ESRF

Experiment title:

Magnetism of 1-D Co wires

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HE-548

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Report:

Atomic engineering is today able to produce nanostructures that disclose the interplay between dimensionality and magnetism. Nearly two-dimensional systems, such as epitaxial ultrathin films and superlattices, are found to display unique magnetic properties without counterpart in bulk materials. Aim of our proposal HE-548 (May 1999) was to explore magnetism in structures of still lower-dimensionality approaching the physical realization of a one-dimensional (1-D) system. We investigated the magnetic behaviour of an ensemble of monatomic Co wires grown by step-edge decoration on a vicinal Pt surface. The Co wires form a regular array on the Pt substrate with a high degree of longitudinal coherence and an even lateral spacing [1]. The decorated surface can be seen as a 1-D superlattice consisting of monatomic Co wires alternated with narrow (~ 7 atom wide) terraces of uncovered Pt [Fig.1]. Magnetic circular dichroism at the Co $L_{2,3}$ absorption edges (770 eV - 830 eV) was used as a probe of the wire magnetization. The experiment took advantage of the high radiation flux at the ID-12B beamlines in order to achieve sensitivity to the small amount (< 10^{15} atoms/cm2) of magnetic material that constitutes the wire array. Moreover, by varying the orientation of the applied magnetic field insights could be gained on the magnetic anisotropies and easy magnetization axis of the 1-D quantum wires.

The Co quantum-wire ensemble displays over a wide temperature range (10 K < T < 300 K) a superparamagnetic behaviour, characterized by a sizable magnetization at high field, low magnetic susceptibility and no magnetic remanence. Representative results on the magnetization of the monatomic wire array at 10 K for different strength and orientation of the applied magnetic field are shown in Fig. 2. Assuming a Langevin function to describe the superparamagnetic behaviour of the monatomic wires, an average size of the superparamagnetic spin-blocks corresponding to ~ 30 Co atoms is estimated from these curves. The quasi-1D geometry of the quantum wire array is remarkably manifested by the strong anisotropy of its superparamagnetic response. A field perpendicularly aligned to the monatomic wire induces a larger magnetization than a field parallelly oriented to the wires, while a only weak differences distinguish the two (i.e. in-plane and out-of-plane) perpendicular directions. Sign and magnitude (10^{-3} - 10^{-4} eV/atom) of the magnetic anisotropy are in good agreement with theoretical predictions for long (> 20 atoms) and supported monatomic Co wires [2]. The anisotropic superparamagnetic response, which favours a magnetization perpendicular to the wire axis, demonstrates that the magneto-crystalline anisotropy prevails over the dipole-dipole interactions within and among the quantum wires. These results constitute to our knowledge the first experimental insights on the magnetism of 1-D monatomic wires.

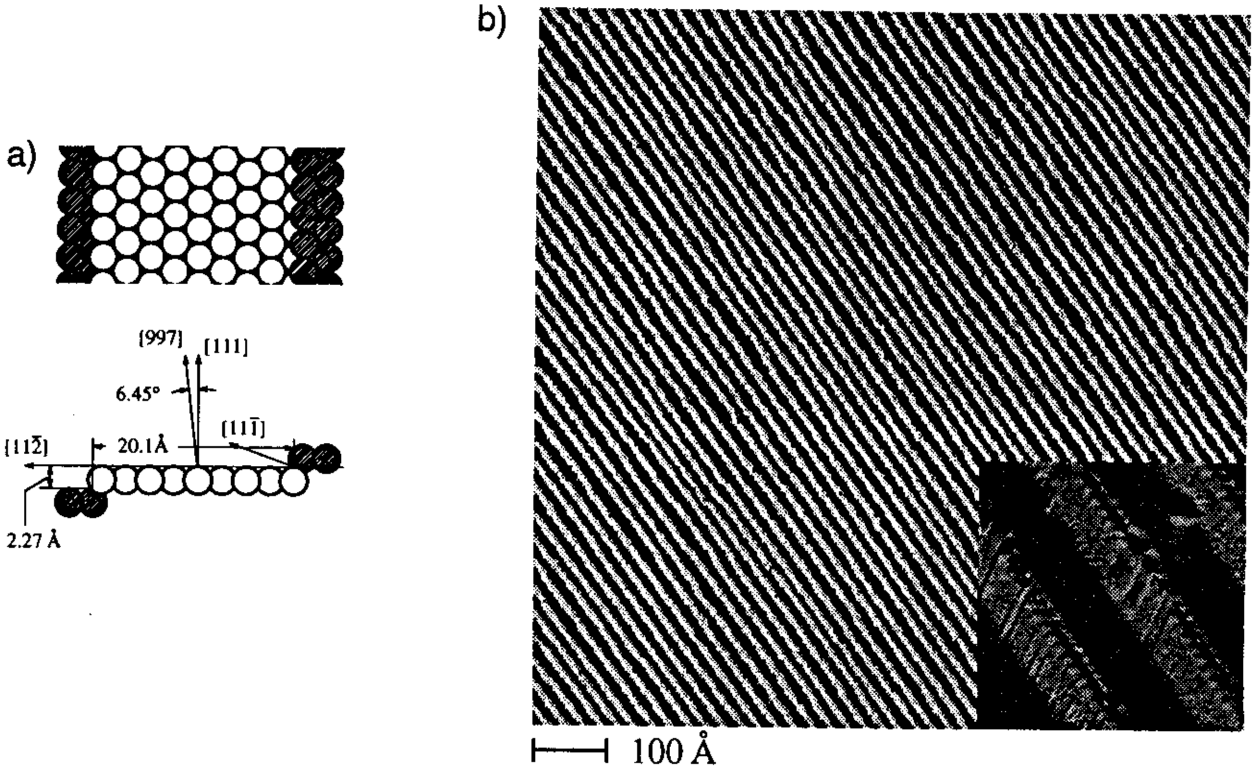
[1] P. Gambardella, M. Blanc, K. Kuhnke, and K. Kern, to be published;
[2] J. Dorantes-Davila, and G. M. Pastor, Phys. Rev. Lett. 81, 208 (1998)

Figure captions

Fig. 1. a) Schematic view of the Pt(997) surface. The (111) terraces are 20±2 Å wide and separated by monatomic steps, which serve as a template for growing nanowires. b) STM picture of a Pt(997) surface. In the frame: STM on an expanded scale showing Co-decorated Pt steps.

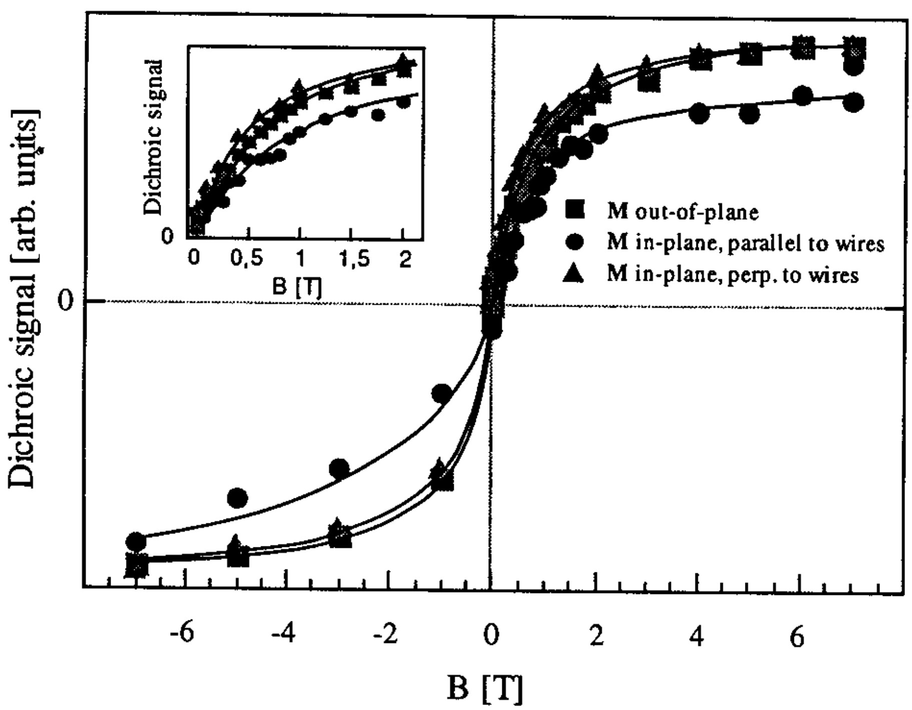
Fig. 2. Magnetic dichroism signal from monatomic Co wires on Pt(997) measured at 10 K in function of applied magnetic field. The symbols indicate the orientation of the magnetic field. Squares: field direction perpendicular to the wire axis and to the surface plane. Triangles: field direction perpendicular to the wire axis and nearly-parallel to the plane. Circles: field direction nearly parallel to the wire axis and to the surface plane.

Fig. 1



a)
[997]
[111]
6.45°
[11$\bar{2}$]
20.1 Å
[11$\bar{1}$]
2.27 Å
b)
100 Å

Fig. 2



Dichroic signal [arb. units]
B [T]
M out-of-plane
M in-plane, parallel to wires
M in-plane, perp. to wires
Dichroic signal
0
0
0,5
1
1,5
2
-6
-4
-2
2
4
6