Template-assisted grown III-V semiconductor nanowires: A transmission electron microscopy study

III-V semiconductor nanowires are, due to their unique properties, one of the most promising nanostructures developed in the last decades. However, the realization of commercial devices made of III-V nanowires, such as transistors and solar cells, has not become feasible yet. In fact, the incompatibility with the CMOS industrial process and the low control on their crystallographic defects, able to strongly reduce the device performance, represent key obstacles to their implementation. During the last few years, an innovative catalyst-free method called template-assisted selective epitaxy (TASE) was developed and used to grow CMOS-compatible nanowires on different Si substrate orientations by achieving a very high level of confidence on the structural quality at the atomic level. In this presentation, the nanowires grown with this method are characterized in detail by various transmission electron microscopy techniques and the results divided in two different branches.

In the first part, we demonstrate the first planar defect-free GaAs nanowires grown on a CMOS-compatible substrate. The polytypism and the high density of planar defects are successfully suppressed thanks to the high degree of freedom allowed by the TASE method. In fact, TASE allows for a wide growth parameter window, still maintaining control of the morphology and growth direction of the nanowire. We also analyzed the atomic structure and composition of stair-rod dislocations, a particular type of defect occurring under certain growth parameters. A correlation with the electronic properties of the defect is achieved by the aid of DFT simulations. They suggest the possibility to obtain strongly localized mono-dimensional charge channels running along these particular defects, which could be relevant for electronic applications.

The second part of the presentation is dedicated to the investigation of the effects induced by p- and n-dopants on the structure and properties of $Ga_xIn_{(1-x)}P$ and GaAs nanowires. We demonstrate that TASE permits a good control of the doping incorporation and that dopant atoms modify the crystal structure and composition of the nanowires. Moreover, we present a series of off-axis holography experiments for the mapping of potential fields in doped nanowires.

We consider these results to play a key role in the advancement of III-V nanowires integration in electronic and optoelectronic devices and anticipate that this innovative growth method will open new paths for novel device architectures.

Keywords: III-V semiconductors, nanowires, doping, transmission electron microscopy, tunnel field-effect transistor, solar cells, crystallographic defects, electron energy-loss spectroscopy, energy dispersive x-ray spectroscopy, off-axis holography