Atomically resolved antiferromagnetic order by SP-STM

In a compensate antiferromagnetic material, atoms sitting on adjacent rows have magnetic moments aligned antiparallely (see red and green atoms in the picture. The arrows indicate the atomic magnetic moment). This means that the net magnetization of the material is zero (or compensate). However, at each single atom location, the magnetic moment is non zero. This is for example the case of 1ML of Mn on a W(110) single crystal surface.

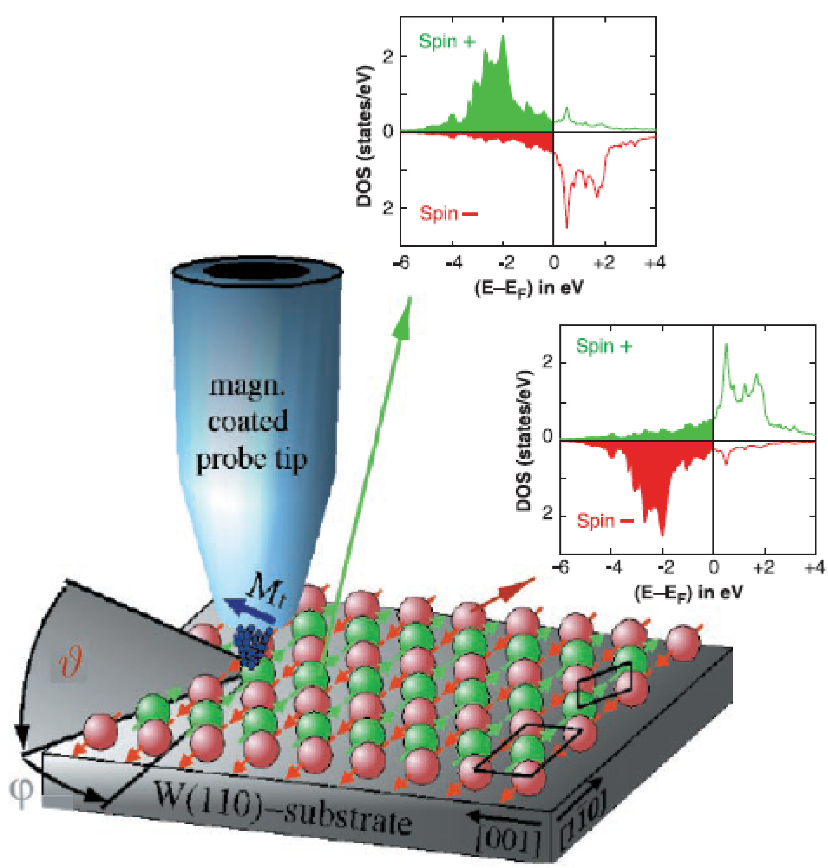
We want to investigate, with atomic resolution, the crystallographic and the magnetic order of such a monolayer. To this purpose we realize a double experiment:

a) We first image the surface of the Mn/W(110) with a W (non magnetic) tip. Which is the structure you expect to observe in the STM image?

b) We repeat the experiment with an Fe coated W tip (magnetic tip) and we assume the tip magnetization to be parallel to the [110] direction (this can be done by applying an external magnetic field parallel to this direction). Which is the structure you expect to observe in the STM image?

c) By applying an external magnetic field we magnetize the tip in the [001] direction. Which is the structure you expect to observe in the STM image?

S. Heinze et al., Science 288, 1808 (2000)

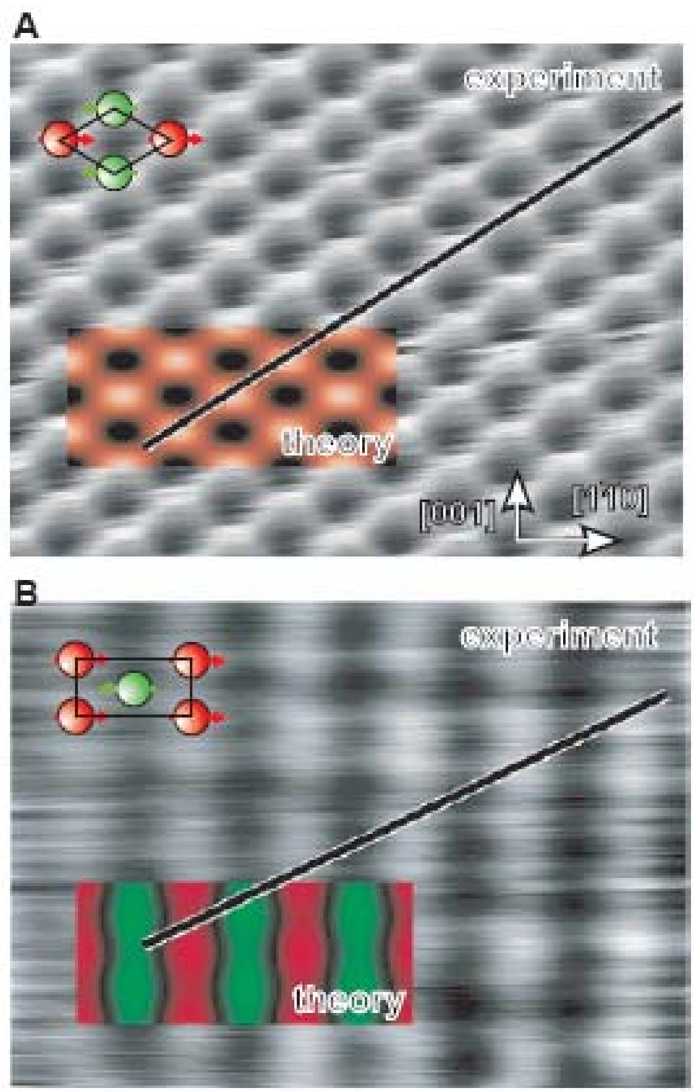


Solution: Atomically resolved antiferromagnetic order by SP-STM

a) The crystallographic unit cell is shown in figure a with the corresponding STM image
b) The magnetic unit cell is shown in figure b with the corresponding SP-STM image
c) In this case the tip magnetization is perpendicular to the atoms magnetic moment which means that the tip is not sensible to the atomic magnetic moment ($P_{tip}P_{atom} = 0$). The STM image is than again identical to that shown in figure a

1x1
unit cell

c 2x2
magnetic
unit cell

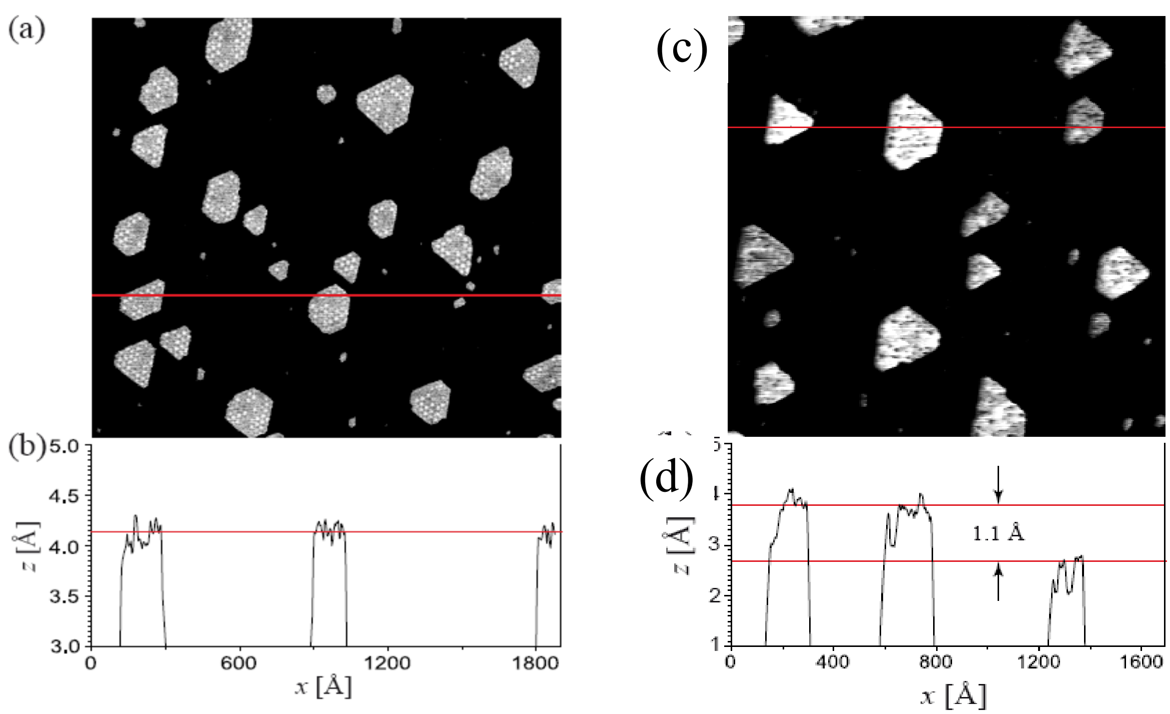


Spin polarization and TMR of nanostructures measured by STM

S. Rusponi et al., Appl. Phys. Lett.**87**, 162514 (2005)

We aim measuring the spin polarization and the tunneling magneto-resistance of Co nanostructures grown by Molecular Beam Epitaxy on a surface of Pt(111). To achieve our goal we scan the sample with an STM, operated in the constant current mode, having first a Tungsten (W) tip and then a Cr-coated W-tip (see fig. below). The tip-vacuum-nanostructure junction can be seen as an ideal MTJ with both the tip and nanostructure having the magnetization pointing perpendicularly to the sample surface.

a) Why have the Co islands two different apparent heights when imaged with a Cr-coated tip?
b) Assuming a tip polarization of P_{tip} = 100%, which is the island polarization?
c) Which is The TMR for islands with opposite magnetization?



Constant current STM image of double-layer Co islands recorded with a W-tip (a) and with a Cr-coated W tip (c) V_t= −0.2 V, I_t=0.3 nA . (b) and (d) Averaged ±5 lines line scan at the indicated position in (a) and (c), respectively. When imaged with a W tip the islands have the same apparent height, while when they are imaged with a Cr coated tip a surprisingly high difference of Δz=1.1±0.1 Å in the apparent height of islands with opposite magnetization is observed.

Solution: Spin polarization and TMR of nanostructures measured by STM

a) Because the STM is operated in the constant current mode the different apparent height of the nanostructures is due to the magneto-resistance effect: islands with the magnetization parallel to the tip magnetization are seen higher than islands with opposite magnetization

b) The spin polarization is given by:

$$P_{tip}P_s = \frac{I_{\uparrow\uparrow} - I_{\uparrow\downarrow}}{I_{\uparrow\uparrow} + I_{\uparrow\downarrow}}; \quad I_{\uparrow\uparrow} = I_0 + I_{spin}; \quad I_{\uparrow\downarrow} = I_0 - I_{spin}$$

Where I_0 and I_{spin} are the spin independent and dependent tunneling current, respectively. Indicating with z_0 the mean island height we get:

$$I_{\uparrow\uparrow} \propto \exp[-2\frac{\sqrt{2m\Phi}}{\hbar}(z_0 - \frac{\Delta z}{2})]; \quad I_{\uparrow\downarrow} \propto \exp[-2\frac{\sqrt{2m\Phi}}{\hbar}(z_0 + \frac{\Delta z}{2})]$$

Note that in the STM image the island with magnetization parallel to the tip magnetization have an higher apparent height i.e. $z = z_0 + \Delta z/2$. This is due to the STM being operated in the constant current mode. In order to keep constant the tunneling current the feedback control has to retires the tip of $\Delta z/2$. This implies that the over-current due to the parallel orientation of the tip and island magnetization is proportional to $\exp(\Delta z/2)$:

This gives:

$$P_{tip}P_s = \frac{\exp[2\frac{\sqrt{2m\Phi}}{\hbar}\Delta z] - 1}{\exp[2\frac{\sqrt{2m\Phi}}{\hbar}\Delta z] + 1}$$

Assuming Φ= 4 eV we get $P_s = 0$ for $\Delta z = 0$ and $P_s = 80\%$ when $\Delta z = 1.1$ Å

c) The TMR is defined by:

$$TMR = \frac{R_{\uparrow\downarrow} - R_{\uparrow\uparrow}}{R_{\uparrow\uparrow}}; \quad R_{\uparrow\uparrow} = V_t / I_{\uparrow\uparrow}$$

$$TMR = \frac{R_{\uparrow\downarrow} - R_{\uparrow\uparrow}}{R_{\uparrow\uparrow}} = \exp(2\frac{\sqrt{2m\Phi}}{\hbar}\Delta z) - 1$$

Assuming Φ= 4 eV we get TMR = 0 for $\Delta z = 0$ and TMR= 850% when $\Delta z = 1.1$ Å