximize the benefits of their investment. In this introductory chapter, the user is given a brief introduction to ALD.

1.1 Atomic Layer Deposition

A description of the Fiji G2 system will make much more sense to the user if they are equipped with at least an introductory knowledge of Atomic Layer Deposition (ALD). In this section of the manual, an introduction to ALD is provided.

ALD is a <u>thin</u> film deposition technique utilizing <u>sequential</u>, <u>self-limiting</u> <u>surface</u> <u>chemical reactions</u>.

Let us consider this sentence in detail. “Thin” is a relative word for describing the thickness of a film. Depending on the deposition technique being considered, “thin” can describe films with characteristic length scales from atomic to macroscopic. For ALD, we are definitely at the thin end of the “thin” spectrum. ALD films tend to range in thickness from 1 to 100nm. Each ALD process will have its own unique deposition rate. Materials that can be deposited quickly may enable films as thick as several hundred nanometers. Films that grow more slowly may have practical maximum thicknesses of several tens of nanometers. If your desired film thickness can be described in terms of “microns” ALD is definitely the wrong solution.

“Chemical reactions” is another import term in the description of ALD. That a chemical reaction is taking place is very important because it is with chemical reactions that we create strong chemical bonds between the substrate and the film and within the film itself. Deposition techniques that rely on physical processes, such as Physical Vapor Deposition (PVD) will not necessarily result in the creation of strong chemical bonds, particularly between the substrate and the deposited film. Without a strong bond between the film and the substrate, the potential for delamination of the deposited film increases. Chemical Vapor Deposition (CVD) certainly involves chemical reactions, but these typically occur in the gas phase above the surface of the substrate and not directly with the substrate surface or perhaps in a less controllable thermal decomposition process on the substrate surface.

What is meant by “surface chemical reactions”? Precursors introduced to the ALD reactor chemically react with chemical species on the surface of the substrate only. By making sure that only one chemical species is in the reactor at one time, gas phase reactions are eliminated. “Self-limiting” indicates that once the reactive sites on the substrate have been consumed with the gas phase chemical precursor, the reaction stops. The precursor chemicals and process conditions are selected so precursors do not thermally decompose or continue to react with each other on the substrate surface.

Above we stated that only one chemical species is in the reactor at one time. This is accomplished with “sequential” introduction of the chemical precursors. ALD typically utilizes two, complimentary chemical precursors. Call them A and B. After a substrate is introduced to the ALD reactor, chemical A is introduced which chemically reacts with the substrate surface to form a monolayer of chemisorbed A on the substrate surface. All excess A is then carried away in an inert gas stream flowing under the influence of vacuum pumping. After all the A precursor is removed from the ALD reactor, precursor B is introduced to the system. Precursor B reacts with the chemisorbed A to form a monolayer of chemisorbed B. Excess B is pumped away. The “sequential” nature of this process ensures that all precursor reactions are on the substrate surface and not in the gas phase by making sure the current precursor is pumped away before introducing the next.

Walking through a standard ALD process is the best way to understand the previous discussion. Here we will consider the deposition of Al_2O_3 using TriMethylAluminum (TMA) ($Al(CH_3)_3$) and water (H_2O). The reactor and substrate to be coated are typically heated to help speed up the chemical reaction between the chemical precursors and promote the purging of excess precursor and reaction by-products from the reactor surfaces. Process temperature will be limited by any thermal decomposition limitations of the precursors being used and the properties of the substrate. Al_2O_3 deposition with TMA and H_2O is frequently performed at 250°C.

ALD typically occurs at sub-atmospheric conditions with precursors delivered to the reactor and excess precursor and reaction by-products removed from the system under the influence of an inert gas stream, such as nitrogen or argon, being acted upon by a vacuum pump. R&D scale ALD systems typically use 10's to 100's of sccms of gas flow and operate in the 100's of milliTorr. A silicon wafer substrate will have a surface native oxide film which will be covered with hydroxyl groups (–OH).

After the substrate has thermally stabilized, TMA is "pulsed" into the ALD system by briefly opening a valve on the precursor delivery system. Figure 1-1 illustrates the process just as TMA is being introduced into the ALD reactor.

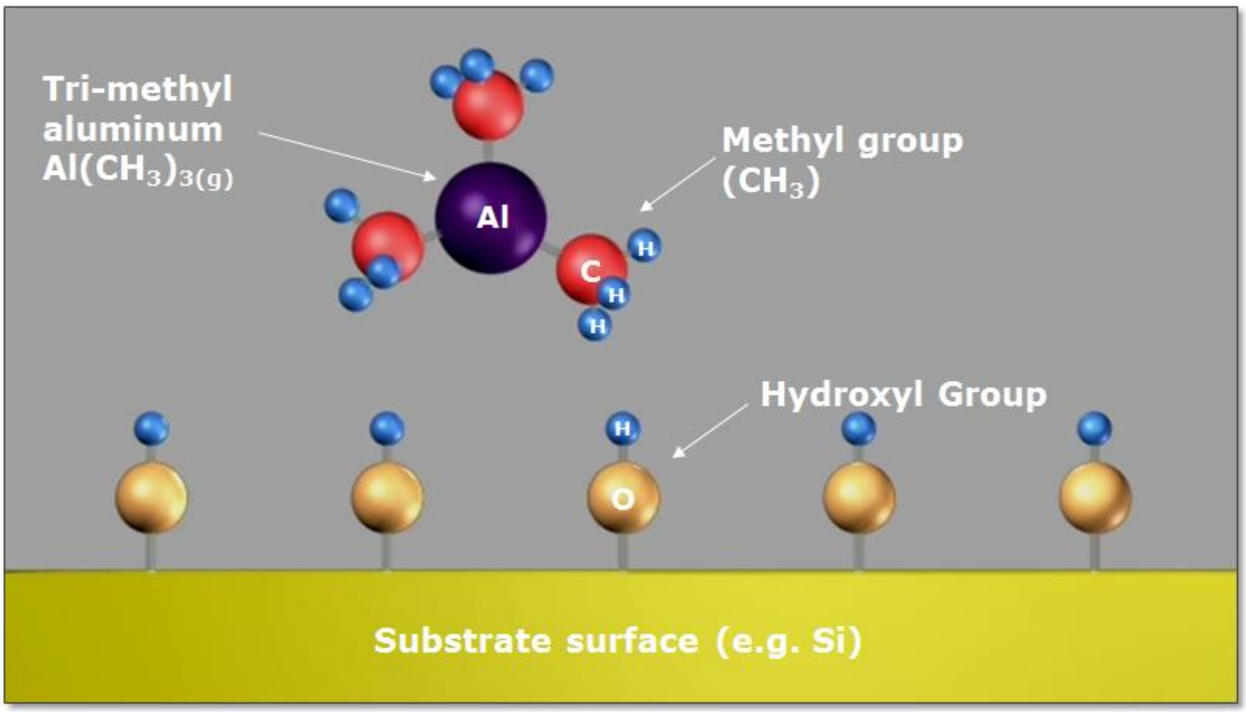


Figure 1-1 – TMA is introduced into the heated ALD reactor. Substrates are often saturated with surface hydroxyl groups from absorbed atmospheric moisture.

The TMA flows into the ALD reactor where methyl groups ($–CH_3$) on the TMA chemically react with the hydroxyl groups on the substrate according to the following reaction.

$Al(CH_3)_3$ (g)	+	Si – OH (s)	→	Si – O – $Al(CH_3)_2$ (s)	+	CH_4 (g)	+	$Al(CH_3)_3$ (g)
TMA		Surface Hydroxyl Group		Chemisorbed TMA		Methane reaction by-product		Excess TMA

The reaction of TMA with the surface hydroxyl groups is shown in Figure 1-2.

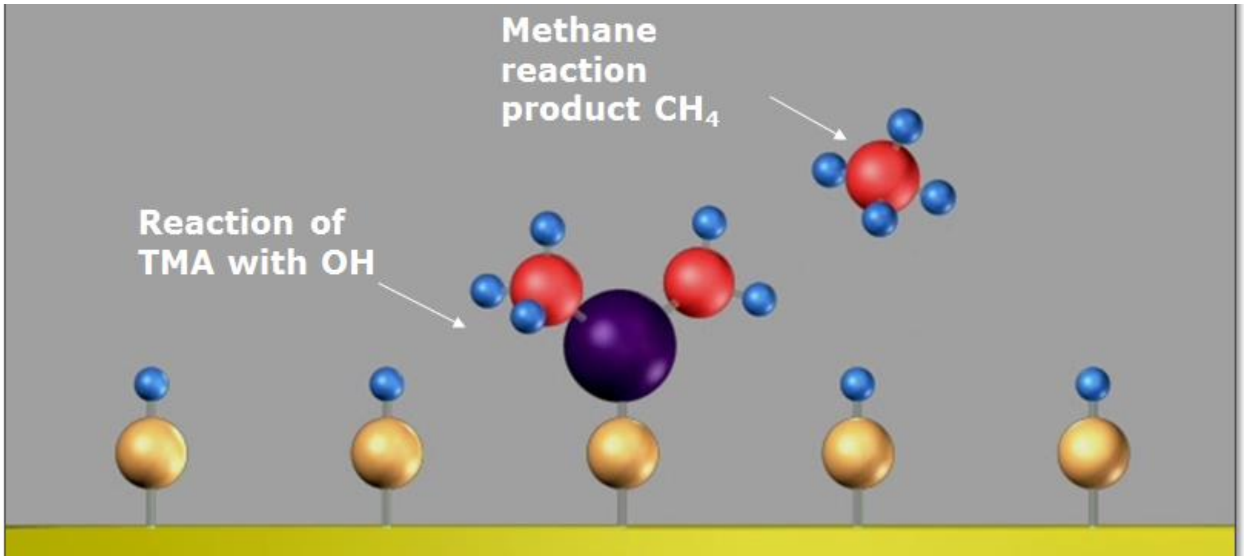


Figure 1-2 – TMA reacts with surface hydroxyl group resulting in a chemisorbed –O-Al(CH_3)$_2$ and a molecule of methane reaction by-product.

The reaction is only between the hydroxyl groups and the TMA. Gas phase TMA does not react further with the chemisorbed TMA ensuring the self-limited nature of the ALD process. Figure 1-3 illustrates the sample surface after all the surface hydroxyl sites have reacted with the TMA and excess precursor and reaction by-products are being purged from the reactor.

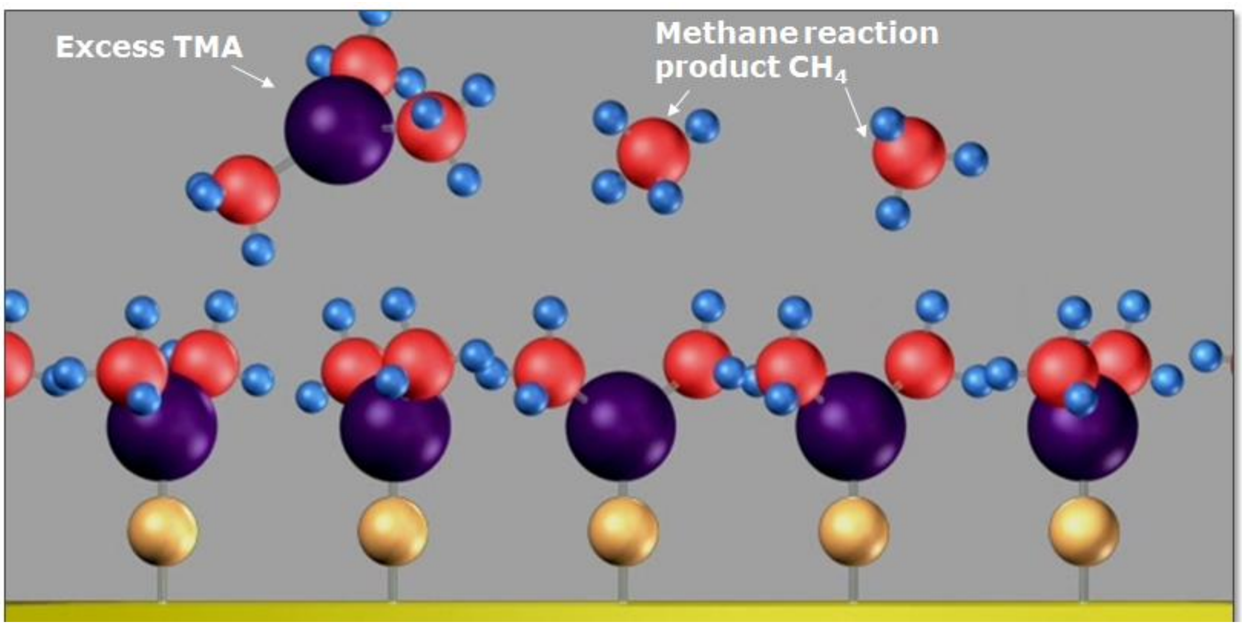


Figure 1-3 – TMA/hydroxyl group reaction completed. Excess TMA and methane reaction by-products purged from the system.

The surface of the substrate is now populated with the methyl groups of the chemisorbed TMA molecules. Following the TMA purge step, H_2O is pulsed into the ALD reactor as shown in Figure 1-4.

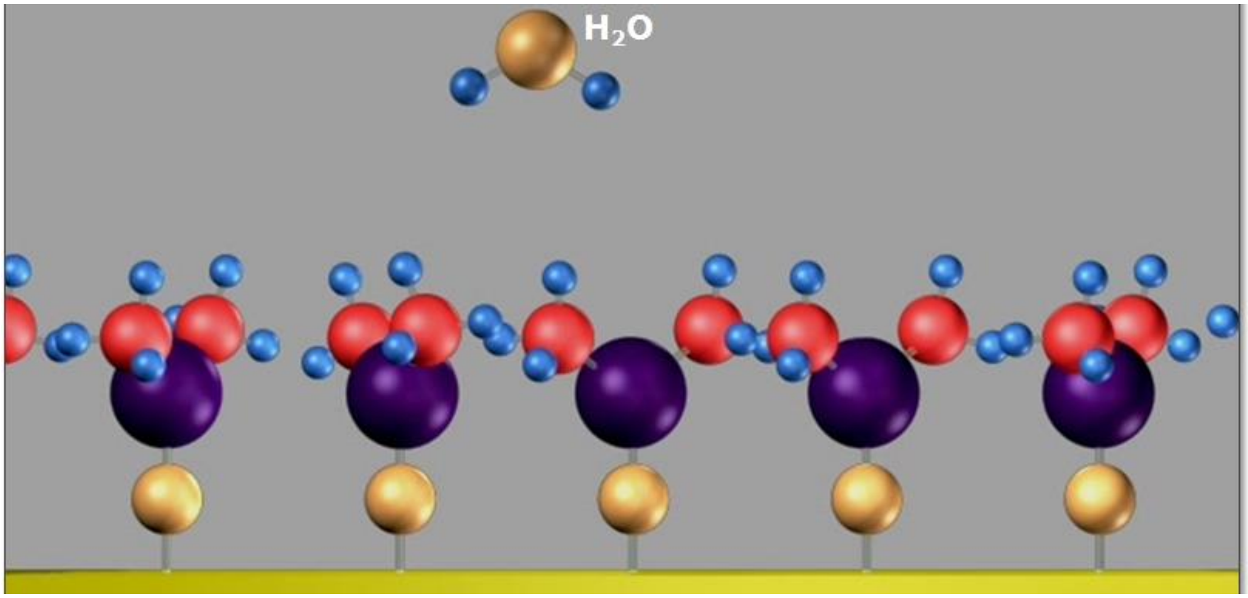


Figure 1-4 – Water is introduced to the reactor with the substrate saturated with surface methyl groups from the TMA exposure step.

The H_2O reacts with the methyl groups of the chemisorbed TMA molecules creating oxygen bridges (– O –) between adjacent aluminum atoms, new hydroxyl groups (–OH), and methane reaction by-product according to the following reaction.

H_2O (g)	+	– O – $Al(CH_3)_2$ (s)	→	– O – $Al(OH)_2$ (s)	+	CH_4 (g)	+	H_2O (g)
				(– O –)$_2$Al(OH) (s)				
Water		Chemisorbed TMA		New Hydroxyl Groups and Oxygen Bridges		Methane reaction by-product		Excess Water

The sample at this stage of the deposition process is shown in Figure 1-5.

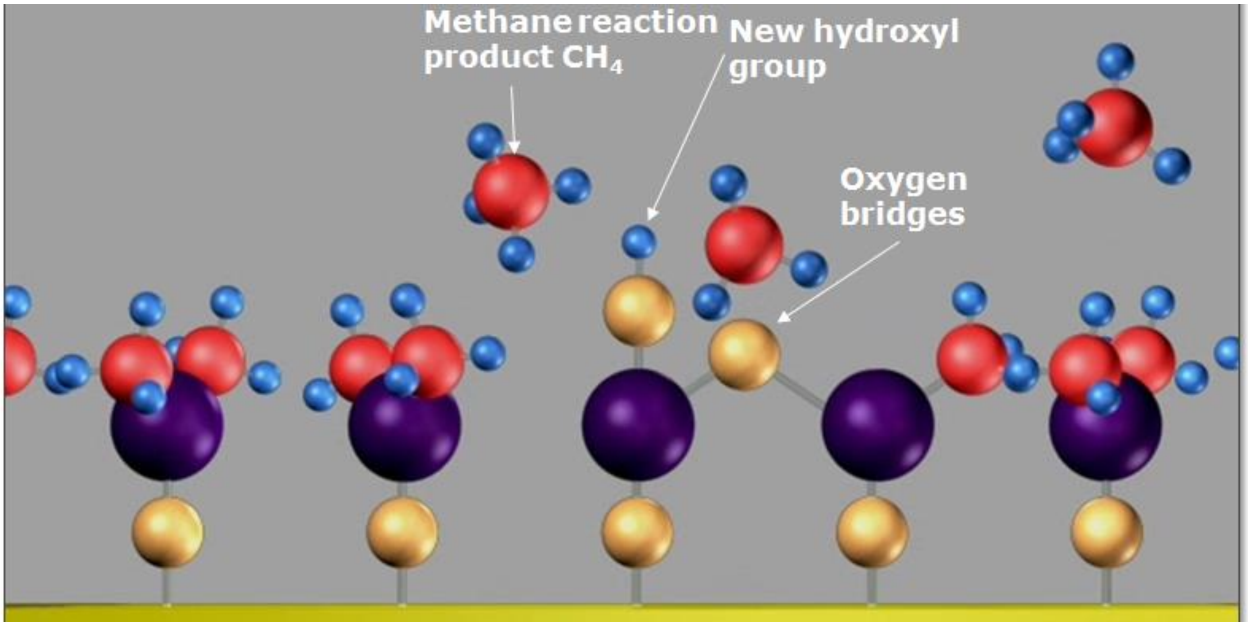


Figure 1-5 – Water reacts with the chemisorbed –Al(CH3)2 forming oxygen bridges between adjacent aluminum atoms and new hydroxyl groups. Again, methane is created as a reaction by-product.

After the methane and excess water are purged away, we notice that the substrate surface looks very similar to when we started. As shown in Figure 1-6, the water pulse has left the surface covered in hydroxyl groups ready to react with the next TMA pulse.

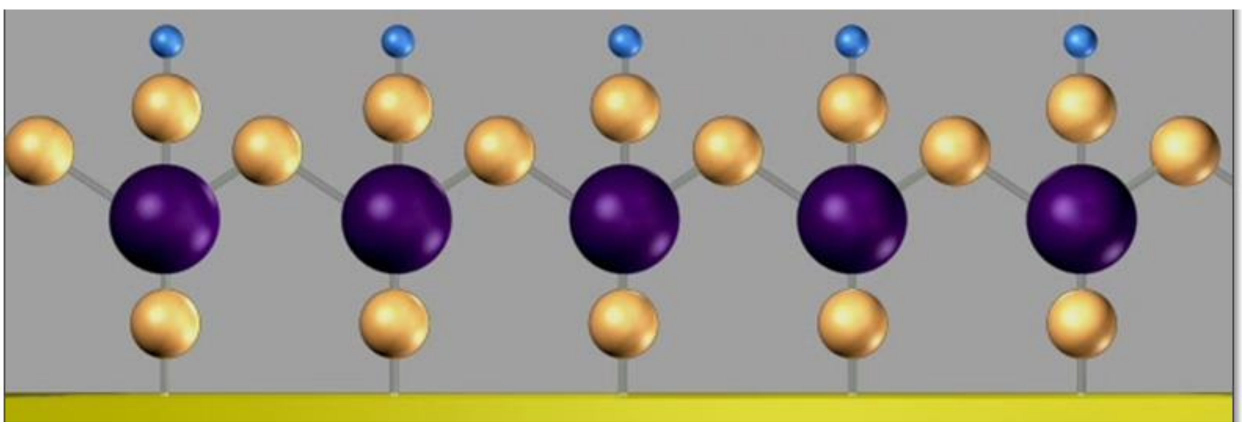


Figure 1-6 – Substrate surface following the water pulse purge step. The surface has a high density of hydroxyl groups similar to when the process was started. The substrate is ready for another TMA pulse.

The ALD process will now continue; TMA, purge, H_2O, purge, TMA, purge, H_2O, purge, TMA, purge, H_2O, purge, etc., until the desired film thickness is achieved. The TMA/H_2O ALD process typically deposits about 1Å per TMA/H_2O cycle. The growing film is depicted in Figure 1-7.

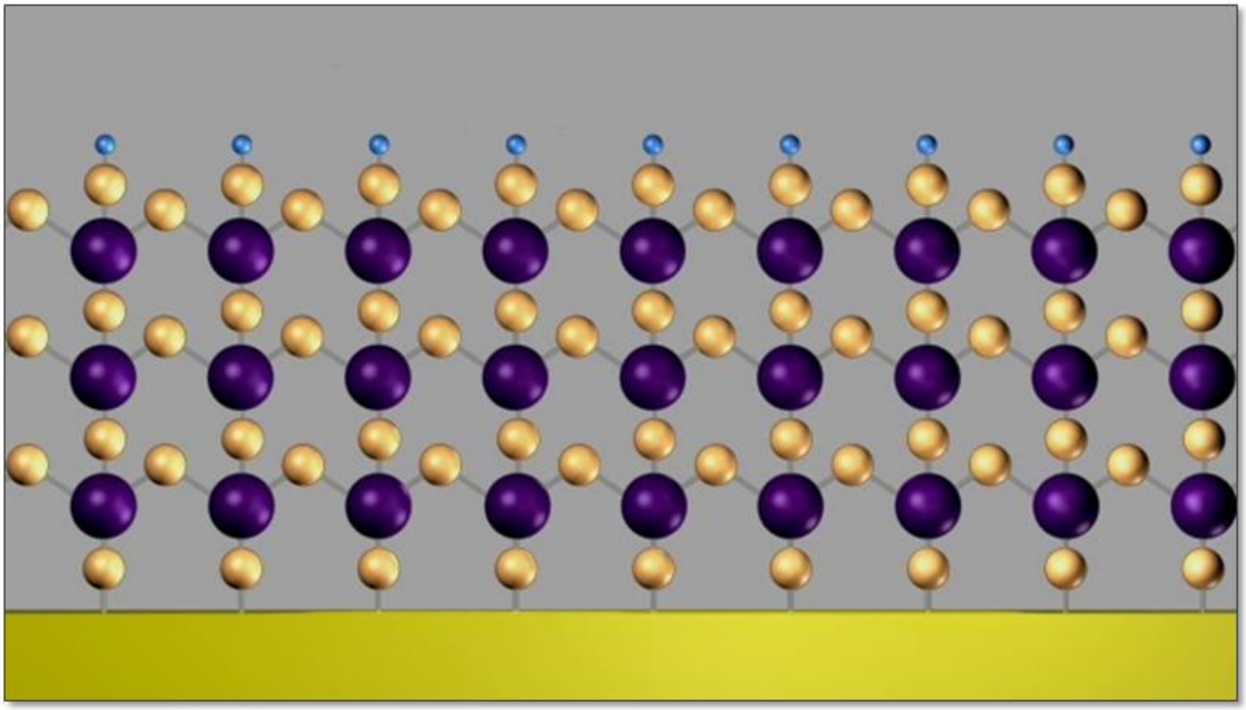


Figure 1-7 – Developing film after several TMA/purge/H_2O/purge cycles. The TMA/H_2O process deposits Al_2O_3 at a rate of about 1Å/cycle.

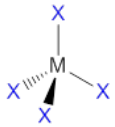
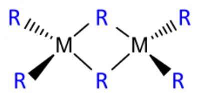
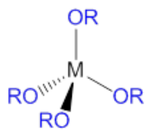
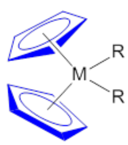
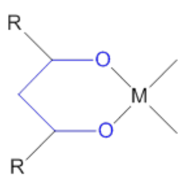
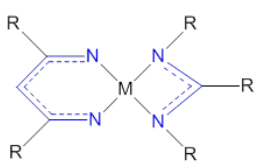
All ALD processes will proceed in a similar fashion. A metal containing precursor paired with a complimentary co-reactant to deposit the desired film. The details of the surface reactions will vary as the nature of the precursor chemicals change but the cyclic nature of the process wherein each precursor pulse sequentially reacts with only the surface groups left by the previous precursor pulse is similar for all ALD processes.

1.2 Precursors

When we discuss ALD precursors, we are typically referring to the chemical specie delivering the metal atom of the desired ALD film to the reactor. In the example above, the precursor is TMA. Aluminum is the metal atom at the center of the molecule. The three methyl groups attached to the aluminum metal atom are referred to as "ligands." The ligands attached to the metal center allow the metal atom to be delivered in the vapor phase from the precursor cylinder to the ALD reactor.

There are many precursor ligand families in use today. Simple ligands like methyl groups do not work or produce suitable ALD precursors for every possible metal atom. Organometallic chemists are continuously expanding the library of available precursors by developing new classes of materials which differ by the collection of ligands surrounding the metal. Common precursor families are listed in Table 1-1 below.

Table 1-1 – Generic structures of some ALD precursors in use.

Ligand Family	Generic Structure	Substitutions	Examples
Metal Halides		X = F, Cl, Br, I	$TiCl_4$ WF_6
Metal Alkyls		R = CH_3, C_2H_5, …	TMA – $Al(CH_3)_3$ DEZ – $Zn(C_2H_5)_2$
Metal Alkoxides		R = CH_3, C_2H_5, …	$Ti(Oi\text{-}Pr)_4$
Metal Amides		R = CH_3, C_2H_5, …	$Hf(NEtMe)_4$ $Ta(NMe_2)_5$
Metallocenes		R = H, X, C_xH_y, NR_x	$(EtCp)_2Ru$ CpIn
Diketonates		R = H, X, C_xH_y	$Pd(hfac)_2$ $La(thd)_3$
Amidinates/ Guanidates			

Precursors are the key to the ALD process. Good ALD precursors should be easy to deliver to the ALD reactor and have a large process window. Below precursor characteristics which impact the usefulness of a chemical for use in ALD are discussed.

1.2.1 Volatility

In order to get the precursor from its container into the ALD reactor, the vapor pressure of the precursor must be higher than that of the reactor. In the example above, TMA and H_2O were pulsed into the reactor. Even at room temperature, these molecules have vapor pressures significantly higher than typical ALD reactor operating pressures and their delivery to the system can be accomplished with a standard vapor draw technique without precursor cylinder heating. For other molecules, room temperature vapor draw will not work.

There are a range of techniques to enhance the delivery of lower vapor pressure materials. The easiest strategy is to heat the precursor. For many important ALD precursors, a modest level of heat increases the vapor pressure to a level sufficient for vapor draw operation to work well. Higher temperatures will produce higher vapor pressures, but care must be given to stay below temperatures where thermal decomposition issues may begin to degrade the precursor in the cylinder. For chemicals with very low vapor pressures or low decomposition temperatures, other means for delivering material to the reactor are available.

1.2.2 Reactivity

A precursor should be able to quickly react with the desired ALD co-reactant in a self-limiting fashion at temperatures below which the precursor would thermally decompose. If the precursor has insufficient reactivity it will not be an appropriate ALD precursor. Reactivity can be increased by operating at higher temperatures. Precursors with low reactivity tend to have small ALD windows because the minimum process temperature approaches the thermal decomposition temperature. Air sensitivity is a good indicator that a chemical will work as an ALD precursor.

1.2.3 Stability

The precursor must be stable at process temperatures for as long as it will be on the substrate before the co-reactant is introduced into the reactor. If the precursor thermally decomposes at the process temperature, the film thickness will be non-uniform and greater than expected as the process becomes more CVD-like than purely ALD.

1.2.4 By-products

For the TMA/H_2O example, the ALD reaction by-product is methane (CH_4). Methane does not react any further with TMA and H_2O. Additionally, it does not react with surface sites competing with the ALD process. Of particular concern are the by-products generated when utilizing halogenated precursor (i.e. HCl). HCl can etch the film that is being deposited impacting film deposition rate and uniformity. Additionally, halogens can diffuse into wall films and become incorporated into subsequently deposited films as contamination.

1.2.5 Availability

Many materials, like TMA, have been around for a long time and are not protected by any patents. These materials are widely available which make them easy to get and cheaper to buy. Recently developed precursors are likely to be protected by patents or their structure maintained as a trade secret. These materials will have fewer suppliers and will be relatively expensive. These new materials are more expensive for several reasons. The manufacturer thinks they have developed a superior product and feel they can charge more for the value they have created. Additionally, recently developed precursors have complicated syntheses for production and are often made in small batches, both which drive up the cost per gram. New precursors with high initial costs that prove useful and gain in popularity may see a price drop in the future as manufacturers can take advantage of economies of scale through larger batch sizes.

There will be publications in the literature in which the researchers have synthesized their own custom precursors. In this case, the precursor is likely not available from any commercial sources and would require a very expensive custom synthesis if you would like to try it on your ALD system.

Veeco does not sell any chemicals. We will provide recipes for many materials with information on obtaining the required precursors from commercial sources. Sources for precursors required for our process recipes include but are not limited to: Sigma-Aldrich and Strem Chemicals. Care must be taken when ordering precursors from these suppliers. They list many materials for CVD and ALD applications. Many CVD precursors will not work for ALD. When looking at a list of materials available for certain metal atom, the cheapest ones may not work. Always make sure you know the appropriate precursor which matches the Veeco supplied recipe before ordering.

1.3 ALD Process Window

The TMA/H_2O process described above is a very robust ALD process that works over very large ranges of operating conditions. A useful concept for discussing additional ALD chemistries is called the "ALD Window" which is depicted below. The 2-D chart has temperature on the x-axis and deposition rate on the y-axis. In the middle of the chart is a box representing the "ALD Window". The window indicates that over a given temperature range, the ALD process will be well-behaved with a well-defined deposition rate. As temperature goes above or below the ALD window, different things can happen, depending on the nature of the particular chemistry being investigated. The ALD window is very large for the TMA/H_2O process. For just about every other ALD process, stronger considerations must be made for possible limitations due to the consequences of operating at temperatures above or below the ALD window.

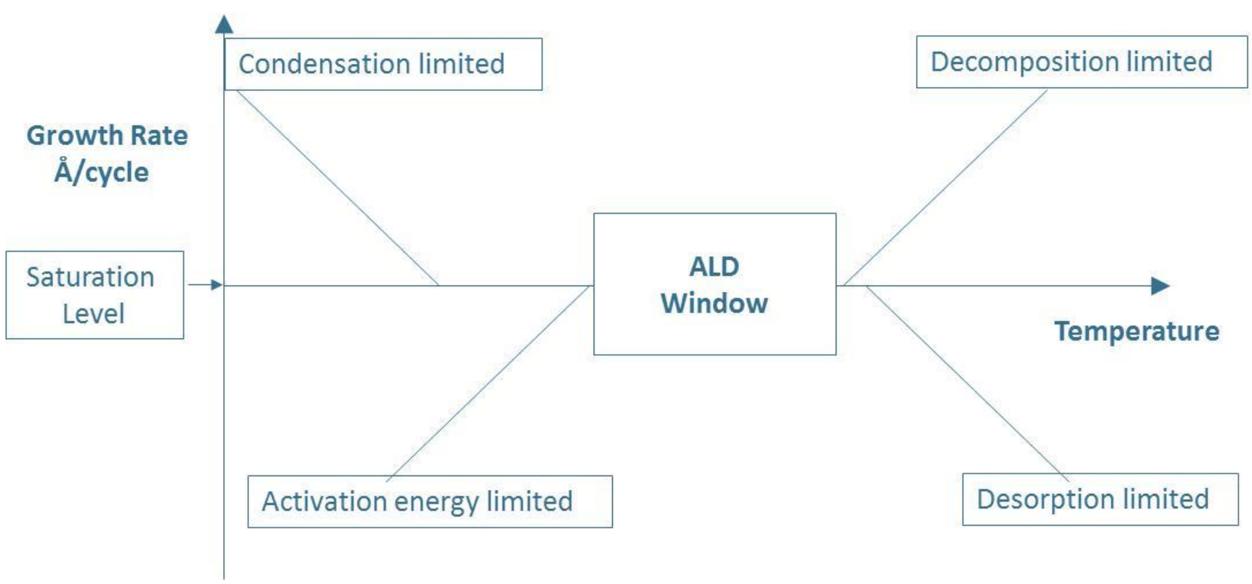


Figure 1-8 – ALD Window

At temperatures lower than the ALD window, one may observe deposition rates greater or lower than the anticipated ALD deposition rate. At lower temperatures, there may be insufficient energy to drive the chemical reaction between the two ALD precursors. This will lead to a lower than expected observed deposition rate. Another possibility is that rather than the monolayer of chemisorbed precursor, a thicker layer of precursor chemical condenses on the substrate surface leading to a higher than expected observed deposition rate.

At temperatures above the ALD temperature window, observed deposition rates can also be higher or lower than expected. If the precursor decomposes on the substrate at the high temperatures, the observed deposition rate can be much higher than expected. Alternatively, the precursor may not stay chemisorbed to the substrate at the higher temperatures. With the precursor desorbing from the substrate prior to introduction of the other precursor, less or no film ends up being deposited on the substrate.

1.4 Co-reactants

1.4.1 Oxides

For the TMA/H_2O example, water was the co-reactant. The water oxidizes chemisorbed TMA to create the Al_2O_3 material. Water is a very popular oxidizing ALD co-reactant for the obvious reasons: it is cheap, easy to handle, and for many materials and process conditions, it works well. But there will be times when water will not be the appropriate co-reactant.

Some ALD oxide processes will require a stronger oxidizer. A popular option is ozone which can oxidize some ALD precursors which are inert to water. Ozone can be generated locally with a system option that converts a portion of an oxygen gas stream to ozone. This dilute ozone source can then be used as an oxidative co-reactant similar to the H_2O vapor.

The Fiji G2 system features a remote ICP source which enables the production of high densities of oxygen radicals from an oxygen feed gas. These oxygen radicals are considerably more reactive than ozone and can broaden the process window significantly by enabling film depositions at much lower temperatures compared to H_2O and ozone.

Water, ozone, and oxygen radicals are the primary oxidizing co-reactants with which we will concern ourselves here. However, many unique oxidizing co-reactants have been tried and are discussed in the literature.

1.4.2 Nitrides

High quality nitrides tend to be harder to produce than oxides. The co-reactants for producing nitrides are not as reactive as their oxide counterparts. Much care must be taken when depositing nitride films that the reactor is free of oxygen and water. This can be accomplished by using a load lock for sample introduction and ensuring that process gases are of the highest purity and using point of use purifiers to remove any remaining trace O_2 and H_2O from the feed gases.

Ammonia, NH_3, is the most common nitride co-reactant for thermal ALD processes.

Depositing nitrides with plasma generated nitrogen radicals provides the best ALD film properties. The reactivity of the nitrogen radicals is substantially higher than that of ammonia. This results in a more complete reaction with the chemisorbed precursor eliminating the constituents of the ligands which would otherwise be left behind as film contaminants.

1.4.3 Metals

There are multiple chemical pathways for the deposition of ALD metals. One class of metal depositions removes all of the ligand components directly through an oxidative process. Common precursors for ruthenium and platinum fall into the metallocene family of precursors. The co-reactant for metal deposition for these precursors is actually oxygen gas. The oxygen reacts in a combustion-like process, producing CO, CO_2, and H_2O as it reacts with the organic ligand species. The precursor ligands are completely removed leaving the metal atom behind.

Another common strategy for metal deposition is to use a three step process wherein an oxide or nitride film is first deposited as a typical ALD process. This film is subsequently exposed to a reducing gas converting the film to the metal. Ni metal is deposited using this strategy. A nickel amidinate is combined with ozone or oxygen radicals from a plasma to deposit NiO. Then the NiO is exposed to H_2 gas or hydrogen radicals to reduce the oxide down to the nickel metal. The reduction step can be part of each ALD cycle. The entire film can be deposited as an oxide and subsequently reduced as a separate process for certain materials. Reducing the bulk oxide film could be done externally in a different piece of equipment if the metal of interest requires process conditions not achievable on your Fiji G2.

1.5 Introduction Summary

In this chapter we have provided the new Fiji G2 user with a basic introduction to ALD that will assist in understanding the operation of the system and allow them to maximize the impact of the ALD technique in their research.

2 Hardware Overview

A standard Fiji G2 system is shown from the front in Figure 2-1. The system has six main subsystems: gas box (left top), electronics rack (left bottom front), Power Distribution box (PD-box) (left bottom rear – not visible), reactor stack (middle), load lock (right top), and system exhaust (middle and right lower). All of these components are critical to the operation of the Fiji G2 system. The more accustomed the user is in the operation of the system, the higher the probability the desired results will be obtained. This chapter will provide the user with a description of the Fiji G2 subsystems.

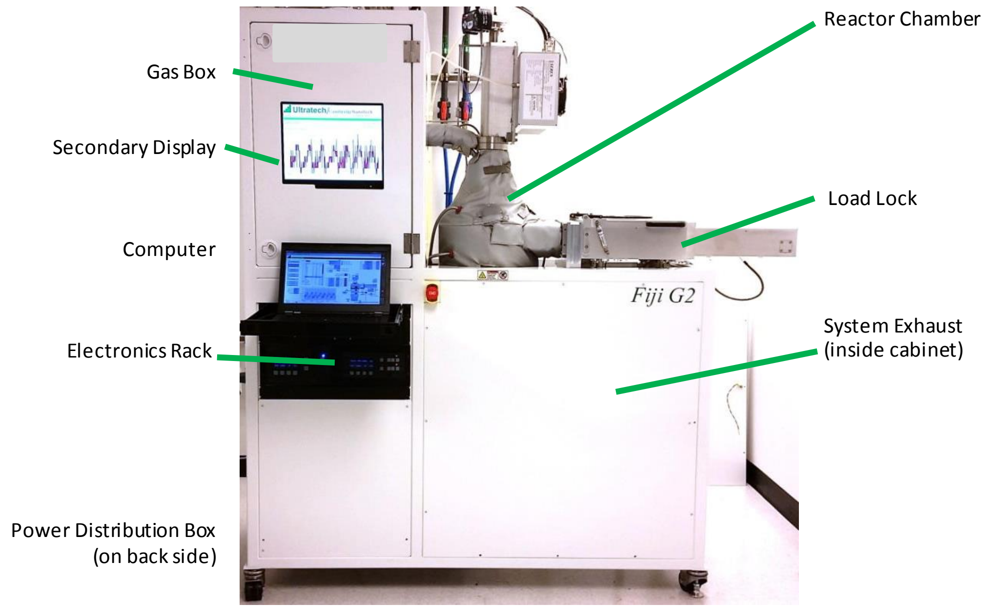


Figure 2-1 – Veeco Fiji G2

2.1 Gas Box

The gas box is a ventilated section of the system from which ALD precursors and co-reactants are delivered to the ALD reactor. Access to the gas box is through one of several doors around its perimeter. At the top of the gas box is a 150mm opening which should be connected to your facilities exhaust system. The bottom of the gas box is a drip pan which will contain any liquid or solid chemicals which may accidentally spill in the gas box.

An overview of the basic gas box configuration is provided in Figure 2-2. The different components of the gas box are detailed below. Depending on installed options, additional components may be present in your gas box.

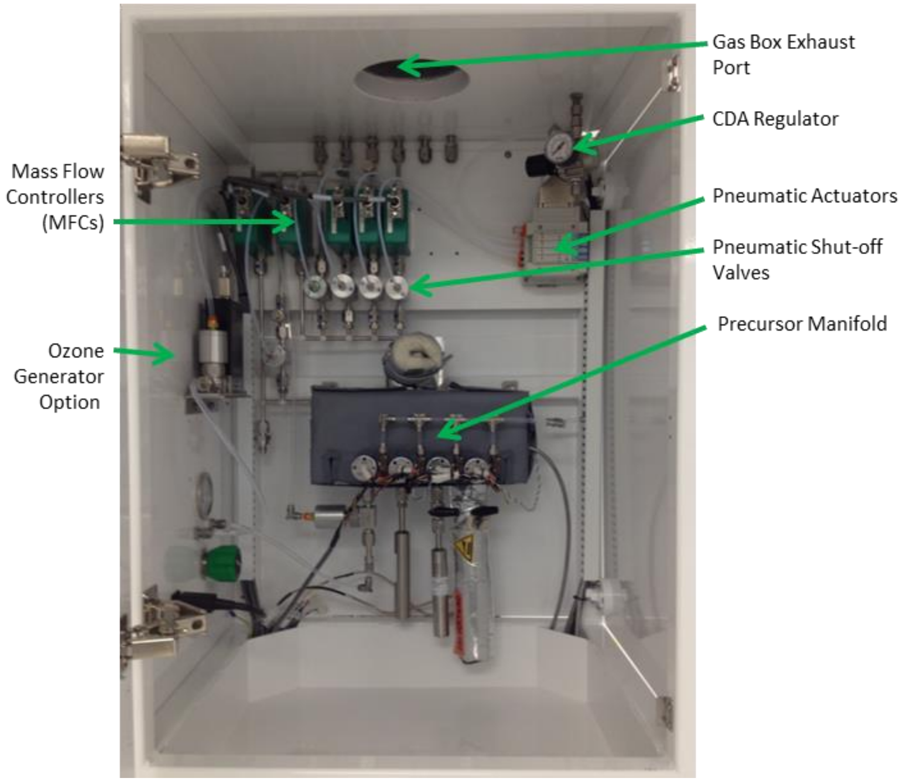


Figure 2-2 – Fiji G2 Gas Box

2.1.1 Gas Delivery

Process gases and pneumatic actuation gas are supplied to the top of the gas box. The details of the gas delivery system are shown in Figure 2-3. The quantity of gases connected to your system depends on your configuration. A standard Fiji G2 installation would include four process gases:

1. argon (Ar)
2. nitrogen (N_2)
3. oxygen (O_2)
4. hydrogen (H_2)

Compressed Dry Air (CDA) is also supplied to the gas box. Two additional, optional gas lines can also be added to the standard configuration to address specific customer needs.

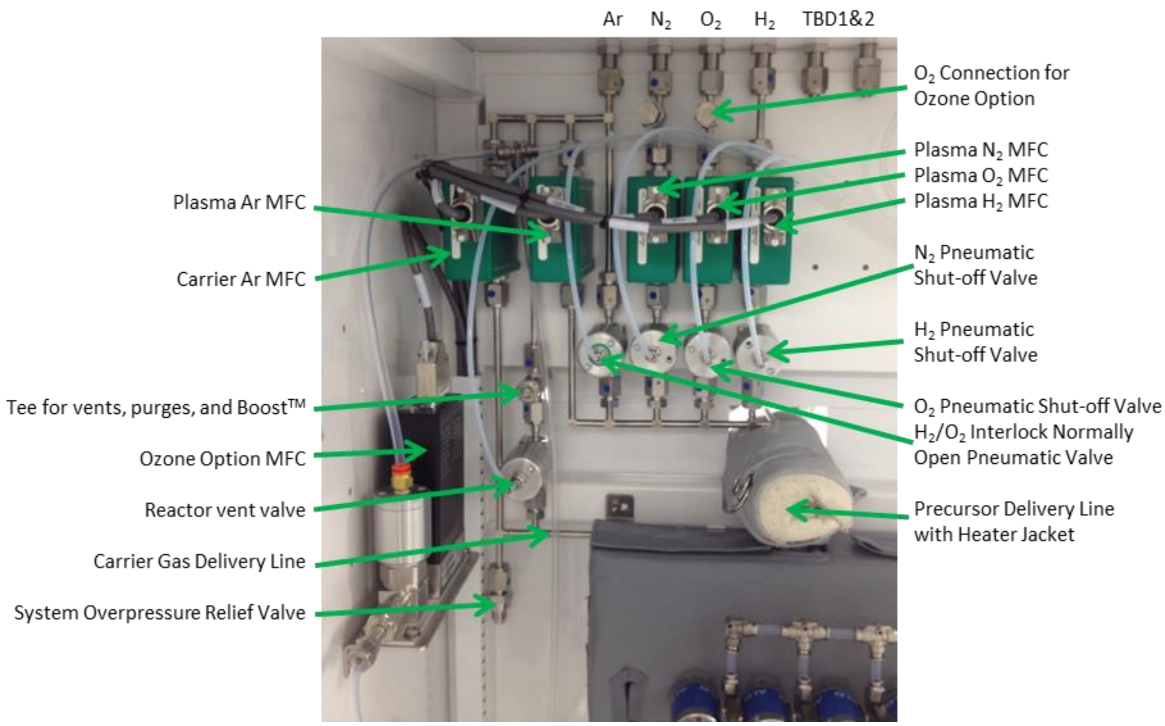


Figure 2-3 – Gas Delivery System

Process gases are expected to be of ultra-high purity/semiconductor grade. Connection points are on the top of the gas box. Each user facility is different, so it is left to the customer to determine the details of these external connections.

Featuring prominently in the gas box are the green Mass Flow Controllers (MFCs) which allow software control of various gas flows within the system. MFCs are rated by their maximum flow rate measured in standard cubic centimeters per minute (sccm). The Fiji G2 utilizes 100sccm and 500sccm MFCs.

Inside the gas box the process gases are distributed as required for proper operation of the system. Viewing the gas box from the left end, the gases coming into the gas box from above are left-to-right: Ar, N_2, O_2, and H_2. Additional gas lines may be installed on your system depending on selected options.

2.1.1.1 Argon

Ar is the primary operating gas for the system and is the most widely distributed gas in the Fiji G2. The Ar inlet line is immediately split into four lines. The left-most Ar line connects to a 100sccm MFC to supply carrier gas to the precursor manifold. On the line connecting the carrier gas MFC to the precursor manifold is a pressure relief valve which will allow gas to escape from the system should the reactor become over-pressurized for some reason.

The next Ar line serves several functions. A 4-way cross splits the Ar to several places. Coming out of the page, a capped port is shown which would be used with the Precursor Boost™ and the Low Vapor Pressure Delivery options. Continuing down straight through the cross is a pneumatic valve that connects to the precursor carrier gas line. This is used for venting the chamber. Going into the page, the cross delivers Ar back out of the gas box for use in load lock venting and various purging applications.

The third Ar branch from the left supplies a 500sccm MFC which controls the flow of Ar to the plasma source. All of the plasma gases are joined together in a line which connects to the top of the plasma source.

There are several pneumatically actuated valves at various points of the gas lines. These have a matte-finished silver tops connected with plastic tubing to the pneumatic gas actuator. These pneumatic valves allow software control of on/off gas flow to different parts of the system. The pneumatic valve on the right-most Ar branch is unique on the system as it has a small green circle around the pneumatic connection point. This indicates that this valve is Normally Open (NO) meaning if there is no pneumatic gas pressure on the valve, it will be open. When pneumatic pressure is removed from the NO valve, argon passes through a flow limiter into the ALD reactor via the plasma source. The argon NO valve is an important part of one of the Fiji G2's safety interlocks, which will be discussed later. All of the rest of the pneumatically actuated valves in the gas box and the rest of the Fiji G2 are Normally Closed (NC), meaning they are closed if there is no pneumatic gas pressure being applied to the valve.

2.1.1.2 Nitrogen

The second from the left gas line is N_2. A 3-way tee in the N_2 line splits the N_2 flow into two lines. The capped end of the tee is reserved for a future option. N_2 flows straight down through the tee to a 100sccm MFC and a pneumatic shut-off valve. MFCs are not positive shut-off devices and without a pneumatic shut-off valve downstream of the MFC, a small flow of gas must be assumed to be leaking past the MFC into the Fiji G2 through the plasma source. Undesirable gases can lead to process variation and non-optimal film properties. This MFC controlled N_2 flow enters the plasma gas delivery line.

2.1.1.3 Oxygen

The third from the left gas line is O_2. A 3-way tee in the O_2 line splits the O_2 flow into two lines. Flowing out of the page, O_2 goes to an optional ozone generator. O_2 flows straight down through the tee to a 100sccm MFC and a pneumatic shut-off valve entering the plasma gas delivery line.

2.1.1.4 Hydrogen

The rightmost gas line is H_2. H_2 flows straight down to a 100sccm MFC and a pneumatic shut-off valve entering the plasma gas delivery line.

2.1.1.5 Optional Gases

Your Fiji G2 system may be plumbed with additional gases. These may be plumbed to the plasma gas delivery line in parallel with the previously described Ar, N_2, O_2, and H_2 gases or they might be connected to an ALD valve inlet to be introduced to the reactor in a similar fashion to precursor delivery.

2.1.1.6 Compressed Dry Air

Compressed Dry Air (CDA) is the preferred gas for pneumatic actuation on the Fiji G2. CDA is connected on the right side of the gas box. Inside the gas box, the CDA immediately enters a regulator. CDA pressure for the Fiji G2 is 70psig. From the regulator, CDA is distributed to several pneumatic actuator banks. CDA is distributed through the system with Teflon™ tubing. The CDA hardware set up in the gas box is shown in Figure 2-4.

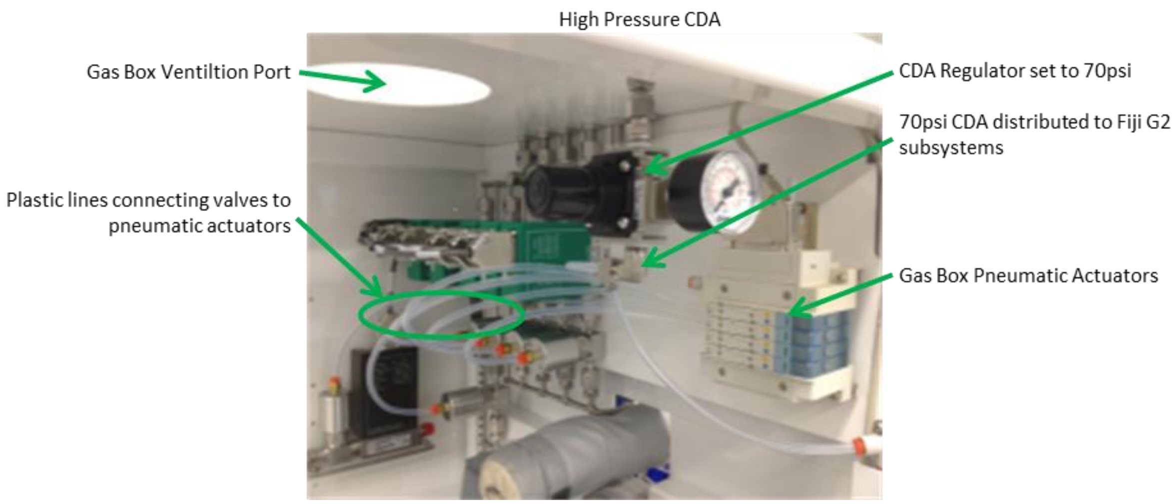


Figure 2-4 – CDA and Gas Box Pneumatic Actuators

2.1.2 Pneumatic Actuator

On the far right of the gas box is a bank of pneumatic actuators. These are also shown in Figure 2-4. This E-box connected device enables software control of the pneumatic valves inside the gas box.

2.1.3 Precursor Manifold

The other major subsystems inside the gas box is the precursor manifold. Figure 2-5 details the components of the precursor manifold. When your Fiji G2 was ordered, the quantity of ALD precursor delivery valves was selected, either 4 or 6. These pneumatically actuated valves have been engineered specifically for ALD precursor delivery featuring: chemically inert wetted parts, very fast and reproducible pulse times, inert carrier gas connection, and heatable.

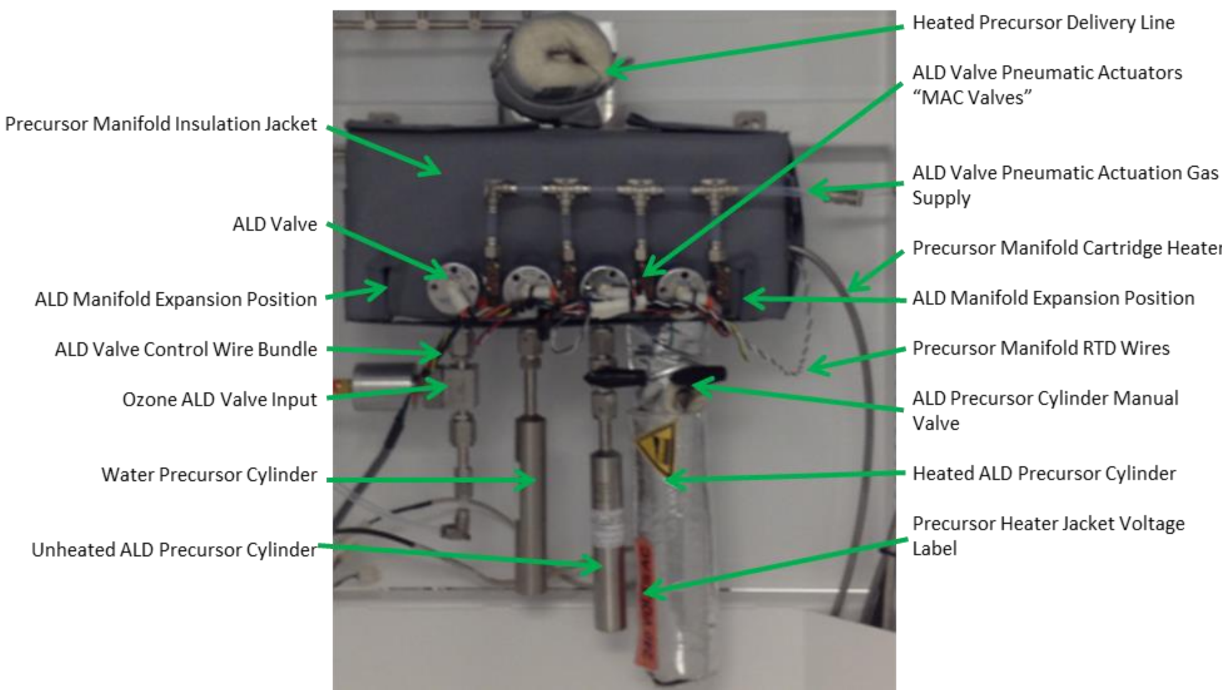


Figure 2-5 – Precursor Manifold

The ALD precursor valves have three ports: precursor inlet, inert carrier inlet, and outlet. During operation, a small inert gas stream continuously flows through the valve from the inert carrier inlet to the outlet. When the ALD valve is actuated, a pulse of precursor flows from the supply cylinder into the inert carrier gas stream. The carrier gas helps deliver the precursor to the reactor and keep the ALD valve clean.

The precursor manifold physically supports the ALD valves in the system for easy connection of the precursor cylinders, inert carrier gas supply, and the outlet delivery to the reactor. The ALD valves are mounted in an aluminum shell which is securely mounted to the system frame. The manifold is covered with a thermally insulating jacket and a cartridge heater allows control of the manifold temperature.

In the orientation that they are mounted in the Fiji G2, the bottom port is the precursor inlet port where the connection is made between the precursor cylinder and the ALD valve. The inert carrier inlet in the back and outlet on the top are hidden inside the manifold. The ALD valve outlets are joined into a single line which connects to the heated precursor delivery line. The four and six port manifolds share several parts. This makes field upgrades easier if you decide to upgrade to a six port manifold in the future. If your system has four ALD valves, it may appear as if parts are missing because the left-most and right-most manifold slots are empty.

The ALD valves are referred to in the software by number. The ALD valves are numbered from left to right starting with ALD0 on the left progressing to ALD3 or ALD5 depending if the system has four or six ALD valves.

Heater jackets are provided for software control of the precursor bottle temperature. Since one ALD valve is typically reserved for H_2O, which is not heated, the Fiji G2 system ships with one less heater jacket than ALD valves.

2.2 Power Distribution Box

Below the gas box on the rear of the system is the Power Distribution box (PD-box). When your Fiji G2 system was installed, an electrician made high voltage connections between the Fiji G2 and your facilities power system inside the PD-box. Within the PD-box, power is conditioned and distributed to the various subsystems.

Several safety features, which will be fully discussed later, have components in the PD-box. These include the Emergency Machine Off (EMO), chuck over-temperature, and gas interlock circuits.

Externally, the PD-box has three features: a mechanical latch, a main power disconnect, and an On/Off button. During normal operation the main power disconnect will be in the “On” position. The main power disconnect, shown in Figure 2-6, prevents the PD-box from being opened when it is in the “On” position.

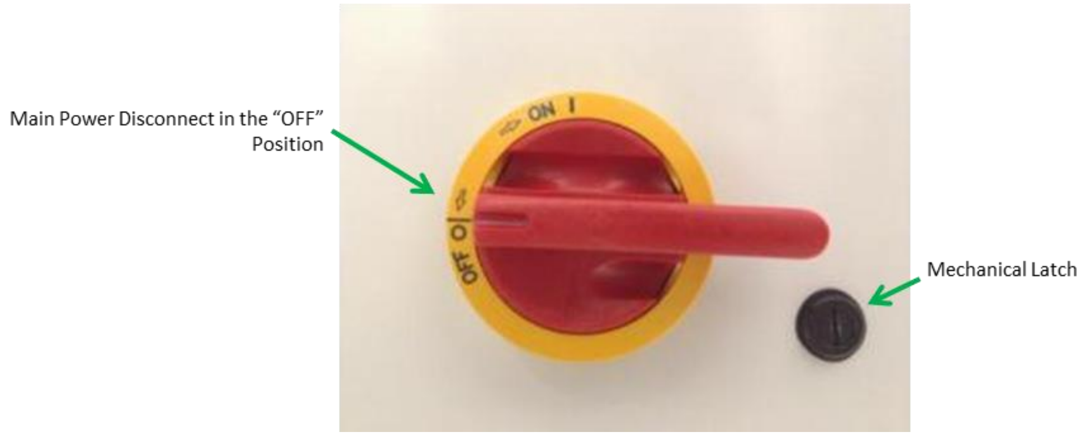


Figure 2-6 – PD-box Main Power Disconnect and Mechanical Latch

Also located on the PD-box is the On/Off button, shown in Figure 2-7. The On/Off button has two separate buttons for On (green – |)and Off (red – O)separated by a power indication light. When the system is first powered on by providing power to the system and turning the Main Power Disconnect to the "ON" position, the On/Off button light will be off. Pressing the On (green – |) will cause power to be delivered to the system. The On/Off button light will illuminate and some sounds may be heard if the system has been previously supplied with CDA pneumatic actuation gas.

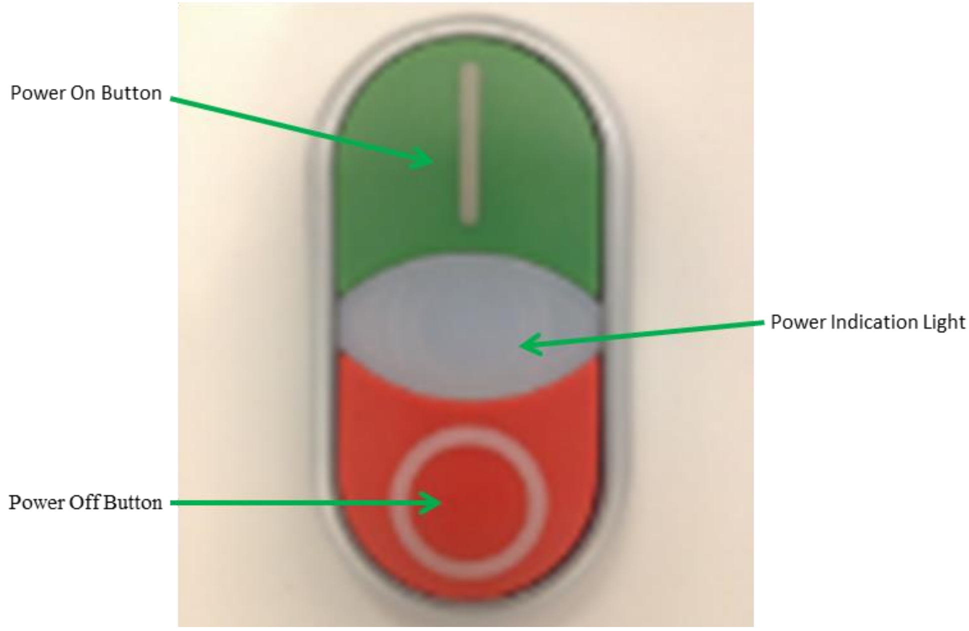


Figure 2-7 – On/Off Button in the Off State.

During system maintenance, trained personnel will turn the system off and switch the main power disconnect level to the "Off" position. When in this position, the main power disconnect can be locked out to ensure the system is not accidently powered on during servicing. Power should be completely removed from the system if the PD-box is to be opened.

2.3 Electronics Rack

Below the gas box on the front of the system is the electronics rack, shown in Figure 2-8. The system laptop computer, E-box, RF hardware, serial hub, and power outlets are located in the electronics rack.

Figure 2-8 – Electronics Rack

The system computer, running Microsoft Windows 7 operating system is located in a pull-out drawer. Custom software operates the Fiji through two Universal Serial Bus (USB) connections. One USB connection communicates with the E-box and the other communicates with a serial port hub. Fiji G2 software source code is not available to end users.

Below the laptop drawer is the E-box. The E-box enables software control of temperature set-points, ALD valve pulsing, gas flows, pneumatic valve actuation, and pressure measurement. The E-box is powered on with a rocker switch on the front panel. Figure 2-9 depicts the rear panel of the E-box showing where various items related to the Fiji G2 are plugged in.

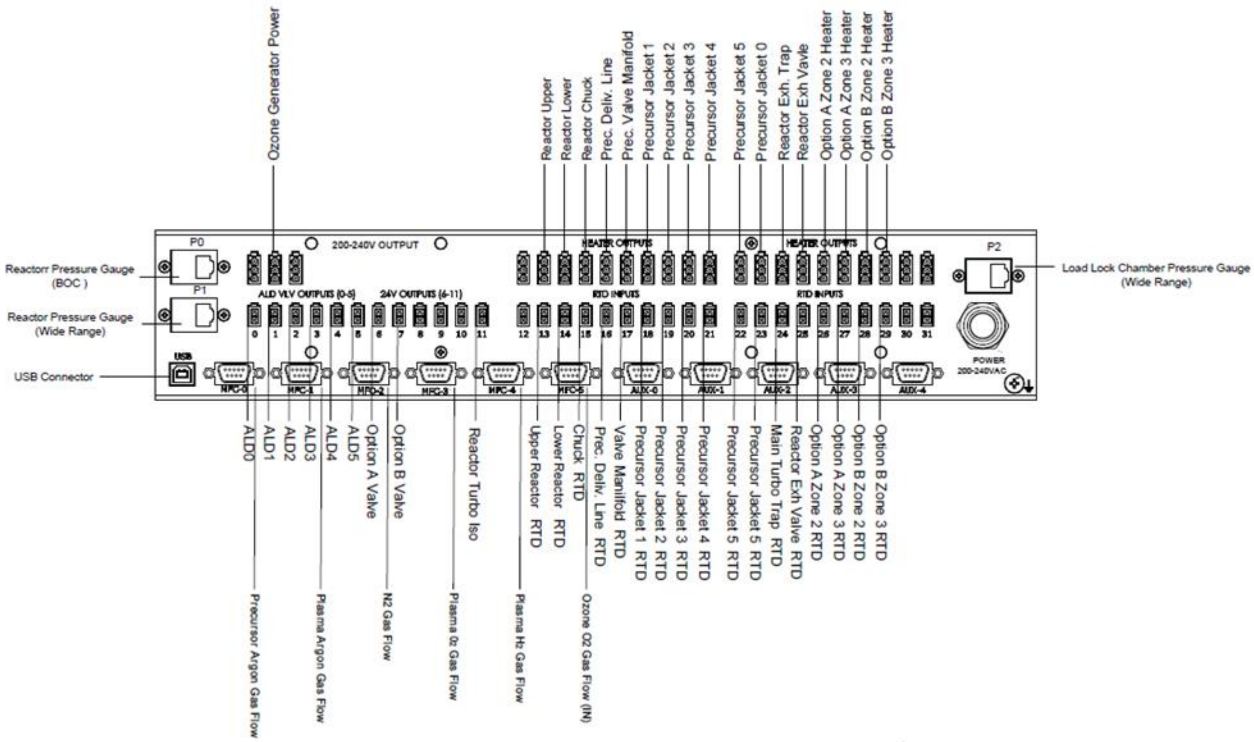


Figure 2-9 – Depiction of the E-box rear panel indicating where items are plugged in.

Under the E-box are components related to the Fiji G2 plasma source. The item on the left is a 300W, 13.56MHz RF generator. An RG5U cable delivers RF power from the generator to the plasma source located on the top of the Fiji G2 reactor stack. The item on the right is the automatic matching network controller. A cable runs from this controller to the matching network associated with the plasma source. Signals from the matching network are measured in the controller which in turn sends signals back to the matching network adjusting the variable capacitor positions to minimize reflected RF power.

The bottom slot on the electronics rack is an outlet strip. Accessible only from the inside, the outlet strip is used to distribute power to items that would normally be plugged into wall sockets. These items include the laptop computer and RF electronics.

A serial port hub is located behind the white panel below the outlet strip. A USB connection between the laptop and the serial hub allows the computer to control several devices using the RS-232 protocol. Serial controlled items include the RF power supply, load lock, and turbo pump(s).

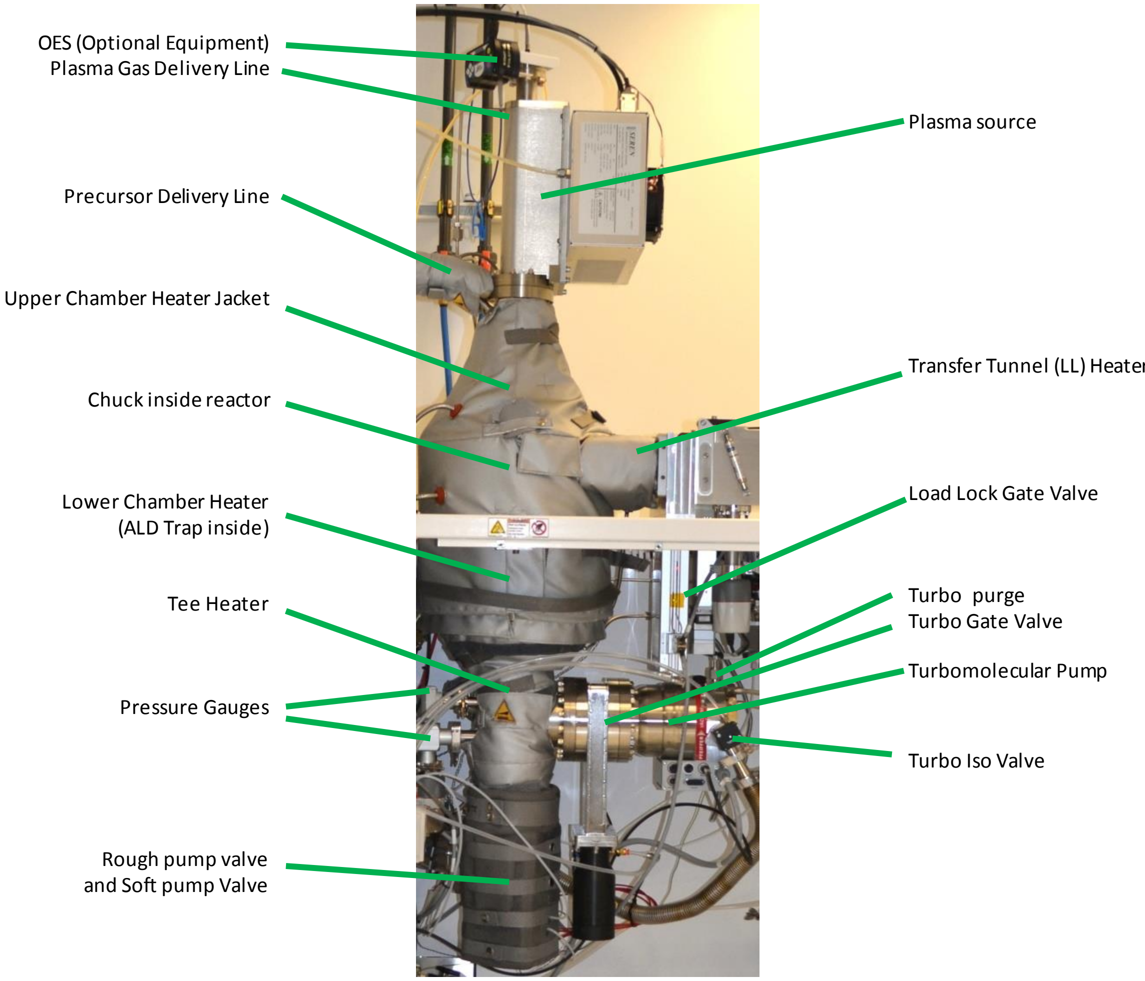


Figure 2-10 – Fiji G2 reactor stack

2.4 Reactor Stack

The reactor stack refers to the stack of components that make up the main Fiji G2 system. These items are identified in Figure 2-10.

2.4.1 Plasma Source

The plasma source, depicted in Figure 2-11, is located at the top of the reactor stack. The plasma source is a custom ICP source designed specifically for high performance PEALD applications. Plasma gases from the gas box MFCs pass through a plasma gas delivery line to the top of the plasma source. The gases then pass through a 3.8cm diameter quartz tube. The quartz tube is wrapped with a multi-turn copper coil. Up to 300W of 13.56MHz RF power delivered from the RF generator is coupled into the coil via the automatic impedance L-type matching network. RF through the coil generates a high-density plasma inside the quartz tube. The high-density plasma dissociates the molecular feed gases into highly reactive radicals which participate in the PEALD process as co-reactants.

If the plasma source cooling water interlock is not satisfied, an “EXT” message will appear on the front panel of the RF generator. Transparent plastic lines connected to the plasma source supply water into the side of the matching with the outlet near the top of the plasma source.

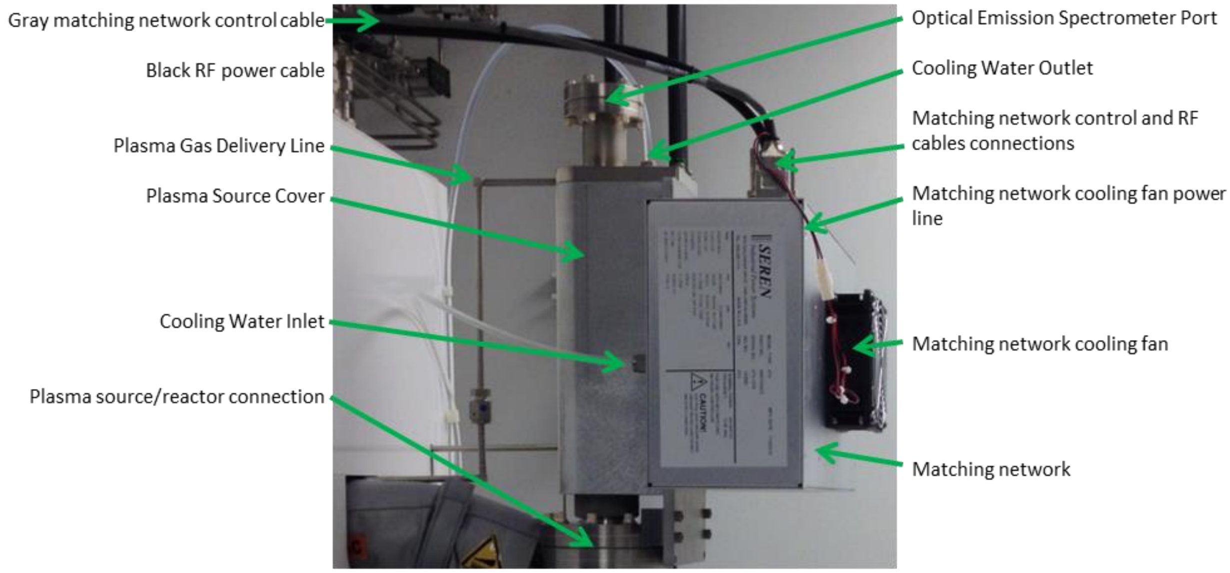


Figure 2-11 – Fiji G2 Plasma Source

2.4.2 Reactor

At the heart of the Fiji G2 is the reactor. This is where the actions of all of the sub-systems come together to produce the desired thin films. Details for a standard reactor are shown below in Figure 2-12. Reactor variations due to selected options are discussed separately in chapters dedicated to those options.

The plasma source is attached to the top of the reactor. Precursor, entrained in the carrier gas from the precursor manifold is delivered to the reactor via the heated precursor delivery line. Precursor is introduced just below the plasma source.

The reactor is covered with a two-zone heater jacket (Upper/Lower) which allows heating of the reactor walls to temperatures up to 300°C. Metal jacketed cables supply power to the jacket and RTD temperature measurements back to the Ebox.

The Transfer Tunnel is used for substrate loading. This rectangular port may be connected to a load lock or just have a simple door that can be opened to insert samples in to the reactor when the reactor has been vented to atmospheric pressure. Inside the reactor is the heated substrate stage(Chuck) on which the sample holder is placed.

Below the chuck, within the lower reactor heater zone, is situated the ALD Trap. This high surface area, high conductance component provides a surface on which excess precursor can be removed from the gas stream via the same ALD process occurring on the substrate surface.

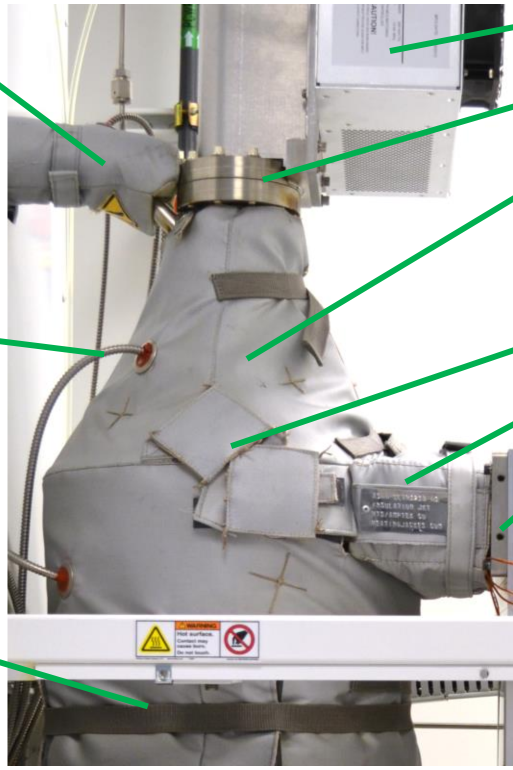


Figure 2-12 – Fiji G2 Reactor

2.4.3 Substrate Heater

Inside the reactor at the level of the reactor door/load lock connection is the top of the substrate heater. This bowl shaped reactor component supports the substrate holder and provides heat for substrate temperature control. With the standard Fiji configuration, the substrate heater maximum temperature is 500°C. An optional 100mm diameter substrate heater can provide temperatures up to 800°C.

2.4.4 System Exhaust

PEALD processes bring together two distinct processing steps: precursor dosing and plasma radical delivery. When precursor chemicals are pulsed into the ALD reactor, they need time to react with the substrate. If the precursor passes through the reactor too fast, very little of it may react with the substrate, resulting in unsaturated substrate precursor dosing and precursor waste. Reducing the system pumping speed to increase the residence time of the precursor in the ALD reactor will promote efficient precursor use and saturated film growth on each ALD cycle.

Plasma radicals are a good ALD co-reactant because they are extremely reactive. But this high reactivity also results in high rates of radical recombination. Radicals that recombine prior to arriving at the substrate surface are not able to participate in the PEALD process. What is needed is a plasma source that generates high radical fluxes and a system that delivers them to the substrate surface with as little recombination as possible.

Thermal ALD processes typically operate at hundreds of mTorr. ICP sources operate most efficiently at tens of mTorr. In addition to generating higher radical fluxes at lower pressure, conducting the plasma radical step at lower pressures and higher pumping speeds reduces radical recombination so the substrate is subjected to a higher flux of plasma radicals, improving film properties and reducing process cycle time.

For the best PEALD results, two different vacuum states are needed: 100’s mTorr, longer residence time for the precursor dosing and 10’s mTorr shorter residence time for the plasma radical delivery. The Fiji G2 system accomplishes this by providing two separate pumping paths. For precursor dosing, the system is directly pumped with a dry (rough) pump. For the radical delivery (plasma) step, a turbo pump is used to achieve lower pressures and shorter residence times. These two pumping systems are described in more detail next.

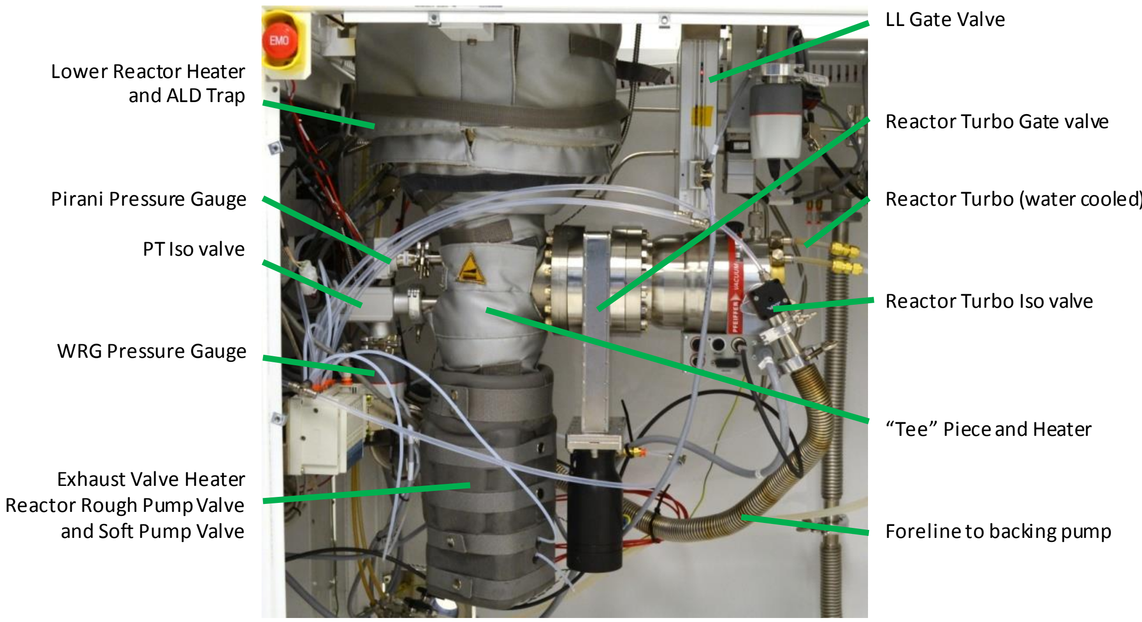


Figure 2-13 – Details of Fiji G2 precursor trap and exhaust system.

2.4.4.1 Lower Reactor and “Tee” Section

Below the heated chuck, is the lower reactor section which contains the ALD Trap. The precursor trap is a heated, stainless steel honeycomb high-conductance structure that provides high surface area for ALD precursors to react and deposit on. Because the trap is heated, it is expected that the ALD process will take place on the surface of the heated honeycomb structure just as it would in the reactor on the substrate. The trap helps to limit the amount of precursor arriving at downstream vacuum components and the vacuum pump.

Below the lower reactor/Trap section resides the Tee section and cone which reduces from a 12 inch ConFlat to a horizontal 6-inch ConFlat flange and a vertical ISO-80 flange. This part is “T” shaped, and splits the flow to the Reactor Turbo (mounted on the side behind a gate valve) and the Reactor Rough attached to the ISO-80 flange. All of these sections are heated with appropriate valves to allow the exhaust flow to be switched between turbo pumping and rough pumping.

As will be discussed in the next section, plasma processes use the turbo pump exhaust line during the plasma step of the PEALD process.

2.4.4.2 Reactor Turbo Pump

The Fiji G2 features a 300 liter per second turbomolecular “turbo” pump. Turbo pumps are very high speed vacuum pumps but only operate at lower pressures and gas flows. The turbo pump must work in tandem with the systems main dry pump which establishes the reactor’s low pressure required for starting turbo pump operation. Turbo pumps cannot maintain large pressure differentials and while process gases are flowing, the dry pump maintains a sufficiently low pressure on the turbo pumps exhaust line for continuous turbo operation. The maximum gas flows through the reactor turbo are ~350 sccm of Ar.

The turbo pump line can be isolated from the system by the turbo gate valve upstream of the turbo inlet, allowing for higher gas flow rates using only the rough pump. Pneumatic actuation enables software control of the turbo gate valve open/close state. On the exhaust port of the turbo pump is mounted a software controlled pneumatic isolation valve.

2.4.4.3 PEALD System Exhaust Procedure

The system exhaust has a number of components and stepping through its operation during a typical PEALD process will help the user understand what is going on. Below, the procedure is described following the picture in Figure 2-14.

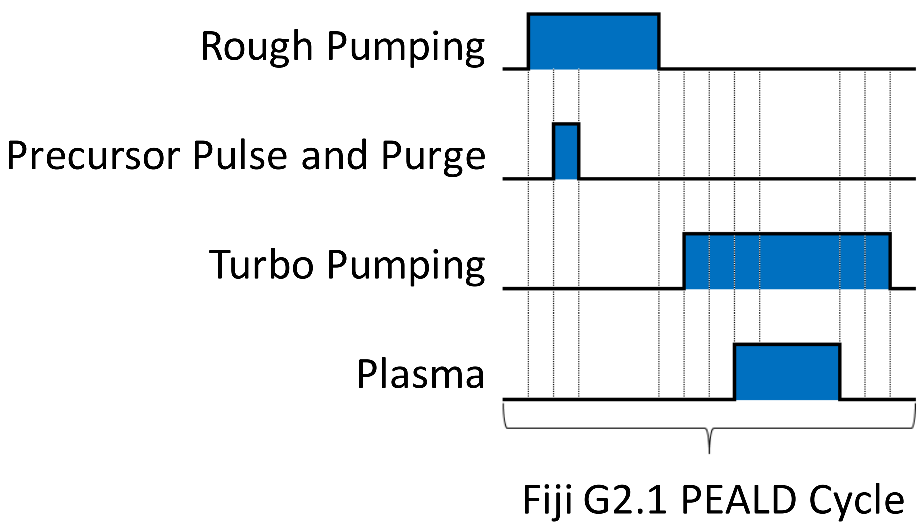


Figure 2-14 – Graphical depiction of the Fiji G2.1 PEALD cycle.

The sequence begins with pumping through the Reactor Rough valve. After the gas flows and pressure are established, a precursor pulse is introduced into the reactor. Following the precursor pulse, the reactor is briefly purged through the rough valve to sweep out excess precursor and reaction by-products.

Following the precursor purge, the pump lines are switched, with the rough valve closed and the turbo isolation and reactor gate valves opened. After flow through the turbo is established, the argon purge through the trap is turned ON and the plasma source is turned ON. Once the plasma step has completed, the plasma source is switched off and system pumping is returned from the turbo line to the rough line and the cycle repeats.

2.4.4.4 Dry Pump

The primary vacuum pumping is provided by an Edwards iGX100N dry pump. The rear of the G2.1 Fiji has an ISO 80 vacuum connection port. Because every customer site is different, it is left up to the customer to complete the connection to the dry pump. The Edwards iGX100N has an ISO63 inlet, this must be converted to ISO80 to connect to the tool exhaust. Dry pump kits provided by Veeco contain a vacuum elbow and size converter to ISO80. For best performance, the pump should be located as close to the Fiji as possible and the vacuum plumbing should have as few bends as possible.

Other pumps of comparable specifications can be substituted by the customer. All process recipes supplied by Veeco have been developed using an iGX100N (62 cfm peak). Pumping curves (pressure vs flow) of other vacuum pumps will be different from the iGX100N and recipe performance may be impacted.

2.4.5 Pressure Gauges

The Fiji G2 reactor features two separate pressure gauges manufactured by BOC Edwards. Connected directly to the reactor is an APGX-H, pirani-type pressure gauge. The APGX-H gauge is rated for 0.23mTorr to 1000Torr in nitrogen. The primary Fiji G2 system gas is Ar. Accurate calibration curves for argon only exist over a limited range and should only be considered reliable between 5mTorr and 10Torr.

The APGX-H is an economical gauge used to monitor system pressure during processing, and thus, is exposed to process chemistries and ALD films deposit on the surfaces of the pressure gauge. ALD coatings on the gauge can cause the pressure readings to drift. Absolute pressure readings from the APGX-H can become unreliable over long periods of time, but pressure variations during ALD recipes, such as from precursor pulses and gas flow adjustments, are still observed. Depending on the thickness and materials of deposition, the APGX-H gauge will require periodic replacement. Veeco has found that these gauges cannot be reliably cleaned and their low cost make it more sensible to replace than to attempt cleaning. Replacement gauges are available from Veeco or BOC Edwards.

Mounted below the APGX-H gauge is a BOC Edwards WRG-S Wide Range Gauge. The WRG-S gauge has a range of 1e-8Torr to 750Torr in nitrogen. The Fiji G2's use of Ar again limits the WRG-S gauge's accuracy above 10Torr. The WRG-S gauge is located behind a pneumatically actuated isolation valve allowing the gauge to be protected from process chemistry. The WRG-S gauge can be used for establishing base pressure of the reactor when using the turbomolecular pump and for verifying the system pressure is appropriate for conducting the APGX-H gauge zeroing procedure.

2.5 Substrate Loading/Unloading

Depositing films on substrates with the Fiji G2 system requires substrate loading and unloading. Depending on your system configuration, this will be accomplished one of several ways. Below, the system configurations related to substrate handling are discussed.

2.5.1 Reactor Door (Simple)

Systems without a load lock are loaded using the supplied transfer wand and sample carrier. The glove box system uses a similar sample carrier and shortened or telescoping transfer wand.

2.5.2 Load Lock

An optional system load lock provides several substrate processing benefits:

1. Substrate insertion and removal from the reactor without exposure of the reactor to atmosphere. After samples are placed into the load lock, the load lock is pumped out. Minimizing the exposure of the reactor to oxygen and moisture can significantly impact the results quality of certain deposition processes such as nitrides.
2. Post deposition substrate cooling in an inert environment can also benefit certain film chemistries. Inert environment cooling can also be completed in the reactor, but cooling the reactor takes a long time and repeated temperature cycling of the reactor can cause delamination of adhered films leading to particle issues.

The Fiji G2 load lock is shown in Figure 2-15. A pneumatically actuated gate valve connects the load lock to the reactor. The load lock has a door on the top and three ports underneath for vacuum pumping, pressure measurement, and venting.

The load lock pressure gauge style depends on whether the load lock is equipped with the optional turbo pump. A system with the load lock turbo will have the a BOC Edwards WRG-S gauge while a system without a load lock turbo will have a BOC Edwards APGX-H gauge. These gauges were discussed above in section 2.4.5.

Inside the load lock is a translation arm which has two directions of motion: up/down and in/out of reactor. On the end of the translation arm is a mechanism which can pick up or drop off the substrate holder from the substrate heater in the reactor.

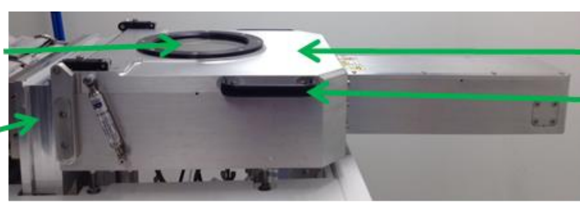


Figure 2-15 – Fiji G2 system load lock.

2.5.3 Load Lock Pumping

Multiple load lock pumping configuration options exist. The load lock may be configured with or without its own turbo pump. Additionally, the load lock pumping setup may share the system dry pump or have its own dedicated dry pump.

Viewing the underside of the Fiji G2 system load lock, multiple subsystem components are visible as shown in Figure 2-16. Subsystems common to all load lock configurations include the gate valve, pressure gauge, vent, and pump valve. Also shown is the optional load lock turbo pump.

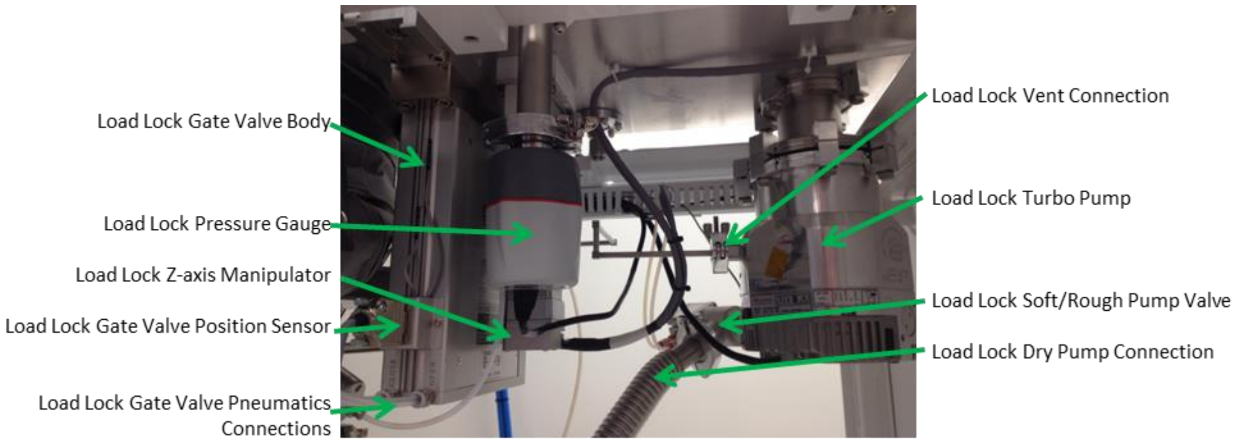


Figure 2-16 – Lower section of load lock showing components of the gate valve, substrate translator, pressure gauge, venting, and pumping systems on a system with a load lock turbo.

The pumping valve on the load lock features two stage operation: soft pump and rough pump. Soft pump enables slow pumping of the load lock down from atmospheric pressure to minimize sample shifting and particle agitation. After the load lock has been pumped to a sufficiently low level through the soft pump, the rough pump feature fully opens the valve to expedite achieving base pressure.

2.5.3.1 Load Lock with Dry Pump Only

While best results will be obtained with turbo pumping of the load lock, the majority of the benefits obtained from using a load lock can be obtained without the use of a load lock turbo pump. The base pressure of the load lock pump down will be limited by the base pressure of the dry pump used. The two stage pumping valve is mounted directly to the bottom of the load lock in the case of no load lock turbo pump.

2.5.3.2 Load Lock with Turbo Pump

For achieving the lowest load lock base pressures, a load lock turbo option is available. The load lock turbo is connected directly to the load lock without an intervening valve. A protective screen prevents any items that fall down the pumping port from reaching the turbo pump. For systems with a turbo pump, the aforementioned pumping valve is placed on the exhaust of the turbo pump. The soft and rough pumping processes are conducted through the turbo pump. Once in the rough pumping mode of the pump down sequence, the turbo pump can be turned on.

To vent the load lock, the pumping valve is closed, the turbo pump is turned off, and the load lock vent valve is opened. The load lock turbo will be heard to wind down as the vent gas fills the load lock. With the system argon at the recommended 30psig delivery pressure, the load lock requires about two minutes to fully vent.

The load lock turbo exhaust can be connected to the main system dry pump or a dedicated dry pump.

2.5.3.3 Load Lock with Shared Backing Pump

For systems using only one rough pump for both the reactor and load lock, the single rough pump supports the reactor soft pump, reactor rough pump, reactor turbo pump, and the Load lock (soft pump, rough pump, and turbo pump). Automated pump sequences and interlocks control the opening and closing of pump line valves to prevent exposure of active turbo pumps to high gas pressures. When pumping the load lock from atmospheric pressure, the reactor gas flows are turned off and the turbo isolation valve is closed until the load lock pressure is sufficiently lowered, at which point the turbo isolation valve can again be opened.

2.5.3.4 Load Lock with Dedicated Backing Pump

When the load lock has a dedicated backing pump (rough pump), the reactor can be operated independently from the load lock pump and vent operations. This additional hardware allows greater freedom of operation for the system, and removes the risk of excessive back pressure on the reactor turbo. Reactor gas flows and pumping do not have to be interrupted during load lock pumping activities. Additionally, load lock (turbo) pumping can be maintained during depositions minimizing wait time at the end of a deposition waiting for the load lock base pressure to be reestablished before sample transfer out of the reactor.

2.6 Heaters

ALD and PEALD processes benefit and often require sections of the system to be maintained at elevated temperatures. Some precursor cylinders must be kept at elevated temperatures to generate appropriate precursor vapor pressure. Other reactor components are typically maintained at temperatures between the precursor vaporization and thermal decomposition temperatures. This will promote the delivery of precursor to the substrate without any loss due to condensation or thermal decomposition.

Heater jackets have several components. A precursor heater jacket is shown in Figure 2-17 illustrating many of the features common to all the system's heater jackets. Exiting the heater jacket is a cable which connects to the Ebox. At the end of the cable are two connectors. The connectors are different, so they cannot be mixed up. The cable with the larger connector is a power connector. The smaller connector is for the Resistive Temperature Device (RTD). RTDs are temperature measurement devices that rely on the predictable variation of resistance of a piece of metal wire with temperature. The Fiji G2 uses 1000Ω Pt RTDs.

Fiji G2 heating jackets have a label indicating 240V operation. Other Veeco and older Cambridge NanoTech ALD systems may have similar looking heating jackets designed for use with lower voltages. Only use heater jackets with the 240V label with your Fiji G2 system.

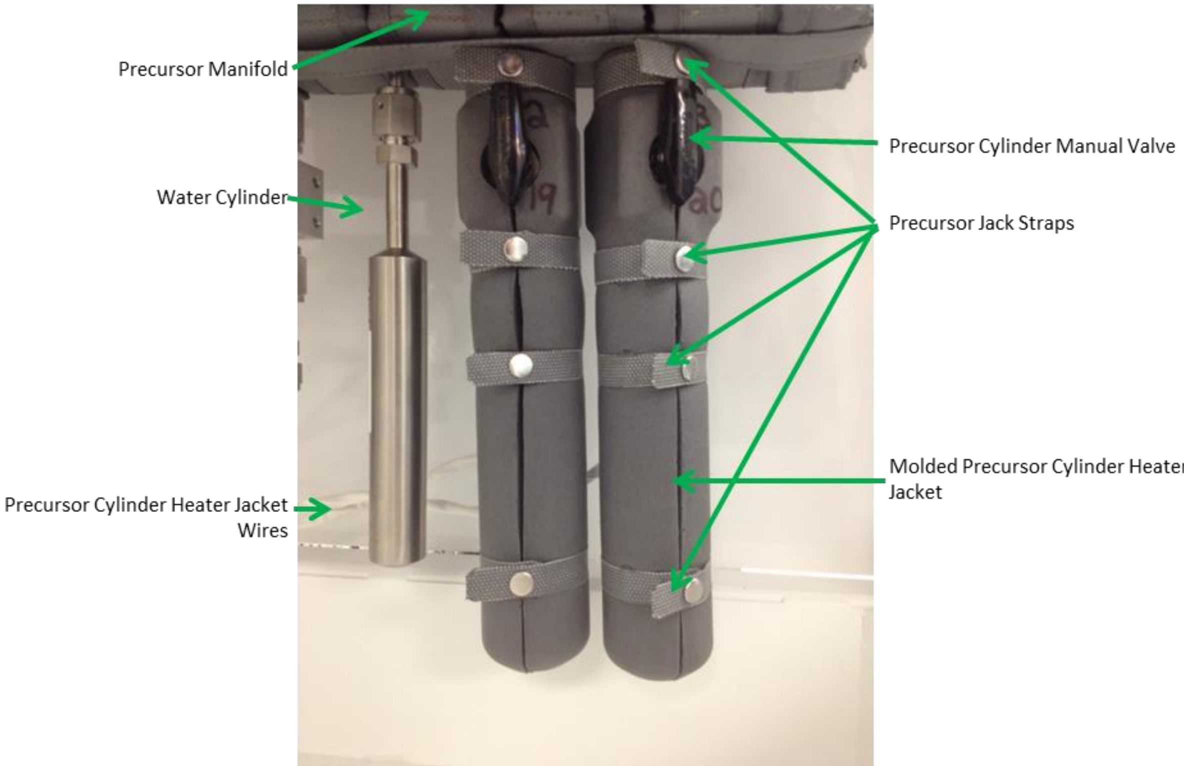


Figure 2-17 – Precursor Heater Jackets

During operation, temperature measurements are continuously made and provided as inputs to a Proportional, Integral, Differential (PID) controller within the software which responds with an appropriate duty cycle for the heating element.

The Fiji G2 system heaters and their default values are shown in Table 2-1. Default values may need adjustment for processing. Veeco supplied process recipes will provide temperature set-point information if non-default values are required.

Table 2-1 - Fiji G2 Heaters

CH #	Heater Description	Default Temperature (°C)	Maximum Temperature (°C)
13	Upper Reactor	200	300
14	Lower Reactor	200	300
15	Substrate Heater - Chuck	200	500
16	Precursor Delivery Line	150	200
17	Valve Manifold	150	200 (1)
18	Precursor Port - 1	Off	190 (2)
19	Precursor Port - 2	Off	190 (2)
20	Precursor Port - 3	Off	190 (2)
21	Precursor Port - 4	Off	190 (2)
22	Precursor Port - 5	Off	190 (2)
23	Precursor Port - 0	Off	190 (2)
24	Exhaust Tee	150	150
25	Exhaust Valve	125	150
26	Option A – zone 2	Off	200
27	Option A – zone 3	Off	200
28	Option B – zone 2	Off	200
29	Option B – zone 3	Off	200
30	Transfer Tunnel	150	175

(1) The temperature of the ALD valve manifold is not limited by the capabilities of the heater, rather the ALD valves themselves have a maximum temperature rating of 200°C.
(2) Each precursor temperature needs to be considered separately. Increasing temperature produces a higher vapor pressure. But care should be taken because at sufficiently high temperatures, precursors will decompose. Additionally, one must consider the limitations of the valve used on the precursor cylinder. The green handled bellows valve installed on the precursor cylinders that ship with the system have a maximum temperature of 220°C. Black handled quarter turn ball valves are commonly used on cylinders containing precursors that do not require high temperatures. These black handled valves should not be heated beyond 115°C.

ALD valve 0 is typically reserved for water co-reactant and a heater jacket is not supplied. Water vapor pressure can exceed precursor cylinder burst pressures at temperatures commonly used for ALD precursor heating. Do not heat water precursor cylinders or use the water precursor cylinder for storage of an unused precursor heating jacket.

2.7 Hardware Interlocks

The Fiji G2 system has three hardware-based interlocks. Hardware interlocks are added when an extra layer of personnel or system hardware safety is necessary or desirable.

2.7.1 H_2/O_2 Interlock

A hardware interlock exists which prevents H_2 and O_2 (or other sets of incompatible gases) from flowing into the reactor at the same time. The hardware for this interlock is located in the PD-box. Whenever the H_2 or O_2 pneumatic shutoff valve is open, the hardware interlock prevents the pneumatic shutoff valve for the incompatible gas from opening. Additionally, if the user tries to cause the pneumatic shutoff valves for the incompatible gases to be open at the same time using the software, an alert will pop up on the computer screen saying this is not allowed.

A final property of the H_2/O_2 interlock is a forced period of argon purge after either the H_2 or O_2 pneumatic shutoff valve is closed before the incompatible gas pneumatic shutoff valve is allowed to be opened. If H_2 has been flowing and the user wants to switch to O_2, the H_2 MFC is set to zero and the H_2 pneumatic shutoff valve is turned off. In section 2.1.1.1, a NO valve on the argon distribution lines was described. Circuitry in the PD-box causes the NO valve to open causing argon to flow into the reactor for five seconds after which the NO valve closes and the O_2 pneumatic valve can be opened. An NO valve is used so that in the case of a CDA failure the safety interlock will fail in the on position.

2.7.2 Water Flow Switch

The plasma source requires cooling water to prevent the copper induction coil from overheating. A water flow switch has been placed on the return leg of the cooling water circuit. Two leads from the flow switch provide continuity if the minimum flow conditions for the switch are met. These leads are connected to an external interlock loop on the RF power supply. If the water flow switch is less than 0.4 liters per minute, the switch will be open and the RF power supply external interlock will not be satisfied. The front panel of the RF power supply will display an “EXT” message. The water flow interlock will need to be satisfied before the plasma source can be activated.

3 Software

3.1 Introduction

The Fiji G2 PEALD system comes with a state-of-the-art software package specifically designed to maximize tool usefulness. The software provides control of virtually every aspect of the Fiji G2 system but also allows for simple, recipe-based film deposition processes.

The intuitive software package maximizes productivity of the system. The software runs on the supplied Microsoft Windows 7-based laptop computer. The software has been developed using the National Instruments LabVIEW package. Elements of the Fiji G2 program may look familiar if you have previously used LabVIEW. The LabVIEW source code for the Fiji G2 system is not available to end users.

This manual assumes the user is familiar with interacting with software packages on a Microsoft Windows system. The Graphical User Interface (GUI) is navigated with the laptop touchpad and buttons and keyboard. The laptop and secondary displays do not have a touchscreen. Within the discussion below there will be references to various user interactions with the software. The available methods of user interaction with the software GUI are described in Table 3-1.

Table 3-1 – Description of methods of interacting with the software GUI with the laptop controls.

Clicking	When the user is instructed to “click” on something in the software, the user must position the mouse pointer over that object with the laptop touchpad or red touch point and then press the left touchpad button.
Double-Clicking	Pressing a touchpad button quickly twice.
Right-Clicking	“Right-clicking” is the same as “clicking” except the right touchpad button is pressed.
Enter	The software has various boxes that can accept user input. When the mouse pointer is placed over one of these boxes, the pointer changes to a text select cursor. Click on the box when the text select cursor displays and a cursor will become active in the input box. Holding the left touchpad button down while moving the text select cursor allows text to be selected.
Floating	By “floating” the cursor over an item, additional information may be provided about the software/hardware feature.

3.2 Starting the Software

Before the Fiji G2 software can be started, the system must be completely powered on and the laptop started. The laptop should always be plugged in to the power source and must have two USB cables plugged in to fully communicate with the hardware. One cable connects to the Ebox and one cable connects to a serial port hub. Figure 3-1 depicts the power and USB connections to the computer. The two USB cables can be plugged into any available USB port.

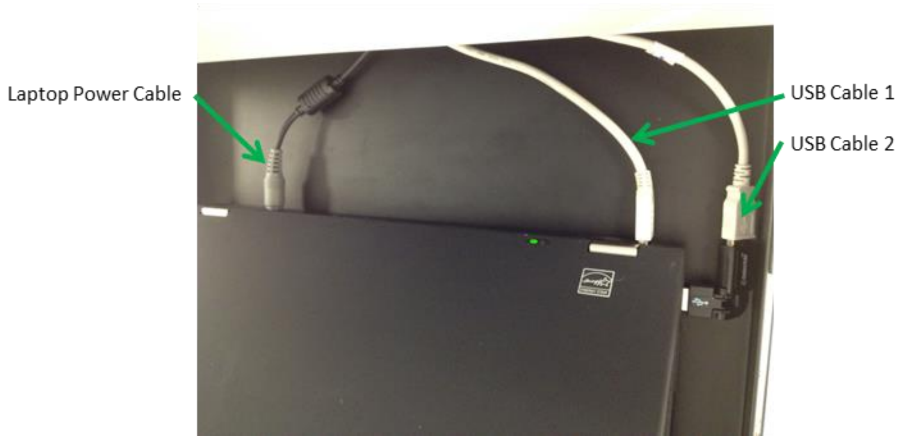
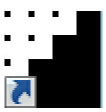


Figure 3-1 – Connections to laptop in rear of laptop drawer. Always keep the power cord plugged in to the laptop. The laptop has two USB cables connected to it. One USB cable is for Ebox communication and the second USB cable is for the serial port hub. The USB port selection for plugging in the USB cables is not critical.

To start the Fiji G2 software, double click the mouse pointer on the software icon on the Windows Desktop, shown in Figure 3-2. The version number indicated on the icon may differ from that on your system.



Fiji (ALD v2015.0.0)

Figure 3-2 – Fiji G2 software icon. Double click on the Veeco logo to start the software.

When the software starts, it reads an initialization file that contains important information regarding the configuration of your Fiji G2 system. The software takes a few moments to load and initialize the communications with the system hardware. When the software has completed loading, you will see the pressure plot in the lower left corner begin to scroll right to left and temperature indicators update. The software is now ready for user interaction.

3.3 Main Software Screen

The main software interface screen along with descriptions of its main features are shown in Figure 3-3.

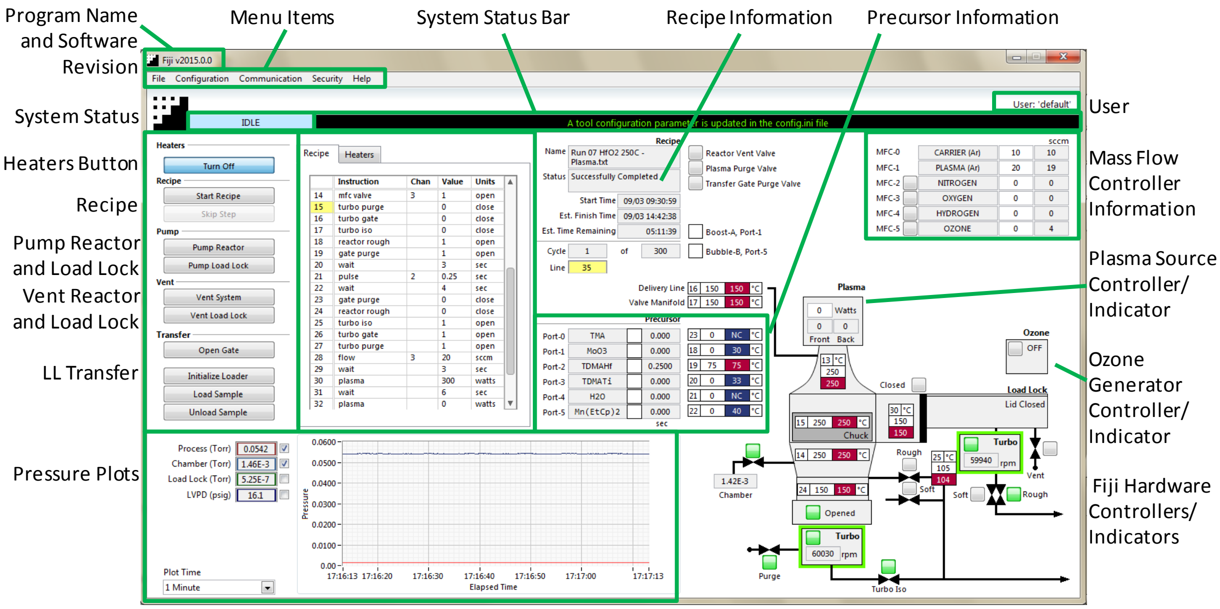
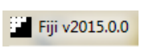


Figure 3-3 – Overview of Fiji G2 main software screen.

3.3.1 Title Bar

The top of the window contains the title bar which displays the application name "Fiji" and the revision number 

. The version number of the software should be included with any support requests.

3.3.2 Menu

Below the title bar is the menu with four options: File, Configuration, Communication, Security, and Help. Different menu options may become available depending on the privileges of the user and options installed on the system.

3.3.2.1 File Menu Option

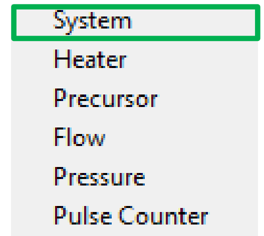
The only option under File is Exit which stops and closes the GUI software. Pressing Ctrl-Q will also stop and close the Fiji software.

3.3.2.2 Configuration Menu Option

The Configuration menu option gives the user access to pop-up windows where information about the system, heaters, precursors, and MFCs can be reviewed and/or changed. At the bottom of each pop-up window are three buttons: OK, Cancel, and Apply.

OK	Updated values are saved to the config file. The pop-up window closes and the new values become active.
Cancel	Any changes made to values in the pop-up are discarded and the pop-up is closed.
Apply	Updated values are saved to the config file and the new values become active. The pop-up

	window stays open.

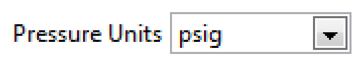


3.3.2.3 System Configuration Window

The System configuration pop-up window displays editable tabs for each functional component of the Fiji system. The System window allows the Tool, Pump, Vent, Recipe, Options Kit, and Load Lock to be configured for the Fiji system.

3.3.2.3.1 System Parameter – Tool

The Tool configuration tab also allows the user to select the number of ALD ports (4 - 6 ports) installed on the system. Type of e-box (Extended is standard) and the hardware configuration of the system (G2.1 is standard). All system options can be selected by either using the drop down menu for configuration or using the check box for the installed hardware. The system load port can be Simple, Glove box, or LoadLock. System options are selected in this tab. The Plasma source can be enabled with the appropriate check box, and number of MFCs are selected in this tab. It is possible to install MFCs and then disable the plasma option. All pressure values can be reported and reviewed by selecting the adjustable pressure units using the drop down box in the top left hand corner of the window. The standard values are reported in Torr.



3.3.2.3.2 System Parameter – Pump

The Pump window allows the reactor pumping to be configured. This includes the transition pressure (cross over pressure) for Soft pump to Rough pump and Rough pump to Turbo. These values are used during the automated pump down sequence and interlock these valves during manual operation. The pump down sequence is complete when the reactor chamber pressure (measured using the WRG pressure gauge with Iso Valve OPEN) is less than the vacuum pressure. During manual operation of the rough and soft pump valves these transition pressures are compared with APGX-H, pirani-type pressure gauge. For semi-automatic sequences the BOC Edwards WRG-S Wide Range Gauge is used with the isolation valve OPEN. If your system is configured without a reactor turbo the full vacuum value should be modified to ~ 40 mTorr.

The system reactor turbo is selected in this window, the standard turbo is the Pfeiffer Hipace 300. There are a number of turbo alarm parameters beyond the alarms and protections provided by the turbo controller. Three protections are available that will turn off the turbo in the software. A power limit (W) can be set with a duration (sec) for an over drive of the turbo unit. If the power and duration are exceeded the turbo will be turned OFF. If the turbo temperature exceeds the temperature limit, the turbo will be turned off. If the turbo is isolated behind the turbo gate and turbo Iso valve for a time > Isolation Time Alarm (sec), the turbo will be turned OFF. In addition to these software specific interlocks. The reactor turbo controller can be viewed using the Turbo Diagnostic window, discussed in a separate section.

After semi-automatic pumping of the reactor chamber, Ar gas flows can be set for both the carrier flow (MFC-0) and the plasma flow (MFC-1) by checking the appropriate check boxes and setting an MFC flow value. The default values are 10 sccm and 20 sccm.

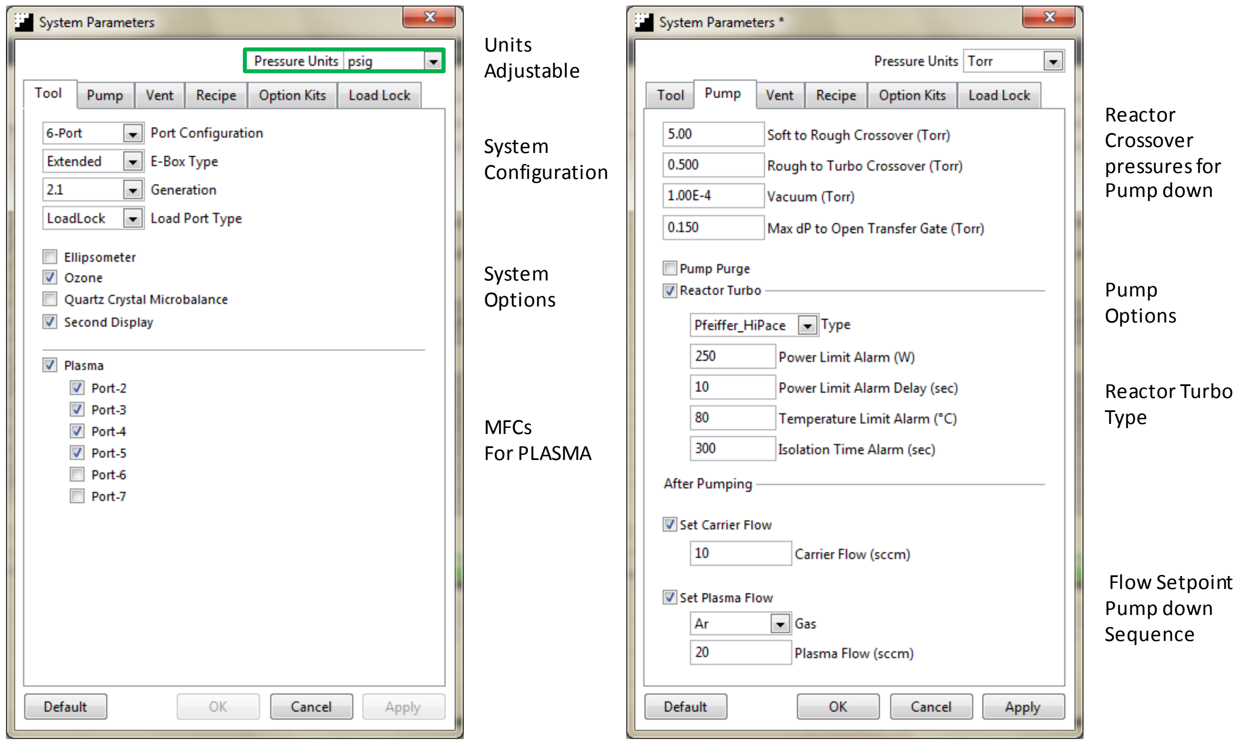


Figure 3-4.1 – Tool and Pump Configuration pop-up window

3.3.2.3.3 System Parameter – Vent

The system vent parameters are defined in this window for the semi-automatic vent sequences. The vent pressure parameter is used for the glove box option and defines the minimum pressure for the reactor vent sequence as measured on the atmospheric gauge. The vent time for the system and the load lock are defined by a vent time (sec) for the vent argon flow. The vent time for both the chamber and load lock are established to be sufficient to completely vent the component. The flow of argon into the system is a function of the argon delivery pressure to the system. If the argon pressure is substantially higher than the recommended 30psi, the vent times should be reduced appropriately. The semi-automatic vent sequence (opens the Transfer gate valve) ensures that the system is not over pressurized by using the LL door (gravity seal) to release the pressure in the vented chamber.

3.3.2.3.4 System Parameter – Recipe

The recipe over pressure parameter defines the max allowable process pressure during a recipe run. If this value is exceeded the process recipe will be aborted and pumped down to base pressure.

The Ar carrier flow (MFC-0) and the Ar (or N_2) plasma flow (MFC-1 (or 2)) can be actively set following a recipe run. At the completion of a process recipe the system will be automatically pumped to base pressure, and if the set carrier flow and set plasma flow boxes are checked, a user defined gas flow through the chamber can be defined. The standard values are 10 sccm and 20 sccm.

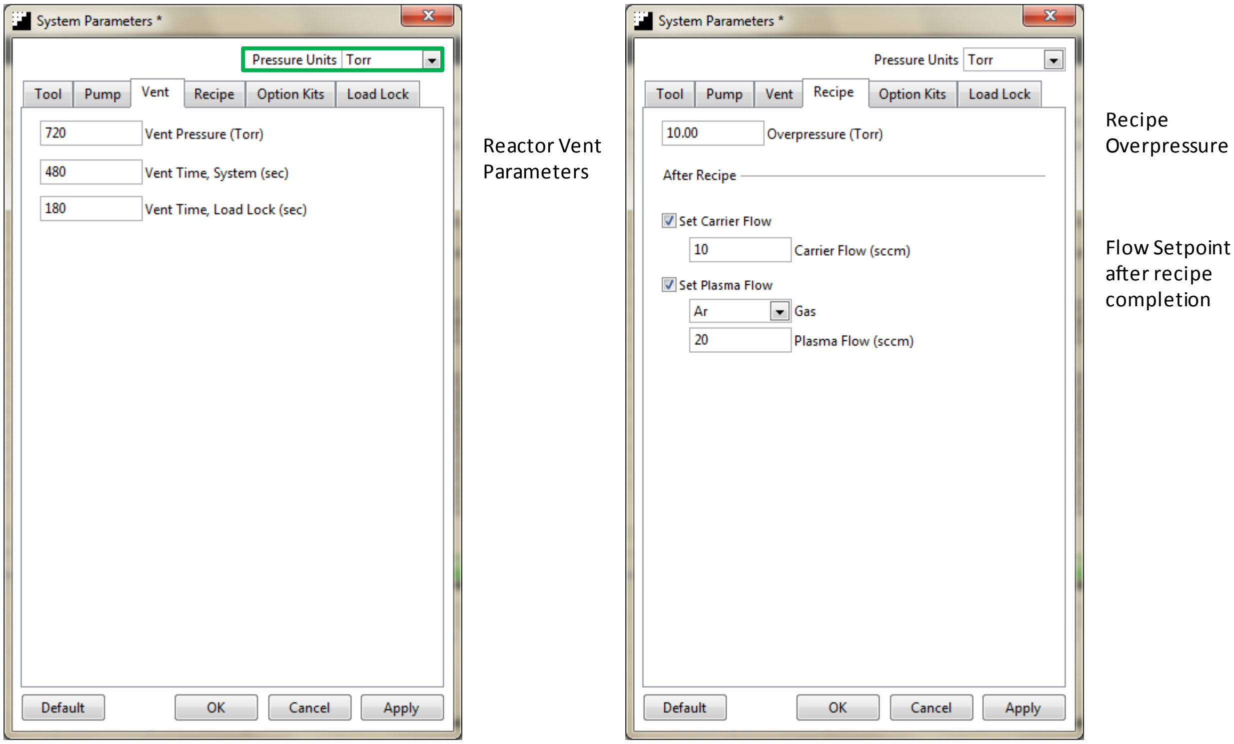


Figure 3-5.2 – Vent and Recipe Configuration pop-up window

3.3.2.3.5 System Parameter – Options Kit

The options installed on the system are defied for Options kit A and B. Using the drop down menu the system can be configured with none, booster, or bubbler (LVPD) options. These options can be installed on any of the ALD ports (ALD-0 to ALD-5). The Min and Max pressure parameters are interlocked and define the usable boost or bubble gas pressure window for the boost and bubbler functionality. This pressure is adjusted and monitored in the gas box, by adjusting the regulator and pressure gauge associated with the booster/bubbler option. If the Ar pressure is outside of the pressure min/max pressure values, the boost and bubble command will not operate and the recipe will be aborted.

3.3.2.3.6 System Parameter – Load Lock (LL)

If the system has a dedicated backing pump on the load lock (a second rough pump only installed on the LL) this parameter should be checked. A dedicated rough pump (backing pump) for the load lock turbo, allows the load lock to be pumped without impacting the reactor pumping and the load lock can operate independently from the reactor chamber. The loadlock turbo is selected (checked) and configured in this window using the drop down menu for the turbo type. The vacuum parameter defines the pressure at which the load lock is considered to be pumped down. For load locks without a turbo, this value should be adjusted to a larger pressure value ~50 Torr.

Load Lock Positions define the teach positions for the automatic load lock transfer. These values should only be changed by an experienced service engineer. Parameters define the x and z positions for both the reactor and load positions.

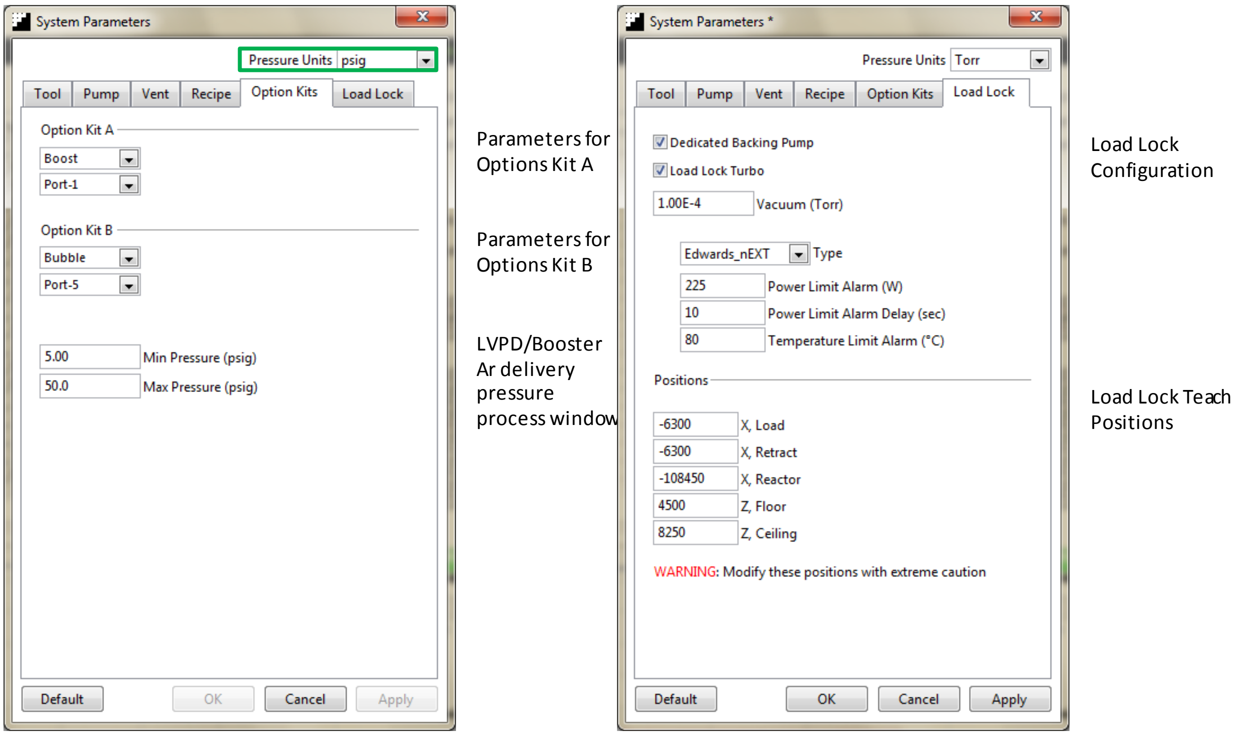
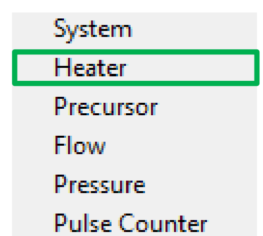


Figure 3-6.3 – Options Kit and Load Lock Configuration pop-up window

3.3.2.3.7 Heaters Configuration Window



Selecting “Heaters” from the Configuration menu produces the pop-up window shown in Figure 3-7. The table shown in the pop-up lists all of the heaters on the Fiji G2 system along with important information regarding the heater which is described in

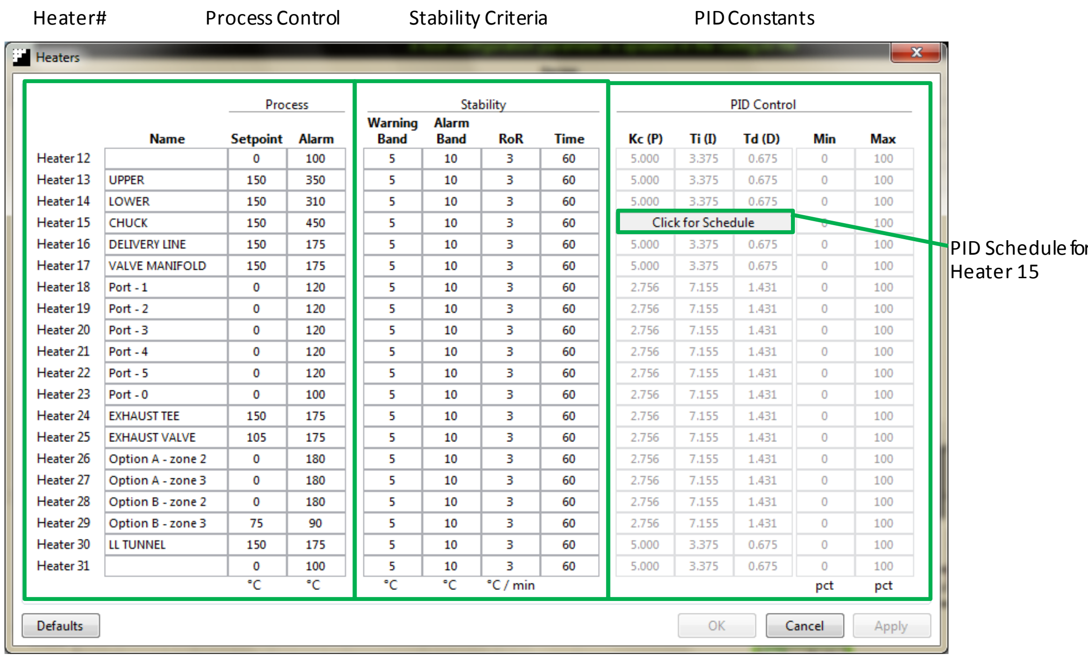
Table 3-2.

Process

Name: A brief description of the heater channel and hardware allocation

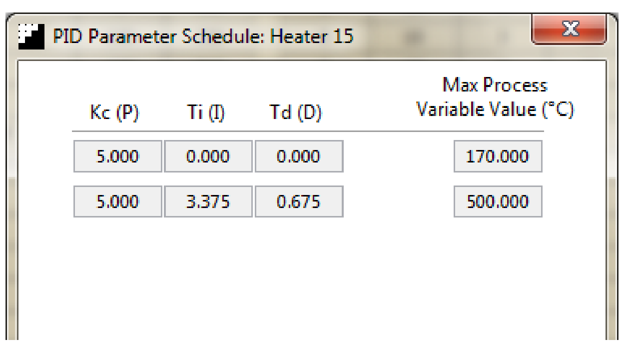
Setpoint: A temperature setpoint > = 0°C, Entering a zero value disables control the heater

Alarm: The maximum temperature of the channel > = 0°C. The heater is turned off if T > T_{ALARM}



	Process			Stability				PID Control				
	Name	Setpoint	Alarm	Warning Band	Alarm Band	RoR	Time	Kc (P)	Ti (I)	Td (D)	Min	Max
Heater 12		0	100	5	10	3	60	5.000	3.375	0.675	0	100
Heater 13	UPPER	150	350	5	10	3	60	5.000	3.375	0.675	0	100
Heater 14	LOWER	150	310	5	10	3	60	5.000	3.375	0.675	0	100
Heater 15	CHUCK	150	450	5	10	3	60	Click for Schedule			0	100
Heater 16	DELIVERY LINE	150	175	5	10	3	60	5.000	3.375	0.675	0	100
Heater 17	VALVE MANIFOLD	150	175	5	10	3	60	5.000	3.375	0.675	0	100
Heater 18	Port - 1	0	120	5	10	3	60	2.756	7.155	1.431	0	100
Heater 19	Port - 2	0	120	5	10	3	60	2.756	7.155	1.431	0	100
Heater 20	Port - 3	0	120	5	10	3	60	2.756	7.155	1.431	0	100
Heater 21	Port - 4	0	120	5	10	3	60	2.756	7.155	1.431	0	100
Heater 22	Port - 5	0	120	5	10	3	60	2.756	7.155	1.431	0	100
Heater 23	Port - 0	0	100	5	10	3	60	2.756	7.155	1.431	0	100
Heater 24	EXHAUST TEE	150	175	5	10	3	60	2.756	7.155	1.431	0	100
Heater 25	EXHAUST VALVE	105	175	5	10	3	60	2.756	7.155	1.431	0	100
Heater 26	Option A - zone 2	0	180	5	10	3	60	2.756	7.155	1.431	0	100
Heater 27	Option A - zone 3	0	180	5	10	3	60	2.756	7.155	1.431	0	100
Heater 28	Option B - zone 2	0	180	5	10	3	60	2.756	7.155	1.431	0	100
Heater 29	Option B - zone 3	75	90	5	10	3	60	2.756	7.155	1.431	0	100
Heater 30	LL TUNNEL	150	175	5	10	3	60	5.000	3.375	0.675	0	100
Heater 31		0	100	5	10	3	60	5.000	3.375	0.675	0	100
		°C	°C	°C	°C	°C / min					pct	pct

Figure 3-7.1 – Heaters configuration window



Kc (P)	Ti (I)	Td (D)	Max Process Variable Value (°C)
5.000	0.000	0.000	170.000
5.000	3.375	0.675	500.000

Figure 3-8.2 – Heater Schedule for PID Parameters window

Table 3-2 – Description of the items displayed on the Heater configuration pop-up window

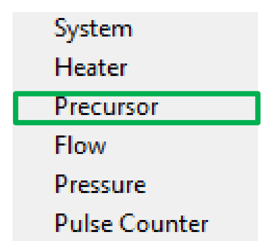
Heaters Configuration Pop-up Item	Description
Heater-number	The heater numbers on the Heaters Configuration Pop-up menu correspond to the heater output and heater RTD channels on the rear of the Ebox. These numbers are also used to control specific heaters in recipes.
Name	The heaters have assigned names. These names are arbitrary and are used as a reference to assist the user. The heater name can be changed.
Process Set-point	The process set-point is the default heater temperature value assigned in the software initialization file. A temperature setpoint > = 0°C. Entering a zero value disables control the heater.
Process Alarm	The process alarm is the default alarm value assigned in the software initialization file. If the heater reaches this temperature, the user will be alerted that the heater has reached an alarm level, and the heater will be turned off.
Stability Band, ROR, and Time	**Warning Band:** Temperature range (°C) that defines circumstances under which the channel is considered to be slightly unstable. The user is warned via an alert when this band is violated, but only after a recipe "stabilize" instruction has successfully executed. No other action besides the alert is taken. (example: a value of 2 = +/- 1°C of the 'Setpoint') **Alarm Band:** Temperature range (°C) that defines circumstances under which the channel is considered to be substantially unstable during the stabilize command. If the "stabilize" instruction has been successfully executed and this band is violated, the user is warned via an alert and the recipe in progress is aborted. (example: a value of 2 = +/- 1°C of the 'Setpoint') A heater is considered "stable" when the following criteria are satisfied: (This relates specifically to the recipe "stabilize" instruction) **ROR**: Change in Temp (°C/min). Rate-of-Rise and Rate-of-Fall is < = the 'ROR' value for stabilize command. **Band:** Range of Temp (°C). Band = Range (example: a value of 2 = +/- 1°C of the 'Setpoint') **Time**: A value > = 0 seconds. For the channel to be considered stable, the ROR and Band conditions must be met for time >= to the period. A heater is considered unstable when the 'Alarm Band' or 'ROR' conditions are not met.
P, I, D Control	The heater temperatures are regulated using a PID controller with the heater channel temperature (°C) as the setpoint. The output power variable is reported

	as the heater duty cycle (0 - 100%). These values are factory set but can be modified if needed in the config.ini file. If needed a PID schedule can be created as shown in Figure 3-5.1 and 3-5.2 for Heater #15 Chuck heater, by modifying the config.ini file directly. **P**: Proportional Gain **I**: Integral Time (min) **D**: Derivative Time (min) **Min**: Duty Cycle (Range = 0%-100%). *0% is required*. **Max**: Duty Cycle (Range = 0%-100%). 100% is recommended.

The heater control parameters are displayed on the Heaters configuration pop-up window but are grayed out and not editable. These items have been established by Veeco and should not require end-user modification. Modification of control loop parameters while the system is operational can lead to unstable behavior. Therefore the ability to adjust these values is restricted to the actual initialization file and a software restart is required for new Control parameters to become active.

3.3.2.3.8 Precursor Configuration Window

Selecting "Precursor" from the Configuration menu produces a pop-up window similar to that shown in Figure 3-9. The table shown in the pop-up lists all of the ALD precursor ports available on the Fiji G2 system along with user definable names for the port. Precursor port refers to the high speed ALD valves on the precursor manifold in the gas box. The ALD valves are numbered from left to right starting at ALD valve 0 (Port 0). ALD port numbers are used in process recipe with the "Pulse" command and for Options using the "Boost" or "Bubble" commands.



The editable names typically refer to the precursor currently installed on the specific valve. These names just provide information to the system user and are not used in the software.

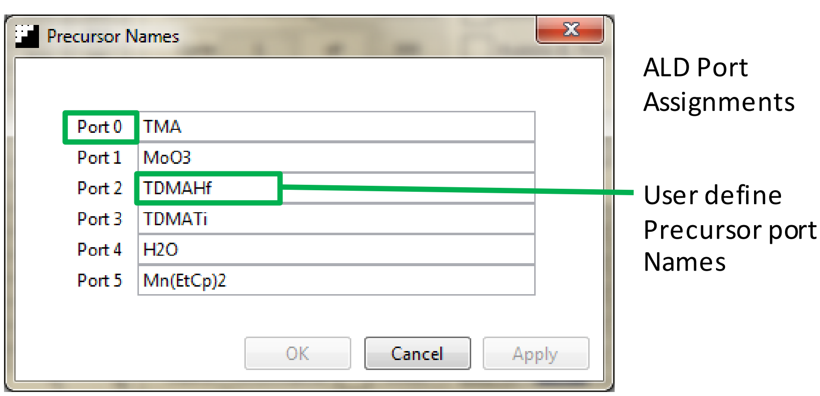
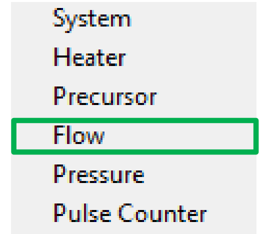


Figure 3-9 – Precursor Configuration Pop-up Window

The names assigned to the ALD ports on the Precursor configuration pop-up window will be displayed near the center of the main software screen in the Precursor Information section.

3.3.2.3.9 Flow Configuration Pop-up Window



The flow configuration interface is factory pre-set with the default values for the MFCs (MFC-0 - 6) a total of 7 MFCs. These values should not be changed unless modified hardware is installed. MFC-0 is the carrier Ar flow which passes through the ALD precursor delivery manifold. MFC-5 is typically dedicated to the Ozone delivery kit. All other MFCs control flow through the plasma source. Each MFC is factory configured for the target gas and should use a k-factor of 1.

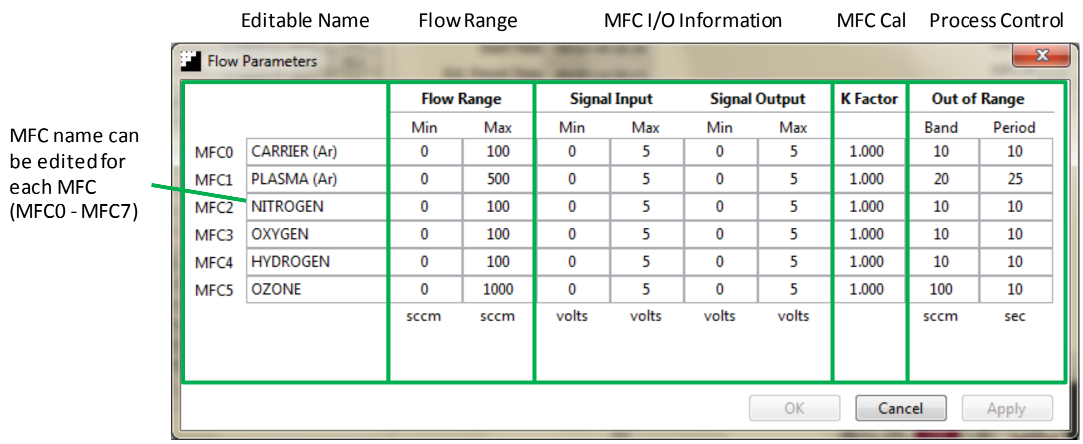


Figure 3-10 – Mass Flow Controller Configuration Window

The section of the MFC configuration window are described below in Table 3-3.

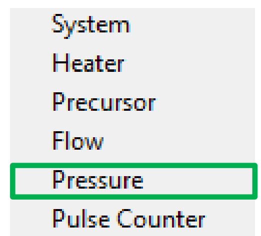
Table 3-3 – Description of the items displayed on the MFC configuration pop-up window

Flow Configuration	Description
Name	This space is for a user defined description of the MFC.
MFC Number	MFCs are numbered starting at 0. The MFC number is used in recipe commands “MFC Valve” and “Flow” for controlling MFC shut-off valves and controlling the MFC set-points.
Flow Range	**Min**: Describes the minimum flow rate measured by the mass flow controller. Value must be set to 0. **Max**: Describes the maximum flow rate measured by the mass flow controller.
Signal Input	**Min:** Describes the minimum flow rate control signal to the mass flow controller. Value must be set to 0. **Max:** Describes the maximum flow rate control signal input to the mass flow controller.
Signal Output	**Min**: Describes the minimum flow rate signal from the mass flow controller. Value must be set to 0. **Max**: Describes the maximum flow rate signal from the mass flow controller.

Calibration	**K factor**: If the MFC was not originally calibrated for the gas it is being used for, a gas correction factor must be used to correct the flow rate measurement. All MFCs shipped with Fiji G2 systems are factory calibrated for the intended gas, so a gas correction factor of 1 is used.
Out of Range	The flow is *“out-of-range”* when the flow rate is outside the flow 'Band' of the ‘Setpoint' for a period > = a time 'Period'. **Band**: A range of flow (sccm). Band = Range (example: a value of 2 = +/- 1sccm of the ‘Setpoint') **Period**: A value > = 0 seconds An MFC flow Alarm will be reported and the process recipe will be aborted.

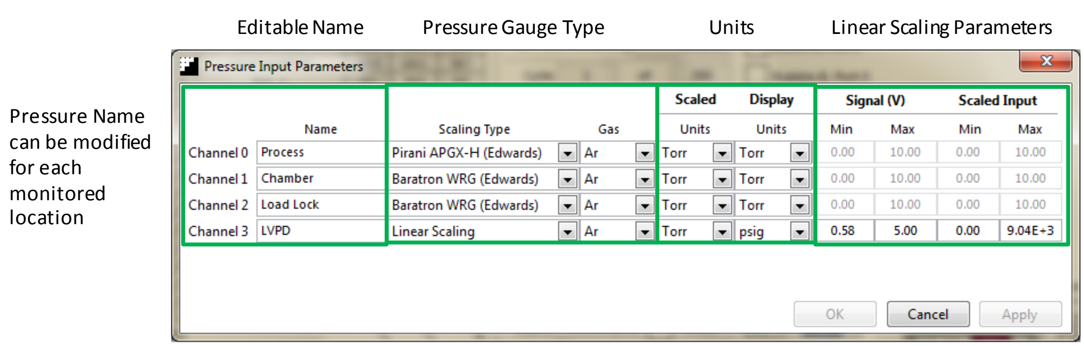
The names assigned to the MFC valves on the configuration pop-up window will be displayed in the upper-right section of the main software screen in the MFC Information section.

3.3.2.3.10 Pressure Configuration Pop-up Window



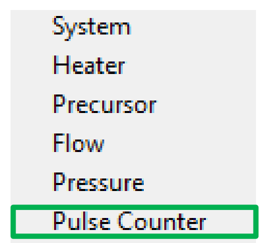
The pressure configuration interface allows the configuration of the various pressure gauges on the system to be managed. The Fiji system has two pressure gauges on the standard system (Channel 0 and 1), with additional gauges associated with the load lock, glove box, and boost/bubbler kit.

Channel 0 is a Pirani APGX-H Edwards gauge which is used to actively monitor the process pressure during the recipe. This gauge is exposed to process gasses and will drift to higher reported values over time. This is a consumable gauge and will need to be replaced on a periodic basis during maintenance.
Channel 1 is a wide range gauge (WRG) located behind an isolation valve. This gauge is protected from process gasses and is used to measure base pressure. This gauge is enabled during automated pump/vent sequences.
Channel 2 is used for either the Load Lock or the Glove Box option and is used for either venting the chamber (glove box configuration) or pumping/ venting the load lock (load lock configuration).
Channel 3 becomes available if one or more boost/bubbler option kits are installed under the “Option Kits” tab of the system configuration interface.

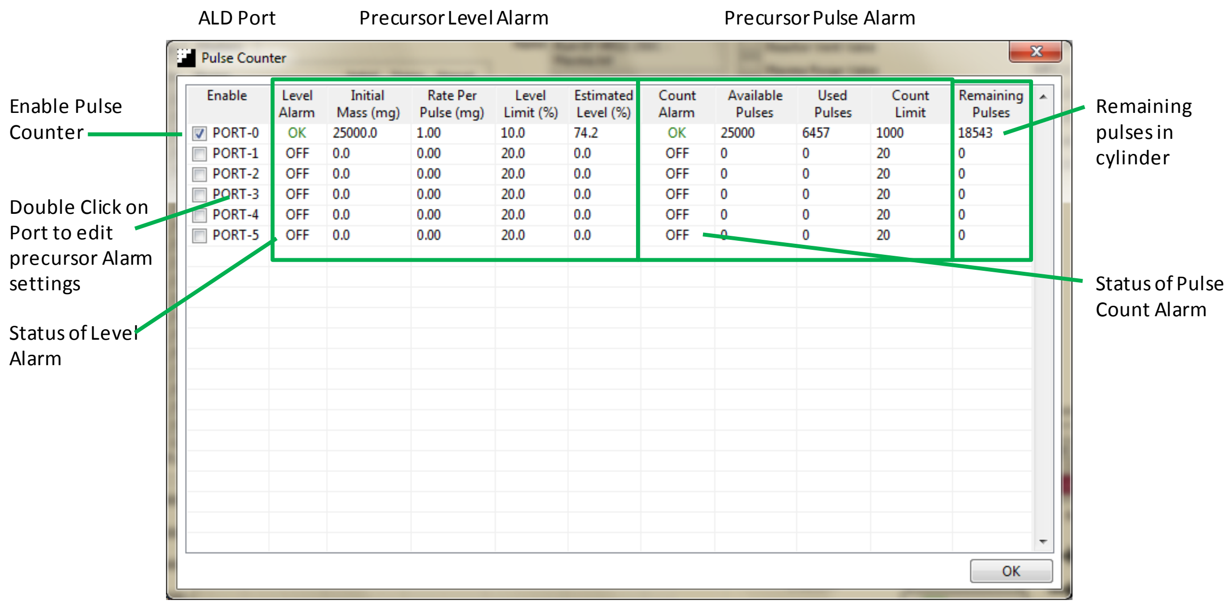


Pressure Configuration	Description
Name	This space is for a user defined description of the pressure gauge.
Scaling Type	Preconfigured scaling parameters have been defined for each default gauge types available. If a default scaling type is selected the “Signal (V)” and “Scaled Input” values will be grayed out and not used for the gauge scaling. If Linear Scaling is selected the linear scaling parameters will become available for editing (white color), and will be used for the pressure gauge installed on the channel.
Gas	The carrier gas type can be adjusted so that pressure gauge properly report pressure. Argon is the default gas.
Units	**Scaled**: All preconfigured pressure gauges use “Torr” for the Scaled units. Do not modify. If Linear Scaling is used the units can be changed to define the full range value for the “Scaled Input” value. **Display**: The working units for the pressure gauge can be designated: atm, bar, mBar, mmHg, psia, psig, Torr, Pa, kPa, MPa.
Scaling Parameters	**Min:** Describes the minimum value for the Voltage signal (V) and Scaled Input (pressure). Parameter is only used with Linear Scaling. **Max:** Describes the maximum value for the Voltage signal (V) and Scaled Input (pressure). Parameter is only used with Linear Scaling.

3.3.2.3.11 Pulse Configuration Window



The pulse counter can be enabled for each precursor cylinder installed on the system. The precursor fill amount (mg) and precursor usage rate (mg/pulse) must be measured for proper use. The pulse counter window summarizes the status of each precursor, (Port 0-3).



Pulse Configuration	Description
Enable	Check box to enable the pulse counter function
Level Alarm	Indicates state of Level Alarm (OFF, OK, ALARM)
Initial Mass	The precursor weight must be know when installing the precursor cylinder and recorded here.
Rate Per Pulse	The precursor usage rate. This is a user defined value (mg/pulse) and can be calculated after each cylinder replacement. [(cylinder pre-weight – cylinder post-weight)/ # pulses].
Level Limit %	Weight% limit of initial mass for pulse counter alarm state. If "Estimated level (%)" < "Level Limit (%)" then level alarm will be indicated.
Estimated Level %	Calculated % value of precursor remaining in the cylinder
Count Alarm	Indicates state of Count Alarm (OFF, OK, ALARM)
Available Pulses	Displays the total number of pulses available for the Full cylinder
Used Pulses	Displays the total number of pulses performed on the cylinder (PORT #)
Count Limit	Limit for pulse count alarm. If "Remaining Pulses" < Count Limit then count alarm will be indicated.
Remaining Pulses	Displays the total number of remaining pulses available

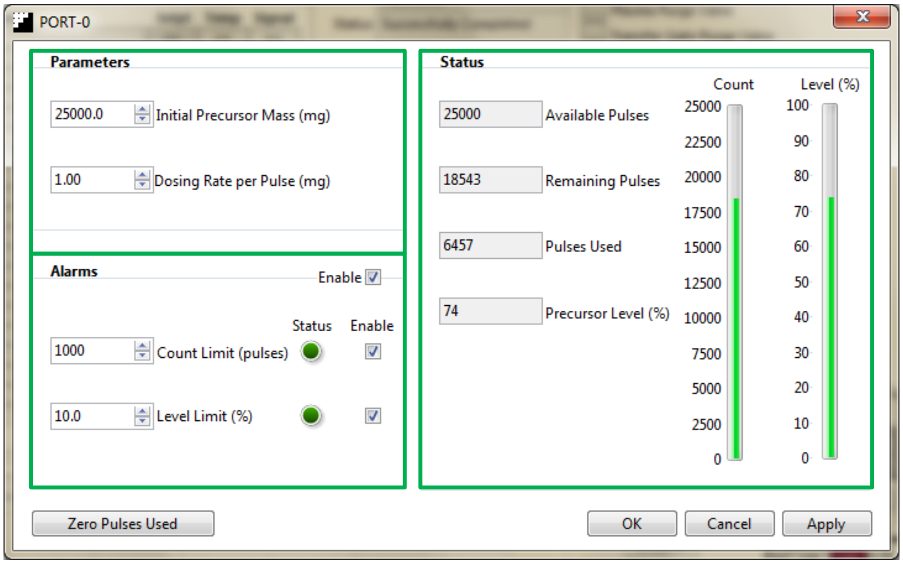
Editing the Pulse Counter Parameters

The pulse counter settings can be accessed by double clicking on the desired precursor PORT (Port 0 - 5). The following interactive window will be displayed.

Precursor Fill (Initial Mass) and Usage Rate (Dosing Rate per Pulse) are needed to calculate total Available Pulses

Enable Alarm by checking boxes

Set Alarm on Min Value (Count and/or Level)



Precursor Status indicates estimated value of precursor remaining in cylinder

Parameters

Initial Precursor Mass (mg): The weight of the precursor material loaded into the cylinder (Precursor Weight = Total Weight – Weight of empty precursor cylinder). The empty weight or fill weight of the precursor cylinder is needed. Note: 1gram = 1,000mg.

Dosing Rate per Pulse (mg): The precursor usage rate per pulse (mg/pulse) is defined by the precursor used, the pulse time, and the precursor temperature. This measured value is used to determine the amount of precursor remaining in the cylinder by counting the number of pulses.

Dosing Rate per Pulse (mg) = (Precursor Cylinder Weight Change)/(Pulses Used)

Alarms (Precursor Level)

Enable: The precursor level alarm can be enabled by checking the appropriate box. Either the Count Alarm and/or the Level Limit alarm.

Count Limit (pulse): Minimum number of remaining pulses without Level ALARM

Level Limit (%): Minimum value for Estimated Level % (Weight %), [(# of pulse *rate per pulse)/(initial weight)]

Status

Available Pulses: Displays the total number of pulses available for the Full cylinder

Remaining Pulses: Displays the total number of remaining pulses available

Pulses Used: Displays the total number of pulses performed on the cylinder (PORT #)

Precursor Level %: Calculated % value of precursor remaining in the cylinder

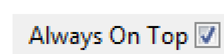
Modifying Settings

To save changes made to the system parameters press “OK” or “Apply”. To cancel changes, select “Cancel”

3.3.2.4 Communication Menu Option

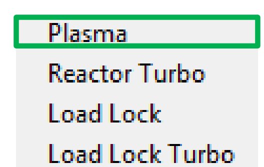
The Communication menu provides additional information for the serial communication of various sub-systems on the Fiji G2 system including: the plasma source RF generator, the main reactor turbomolecular vacuum pump (TMP or Reactor Turbo), the Load Lock, and the optional load lock turbomolecular vacuum pump (LL TMP or Load Lock Turbo).

The communications windows only provide information to the user. There are no available inputs on these pop-up windows. The serial COM ports reported on the communication pop-up windows are hard-coded into the software.

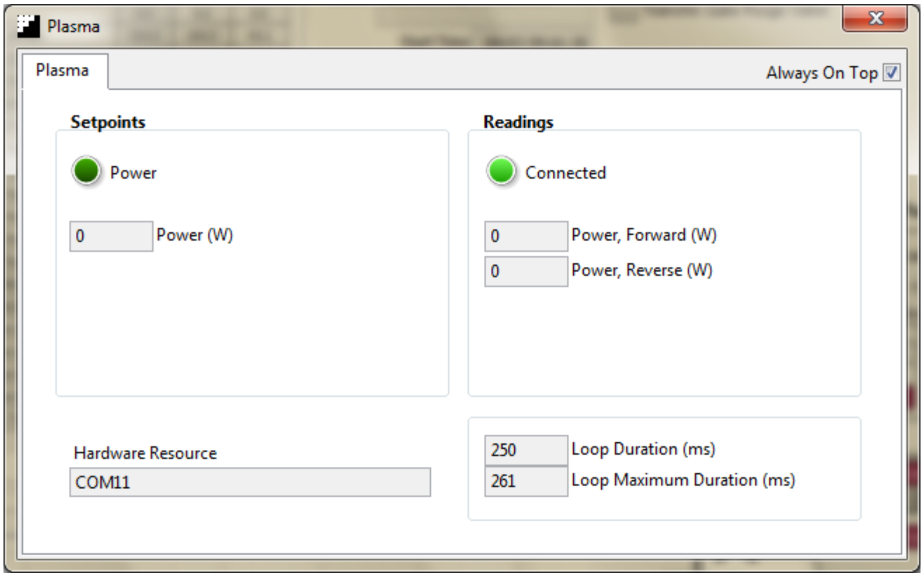


In the upper right corner of each pop-up window is an “Always On Top” check box. If the box remains checked, the window will stay on top of the main software GUI screen. If the box is unchecked, the pop-ups window will stay open but will become hidden behind the main screen.

3.3.2.4.1 Plasma Communications Window



The Plasma Communications window is displayed below in Figure 3-11.



Check Box to keep Window on top of GUI

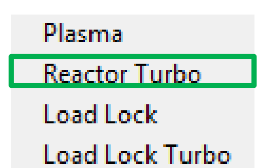
Figure 3-11 – Plasma Communications Pop-up Window

The sections of the Plasma Communication Pop-up Window are described below in Table 3-4.

Table 3-4 – Plasma Communications Pop-up window elements descriptions

Item	Description
Plasma Power On/Off	This digital indicator turns bright green when the plasma source is on and dark green when the plasma source if off.
Plasma Power (W)	This numeric indicator shows the current RF power set-point.
Hardware Resource	Indicates the serial COM port where the RF power supply is installed
Readings Connected	This digital indicator turns bright green when the plasma source is connected and communicating. Dark green indicates no connection.
Power, Forward (W)	This is the most recent forward power measurement reported by the RF power supply.
Power Reverse (W)	This is the most recent reflected power measurement reported by the RF power supply.
Loop Duration (ms)	Time interval for the serial COM (RS-232) data sampling rate
Loop Max Duration (ms)	Max time interval for the RS232 sampling rate

3.3.2.4.2 Reactor Turbo Communications Window



The Reactor Turbo Communications window is displayed below in Figure 3-12. The standard turbo option for the Fiji is the Pfeiffer Highpace turbomolecular vacuum pump (TMP). The communications window indicates information from the turbo controller as provided by the original manufacturer. These parameters include operating values including rpm, power (W), current (A), Alarm States, and Error Codes for the unit.

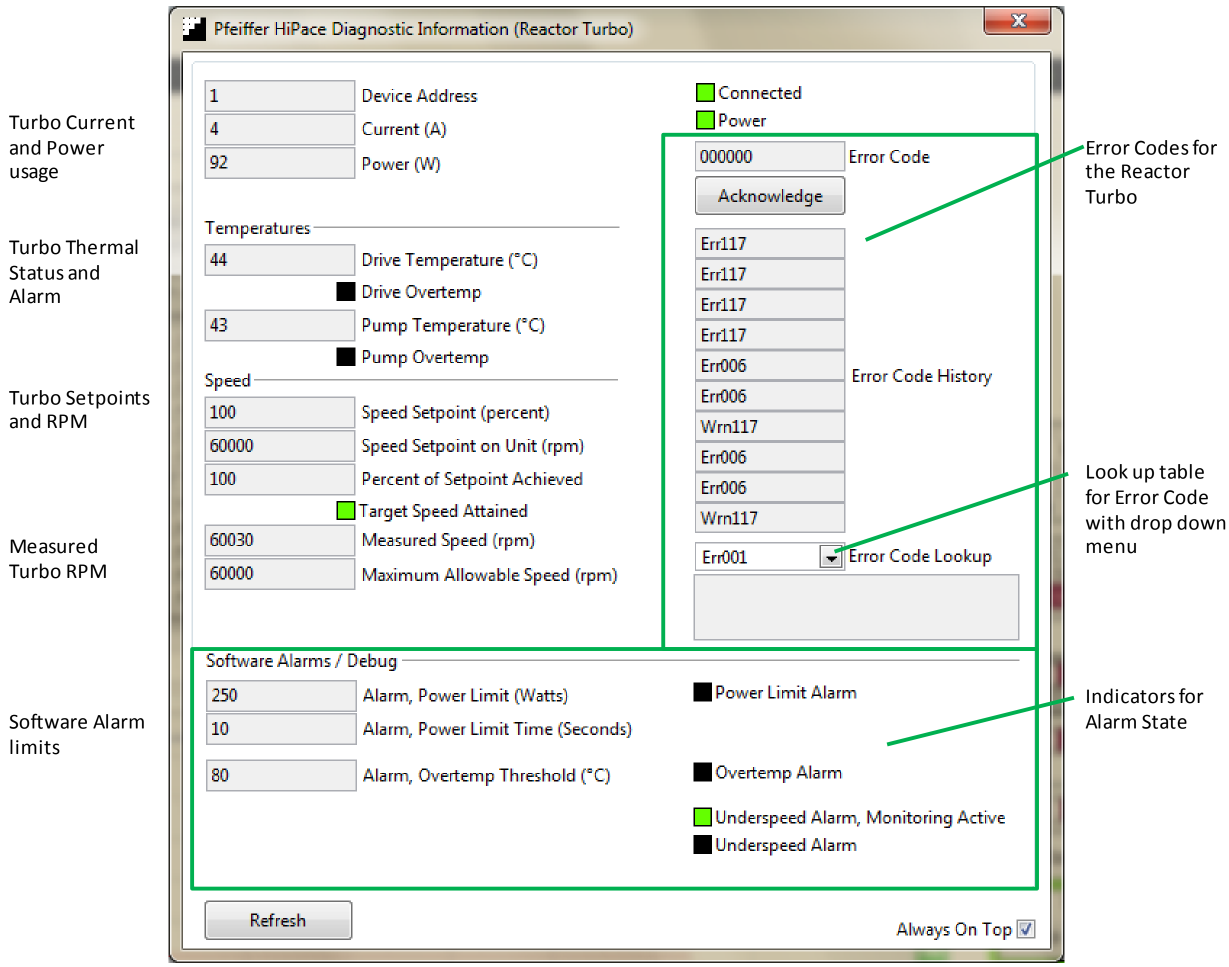


Figure 3-12 – Reactor Turbo Communications Pop-up Window

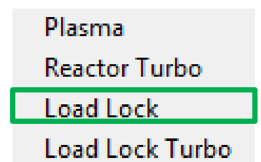
The functional components of the Reactor Turbo Communication Window are described below in Table 3-5.

Table 3-5 – Reactor Turbo Communications Pop-up window elements descriptions

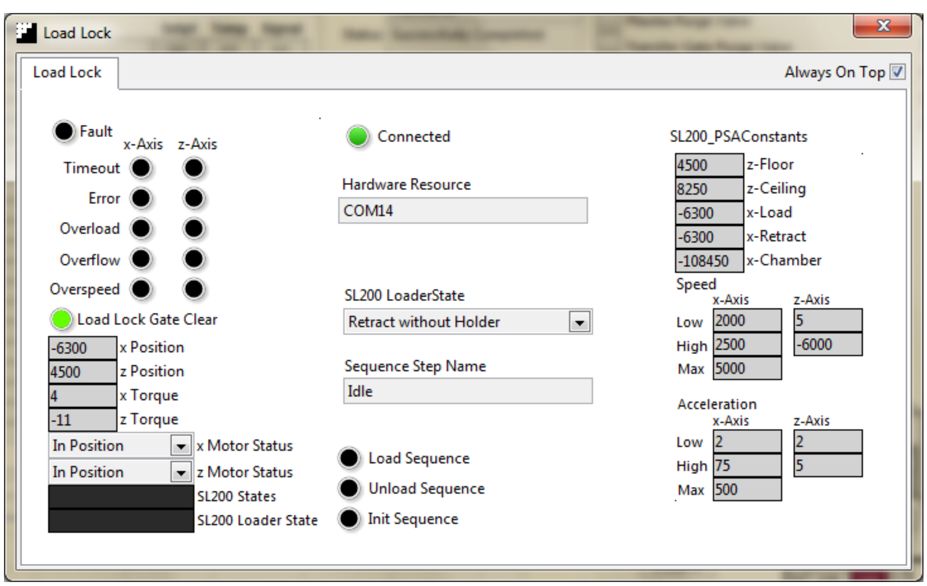
Item	Description
Turbo Connected and Power On/Off	These digital indicators turn bright green when the reactor TMP is connected and powered ON. Black indicates no connection and/or off.
Device Address	Serial port used for communication with the reactor TMP.
Current and Power	Indicate the actual power (W) and current (A)usage in real time
Temperatures	Indicates actual temperatures of the hardware and whether an over temperature condition exists (Green = TRUE, OverTemp condition).
Speed	The rotational rate in revolutions per minute (rpm) and percent (%) are reported. Setpoint and achieved values are presented. (Green = TRUE, Target Speed Attained). Turbo RPM setpoint can be set using percent values in the process recipe. Default ON is 100% of Max rpm (60,000).
Measured Speed (rpm)	This numeric indicator shows the current TMP rotation rate.
Software Alarms / Debug	**Alarm Power Limit**: This numeric indicator shows the maximum power (W)

	limit of the TMP motor. **Power Time Limit Time**: Indicates the time limit (sec) If Power > Power Limit for t > power limit time the Turbo will be turned OFF **Power Limit Alarm**: Green = TRUE, Alarm State occurred
Error Codes / History	**Error Code**: The active error code is reported **Acknowledge**: clears the active error code on the system **Error Code History**: Displays the last 10 errors. The most recent error is displayed at the top **Error code Lookup**: Using the drop down menu the error code will be described in detail in the dialog box.
Overtemp Alarm	Indicates if over temperature alarm has occurred (Green = TRUE)
Underspeed Alarm Monitoring Active	Indicates that active monitoring of turbo speed is active.
Underspeed Alarm	Indicates if under speed alarm has occurred (Green = TRUE)

3.3.2.4.3 Load Lock Communications Window



If installed, the Load Lock Communications window can be viewed as shown below in Figure 3-13. This window provides active status of the load lock module including faults, position, and sequence status for the x-axis and z-axis motors. This window is used to verify the speed and acceleration of both the x-axis and z-axis motors. This communication window should be used with the load lock Users Manual and the Maintenance Manual for modification of parameters.

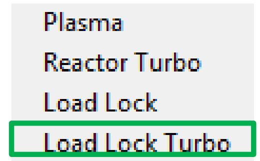


Check Box to keep Window on top of GUI

Figure 3-13 – Load Lock Communications Pop-up Window

3.3.2.4.4 Load Lock Turbo Communications Pop-up Window

If your system has a load lock turbo pump, the Load Lock Turbo Communications window will be available. The standard load lock turbo is the Edwards nEXT P2 turbomolecular pump.



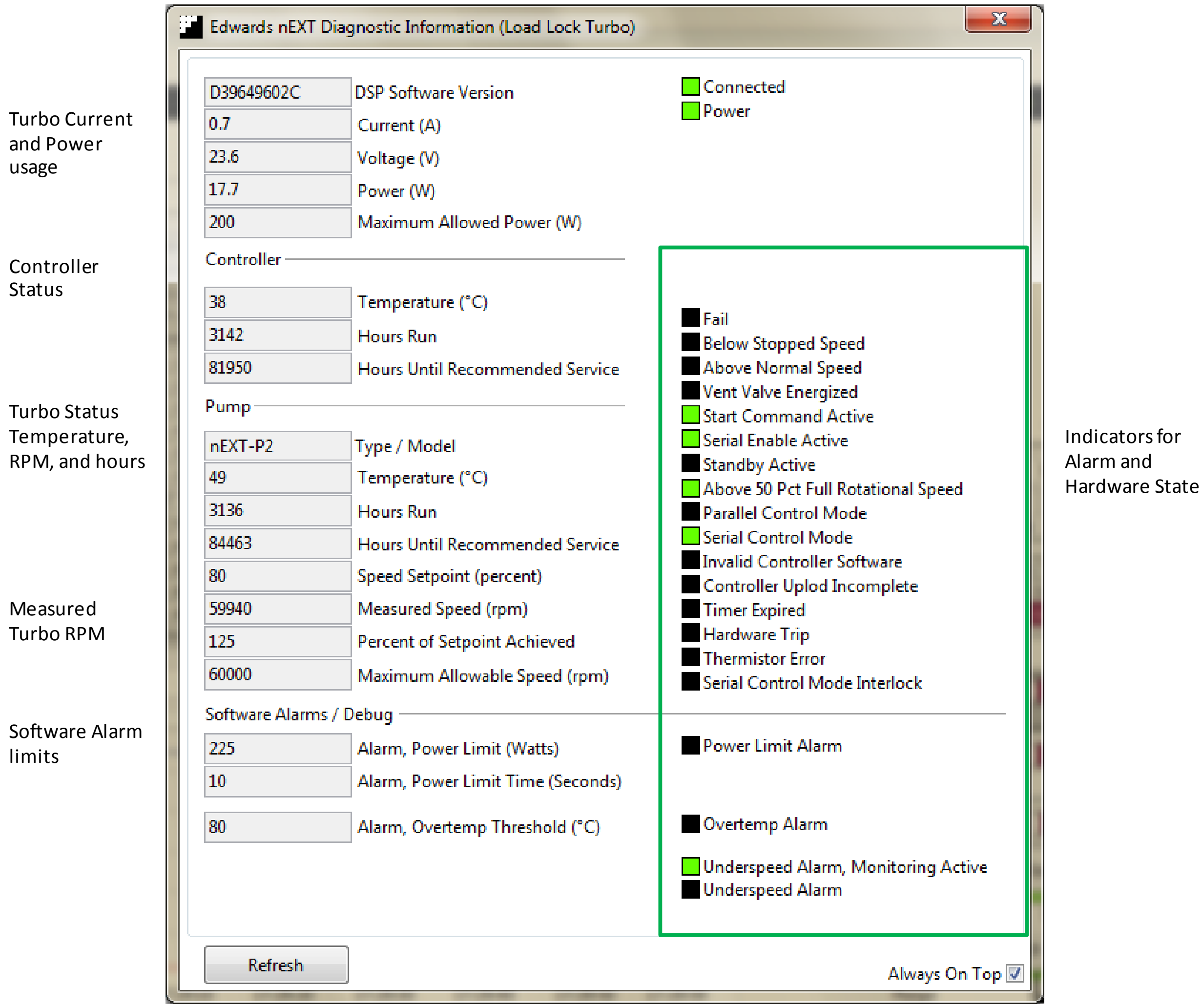
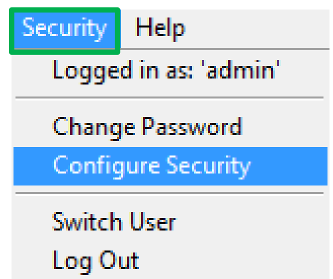


Table 3-6 – Load Lock Turbo Communications Pop-up window elements descriptions

Item	Description
Turbo Connected and Power On/Off	These digital indicators turn bright green when the reactor TMP is connected and powered ON. Black indicates no connection and/or off.
DSP Software version	Displays turbo driver software version
Current and Power	Indicate the actual power (W) and current (A)usage in real time
Controller	**Temperature**: Indicates actual temperatures of the turbo. **Hours Run**: Total run time of turbo (hours). The factory recommended service interval is indicated .

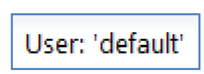
Pump	Indicates the status of the turbo pump including temperature, hours run, recommended service interval. Speed (percent and rpm): The rotational velocity is reported in revolutions per minute (rpm) and percent (%). The speed setpoint and max allowable speed are factor set and cannot be adjusted.
Measured Speed (rpm)	This numeric indicator shows the current TMP rotation rate.
Software Alarms / Debug	**Alarm Power Limit**: This numeric indicator shows the maximum power (W) limit of the TMP motor. **Power Time Limit Time**: Indicates the time limit (sec) If Power > Power Limit for t > power limit time the Turbo will be turned OFF **Overtemp Threshold**: If the T > T(threshold) the turbo will be turned OFF
Indicator Errors and Alarms	Multiple status, error, and alarm codes are monitored in the turbo controller software/hardware. A large selection and are reported on the GUI communication window. **Green** = True **Black**: = False

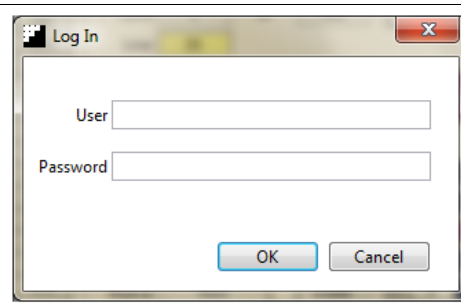
3.3.2.4.5 Security Module User Window



System security can be enabled or disabled in the Fiji software under the Security tab. The system administrator (admin) can modify and change access levels to all system users. New individual users can be added to the system with a unique log in name. Five different Group levels are available: Default, Production, Operator, Engineer, and Maintenance.

If the Security function is disabled, the administrator will need to logon to enable the security function. With the security function disabled, all functionality is available.

Security Item	Description
Change Password	Allows the logged in user to change their password. If the user does not have permission to change their password, this option is grayed out.
Configure Security	Allows the access levels to be modified for each User group. Requires "Permission Editor" access.
Switch User	Logs out current user, and Logs in new user, assuming credentials are entered correctly. The User can be changed by click on User (top right corner) in Main Menu window. 
Log Out	Logs out the current user. Once the User is logged out, the "default" user becomes the presently logged in user.



Logged in as: Indicates who is logged into the system. When the software is started, the logged in user is set to "default" with no password.

Caution: Be very careful setting the password for “admin”, as there is no easy way to recover this password. In this unfortunate event, please contact the support staff of Veeco/CNT. To avoid most consequences of this scenario, it may be prudent to create a backup admin user and assign that user the “Permission Editor” permission, detailed below.

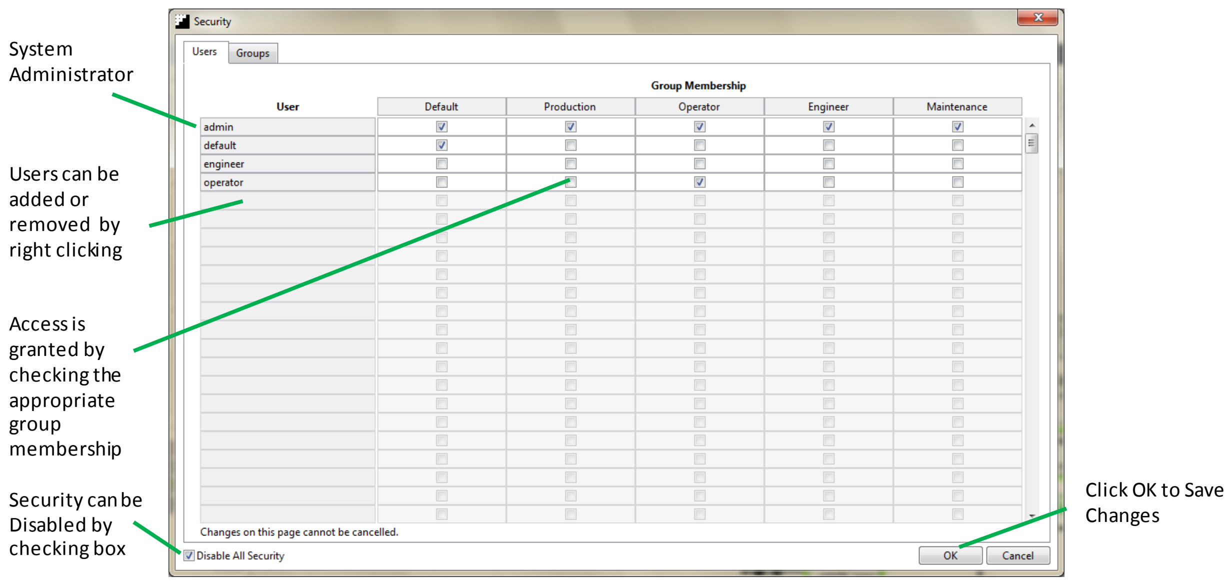
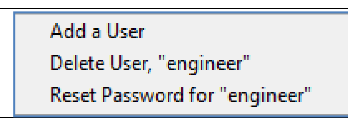
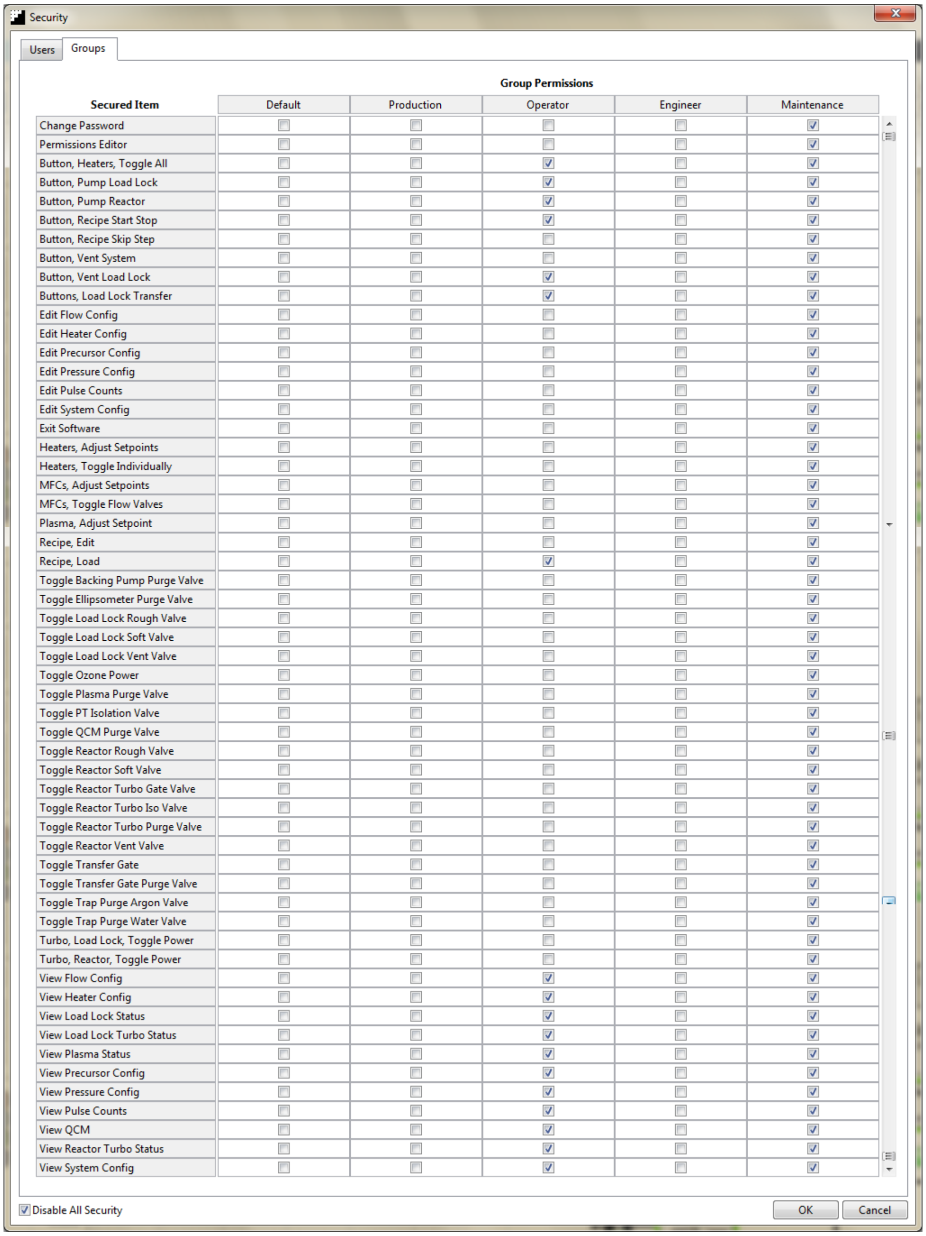


Table 3-7 – Security User window descriptions

Security Item	Description
User	Right clicking on the User box allows the addition/removal of Users and modification of the User password 
Group Membership	Using the Check boxes Users are granted system access associated with the selected Group
Disable All Security	Security can be disabled by checking this box and acknowledging the action upon exit of the security module
OK / Cancel	**Ok** – Saves changes upon exiting **Cancel** – No modifications are made to the Security Module, except for User Modifications

3.3.2.4.6 Security Module Groups Screen

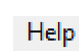
The five group permissions (Default, Production, Operator, Engineer, and Maintenance) are defined on this screen. All of the system functional operations can be granted access with a check mark. Certain functional areas can be granted “View” permission, were no changes can be made. Access to “Button”, “Toggle”, and “Edit” allow for system modification and manual operation of the component. Note that permissions are assigned solely to groups, and not to individual users. To assign a privilege to a user, one must grant permission to a group and make the User a member of that group.



Secured Item	Default	Production	Operator	Engineer	Maintenance
Change Password	☐	☐	☐	☐	☑
Permissions Editor	☐	☐	☐	☐	☑
Button, Heaters, Toggle All	☐	☐	☑	☐	☑
Button, Pump Load Lock	☐	☐	☑	☐	☑
Button, Pump Reactor	☐	☐	☑	☐	☑
Button, Recipe Start Stop	☐	☐	☑	☐	☑
Button, Recipe Skip Step	☐	☐	☐	☐	☑
Button, Vent System	☐	☐	☐	☐	☑
Button, Vent Load Lock	☐	☐	☑	☐	☑
Buttons, Load Lock Transfer	☐	☐	☑	☐	☑
Edit Flow Config	☐	☐	☐	☐	☑
Edit Heater Config	☐	☐	☐	☐	☑
Edit Precursor Config	☐	☐	☐	☐	☑
Edit Pressure Config	☐	☐	☐	☐	☑
Edit Pulse Counts	☐	☐	☐	☐	☑
Edit System Config	☐	☐	☐	☐	☑
Exit Software	☐	☐	☐	☐	☑
Heaters, Adjust Setpoints	☐	☐	☐	☐	☑
Heaters, Toggle Individually	☐	☐	☐	☐	☑
MFCs, Adjust Setpoints	☐	☐	☐	☐	☑
MFCs, Toggle Flow Valves	☐	☐	☐	☐	☑
Plasma, Adjust Setpoint	☐	☐	☐	☐	☑
Recipe, Edit	☐	☐	☐	☐	☑
Recipe, Load	☐	☐	☑	☐	☑
Toggle Backing Pump Purge Valve	☐	☐	☐	☐	☑
Toggle Ellipsometer Purge Valve	☐	☐	☐	☐	☑
Toggle Load Lock Rough Valve	☐	☐	☐	☐	☑
Toggle Load Lock Soft Valve	☐	☐	☐	☐	☑
Toggle Load Lock Vent Valve	☐	☐	☐	☐	☑
Toggle Ozone Power	☐	☐	☐	☐	☑
Toggle Plasma Purge Valve	☐	☐	☐	☐	☑
Toggle PT Isolation Valve	☐	☐	☐	☐	☑
Toggle QCM Purge Valve	☐	☐	☐	☐	☑
Toggle Reactor Rough Valve	☐	☐	☐	☐	☑
Toggle Reactor Soft Valve	☐	☐	☐	☐	☑
Toggle Reactor Turbo Gate Valve	☐	☐	☐	☐	☑
Toggle Reactor Turbo Iso Valve	☐	☐	☐	☐	☑
Toggle Reactor Turbo Purge Valve	☐	☐	☐	☐	☑
Toggle Reactor Vent Valve	☐	☐	☐	☐	☑
Toggle Transfer Gate	☐	☐	☐	☐	☑
Toggle Transfer Gate Purge Valve	☐	☐	☐	☐	☑
Toggle Trap Purge Argon Valve	☐	☐	☐	☐	☑
Toggle Trap Purge Water Valve	☐	☐	☐	☐	☑
Turbo, Load Lock, Toggle Power	☐	☐	☐	☐	☑
Turbo, Reactor, Toggle Power	☐	☐	☐	☐	☑
View Flow Config	☐	☐	☑	☐	☑
View Heater Config	☐	☐	☑	☐	☑
View Load Lock Status	☐	☐	☑	☐	☑
View Load Lock Turbo Status	☐	☐	☑	☐	☑
View Plasma Status	☐	☐	☑	☐	☑
View Precursor Config	☐	☐	☑	☐	☑
View Pressure Config	☐	☐	☑	☐	☑
View Pulse Counts	☐	☐	☑	☐	☑
View QCM	☐	☐	☑	☐	☑
View Reactor Turbo Status	☐	☐	☑	☐	☑
View System Config	☐	☐	☑	☐	☑

3.3.2.4.7 About Screen – Help Pop Up Window

The help tab provides information about the software and software version. This includes the copyright and all rights reserved by Veeco for its use.



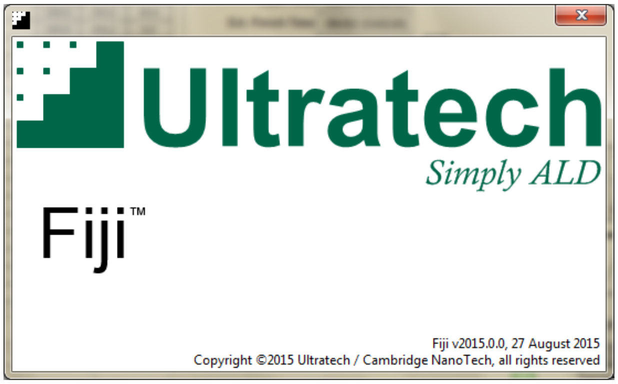
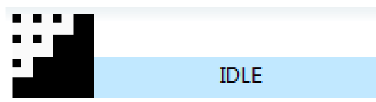


Figure 3-14 – Fiji software information window

3.3.3 System Status Indicator

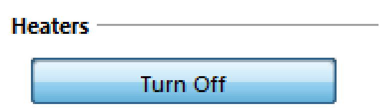


Below the menu tab is a system status indicator. This combination color/text box provides the user instant feedback on the state of the Fiji G2 system at that time. System statuses include the following: Idle/Blue, Process/Green, Obligatory/Yellow (Requires user attention), Abnormal/Red, Emergency/Flashing Red.

3.3.4 Semi-Automatic Action Buttons

Along the left side of the Graphic User Interface (GUI) on the Main screen are a series of buttons which provide easy access to various functionalities of the software. The number of buttons will depend upon the hardware options installed.

3.3.4.1 Heater Button



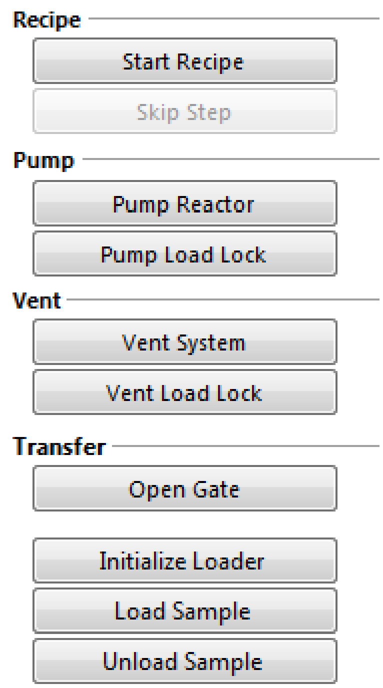
The heaters button is a shortcut button which toggles all the controllable heaters on the system between OFF and the default values set in the Heaters configuration window. When heaters are OFF the button displays “TURN HEATERS ON”. When heaters are ON, the heaters button displays “TURN HEATERS OFF”. In the GUI heaters the ON indicators will be red and heaters buttons will be GREEN = ON.

Care should be used when using the heaters button to turn on all the heaters to their default initialization file values. If a default value has been set for one of the precursor heater jackets, one may inadvertently heat a precursor to an undesirable value. With a Fiji G2 system that has many users using a variety of chemistries, it is best to set precursor heater defaults to “0” so those heater jackets remain off until specifically adjusted by the user on the main interface screen or in a recipe.

3.3.4.2 Recipe Buttons

3.3.4.2.1 Start/Stop Recipe

The Start/Stop Recipe button allows the user to start a recipe if the system is in “Idle” mode or stop a recipe if in “Process” mode. When idle, the button is grey and displays “START RECIPE”. When a recipe is executing, the button displays “STOP RECIPE”.



3.3.4.2.2 Skip Step

The “SKIP STEP” button may be pressed to immediately move on to the next recipe step. This may be used to move past a heater stabilization or wait command. This function is useful for R&D process development.

3.3.4.3 Pump Buttons

The pump reactor and pump load lock function is an automated process sequence used to pump the component to base pressure. The PUMP buttons will handle the sequence appropriately for all hardware configurations and automatically bring the respective sub-system under vacuum.

3.3.4.4 Vent Buttons

The Vent system button will automatically vent the reactor chamber. If a load lock option is installed, the sequence will vent both the reactor and the load lock for maintenance. The vent load lock button will vent the load lock and bring the chamber up to atmospheric pressure.

3.3.4.5 Transfer Buttons

If your Fiji G2 system is configured with a load lock, there will be three additional buttons displayed: “Open Gate”, “Initialize Loader”, “Load Sample”, and “Unload Sample”.

Open Gate: Opens the Transfer Gate Valve for either a load lock or glove box system

Initialize Loader: When the software is started, the load lock transfer arm conducts its initialization sequence to establish the home position. If for some reason the transfer arm location information becomes compromised during operation of the Fiji G2, the initialization sequence can be manually performed without restarting the software.

Load Sample: Activates a sequence which moves the sample holder from the load lock and places it on the heated chuck in the reactor. The Transfer Gate Valve must be open prior to issuing this command.

Unload Sample: Activates a sequence which moves the sample holder from the heated chuck to the load lock. The Transfer Gate Valve must be open prior to issuing this command.

3.3.5 Pressure Plots

The lower left section of the screen, shown in Figure 3-15 contains a plot which displays system pressure data. Up to four plots can be displayed depending on the hardware configuration of your Fiji G2 system.

The standard systems contain two pressure gauges on the reactor. The “Process” pressure gauge is a Pirani-type pressure gauge which is always displaying the pressure in the process reactor allowing visualization of process pressure fluctuations due to precursor pulsing and gas flow changes. The “Chamber” pressure gauge is a wide-range gauge which is isolated from the reactor by a pneumatic valve when deposition processes are being run. This gauge allows calibration of the “Process” gauge and measurement of the ultimate base pressure achievable through turbomolecular vacuum pump use. The “Load Lock” pressure gauge is identical to the “Reactor” wide range pressure gauge.

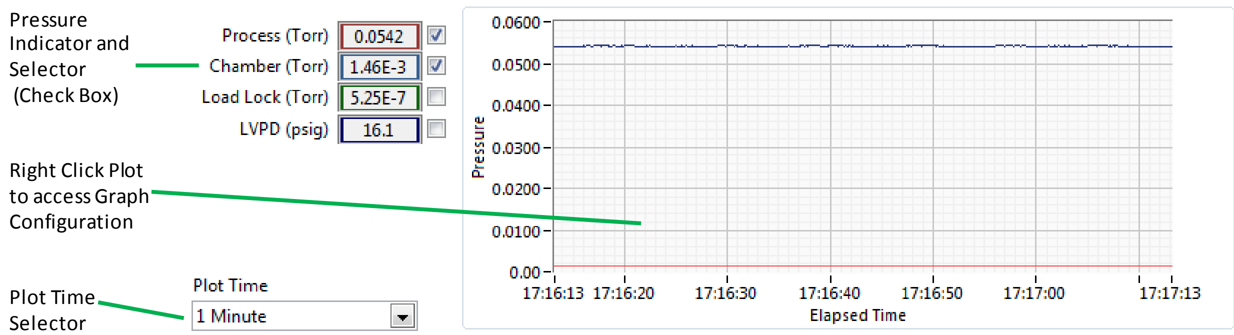


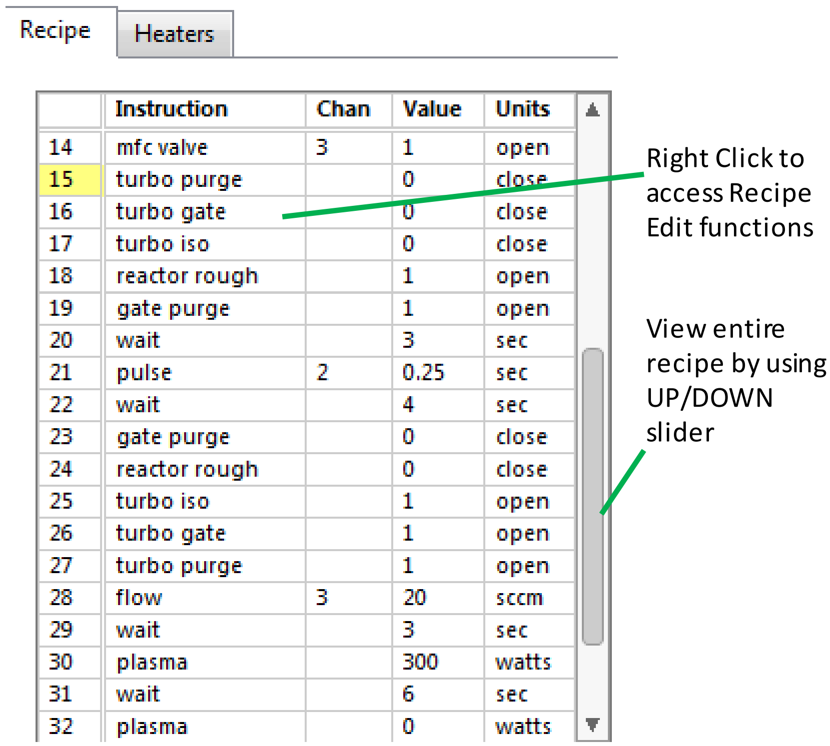
Figure 3-15 – Detail of pressure plot

Real-time pressure plotting of the reactor is presented in the chart. (Additional transducer inputs may also be plotted depending on the system configuration.) By placing a check mark in the respective selection check box, the pressure is plotted on the y axis of the chart. Multiple channels can be plotted at the same time. The plot time can be adjusted to display the pressure history in durations ranging from 10-seconds to 1-hour in length. Additional customization options are available by right clicking on the plot area. The scale and precision can be adjusted in the plot.

Short plot times allow examination of fine pulse details. Intermediate times are good for viewing the pressure characteristics of ALD cycles. Longer plot times help identify issues that can happen over long periods of time such as depletion of a precursor cylinder and pressure drift.

3.3.6 Recipe/Heater Box

The recipe table is used for developing, running and viewing process recipes. Refer to the Recipe Development section for more details. Process Recipes are loaded and Started from this Tab Window.



	Instruction	Chan	Value	Units
14	mfc valve	3	1	open
15	turbo purge		0	close
16	turbo gate		0	close
17	turbo iso		0	close
18	reactor rough		1	open
19	gate purge		1	open
20	wait		3	sec
21	pulse	2	0.25	sec
22	wait		4	sec
23	gate purge		0	close
24	reactor rough		0	close
25	turbo iso		1	open
26	turbo gate		1	open
27	turbo purge		1	open
28	flow	3	20	sccm
29	wait		3	sec
30	plasma		300	watts
31	wait		6	sec
32	plasma		0	watts

Figure 3-16 – Recipe table tab

Figure 3-17 shows the heaters tab. On the heaters tab, all the system's controllable heaters are displayed listed by their number and a descriptive name which can be set in the Heaters Configuration Pop-up window. An indicator, to the left of the heater channel a state indicator is shown Gray = OFF and Green = ON for each heater.

Button	Enable or disable individual heater. Green = ON, Gray = OFF
Ch	The heater channel #
Name	A description of the heater zone (Modifiable in Heater config window)
Setpt	The target control temperature
Temp	The actual temperature of the heater
Signal	The control duty-cycle of the output channel (0 – 100%)

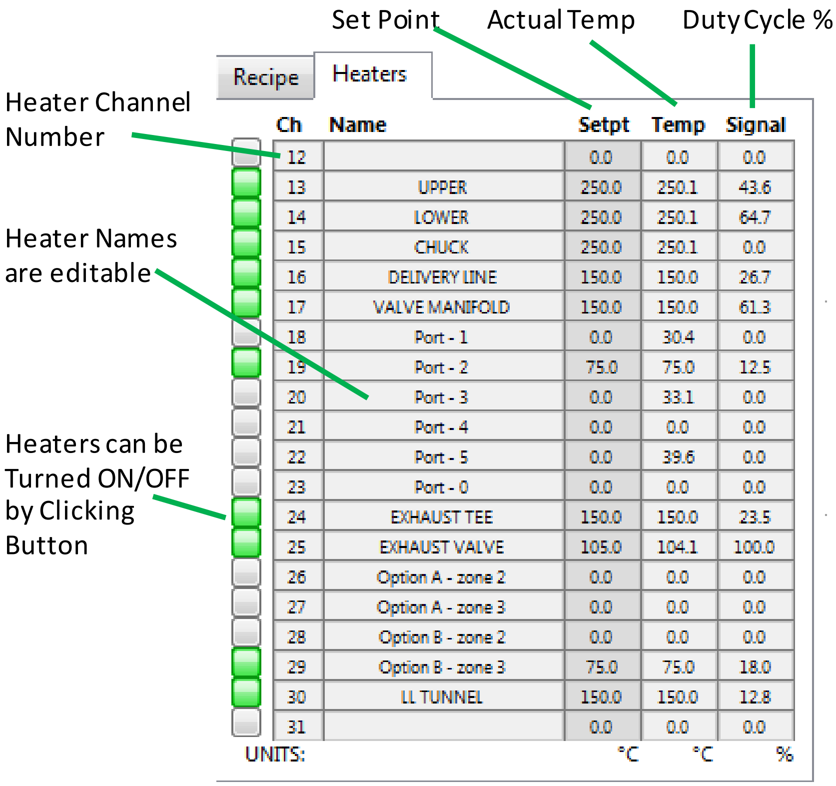


Figure 3-17 – Heaters information tab

3.3.7 Recipe Information

Next to the recipe box are several text boxes that display useful information about the currently loaded/running recipe. These are displayed in Figure 3-18.

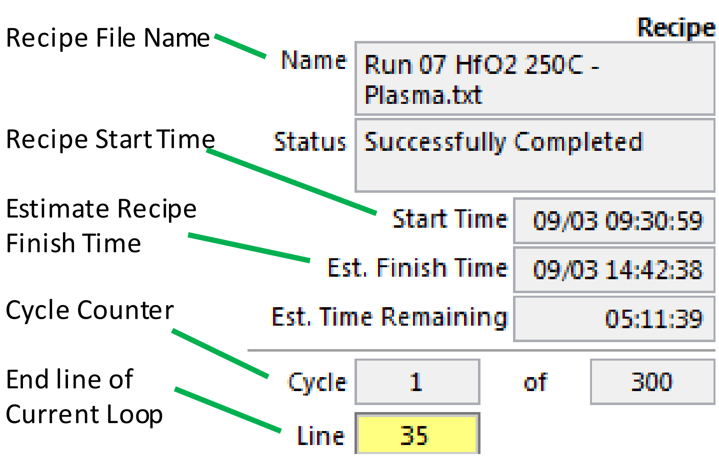


Figure 3-18 – Recipe information.

If the recipe has been saved to the computer hard drive, the name of the file is displayed in the “Name” box. The “Status” box provides some useful information regarding the recipe displayed in the recipe box including: “Recipe loaded” and “Recipe changed but not saved”.

Below the “Status” box are the “Start Time”, “Est. Finish Time”, and “Est. Time Remaining” boxes. If the system status is “Idle” “Start Time” indicates the current time, “Est. Finish Time” indicates an estimate of when the recipe would finish if it was started presently, and “Est. Time Remaining” is an estimate of the total time it will take the current recipe to complete. The system provides time estimates only because some recipe commands involve variable time to complete such as those requiring temperature stabilization. If the system status is “Process” “Start Time” indicates the time the recipe was started, “Est. Finish Time” indicates an estimate of when the recipe will run to completion, and “Est. Time Remaining” is an estimate of the total time it will take the current recipe to complete.

As will be shown in the Recipe Development chapter, ALD processes rely heavily on repetition of individual ALD cycles. These cycles are achieved by using loop structures. It is often useful to know where the recipe execution is in terms of the number of the ALD cycles that have been completed. Under the “CYCLE” heading are several informational boxes that provide information on the current loop being executed. The “Line #” box indicates the line number of the goto command for the current loop. The recipe line numbers of the beginning and end of goto loops are color matched to make the recipe structure easier to follow. The “Line #” box will be colored to match the color of the active goto loop color coding. Next to the “Cycle” label are two boxes. The right-hand box indicates how many cycles are in the current loop and the center box indicates which iteration of that loop is currently running. Nested loops are common for ALD processes and sometimes multiple loops start at the same recipe step. In these cases, the box indicating how many cycles are in the current loop can help sort out the ambiguity of which loop is active.

3.3.8 Precursor Information

Near the center of the screen information regarding the chemical precursors is displayed. This is shown in Figure 3-19.

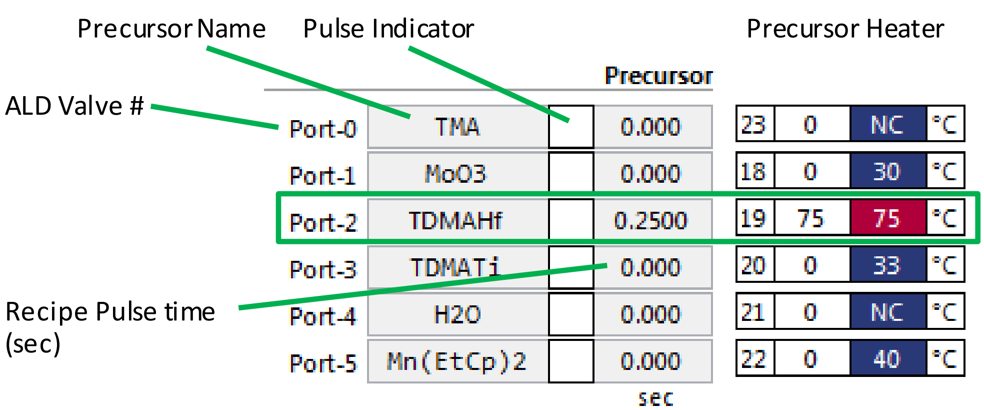


Figure 3-19 – Precursor information.

On the left side, the ALD valve ports are listed (Port-0 to Port-5). These refer to ALD valves on the precursor manifold. The ALD valves in the manifold are numbered from left to right starting at Port-0. Systems with a four port manifold have PORT-0 to PORT-3 while systems with a six port manifold will have PORT-0 to PORT-5. The PORT number (0-5) is used in the process recipe with the “Pulse”, “Boost”, and “Bubble” commands and indicate which ALD valve is pulsed in recipes.

To the right of the PORT-# label, a text box exists in which a descriptive label for the installed precursor can be displayed. The precursor name can be entered in the Precursor Configuration pop-up window. There is no mechanism for the system to automatically know what precursors are loaded on the manifold and it is the responsibility of the user to keep the labels accurate and up-to-date.

To the right of the label box is a pulse indicator (Green = OPEN, White = CLOSED) and the pulse duration, in seconds, of the most recent precursor pulse for that ALD valve.

Precursor bottle heater jacket control/information is provided adjacent to the precursor cylinder information (Heater #, Set point, Actual Temperature).

3.3.9 Heater Information

For all of the user controllable heaters on the Fiji G2 system, there is a box on the main software screen located approximately at the heaters location in the graphical representation of the Fiji G2 system. Several of these boxes related to the precursor cylinder, manifold, and delivery line heaters are shown in Figure 3-20.

Each box is divided into four parts: the heater number, current heater set-point, current measured heater temperature, and temperature units. The heater number corresponds to the Ebox channel into which the heater and RTD are plugged. The heater number also matches the numbers in the Heater Configuration pop-up window. Next to the heater number is the current heater set-point. A set-point of “0” is used to turn off a heater. Individual heater set-points can be manually adjusted

The current temperature measurement is shown in the third section of the box. A blue background indicates the heater is off while a red background indicates the heater is on. “NC” indicates the Ebox does not sense an RTD connected on that channel.

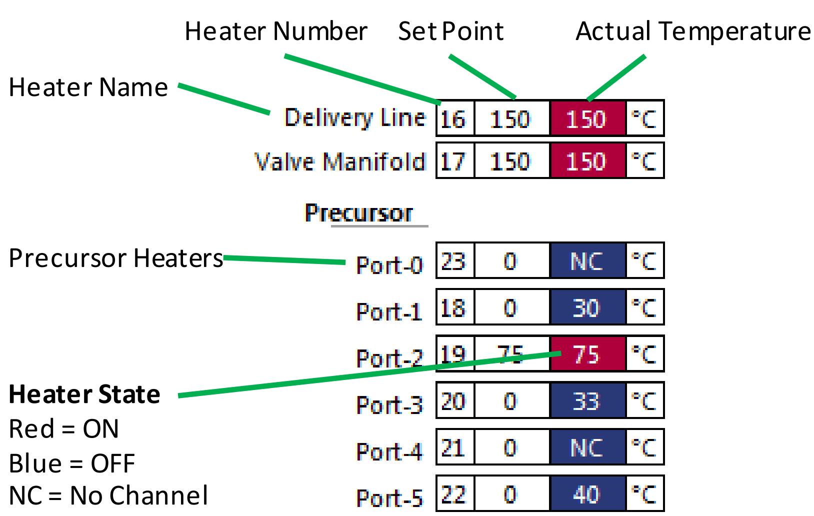


Figure 3-20 – Precursor, precursor manifold, and precursor delivery line heater

3.3.10 Gas Mass Flow Controller Interface

In the upper right corner of the main software screen the Mass Flow Controller (MFC) interface is presented. The MFCs are used to control the gas flow rate into the system. Carrier Ar gas flow (MFC-0) is through the ALD manifold and is recommended to always have a small continuous flow value of >10 sccm. MFC-1,2,3,4,6, and 7 control gas flow through the plasma unit, and MFC-5 is typically used to control O_2 flow into the optional ozone generator.

MFC Name: Identifier of the MFC gas and location. Names are editable in the configuration tab.
MFC Valve: Isolation valves are installed on MFC-2 to MFC-7 and must be open (Green) to flow process gas. These valves are on all non-argon process gasses. These valves can be manually toggled on the GUI.
Set Point: A flow value can be entered as a set point for the corresponding MFC (sccm).
Actual Value: Reports the flow rate of the MFC (sccm).

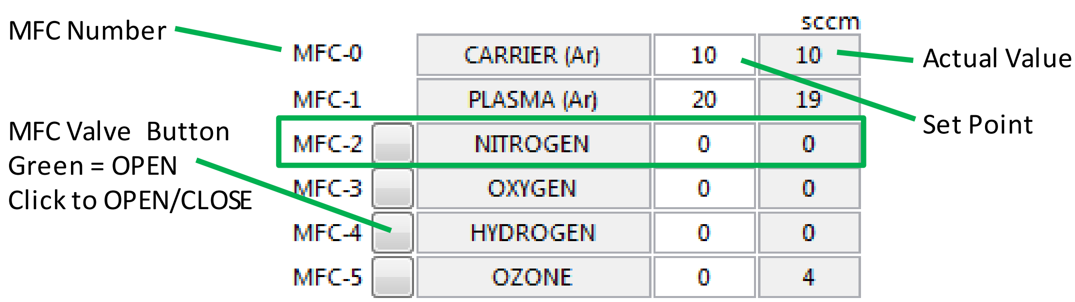


Figure 3-21 – Gas flow interface showing MFC set points and flow rates and shut-off pneumatics controls and statuses.

MFCs are not positive shut-off devices. Therefore a pneumatic shut-off valve is placed downstream of the reactive gas MFCs to prevent small flows of unwanted gas into the plasma source and ALD reactor. All of the non-argon MFCs have dedicated pneumatic shut-off valves downstream of the MFC outlet to prevent trace flows of these undesired gases. The controller/indicator for these valves is to the right of the MFC-# label. The pneumatic shut-off valves can be opened or closed using the “mfc valve” recipe command discussed in section 6.3.10 of this manual.

If your Fiji G2 system has an ozone generator, one of the MFC channels is used to deliver O_2 gas to the ozone generator. The pneumatic actuator for the ozone MFC opens two pneumatic valves: one downstream of the ozone O2 MFC and a second one upstream of the ALD valve used for ozone pulsing to the reactor. The ozone generator option is discussed further in section 8.1.

The Fiji G2 system can handle up to 8 MFCs. Five are standard MFCs (carrier Ar, plasma Ar, N_2, O_2, and H_2) and three optional MFCs for ozone and additional customer selected gases.

3.3.11 Operational Valves and Valve State Indicators

Operational Valves (Toggle Button) can be toggled by clicking on the GUI to manually actuate the valve (Green = OPEN, White = CLOSED).

Valve State Indicators cannot be toggled and indicate the state of the valve (Green = OPEN, White = CLOSED). This applies to ALD valves, Boost™ valves, and LVPD bubble gas valves

Reactor Vent: Opens and Closes the ALD Chamber Vent Valve. It is recommend the automatic Vent procedure, available with the button on the left, be used to vent the chamber.

Plasma Purge Valve: The Fiji G2 has a hardware interlock to protect from flowing incompatible gases simultaneously into the system. This is described in 9.19.1.1. Part of the interlock sequence involves an elevated flow of argon through the system to purge reactive gases. The pneumatic valve which controls the flow of purge gas, described in 2.1.1.1, can be controlled from the software front panel.

Transfer Gate Purge: The transfer gate purge is used to protect the transfer tunnel (LL tunnel and loader tunnel) from precursor and deposition. The recommended flow rate for the transfer gate is 25 sccm (adjusted by needle valve).

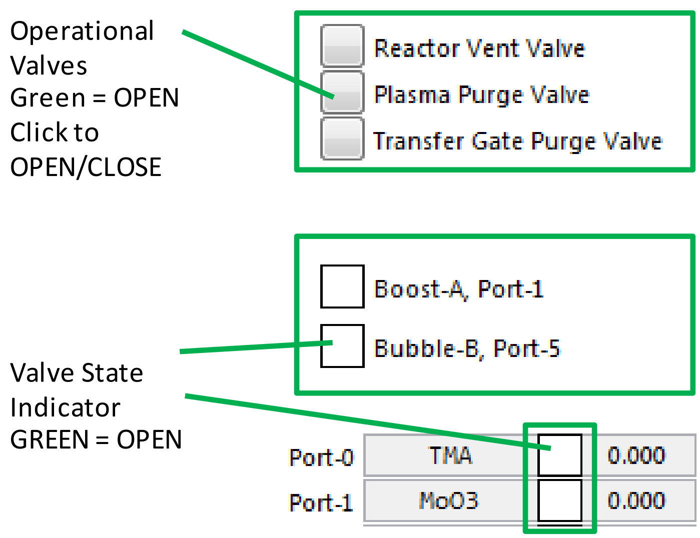


Figure 3-22 – Software operational valve indicators/controllers and valve state indicators.

3.3.12 System Schematic

A schematic of the system is located on the right side of the main software screen. This is shown in Figure 3-23. This area provides the user with a large amount of information and interactive system control. The functions of these items are described below in Table 3-8.

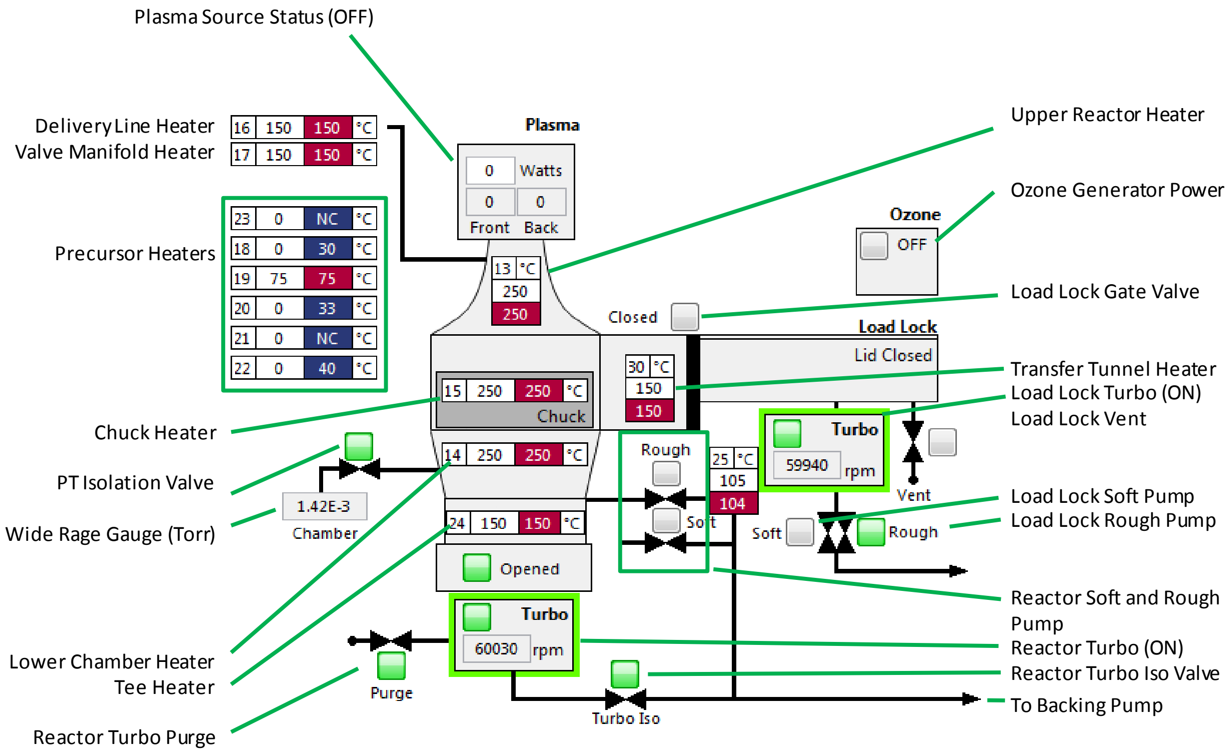
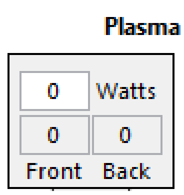
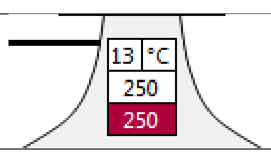
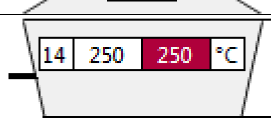
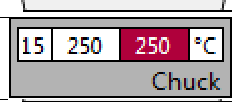
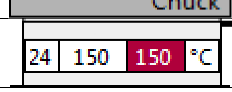
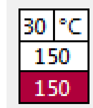
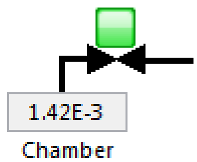
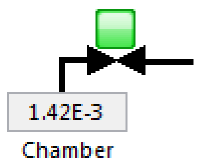
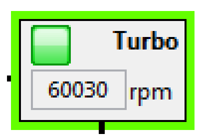
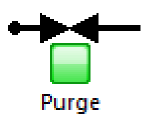
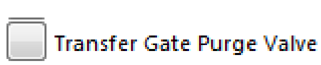
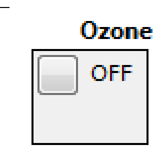
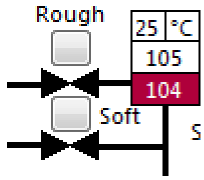
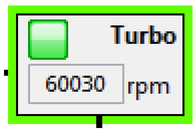
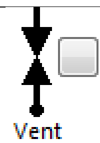
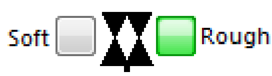


Figure 3-23 – Main software screen system schematic

Table 3-8 – Description of items in the System Schematic on the main screen of the Fiji G2 software.

Plasma Source Information		RF power supply - control and feedback of the plasma source. **RF power** (Watts) set-point can be manually adjusted (0-300 Watts). Green Box = ON During recipe execution, the "plasma" commands set the RF power set-point (Watts). **Front** = Forward power **Back** = Reflected power reported by the RF generator (typically < 15 Watts)
Upper Reactor Heater Controller/Indicator		The upper reactor uses heater #13.(0-300°C)
Lower Reactor Heater Controller/Indicator		The lower reactor uses heater #14. (0 – 300°C)
Substrate Heater Control/Indicator		Substrate heater is heater #15. (0 – 500 °C)
Tee Heater		The Tee Heater uses heater #24 (0 - 150 °C)

Transfer Tunnel Heater		The transfer tunnel (LL tunnel) Heater uses heater #30 (0 - 150 °C)
Reactor Turbo Gate Valve Control/Indicator		Toggle button for the reactor gate valve Green = OPEN and text will say “Opened”. Gray = CLOSED and the text will say “CLOSED”. The gate valve position can also be toggled with a recipe command “Turbo Gate”.
Isolation Valve for the Reactor Wide Range Gauge		Toggle Button of the isolation valve. The wide range gauge on the reactor must be protected from process chemicals so it is placed behind a pneumatic isolation valve. The isolation valve must be opened to measure pressure on the wide range gauge. Green = OPEN Gray = CLOSED
Chamber Pressure Reactor Wide Range Gauge Readout		A digital display shows the current measurement of the reactor wide range gauge. This value is only meaningful when the isolation valve is open (Green).
Reactor Turbo Control and RPM Readout		The reactor turbo can be toggled on/off with the control/indicator or with a recipe command. Green = ON The digital indicator provides a value of the turbo rotation velocity (rpm). 100% = 60,000 rpm Recipe Command “reactor turbo”
Reactor Turbo Purge valve		Toggle button for the turbo purge valve control/indicator. Green = OPEN Gray = CLOSED Recipe Command “turbo purge”
Reactor Turbo Isolation Valve		Toggle button for the turbo isolation valve. Located downstream of the Reactor turbo. Green = OPEN Gray = CLOSED Recipe Command “turbo iso”
Gate Purge Pneumatic Valve Control/Indicator		Toggle button for gate purge valve Green = OPEN Gray = CLOSED Recipe Command “gate purge”
Ozone Generator Control/Indicator		Optional ozone generator control/indicator Green = Power ON Gray = Power OFF

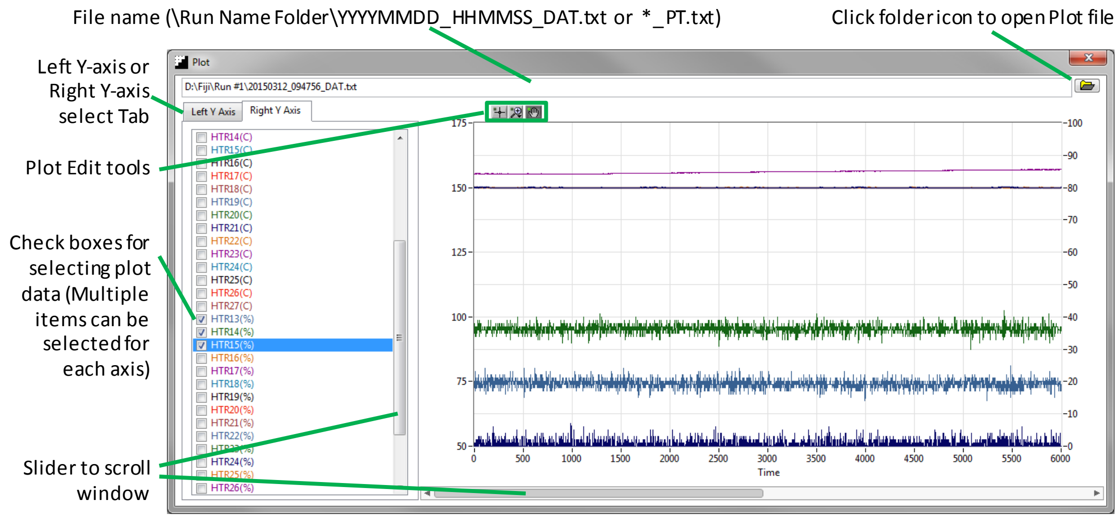
Reactor Soft Pump, Reactor Rough pump, and Tee Heater		Toggle buttons for Reactor Soft pump and Reactor Rough pump. Green = OPEN Gray = CLOSED The Tee (exhaust line) heater. The heater for this region is #25.
Load Lock Turbo Controller/Indicator		If installed, the load lock turbo can be turned on/off with the toggle button. When active, the indicator will be green with a green box around the Turbo. The digital indicator provides feedback on the rotation rate of the turbo pump (rpm).
Load Lock Vent Pneumatic Controller/Indicator		Toggle buttons for the Load Lock Vent. Green = OPEN Gray = CLOSED
Load Lock Soft/Rough Pump Pneumatic Controller/Indicator		Toggle buttons for Soft and Rough pump on the load lock Green = OPEN Gray = CLOSED The load lock pressure is reduced from atmosphere slowly using the soft pump condition to minimize particle agitation and disturbance of samples on the sample holder. After the initial soft pump, pumping is switched to the rough pump setting.

3.4 Log Plotter Utility

To launch the Log Plotter utility, locate either the shortcut on the Windows desktop or (shown below) or in the following location on the hard drive, C:\Program Files\logPlotter. This utility is included and installed on the laptop provided with your system. The utility can also be run on a deskptop computer in the office.

Log Plotter

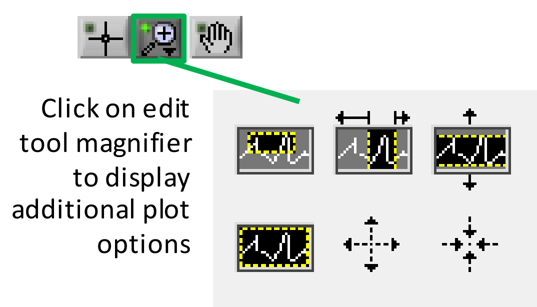
This utility provides the ability to analyze the pressure and data log files (*_PT.txt and *_DAT.txt files) recorded during a process recipe. Selected channels are plotted as a function of time (sec). To open a log file, click on the folder icon  at the top right corner of the window and select the appropriate pressure or data log file. All log files are located in the “C:\Cambridge Nanotech\log\data\” folder. Within this directory the User must locate the folder corresponding to the process run of interest, the all log files associated with the process run are located in these folders. The naming convention for the run folders is as follows, YYYYMMDD_HHMMSS_"Recipe Name".



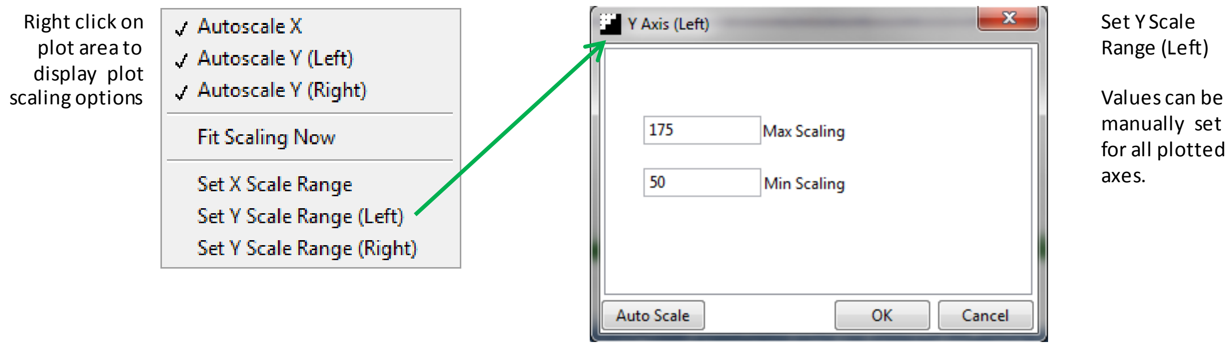
3.4.1 Pressure (*_PT.txt) and Data (*_DAT.txt) files

Data can be plotted on either the left or right Y-axis as a function of time (sec) by selecting the axis tab and checking the desired parameters to plot. The Fiji system has a number of pressure gauges installed. Typically the Process pressure is of greatest interest to view for the process run. With the addition of optional equipment, additional pressure gauges may be installed on your system. The DAT file allows the User to analyze all reported parameters for the process run. These include values for MFCs, Heaters, Plasma, Turbo, etc. For multiple variable analyses, two axis plots are a valuable technique for troubleshooting and optimizing the recipe.

Plot edit tools provide access to a number of tools which allow the User to zoom in and adjust the figure. Each edit tool is selected with a click, and allows the plot to be manipulated by zooming in, cropping the plot, or grabbing the plot and moving in either x or y directions.



Right-clicking on the plot area, yields the following menu for scaling the various axes of the plot window. **Fit Scaling Now** – will automatically re-scale the entire data set. , with a number of a context menu offers several scaling options.



Additionally Max and Min values can be manually entered (typed) on the plot X-axis and Y-axis to modify the plot range.

3.5 Data Logging

The Fiji software automatically logs data for each process run and event logs for all activities. There are four different types of data being logged and saved in the following folder ***C:\Cambridge nanotech\Log*** . The following is a list of these four types:

Event Files
Heater Data
Pressure Data
Reports

3.5.1 Software Data Folder Structure

The following set of directories are created by the installer:

C:\Cambridge Nanotech\configuration	Location of the software configuration files
C:\Cambridge Nanotech\recipes	Location designated for process recipes
C:\Cambridge Nanotech\log\event	Location for all system event logging
C:\Cambridge Nanotech\log\data	Location for all Process recipe data logging

3.5.2 Data logging files and llocation

The Fiji software creates and records event files and process run files to record the activity of the system during Idle time and during process runs. The following log files are created to troubleshoot and optimize the performance of the equipment.

System Event Files		
File Type	**File Name**	**File Directory**
Event File	YYYYMMDD_HHMMSS_EVT.txt	**C:\Cambridge Nanotech\log\event**
Process Run Files		
File Type	**File Name**	**File Directory**
Event report	YYYYMMDD_HHMMSS _EVT.txt	**C:\Cambridge Nanotech\log\data \ YYYYMMDD_HHMMSS _RecipeName**
Data	YYYYMMDD_HHMMSS _DAT.txt	
Pressure data	YYYYMMDD_HHMMSS _PT.txt	
Run summary	YYYYMMDD_HHMMSS _SUM.txt	
Run report	YYYYMMDD_HHMMSS.jpg	

3.5.3 System Event file

This is a text file that records all major events. Every record contains the date and time when it occurred for the entire system state including system idle and system recipe processing. The file is created when the software starts and events are added to it as they occur. The events files are located in C:\Cambridge Nanotech\log\event folder. The following is an example of an event file:

12/07/10 19:41:14: Program Started
12/07/10 19:41:14: System initialized correctly
12/07/10 19:41:30: Heaters On

3.5.4 Process Run Files

All files associated with a process run are located in a process run folder defined by the process run date and recipe name. The folder name structure is:

C:\Cambridge Nanotech\log\data\YYYYMMDD_HHMMSS_"Recipe Name".

The process run files are a very valuable set of data for diagnostics and troubleshooting the system. When seeking assistance from the Veeco Support and Technical team, please forward these files for proper assistance.

3.5.4.1 Event File

The event file (EVT.txt file) captures all of the events associated with a process recipe run . These events are a subset of those recorded by the system event log and capture all of the events that occurred during the recipe.

3.5.4.2 Data File

The process data file (DAT.exe file) logs the MFCs, the heaters, heater duty cycle %, plasma, ozone, turbo, etc. The software logs all system parameters every 2 seconds. This data file is only generated during the process run. The DAT files are named by the date and are placed in the process run folder.

3.5.4.3 Pressure Data File

The software logs the pressure (PT.txt file) with a time stamp every 0.15 seconds. This data file is only generated during a process run. This is the actual data that you see in the real time software display during a run. When you plot this data you can see your pressure peaks and process pressure during the run as measured with the Process pressure (Pirani stype) gauge.

3.5.4.4 Run Summary File

The run summary (SUM.txt file) contains a top level summary of the process recipe, recipe run statistics, parameters, system configuration, and the status of run completion. This file is designed to be an overall run summary for evaluating the success or failure of a process run.

3.5.4.5 Run Report File

The software takes a screen capture at the end of every run (YYYYMMMDD_HHMMSS.jpg). The software stores this screen capture in C:\Cambridge Nanotech\log\ data\YYYYMMDD_HHMMSS_RecipeName\. These screen shots can be quite useful and is a quick check that the user can do before they would review the other run summary data files.

3.6 Modifying the config.ini file

The config.ini file is located in C:\Cambridge Nanotech\configuration folder. This file is meant for the experienced user and Support Engineer. Do not attempt to change this file unless you have consulted the Technical support team at Veeco / Cambridge Nanotech.

Be sure to make a back-up copy of the original config.ini file before editing, incase the file is un-intentionally modified or corrupted.

4 Fiji G2 Start-up Procedure

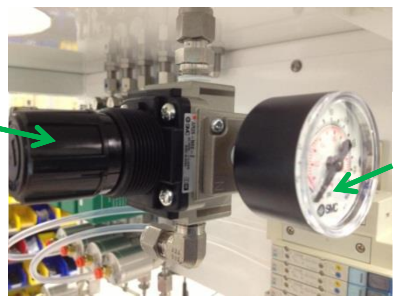
Congratulations on your purchase of the Veeco Fiji G2 plasma enhanced atomic layer deposition system. In this section we will guide you through the start-up process to get your system up-and-running as fast as possible. These guidelines assume the tool has been installed according to the instructions in chapter 11 - Installation.

4.1 Gas Supplies De-Energized Before Start-up

All gas line seals and fittings must be verified as leak tight with a leak test prior to system start up.

All gas supplies should be de-energized prior to system start-up. This includes the gas used for pneumatic actuation of system valves. A small regulator inside the system gas box shows the pressure of the actuation gas. This regulator in a de-energized state is shown in Figure 4-1.

Pressure adjustment knob. Pull out to adjust. Push in to lock.



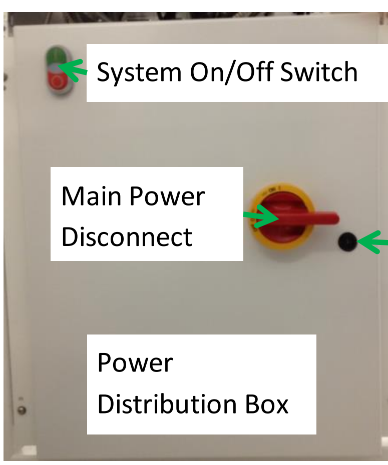
De-energized pneumatic actuation gas regulator. P = 0

Figure 4-1 – Deenergized pneumatic gas supply

The pneumatic actuation gas regulator pressure set-point should be turned all the way down before turning on pneumatic gas to the system. To turn the set-point down, pull the knob out and rotate counter clockwise until the knob spins easily.

4.2 Turn on the Power Distribution (PD) Box

The PD box is located below the gas box on the rear of the system. Here it is shown in the powered down state.



Door Latch

Figure 4-2 – Power Distribution Box (PD box).

The PD box should be closed with the door latch after the system wiring is completed. The door latch can be turned with a flat head screwdriver. With the door closed, the red handled Main Power Disconnect can be turned to the “On” position. With the Main Power Disconnect in the “On” position, the door cannot be opened. The Main Power Disconnect can also be used for Lockout/Tagout procedures.

The green and red buttons in the upper left corner of the PD box are the On/Off buttons. Pressing the green “|” button will cause power to be delivered to the Fiji G2 hardware. When powered, the area between the green and red buttons will illuminate. To stop delivering power to the hardware, press the red “O” button.

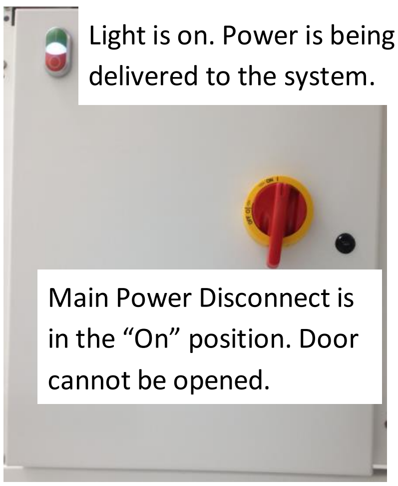


Figure 4-3 – Powered on PD box.

4.3 Turn on the computer

The computer must be turned on prior to applying power to the E-box to ensure proper loading of the E-box device drivers. The computer is located inside the drawer above the E-box. If the drawer is closed, push the tabs inwards on the two locking mechanisms and pull the drawer open.

Figure 4-4 – Computer drawer.

Open the lid of the laptop and press the power button to begin the computer boot up process.

4.4 Turn on the Electronics Box (E-box)

When the computer has finished booting, turn on the E-box. The components of the electronics rack are shown in Figure 2-8. The E-box is a black box located in the electronics rack beneath the laptop drawer. The E-box has a single orange On/Off switch on the left side and a cooling vent in the middle. Actuate the On/Off switch by pressing it to the “|” position. The switch will illuminate indicating power is being delivered to the E-box.

4.5 Turn on RF Electronics

There are two items in the electronics rack associated with the plasma source: the RF power supply and the matching network controller. Each of these has a dedicated front panel On/Off button. When turned On the displays on both devices will illuminate. If the RF generator does not turn on, check that the additional On/Off rocker switch on the back of the RF generator unit is set to the on position.

4.6 Start the Software

Start the Fiji G2 software by double clicking the desktop icon with the Veeco stepper logo, shown to the right. The software will take a few moments to load and then the user will be presented with a screen similar to the one in Figure 4-5.

Fiji

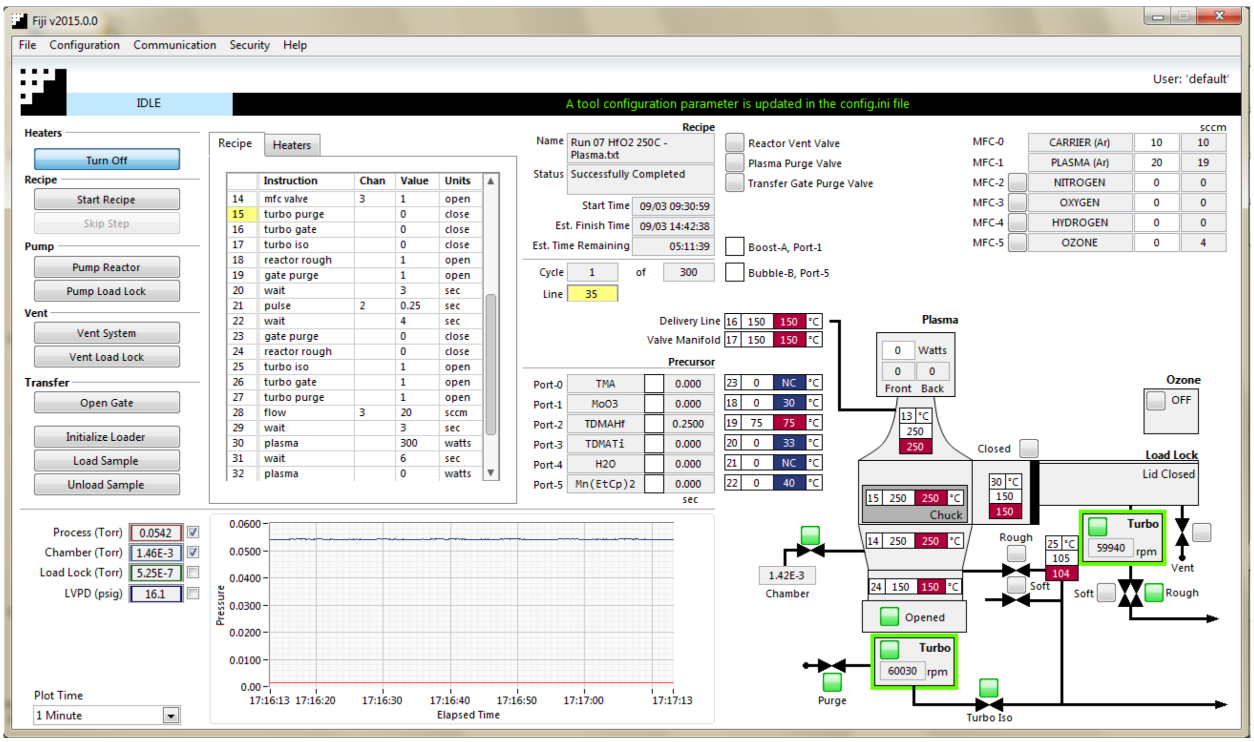


Figure 4-5 – Fiji G2 software screenshot.

4.7 Verify Plasma and Turbo Water Supply

The Fiji G2 plasma source requires a flow of cooling water to maintain proper operation. Water connections are made through the facility panel on the rear of the machine.

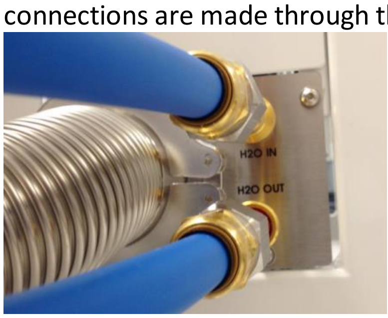


Figure 4-6 – Fiji G2 plasma source cooling water inputs.

The flow detector is direction sensitive, so make sure the water direction indicators “H2O In” and “H2O Out” are observed. The water flow switch is connected to the external hardware interlock on the Seren RF power supply. If the water flow switch is not satisfied, an “EXT” message will illuminate on the front panel of the Seren power supply. Figure 4-7 shows the Seren RF power supply with and without the “EXT” message illuminated.

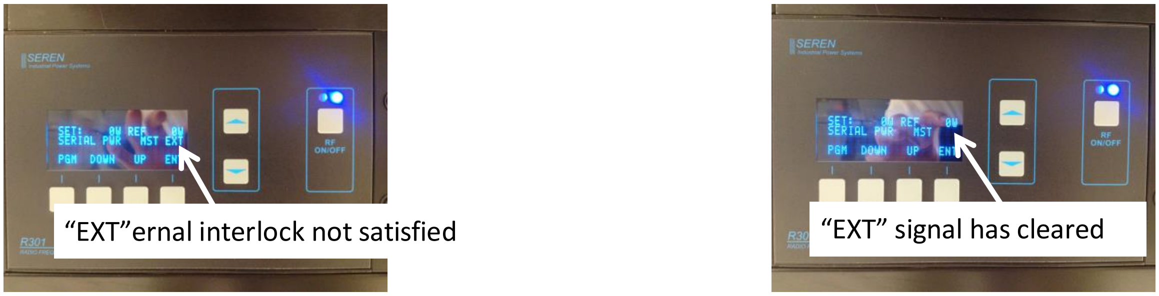


Figure 4-7 – Pictures illustrating the RF power supply with and without the “EXT” external interlock message illuminated on the front panel. When “EXT” is displayed, the plasma source water switch is indicating insufficient water flow.

4.8 Initialize Reactor Gate Valve and Pneumatic Actuation Gas

The main reactor gate valve requires a start-up procedure to maintain pressure balance between the pressure on two sides of the air piston which opens and closes the valve.

Safety intelocks built into the software need to be bypassed during this section of the start-up procedure. This can be done safely because the entire system is vented to atmosphere and the vacuum pumps are all off with all vacuum lines vented. If the system is being restarted check that the vacuum pumps are all off and the vacuum lines to the system are fully vented.

Remove the front panel from the system and disconnect the cables from the reactor pressure gauges as shown in Figure 4-8.

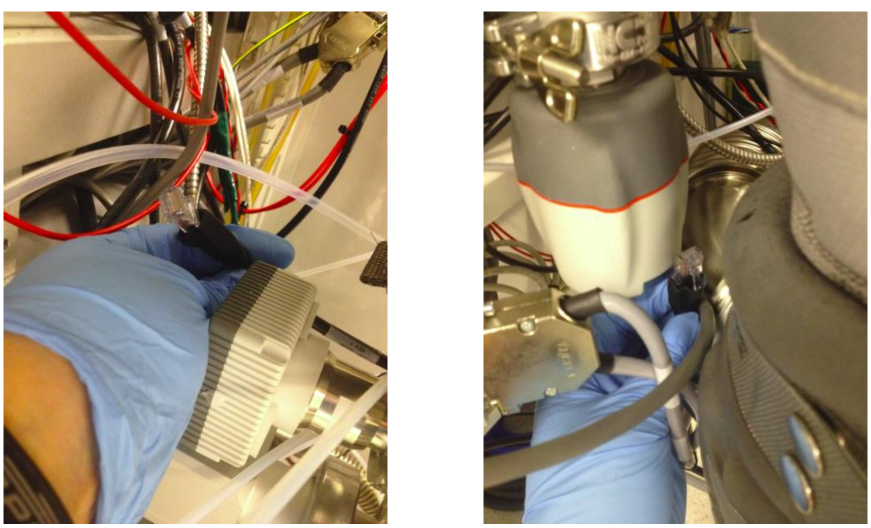


Figure 4-8 – Remove the Ethernet cables from the two reactor pressure gauges to bypass interlocks during system start-up.

Whenever the system loses pneumatic gas pressure, this procedure should be repeated. If this procedure is done when the argon line is energized, the normally open argon supply valve which is part of the O_2/H_2 interlock will open and argon will flow into the reactor until the pneumatic actuation gas pressure increases to a level that will close the normally open valve.

Make sure the pneumatic actuation gas regulator is set to 0 as described above in the 4.1 Gas Supplies De-Energized Before Start-up section before turning on the pneumatic actuation gas to the system. Turn on pneumatic actuation gas to the system. In the following procedure use the Reactor Turbo Gate Valve Control/Indicator shown below in Figure 4-9.

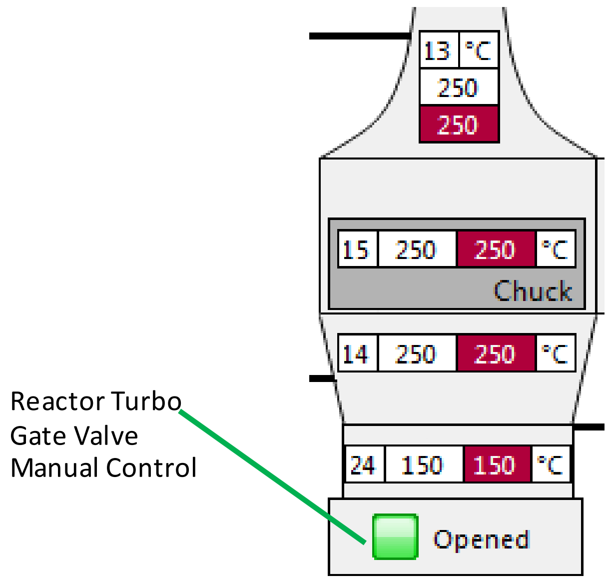


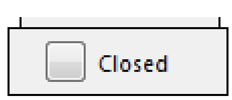
Figure 4-9 – Reactor turbo gate valve control/indictor

The software will not allow the reactor gate valve to be opened unless the turbo isolation valve is open. The turbo isolation valve appears below and to the right of the reactor graphic. When it is closed the valve will appear as: 

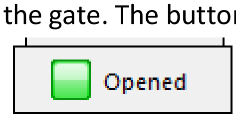
. On the software screen, press the grey box above the Turbo Iso valve.

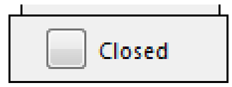
The box will turn green, 

, but you will not hear any actuation because the pneumatic actuation gas is currently turned off. Now the start-up procedure for the reactor gate valve can proceed.

1. At the start, the gate valve is closed. 

2. Pressing the grey button next to the "Closed" text will switch the gate valve pneumatics to open the gate. The button will change to a green color and the text will change to "Opened".



3. Increase the pneumatic actuation gas pressure by 5psi.
4. Switch the gate valve pneumatics to close the gate.
5. Switch the gate valve pneumatics to open the gate.
6. Repeat steps 3-5 until the pneumatic gas actuation pressure is 70psig. Do not exceed 70psig on the pneumatic gas actuation pressure regulator.
7. Before proceeding make sure the gate valve is closed 

and the turbo isolation valve are closed.
8. Reconnect the Ethernet cables to the reactor pressure gauges.

4.9 Turn on Gases to the System

At this point it is safe to turn on process gases to the Fiji G2 system. Note: as stated above all input lines must be verified as leak tight with a Helium leak detector or other method before pressure is applied to the lines. Maximum gas pressure for the Fiji G2 system mass flow controllers is 50psig. Do not exceed 50 psig gas delivery pressure to the system. Veeco recommends a gas delivery pressure of 30 psig for standard gases, except for Hydrogen which must be at 3 psig. Some of the system purges are based on gas flow through an orifice or needle valve and at pressures significantly higher than 30psig, these orifices or needle valves may require adjustment from factory settings.

4.10 Verify Load Lock/Reactor Door is Closed

The default Fiji G2 configuration includes a load lock. At this time make sure there are no foreign materials in the load lock and verify that the door is closed.

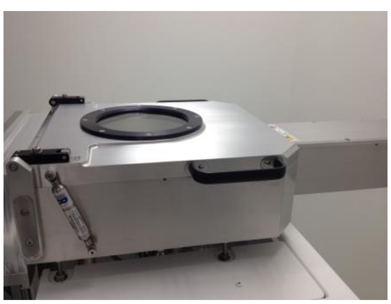


Figure 4-10 – Fiji G2 load lock with door closed.

If your system is not configured with a load lock, make sure the reactor door is installed and in the closed position.

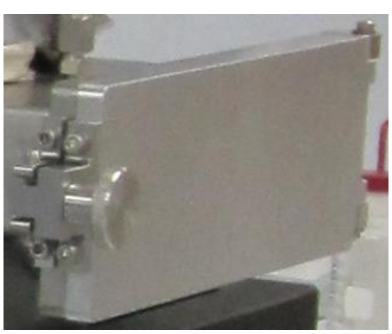


Figure 4-11 – A closed reactor door on systems without a load lock.

4.11 Verify Valves Closed

Verify that the software is reporting the following valves as being closed (Button is grey, not green): the Reactor Rough and Soft pump valves, the reactor Turbo Iso valve, and the Load Lock Rough and Soft pump valves.

4.12 Turn on Main System Dry Pump

Turn on the main system dry pump according to the instructions supplied with the pump.

4.13 Turn on Load Lock System Dry Pump

If your Fiji G2 system is configured with a separate dry pump for the load lock, turn it on now following the instructions which accompanied the pump.

4.14 Rough Pump Main Reactor

We are now ready to rough pump the main reactor. If the system does not have a load lock, make sure the reactor door is closed. If the system does have a load lock, make sure the load lock gate valve is closed. (See Figure 4-12 below).

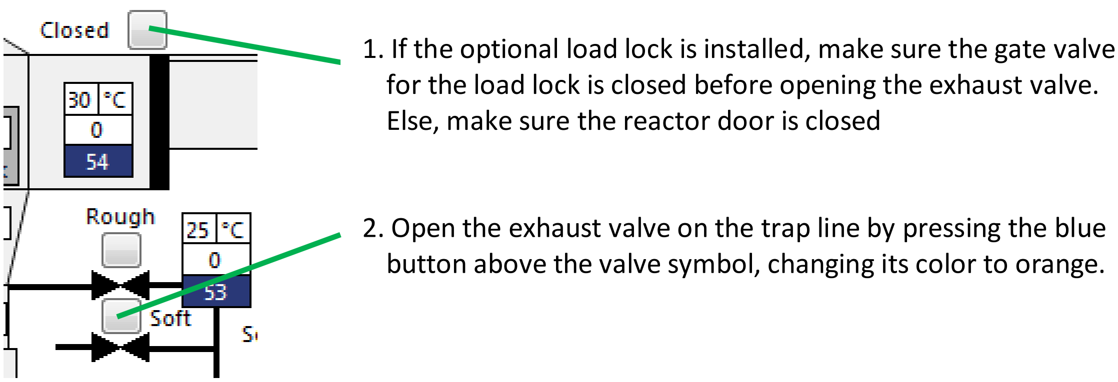


Figure 4-12 – Section of the main software screen depicting the graphical buttons for the load lock gate valve and the main chamber soft and rough pumpexhaust valve.

Open the Reactor Soft pump by clicking on the grey button above the Soft valve in the on-screen schematic.

The sound coming from the vacuum dry pump will briefly change as the pulse of atmospheric pressure gas is pumped from the system. The pressure in the reactor will quickly drop and approach the base pressure of the vacuum pump (10’s mTorr). If the start-up procedure is repeated in the future, the base pressure from the reactor pressure gauge may be different due to pump condition, pump purges, and deposits on the pressure gauge.

When the reactor pressure has dropped below 0.100 Torr close the Soft valve and open the Rough valve. When the reactor base pressure has stabilized <50mTorr, you are ready to proceed to the next step.

4.15 Start Reactor Turbo Pump

Guidelines for starting the reactor turbo are shown below in Figure 4-13. The reactor can be pumped through either the turbo pump line or the rough pump line, but not both at the same time. Before we can begin using the turbo pump, we must close the rough pump line. Click on the green button above the Rough pump valve, closing it and turning the button grey.

1. Open the Turbo Iso valve. Any gas that had been trapped between the gate valve and the turbo isolation valve will now be evacuated.
2. Open the reactor turbo gate valve.
3. In the box labeled "Reactor Turbo" there is an rpm indicator and an ON/OFF button. The rpm indicator indicates the rotation rate of the turbo pump in revolutions per minute. Currently the turbo is stopped so it will indicate 0 rpm. Pressing the grey button will turn the turbo pump on. The rpm indicator will increase until it reaches full speed at 60000rpm. It is normal for the pump to report values slightly lower than the rated 60000rpm while operating at full speed. When the turbo is turned on, the turbo purge will automatically open.

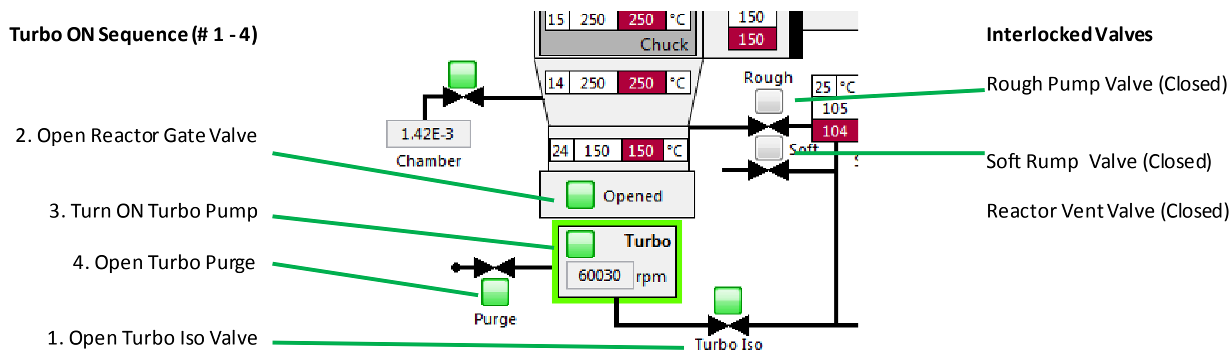
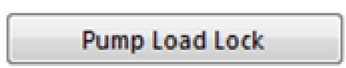


Figure 4-13 – Procedure for starting the reactor turbo pump.

4.16 Rough Pump Load Lock

The load lock is pumped through a two stage (soft/rough) valve. If your system is configured with a load lock turbo pump, the load lock is rough pumped through the turbo. The two stage valve allows the load lock to be pumped out in two stages.

Make sure the load lock door is closed . Press the 

on the left side of the screen. This starts a sequence which soft and rough pumps the load lock and turns on the turbo pump, if present.

4.17 Turn on Heaters to Standby Values

ALD processes typically operate above room temperature. Keeping the reactor hot will minimize gases adsorbed onto the walls that could impact the ALD process and the resulting film properties. The Fiji G2 has up to 18 controlled heater channels. The default heater configuration is listed in Table 2-1.

Setting the heaters set-points from the main system software screen can be done three different ways as shown in Figure 4-14. In the upper left of the screen there is a "TURN HEATERS ON" button. Pressing this button will set all the heater values to the default values which are set in the system initialization file or on the heaters configuration pop-up window discussed in 3.3.2.3.3. Alternately, in the center of the screen is a section that either displays the heater information or the currently loaded process recipe, depending on which tab has been clicked. Finally, the heater indicator/controllers placed on the system schematic can also be used to control the heaters.

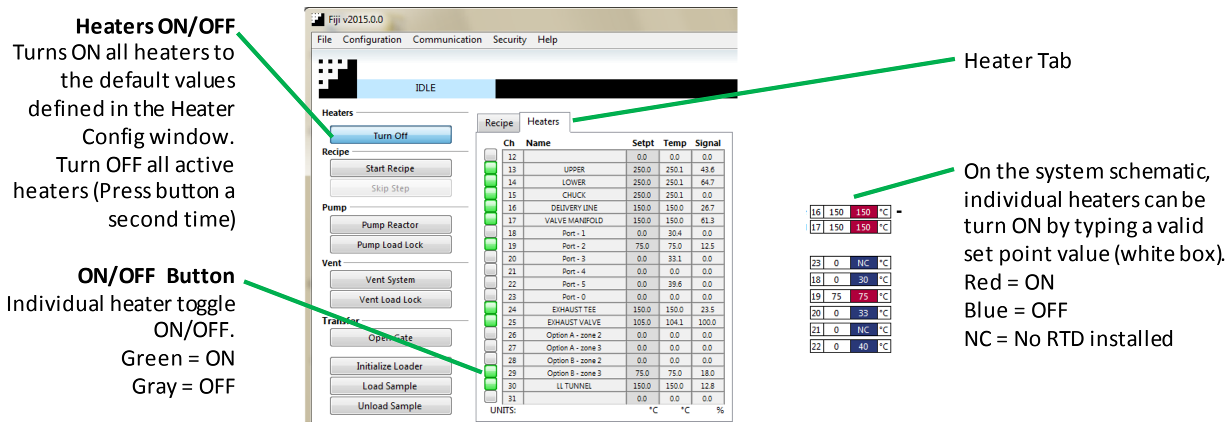


Figure 4-14 – Descriptions of three techniques for working with heater set-points from the main software screen.

4.18 Turn on Gas Flows to Standby Values

Similar to the logic regarding keeping the system hot, maintaining a small flow of gas through the system helps keep it at peak performance by minimizing any condensables in the system. Hot walls and flowing gases under vacuum conditions help to sweep these undesirable species out of the system. The Fiji G2 system reactor has gas flows originating from three locations: the precursor carrier gas from the manifold, the plasma gases, and the door purge gas. Here, we will set these gas sources to standby values. Standby gas flows may already be active due to Reactor or Load Lock pump sequences activated by buttons along the left side of the screen. Standby flow values are established in the "Pump" tab of the "System" menu described in 3.3.2.3.2.

The precursor manifold is only plumbed with argon. 2.5sccm per ALD valve is recommended. A standard 4-port manifold should have a 10sccm purge while an upgraded 6-port manifold should have a 15sccm purge.

The plasma source has several gas sources typically including: argon, nitrogen, oxygen, and hydrogen. The purge gas from the plasma source should be inert which leaves us with a choice of argon or nitrogen. Nitrogen is typically much cheaper than argon, so it is the more prudent choice for the plasma source purge gas. Turning on the nitrogen is a two-step process. First, the pneumatic isolation valve downstream of the nitrogen mass flow controller must be opened. In the upper, right corner of the screen is the plasma gas informational box as described in 3.3.10. The buttons down the left side are the pneumatic isolation valves for the non-argon gases. Pushing the appropriate grey button, turning it green, opens the pneumatic isolation valve for that gas. To the right of each gas name are two boxes.

The darker box is the adjustable set-point and the lighter color box is the measured flow rate reported from the mass flow controller.

Open the nitrogen pneumatic isolation valve by pressing the grey button to the left of the Nitrogen label in the plasma gas information box. If the Fiji G2 is in a quiet location, you may here the pneumatic valve opening. A small quantity of gas will likely be trapped between the MFC and the pneumatic isolation valve resulting in a slight pressure transient as the trapped gas is pumped through the system. Now, use the mouse to click in the dark box next to the Nitrogen label. Adjust the value in the box to 50 to set the nitrogen flow to 50sccm. If the value in the light colored box does not rise to about 50 in a couple seconds, nitrogen might not be supplied at a sufficient pressure to the system or the pneumatic actuation gas is insufficient to open the pneumatic isolation valve. Double check that the nitrogen supply to the Fiji G2 is set to 30psig and the pneumatic actuation gas is at 70psig.

4.19 Set Gate Purge

The portion of the reactor through which the sample holder passes when loading and unloading is purged with an argon flow during processing. The gate purge flow is turned on and off with a pneumatic valve and the flow rate is controlled with a needle valve. These parts are shown in Figure 4-15. The gate purge will have been set at the factory, but because a different argon pressure may have been used, it is a good idea to verify the gate purge flow rate before starting to use your new system and whenever the system argon delivery pressure may have changed.

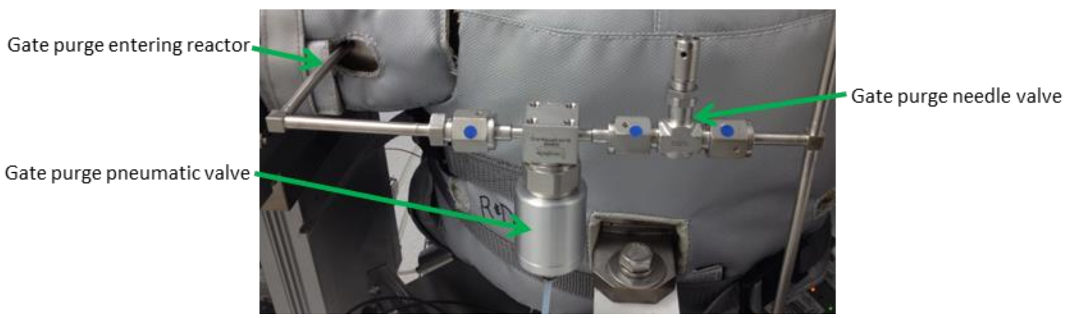


Figure 4-15 – Valves and tubing for gate purge.

Use the following procedure to set the gate purge flow rate.

1. Turn off all gas flows and purges to the reactor.
2. Set the system pumping through the exhaust valve.
3. Open the PT Isolation Valve to allow reading of the Wide Range Gauge as shown in Figure 3-23.
4. Set the carrier Ar MFC to 25sccm.
5. Note the pressure indicated on the reactor wide range gauge.
6. Set the carrier Ar MFC to 0sccm.
7. Open the gate purge pneumatic by clicking the Transfer Gate Purge Valve discussed in 3.3.11.
8. Adjust the gate purge needle valve so the indicated wide range gauge pressure is equal to the value reported when flowing 25sccm carrier Ar.
9. Close the gate purge pneumatic by clicking the Transfer Gate Purge Valve.

5 Fiji G2 System Operation

Under normal conditions, operation of the Fiji G2 system is straightforward.

1. A precursor cylinder containing the appropriate precursor for the desired thin film deposition process must be installed on the precursor manifold.
2. The substrate to be coated must be loaded into the reactor via the reactor door or the load lock.
3. A recipe is entered or loaded from a saved file.
4. The recipe is executed.
5. The substrate is removed from the reactor.

In this chapter, these standard operating procedures are discussed.

5.1 Precursor installation and removal

The precursor cylinders are filled under inert atmosphere, such as in a glovebox, by the chemical supplier or a trained individual at your facility. Never disconnect manual valves from the precursor cylinders outside of a controlled, inert atmosphere such as that found in a glovebox. Always make sure the precursor cylinder manual valve is closed when disconnecting from the Fiji G2 precursor manifold.

The Fiji G2 system will ship with as many precursor cylinders as there are ALD valves on the precursor manifold. One of the cylinders will not have a manual valve, which is used for water. The remaining cylinders all have manual, bellows-type valves (Swagelok part SS-4H-VCR). In order to minimize the exposed internal area that can accumulate precursor (and can contribute to clogged valves), the arrow on the side of the valve should be pointed toward the chemical side of the cylinder assembly.

5.2 Precursor Cylinder Replacement/Installation Procedures

Precursor cylinders containing the appropriate chemistry for the desired process must be installed on the system's ALD valves prior to starting the deposition recipe.

5.2.1 Safety Cautions

	**WARNING: CHEMICAL HAZARD!** Wear chemical-resistant garments and eye protection while performing system maintenance. Avoid skin contact and inhalation of any component exposed to process chemicals/gases. NEVER open a precursor cylinder unless it is properly attached to a degassed plumbing system.
	**WARNING: BURN HAZARD!** Allow system components to properly cool prior to performing maintenance to avoid personal injury.
	**DANGER: FIRE HAZARD!** Follow instructions carefully. Never open any valves until specifically directed to do so. Certain precursors will ignite upon exposure to air. Some precursors, such as Trimethylaluminum (TMA), are pyrophoric and will ignite upon exposure to air. TMA reacts with water vapor in the air. For this reason, the TMA bottle may only be opened in a glove box with inert atmosphere by experienced professionals such as at the chemical supply companies (Strem, Sigma-

	Aldrich etc). Note: Not all Precursors need to be heated and TMA should NOT be heated.

5.2.2 Required Parts

Part Number	Description	QTY
SS-4-VCR-2 **or** **SS-4 VCR-2-GR (with retaining clip)**	**¼” metal VCR gaskets**	**1 per bottle**

5.2.3 Required Tools

- ¾” open end wrench for turning the VCR connection
- 13/16” open end wrench for holding the manual valve on the precursor cylinder. Precursor cylinders purchased outside of the USA may have a different, metric sizing for the manual valve base.
- (for H_2O cylinder only) 5/8” open end wrench for holding the VCR connection on the water bottle

5.2.4 Removing Precursor Cylinder

If a precursor cylinder becomes empty or an ALD valve must be freed up to make room for a different chemistry, the precursor cylinder must be removed. It is also recommended to remove precursor cylinders in the event that the Fiji G2 system must be shut down for a period of time.

It is best practice to begin the precursor cylinder removal process with the precursor cylinder at its process temperature and the Fiji G2 system running. Below are procedures for cylinder removal. Figure 5-1 depicts several precursor cylinders installed on a Fiji G2 precursor manifold.

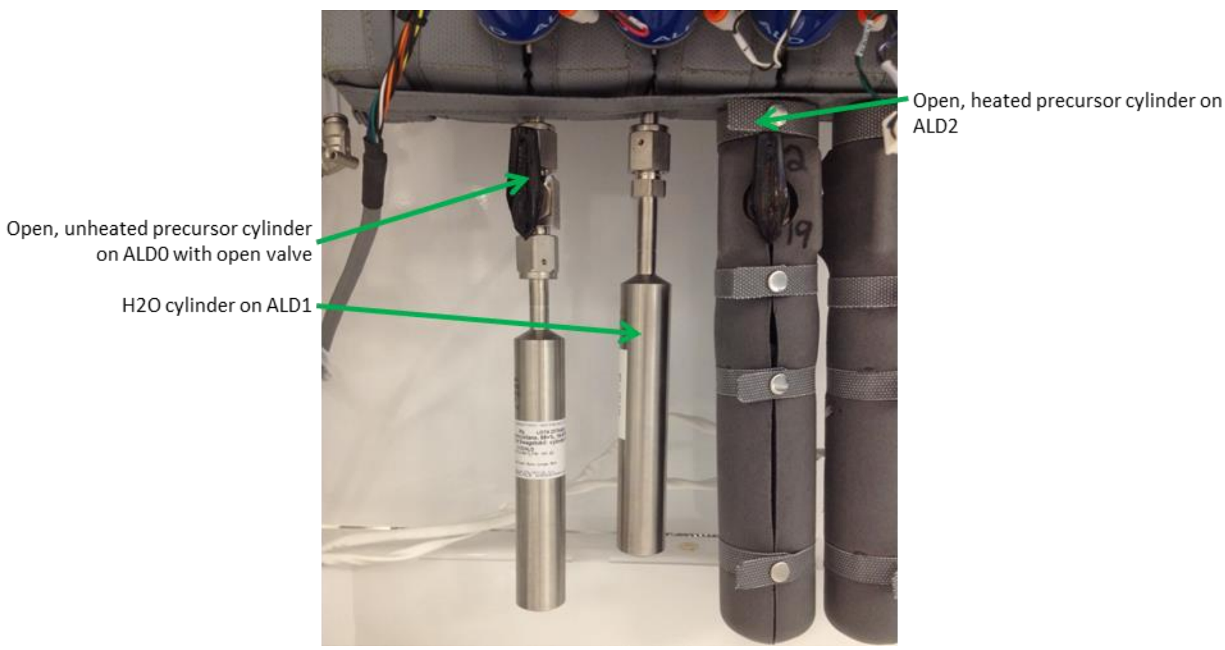


Figure 5-1 – Precursor cylinders installed on the precursor manifold with open manual valves.

5.2.4.1 Close Precursor Cylinder Manual Valve

The first step in removing a precursor cylinder from the ALD manifold is to close the manual valve. Close the manual valve by turning the valve handle clock-wise. Green handled, high temperature bellows valves screw down several turns before being closed. Do not over tighten. Black handled, low temperature valves will turn 90° and stop. The unheated precursor cylinder shown in Figure 5-1 has had its manual valve closed in Figure 5-2.

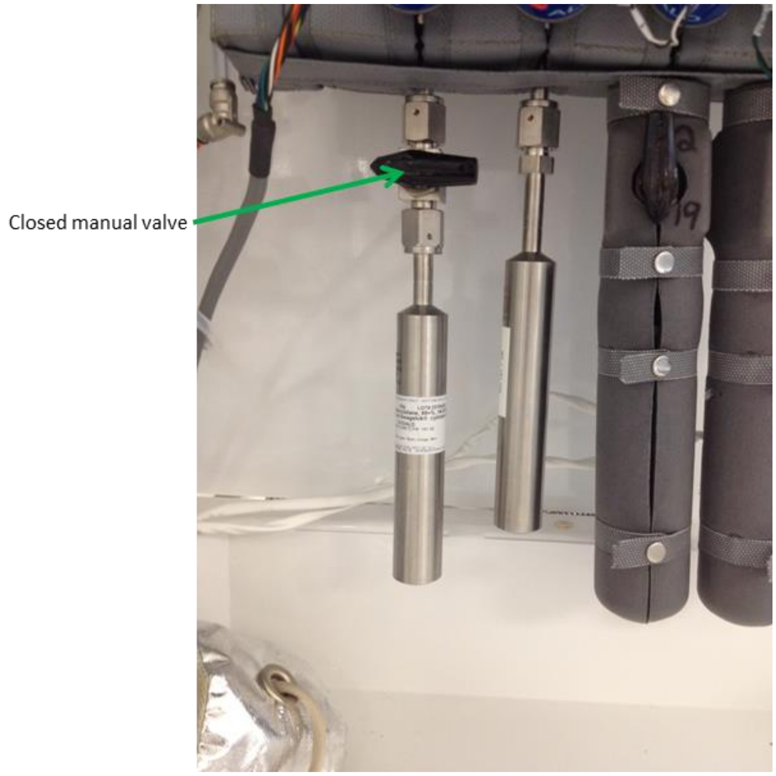


Figure 5-2 – Depiction of precursor cylinder with the ¼-turn manual ball valve in the closed position.

The water cylinder does not have a manual valve. Since the water and water vapor in the cylinder do not pose any risks, the water cylinder can be removed anytime a recipe is not being run.

5.2.4.2 Evacuate Headspace

Prior to disconnecting the precursor cylinder from the ALD valve, the precursor material trapped between the cylinder manual valve and the ALD valve needs to be evacuated. The process must be done with the precursor cylinder at its recommended process temperature to ensure precursor in the trapped volume is in the vapor phase.

With the precursor cylinder at process temperature and the manual valve closed, run a short recipe to pulse the ALD valve a series of times to evacuate any trapped material. An appropriate recipe is shown in Table 5-1.

A sample pressure transient is shown for the pulse purge of the trapped precursor prior to removal of a tris(dimethylamido)silane (3DMAS) cylinder. Depending on the vapor pressure of the material, the pulse height may be considerably larger or so small as not to be observable. Even after the pulse height has been reduced below the observable threshold, at least ten additional pulse/purge cycles should be completed to minimize the amount of material exposed to atmosphere.

Table 5-1 – Recipe for pulse purging prior to removal of precursor cylinder from ALD valve. This recipe is also appropriate for removing air from between the ALD valve and the precursor cylinder manual valve after precursor cylinder installation.

	INSTRUCTION	CHAN	VALUE	UNITS	
0	turbo gate		0	close	Lines 1-4 switch pumping to rough pump line.
1	turbo purge		0	close	
2	reactor turbo		0	off	
3	turbo iso		0	close	
4	exhaust valve		1	open	
5	flow	0	20	sccm	Set pulse purge flow rates.
6	flow	1	30	sccm	
7	gate purge		1	open	Turn on gate purge.
8	wait		10	sec	
9	pulse	0	1	sec	Pulse ALD valve 0 for 1 second.
10	wait		10	sec	Wait 10 seconds.
11	goto	9	20	cycles	Repeat the 1s pulse/10 second wait 20 times.

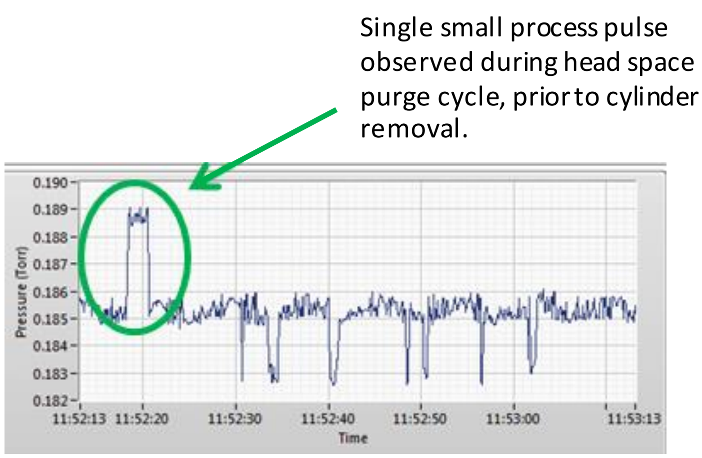


Figure 5-3 – Depiction of the single, small precursor pulse observed during the purge process prior to cylinder removal.

5.2.4.3 Disconnect Precursor Cylinder

After the precursor cylinder headspace has been evacuated, any heater jacket installed on the cylinder should be turned off (temperature set point set to 0) and removed. Hot cylinders can cause burns when handling, so it is recommended the cylinder be allowed to cool prior to removal. Once the cylinder has achieved a manageable temperature, the cylinder is ready to be removed from the ALD valve. Removing the precursor cylinder requires two open end wrenches: a 13/16” wrench to hold the body of the precursor cylinder manual valve and a ¾” wrench to turn the ¼” VCR nut. Be very careful not to accidently disconnect the precursor cylinder body from the manual valve by loosening the incorrect VCR connection below the manual valve.

To minimize potential damage to the sealing surfaces on the ALD valve and the precursor cylinder manual valve, every effort should be made to turn the VCR nut while holding the valve body still. If the valve body is turned during the removal or installation procedures, the sealing surfaces will be ground against the VCR gasket, possibly creating seal damage which could lead to leaks. Since the precursor vapor pressure is sub-atmospheric, a leak at the precursor manual valve/ALD valve interface will result in air leaking into the precursor cylinder, likely damaging the chemicals contained within.

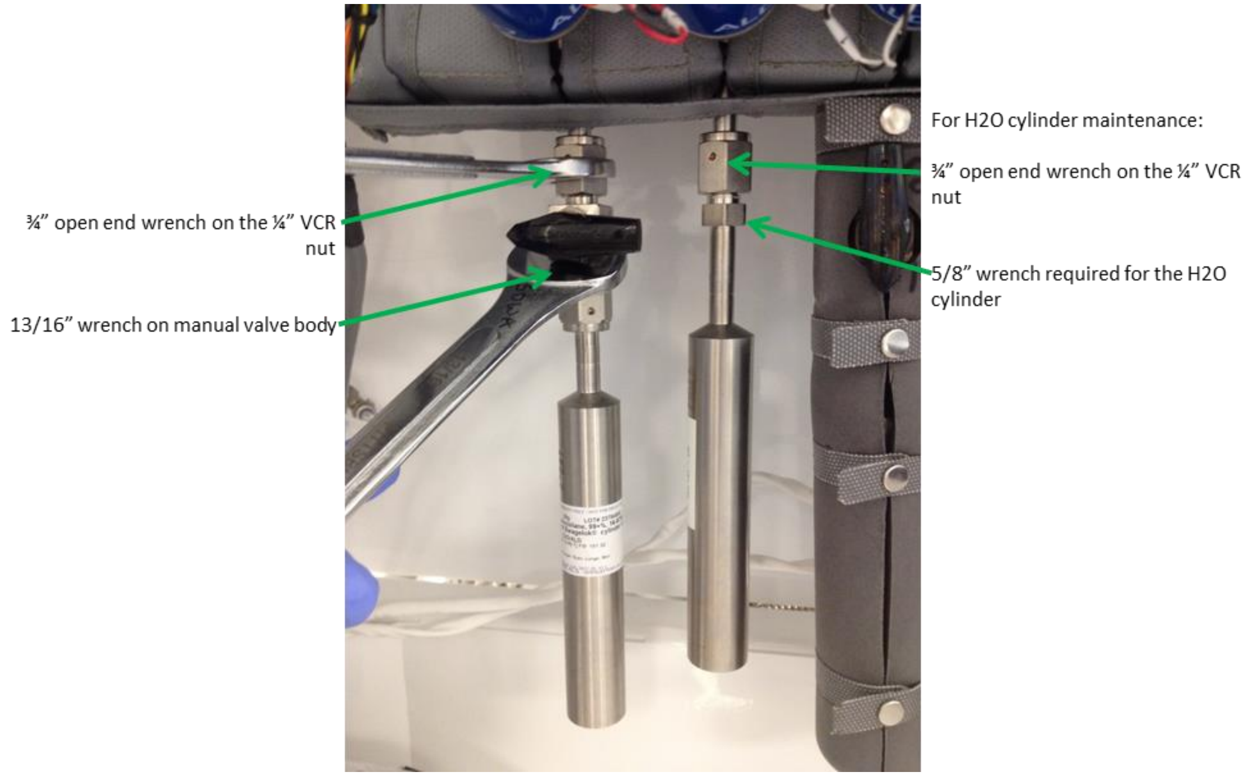


Figure 5-4 – Wrench positioning details for the removal/installation of precursor cylinders on the Fiji G2 manifold.

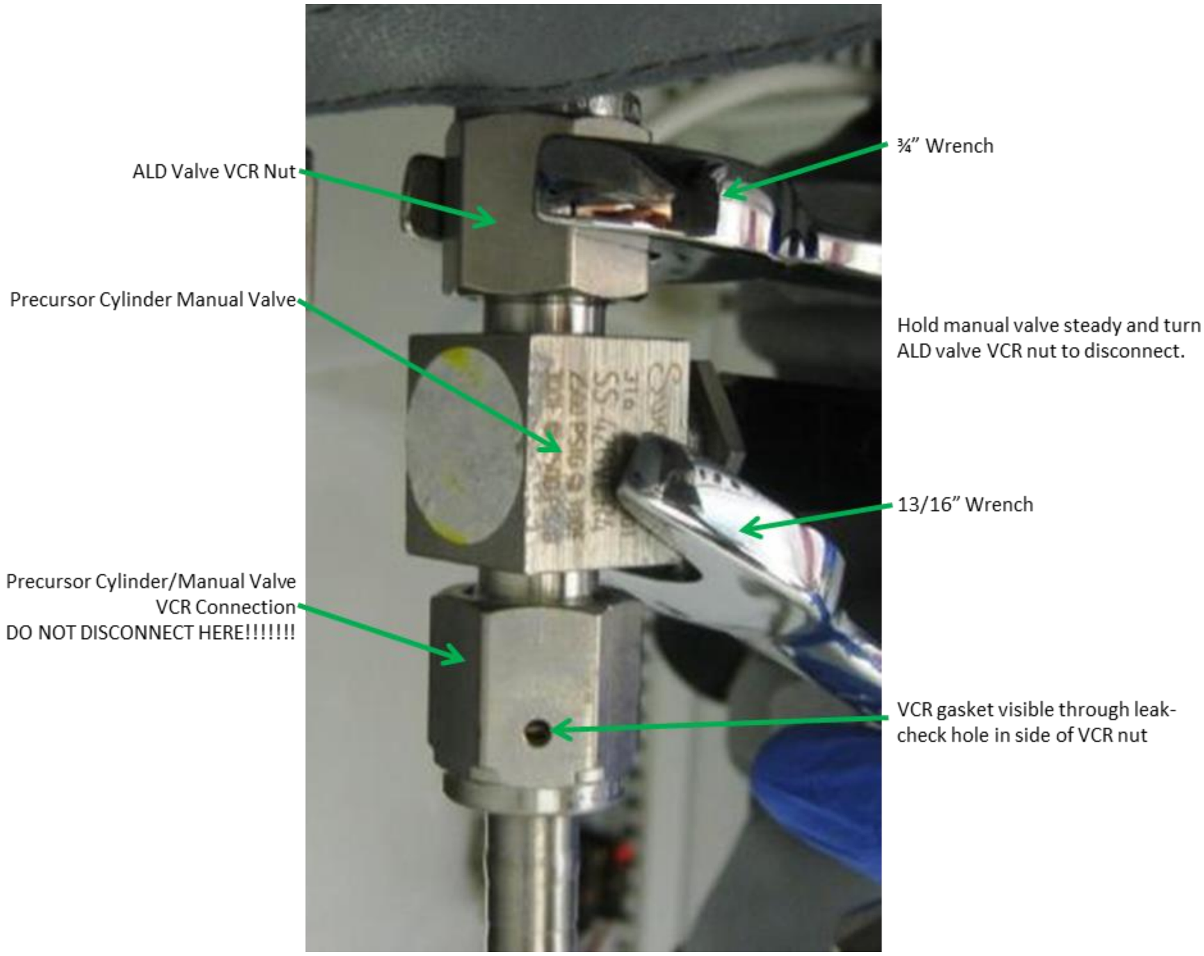


Figure 5-5 – Close-up of wrench positioning for installation and removal of precursor cylinder on an ALD valve. While holding the manual valve still with a 13/16" wrench, loosen the ¼" VCR nut with a ¾" wrench. Do not loosen the ¼" VCR nut below the manual valve, as this will expose the precursor to air.

5.2.5 Weighing Precursor Cylinder

It is a good practice to weigh your precursor cylinders when it is new and each time it is installed on the system and each time it is removed from the system. An empty precursor cylinder with an installed manual valve weighs 300-350g. Typical precursor fills are 25g and less. A scale with a minimum capacity of 400g and milligram resolution is recommended.

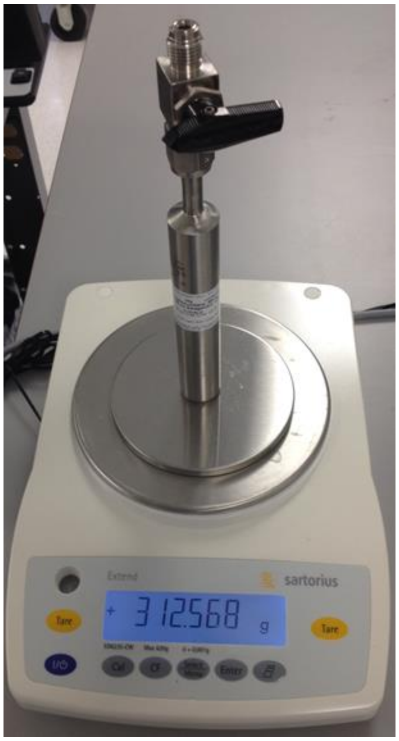


Figure 5-6 – Keeping track of the cylinder mass is a good way to develop an understanding of your precursor consumption rate and to alert you when it getting close to order new material.

5.2.6 Installing Precursor Cylinders

The precursor cylinder installation procedure requires two open end wrenches: a 13/16” wrench to hold the body of the precursor cylinder manual valve and a ¾” wrench to turn the ¼” VCR nut. When installing a water cylinder, a 5/8” wrench is used to hold the bottle rather than the 13/16” wrench. Additionally, a new ¼” VCR gasket is required. VCR gaskets can be purchased with or without a retaining clip which helps keep the gasket in place when making the connection. A typical new VCR gasket package is shown in Figure 5-7.

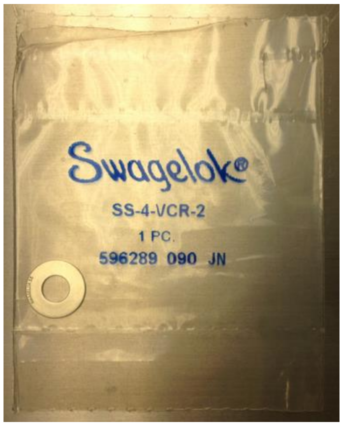


Figure 5-7 – Typical VCR gasket package from supplier.

5.2.6.1 Precursor Cylinder VCR Connection

Place the new VCR gasket on the top of the male VCR connection port on the precursor cylinder manual valve as shown in Figure 5-8.

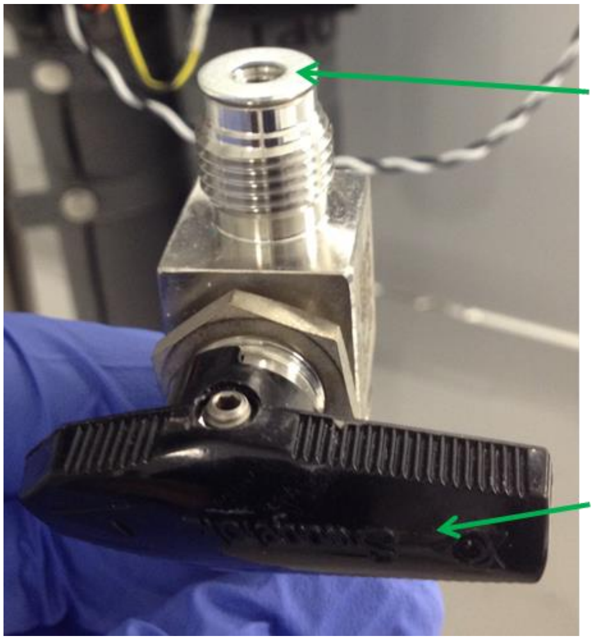


Figure 5-8 – Picture of new VCR gasket placed on manual valve in preparation for installing on ALD valve.

Insert the top of the precursor cylinder manual valve into the bottom of the ALD valve. Holding the manual valve such that the valve handle is in its preferred orientation, finger-tighten the VCR nut, trapping the VCR gasket in between the sealing faces of the manual valve and the ALD valve. Be careful not to cross-thread the fitting. Once the VCR connection is finger-tight, complete the connection by using the ¾” wrench to turn the VCR nut an addition 1/8-turn (45°) while holding the precursor cylinder manual valve steady with a 13/16” wrench. Do not over tighten. Wrench positioning was shown in Figure 5-4 and Figure 5-5.

As shown in Figure 5-5, in the side of the VCR nut is a hole through which the VCR gasket is visible when the connection is at least finger tight. If there is any doubt that a gasket was installed, it can be checked by looking through the hole to see if a gasket is present.

5.2.6.2 Purge Headspace

After the precursor cylinder has been installed on the ALD valve, a volume of air will be trapped between the manual valve and the ALD valve. It is critical that this trapped volume of air be removed prior to opening the precursor cylinder manual valve.

The pulse purge process discussed above in 5.2.4.2 can be reused for the air purging step. The initial pulse height in the pressure plot will be several Torr, substantially higher than that observed when purging the head space prior to cylinder removal as shown in Figure 5-3 due to the relatively high pressure of ambient air. After the headspace has been initially purged, it is recommended that prior to opening the cylinder manual valve the system be allow to sit for about 15 minutes at which point the purge recipe is run again. A small pulse may be initially observed as precursor or water is desorbed from the surfaces as the bottle warms slightly from being in contact with the heated precursor manifold. A larger pulse at this point may indicate a leak at the manual valve/ALD valve VCR connection point. The 15-minute wait/pulse-purge recipe cycle should be repeated until the pulse-purge recipe execution results in a clean pressure transient with no observable pulse peaks.

5.2.6.3 Water Cylinder Installation

The procedure for installing a water cylinder without a manual valve is slightly different. A pulse/purge type recipe should be used to remove the air in the cylinder vapor space and allow water vapor to be established. A recipe similar to that shown in Table 5-1 is appropriate however the pulse time should be reduced. Additionally, more cycles are required to stabilize the water vapor pulse height.

Table 5-2 – Recipe for pulse purging a newly installed water cylinder. Shorter purge times are necessary and more cycles are required to achieve stable water vapor pulse height. Adjust the CHAN value in line 11 to the ALD valve on which the water cylinder is installed.

	INSTRUCTION	CHAN	VALUE	UNITS	
0	turbo gate		0	close	Lines 1-4 switch pumping to trap line.
1	turbo purge		0	close	
2	reactor turbo		0	off	
3	turbo iso		0	close	
4	exhaust valve		1	open	
5	wait		5	sec	
6	flow	0	30	sccm	Set pulse purge flow rates.
7	flow	1	80	sccm	
8	gate purge		1	open	Turn on gate purge.
9	wait		10	sec	
10	pulse	H2O	0.015	sec	Pulse ALD valve with water cylinder for 15 milliseconds.
11	wait		10	sec	Wait 10 seconds.
12	goto	10	30	cycles	Repeat the 15ms pulse/10 second wait 10 times.

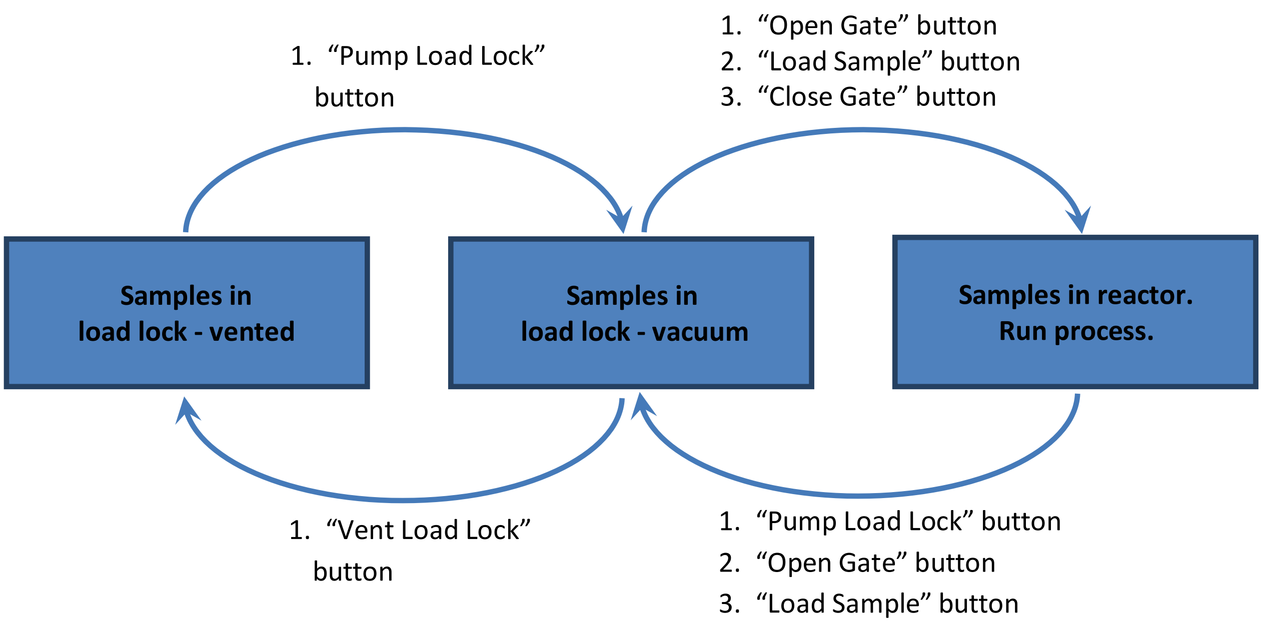
5.3 Sample Loading/Unloading

Substrates to be coated are placed on a substrate holder and inserted in the Fiji G2 reactor. The procedure for inserting the substrate holder depends on your system configuration, ie, whether or not your system has an integrated load lock. Once inserted into the reactor, the sample holder requires 20 minutes to achieve thermal equilibrium with the substrate heater.

5.3.1 Load Lock Systems

Systems with load locks can be configured with or without a load lock turbo pump. For systems with the load lock turbo pump option, sample transfer is completed after base pressures in the reactor and load lock have both been established with those sub-system's respective turbo pumps. For load lock systems without a load lock turbo pump, sample transfer is completed after base pressures in the reactor and load lock have both been established when pumping on those sub-systems with the dry pump alone. Below, procedures for the accomplishing substrate loading/unloading on systems with load locks are outlined. Software updates in the future may automate some of the steps for sample introduction and removal.

The Fiji G2 system may be in one of several states which will determine which steps must be performed to load and unload samples using the semi-automatic commands.



5.3.1.1 Load Lock Turbo Systems

5.3.1.1.1 Moving Substrate Holder in Reactor to Load Lock

The semi-automatic buttons perform the following actions automatically as indicated above. It is recommended to use the semi-automatic buttons for all sample transfer actions.

1. Turn off all gas flows to reactor.
    1.1. carrier gas flow
    1.2. plasma gas flows
    1.3. door and any other peripheral purges
2. Pump reactor to base pressure (Reactor Pumped Down). Skip step 3 with a dedicated backing pump installed on the load lock.
    2.1. Soft Pump, then Rough pump
    2.2. Close Rough pump, Open Turbo Iso, Open Reactor Gate, Turn ON Reactor Turbo, Turn On Reactor Purge
3. Establish load lock base pressure
    3.1. close turbo isolation valve
    3.2. open LL soft pump, pump to 4 Torr
    3.3. Close Soft pump valve, open LL rough valve
    3.4. turn load lock turbo on
    3.5. Once load lock turbo has achieved full rotation speed, proceed.
4. Pump load lock to achieve base pressures, ~1e-6 Torr.
5. Open transfer Gate valve (between the reactor and Load Lock).

6. Press the “Unload Sample” button.
    6.1. An automated sequence will proceed in which the load lock transfer arm will pick up the sample holder and return it to the load lock.
    6.2. While the sequence is executing, the load lock control buttons will be greyed-out.
    6.3. Wait for the sample holder to come to a stop inside the load lock.
    6.4. The “Unload Sample” sequence is complete.
7. Close the transfer gate valve.
    7.1. The load lock gate valve is now closed.
8. The substrate holder is now in the load lock with the load lock under vacuum, the sample can be cooled in a vacuum environment.

5.3.1.1.2 Venting Load Lock with Load Lock Turbo Pump

The semi-automatic buttons should be used for standard operation of the Fiji system and will automatically perform all actions required to safely move from vented to pumped states.

1. Close the Transfer Gate valve (Close Gate).
2. Turn off load lock turbo pump.
3. Close load lock rough pump valve and load lock soft pump valve.
4. Turn On load lock vent gas. The load lock turbo pump will quickly spin down (safely).
5. With system argon delivery pressure at the recommended 30psi, load lock venting is accomplished in about 2 minutes.

	**BURN HAZARD** The samples and sample holder will be at the temperature of the substrate heater (as high as 500°C) when they are first removed from the reactor if not cooled in the Load Lock prior to venting. Extreme care must be used to prevent being burned due to contact with substrates and the substrate holder.

6. When the load lock achieves atmospheric pressure:
    6.1. Open the top load lock door.
    6.2. Turn off the load lock vent gas.

Samples can be loaded/unloaded from the sample holder.

5.3.1.1.3 Load Lock Pumping with Load Lock Turbo Pump

The semi-automatic buttons should be used for standard operation of the Fiji system and will automatically perform all actions required to safely move from vented to pumped states.

5.3.1.1.3.1 Shared System Dry Pump (Single backing pump)

1. Turn off all gas flows to reactor.
    1.1. carrier gas flow, plasma gas flows, all purge flow valves, vent valves, etc.
2. Isolate the Reactor Chamber

2.1. Close Turbo purge, turbo gate valve, turbo, Iso Valve, reactor soft pump valve, reactor rough pump valve.

3. Pump down Load Lock
   3.1. LL Soft pump to cross over pressure
   3.2. Close LL Soft pump, Open LL Rough, turn ON LL Turbo pump
   3.3. LL pumped Down

5.3.1.1.3.2 Independent Load Lock Dry Pump(Dedicated Backing Pump)

4. Pump down Load Lock
   4.1. LL Soft pump to cross over pressure
   4.2. Close LL Soft pump, Open LL Rough, turn ON LL Turbo pump
   4.3. LL pumped Down

5.3.2 Non-Load Lock Systems

For systems without a load lock, the Fiji G2 reactor must be vented each time the sample carrier is to be removed. The semi-automatic buttons should be used for standard operation of the Fiji system and will automatically perform all actions required to safely move from vented to pumped states.

6 Fiji Recipe Development

In this section, the user is introduced to recipe development on the Fiji. The Fiji software provides a very flexible platform for ALD recipe development. Effective recipe development has several key aspects.

1. Recipe commands – The user will be introduced to all of the recipe commands available in the Fiji software and their usage.
2. Recipe structure – The logic of the overall recipe structure will be demonstrated in the context of using the Fiji to deposit various ALD films.
3. Recipe development and results interpretation – Developing good recipes requires understanding of the underlying ALD chemistry and interpretation of deposition results. Basic concepts for interpreting the results of ALD processes are discussed. Only through an iterative process where deposition results are optimized through a systematic modification of the process recipe details can robust Fiji recipes be developed.

ALD is typically accomplished with two precursors which are alternatively dosed into a heated vacuum system in which is placed the target substrate. The precursor pulses are separated in time by a purging step, during which excess precursor and reaction by-products are purged from the reactor volume. ALD recipe development primarily concerns itself with three things: process temperature, precursor dosing, and precursor purging.

6.1 Recipe Development Box

The recipe table from the main software screen is shown below in Figure RD 1.

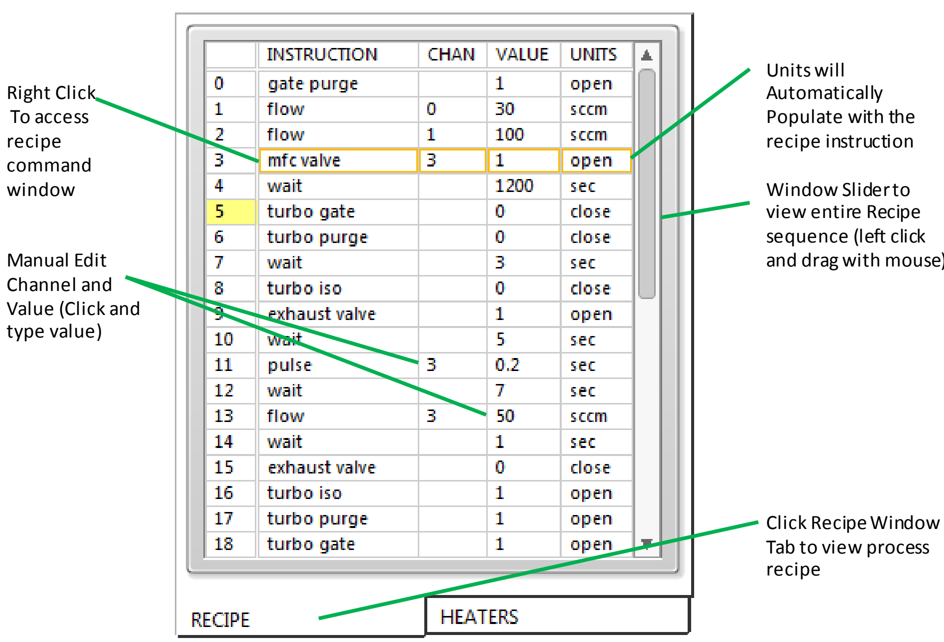
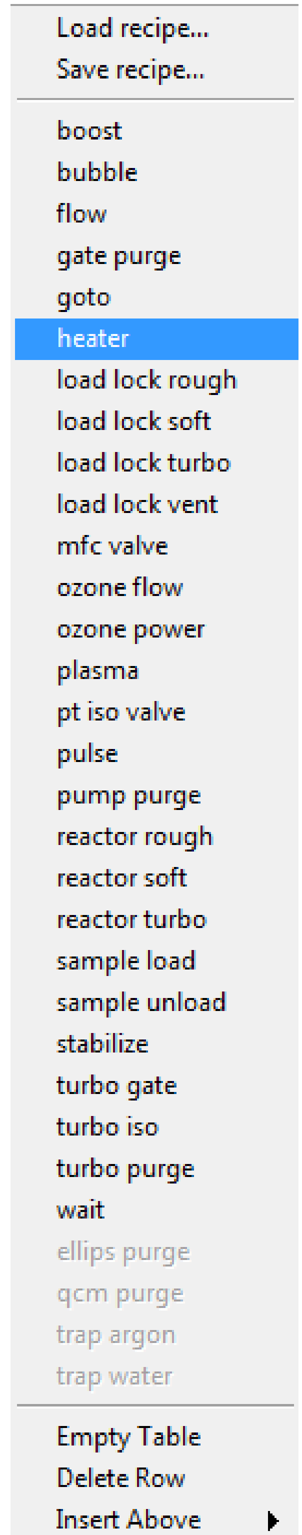


Figure RD 1 – Main software screen recipe table.

The recipe development box consists of five columns. The leftmost column is the recipe line number, starting with 0. The software automatically updates the recipe line number. The ”INSTRUCTION” column contains the recipe commands, discussed in detail in the following section. The recipe commands can take one or two arguments, entered in the "CHAN" and "VALUE" columns. The "UNITS" column contains the software assigned units for the number in the "VALUE" column or open/close information for commands that control valves.



6.2 Recipe Table Menu

The recipe table Menu is obtained by right-clicking on the recipe line item in the Recipe Development box, shown to the right.

To enter arguments in the "CHAN" and "VALUE" box, place the mouse pointer over the cell and left click. A cursor will blink in the activated cell. Information can then be entered into the recipe using the keyboard.

Load recipe…: Prompts the user with a dialog box to select a recipe to load.
Save Recipe…: Prompts the user with a dialog box to save the current recipe in the table.

The default file location for both options is:
C:\Cambridge Nanotech\Recipes
-Sub folders can be created to manage system recipes as required.

Insert Row Before: This operation presents the user with a sub-menu containing all available recipe instructions. The selected instruction is placed in a new row inserted above the row that was right-clicked.
Empty Table: Selecting this option clears the entire table.
Delete Row: This action deletes the right-clicked row.

6.3 Recipe Commands

Below the recipe commands are described and their use illustrated. The menu defines the complete set of valid recipe instructions. Clicking on an instruction enters this command into the recipe.
Recipe commands shown in **GRAY** are disabled commands. These commands are associated with options not installed on the system

6.3.1 Boost (Optional Equipment)

The "boost" command is a recipe command associated with the booster hardware option kit. The boost command is used with the ALD pulse command as described in the boost section. The booster hardware needs to be installed in the Options configuration window. The "CHAN" column requires an ALD port number, and the "VALUE" describes a boost time in seconds.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	boost	1	0.5	sec	Boost time on ALD port 1
	wait		0.5	sec	Wait time between boost and pulse of ALD-1
	pulse	1	1	sec	Pulse time on ALD port 1

6.3.2 Bubble (Optional Equipment)

The “bubble” command is a recipe command associated with the low vapor pressure delivery (LVPD) kit. The bubbler hardware kit must be installed and configured in the options configuration window. If not installed the recipe command will be shown in gray. Additional information for the LVPD option is provided in the Options manual for the LVPD kit. The “CHAN” column defines the ALD port which will be pulsed with the bubble command, The “VALUE” will define the time in seconds.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	bubble	1	4	Sec	4sec bubble time on ALD port 1 (ALD-1)

6.3.3 Flow

The “flow” command is used to set an MFC set-point. The “CHAN” column requires the MFC number. The MFC numbers can be found in the MFC window, shown to the right. The “VALUE” column contains the desired MFC flow rate in sccm. Typically carrier and plasma source argon will be set at the beginning of the recipe and reactive plasma gases (N_2, O_2, etc.) added in during the plasma portion of the ALD cycle. At the end of a recipe, the reactive gases will be turned off and gas flowsset to stand-by values as described in 3.3.2.3.4.

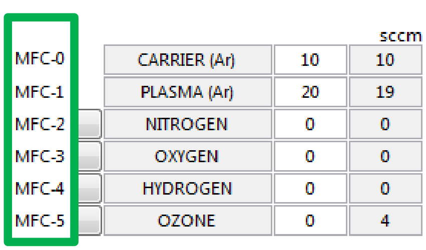


Figure 6-1 – Showing the location of the MFC numbers to use in the “CHAN” column argument of the recipe “flow” command.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	flow	0	30	sccm	Set carrier argon to process conditions
	flow	1	80	sccm	Set plasma argon to process conditions
	flow	3	50	sccm	Turn oxygen flow on for plasma step

For all non-argon MFCs, the MFC pneumatic valve must be open to flow gas. The recipe command for controlling the valve is discussed in 6.3.10.

6.3.4 Gate purge

The section of the reactor through which the sample passes during loading and unloading can be a dead volume from which precursor may not purge as quickly as from other parts of the reactor. A gate purge introduces a flow of argon to this area of the reactor to minimize the influx of precursor and purge any precursor that enters. The "gate purge" command toggles the argon purge flow to this area. Nothing is entered in the "CHAN" column. A "VALUE" of 1 opens the valve while a value of 0 closes the valve. Typically, the gate purge would be turned on near the beginning of a recipe before process chemicals have begun being delivered to the reactor and then turned off near the end of the recipe after the deposition process is completed. The gate purge is also typically turned off for plasma steps.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	gate purge		1	open	Open the gate purge pneumatic control valve.
	gate purge		0	close	Close the gate purge pneumatic control valve.

6.3.5 Goto

ALD processing is very cyclic in nature: precursor A, purge, precursor B, purge, repeat. The "goto" command fulfills the "repeat" aspect of the typical ALD process in a controllable manner. The "goto" command is placed at the bottom of the group of recipe commands which are to be repeated. When using the "goto" command, enter the recipe line number of the first line of the group of recipe commands to repeat in the "CHAN" column and enter the number of times to repeat the "goto" loop in the "VALUE" column.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
18	pulse	3	0.06	sec	Pulse ALD valve 3 for 0.06s.
20	pulse	0	0.1	sec	Pulse ALD valve 0 for 0.1s.
25	goto	20	5	cycles	Repeat recipe lines 20-25 five times.
27	goto	18	20	cycles	Repeat recipe lines 18-27 twenty times.

The recipe example code above contains two goto loops, one nested inside another larger goto loop. The software automatically color codes the line number boxes of the "goto" command lines and the command line to which they point. This color coding helps the user visualize the loop structure(s) in a recipe.

6.3.6 Heater/stabilize

The "heater" command is used to set a heater temperature set-point. The "CHAN" column requires the heater number (Ch) of the heater. The heater number (Ch) can be found in several locations in the GUI software, a summary of the heaters is found in **Error! Reference source not found.**.

Ch	Name	Setpt	Temp	Signal
12		0.0	0.0	0.0
13	UPPER	250.0	250.1	43.6
14	LOWER	250.0	250.1	64.7
15	CHUCK	250.0	250.1	0.0
16	DELIVERY LINE	150.0	150.0	26.7
17	VALVE MANIFOLD	150.0	150.0	61.3
18	Port - 1	0.0	30.4	0.0
19	Port - 2	75.0	75.0	12.5
20	Port - 3	0.0	33.1	0.0
21	Port - 4	0.0	0.0	0.0
22	Port - 5	0.0	39.6	0.0
23	Port - 0	0.0	0.0	0.0
24	EXHAUST TEE	150.0	150.0	23.5
25	EXHAUST VALVE	105.0	104.1	100.0
26	Option A - zone 2	0.0	0.0	0.0
27	Option A - zone 3	0.0	0.0	0.0
28	Option B - zone 2	0.0	0.0	0.0
29	Option B - zone 3	75.0	75.0	18.0
30	LL TUNNEL	150.0	150.0	12.8
31		0.0	0.0	0.0
NITS:		°C	°C	%

Figure 6-2 – List of heaters from the front panel heater tab showing the location of the "Ch" values used in recipe heater commands.

The "VALUE" column contains the desired heater temperature in "UNITS" of °C. Entering a "VALUE" of 0 will turn the heater off.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	heater	19	100	°C	Set ALD2 heater set-point to 100°C
	heater	19	0	°C	Turn OFF ALD2 heater set-point = 0°C

When the heater is on the temperature measurement window will change from red to blue. When the heater is off the heater set-point box has a 0 and the temperature measurement box is blue.

19	100	22	°C

Heater Set point 100°C

19	0	20	°C

Heater OFF

Temperature changes are not instantaneous. As seen in the image above, although the set-point has been changed to 100, the actual heater temperature is still 22°C. It will take some time for heater 19 to reach the set-point. If the recipe continues, much of the process may take place while the heater temperature is ramping up to its desired value. It takes time for a reactor component to change temperatures and stabilize at the new value. The "stabilize" command causes the recipe to pause while heaters achieve their set-points.

The "stabilize" command stabilizes all active (ON) heaters. The "CHAN" argument is empty and the "VALUE" argument defines the minimum wait time for the stabilize step. If all heaters satisfy the stability criteria the minimum stabilize period is defined by the stabilize time (Value). Below the previous example is enhanced with the addition of a "stabilize" command.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
6	heater	19	100	°C	Set the ALD2 precursor heater set-point to 100°C

7	stabilize		1800	sec	Wait for all active heater set-points to achieve the stabilization criteria. Minimum wait time = 1800 seconds

The criteria for what is "stable" for a given heater is established in the Stability section of the Heater Configuration Window in the Fiji G2 software discussed in 3.3.2.3.7. The stability criteria will remain ON for the entire process recipe and will abort the recipe if the ON heaters become unstable, i.e. do not satisfy the stability criteria. If a heater set point is changed after a stability command, the heater will be excluded from the stability criteria, until it re-establishes stability criteria, after which it will be monitored for stability with all other ON heaters.

The stabilize command does not have a timeout. If a heater does not satisfy the stability criteria, the program will pause indefinitely at the stabilize command waiting for stability to be achieved.

The "Skip Step" button discussed in section 3.3.4.2.2 can be used to move on from a recipe "stabilize" command before heater stability has been achieved or the full minimum wait time has elapsed.

6.3.7 load lock rough / load lock soft

The load lock vacuum pump valve has three available states: Closed, Soft, and Rough. "Closed" is fully closed and "Rough" is fully open. "Soft" is a partially opened state used to initially reduce the load lock pressure slowly to minimize sample shifting on the substrate holder and particle agitation.

Executing the "load lock rough" and "load lock soft" recipe commands with an open (VALUE = 1) argument sets the load lock vacuum valve to their respective states. Either command with a close (VALUE = 0) argument closes the valve.

6.3.8 load lock turbo

The "load lock turbo" command turns ON/OFF the load lock turbo, if the option is installed on the system. Value = 0 = OFF, VALUE = 1 = ON. Interlocks associated with the Pressure must be satisfied for this command to be executed.

6.3.9 load lock vent

The "load lock vent" command toggles the Ar flow to the load lock vent valve. Opening the load lock vent initiates the venting of the load lock chamber, after a period of time the load lock vent should be closed. The vent command requires that the LL soft, LL rough and LL turbo are CLOSED or OFF.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
13	load lock vent		1	open	Open the load lock vent valve.
	wait		240	sec	
	load lock vent		0	close	Close the load lock vent valve.

6.3.10 mfc valve

MFCs are not positive shut-off devices. Even when an MFC set to zero flow, one can expect to see a leak-by of gas up to 1% of the MFCs full-scale flow rate for a 40psi pressure differential. Downstream of each of the reactive plasma gas MFCs (N2, O2, H2, etc.) there is a pneumatic positive shut-off valve to prevent through MFC gas leaks from impacting the process.

The “mfc valve” command is used to toggle this pneumatic valve open and closed. The MFC number, as was discussed in the “flow” command above, is entered in the “CHAN” column. A “VALUE” of 1 opens the valve while a “VALUE” of 0 closes the valve. The “mfc valve” and “flow” commands are often used together in a recipe.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	mfc valve	3	1	open	Open the pneumatic for the oxygen MFC.
	flow	3	50	sccm	Set the oxygen MFC to 50sccm.
	flow	3	0	sccm	Set the oxygen MFC to 0sccm.
	mfc valve	3	0	close	Close the pneumatic for the oxygen MFC.

6.3.11 Ozone flow

The ozone generator option comes with a dedicated oxygen MFC for supplying oxygen to the generator. This MFC has a positive shut-off valve similar to the configuration of the plasma gas MFCs. Also, there is a pneumatic shut-off valve where the ozone delivery line is connected to the ALD valve which controls the dosing of the ozone to the reactor.

The “ozone flow” command is used to open these two pneumatic valves which enables the flow of ozone to the reactor. A “VALUE” of 1 opens the valves while a “VALUE” of 0 closes the valves. The “ozone flow” command and a “flow” command are commonly used together to enable the delivery of oxygen to the ozone generator and ozone to the reactor.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
8	ozone flow		1	open	Open the ozone oxygen MFC valve.
9	flow	5	500	sccm	Set the ozone oxygen MFC to 500sccm.
42	flow	5	0	sccm	Set the ozone oxygen MFC to 0sccm.
43	ozone flow		0	close	Close the for the ozone oxygen MFC valve.

6.3.12 Ozone power

The ozone generator is not always powered on. Certain process conditions, such as oxygen pressure and flow, should be satisfied before the ozone generator should be turned on. Details on these conditions are discussed in the section on the ozone generator option, 8.1. It can be turned on with a software front panel control or through a recipe command. The “ozone power” command is used to toggle the ozone generator on and off. No “CHAN” arguments are required but a “VALUE” of 1 turns on the generator while a 0 turns it off.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	ozone power		1	on	Turns on the ozone generator.
	ozone power		0	off	Turns off the ozone generator.

6.3.13 Plasma

The "plasma" command is used to set the RF power level for producing a plasma and activating the RF generator. No "CHAN" arguments are used but the "VALUE" is used to specify the requested RF power in Watts. For a standard Fiji G2 system, the acceptable range for the "VALUE" argument is 0 to 300.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	plasma		300	Watts	Set the RF generator to 300W, Power ON.
	plasma		0	Watts	Set the RF generator to 0W, Power OFF

6.3.14 Pt iso valve

The Fiji G2 reactor has two pressure gauges: a pirani type gauge which is always exposed to the process and a wide range gauge (Channel 1 – Chamber Pressure) which is isolated behind a pneumatic valve during processing to protect it from ALD chemicals and plasma radicals.

The pressure transducer isolation valve (pt iso valve) command toggles the pneumatic isolation valve that protects the wide range pressure gauge. The default state for this valve is closed during process. The pt iso valve can be opened to measure pressure for load/unload commands associated with the load lock option. This command has no "CHAN" argument. VALUE = 0 = CLOSED, VALUE = 1 = OPEN.

6.3.15 Pulse

Precise dosing of ALD precursor chemicals into the reactor is achieved through pulsing of the fast acting ALD valves to which the precursor cylinders are attached. The "pulse" command is used for this task.

The "pulse" command takes two arguments. In the "CHAN" column, the port number of the ALD valve is entered. The ALD valves are numbered according to their physical location in the gas box. They are numbered left to right starting at 0. In the "VALUE" column, the duration (sec) of the precursor pulse is entered.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	pulse	0	0.015	sec	Pulse ALD valve 0 (left-most valve) for 15ms.
	wait		15	sec	
	pulse	5	1	s	Pulse ALD valve 5 (right most valve) for 1s.

6.3.16 Pump purge

Purging the dry pump with N_2 to protect the internal components of the rough pump is necessary for corrosive precursors and gases. A N_2 purge can extend the life of the backing rough pump. The pump purge command allows an N_2 backing pump purge to be turned ON at the beginning of a corrosive process run. The purge default state is OFF/CLOSED in order to prevent unnecessary waste of purging gas. This simple On/Off recipe command uses no "CHAN" arguments and a "VALUE" argument of 1 for on and 0 for off.

6.3.17 Reactor rough / reactor soft

The "reactor rough" command actuates the rough pump valve (for non-turbo reactor process vacuum conditions). The "reactor soft" pump command actuates the reactor soft pump valve (not typically used during recipes). No value is entered in “CHAN” for either command. A “VALUE” of 1 opens the valve while a value of 0 closes the valve.

The reactor rough valve is typically left open continuously during a thermal ALD process. During PEALD processes, the rough valve will be closed during the plasma cycle, which utilizes the turbo pumping. Also, the rough valve is closed periodically during Exposure Mode™ processes for conformal coating of high aspect ratio features.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	reactor rough		1	open	Open the trap line exhaust valve.
	reactor rough		0	close	Close the trap line exhaust valve.

The “reactor soft pump” command is used for pumping the chamber from atmosphere to ~5 Torr, and operates similarly to the reactor pump command. This functionality is not typical for standard process recipes but may be employed for load lock systems with one backing pump.

6.3.18 Reactor turbo

The “reactor turbo” command turns the reactor turbo pump on or off. This command is used to establish plasma process pressures in plasma recipes and to achieve baseline reactor pressures prior to sample transfer to the load lock. This command is interlocked and requires the “turbo gate” and “turbo iso valve” to be OPEN to turn ON. The reactor turbo can be left ON for PEALD process, behind the closed reactor gate and turbo Iso valve.

This simple On/Off recipe command uses no “CHAN” arguments and a “VALUE” argument of 1 for on and 0 for off.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	reactor turbo		0	off	Turns off the reactor turbo pump.
	reactor turbo		1	on	Turns on the reactor turbo pump.

6.3.19 Sample load/sample unload

The “sample load” command allows the sample holder to be loaded during a recipe. The command includes the “Open Gate” button feature and the “Load Sample” button functionality in the software front panel. The “sample unload” command opens the transfer gate valve and unloads the sample holder. These recipe load lock commands allow samples to be automatically loaded/unloaded in the process recipe.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	sample load				Opens transfer gate valve, Loads sample to the chuck in the reactor, close transfer gate valve.
	sample unload				Opens transfer gate valve, unloads sample from the chuck in the reactor, close transfer gate valve.

6.3.20 Stabilize

See "heater/stabilize" discussion above in 6.3.6.

6.3.21 Turbo gate

The "turbo gate" command toggles the gate valve located between the reactor and the reactor turbo pump. No value is entered in the "CHAN" column. A "VALUE" of 1 opens the valve while a value of 0 closes the valve. During PEALD processes, the turbo gate valve is opened for the plasma steps and closed for precursor pulse steps.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
13	turbo gate		1	open	Open the turbo gate valve.
19	turbo gate		0	close	Close the turbo gate valve.

6.3.22 Turbo iso

The "turbo iso" command toggles the reactor turbo pump isolation valve located downstream of the reactor turbo before the turbo pump foreline joins the main system pumping line to the dry pump. No value is entered in the "CHAN" column. A "VALUE" of 1 opens the valve while a value of 0 closes the valve. During PEALD processes, the turbo isolation valve is opened during the plasma steps when pumping is through the reactor turbo pump. The turbo isolation valve is closed during the precursor pulsing step of a PEALD process and throughout a thermal ALD process.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	turbo iso		1	open	Open the turbo isolation valve.
	turbo iso		0	close	Close the turbo isolation valve.

6.3.23 Turbo purge

The "turbo purge" command toggles the pneumatic valve which allows the flow of purge gas to the reactor turbo bearings. Purging the turbo bearings of the turbo pump can extend the life of the turbo pump. This command has no "CHAN" argument. VALUE = 0 = CLOSED, VALUE = 1 = OPEN.

6.3.24 Wait

The "wait" recipe command causes the recipe to pause for a specified amount of time. No value is entered in the "CHAN" column, while the number entered in the "VALUE" column indicates the software wait time in units of seconds.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	Wait		5	sec	Wait 5 seconds.
	Wait		7200	sec	Wait 2 hours.

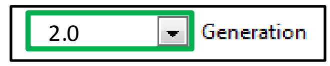
The "Skip Step" button discussed in section 3.3.4.2.2 can be used to move on from a recipe "wait" command before the full time has elapsed.

6.3.25 Ellips purge/qcm purge

On systems with optional ellipsometry ports or qcm, the "ellips purge" and "qcm purge" command toggles the argon purge flow to these ports. No value is entered in the "CHAN" column and a "VALUE" of 1 opens the valve while a value of 0 closes the valve. Typically, the purge would be turned on near the beginning of a recipe before process chemicals have begun being delivered to the reactor and then turned off near the end of the recipe after the deposition process is completed.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	ellips purge		1	open	Open the ellipsometry purge pneumatic valve.
	ellips purge		0	close	Close the ellipsometry purge pneumatic valve.

6.3.26 Trap argon/trap water (G2.0 Hardware)



These two command support Generation 2.0 Hardware functionality, selectable in the System\Tool configuration Tab. These recipe commands will be Grayed out with Generation 2.1 hardware.

The Fiji G2.0 hardware configuration has an integrated heated trap on which excess ALD precursors will deposit film when operating in thermal deposition mode. This precursor trapping technique does not work well for plasma processes because the lifetime of plasma generated radical is short and they do not make it to the trap. In order for the trap to be effective, it must be supplied with a co-reactant to complete the ALD reaction and prepare the trap surface for the next ALD precursor pulse.

The Fiji G2.0 has a unique pumping arrangement for plasma processing that routes process chemistry through a heated trap and plasma gases through a turbo pump. During the plasma portion of the PEALD cycle, the thermal ALD process on the trap is completed by providing the trap with a dose of water vapor. A separate argon purge for the trap carries excess water vapor and reaction by-products away to the vacuum pump.

The “trap argon” command is used to toggle the pneumatic valve which controls the flow of argon into the trap line. The “trap water” command is used to toggle the pneumatic valve which controls the flow of water vapor to the trap line. Neither command utilizes a “CHAN” arguments and both use “VALUE” of 0 for off and 1 for on.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	trap argon		1	on	Turns trap argon flow on.
	wait		1	sec	
	trap water		1	on	Turns trap water vapor flow on.
	wait		0.5	sec	
	trap water		0	off	Turns trap water vapor flow off.
	wait		8.5	sec	
	trap argon		0	off	Turns trap argon flow off.

6.4 Recipe Development – Thermal ALD Al_2O_3

Developing an ALD recipe has two aspects: syntax and logic. The recipe command definitions above have laid the groundwork for the recipe syntax. Now, the logic that must be used when developing a robust ALD process recipe will be discussed. For illustrative purposes, the process for depositing Al_2O_3 via trimethylaluminum (TMA) and water (H_2O) will be considered. Some of the recipe command details discussed above will be reiterated as steps are added to the developing recipe.

6.4.1 TMA Pulse

Consider a substrate which has been inserted into a heated process reactor through which a precursor carrier gas is flowing at reduced pressures due through the action of a vacuum pump. The first step of the Al_2O_3 deposition process is the introduction of the TMA pulse. For this example, the TMA is assumed to be installed on ALD valve 2. The command below introduces a 15 millisecond TMA pulse.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	Pulse	2	0.015	sec	15ms TMA pulse.

6.4.2 TMA Pulse Purge

After the TMA pulse, the recipe is paused momentarily to give any excess TMA and reaction by-products a chance to be purged out of the system with the flowing precursor carrier gas. For this example, a 10 second purge step will be added to the recipe after the TMA pulse

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	pulse	2	0.06	sec	60ms TMA pulse.
1	wait		10	sec	10s purge following the TMA pulse.

The first half of the Al_2O_3 cycle is now finished. Now the second half of the ALD process, H_2O pulse and purge, must be included.

6.4.3 H_2O Pulse and Purge

Similar pulse and purge durations are used for the water pulse. For this example, the water precursor is located on ALD valve 0.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	pulse	2	0.06	sec	60ms TMA pulse.
1	wait		10	sec	10s purge following the TMA pulse.
2	pulse	0	0.060	sec	60ms H2O pulse.
3	wait		10	sec	10s purge following the TMA pulse.

6.4.4 Goto Command

The recipe now contains one cycle of the Al_2O_3 process. Single ALD cycles tend to put down very small amounts of material, typically sub-monolayer growth is observed as precursor ligand steric hindrances impede the ability to react with every active site on every ALD cycle. Thus, the single ALD cycle must typically be repeated many times to build up films of the desired thickness. Systematic repetition of sections of a recipe is accomplished with the “goto” command.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	pulse	2	0.06	sec	60ms TMA pulse (ALD Port-2).
1	wait		10	sec	10s purge following the TMA pulse.
2	pulse	0	0.06	sec	60ms H2O pulse (ALD Port-0)
3	wait		10	sec	10s purge following the TMA pulse.
4	goto	0	300	cycles	Repeat the TMA/H2O cycle 300 times.

The Fiji software automatically highlights the line number cell at the beginning and ending rows of a goto loop with the same color. This makes it very easy to see which section of the recipe is going to be repeated in the recipe loop. The above example shows the TMA/purge/H_2O/purge repeated in a loop 300 times. As will be discussed later, multiple loops can exist in a recipe and each will have its own unique color.

6.4.5 Heater/Stability Command

The Al_2O_3 recipe developed above will run at the temperature the system is currently operating. As has been discussed previously, the Fiji G2 system has numerous heaters which can impact the ALD process. Each heater has a name and a number. For example a 250°C process requires that Heaters 13 (upper heater), 14 (lower heater), and 15 (chuck) will be set to 250°C. Heater set-points can be set via software controls separate from the recipe or from a recipe step. Even if the reactor is always kept at the desired processing temperature, adding “heater” commands to your recipe files can be a good way of documenting the process conditions.

“Heater” and “Stability” commands are typically placed in the recipe before the pulsing the ALD chemistry in the reactor. Right clicking on the TMA pulse row brings up the pop-up menu. Select “Insert Row Above” near the bottom of the menu. The inserted recipe will be added before the current row. This insert command can be used to add heater steps to the process recipe and either a Stability step or a Wait step to achieve thermal stability.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	heater	13	250	°C	Set the upper reactor heater to 250°C.
1	heater	14	250	°C	Set the lower reactor heater to 250°C.
2	heater	15	250	°C	Set the chuck heater to 250°C.
3	stabilize		1800	sec	Stabilize All Heaters (Min wait 1800 sec)
4	pulse	2	0.06	sec	60ms TMA pulse (ALD Port-2).
5	wait		10	sec	10s purge following the TMA pulse.
6	pulse	0	0.06	sec	60ms H2O pulse (ALD Port-0)
7	wait		10	sec	10s purge following the TMA pulse.
8	goto	4	300	cycles	Repeat the TMA/H2O cycle 300 times.

Notice that the line numbers associated with the TMA/purge/H2O/purge/goto commands are automatically incremented each time a new line is inserted/added. Importantly, the “CHAN” value for the goto command also incremented, so the goto loop structure is maintained. Whenever the “Insert Above” or “Delete Row” commands are used, the “goto” command “CHAN” arguments are automatically updated.

The Stabilize command is used to verify the temperature of the Chamber heaters before proceeding to the ALD pulse purge section of the recipe. A long “wait” command can also be used to stabilize the temperature before pulsing precursors, but some uncertainty in how long it will take to stabilize the system at the new temperature set points.

Adding the stabilize command forces the recipe to pause until the reactor walls and chuck have achieved their 250°C set-points. The stabilize command ensures that the recipe is paused for at a minimum of the time specified in the UNITS value

If the reactor and chuck heaters were stable at 250°C when the recipe was started, the “stabilize” commands will wait for the specified time, Units (sec).

6.4.6 Flow Command

The Fiji in its standard configuration has five mass flow controllers (MFCs): precursor carrier Ar, plasma Ar, plasma N_2, plasma O_2, and plasma H_2. The MFCs on your Fiji G2 system are displayed in upper left hand corner of the GUI

MFC set-points need be set at the beginning of the process recipe for carrier and plasma argon flow, (MFC-0) and (MFC-1). Gas flow through the ALD manifold and plasma source are critical, for both thermal and plasma deposition processes. Gas flow through the plasma source establishes flow lines in the reactor critical for process uniformity and prevents precursor back-streaming into the remote plasma source tube.

During stabilization steps, low flows can be used to conserve Ar gas. Then, prior to beginning the deposition, gas flows can be increased to process conditions. MFCs and system pressure stabilization can take a few seconds, so often a short “wait” step is added between “flow” commands and deposition commands.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	flow	0	10	sccm	10sccm carrier Ar during heat-up/stabilization
1	flow	1	30	sccm	30sccm plasma Ar during heat-up/stabilization
2	heater	13	250	°C	Set the upper reactor heater to 250°C.
3	heater	14	250	°C	Set the lower reactor heater to 250°C.
4	heater	15	250	°C	Set the chuck heater to 250°C.
5	stabilize		1800	sec	Stabilize All Heaters (Min wait 1800 sec)
6	flow	0	30	sccm	30sccm carrier Ar for process
7	flow	1	80	sccm	80sccm plasma Ar for process

8	wait		10	sec	10s wait for MFCs/pressure to stabilize
9	pulse	2	0.06	sec	60ms TMA pulse (ALD Port-2).
10	wait		10	sec	10s purge following the TMA pulse.
11	pulse	0	0.06	sec	60ms H2O pulse (ALD Port-0)
12	wait		10	sec	10s purge following the H2O pulse
13	goto	10	300	cycles	Repeat the TMA/H2O cycle 300 times.

Following the process recipe the chamber is pumped down to base pressure and the carrier and plasma flow rates are set to the “After Recipe” values defined in the Recipe Configuration tab.

6.5 Recipe Development - Plasma (PEALD) Mode Recipe

Plasma Enhanced Atomic Layer Deposition (PEALD) is where the Fiji system really shines. A typical use of plasma mode is to replace the co-reactant used in thermal ALD processes with atomic radicals generated using a remote plasma source. In this manner oxides are deposited with an O_2 plasma rather than H_2O or O_3. Nitrides are deposited with N_2 and/or H_2 plasmas. Depending on the precursor and process conditions, O_2, N_2, and H_2 can play a role in depositing metals.

The procedure for plasma mode processing is as follows:

1. Establish system temperatures
2. Open required MFC pneumatic valves
3. Establish precursor pulsing gas flows and pumping conditions
4. Pulse precursor A
5. Purge precursor A
6. Establish plasma gas flows and pumping conditions
7. Turn on remote plasma source
8. Expose substrate to reactive radicals from plasma source for set time
9. Turn off remote plasma source
10. Turn off and purge plasma gas
11. Repeat 3 – 10 until desired film thickness is achieved
12. Establish standby temperatures

1. Temperatures – The reactor walls and substrate heater temperatures are important process parameters. ALD processes typically benefit from higher processing temperatures but must be compatible with the substrate limitations and not lead to precursor decomposition on the time scale of an ALD cycle. The reactor walls and substrate holder temperature set-points are typically fairly close. If the substrate heater temperature needs to be set low, the reactor walls cannot remain significantly hotter because heat transfer will occur between the walls and the substrate heater, preventing the substrate from getting as cool as required. It can take over 10 minutes for a substrate to achieve a steady state temperature after being inserted into the reactor. If you set the reactor walls temperature too high relative the substrate holder, the substrate holder heater duty cycle will go to zero and you no longer be controlling the substrate holder temperature.

2. Open MFC pneumatic valves – Each of the reactive plasma gas MFCs has a downstream pneumatic shutoff valve. This valve must be opened in order to deliver a controlled gas flow from the reactor through the MFC. The reasoning for the valve and the recipe command are described in detail below.

3. Precursor pulse pumping – Precursor pulsing is more effective with low flow/high pressure/long residence time to give the precursor sufficient time to interact with the substrate surface. The optimal gas flow, pressure and residence time conditions for precursor differ from the plasma steps. Pumping for precursor pulsing is performed using the reactor rough pumping line, not the turbo pumping line.
4.&5. Precursor pulse and purge – The previous discussions for precursor pulsing and purging apply here.

3.& 6. Plasma gas flow and pumping – The plasma step typically uses low flow/low pressure/short residence time conditions in the chamber. The short lifetime of the plasma radicals generated in the plasma source provides better conduction to the substrate at low vacuum pressures. The vacuum pumping speed can be rapidly changed between the two regimes by switching the pumping paths between rough pumping and turbo pumping.

7. Turn on the plasma – Once the gas flows are established, the plasma source is turned on and the characteristic plasma glow can be seen in the ICP source (Reflected Power < 15 Watts). Radicals generated in the plasma source flow down to the substrate surface and react with the chemisorbed precursor, volatilizing the precursor ligand constituents and becoming incorporated into the resulting PEALD film. The plasma source is turned on with the plasma command which is described below.

8. Plasma exposure time – The plasma step has a duration which differentiates it from the precursor A pulsing. The flux of radicals from the plasma source continuously reacts with the growing film. The longer the plasma step, the more completely the precursor A ligands are removed from the surface (less impurities). Typical plasma times on the Fiji are 6 - 20 seconds. The plasma exposure time is accomplished with a wait command between the plasma on and plasma off commands. Just as in thermal ALD processing, a saturation curve should be developed for the plasma step with the plasma duration being varied.

9. Turn off the plasma – The plasma is turned off with the same plasma command as described below.

10. Turn off and purge plasma gas and reaction by-products – Some precursors/plasma gas combinations are reactive and the plasma gas must be turned off for the precursor pulsing step. N_2 will not be reactive with precursors and can be left on. Also, a brief purge following the plasma step clears the system of any reaction by-products. A clear advantage to PEALD processing is the short required purge following the plasma step. When doing low temperature oxides with H_2O coreactant, purge times in excess of 60s can be required to fully purge the excess H_2O from the system. O_2 is purged quickly from the system, even at low temperatures, and the long purge time is not needed.

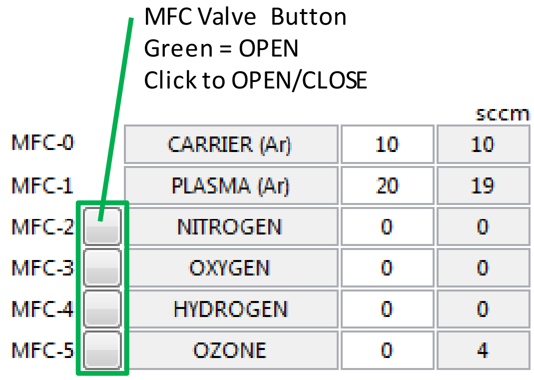
11. Repeat – The precursor pulse/purge/plasma/purge cycle is repeated many times to produce the desired PEALD film thickness.

12.-14 Standby – When the deposition is complete, the recipe can perform several actions to put the Fiji in a standby state until the operator can return to remove their substrate. Reducing the gas flows can save argon and fully opening the throttle valve on turbo systems can maximize pumping out of any residual precursors in the system. It is not a good idea to completely turn off the gas flows. It is good to keep the reactor hot. Thermal cycling of the reactor can generate particles due to mismatch of thermal coefficients of expansion of the reactor materials and the adhered ALD films on the reactor walls.

6.5.1 MFCvalve Command

MFCs are not positive shutoff devices. This means that even when zero flow is requested from the MFC, a small amount may trickle past the device. For the MFCs used on the Fiji, the specification for flow past a closed valve is <1% full scale. The N_2, O_2, and H_2 MFCs on the Fiji are 200 sccm full scale. This means that up to 2 sccm of gas can flow through these MFCs when they are set to zero. This could lead to some undesirable conditions. For example, if trace amounts of O_2 are present in the plasma gas flow when nitrides are being deposited, the film will be left with considerably higher levels of O-impurity. This will most likely negatively impact the desired film properties. To combat this, each of the MFCs for the reactive plasma gases have downstream pneumatic positive shut-off valves.

Looking at the MFC readouts, there are buttons to the left of the N_2, O_2, H_2, and ozone indicators. These buttons indicate the status of the pneumatic valves and allow manual control of the valves. Clicking on the button opens the valve and the button changes to bright green. Clicking again closes the valve and the button returns to gray. Before the reactive plasma gases are utilized in a deposition recipe, the MFCvalve must be opened in the process recipe with the MFCvalve command.



The MFCvalve recipe command takes two arguments. The # argument is the MFC number and value is either 0 for closed or 1 for open.

Safety Interlock MFCvalve - The Fiji system has hardware/software safety interlocks that prevents the O_2 and H_2 MFC pneumatic valves from being open at the same time. This interlock is tied into the Ozone O_2 MFCvalve. Additionally, whenever an O_2 and H_2 MFC pneumatic valve is closed, the interlock causes a large argon flow to flush any remaining reactive plasma gases from the system for 5 seconds before allowing either the O_2 or H_2 MFC pneumatic valve to be opened. Some processes (such as low temperature Pt) require switching between O_2 and H_2 during each ALD cycle. A wait step should be inserted into the recipe following the command closing the O_2 and H_2 MFC pneumatic valve to accommodate the 5 second purge.

6.5.2 Turbo Pump Isolation (Rough Pumping of Reactor)

As mentioned previously, the method of vacuum pump isolation depends on the system configuration. The Turbo pumping line should be isolated and the turbo should be turned OFF.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	turbo purge		0	close	Turn Off turbo purge flow
	turbo gate		0	close	Close gate valve before turbo
	turbo iso		0	close	Close isolation valve behind turbo
	reactor turbo		0	Off	Turn Off turbo pump
	reactor rough		1	open	Open reactor rough pumping line

6.5.3 Reactor rough command

The "reactor rough" command allows the recipe to open/close control of the heated ISO-80 stop valve situated at the base of the Fiji between the ALD reactor and the vacuum rough pump line.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	reactor rough		0	close	Closes the reactor rough pump valve
			1	open	Opens the reactor rough pump valve

The reactor rough command only takes a value argument: 0 to close and 1 to open.

6.5.4 Plasma command

The plasma command controls the operation of the plasma source. The plasma command takes only one argument in the value column. A value greater than 0 turns on the rf output and the rf generator attempts to put out the requested wattage. A value of 0 puts the rf set-point at 0W and turns off the rf output.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
	plasma		0	watts	Plasma OFF
	plasma		1-300	watts	Plasma ON, Power from 1 to 300 Watts Forward RF power

The PEALD recipes provided from Veeco will typically utilize 300W for all plasma processes.

Below is an example TiN recipe that utilizes most of the commands and concepts that have been discussed above. This recipe includes commentary that explains the purpose of the recipe commands.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment

0	flow	0	20	sccm	Set carrier Ar flow – Idle flow
1	flow	1	30	sccm	Set plasma Ar flow
2	heater	TDMAT	75	°C	Heat precursor
3	heater	13	270	°C	Set Heater Temperatures
4	heater	14	270	°C	
5	heater	15	270	°C	
6	heater	16	150	°C	
7	heater	17	150	°C	
8	heater	24	150	°C	
9	heater	25	125	°C	
10	heater	30	150	°C	
11	stabilize		3600	sec	Stabilize heaters (Wait > 3600s)
12	mfc valve	2	1	open	Open N2 MFC valve
13	flow	2	5	sccm	N2 process flow
14	turbo purge		0	close	Close Turbo Pumping line And Pump through reactor rough valve
15	turbo gate		0	close	
16	turbo iso		0	close	
17	reactor rough		1	open	
18	gate purge		1	open	
19	flow	0	30	sccm	Set precursor pulse gas flow
20	flow	1	100	sccm	
21	wait		2.5	sec	
22	pulse	TDMAT	0.25	sec	Pulse precursor
23	wait		2	sec	
24	gate purge		0	close	
25	flow	0	10	sccm	Set plasma gas flow rate
26	flow	1	0	sccm	
27	reactor rough		0	close	Close rough pumping line And pump through the turbo pumping line
28	turbo iso		1	open	
29	turbo gate		1	open	
30	turbo purge		1	open	
31	wait		0.5	sec	
32	plasma		300	watts	Plasma exposure 300 Watts
33	wait		10	sec	
34	plasma		0	watts	
35	goto	14	300	cycles	300x PEALD cycles

6.6 Exposure Mode Recipe

Below is an example of an Exposure Mode™ recipe utilizing the reactor rough command. All exposure mode recipes are thermal process recipes.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	flow	0	10	sccm	Set carrier Ar flow
1	flow	1	30	sccm	Set plasma Ar flow
2	heater	13	200	°C	Set heaters for process
3	heater	14	200	°C	
4	heater	15	200	°C	
5	heater	16	150	°C	
6	heater	17	150	°C	
7	heater	24	150	°C	
8	heater	25	125	°C	
9	heater	30	150	°C	
10	stabilize		1800	sec	Stabilize heaters (Wait > 1800s)
11	turbo purge		0	close	Turn OFF and isolate turbo pump
12	turbo gate		0	close	
13	turbo iso		0	close	
14	reactor turbo		0	off	
15	exhaust valve		1	open	Open reactor rough pump line
16	gate purge		1	open	Transfer gate purge = ON
17	flow	0	40	sccm	Set carrier process flow
18	flow	1	200	sccm	Set plasma process flow
19	wait		10	sec	
20	exhaust valve		0	close	Begin Expo of TMA cycle
21	pulse	TMA	0.06	sec	Pulse TMA
22	wait		60	sec	
23	exhaust valve		1	open	Purge TMA exposure
24	wait		60	sec	
25	exhaust valve		0	close	Begin Expo of H2O cycle
26	pulse	H2O	0.06	sec	Pulse H2O
27	wait		60	sec	
28	exhaust valve		1	open	Purge H2O exposure
29	wait		60	sec	
30	goto	20	200	cycles	200 ALD cycles

6.7 Recipe Information Section

The Recipe status is summarized in the GUI. This section of the main screen displays the loaded recipe, “Start Time”, “Est. Finish Time”, and “Est. Time Remaining.” If a recipe is actively running, the “Start Time” indicator displays the time the recipe was started, the “Est. Finish Time” is an estimate of the time the recipe will finish, and the “Est. Finish Time” displays the estimated finish time for the recipe. Finish times are estimates due to potential uncertainties in recipe duration when using the “stabilize” command. The software adds no time to the recipe time calculation for the “stabilize” command. When the software is in stand-by, “Start Time” indicates the current time, “Est. Finish Time” indicates the approximate time the current recipe displayed in the recipe box would finish, and “Est. Time Remaining” indicates the approximate total time required to complete the current recipe displayed in the recipe box.

Below the timing indicators, a set of indicators give information of the currently executing “goto” loop. “Line #” indicates the line number of the current “goto” command. The color of the “Line #” box corresponds to the color coding of line numbers on the recipe box.

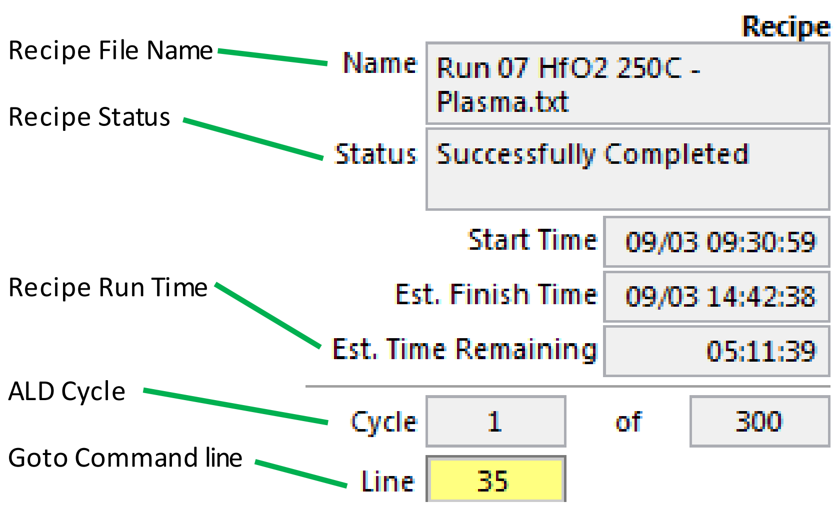


Figure RD 2 – Recipe information.

6.8 Recipe files

Recipes can be saved and loaded using the Save recipe and Load recipe selection available from the right-click pop-up menu in the recipe dialog box. The default location for saving recipes is C:\Cambridge NanoTech\Recipe\. Sub folders can be made in this folder to better organize the Fiji recipes.

Recipe files are saved to the hard disk as tab delimited text files and can be viewed and edited in a text editor program such as Microsoft Notepad.

The recipe file format is as follows:

INSTRUCTION<tab>CHAN<tab>VALUE<tab>UNITS ↵

```
flow→ 0  →  30 → sccm¶
flow→ 1  →  80 → sccm¶
heater→13 → 250 → °C¶
heater→14 → 250 → °C¶
```

Insert a tab using the “Tab” key found on the left side of keyboards with a US layout.

If the Instruction does not require a CHAN argument (for example the “ wait” command), it is omitted and the line will look like this:

wait → → 360 → sec¶

In this case “units” is not required and is omitted from the recipe.

INSTRUCTION<tab>CHAN<tab>VALUE<tab><cr><lf>

Note that recipe files do not include recipe line numbers. If you edit your recipe externally from the Fiji software package, double check the line numbers referenced by “goto” statements to make sure the loops include all of the desired recipe steps.

The text file for the recipe on the previous page will look as follows:

```
flow      0     10     sccm
flow      1     30     sccm
heater    13    250    °C
heater    14    250    °C
heater    15    250    °C
stabilize              1800   sec
flow      0     30     sccm
flow      1     80     sccm
wait            10     sec
pulse     2     0.06   sec
wait            10     sec
pulse     0     0.06   sec
wait            10     sec
goto      9     300    cycles
```

7 ALD Theory

7.1 Thermal ALD Process Development Theory

This is a good point to start considering some of the quantitative aspects of thermal ALD process development. If the recipe that has been developed up to now is analyzed, the structure of the recipe makes sense given the understanding of how ALD works. Precursors are alternately pulsed into the reactor separated by a purge steps. The energy to generate the chemical reaction is supplied by the heaters which maintain the temperature of the reactor and substrate holder. Qualitatively the recipe makes sense, but where do the exact values for gas flows, precursor doses, and temperatures come from? These numbers come from experimentation. When a new ALD process is being considered, initial experimentation must be conducted to ascertain the appropriate process conditions and recipe parameters.

7.1.1 The ALD Window

A very useful concept for understanding the ALD recipe development process is called the "ALD window" which is depicted in Figure RD 3. The 2-D chart has temperature on the x-axis and deposition rate on the y-axis. In the middle of the chart is a box representing the "ALD window". The window indicates that over a given temperature range, the ALD process will be well behaved with a well-defined deposition rate. As temperature goes above or below the ALD window, different things can happen, depending on the nature of the particular chemistry being investigated.

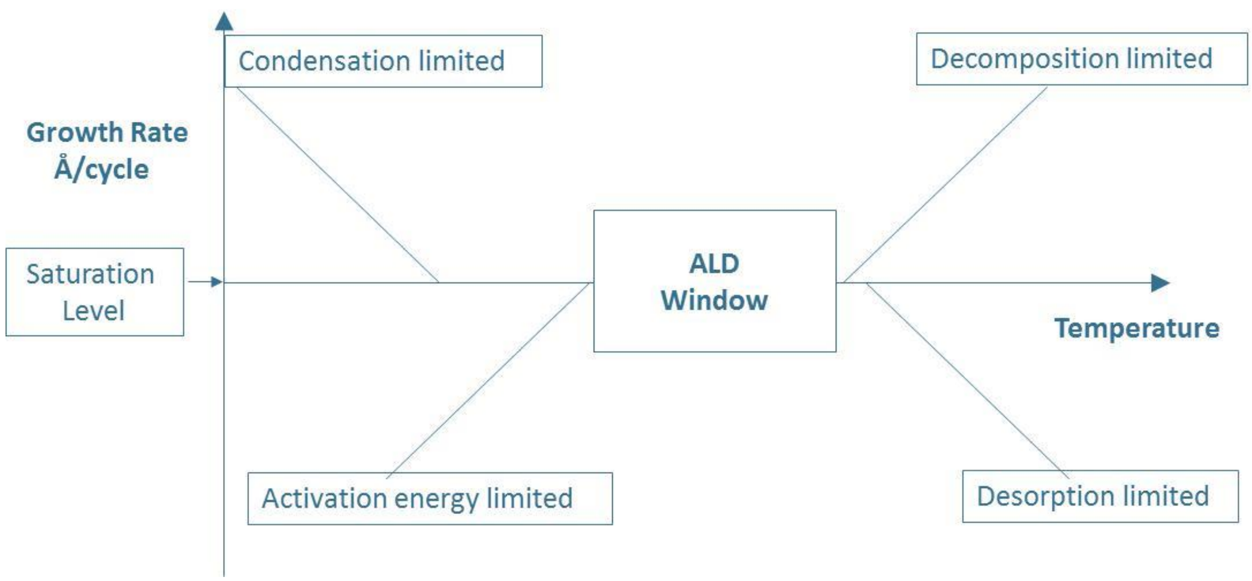


Figure RD 3 – Depiction of ALD window for thermal ALD processing.

At temperatures lower than the ALD window, one may observe deposition rates greater or lower than the anticipated ALD deposition rate. At lower temperatures, there may be insufficient energy to drive the chemical reaction between the two ALD precursors. This will lead to a lower than expected deposition rate. Another possibility is that rather than the monolayer of chemisorbed precursor, a thicker layer of precursor chemical condenses on the substrate surface. This will likely lead to a higher than expected observed deposition rate.

At temperatures above the ALD temperature window, observed deposition rates can also be higher or lower than expected. If the precursor decomposes on the substrate at the high temperatures, the observed deposition rate can be much higher than expected. Alternatively, the precursor may not stay chemisorbed to the substrate at the higher temperatures. With the precursor desorbing from the substrate prior to introduction of the other precursor, less or no film ends up being deposited on the substrate.

7.1.2 Precursor saturation curves

When precursor is dosed into the ALD system, it reacts with the surface of the substrate to deposit the desired film. Ideally, the amount of material that is dosed into the reactor is just enough to saturate all the available sites on the substrate surface. Operating at the bare minimum in precursor dosing is not a good idea. A slight excess of material accommodates any process or equipment fluctuations. How big a dose is required is determined by generating what are referred to as saturation curves.

In order to generate a saturation curve, the system temperatures are set at a point that previous experience suggests would be close to the ALD window. If no such insights are available, it is recommend to start at lower temperatures and increase temperature until deposited films are observed. Figure RD 4 depicts an idealized saturation curve for an ALD process at a temperature in the ALD window. This plot shows percentage of saturated deposition rate as a function of the percentage of the saturated precursor dose. The saturated precursor dose delivers sufficient precursor chemical to the reactor to react with all of the available sites on the substrate surface. By reacting with all the available sites on the substrate, the highest available ALD deposition rate is achieved. The highest available ALD deposition rate is not to be confused with higher deposition rates that can be produced when there is precursor condensation or decomposition as discussed above with respect to the ALD window.

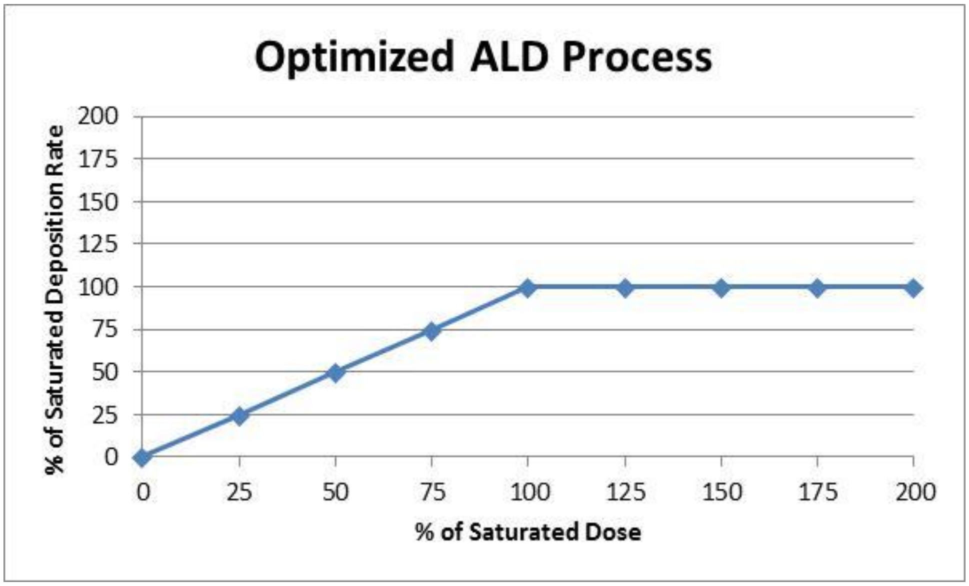


Figure RD 4 – Saturation curve for an idealized thermal ALD process.

As the precursor dose is increased, the deposition rate increases until it saturates. Once at saturation, any additional precursor introduced into the reactor is wasted. The optimized process is the goal of the recipe development process. When the recipe development process is started, the saturated precursor dose and the saturated deposition rate are probably unknown.

Consider a plot very similar to the one above shown in Figure RD 5:

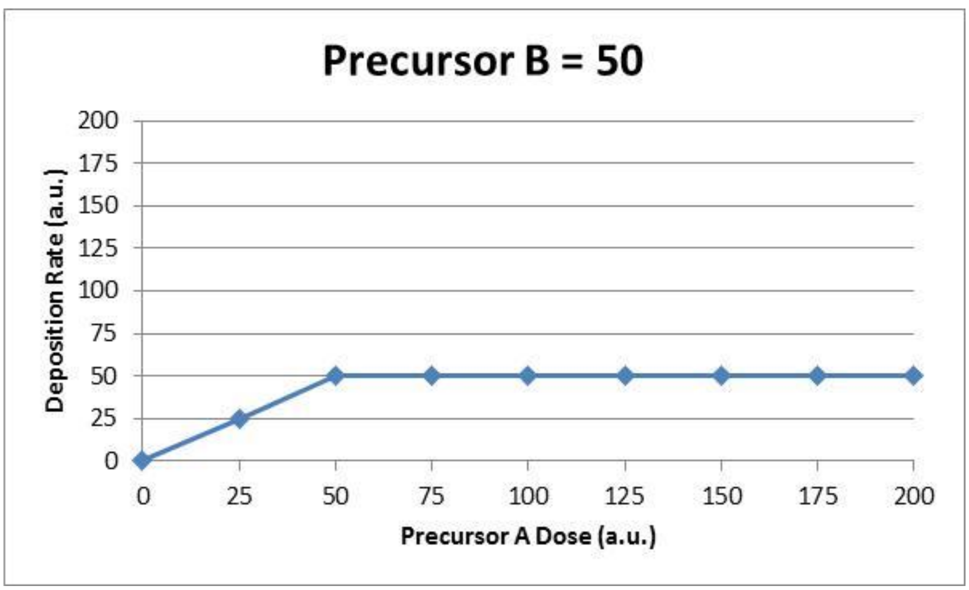


Figure RD 5 – Saturation curve for an thermal ALD process wherein the co-reactant is under-dosed.

Remember that ALD is a two-step process. Both precursors, call them precursor A and precursor B, must both be optimized to determine the ALD window. It appears that the process is nicely saturated at a precursor A dose of 50. It is important that we do not let a nice plot like this fool us into thinking we have everything figured out. The deposition rate for various precursor A doses must be compared at various precursor B doses. If the precursor A dose scans are repeated at various precursor B doses, a plot like that shown in Figure RD 6 may be generated.

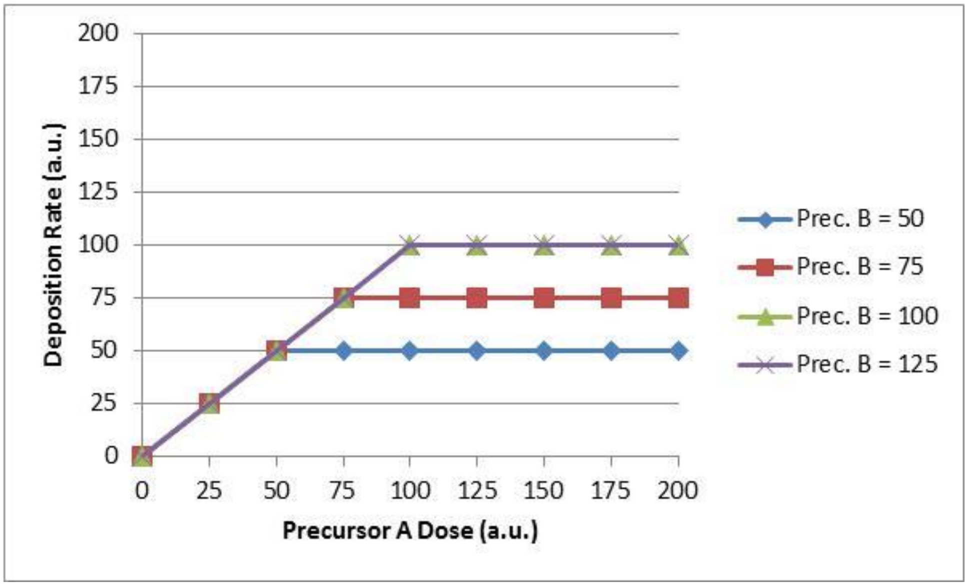


Figure RD 6 – Saturation curves for precursor A dose at precursor B doses of 50%, 75%, 100%, and 125% of saturation.

When precursor B was increased from 50 to 75 and from 75 to 100, the apparent saturated deposition rate increased. The curves for the 100 and 125 precursor B doses overlap indicating that the precursor B dose = 100 was a saturated condition. This example serves to emphasize that precursor dosing must be optimized for both precursors. Failure to do so generates misleading results.

7.1.2.1 Precursor Depletion

There is another consideration when increasing the precursor dose when generating saturation curves. Increasing the precursor dose is typically achieved by increasing the length of time the ALD valve is open with the pulse command. The headspace is the portion of the precursor cylinder between the top of the liquid or solid precursor and the ALD valve which becomes filled with the precursor vapor. If the ALD pulse is long enough, the vapor in this space can be completely depleted. Longer ALD pulses would result in the same amount of precursor being delivered to the reactor. This could generate a false impression that saturation has been achieved when actually the process is still under-dosed, but the system cannot deliver any addition material by lengthening the pulse duration.

There are a couple techniques that can be used to determine if the precursor cylinder vapor is being depleted on each pulse. If the size of the pressure pulse does not change, that is one indicator. Slightly increasing the temperature of the precursor will increase the vapor pressure in the cylinder which will lead to a larger dose for the same pulse length. Care must be taken when increasing the precursor temperature if operating near the temperature at which the precursor will decompose. A final technique to check for vapor depletion is to double pulse the precursor. By pulsing once, then giving sufficient time to reestablish the vapor pressure, and pulsing a second time, essentially a double dose of precursor can be delivered to the system to quickly check if the observed deposition saturation is actually a precursor depletion issue.

7.1.2.2 Temperature Considerations

Understanding the potential impact on the saturation curves when operating outside the ALD window can help decipher other observations when developing ALD recipes. Consider the plot below in Figure RD 7 with saturation curves obtained at three different temperatures.

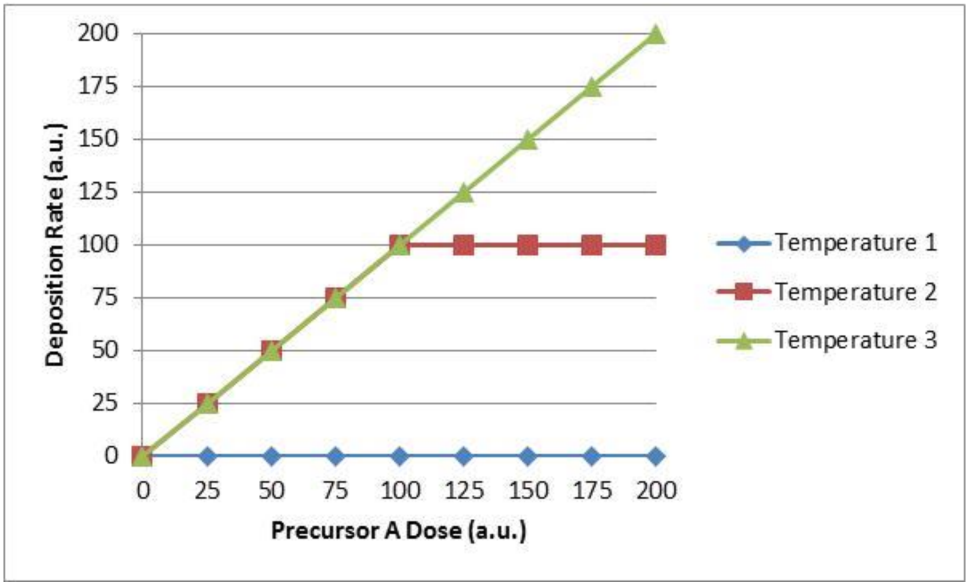


Figure RD 7 – Saturation curves obtained at three different substrate temperatures.

The Temperature 2 saturation curve has the characteristic shape of a well-behaved ALD process. The Temperature 1 data shows no deposition while Temperature 3 shows a lack of saturation. Depending on how Temperatures 1 and 3 compare to Temperature 2, some insight into the process chemistry can be made if the previous discussion regarding the ALD window is taken into account.

If Temperature 1 is less than Temperature 2, the ALD window discussion would suggest that the temperature is too low to provide the energy required to generate the chemical reaction. If Temperature 1 is greater than Temperature 2, the high temperature of the substrate is likely leading to precursor desorption before the next precursor pulse is introduced into the system.

Likewise, if Temperature 3 is less than Temperature 2, the ALD window discussion would suggest that the precursor condensation is leading to enhanced deposition rates. If Temperature 3 is greater than Temperature 2, the high temperature of the substrate is likely leading to precursor decomposition which also leads to enhanced deposition rates.

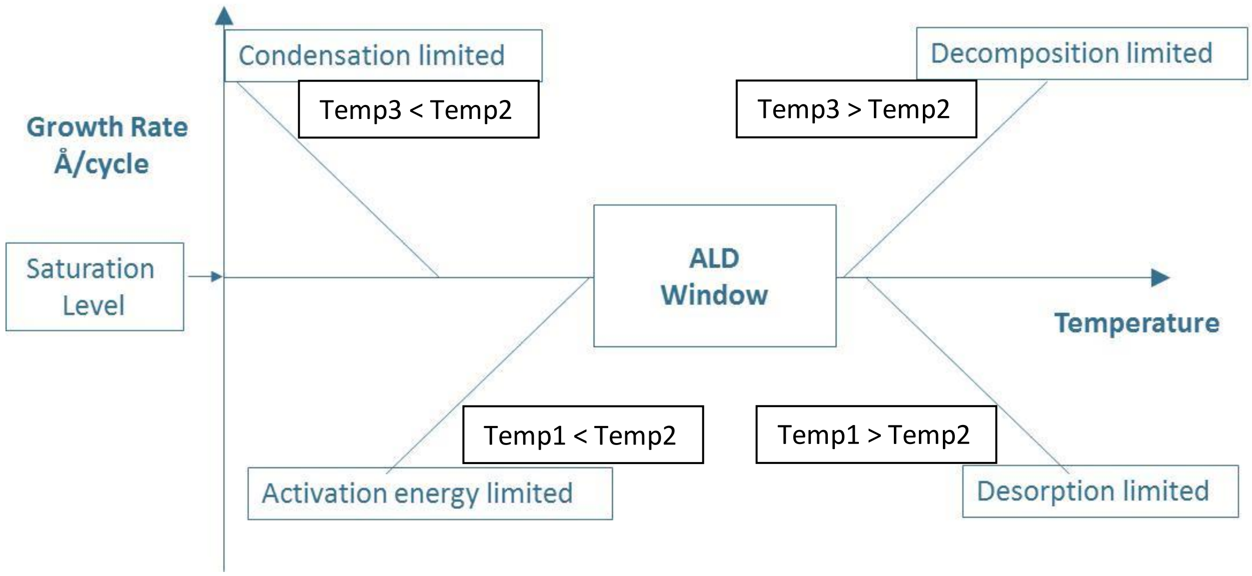


Figure RD 8 – ALD window with potential non-ideal phenomena labeled to match the saturation curves in Figure RD 7

7.1.3 ALD Process Kinetics

The plots in this section are idealized and data that is generated in the process of optimizing real ALD recipes are rarely as neat and clean as the plots shown here. The above discussion has really only considered the thermodynamic aspects of the ALD process. Thermal ALD is a chemical reaction and in addition to the thermodynamics, kinetic factors can also play a role in the obtained deposition results.

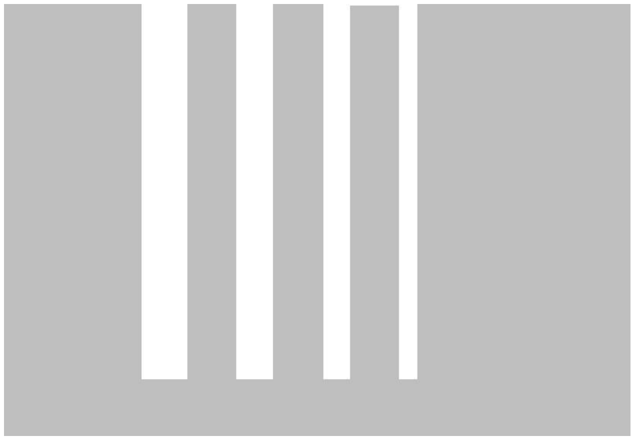
The deposition rates obtained while generating the "ALD window" data can also vary with dynamic aspects of the process conditions which are a function of gas flow rates, pumping speed, and purge times.

It is hoped that the trends and general observations discussed here will enable you to run the appropriate experiments and interpret the resulting data to enable you to produce optimized ALD recipes of your own.

The discussions here have focused on continuous, thermal, ALD processes. The Fiji is also capable of depositing films in Exposure Mode™ and plasma enhanced mode. All of the discussions up until now apply, but there are additional considerations and recipe commands to discuss to enable you to successfully develop optimized recipes for these operating modes.

7.2 Exposure Mode™ Process Theory

Consider the magnified detail of a substrate cross-section shown below.

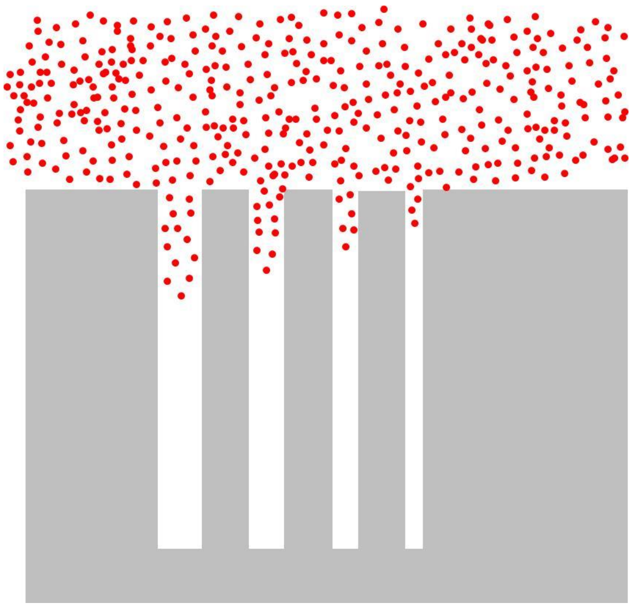


This substrate has some high aspect ratio features that the ALD user wants to conformally coat. Defining the aspect ratio will have to take into some account details of the substrate to be coated, but it is typically calculated as the ratio of the depth to width of the features of interest.

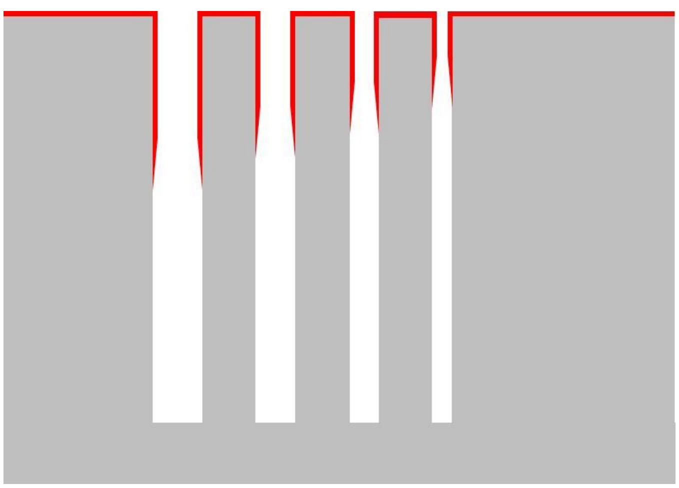
$$Aspect\ Ratio = \frac{Depth}{Width}$$

A hole that is 1µm deep and 10nm in diameter will have an aspect ratio of 100. If instead of a hole, the high aspect ratio feature is a trench with a depth of 1µm and a width of 10nm, the aspect ratio is not 100 but actually 50 for this discussion. This factor of 2 difference is due to the extra degree of freedom for precursor diffusion in the trench as compared to the hole.

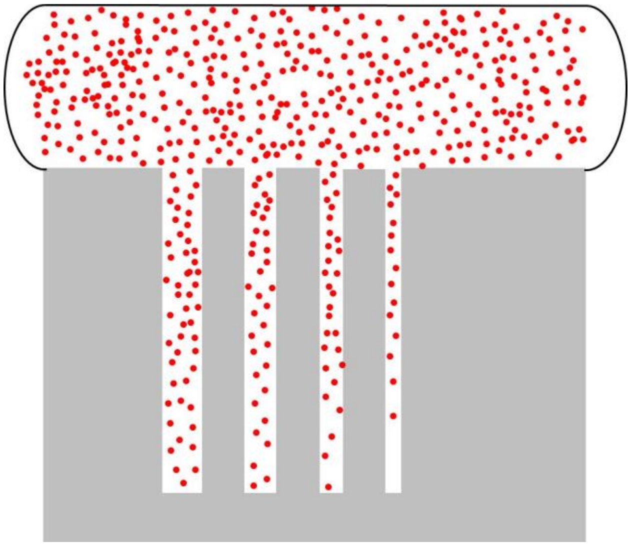
Below is a schematic of what may happen if an ALD recipe developed for a planar substrate is utilized to coat a substrate with high aspect ratio features. The precursor (represented by red dots) is dosed into the processing chamber. The precursor will diffuse into the high aspect ratio features of the substrate, but may not diffuse to the bottom before the purge cycle of the recipe pumps away the remaining precursor.



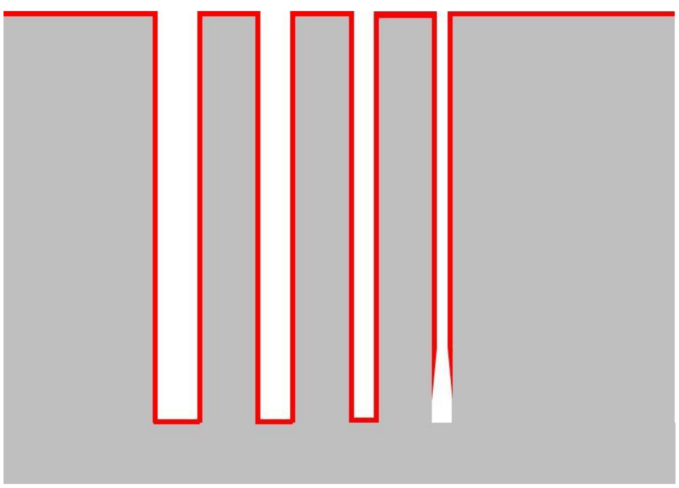
The result would be that the surface of the substrate as well as the portions of the high aspect ratio features near the substrate surface are coated. But the high aspect ratio features are not conformally coated all the way to the bottom. Lower aspect ratio features are more coated than higher aspect ratio features.



Consider the situation where following the pulse step instead of immediately purging the system, the ALD reactor is isolated from the system pump. The substrate is exposed to the precursor for a period of time, giving the precursor time to diffuse down into the high aspect ratio features. Then the pumping is reactivated and sufficient purge time is provided to allow excess precursor and reaction by-products to diffuse back out of the high aspect ratio features. By following this type of precursor exposure procedure for both of the ALD precursors, uniform, conformal films can be deposited on high aspect ratio features.



In the picture below, the leftmost three features are conformally coated. Insufficient time was allowed for full precursor diffusion into the rightmost feature with the highest aspect ratio. Exposure times will have to be extended to conformally coat the highest aspect ratio feature.



7.2.1 Technical Information for High Aspect Ratio Depositions

For the interested reader, below is a discussion of the some technical aspects of coating high aspect ratio features utilizing ALD. When beginning a development process for coating new high aspect ratio features, the equations below can provide some guidance regarding precursor dosing and exposure times. This discussion follows from the following reference,

Gordon, R. G.; Hausmann, D.; Kim, E; Shepard, J. "A kinetic model for step coverage by atomic layer deposition in narrow holes or trenches" Chemical Vapor Deposition 2003, 9, 73.

For a hole of length L, diameter d, and aspect ratio a, the exposure $(P \cdot t)$ required for coating the sidewalls of the hole is given by:

$$(P \cdot t)_{sidewalls} = S \cdot \sqrt{2\pi mkT} \cdot \left[4a + \frac{3}{2}a^2\right]$$

$$Let\ k' = S \cdot \sqrt{2\pi mkT}$$

$$(P \cdot t)_{sidewalls} = k' \cdot \left[4a + \frac{3}{2}a^2\right]$$

P = Reactant partial pressure, and t = time needed to coat the entire hole length

T= Temperature

k = Boltzmann Constant

m = molecular mass of the reactant

S = saturated surface coverage per cycle (no. of molecules/ square meter)

Coating of the bottom of the hole is given by the following expression:

$$(P \cdot t)_{bottom} = k' \cdot \left[1 + \frac{3}{4}a\right]$$

Combining equations gives the total exposure needed to cover both the sidewalls and bottom of the hole.

$$(P \cdot t)_{total} = k' \cdot \left[1 + \frac{19}{4}a + \frac{3}{2}a^2\right]$$

7.2.2 Scientific References Pertaining to High-Aspect Ratio ALD Coatings

Kucheyev, S. O.; Biener, J.; Baumann, T. F.; Wang, Y. M.; Hamza, A. V.; Li, Z.; Lee, D. K., Gordon, R. G. “Mechanisms of atomic layer deposition on substrates with ultkahigh aspect ratios” Langmuir 2008, 24, 943

C. Detavernier, J. Dendooven, D. Deduytsche, and J. Musschoot, “Thermal Versus Plasma-Enhanced ALD: Growth Kinetics and Conformality” ECS Transactions 2008, 16, 239.

Gordon, R. G.; Hausmann, D.; Kim, E; Shepard, J. “A kinetic model for step coverage by atomic layer deposition in narrow holes or trenches” Chemical Vapor Deposition 2003, 9, 73.

Sundaram, G. M.; Deguns, E.W.; Bhatia, R.; Dalberth, M. J.; Sowa, M. J.; Becker, J. S. Solid State Technology, June 2009.

7.2.3 Exposure Mode™ Recipe Development

The general technique for accomplishing Exposure Mode™ depositions on the Fiji is to:

1. Isolate the reactor from the vacuum pumping

2. Pulse in precursor A
3. Allow time, t_{A1}, for precursor A to diffuse into high aspect ratio features
4. Restablish vacuum pumping and pump/purge system for $t_{A2} > t_{A1}$
5. Isolate the reactor from the vacuum pumping
6. Pulse in precursor B
7. Allow time, t_{B1}, for precursor B to diffuse into high aspect ratio features
8. Restablish vacuum pumping and pump/purge system for $t_{B2} > t_{B1}$
9. Repeat until desired film thickness is achieved

1. Reactor isolation – This is accomplished one of two ways depending on whether the Fiji being used is configured with a turbo pump/throttle valve option. If there is no turbo pump/throttle valve option, the stopvalve is closed with the stopvalve command discussed below. If there is a turbo pump/throttle valve, the throttle valve is closed with the APC command discussed below.

2. Precursor pulsing is accomplished with the pulse command just as in a continuous mode ALD recipe, however, it should be noted that the precursor dose will be larger than that used in continuous mode. The required dose will depend on the chemistry but using 5x the continuous mode dose is a good starting point. At this point gas flows may be adjusted as well. During the exposure step, the gas flows from the precursor manifold and the plasma source should not be completely turned off. Keeping a small positive gas flow through the manifold and the plasma source into the reactor minimizes precursor backstreaming into these parts of the reactor. The recommended minimum gas flow rates during the exposure step are 20sccm for the precursor manifold and 75sccm for the plasma source.

3. t_{A1} exposure – The exposure time needs to be sufficiently long to allow for full diffusion of precursor into the high aspect ratio features. This may require some experimentation to determine the appropriate length of time for the exposure. The time is constrained by the fact that there is a positive gas flow into the reactor and the reactor pressure will climb continuously throughout the exposure step. A maximum pressure of 76Torr is recommended for the exposure step. For the 19L reactor with 20sccm from the precursor manifold, 75sccm from the plasma source, and 50sccm from the door purge, the maximum exposure time is 13 minutes.

4. t_{A2} vacuum/purge – The time for pumping excess precursor and reaction by-products from the high aspect ratio features needs to be slightly longer than the time allowed for precursor diffusion into the high aspect ratio features. It is very important that any excess precursor A is pumped from the system before introducing precursor B so there are no CVD-like chemical reactions inside the high aspect ratio structures. If thicker films are observed inside the high aspect ratio features compared to the substrate surface, CVD due to insufficient pumping is the likely cause. Care must also be made when opening the throttle valve after a long exposure so as to not exposure the turbo pump to a sudden high pressure. This can be avoided by opening the throttle valve slightly enabling the bulk of the reactor contents to pump out slowly before completely opening the throttle valve to fully pump out the reactor before precursor B.

5-8. Precursor B – In general, the precursor B exposure will proceed similarly to that of A. Depending on the specifics of the precursor molecule diffusion properties, precursor B may need different times for diffusion in and out of the high aspect ratio features.

7.2.4 High Aspect Ratio Features with Temperature Sensitive Precursors

In continuous mode ALD at higher temperatures, the precursors tend to only be exposed to high temperatures for a few seconds before either being incorporated into the film through the ALD reaction or being pumped away. During Exposure Mode™ processing, the precursor molecules are intentionally kept in contact with the substrate for extended periods of time. Temperature sensitive precursors may be fine in the continuous mode ALD but may exhibit extensive thermal decomposition if utilized in Exposure Mode™ processes at the same temperatures. A good technique for identifying this problem is to insert a silicon wafer coupon and expose it to a couple 100 precursor exposures with the desired exposure time and processing temperature. If the silicon sample comes out discolored, this is a strong indicator that the precursor will thermally decompose with the current exposure time/processing temperature conditions. Tests should be conducted to determine what temperature range the proposed Exposure Mode™ process will work with.

7.2.5 High Aspect Ratio Features with Plasma

Plasma enhanced ALD films are limited to a maximum aspect ratio of approximately 30:1 for holes and vias, depending on the process chemistry. The reason for the limitation is the high radical reactivity which leads to radical recombination on the sidewalls of the high aspect ratio features. Within just a couple wall collisions, all radicals will be lost due to recombination. Once the radicals are recombined, they are no longer available to participate in the PEALD reaction process. No special recipe or equipment design considerations are going to enable higher aspect ratios to be coated with plasma processes. If higher aspect ratios are claimed with PEALD, check the details of the features. If the features are not holes, it is the extra degree of freedom for radical diffusion that is enabling the higher aspect ratio to be coated, not anything particularly unique regarding the process or equipment.

7.3 Plasma Source Operation and Theory

The plasma source can generate a plasma with just about any mixture of gases and pressures that can be produced on the Fiji. It makes sense that the best way to deposit a PEALD film is to produce the highest flux of radicals possible during the plasma step. One may assume that to generate the largest, for example, oxygen radical flux to the surface, they would turn the O_2 MFC to its maximum flow rate and start the plasma. This is, however, rarely the case due to the nonlinear behavior of plasmas.

Plasmas work best with gases that are easily ionized so that a large concentration of free electrons can be generated. These electrons can be accelerated to sufficiently high energies to dissociate the reactive plasma gases into reactive radicals. The noble gases are good examples of easily ionized gases. As one goes down the noble gas column of the periodic table, (He, Ne, Ar, Kr,…) the gases become easier to ionize. Because of their chemical inertness, the noble gases also make for a good carrier gas for PEALD activities. N_2 is the preferred carrier gas in thermal ALD systems, but if it was used as the carrier gas for

PEALD activities, one would certainly get nitrogen incorporated into their films when it was not desired. Argon is used for Fiji activities because it strikes a balance between inertness, ionizability, and price.

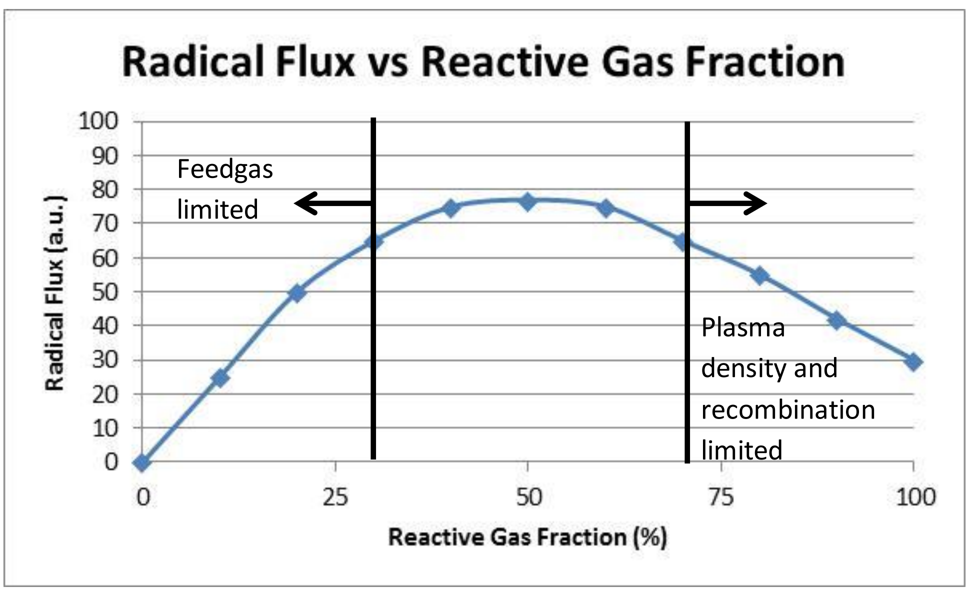
Oxygen and nitrogen are fairly electronegative. In a plasma, oxygen and nitrogen will have a tendency to remove free electrons from the plasma through electron attachment. Because of this phenomenon, plasmas with high oxygen and nitrogen fractions will have lower densities of free electrons. Less electrons means fewer radical dissociation events. This can lead to the counter-intuitive result of lower radical fluxes at higher reactive gas fractions.

The radicals produced in the plasma stream out into the reactor, carried along with the overall gas flow. The radicals are very reactive and will react quickly with the chemisorbed precursor on the substrate and reactor walls or recombine on the walls or in the gas phase. Radical recombination events will be reduced by operating at low pressure/high flow rate/short residence time. This is the primary reason that the turbo pump/throttle vale option benefits the PEALD process.

It turns out there will be a maximum radical flux at intermediate reactive gas fractions. At low reactive gas fractions the radical flux will be limited by the availability of the feed gas. At high reactive gas fractions, the radical flux will be limited by reduced plasma density and radical recombination.

$$Reactive\ Gas\ Fraction = \frac{Reactive\ Gas\ Flow}{Reactive\ Gas\ Flow + Inert\ Gas\ Flow}$$

(Plasma step can be established with saturation curve methodology. GPC may not be the best deposition response for saturation curve. resistivity for TiN)

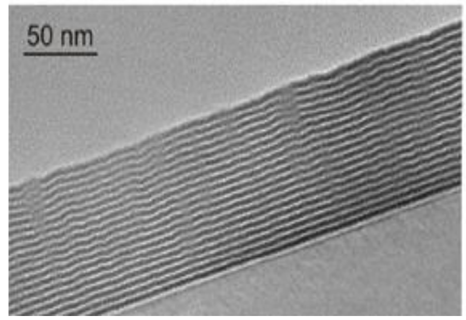


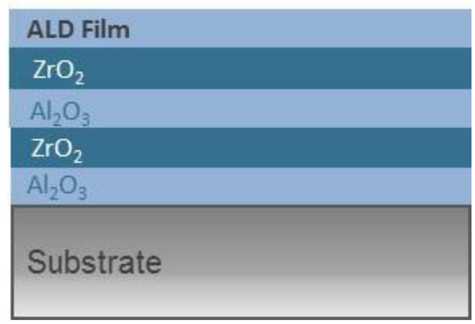
7.4 Nanolaminates and Doping

Certain applications do not rely on just one set of precursors to deposit a continuous, uniform film. Mixing of thin film materials as nanolaminates or through doping can produce novel results. Below these topics are discussed briefly along with examples of recipes to deposit example films.

Nanolaminates are alternating stacks of multiple discreet materials. Shown here is an SEM image of a stack of alternating 5nm layers of Al_2O_3 and ZrO_2 deposited via thermal ALD for the purpose of establishing a water permeation barrier. (Meyer, J., et al., Adv. Matls 2009, 21, 1845-1849; Meyer, J., et al., Appl. Phys. Lett. 2009, 94 233305-233303.)

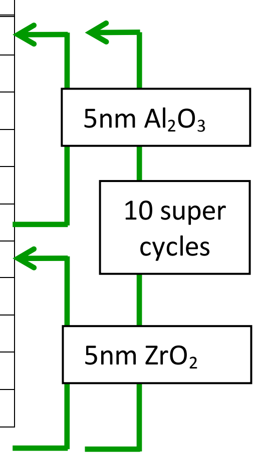
To deposit such a structure on the Fiji is straightforward. By nesting several loops together, the recipe is set up to automatically generate the nanolaminate structure.





7.4.1 Nanolaminate Recipe Example

	INSTRUCTION	CHAN	VALUE	UNITS
0	wait		5	sec
1	pulse	TMA	0.06	sec
2	wait		10	sec
3	pulse	H2O	0.06	sec
4	wait		10	sec
5	goto	1	45	cycles
6	pulse	TDMAZr	0.25	sec
7	wait		10	sec
8	pulse	H2O	0.06	sec
9	wait		10	sec
10	goto	6	45	cycles

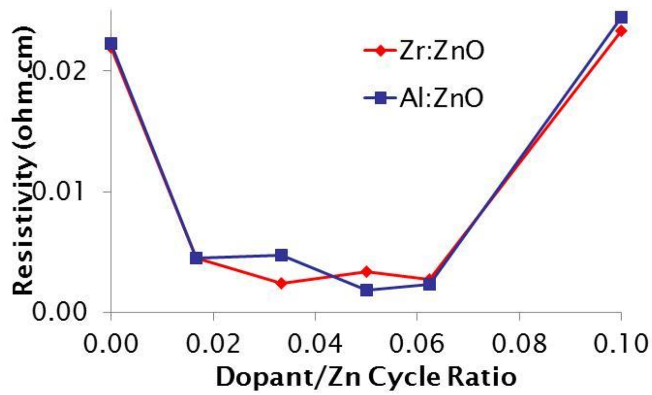


11	goto	0	10	cycles

The example has three loops. The first loop deposits 5nm of Al_2O_3. Then a second loop deposits 5nm of ZrO_2. Both of these loops are nested inside a larger loop which controls the number nanolaminates to deposit. Notice how the loops are all color coded to make it easier to see the recipe structure. The wait command in line #0 is just a placeholder for the outer nanolaminate loop. This could have been omitted and the outer nanolaminate loop could have repeated back to the pulse command on line #1 with no real difference in how the recipe operates. But then the loop color coding would not be as obvious as line numbers 1, 5, and 11 would all be yellow.

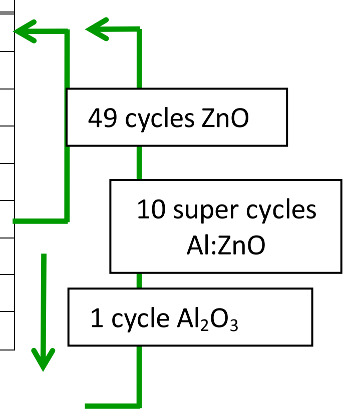
7.4.2 Doping

Doping is the process of inserting very small amounts of a different material into a bulk film to change the bulk film properties in a useful way. An example of this is to dope ZnO with low levels of Al to improve the conductivity of the transparent conductor. The graph shows how low levels of dopant in an ALD ZnO film can drastically reduce the film resistivity.(Bhatia, R., et al. ALD 2009, Monterey, CA, USA) ZnO is deposited with DiEthylZinc (DEZ) and H_2O. Doping the ZnO with Al is accomplished by periodically replacing one of the DEZ pulses with a TMA pulse. By replacing as little as every 50th DEZ pulse with a pulse of TMA, the film resistivity is reduced by nearly an order of magnitude.



A sample recipe to achieve this type of doping is provided below. The doping recipe and the nanolaminate recipe only differ in that the doping recipe runs through the second sub-loop only once per supercycle. If the goto command in line #10 in the nanolaminate recipe had a 1 in the value column, it would have the same functionality as the example doping recipe.

	INSTRUCTION	CHAN	VALUE	UNITS
0	wait		5	sec
1	pulse	DEZ	0.06	sec
2	wait		10	sec
3	pulse	H2O	0.06	sec
4	wait		10	sec
5	goto	1	49	cycles
6	pulse	TMA	0.06	sec
7	wait		10	sec
8	pulse	H2O	0.06	sec



9	wait		10	sec
10	goto	0	10	cycles

7.5 Recipe Development Summary

In this section, the user has been introduced to the Fiji recipe development process. To successfully develop recipes on the Fiji, the user must understand the available recipe commands, the recipe programming structure, and be able to properly interpret results from test depositions such that the recipe specifics can be appropriately adjusted to produce high quality ALD films. If the user understands the recipe commands and programming methods and always keeps in mind the basic concepts introduced in the discussion of the ALD window and saturation curves, they will be well on their way to developing their own optimized Fiji ALD recipes for thermal continuous, Exposure Mode™, and plasma enhanced ALD processes.

8 Fiji G2 Options

8.1 Fiji G2 Ozone Generator

The ozone generator provides a constant flow of ozone (O_3) generated from oxygen gas (O_2). The oxygen flow rate can be adjusted (via the 1000 sccm Ozone MFC (#5) by the end user to develop recipes at characterized ozone concentrations. The ozone concentration can be adjusted by varying the O_2 flow and ozone cell backpressure. Process ozone is delivered to the system using a standard rapid response ALD valve. The ozone generator is shown installed on a Fiji system. A simple schematic of the ozone delivery system is outlined on the following page.

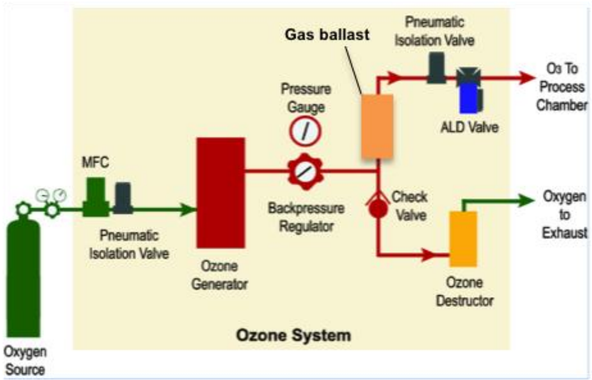
The ozone kit is fully integrated into the Fiji system and includes:

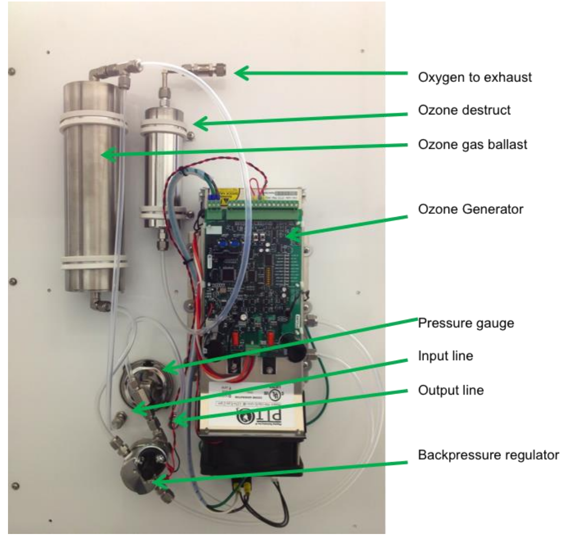
- recipe controlled operation (Ozone Flow, Ozone Power commands)
- adjustable concentration via O_2 flow to ozone generator (Ozone MFC)
- pulse delivered ozone
- H_2 interlock
- ozone destruct
- ozone generator components also include: ballast tank, ozone cell backpressure regulator, under pressure switch, LED indicators, check valve, and Mass Flow Controller (MFC)

Fiji Gen2 Ozone Generator (outside back panel)

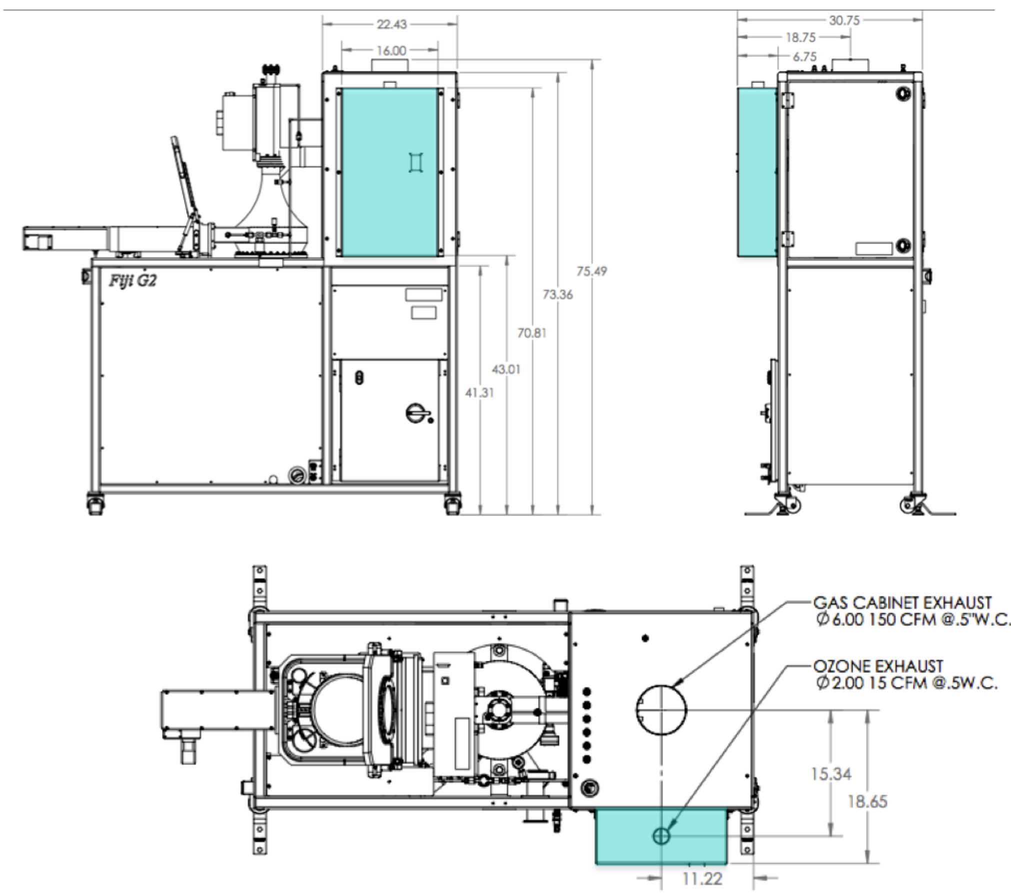
Fiji Gen2 Ozone Gas Panel (inside gas cabinet)

Figure 8-1





Schematic of zone generator arrangement ***Ozone generator assembly (lid removed)***



Gen2 Fiji and ozone generator – Facilities drawings

Figure 8-2

8.1.1 Ozone output concentration

Process ozone is adjusted as a recipe selectable parameter using the ALD pulse time. Typical ozone pulse times range from 0.015sec to 0.5sec depending upon the amount of ozone required for your ALD process. The oxygen flow to the ozone unit (Ozone MFC [#5], O_2/O_3) can be adjusted in the recipe from 50sccm to 1000sccm. The recommended O_2/O_3 flow is 500 sccm. The ozone output is summarized in the charts below for the recommended operating pressure of 5 psi.

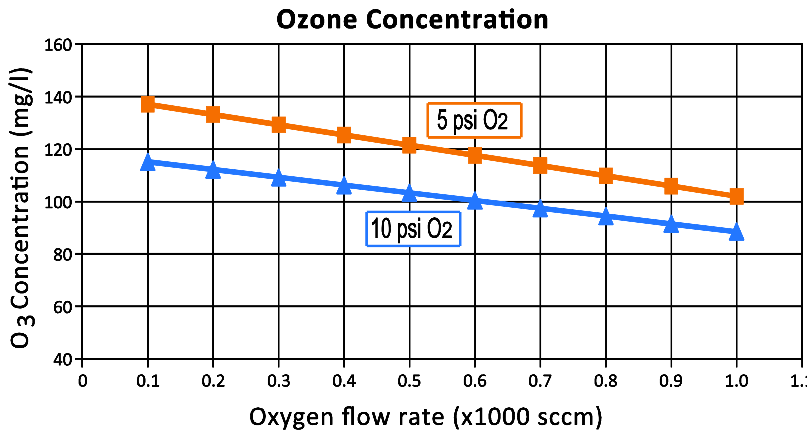


Figure 8-3 – Ozone generator output at 5psig and 10psig O2 as a function of oxygen flow rate

8.1.2 Ozone Destruct

When the ozone is not being used to dose a film (i.e. the ALD valve is closed), a 1/3 psid check valve diverts the O_3 stream to an O_3 destruct unit located within ozone kit enclosure. The destruct will recombine all excess, unused ozone as O_2. The recombined O_2 is exhausted from the ozone kit enclosure via a 2" outer diameter duct.

8.1.3 Minimum Oxygen Flow Interlock

The ozone generator will not turn ON at oxygen supply pressures below 2 PSIG. This oxygen pressure interlock is designed to protect internal electronics from operating with insufficient gas flow or at vacuum. Operation of the ozone generator at sub atmospheric pressures (<760 Torr) will damage the ozone cell and internal components.

8.1.4 Ozone Leak and Safety Monitoring System

A customer-supplied ozone detector system MUST be installed to monitor the destruct efficiency and safety of the exhaust stream and the surrounding work environment. At a minimum, ozone detectors must be installed:

- at the top inside of the gas delivery box
- in the exhaust line of the ozone generator kit

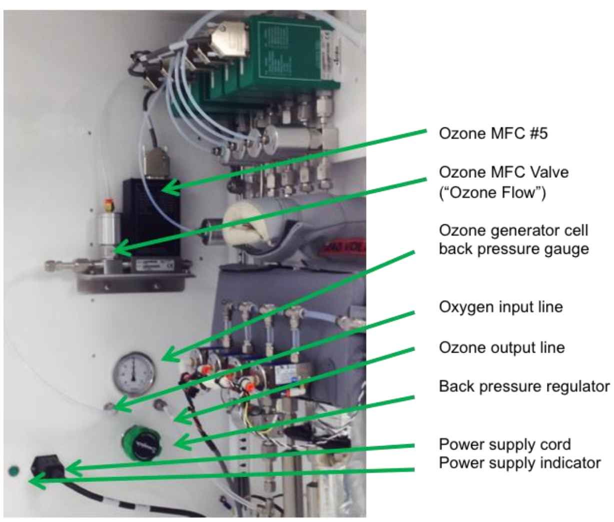
Ozone detectors should be hard-wired per industry, local, and national code standards to disable the production of ozone in the event of a detected leak.

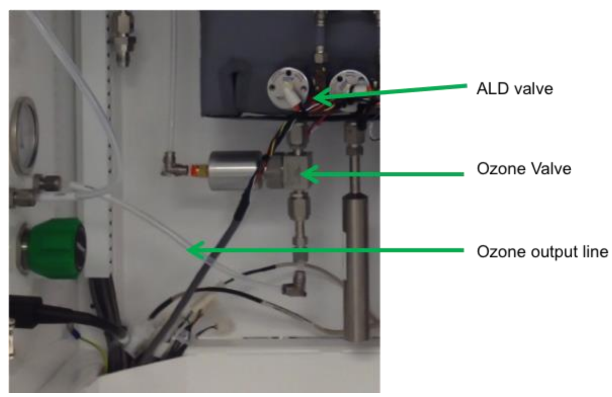
Installation, service, and verification of ozone detector and safety monitoring equipment are solely the responsibility of the end user. No ozone detection equipment and hardwired leak detection interlocks are provided with the unit.

Ozone can NOT be used with H_2 or H_2 plasma. The Fiji system is interlocked to prevent H_2 and O_2 or O_3 flow without purging the chamber. Do not defeat or circumvent this safety interlock.

8.1.5 Ozone Generator Specifications

Item	Specification
Dimensions (W x H x D) inclusive of integrated mounting panel	310 mm x 325 mm x 493 mm (21.93" x 31" x 6.75")
Approximate weight	21 kg (46.3 Lb.)
Gas connections	Oxygen inlet: ¼" Swagelok compression fitting Ozone generator cell backpressure regulator: Two-stage, capable of controlling at 5-10 PSIG Ozone outlet: ¼" Swagelok compression fitting
Generator AC power	110/220 VAC
Oxygen flow	0 –1000 sccm
Required ozone generator cell backpressure	5 – 10 PSIG
Maximum ozone output concentration	120 mg/l @ 500 sccm pure O_2 flow @ 72°F
Cooling requirements	The system is air-cooled. Do not block vents which are located on the bottom of the ozone generator enclosure





Internal view of ozone generator in Gen2 Fiji Gas Cabinet

Connection from ozone panel to ALD valve manifold in Gen2 Fiji Gas Cabinet

Figure 8-4

** When setting Ozone Flow to 1 (or 0) in a recipe, both the Ozone MFC valve and the Ozone Valve upstream to the ALD pulse valve will be activated.*

8.1.6 Operation of System with Ozone Generator

8.1.6.1 Ozone Unit Manual Operation

CAUTION! Temperature Sensitive.

The ozone generator is sensitive to temperature and should be kept as cool as possible. Never block the cooling vents at the bottom of the unit. The unit will flash a red LED labeled 'HS TEMP' through the top viewing window if it overheats, and may automatically shut down to cool.

8.1.6.2 Ozone Operation Summary

Step	Action	Details
1.	Verify O_2 supply pressure > 20 psi	Check the regulator at the oxygen source (different from backpressure regulator inside the precursor gas box)
2.	Open the O_2/O_3 MFC valve through the control software.	Recipe command: ***Ozone Flow 1***
3.	Turn on the flow of O_2 through the Ozone MFC 5 at the desired rate of flow.	Flow range: 50sccm to 1000sccm Recommend flow rate: 500sccm Recipe command: ***Flow 5 500***
4.	Wait 15 seconds for the oxygen flow to stabilize.	
5.	Open the panel to the vented precursor gas box and adjust the backpressure regulator to achieve the desired cell backpressure (typically 5 psig to 10 psig).	
6.	Turn ON the ozone generator	Recipe command: ***Ozone Power 1*** The FIJI ozone unit is powered "ON" with 220V (or 208 V) from the e-box controller using the recipe command Ozone Power Upon powering up the ozone generator the ozone box will turn on the cooling fan and sequence through all of the indicator lights (3x green, 2x yellow, 5x red – visible through window on ozone box back panel). This is normal behavior. When the unit is powered and running in steady state and the oxygen pressure in the unit is greater than 3psig there will be three green lights displayed on the ozone bock unit (verify the INV ON, +5V, LOCKED LEDs maintain green). This is required for ozone generation and proper recipe operation.
7.	Run a process recipe, as desired.	See example recipes.
8.	Turn off the ozone generator	Recipe command: ***Ozone Power 0*** This action will turn off the ozone generator unit and the indicator light will turn OFF.
9.	With the ozone generator's power OFF, flow oxygen through the ozone generator for 1-2 minutes to purge any remaining ozone out of the unit.	
10.	Set O_2 flow to zero then close the O_2 inlet MFC valve.	Recipe command: ***Flow 5 0***
11.	Close the O_2/O_3 MFC valves.	Recipe command: ***Ozone Flow 0***

8.1.6.3 *Standard Ozone Process Recipe*

Below is a standard ozone recipe for Al_2O_3 deposition at 200ºC – 250˚C using trimethylaluminum (TMA). Ozone MFC #5 controls the flow of oxygen through the ozone generator.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	flow	0	20	sccm	
1`	flow	1	50	sccm	
2	heater	13	250	°C	Set Heaters
3	heater	14	250	°C	
4	heater	15	250	°C	
5	heater	16	150	°C	
6	heater	17	150	°C	
7	heater	24	150	°C	
8	heater	25	125	°C	
9	heater	30	150	°C	
10	stabilize		1800	sec	Stabilize Heaters
11	turbo purge		0	close	Close Turbo Pumping line
12	turbo gate		0	close	And Pump through reactor rough valve
13	turbo iso		0	close	
14	reactor turbo		0	off	
15	exhaust valve		1	open	
16	flow	0	30	sccm	Set carrier process flow
17	flow	1	80	sccm	Set plasma process flow
18	wait		10	sec	
19	ozone flow		1	on	Open ozone Iso valve (MFC valve)
20	flow	5	500	sccm	Set 500 sccm flow O2 to ozone generator
21	wait		15	sec	
22	ozone power		1	on	Ozone generator power = ON
23	wait		360	sec	Ozone purge
24	pulse	O3	0.075	sec	
25	wait		15	sec	
26	goto	24	5	cycles	5 cycle purge of ozone delivery line
27	wait		10	sec	
28	pulse	TMA	0.06	sec	Pulse precursor
29	wait		10	sec	
30	pulse	O3	0.15	sec	Pulse Ozone
31	wait		10	sec	
32	goto	28	200	cycles	200x ALD cycles
33	ozone power		0	off	Ozone generator power = OFF
34	wait		180	sec	Purge ozone
35	flow	5	0	sccm	Set 0 sccm flow O2 to ozone generator
36	ozone flow		0	off	Close ozone Iso valve (MFC valve)

In the recipe, the first "goto" loop highlighted in blue is designed to repeatedly pulses ozone into the chamber and purge the ozone gas delivery line. After purging the ozone delivery line, ALD process can begin with steady state concentration of ozone and oxygen in the process ozone gas line. The ALD process loop, shown in orange, alternately pulses TMA and ozone for 200 cycles of alumina (Al_2O_3) film growth. The growth rate for TMA + O_3 is typical in the range of 0.8 to 0.9 Angstrom/cycle.

When developing new process recipes using the ozone generator, pulse times longer than 1.0 sec will evacuate the O_2/O_3 gas delivery line to the ALD valve. Sub-atmospheric pressure in the gas delivery line may damage your ozone hardware and affect the integrity of your ozone process recipe. The under-pressure switch is designed to shut off power to the ozone generator at cell pressures less than (2) psi. If your process demands more ozone exposure than 1.0 sec, we suggest that multiple ozone pulses can be used, for example 2x ozone pulse followed by 1x precursor pulse.

8.1.6.4 Ozone Test Recipe

Below is an ozone test recipe to determine if the ozone unit is operating correctly.

The ozone unit is turned ON and pulsed as specified in the process recipe. Ozone is installed on ALD-0, MFC 5 controls the oxygen flow to the ozone generator.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
0	turbo purge		0	close	Close Turbo Pumping line
1`	turbo gate		0	close	And Pump through reactor rough valve
2	turbo iso		0	close	
3	reactor turbo		0	off	
4	exhaust valve		1	open	
5	flow	0	30	sccm	Set carrier process flow
6	flow	1	80	sccm	Set plasma process flow
7	mfc valve	5	1	open	Open ozone Iso valve (MFC valve)
8	flow	5	500	sccm	Set 500 sccm flow O2 to ozone generator
9	wait		15	sec	
10	ozone power		1	on	Ozone generator power = ON
11	wait		360	sec	Ozone purge
12	pulse	O3	0.075	sec	Pulse Ozone
13	wait		20	sec	
14	goto	12	10	cycles	
15	ozone power		0	off	Ozone generator power = OFF
16	wait		180	sec	Purge ozone
17	flow	5	0	sccm	Set 0 sccm flow O2 to ozone generator
18	mfc valve	5	0	close	Close ozone Iso valve (MFC valve)

8.1.6.5 Ozone Generator Indicator Lights

During power up, the ozone generator will turn on the cooling fan and sequence through all of the indicator lights (3x green, 2x yellow, 5x red). This is normal behavior. The ozone generator indicator lights are viewed through the window on the side of the unit. During normal operation, three green lights will be lit:

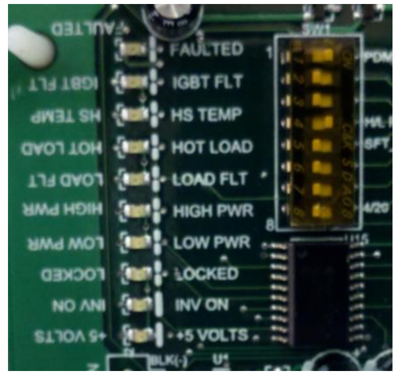
The green "+5 VOLTS" light indicates proper cell voltage.

The "INV ON" green light is lit when the ozone generator inverter board is powered and operating.

The "LOCKED" light is lit when the inverter is locked into its proper operating range.

If either the "HS TEMP" red light or "HOT LOAD" light flashes, the unit is too hot and needs to be cooled.

Ozone Generator Indicator lights (3 green lights - proper operation)
LOCKED – Locked in output
INV ON - Inverter is powered and operating
+5 Volts - Proper Cell Voltage



8.1.6.6 Ozone Generator Troubleshooting

<table>
<tr><th>Sympton</th><th>Solution</th></tr>
<tr><td>Ozone leak detected from ozone kit enclosure</td><td>Before performing any troubleshooting techniques, review Appendix A – Safety. Ozone is a hazardous and toxic gas.
Check all fittings in the ozone kit enclosure then perform a static pressure test to determine system integrity:
<table>
<tr><th>Step</th><th>Action</th><th>Details</th></tr>
<tr><td>1.</td><td>Remove the ozone kit enclosure.</td><td>Remove exhaust at top, then remove screws as necessary to remove the cover panel.</td></tr>
<tr><td>2.</td><td>Use a ¼” Swagelok compression cap to seal the outlet of ozone destruct unit.</td><td></td></tr>
<tr><td>3.</td><td>Pressurize the cell:</td><td>Set Ozone Flow to 1 (open)
Set Ozone MFC5 flow
Adjust the backpressure regulator to 5 psig achieve 15 psig</td></tr>
<tr><td>4.</td><td>Set flow to zero</td><td>Set Ozone MFC5 flow to zero</td></tr>
<tr><td>5.</td><td>Close Ozone Valve</td><td>Set Ozone Flow to 0 (closed)</td></tr>
<tr><td>6.</td><td>Monitor the pressure decay (if any) in the cell.</td><td>Record cell pressure from the backpressure gauge at regular intervals of 8 hours, 16 hours, and 24 hours.</td></tr>
</table></td></tr>
<tr><td>Ozone generator shuts down with “HS TEMP” red light or “HOT LOAD” light flashing</td><td>The unit is too hot and needs to be cooled.
Check vents at bottom of unit. Ensure vents are clear. Avoid flow of hot air from adjacent equipment onto the ozone generator housing.</td></tr>
</table>

8.1.6.7 Ozone Generator, Additional Safety Notices

8.1.6.7.1 Ozone Safety Notice

For use with systems equipped with an ozone generator.

WARNING!

Ozone (O_3) is a toxic gas. High concentrations of ozone are dangerous and harmful to humans. The current maximum 8-hour exposure limit for ozone is 0.1 ppm (0.2 mg/m^3) according to U.S. OSHA® and NIOSH. Use all-stainless steel gaskets for VCR® gas connections. Use ozone-compatible materials including 316L Stainless steel, Teflon®, Chemraz® and Kynar®.

The ozone generator unit should only be operated as specified in this manual.
Consult the MSDS (Material Safety Data Sheet) in regards to the hazards associated with ozone use.

If ozone is detected, immediately turn off the ozone generator unit and consult the Veeco Service Department.

Ozone is a powerful oxidant and should not be simultaneously pulsed/mixed in the chamber with H_2 gas or other flammable precursor.

Electrical Hazards

Hazard Type	Hazard Location	Hazard Notes
 Electrical shock hazard	Internal to precursor gas box at wiring connection, and internal to unit (behind covers).	The ozone generator is powered by 110 VAC, 1 Phase 50/60 Hz. The Fiji system is typically powered by 208 VAC. Please consult the *Fiji Installation and Use Manual* before removing any covers on the system. The main input power connection is located at the rear of the unit. **DANGER:** Electrical Hazard. DO NOT OPEN COVERS to access electrical equipment with the power on, unless you are certified to perform specific troubleshooting/repair tasks.

Chemical and Fire Hazards

Hazard Type	Hazard Location	Hazard Notes

  Chemical and Fire Hazards	System	**DANGER! TOXIC HAZARD** Ozone (O_3) is a toxic gas. High concentrations of Ozone are dangerous to humans. Take reasonable steps to avoid exposure. The OSHA maximum 8-hour exposure limit for Ozone is 0.1 ppm. If ozone is detected, immediately turn off the ozone generator unit and consult the Veeco Service department. Ozone can NOT be used with H_2, or formic acid. OZONE DETECTION EQUIPMENT: Install safety monitoring equipment to stop the generation of ozone in the event of a system leak. MATERIAL COMPATIBILITY: Use 316L Stainless, Teflon®, Chemraz® and Kynar®. Do NOT use Viton® seals! Use only **stainless steel** unplated gaskets for VCR® gas connections. **Do NOT** use silver-plated gaskets.
	Material Safety Data Sheets (MSDS)	Material Safety Data Sheets (MSDS) for every chemical used with the system should be available to all users of the system at all times. Each user should be trained on the specific gases/chemicals used with the system, and be certified in safe operation of the system. The MSDS covering all materials used in the process must be prominently displayed in the immediate vicinity of the machine.

*Refer to OSHA standards for updates.

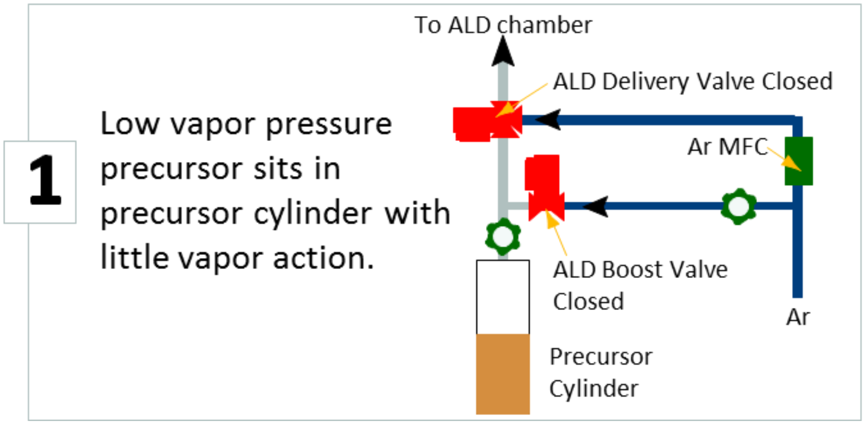
8.2 Boost Hardware

A key aspect to the ALD process, whether it is thermal or plasma enhanced, is the delivery of a saturating dose of precursor to the substrate surface. Some precursors lack the vapor pressure characteristics to generate a sufficient precursor dose via the standard vapor draw method. Increasing the precursor temperature is the easiest way to enhance the available deliverable vapor. But temperature limitations of the chemistry or the hardware may prevent the vapor pressure being sufficiently increased through additional heating. If a vapor pressure >1 Torr cannot be achieved at temperatures less than 200°C that do not lead to thermal decomposition, some precursor delivery enhancement will be required.

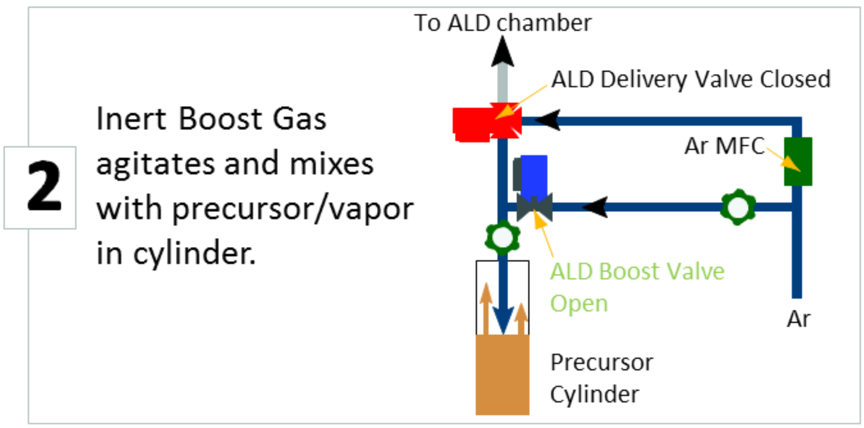
For cases such as these, Veeco has developed products to enhance the delivery of low vapor pressure materials to the reactor. One of these products is called the "Boost."

8.2.1 Boost Overview

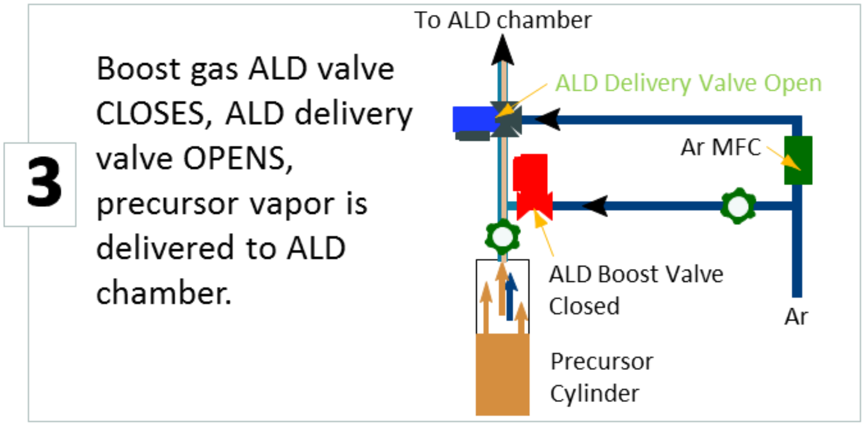
The ALD precursor Boost kit provides the capability to inject a controlled amount of pressurized inert gas (typically Ar carrier gas when used on the Fiji G2 system) into the precursor cylinder to aid in the efficient transport of low-volatility precursors. The boost kit can provide sufficient dose for precursors with vapor pressures >0.1 Torr. An overview of the process is shown below:



At steady state, precursor vapor exists in the heated cylinder vapor space but at a pressure lower than the precursor manifold so pulsing of the ALD valve does not lead to any delivery of material from the cylinder to the Fiji reactor.



The ALD Boost valve, shown above in blue, is opened briefly to allow a pulse of Ar to enter the headspace of the precursor cylinder. This pulse of Ar provides some agitation to the solid or liquid precursor. The precursor now exists in the Ar boost gas at a partial pressure similar to the precursor's vapor pressure at the current cylinder temperature.



By opening the ALD valve on which the precursor cylinder and Boost hardware are installed, the pressurized Ar from the cylinder is pulsed into the Fiji reactor, carrying along with it the low vapor pressure precursor material. This method is much more efficient at delivering low vapor pressure materials to the Fiji reactor compared to the standard vapor draw method.

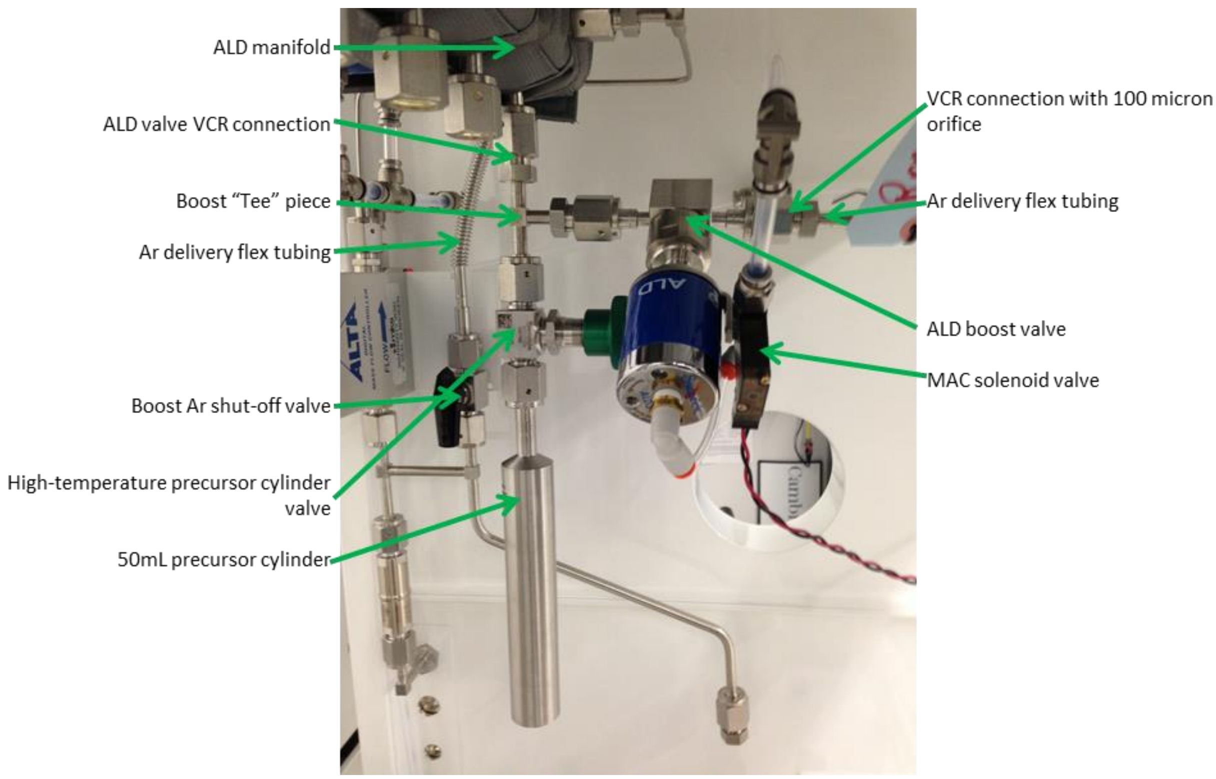


Figure 8-5 – Picture showing the installation on a Savannah system, however the Fiji G2 installation is similar. Picture depicts the setup without the heater jacket installed so configuration details are visible.

8.2.2 Boost Kit Component and Installation

The ALD Precursor Boost can be installed at the factory or in the field. If your Boost installation was installed at the factory, the below description will help you understand how it works. If you have received a field Boost retrofit kit, follow the instructions to install this on your system.

A field retrofit kit includes:

- FFM ¼” VCR tee
- 100micron orifice on ¼” VCR gaskets
- Standard ¼” VCR gaskets
- MM ¼” VCR union
- PTFE tubing and tee connector
- ¼ turn ball valve
- ¼” VCR flexible stainless steel tubing
- Two port boost valve with MAC solenoid valve
- Wiring for connecting MAC solenoid valve to Ebox
- 240V Boost kit heater jacket

The ALD Precursor Boost kit includes appropriate plumbing (tubes, tees, manual valve, and connectors) to easily install the boost capability on the Fiji G2 system. Consult Figure 8-6 as the description of the hardware setup is given below.

1. The ALD Boost installation starts by installing the Boost “Tee” piece on the desired ALD valve on the precursor manifold with a standard VCR gasket. The tee piece will point away from the reactor.
2. The output of the ALD Boost valve is connected to the horizontal section of the boost tee with a standard VCR gasket.
3. The supplied flexible stainless steel tubing with VCR connections is provided for making the connection between the Ar supply and the ALD Boost valve. An Ar connection point has been established on the Ar distribution manifold in the gas box. Figure 2-3 indicates the location of the cross piece on the Ar distribution line for making the Boost Ar connection. This Ar connection point is at the pressure of the Ar delivery line to the tool.
    3.1. Isolate/deenergize the Ar delivery gas prior to opening the cross connection to attach the flexible stainless steel tubing.
    3.2. Remove the cap from the Ar delivery line cross.
    3.3. Connect the short MM ¼” VCR union to the cross with a standard ¼” VCR gasket.
    3.4. Connect the ¼-turn ball valve to the union with a standard ¼” VCR gasket.
    3.5. Connect the stainless steel flexible line to the ¼-turn ball valve with a standard ¼” VCR gasket.
    3.6. Connect the other end of the stainless steel flexible line to the input of the Boost valve using a **100micron ¼” VCR gasket**.
4. The Boost valve requires additional connections for CDA and electrical control.
    4.1. CDA connection
        4.1.1. Temporarily isolate/deenergize CDA to the system.
        4.1.2. Replace a 90° elbow in the CDA distribution system with a tee. Check that the length of supplied PTFE tubing is sufficiently long to connect from the selected tee position to the Boost valve location.
        4.1.3. Use the newly available CDA port on the tee to connect the MAC solenoid valve on the Boost valve to the Fiji G2 CDA distribution system with the supplied length of PTFE tubing.

Tubing may be cut to length as appropriate for the position of the Boost kit and the connection point to the CDA.

4.1.4. Reenergize the CDA to the system.

4.2. Control connection

4.2.1. Using the supplied electrical cable, connect the MAC solenoid valve electrical input to the 24V OUTPUT 6 (Option A Valve) or 24V OUTPUT 7 (Option B Valve) on the rear of the Ebox as depicted in Figure 2-9. Note which output is selected as that will determine information used in a recipe to control the Boost valve.

5. The Boost kit includes a heating jacket which heats the precursor cylinder, Boost tee, and Boost valve to minimize opportunities for precursor condensation. The heater jacket has two electrical connections to the Ebox: a three pin power connector for the heating element and a two pin RTD connection for temperature measurement. The heater power and RTD connections are made on the rear of the Ebox. Heaters 18 – 23 are set aside for heaters associated with ALD valves 1 – 5. Plug the power and RTD connectors into the selected heater channel for the Boost heater jacket. Note the channel selected as that will be used for controlling the Boost precursor hardware temperature from the software front panel and process recipes.
6. Pump out Ar lines to remove air. Turn Ar back on.
7. Using standard precursor installation procedures, pulse/purge the trapped volume of air between the precursor cylinder manual valve, the Boost valve, and the ALD pulse valve prior to opening the precursor cylinder manual valve.

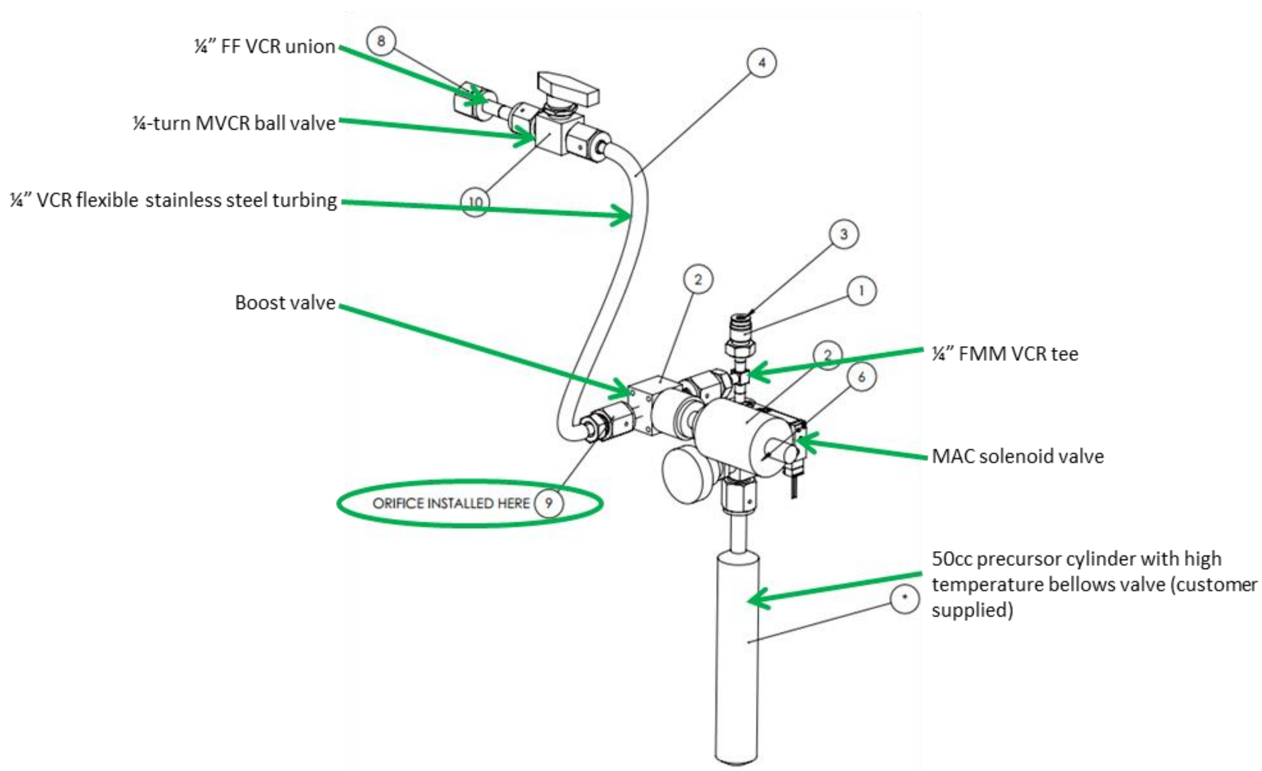


Figure 8-6 – Diagram of a single boost kit installation on a Fiji G2 system.

In order to more accurately control the pressure introduced into the precursor cylinder, a 100 micron VCR restriction gasket is installed on the SS flexible line side of the ALD valve, in lieu of a standard VCR® gasket. The flow of Ar through the orifice is a function of the Ar delivery pressure to the Fiji G2 system. Boost recipe examples will assume that Ar is being delivered to the system at the recommended pressure of 30psi. If higher pressures are used, the pulse times for the boost valve may need to be shortened.

8.2.3 Boost Application Modes

The ALD boost can be used in the following modes:

- Single Boost
- Multi-Boost

Examples of each mode are provided below.

8.2.3.1 Single Boost

The single boost is the standard mode of operation for the boost configuration. The boost valve is pulsed, introducing a controlled charge of Ar into the precursor cylinder followed by a pulse of the associated ALD valve to deliver the combined Ar boost gas/low vapor pressure precursor pulse to the reactor. A partial listing of an example single boost recipe is shown in Table 8-1 and an example pressure chart is shown in Figure 8-7. The pressure spike for the boosted precursor pulse will be considerably larger than observed for typical un-boosted precursor pulses. As opposed to un-boosted, vapor draw pulsing, the height of the pulse is primarily a function of the duration of the boost valve pulse (line 18), which determines how much Ar is transferred to the precursor cylinder, rather than the length of the ALD valve pulse time (line 20).

Table 8-1 – Sample single boost recipe partial listing.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
…	…	…	…	…	Recipe set-up lines removed
16	pulse	H2O	0.06	sec	Pulse water
17	wait		10	sec	
18	boost	2	0.5	sec	boost valve (ALD port 2)
19	wait		0.5	sec	
20	pulse	2	1	sec	Pulse valve(ALD port 2)
21	wait		10	sec	
22	goto	16	200	cycles	Repeat cycle.
…	…	…	…	…	Recipe shut-down lines removed.

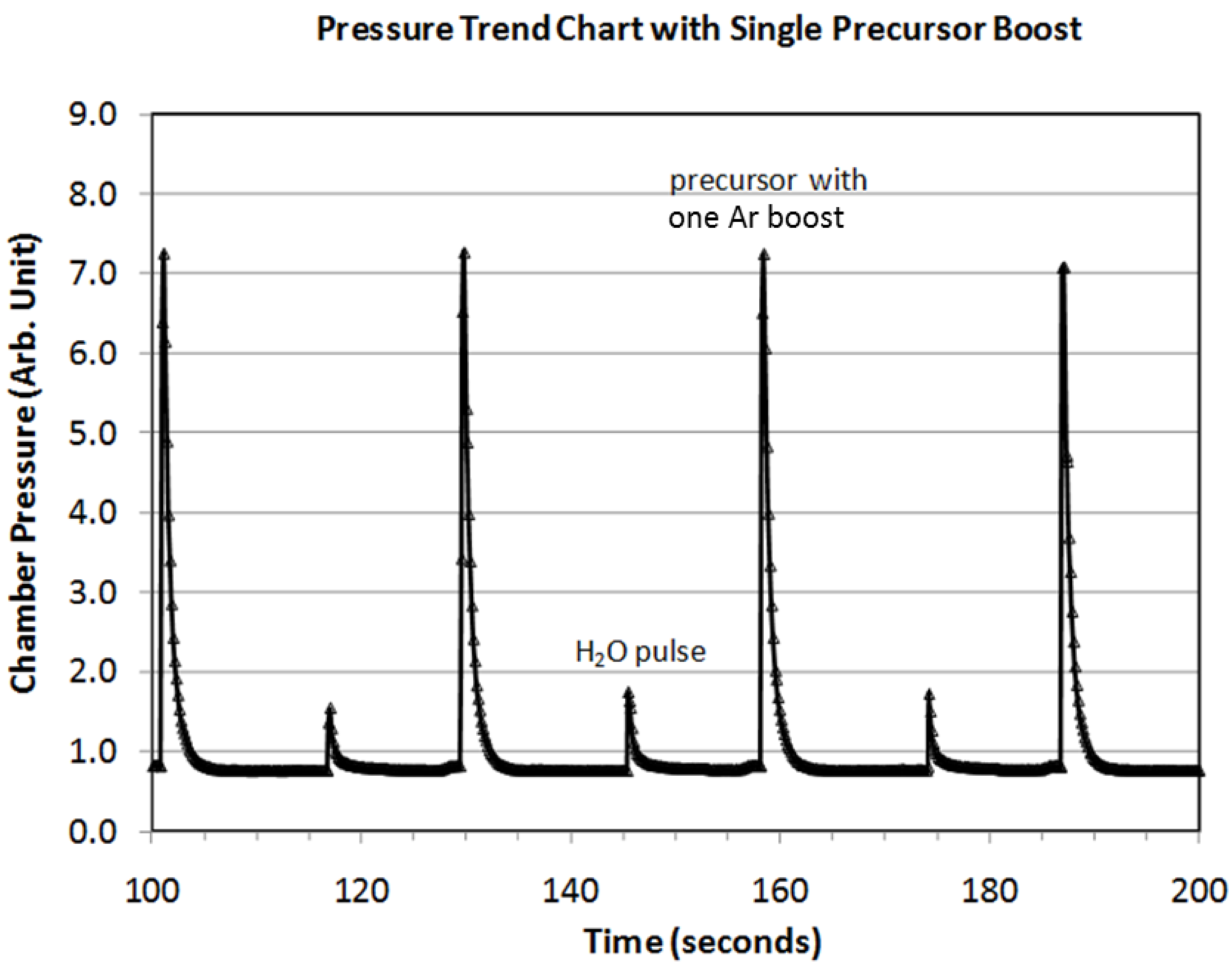


Figure 8-7 – Sample pressure chart from a thermal ALD process with using the boost.

8.2.3.2 *Multi Boost*

Sometimes a single boosted precursor pulse is insufficient for delivering a saturating dose to the reactor. In these cases, multiple boost steps can be linked together in a nested goto loop in the recipe.

	INSTRUCTION	CHAN	VALUE	UNITS	Comment
…	…	…	…	…	Recipe set-up lines removed
16	Pulse	H2O	0.06	sec	Pulse water
17	Wait		10	sec	
18	Boost	2	0.5	sec	boost valve (ALD port 2)
19	Wait		0.5	sec	
20	Pulse	2	1	sec	Pulse valve(ALD port 2)
21	Wait		2	sec	
22	Goto	18	3	cycles	Triple Boost (3 cycles)
23	Wait		9	sec	
24	Goto	16	200	cycles	ALD cycle
…	…	…	…	…	Recipe shut down lines removed

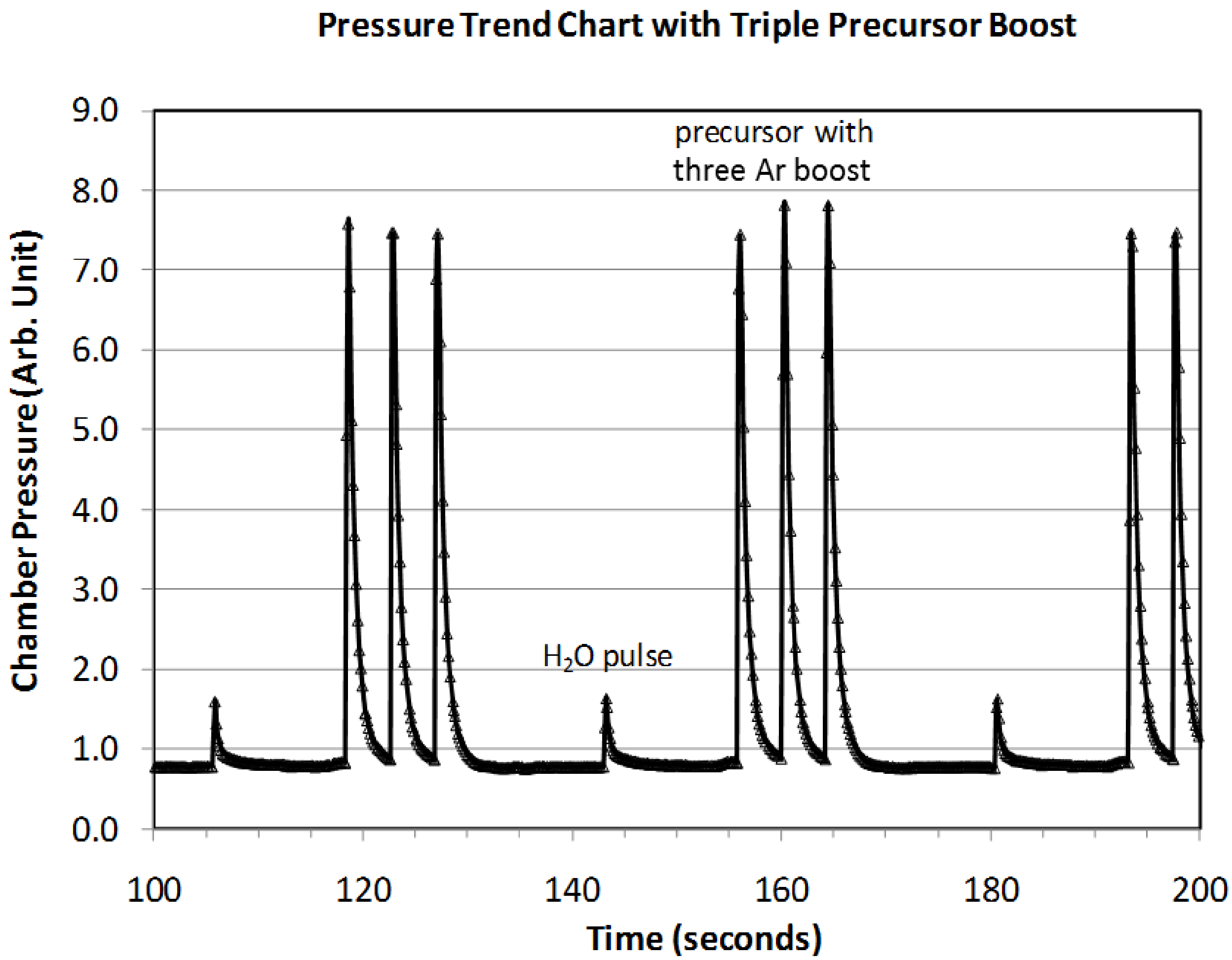


Figure 8-8 – Sample pressure chart from a thermal ALD process with using a 3x boost.

8.2.4 Boost Kit Installation

The Fiji G2 system has sufficient capabilities to enable the installation of two Boost kits, as shown in Figure 8-9. The Ar connection is accomplished with a tee rather than a union to allow both kits to share the same Ar distribution point. The Boost valve's Ebox connections will necessitate the use of both the 24V OUTPUT 6 (Option A Valve) and 24V OUTPUT 7 (Option B Valve) on the rear of the Ebox as depicted in Figure 2-9.

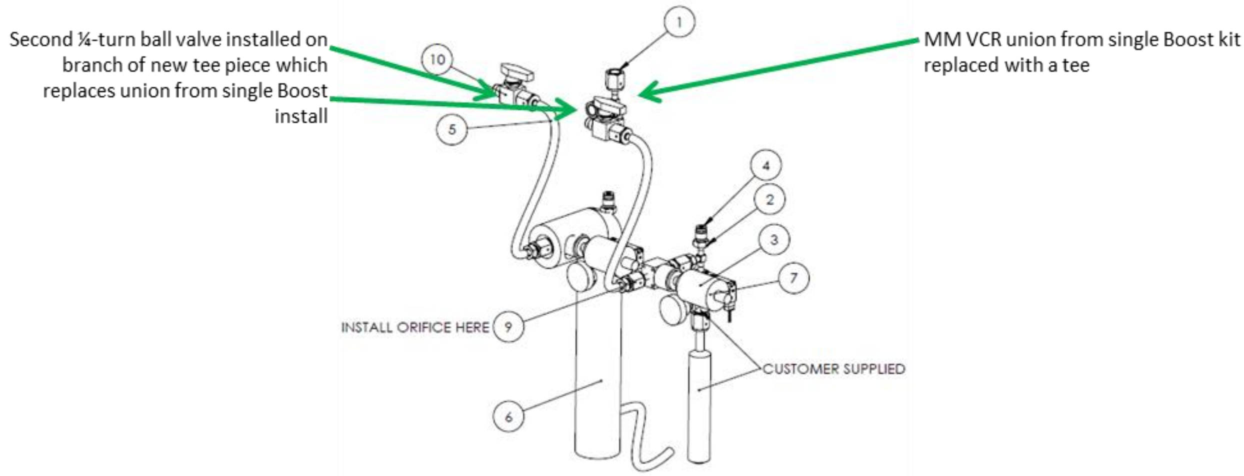


Figure 8-9 – Double Boost kit on the Fiji G2. Two Boost kits share the Ar connection with a tee piece rather than the single Boost kit union.

9 Safety

9.1 Introduction

The Fiji G2 system has been engineered with safety as paramount. While every effort has been made to ensure the health and safety of all involved in the operation of the Fiji G2, a review of hazards present with PEALD processing along with a description of the engineered safety solutions on the Fiji G2 system will minimize risks for the operator.

Read and follow these safety instructions. Task and equipment specific warnings, cautions, and instructions are included in equipment documentation where appropriate.

Make sure all equipment documentation, including these instructions, is accessible to persons operating or servicing equipment.

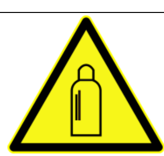
9.2 Definitions for Signal Words

The following are definitions for signal words for this system:

Label	Meaning
DANGER	Indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury.
WARNING	Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury.
CAUTION	Indicates a potentially hazardous situation which, if not avoided, may result in minor or moderate injury, or damage to equipment.

9.3 Safety Symbols

Symbol	Meaning
	**SHOCK HAZARD** Electric voltage present. Take appropriate measures to protect yourself from electrical shock. The “lightning bolt within a triangle” symbol (reference IEC Publication 417, Symbol No. 5036, and ISO Publication 3864, No. B.3.6) is used in and/or on the equipment to alert the user, operator, or service personnel to the presence of un-insulated voltage within the enclosure of sufficient magnitude to constitute a risk of electric shock. **Only authorized service personnel with a thorough knowledge of the voltages existing within the equipment shall remove covers or panels from the product bearing this symbol.** This symbol is also used within the product manual itself to identify important operating and/or maintenance instructions, which, if not

	followed carefully, could result in personal injury or even death.
	**RISK OF FIRE** The "flame within a triangle" symbol (reference IEC Publication 417, and ISO Publication 3864) is used in and or on the equipment to **alert the user, operator, or service personnel to the potential of fire hazard, including that caused by gases which may ignite upon contact with air (pyrophoric gases). Only authorized service personnel with a thorough knowledge of the gases existing within the equipment shall remove covers or panels from the product bearing this symbol.** This symbol is also used within the product manual itself to identify important operating and/or maintenance instructions, which, if not followed carefully, could result in personal injury or even death.
	**PINCH HAZARD** This symbol is used in the product manual to identify a pinch hazard such as a door, panel, fixture, or overall system handling which could cause a pinch or crushing hazard.
	**TOXIC MATERIAL HAZARD** This symbol is used in the product manual to identify sources of toxic gas materials. While the system is NOT shipped with any precursors or other gases, the customer and end-user must be aware of on-site gas usage and its resulting hazards.
	**BURN HAZARD** This symbol is used in the product manual to identify sources of burn hazards. Do not touch hot surfaces! Allow the system components to fully cool before performing maintenance tasks or touching hot parts.
	**HEAVY/AWKWARD OBJECT LIFT HAZARD!** This symbol is used in the product manual to identify procedures where a minimum of two people are required to lift a heavy or unbalanced/awkward object.
	**COMPRESSED GASES** This symbol is used in the product manual to identify sources of compressed gases or other situations where a large pressure differential exists, such as between atmosphere and an evacuated

	vacuum chamber.
	**UV RADIATION** This symbol is used in the product manual to identify sources of ultraviolet radiation.

9.4 Equipment Safety Labels Locations

System hazards are identified via safety labels attached to the cabinet, modules and components of the system where appropriate. Labels help to identify potential system hazards. They do not replace the safety rules and regulations established at the customer's facility. The labels and their location on the cabinet vary with component configuration, but are always placed on panels to alert the trained maintenance technician to a potential hazard.

9.5 Intended Use

Use of Veeco equipment in ways other than those described in the documentation supplied with the equipment may result in injury to persons or damage to equipment or property.

Some examples of unintended use of equipment include:

- using incompatible materials
- making unauthorized modifications
- removing or bypassing safety guards or interlocks
- using incompatible or damaged parts
- using unapproved auxiliary equipment
- operating equipment in excess of maximum ratings

9.6 Qualified Personnel

Equipment owners are responsible for making sure that Veeco equipment is installed, operated, and serviced by qualified personnel. Qualified personnel are those employees or contractors who are trained to safely perform their assigned tasks. They are familiar with all relevant safety rules and regulations and are physically capable of performing their assigned tasks.

9.7 Regulations and Approvals

Make sure all equipment is rated and approved for the environment in which it is used. Any approvals obtained for Veeco equipment will be voided if instructions for installation, operation, and service are not followed.

9.8 Client Modifications

Modifications to the system including, but not limited to changes to vacuum hardware, electronics, and software, void all warranty and liability.

9.9 Personal Safety

To prevent injury follow these instructions:

DANGER: Do not operate or service equipment unless you are qualified and have fully read and understood the manual and warning labels on the system. Contact Veeco with any questions in case of uncertainties.

DANGER: Removal of power cables from the system must be performed by a trained and licensed electrician or service personnel.

DANGER: Obtain and read Material Safety Data Sheets (MSDS) for all materials used and films being created. Follow the manufacturer's instructions for safe handling and use of materials, and use recommended personal protection equipment.

WARNING: Do not operate equipment unless safety guards, doors, or covers are intact and automatic interlocks are operating properly. Do not bypass or disarm any safety devices.

WARNING: Before adjusting or servicing equipment, or touching any of the parts, turn off the heaters in the software, wait until all temperature sensors are at room temperature, then shut off the power supply and unplug/disconnect the main power and wait until all unmonitored parts have cooled down. Lock out power and secure the equipment.

WARNING: Relieve (bleed off) pneumatic pressure before adjusting or servicing pressurized systems or components, such as gas cylinders. Never disconnect high pressure gas cylinders without specific knowledge. Refer to your supplier for instructions.

WARNING: To prevent injury, be aware of less-obvious dangers in the workplace that often cannot be completely eliminated, such as hot surfaces, sharp edges, energized electrical circuits, and moving parts that cannot be enclosed or otherwise guarded for practical reasons.

CAUTION: DO NOT use this equipment in any manner not specified by the manufacturer. If the equipment is used in a manner other than as specified in this document, the safety protections may be impaired.

CAUTION: Fittings and components damage easily: handle all components with extreme care. DO NOT scratch or over-tighten any component.

CAUTION: End of life statement. De-commissioning of, or any part of, the system shall be in a manner that is consistent with appropriate regulations and guidelines.

9.10 Fire Safety

To avoid a fire or explosion, follow these instructions.

• Do not place flammable materials underneath, on or near the unit. Do not place paperwork, clothing etc. on or near the unit.

• Do not run the system unattended. Note that in standby mode, all heaters are at process temperatures with the door/s closed and under vacuum.

• Do not heat materials to temperatures above those recommended by the manufacturer. Make sure heat monitoring and limiting devices are working properly.

• The pump may exhaust small amounts of unreacted precursor. Since Veeco does not supply the chemicals, responsibility for safe venting and exhausting lies with the customer. General exhaust recommendations include using fireproof metallic exhaust lines to prevent fire. Refer to local codes or material MSDSs for guidance. Minimize precursor use. Do not add vapor traps in the pumping line; upon exposure to air, large amounts of trapped precursor may ignite or cause chemical burns.

• The system exhaust must be connected to an appropriate facility exhaust for the chemicals used. Refer to facility requirements drawing for specifications.

• Know where shutoff valves and fire extinguishers are located.

• Clean, maintain, test, and repair equipment according to the instructions in your equipment documentation.

• Use only replacement parts that are designed for use with original equipment. Contact your Veeco representative for parts information and advice.

9.11 Electrical Safety

High voltage power is delivered to the Fiji G2 system at the Power Distribution box (PD box) located in the rear of the tool below the gas box and electronics rack. Before opening the PD box, power to the system must be disconnected and locked out. Even after power to the system has been completely isolated care must be taken to understand the potential for stored electrical power in system power supplies.

Only qualified personnel should perform electrical related installation and maintenance on the Fiji G2 system.

Personnel performing non-electrical related installation and maintenance activities on the Fiji G2 should also disconnect and lock-out power to the system before starting. If the designated activities cannot be practically completed without the system being operational, extreme care and caution should be used and never work alone. DO NOT OPEN COVERS to access electrical equipment with the power on, unless you are certified to perform specific troubleshooting/repair tasks.

9.12 Mechanical Hazards

Depending upon selected options, the Fiji G2 system weighs 650 to 800lbs (295 to 363kgs). Crushing or pinching hazards exist during the initial uncrating and positioning of the system. Veeco recommended professional movers/riggers for the initial uncrating and positioning of the system.

9.12.1 Mechanical Hazard Locations

Once installed, the Fiji G2 system still poses some mechanical hazards the operator should be aware of. The Fiji G2 system has multiple pneumatically actuated valves. Depending on system configuration, one or two larger gate valves are located on the Fiji G2 system: 1) between the load lock and the reactor and 2) between the reactor and the main reactor. Any body parts placed in the path of these gate valves when they were closed would be subject to crushing injury. During normal operation of the Fiji G2 system, these valves are mostly inaccessible but could be possibly accessed during maintenance or non-standard operation activities.

When loading samples for coating, a portion of the system must be vented to atmospheric pressure for access to the system through a door. To reestablish vacuum conditions for running process or sample transfer from the load lock to the reactor, this vented portion of the system must be returned to vacuum conditions. A potential crush hazard exists at the access door if vacuum is reintroduced to the system when body parts are located between the access door and the main system body. Before pumping down the system, the user should verify that the door is fully closed with nothing interfering with a vacuum seal being successfully made between the door and the main system body.

The optional load lock for the Fiji G2 system contains two stepper motors for controlling the motion of the transfer arm. A potential crushing hazard exists between the sample holder or transfer arm and body parts present in the load lock when the transfer arm is put into motion.

System panels are heavy and difficult to handle. When installing or removing system panels for maintenance activities, one must use caution not to let the panels fall on toes/feet. Steel toed boots are recommended for anyone performing maintenance activities on the Fiji G2 system.

When working within the gas box or inside the frame, one must be careful about bumping their head on adjacent hardware components.

9.13 Chemical Hazards

Reactive chemicals are unavoidable when conducting ALD activities. Educate yourself about the chemicals being used prior to starting to use them.

9.13.1 MSDS

Material Safety Data Sheets (MSDSs), available from the chemical supplier, are the best place to learn about the safety issues associated with a chemical. Below, the sections typically found in an MSDS are listed.

1. SECTION 1: Identification of the substance/mixture and of the company/undertaking
    1.1. Product identifier
    1.2. Relevant identified uses of the substance or mixture and uses advised against
    1.3. Details of the supplier of the safety data sheet
    1.4. Emergency telephone number
2. SECTION 2: Hazards identification
    2.1. Classification of the substance or mixture
    2.2. Label elements
    2.3. Other hazards
3. SECTION 3: Composition/information on ingredients
    3.1. Substances
    3.2. Mixtures
4. SECTION 4: First aid measures
    4.1. Description of first aid measures
    4.2. Most important symptoms and effects, both acute and delayed
    4.3. Indication of any immediate medical attention and special treatment needed
5. SECTION 5: Firefighting measures
    5.1. Extinguishing media
    5.2. Special hazards arising from the substance or mixture
    5.3. Advice for firefighters
6. SECTION 6: Accidental release measures
    6.1. Personal precautions, protective equipment and emergency procedures
    6.2. Environmental precautions
    6.3. Methods and material for containment and cleaning up
    6.4. Reference to other sections
7. SECTION 7: Handling and storage
    7.1. Precautions for safe handling
    7.2. Conditions for safe storage, including any incompatibilities
    7.3. Specific end use(s)
8. SECTION 8: Exposure controls/personal protection
    8.1. Control parameters
    8.2. Exposure controls
9. SECTION 9: Physical and chemical properties
    9.1. Information on basic physical and chemical properties
    9.2. Other information
10. SECTION 10: Stability and reactivity
    10.1. Reactivity
    10.2. Chemical stability
    10.3. Possibility of hazardous reactions
    10.4. Conditions to avoid
    10.5. Hazardous decomposition products
11. SECTION 11: Toxicological information
    11.1. Information on toxicological effects
12. SECTION 12: Ecological information
    12.1. Toxicity
    12.2. Persistence and degradability
    12.3. Bioaccumulative potential
    12.4. Mobility in soil
    12.5. Other adverse effects
13. SECTION 13: Disposal considerations
    13.1. Waste treatment methods
14. SECTION 14: Transport information
    14.1. UN number
    14.2. Transport hazard class(es)
    14.3. Packing group
    14.4. Environmental hazards
    14.5. Special precautions for user
    14.6. Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code
15. SECTION 15: Regulatory information
    15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture
    15.2. Chemical safety assessment
16. SECTION 16: Other information

Many chemicals used for ALD have incomplete MSDS information. When information is incomplete, one must assume worst case scenarios. Best to be prepared for the worst situation.

The time to learn about a chemical and review its potential hazards is before the chemical is ordered. It should be verified that the chemical can be used at your location before placing an order. Shipping chemicals requires special training. It may not be possible to return an unusable/unwanted chemical. Do not order more material than is needed, even if you qualify for a bulk discount. Disposal of the unwanted/unused chemical may be more expensive than the original chemical purchase.

Having a complete plan for chemicals from initial receipt to final disposal is recommended.

Additionally, this plan should also include the films being deposited as personnel may be exposed to these materials during system maintenance activities.

9.13.2 Personal Protective Equipment

Personal Protective Equipment (PPE) may be required for safe handling of chemicals. PPE includes such items as gloves, gauntlets, aprons, face shields, etc.

Identification of appropriate PPE for a chemical can be completed by reviewing the MSDS. Any PPE that your organization does not already stock that is required for safe handling of the new chemical should be ordered prior to the precursor so it is available when the chemical arrives.

9.13.3 Glove Box Handling

Precursor chemicals can be purchased in glass bottles or preloaded in compatible precursor cylinders. ALD precursors are typically air sensitive requiring handling in an inert environment. The sensitivity ranges from decomposition to pyrophoric ignition upon exposure to air. If transfer of purchased chemicals from glass bottles to precursor cylinders is required, this must be done in an inert environment. A glove box is recommended for this process.

DANGER! FIRE HAZARD

Some precursors such as trimethylaluminum (TMA) are pyrophoric--they burn upon exposure to air. Precursors should never be disconnected from the manual valve they were supplied with. Make sure that manual valve is closed before removing the precursor-valve combination from the system.

Pump/purge the space between ALD valve and manual valve before disconnecting any precursor. Always wear proper protection equipment when removing precursors. Precursor replacement should only be conducted by qualified personnel. Read the section on precursor removal before proceeding. Veeco can be reached for safety assistance with precursor replacement/removal procedure, although the final responsibility lies with the user.

Proper glove box operation requires training. Identify someone trained in the proper use of your facilities glove box or receive the training yourself. Veeco cannot provide guidance for the use of your facilities glove box. Some high level instructions for precursor loading in a cylinder are provided in the System Operations section of the manual.

The manual valve on a precursor cylinder should never be removed outside of a glove box. The manual valve should never be opened unless the cylinder has been properly installed on the ALD system precursor manifold.

9.13.4 Location of Chemicals

All chemical/gas connections are located in the gas cabinet.

9.14 Temperature Hazards

Most ALD processes, PEALD included, are conducted at elevated temperatures. There are 16 heating zones throughout the Fiji G2 system. These heaters, along with default and maximum temperatures are listed in Table 9-1. Temperatures are high enough to cause significant pain and injury.

Table 9-1 – List of Fiji G2 heaters with their default and maximum temperatures.

CH #	Heater Description	Default Temperature (°C)	Maximum Temperature (°C)
13	Upper Reactor	200	300
14	Lower Reactor	200	300
15	Substrate Heater - Chuck	200	500
16	Precursor Delivery Line	150	200
17	Valve Manifold	150	200 (1)
18	Precursor Port - 1	Off	190 (2)
19	Precursor Port - 2	Off	190 (2)
20	Precursor Port - 3	Off	190 (2)
21	Precursor Port - 4	Off	190 (2)
22	Precursor Port - 5	Off	190 (2)
23	Precursor Port - 0	Off	190 (2)
24	Exhaust Tee	150	150
25	Exhaust Valve	125	150
26	Option A – zone 2	Off	200
27	Option A – zone 3	Off	200
28	Option B – zone 2	Off	200
29	Option B – zone 3	Off	200
30	Transfer Tunnel	150	175

(1) The temperature of the ALD valve manifold is not limited by the capabilities of the heater, rather the ALD valves themselves have a maximum temperature rating of 200°C.
(2) Each precursor temperature needs to be considered separately. Increasing temperature produces a higher vapor pressure. But care should be taken because at sufficiently high temperatures, precursors will decompose. Additionally, one must consider the limitations of the valve used on the precursor cylinder. The green handled bellows valve installed on the precursor cylinders that ship with the system have a maximum temperature of 220°C. Black handled quarter turn ball valves are commonly used on cylinders containing precursors that do not require high temperatures. These black handled valves should not be heated beyond 115°C.

Every effort has been made to cover these heated areas with insulation, not only to maximize heater efficiency, but also to protect personnel from injury due to touching hot surfaces. There are several places where insulation is not practical such as where the reactor is mounted to the frame. Areas with exposed hot metal have warning labels nearby to warn of the hazard. An example of a hot surface warning label is shown below in Figure 9-1.

Figure 9-1 Hot surface warning label

The base of the reactor is an example of an area that is hot from the action of nearby heaters but is impractical to completely insulate. This area and the nearby warning sticker are shown in Figure 9-2.

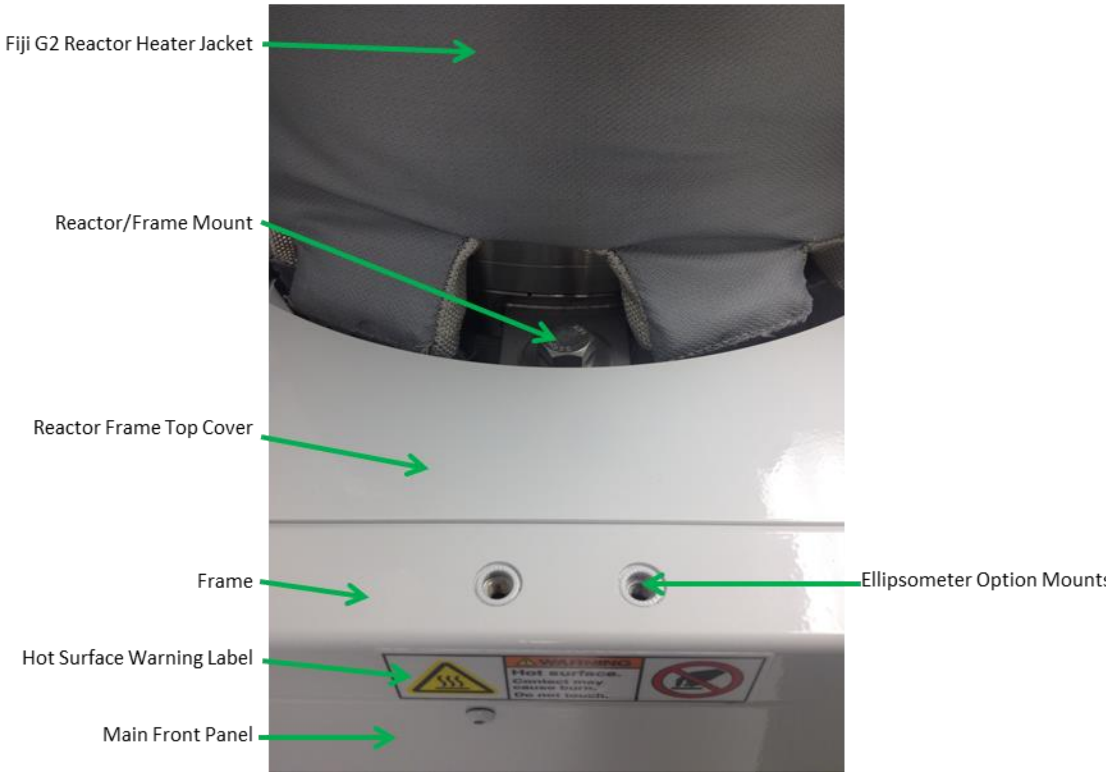


Figure 9-2 – Example of exposed hot surface and the associated warning label.

All of the heaters on the Fiji G2 system are resistive heaters which convert electric power to heat. Electric leads from the Ebox connect each heater to the electrical power source. Additionally, each heater has a built in RTD for temperature measurement, which is also connected to the Ebox. Connections with the Ebox should only be made or broken when the Ebox is powered down.

9.15 Gas Hazards

The Fiji G2 system has multiple gas connections. These gas lines introduce multiple potential hazards. It is critical that system gas lines be installed by experts and all lines be leak checked prior to first use. Below are examples of potential hazards presented by gases used on Fiji G2 systems. Many gases have multiple hazards and examples listed below are illustrative of various hazards and not intended to provide complete hazard information about any specific gas used on the Fiji G2.

1. Air displacement – Inert gas leaks from the argon and nitrogen lines can displace room air reducing the oxygen content in the room below levels safe for personnel. An oxygen leak can lead to oxygen levels in the room becoming too high, which is also hazardous.

2. Flammable gases – Hydrogen gas is highly flammable and a leak from the H_2 feed gas line could present a dangerous situation. Hydrogen gas can also be effectively monitored with gas detectors.
3. Toxic gases –When toxic gases are used, gas detectors must be used to sample the worker air supply so appropriate alerts can be provided to protect personnel. Additional detectors on exhaust lines might be required to protect the environment.
4. Corrosive gases – Corrosive gases injure the eyes, skin, and the respiratory tract. Corrosive gases can also be effectively monitored with gas detectors.
5. Gas pressure – Compressed gas cylinders and gas lines contain substantial amounts of stored mechanical energy that can present a dangerous situation if a gas line experiences a leak or rupture. Rapid expansion of gases often leads to loud noises and expansive cooling of the gas.

Consult with your institution's safety representative on appropriate gas monitoring devices/alarms/gas supply interlocks that would be appropriate for your Fiji G2 system installation.

9.16 Vacuum Hazards

The hazards associated with vacuum are similar to those of compressed gases. The large pressure differential between the atmospheric and vacuum side presents a large amount of energy that can pose a danger if rapidly released. Care should be used when disassembling vacuum components. If possible, the system area being worked on should be vented to atmospheric pressure in a controlled manner before working on any vacuum connections.

Care should also be used around any breakable parts on the system when the system is under vacuum. These include the quartz tube of the plasma source and the quartz windows in the spectroscopic ellipsometry option.

9.17 RF Hazards

The Fiji G2 plasma source utilizes a 300W 13.56MHz RF power supply. Very high DC and RF voltages and currents can be present along the entire RF circuit that includes the RF power supply, RF cable, matching network, and plasma source.

The Fiji G2 system power should be locked out prior to any maintenance activities being performed on the plasma source or any of the associated componentry.

Never attempt to operate the plasma source or deliver RF power to the system without all of the plasma source and matching network covers in place using all screws and all RF power and matching network cables securely installed.

9.18 UV Hazards

In the normal operation of the plasma source, ultraviolet (UV) radiation is generated. The plasma source cover is designed to minimize the release of radiation however some stray light may escape following multiple reflections on inner surfaces of the plasma source cover and other plasma source hardware.

A quartz window, positioned on the top of the plasma source for use with an Optical Emission Spectroscopy (OES) option poses a route for UV photon emission from the system. It is considered a low probability that UV photons emitted from this top window would present a risk to the user. If the particular configuration of the facility enables direct viewing of this top port, the quartz window can be replaced with a stainless steel blank 2-3/4" ConFlat flange.

9.19 Interlocks

The Fiji G2 system has numerous built-in interlocks. Some interlocks are hardware based while others are implemented entirely through the software.

9.19.1 Hardware Interlocks

9.19.1.1 H_2/O_2 Interlock

The Fiji G2 system can have both flammable and oxidizing gases connected to the system at the same time. If these gases were allowed to flow into the reactor at the same time, an explosive gas mixture could be created. A hardware interlock has been designed to prevent from commixing of these gasses in the reactor chamber. The electronics for this interlock are located in the power distribution box. Review all MSDS for all materials and gasses installed on the Fiji system.

Downstream of each of the reactive gas MFCs, a pneumatic positive shut-off valve is positioned in the gas line. The H_2/O_2 interlock electronics prevent the pneumatic valves associated with incompatible gases from being simultaneously open. Additionally, whenever one of these pneumatic valves is closed, for the next 5 seconds, the interlock hardware will flow a volume of argon corresponding to several reactor volumes and prevent any other MFC gas pneumatic valves from being opened.

9.19.1.2 Plasma Source Water Switch Interlock

The plasma source requires a flow of cooling water to prevent the plasma source inductive copper coil from overheating. A water flow switch has been placed in the return leg (hot leg) of the plasma source water cooling loop. This switch is connected to an external interlock continuity loop from the RF power supply. If insufficient water is flowing through the water switch, the interlock loop will be open and the RF generator will not output RF power. The front panel of the RF generator will display "EXT" to indicate the external interlock is not satisfied.

9.19.1.3 Load Lock Door Switch

The load lock manual door is interlocked so that the load lock cannot be pumped down with this door without satisfying the door closed switch.

9.19.2 Software Interlocks

The software has many interlocks designed to protect the User and the hardware from unintended operation and risk. These interlocks are tied into sequences and components so that precursors and process gasses can only be actuated when the system is pumped down. Many of these interlocks are associated with the securing of valves for safety and interlocking their operation so that they are not actuated when it is not appropriate. Below are a number of interlocks installed in the software.

9.19.2.1 H_2/O_2 Interlock

To back-up the hardware H_2/O_2 interlock discussed above, the software will also prevent the user from creating hazardous gas mixtures.

9.19.2.2 Precursor pulse Interlock

Allows precursor pulses to occur only when the system is under vacuum conditions

9.19.2.3 RF/Pressure Interlock

The software will prevent the RF generator from delivering RF to the plasma source if the system pressure is above 1 Torr.

9.19.2.4 Transfer Arm Interlocks

The software will not allow the transfer arm to move if the load lock is vented or if the gate valve between the load lock and the reactor is closed.

9.19.2.5 Turbo Purge Interlock

The software will not allow the turbo pump to run if the turbo gate and isolation valves are closed and the turbo purge is on.

9.19.2.6 Overpressure Interlock

If the pressure in the reactor rises above a configured pressure value (configurable), the system will stop all gas flows and turn off active components, and pump down the reactor chamber.

9.19.2.7 MFC Out of Range Interlock

If the software detects that the MFC flow rate is not at the set-point during a recipe, the recipe will abort.

9.20 Recommended Practices

9.20.1 Best Practices

• Connect all input gas and electrical lines according to the manufacturer specifications or best commercial practice. Always check the fittings before operating.

• USE THE BUDDY SYSTEM: ALWAYS perform maintenance procedures in teams of two or more people; one to monitor the surrounding systems, the maintenance environment, your actions, and to ensure all documentation and safety steps are followed.

• ALWAYS observe all warning labels.

9.20.2 Help

Always work in teams of two or more when performing any tasks which require the removal of system panels.

Always seek additional help when:

• You are instructed by any procedure.

• You see an emergency or dangerous situation.

• You are not trained or qualified/certified to perform a task.

• You feel uncomfortable performing a task.

9.21 Evacuations

In case of an emergency evacuation:

• EXIT the building through the nearest exit and report to your assigned evacuation area.

• DO NOT stop to turn off any machines.

• DO NOT move any carts or equipment during evacuation.

• Obey all commands from the emergency response team.

• Return to the building ONLY AFTER being instructed to do so by the emergency response team.

9.22 Action in the Event of a Malfunction

If a system or any equipment in a system malfunctions, shut off the system immediately and perform the following steps:

• Disconnect and lock out system electrical power. Close valves and relieve pressures.
• Identify the reason of the malfunction and correct it before restarting the system.

9.23 Cleaning and Maintenance

There are sections of the Fiji G2 system which require periodic maintenance and cleaning which have been exposed to process chemistries. These parts include but may not be limited to the: precursor cylinders, ALD valves, precursor manifold, precursor delivery line, plasma source, reactor, cone, gate valves, chuck, sample holder, foreline components, trap, and vacuum pumps. Depending upon the nature of the film chemistries that have been introduced to the system, these components could pose hazards to the personnel handling the parts during disassembly, parts cleaning, and maintenance.

Personnel could come into contact with residual precursor material, toxic film materials, and particles from delaminated film materials.

A list of all precursors introduced to the system and film chemistries potentially on the system components should be maintained. This information should be maintained as a separate document but could be extracted from the contents of a laboratory notebook associated with the Fiji G2 system. The chemical and film list along with MSDSs for these materials should be made available to anyone servicing the system; particular those who will be exposed to wetted vacuum components.

Some components will require bead blasting for removal of adhered films. 3rd party resources are available for this service, but they will require information regarding the materials being cleaned from the components, so they can safely handle the parts and dispose of the generated waste in an appropriate manner.

Individuals performing vacuum pump maintenance will also require information regarding chemistries to which the equipment they are servicing has been exposed.

9.24 Disposal

At the tool end of life, the system components will require disposal. Dispose of equipment and materials used in operation and servicing according to local codes. Lists of chemistries used and deposited film materials will be necessary for proper equipment disposal.

10 Fiji G2 Facility Requirements and Customer Supplied Parts

10.1 System Dimensions

System	Length	Width	Height	Typical Service Area Footprint[1]
Fiji G2 with load lock	72.75”	28.32”	75.49”	96” x 144”
	1848mm	719.25mm	1917mm	2400mm x 3700mm
Fiji G2 without load lock	62.95”	28.32”	75.49”	96” x 134”
	1599mm	719.25mm	1917mm	2400mm x 3400mm
Add ozone option	unchanged	32.20”	unchanged	unchanged
		817.88mm		
Edwards iGX100N dry pump option	28”	11.5”	16”	
	720mm	290mm	410mm	

10.2 Exhaust Requirements

WARNING

HAZARDOUS GAS EXHAUST POTENTIAL

All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads.

Component	Exhaust Requirements
Fiji Cabinet Exhaust	• A 6” diameter exhaust duct port is provided at the top of the system. This port must be connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases.

[1] Service area foot print can typically be shared with adjacent equipment

- Exhaust draw should be 150 CFM at 0.5” W.C.

Pump Exhaust

- Connection: NW40 at silencer outlet
- Exhaust should be capable of handling any toxic gases and related effluents from your system.

All processes are run through the system pump. Each user’s environmental requirements are different due to the chemical processes being employed. Consult the MSDS sheets of the precursors and contact your local safety office for appropriate venting precautions.

Ozone Generation Option Exhaust

The ozone generator requires an appropriate exhaust system which is capable of safe handling of the exhaust gases. Use of a non-rigid exhaust connect will aid in performing service to the unit (to remove the ozone kit enclosure)

- Ozone generator box exhaust port is 2” diameter
- 15 CFM
- 0.5”WC.

DANGER

HAZARDOUS GAS EXHAUST POTENTIAL

All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads.

10.3 Power Requirements

	United State/Japan	Europe
Voltage	200 – 240V	230V
Frequency	50 – 60Hz	50Hz
Current	30A	30A

10.4 Facility Gas Requirements

Gas	Regulated supply pressure	Max. Flow Rate (sccm)	Fitting
Argon	30psig	3000	
Nitrogen (plasma)	30psig	100	
Oxygen (plasma)	30psig	100	
Hydrogen	3psig	100	¼” VCR[2]
Optional	30psig	Varies	
Optional	30psig	Varies	
Oxygen (ozone options)	30psig	500	
CDA for pneumatic actuation	80 – 100psig		
Nitrogen (iGX100N dry pump purge)		5000	¼” Swagelok

10.5 Cooling Requirements

Cooling water is required for the Fiji G2 plasma source and the optional Edwards iGX100N dry pump.

Subsystem	Plasma Source	Edwards iGX100N	Comments
Temperature Range	10 – 24°C	10 – 30°C	Cooling water temperature must be above the dew point of the facility to prevent condensation on system components.
Pressure	30 – 80 psig	36 – 100psig	
Minimum Flow Rate	0.5 liters per minute	1 liter per minute	
Heat Removed From System	30W	1000W	Plasma source heat load estimated.
Maximum Particle Size		$0.03mm^2$	
pH		6.5 to 8.0	

[2] ¼” butt weld tube optional

Hardness		< 100ppm
Resistivity		> 1kΩ-cm
Solids (turbidity)		< 100ppm
Materials in contact with water	Stainless steel, PTFE, copper	Stainless steel, PTFE, copper, brass and fluoroelastomer

10.6 Required Parts – Customer Supplied

Category	Description	Vendor/Part Number	Quantity
Mechanical	Seismic anchor bolts for Fiji G2 and dry pump		8
	Support bracket for mechanical pump exhaust silencer		
Water	Inlet/Outlet Tubing	Recommended: Tubing, PUSH-LOK Plus Parker Part # 801-9 [WP 2.1 MPa (300 PSI) MSHA IC-40/22 12.5 mm (1/2”)] (tubing shown with supplied fittings and with optional customer-supplied push-on barbed hose fittings)	2

			
	Inlet/Outlet tubing hose barbs, recommended for use with supplied water inlet/outlet fittings	Push On Hose Fittings: Swagelok Part # SS-PB8-TA8 	2
	Loctite 577 for water line male thread connectors and (qty. 2) 3/8” male BSPP adapter for supply and return cooling lines connection to provided quick connectors with the Edwards iGX100N rough pump.		
Electrical	Fiji G2 input wiring	10 AWG	Site installation dependent.
	Wire ferrules	Use properly-sized, industry-standard ferrules such as Altech® ferrules with an appropriately sized crimper to attached ferrules to the end of each power wire 	10+

	Ferrule crimper	As required for ferrule type and size	1
	Pump input wiring	10AWG	Site installation dependent.
Gas	Welding equipment and supplies, as required for butt-tube welding of gases to system inlets		As needed.
	STANDARD SYSTEMS: ¼" Silver-plated stainless steel VCR® gaskets **OZONE SYSTEMS:** **UNCOATED** ¼" stainless steel VCR® gaskets	SS-4-VCR-2, or SS-4 VCR-2-GR (with retaining clip) SS-4-VCR-2-VS, or SS-4 VCR-2-GR-VS (with retaining clip)	1 for each precursor cylinder installation. Additional gaskets should be available at all times. Gaskets can only be used once. Standard gaskets have silver flashing. Due to reactivity between silver and ozone, uncoated gaskets must be used on systems with ozone generators.

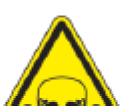
WARNING

HAZARDOUS GAS LEAK POTENTIAL

Never use silver coated or nickel-coated gaskets on systems with ozone as deterioration of the seals will occur. See installation and use instructions provided with the ozone generator option.

Vacuum	Vacuum tubing, clamps, and o-rings for making the vacuum connection between the Fiji G2 process exhaust port (ISO-80) and the vacuum pump inlet (ISO63 must be converted with adapter). The dry pump must be installed with 3 meters or less of ISO80 sized or larger tubing between the pump connection on the Fiji G2 frame and the pump inlet. "Remote" pump locations with more than 3 meters of vacuum tubing will negatively impact process results and/or cycle time.

All internal gas connections use standard VCR or Swagelok® compression fittings. External fittings for process gases are ¼" VCR connections (¼" butt weld tubing optional) and ¼" Swagelok compression fittings for the CDA pneumatic actuation gas and Edwards iGX100N nitrogen purge gas connections. Use standard fitting equipment and techniques to make high-purity, leak-tight connections.



WARNING

HAZARDOUS GAS LEAK POTENTIAL

All plasma gas lines must be helium leak tested to ensure they are leaktight. Secondary containment and hazard gas detectors and other hazardous gas handling and detection equipment is solely the responsibility of the end user. See installation steps.

CAUTION

PROCESS/MOISTURE/PARTICLE ISSUE

DO NOT USE plastic tubing for Argon line.

The argon purge-gas line must be stainless steel. Plastic or Teflon® tubing should NOT be used due to the ability to attract and retain moisture and other impurities which will affect the ALD process.

Required Tools

• level

• metal tubing tools/fixtures: welding equipment and supplies, tubing cutter, tubing bender and related tools, if applicable

• helium leak checking equipment (for facility gas line installation)

• standard electrical and mechanical tool kits

• 1/2”, 5/8”, 9/16”, and 3/4” open end wrenches

• 5/16” 12-point box end wrench

(additional open end and box wrench sets should be available, English and Metric)

• socket wrench and ratchet driver, English and Metric

• crimpers for 6-8AWG stranded wire (as necessary to attach ferrules)

• wire cutters, various sizes

• small screwdrivers, flat and Phillips

• set of Allen wrenches, English and Metric

• tie wraps (various sizes)

• cleanroom wipes

10.7 Additional Safety Cautions

WARNING

HEAVY OBJECT

Two to four people are required to perform the following procedures

due to the weight and location (height) of the top frame assembly.

WARNING

PINCH HAZARD

Protect yourself from any pinch or crush hazard.

10.8 Recommended Precursors – Customer Supplied

The Fiji G2 systems ship with one empty water cylinder (no valve), and the remaining precursor cylinders with valves. Precursor are not shipped with the Fiji system and need to be filled by the customer.

Veeco does not sell any chemicals. Specialty chemical suppliers can supply precursors for your Fiji G2 system. Veeco can provide guidance on appropriate

Precursor	
Water	Distilled or HPLC water from chemical suppliers is acceptable.
Trimethyl Aluminum (TMA)	TMA is the standard precursor for the deposition of Al_2O_3 films using water, ozone, or O2 plasma co-reactants. CAS#: 75-24-1 Purity: 98% minimum

WARNING

FIRE HAZARD

Trimethylaluminum (TMA) is a liquid at room temperature and is pyrophoric. This means that it burns upon exposure to air. The TMA precursor cylinder must only be opened when appropriately installed on the Fiji G2 precursor manifold or in a glove box with inert atmosphere operated by someone properly trained in its use.

Precursor material bulk containers or preloaded in Fiji G2 precursor manifold compatible cylinders are available from several chemical suppliers. These include, but are not limited to, Strem Chemicals, Inc. and Sigma-Aldrich.

Company	Website	Precursor Webpage[3]
Strem Chemicals, Inc.	http://www.strem.com	http://www.strem.com/catalog/d/mocvd/
Sigma-Aldrich	http://www.sigmaaldrich.com	http://www.sigmaaldrich.com/materials-science/micro-and-nanoelectronics/cvd-ald-precursors.html

Film deposition recipe sheets available Veeco contain information about precursor specifics, including sources.

[1] ***Web page addresses subject to change.***

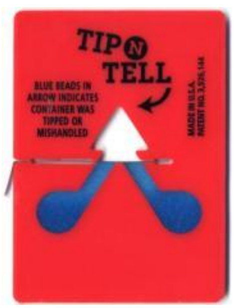
11 Installation

11.1 Uncrate and Locate System

1) Verify all SHOCKWATCH and TIP N TELL indicators show no sign of rough handling during transit. Make note on Bill of Lading and check for damage.

SHOCKWATCH – Proper Shipment (RED) Indicator

SHOCKWATCH – Bad Shipment with Failed



TIP N TELL – Proper Shipment Indicator

TIP N TELL – Bad Shipment with Failed (Blue)

If either indicator is in the failed state, Red for SHOCKWATCH or Blue for TIP N Tell, photograph the entire shipping create and the Fiji system upon unpacking. There is a risk of damage associated with the shipping and handling of the wooden crate.

Step	Action	Details
1	IMPORTANT: Verify the integrity of the shock tab on the crate upon receiving the equipment. Inform the shipper and Veeco immediately if a shock tab has been activated. Note: Please consult professional movers. Casters are provided on the system to aid in installation. Unpack the crates carefully and inspect the system for damage that may have occurred during shipping. Remove all wood, strapping, cardboard, and outer protective wrappings prior to bring the system into a clean environment. DO NOT open the inner clean bags at this time.	The system is typically shipped in 3 or more crates or boxes, similar to those shown below:  CAUTION: Avoid Particulate Contamination. If the unit is to be used in a cleanroom environment, DO NOT remove the inner clean bags on any item until immediately before installation. Notify the carrier immediately if any damage is found. Retain the shipping cartons and packing material for the carrier's inspection and for repackaging should reshipment become necessary.
2	Move the Main System crate to an appropriate uncrating location.	Preferably indoors close to the final installation location. A forklift
3	Remove top panel of crate.	Screws holding the top panel of crate must be removed first. Cordless, electric screwdriver recommended.

4	Remove wooden top braces extending across the top of the gas box.	Screws holding the top braces are removed from the crate sides.
5	Remove crate sides.	Screws along the edges of the crate hold the sides together must be removed.
6	Remove the Fiji G2 from the pallet.	Lift the Fiji G2 from the shipping pallet with a forklift. Slide pallet away. Gently place Fiji G2 on floor. The Fiji G2 weighs 650 – 800lbs. (300 – 360kgs)
7	Prepare Fiji G2 for moving	Partially remove the plastic wrapping from the casters. The adjustable feet must be in a raised position to allow the Fiji G2 to freely roll on the integrated casters.
8	Move the Fiji G2.	Carefully move the system into its final position.
9	Level the system.	Using the 4 adjustable feet, level the Fiji G2 system.
10	Secure the system.	Optionally, secure the system to the floor with the supplied seismic brackets. Refer to installation drawings.

11.2 Install Exhaust Connections

Step	Action	Details
1	Connect the cabinet exhaust connection to an appropriate facility exhaust. The exhaust connection is located at the top of the system. The connection is a 6” diameter duct. Install an air flow meter into the exhaust draw and regulate the air flow (with panels on) to a flow of 150 CFM and a draw of .5” W.C. The approximate heat load	 **WARNING** **HAZARDOUS GAS EXHAUST POTENTIAL** All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads.  **WARNING** **FIRE HAZARD** Connect the system only to an exhaust

generated by the gas box is <1kW.

system that has been approved for your process effluents and your process gases.

2 If the system is equipped with an ozone generator (as shown), connect the unit to an appropriate exhaust system which is capable of safe handling of the exhaust gases. Use of a non-rigid exhaust connect will aid in performing service to the unit (to remove the ozone kit enclosure)

Ozone exhaust port, located on the top of the optional ozone generator box, is 2” diameter, with a required flow rate of 15 CFM and 0.5” WC.

DANGER

HAZARDOUS GAS EXHAUST POTENTIAL

All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads.

11.3 Connect Input Power

DANGER

HIGH VOLTAGE! SHOCK HAZARD!

A trained electrician should perform this installation in accordance with all applicable local wiring codes including any required conduit installation.

Step	Action	Details
1.	System Power Information	Ferrules ensure reliable electrical connections when terminating stranded flexible wire in terminal blocks.
	Wire must be 10 AWG stranded.	Insulated ferrules prevent conductor breakage due to bending, wire stress or vibration while facilitating wire insertion into the terminal clamp.

Current <30 Amps in continuous operation.

Refer to the wiring specifications below for your installation site. The final disconnect device is the main circuit breaker CB1 in the power distribution box (PD Box). A wallmount lockable device should also be installed to isolate all power from the system.

Use properly-sized, industry standard ferrules (such as Altech® ferrules) with an appropriately sized crimper to attached ferrules to the end of each power wire, as shown below:

Power supplied from (30A US / 30 A EU) circuit using 10 AWG stranded cable (supplied by customer) according to chart below:

	United States/Japan	Europe
Voltage	200 – 240V	230V
Frequency	50 – 60Hz	50Hz
Current	30A	30A
Wiring	10 AWG	10 AWG
L1	Hot – Black	Hot – Brown
L2	Hot – Red	Neutral – Blue
G	Ground – Green or Green with Yellow Stripes	G – Green with Yellow Stripes

Ferrule

Ferrule crimped on stranded

wire

IMPORTANT:

2. The Fiji G2 must be hard wire to facilities power following national and local wiring codes.

Even if national and local wiring codes do not require a lockable power disconnect switch to feed power to the Fiji, it is highly suggested that one is used.

Power connections are made inside the Power Distribution (PD) box. The PD box, pictured below, is located on the rear of the Fiji G2.

The table below indicates connections to be made inside the PD box.

Connecting to the facilities Mains:

Main	SW1	Ground Terminal Block
L1	1L1	
L2	3L2	
PE		1

The picture below shows the wire connections on the inside of the PD box.

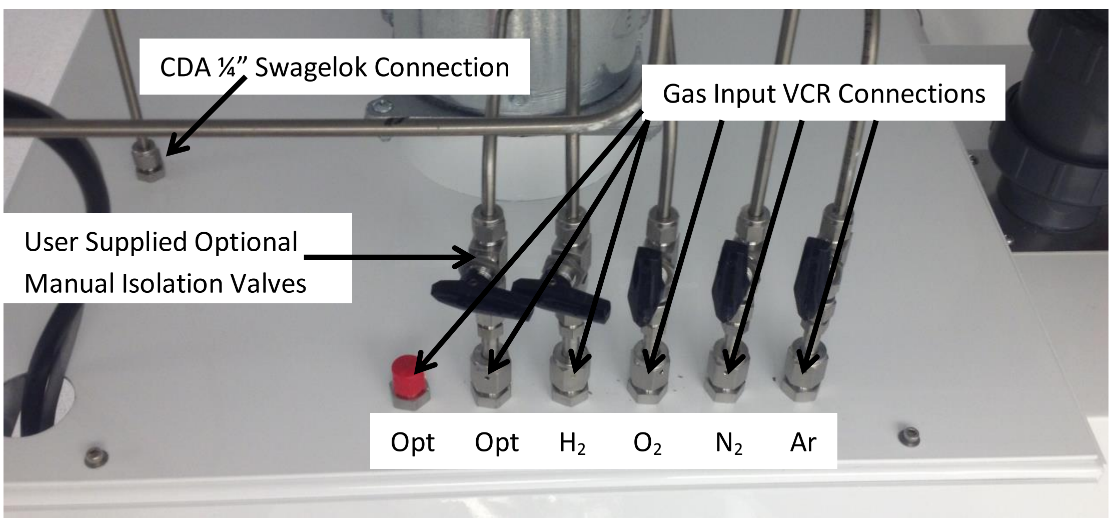

L1
L2
PE
CB1-1
CB1-3
1 L1
3 L2
5 L3
CB2-1
CB2-3
CB3-1
CB3-3
1L1
3L2
K1
D30
D30
D20
D20
D10
D10
CB1-2
CB1-4
CB2-2
CB2-4
CB3-2
CB3-4
SW1

11.4 Connect Facility Gases

Action	Details
Connect facility gases	For each of your Fiji G2 system gas inputs, there will be a VCR connection on the top of the system gas box.

The VCR connections use bulkhead fittings but are not secured to the top plate of the Fiji G2 gas box. In order to make a proper VCR connection use a ¾" wrench on the bulk head fitting wrench flats, which are located inside the gas box, when tightening the VCR nut above the gas box top.

The figure below shows the standard gas inputs for a Fiji G2 located on the top of the gas box. Your system will ship with male ¼" bulkhead connections for system process gases and a ¼" Swagelok compression fitting for the system pneumatic actuation gas. Dimensional details for gas input locations can be found in the Appendix.



The end user must make connections between their facility gas supplies and the Fiji G2 inputs such that the conditions in the below table are satisfied.

Gas	Regulated supply pressure	Max. Flow Rate (sccm)	Fitting
UHP Ar	30psig	3000	
UHP N_2	30psig	100	
UHP O_2	30psig	100 (600 with O_3 option)	¼” VCR[4]
UHP H_2	3psig	100	
Optional	30psig	Varies	
Optional	30psig	Varies	
CDA for pneumatic actuation	80 – 100psig		¼” Swagelok

Leak check each line using standard Helium leak checking procedures. Consult with an experienced gas installation engineer.

Typically, each line should be purged with inert gas prior to the introduction of a potentially reactive gas such as Oxygen or Hydrogen, etc. Consult Veeco or your gas welder/installer or gas supplier with any questions.

DANGER

LEAK HAZARD

All gas connections should be performed by properly licensed and trained plumbers for the specific gas types used on the system. All connections and lines must be leak-checked to ensure safety from fire, explosion, and/or release of toxic or other gas hazards.

Check all fittings, lines, and wire connectors to ensure that all components are secured properly.

Any facility and/or external sensors should be certified to be working properly before proceeding.

[4] ¼” butt weld tube optional

11.5 Install Facility Cooling Water Lines

Action	Details
Use the supplied quick disconnect fittings which terminates in ½" Swagelok compression fitting to make inlet and outlet hoses for the required chilled water supply and return lines.	The system is shipped with the following quick-disconnect fittings: Fitting: Male Water (Return) Fitting Part #: Swagelok # SS-QC8-D-810

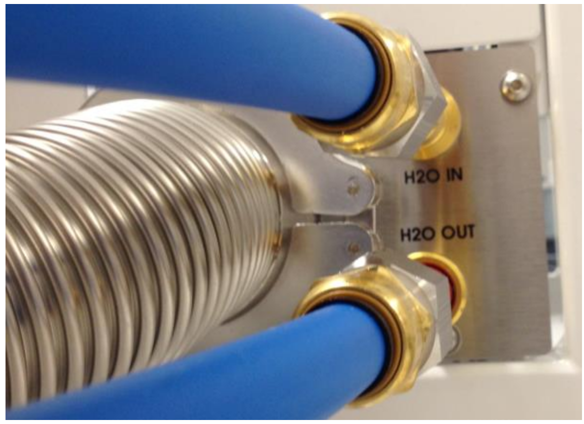
Fitting: Female Water (Supply) Fitting

Part #: Swagelok # SS-QC8-B-810

Action	Details
Use of hose barbed fittings and appropriate hose material is recommended. See Required Parts for details.	Inlet/Outlet tubing hose barbs, recommended for use with supplied water inlet/outlet fittings: customer-supplied Push On Hose Fittings: Swagelok Part # SS-PB8-TA8

Action	Details
Complete water connections to the Fiji G2.	NOTE: Verify plasma cooling connections are complete before making chilled water connections or turning on flow to the Fiji G2 system.

The connections for chilled supply and returns lines to the Fiji G2 system are located below the process chamber, mounted on the rear of the system frame, as shown below.



11.6 Install the Vacuum Pump

The dry pump must be installed with 3 meters or less of ISO80 sized or larger tubing between the pump connection on the Fiji G2 frame and the pump inlet. "Remote" pump locations with more than 3 meters of vacuum tubing will negatively impact process results and/or cycle time.

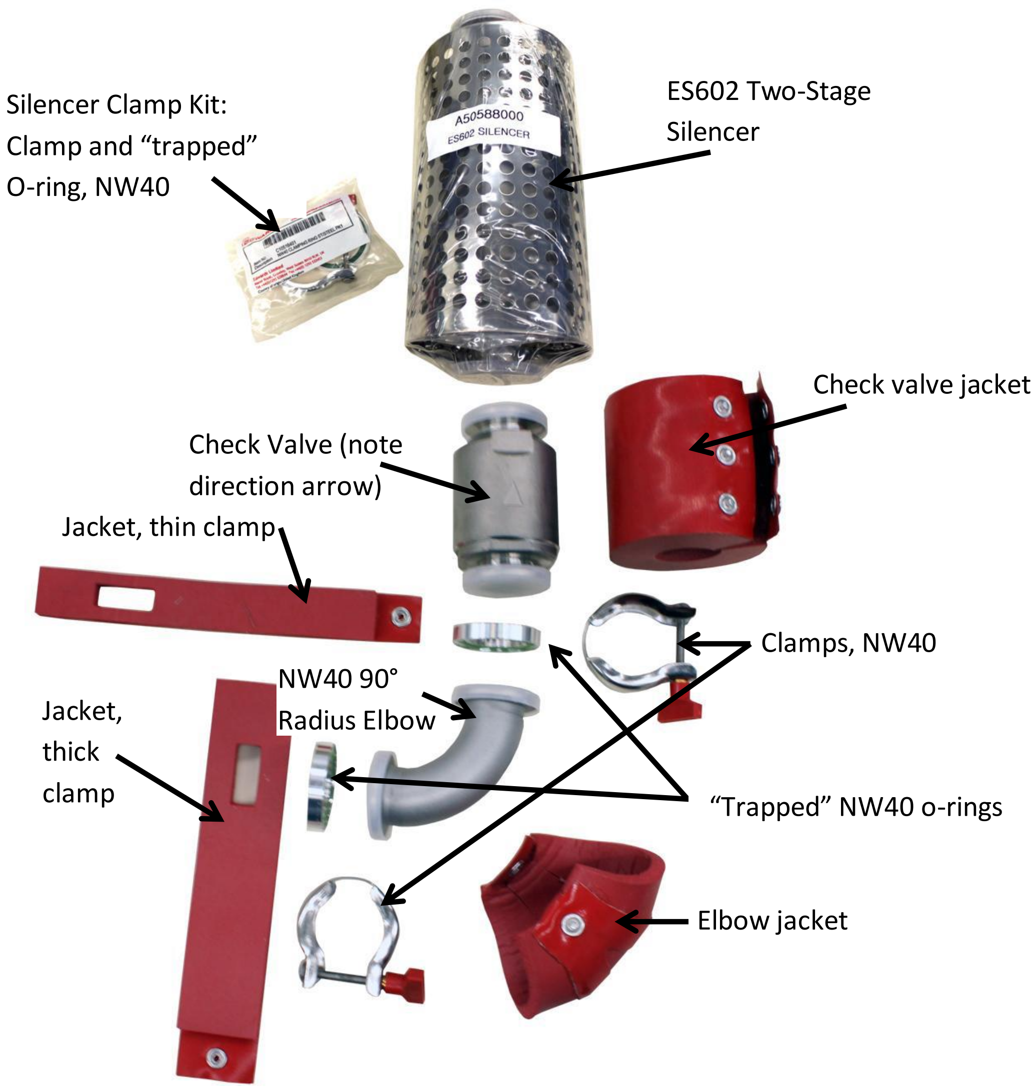
The following instructions are provided for installation of the Edwards iGX100N vacuum pump. Refer to the manufacturer's manual for additional details and important notices.

Required Equipment

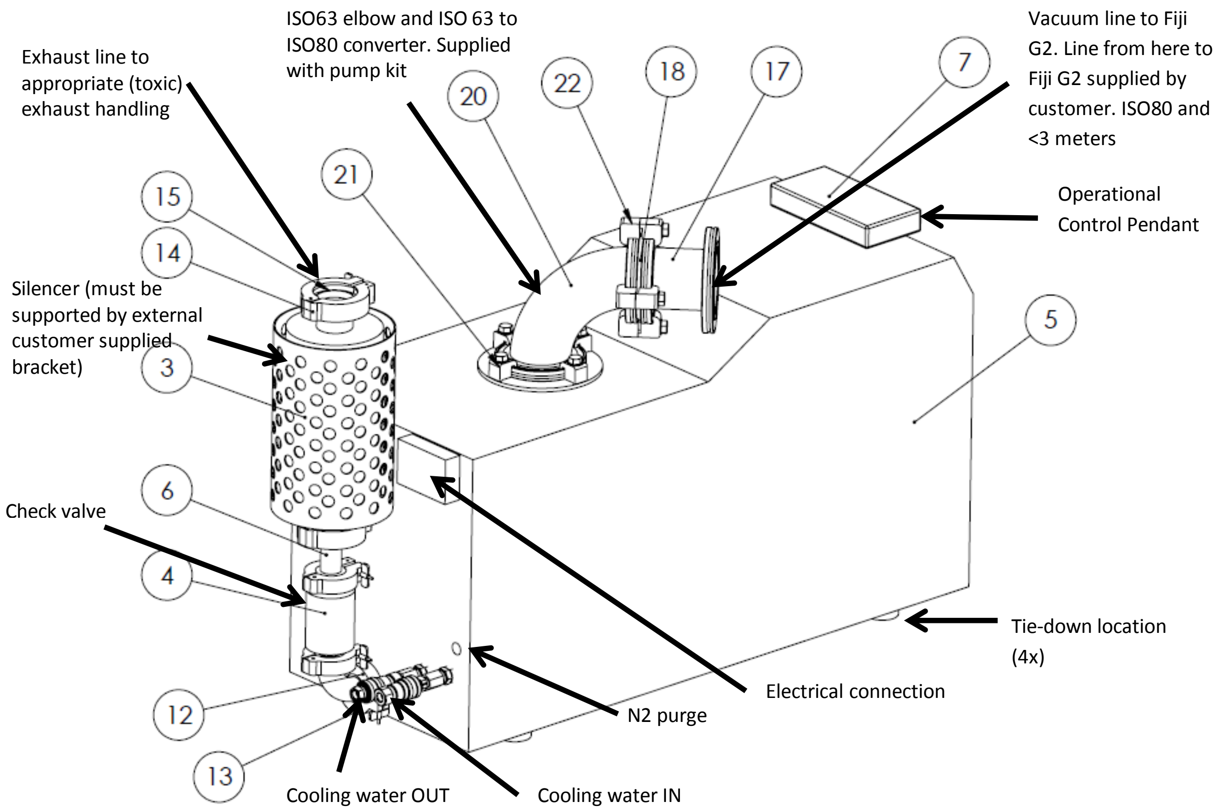
Water coupling fittings	Adapters (customer supplied) are required to connect the water line to the provided quick-connects terminating in 3/8" BSPP female fittings
Required Tools	Loctite 577 for water line male thread connectors
	½" wrench, ¾" wrench, adjustable wrench
	Metric and Standard Allen wrench sets
	Small flat screwdriver
Pump Kit Contents	Pump
	Operation Control Pad (Pendant)
	Pump exhaust flange connection, mounting bolts and washers

Pump 3/8" water fittings with quick disconnects (male and female)

11.6.1 Exhaust Kit Contents



The pump can be placed in a chase, in a utility closet, or alongside the system.



Action	Details
Position the vacuum pump as close as practical to the Fiji G2 system	The dry pump must be installed with 3 meters or less of ISO80 sized or larger tubing between the pump connection on the Fiji G2 frame and the pump inlet. “Remote” pump locations with more than 3 meters of vacuum tubing will negatively impact process results and/or cycle time.
	Adjust the leveling feet to ensure the system is level and not supported by any castors.
	The pump weighs approximately 120 Kg
	Vibration Transmission:
	If vibration transmission to the floor is a concern, install suitable vibration isolators (not supplied) between the mounting angles and a bolt or stud to secure the pump to the floor. Removal the leveling feet is required when

vibration isolators are installed.

Seismic Tiedowns:

The system can be secured to the floor using suitable bolts or studs (not supplied) through the 17.5 mm hole in the seismic brackets. If vibration transmission to the floor is a concern, suitable vibration isolators (not supplied) should be fitted between the seismic brackets and the bolt or stud.

Used supplied vacuum tubing and/or customer-supplied vacuum tubing, o-rings, and clamps to connect the pump to the Fiji G2 system.

Notes:

- To get the best pumping speed, ensure that the pipeline which connects the Fiji G2 system to the iGX system is the minimum length possible and has an internal diameter not less than the iGX system inlet-port.
- Ensure that all components in the vacuum pipeline have a maximum pressure rating which is greater than the highest pressure that can be generated in your system.
- Incorporate flexible pipelines in the vacuum pipeline to reduce the transmission of vibration and to prevent loading of coupling-joints. We recommend that you use Edwards braided flexible pipelines. The pipelines should be suitable for 110 °C.
- Adequately support vacuum/exhaust pipelines to prevent the transmission of stress to pipeline coupling joints.

Connect the nitrogen supply to the pump using the ¼” compression fitting.

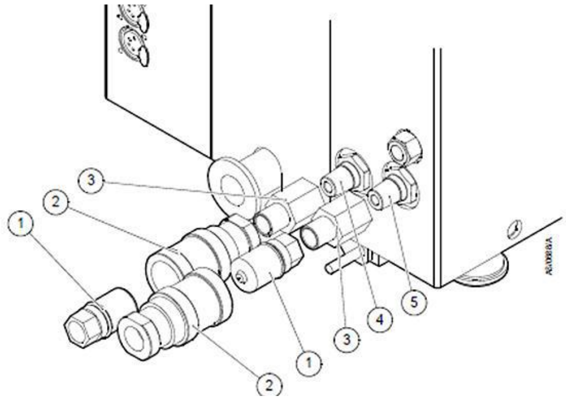
Connect the electrical supply to the pump.

Refer to the pump manual for details on the electrical wiring.

This work must be performed by a trained electrician.

Connect the water supply (IN) and return (OUT) using supplied connectors.

Use of leak-free quick-disconnect connectors is recommended be used to reduce the risk of water spillage during connection/disconnection. Several options are available for use. The instructions below detail the use of fittings and couplings which are supplied unassembled with the system:



1. Remove the dust-caps from the cooling-water inlet and outlet

2. If not pre-assembled, apply Loctite® 577 (not supplied) to all male threads prior to installation.

3. Connect the reducing bushing (3) to the threaded end of the coupler (2).

4. Connect this sub-assembly to the water return port on the pumping system (4).

5. Connect the threaded end of the nipple (1) to the customer water return line.

6. Connect the reducing bushing (3) to the threaded end of the nipple (1).

7. Connect this sub-assembly to the water supply port on the pumping system (5).

8. Connect the threaded end of the coupler (2) to the customer water supply line.

9. Connect the customer supply and return hoses to the pump.

10. Turn on the cooling-water supply.

11. Inspect the water hoses, pipelines and connections and check that there are no leaks.

12. Turn off the water supply while you complete the remainder of the installation procedures.

Note: An adapter (customer supplied) is required to connect the coolant line to the provided quick connects terminating in 3/8” BSPP female fittings

Connect the exhaust elbow, check valve, and silencer to the pump exhaust fitting.

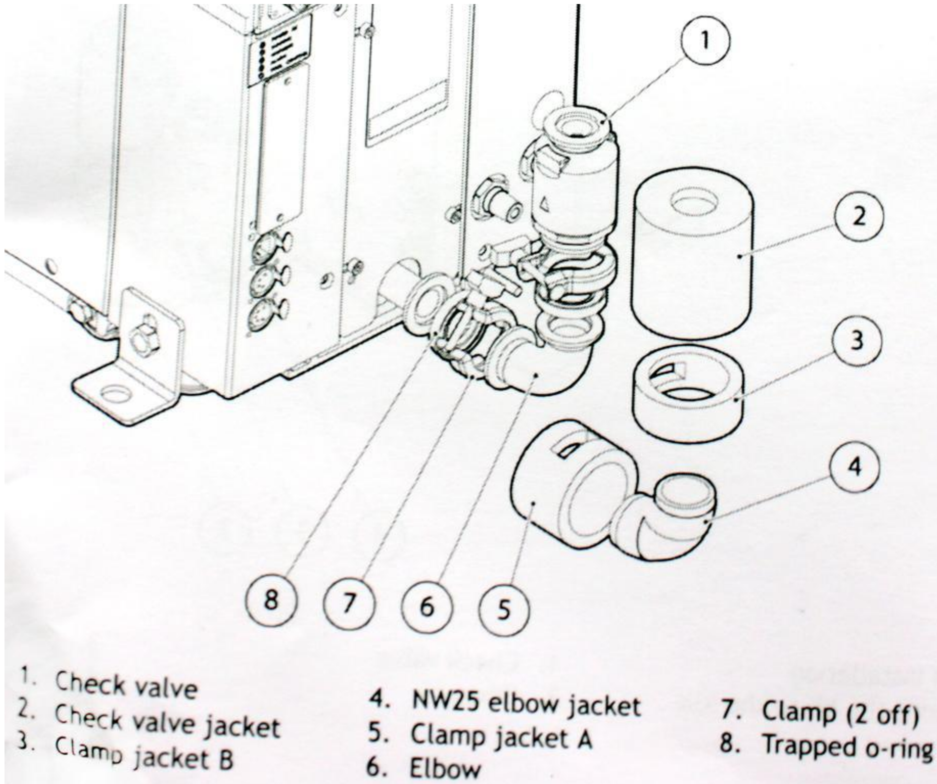
1. Connect the supplied elbow to the rear of the pump.

2. Connect the check valve to the elbow. Verify that the arrow on the check valve is pointing up, away from the pump.

3. Connect the silencer to the check valve.

4. Fully support the exhaust line immediately above the ES602 silencer using pipeline brackets that are strong enough to support the ES602.

Ideally, a short piece of flexible braided stainless steel pipe or bellows can be installed between the check valve and the silencer. This prevents vibration from being transmitted from the pump system to the exhaust line, allows for thermal expansion and contraction, and avoids loading of coupling joints.

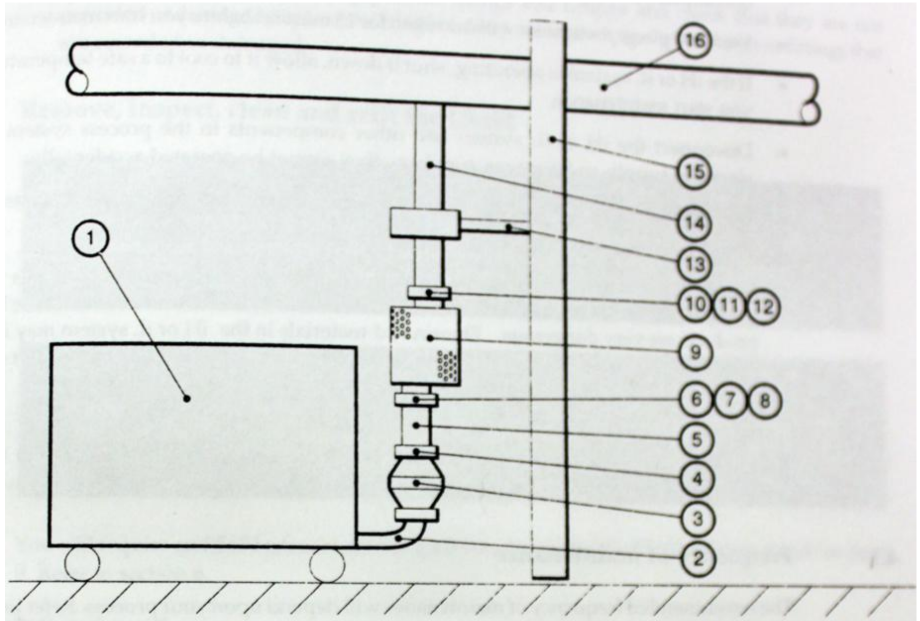


WARNING

GAS LEAK POTENTIAL

The ES602 exhaust silencer MUST be supported by an external bracket. The pump is not designed to support external loads, including the silencer and tubing.

Below is an illustration from the pump manual with a suggested exhaust line support installation.



1. Pumping system
2. Exhaust pipe outlet
3. Check valve
4. NW40 trapped O-ring and clamping ring
5. Flexible braided pipeline or bellows
6. Outlet of flexible braided pipe or bellows
7. NW40 trapped O-ring and clamping ring
8. Inlet of ES602
9. ES602 silencer
10. Outlet of ES602
11. NW40 trapped O-ring and clamping ring
12. Inlet to exhaust line
13. Exhaust line support bracket
14. Exhaust line
15. Unistrut or other pipeline support
16. Main exhaust ducting

Install insulation blankets on each of the exhaust components, as detailed.

Install the blankets in the following order:

1. Large blanket strip: on the fitting/clamp closest to the pump.

2. Elbow blanket

3. Small blanket strip on the clamp between the elbow and the check valve

4. Check valve blanket

This order of assembly will allow proper fitting and easier access for maintenance of the check valve.

Connect the exhaust line terminating in an NW40 fitting from the outlet of the silencer to an appropriate facility system exhaust

DANGER

HAZARDOUS GAS EFFLUENT

All gas connections should be performed by properly licensed and trained fitters. The system exhaust must be connected to an appropriate facility exhaust which is that is capable of properly handling all effluents from the process chamber.

capable of handling the gases and chemicals which are present or which can be created as part of the system operation. Consult your local facility safety engineers to ensure you are in compliance with all local, regional, national, and industry-standard safety guidelines. All connections and lines must be leak-checked to ensure safety from fire, explosion, and/or release of toxic or other gas hazards.

12 Acronyms

ALD	Atomic Layer Deposition
Ar	Argon gas
CDA	Compressed Dry Air
CVD	Chemical Vapor Deposition
E-box	Electronics box
EMO	Emergency Machine Off
GUI	Graphical User Interface
H2	Hydrogen gas
ICP	Inductively Coupled Plasma
LVPD	Low Vapor Pressure Delivery
MFC	Mass Flow Controller
MSDS	Material Safety Data Sheet
N2	Nitrogen gas
NC	Normally Closed pneumatic valve, or Not Connected RTD.
NO	Normally Open
O2	Oxygen gas
OES	Optical Emission Spectroscopy
PD-box	Power Distribution box
PEALD	Plasma Enhanced Atomic Layer Deposition
PID	Proportional, Integral, Derivative temperature control scheme
PPE	Personal Protective Equipment
PVD	Physical Vapor Deposition
ROR	Rate Of Rise
RTD	Resistive Temperature Device
sccm	standard cubic centimeters per minute
TMA	TriMethylAluminum
TMP	TurboMolecular Pump
UV	UltraViolet
USB	Universal Serial Bus