Magnetic Anisotropy of a Single Cobalt Nanocluster

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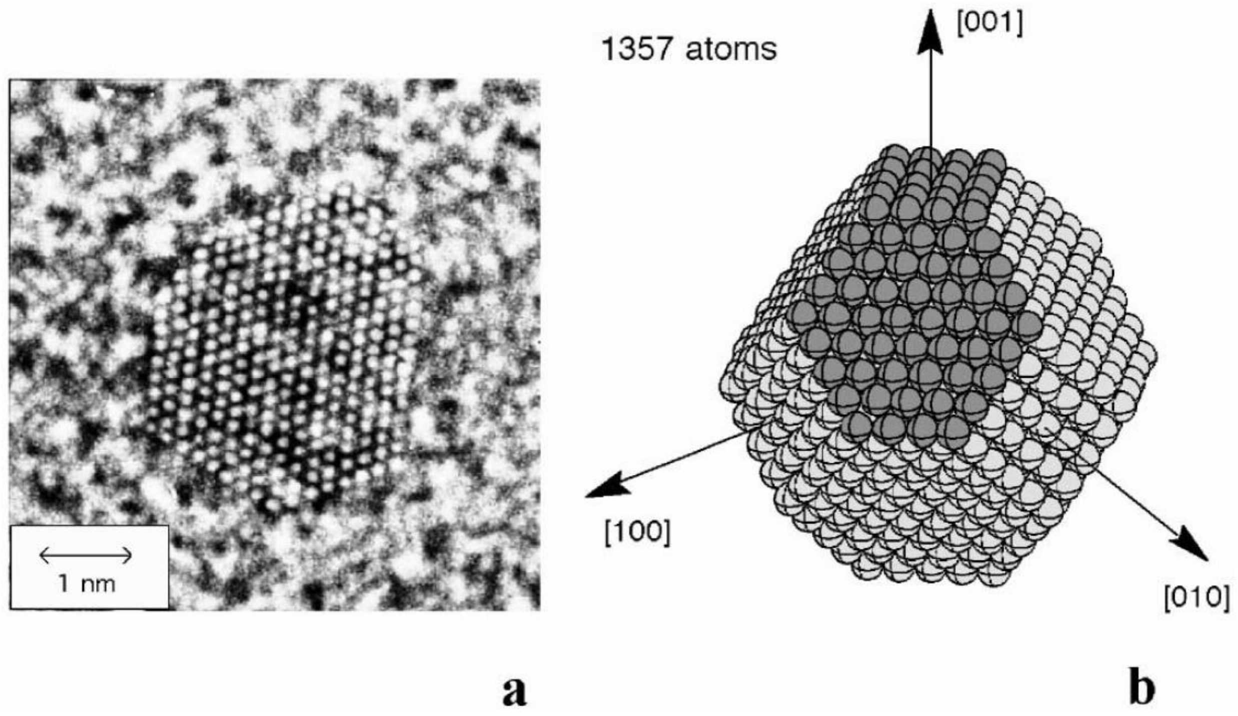
cobalt clusters (0D)

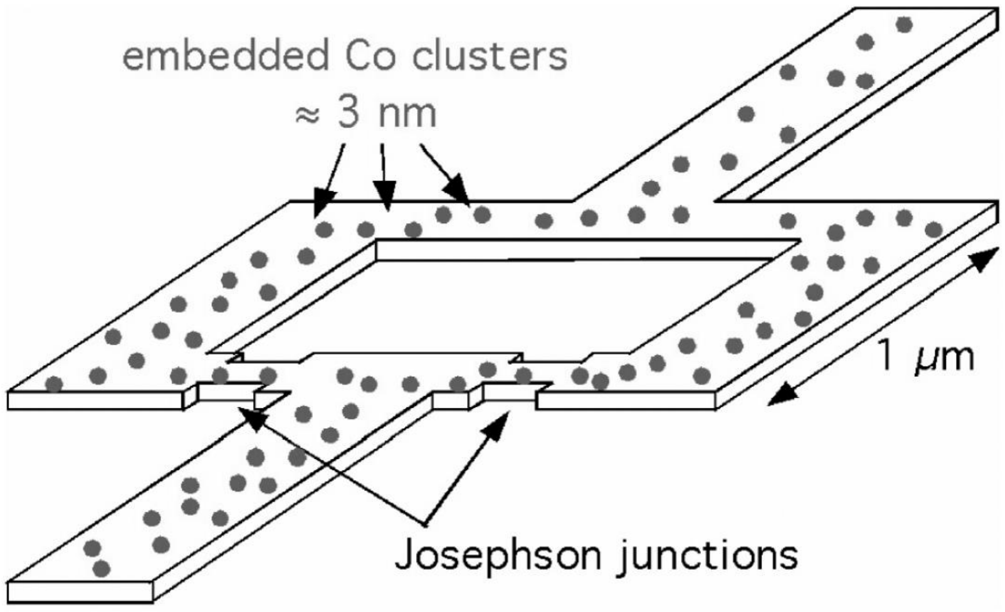
1000-3000 atoms in one cluster



(a) High resolution transmission electron microscopy(HRTEM) observation along a [110] direction of a typical 3 nm cobalt cluster exhibiting a fcc structure.

(b) A characteristic cluster simulated for our magnetic calculations with light atoms belonging to the truncated octahedron basis and dark atoms to the (111) and (001) added facets.

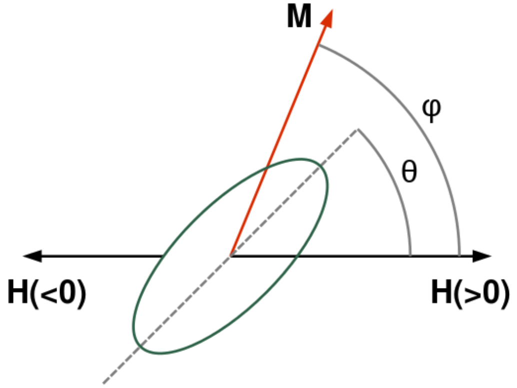
Method: (LECBD) low energy cluster beam deposition



Schematic drawing of a micro-bridge-SQUID which is patterned out of a 20-nm-thick superconducting niobium film containing a low density of 3 nm cobalt clusters (dots).

The desired sensitivity is only achieved for Co clusters embedded into the microbridges

Stoner–Wohlfarth model



Dash line is easy axis

The magnetization reversal is described by the potential energy

$$E(\vec{m},\vec{H}) = E_0(\vec{m}) - \mu_0 v M_s m \cdot Hcos(\varphi)$$
$$E_0(\vec{m}) = K_u v sin^2(\varphi - \theta)$$

where v and M_s are the magnetic volume and the saturation magnetization of the particle, respectively, and **H** is the external magnetic field. $E_0(\vec{m})$ is the magnetic anisotropy. K_u is anisotropy parameter.

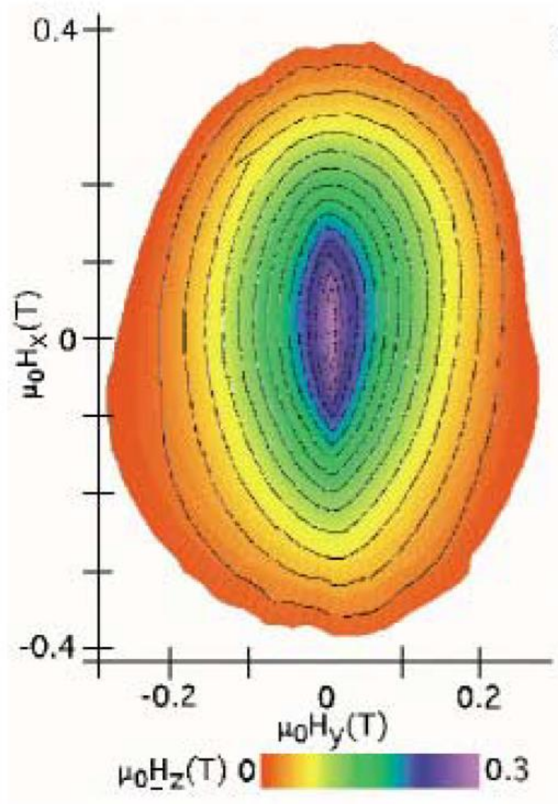
The switching field is the point where the solution switches from an energy minimum ($\partial^2 E/\partial \varphi^2 > 0$) to an energy maximum ($\partial^2 E/\partial \varphi^2 < 0$)

First, the magnetization of the particles is saturated in a given direction (at T 35 mK).
Second, a field is applied at a temperature between 35 mK and 30 K which may or may not cause a magnetization switching.
Finally, the SQUID is switched on (at T 35 mK) and a field is applied in the SQUID plane to probe the resulting magnetization state.

This method can scan the entire field space.

$$E_0(\mathbf{m})/v = -K_1 m_z^2 + K_2 m_y^2 - K_4(m_{x'}^2 m_{y'}^2 + m_{x'}^2 m_{z'}^2 + m_{y'}^2 m_{z'}^2)$$

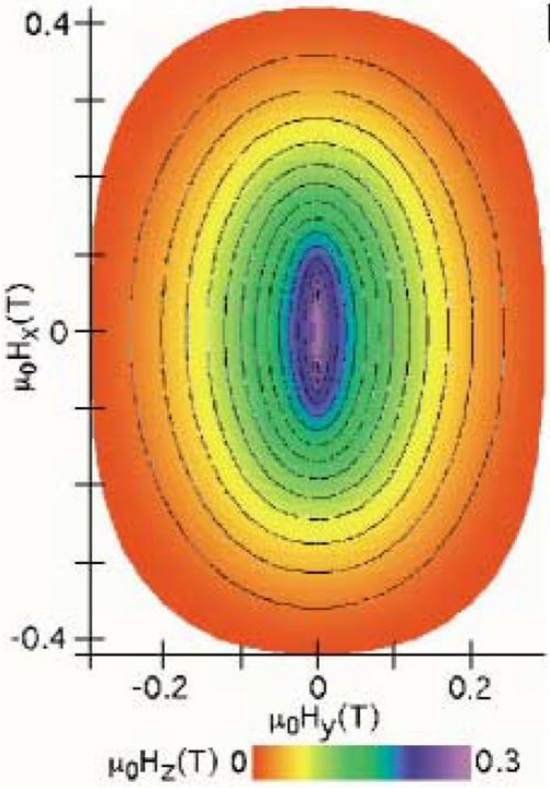
K_1 and K_2 are the anisotropy constants along z (easy axis)and y (hard axis). K_4 is the fourth order anisotropy constant, and the $x'y'z'$ coordinate system is deduced from xyz by a 45 degree rotation around the z axis with $z'=z$.

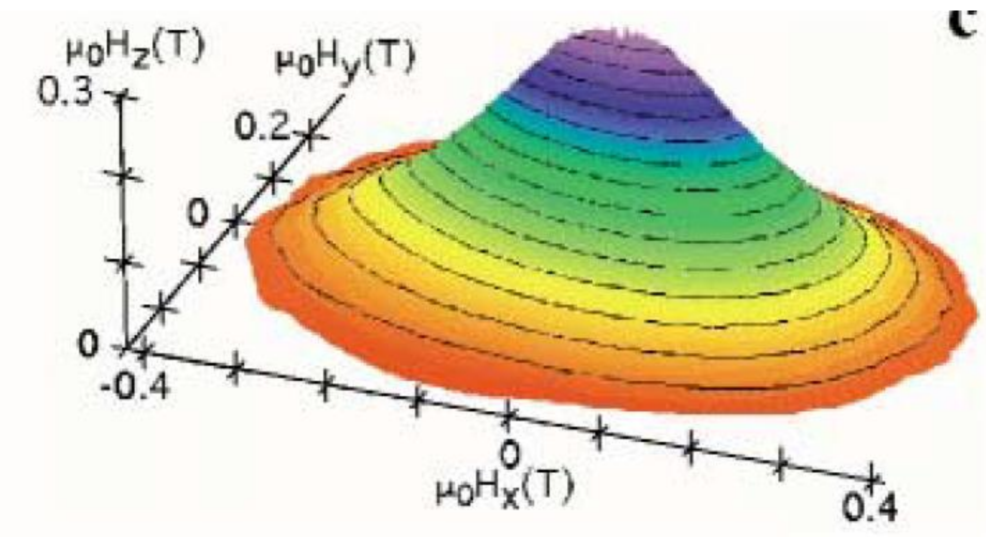


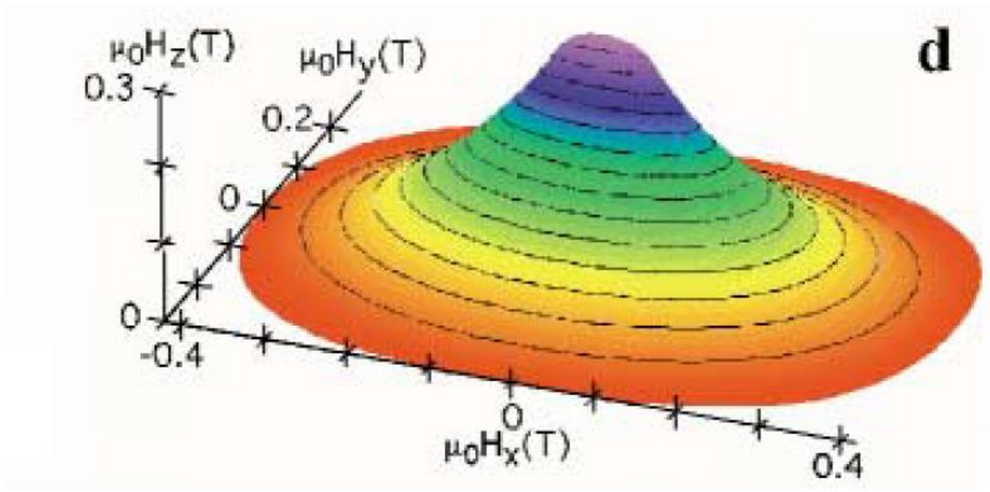
Top and side view of experiment

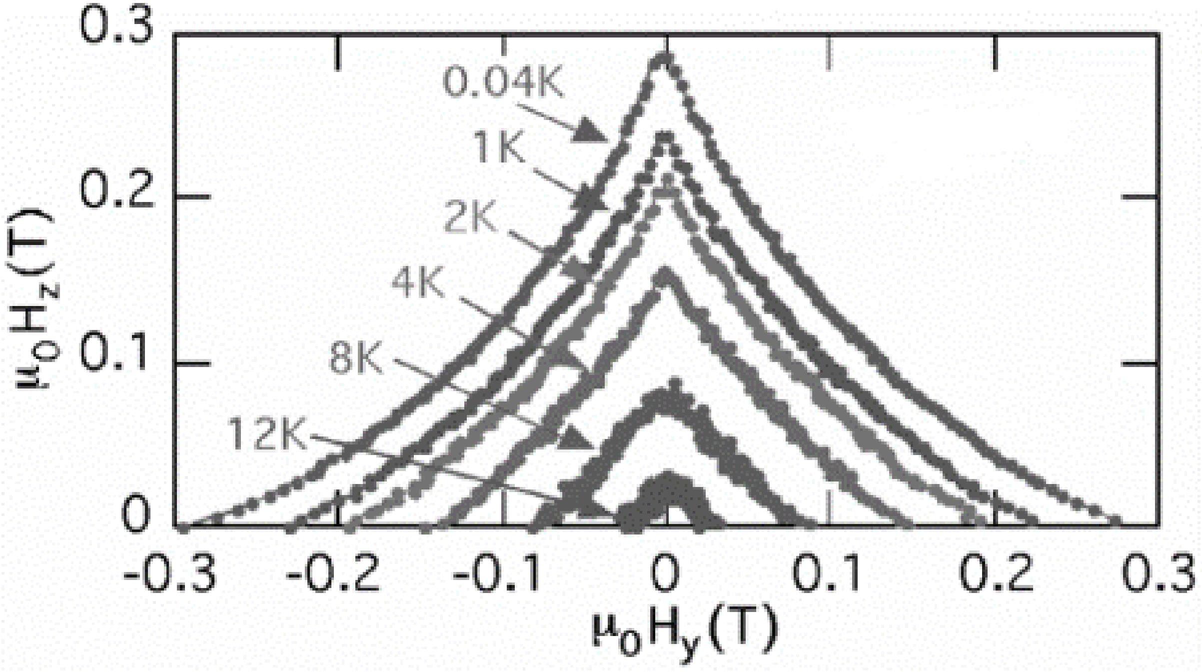
Top and side view of theory

	theory	experiment
$K_1(10^5 J/cm^3)$	2.2	2.0±0.3
$K_2(10^5 J/cm^3)$	0.9	0.8±0.3
$K_4(10^5 J/cm^3)$	0.1	0.1±0.05









Temperature dependence of the switching field measured in the H_y -H_z plane

$$E_0(\mathbf{m}) = E_{\text{shape}}(\mathbf{m}) + E_{\text{surface}}(\mathbf{m}) + E_{\text{ME}}(\mathbf{m}) + E_{\text{MC}}(\mathbf{m}).$$

E_{shape} is the magnetostatic energy related to the cluster shape.

E_{surface} is due to the symmetry breaking and surface strains. (main contribution)

E_{ME} is the magnetoelastic anisotropy which is induced by the relaxation inside the particle if there is external stress.

E_{MC} is the cubic magnetocrystalline anisotropy arising from the coupling of the magnetization with the fcc crystalline lattice as in the bulk.

conclusion

1. Micro-SQUID technique combined with the LECBD is a powerful method to investigate the magnetic properties of nanosized magnetic particles.
2. They measure in three dimensions the switching field of individual grains, giving access to its magnetic anisotropy energy.
3. The temperature dependence of the switching field is measurable.
4. Cluster-matrix interface provides the main contribution to the magnetic anisotropy.