MAGNETIC NANOSTRUCTURES

Edge atoms do all the work

Controlling the magnetization reversal behaviour of nanostructures is vital if they are to be used as tiny information units in future storage devices. Now it seems that the magnetic edge atoms make all the difference.

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The data density of information storage devices (such as hard disk drives) has increased to the point that scientists are now pushing towards the ultimate density limit for magnetic data storage. Getting there means replacing the nanocrystalline materials used today as magnetic media by nanostructured materials, in which individual data bits are represented by the two possible directions of magnetization of single, non-interacting magnetic particles. A key quantity determining the stability of the stored information is the magnetic anisotropy. This is the energy needed to force the magnetization direction away from its preferred easy axis, and governs the magnetization reversal behaviour of small magnetic particles.

On page 546 of this issue, Rusponi and colleagues describe how the magnetic anisotropy of nanoscale two-dimensional magnetic Co islands on a Pt crystal surface strongly depends on their size[1]. The authors separate the contributions made by atoms sitting at the outer perimeter of the two-dimensional magnetic nanostructures from those of the atoms inside, and find that the magnetic anisotropy of the nanostructures is nearly exclusively caused by the edge atoms alone (Fig. 1). The drastic difference between atoms at the outer edge and inside the islands may have implications for the design of magnetic media, and for our fundamental understanding of magnetic anisotropies in materials of reduced dimensions.

In a three-dimensional crystalline magnetic crystal, the magnetic anisotropy and the preferred directions of magnetization are related to the crystal axes by the quantum-mechanical spin–orbit interaction. As the dimension of a magnetic sample is reduced, for example in the ultrathin films (a few atomic layers) used in the latest hard-disk read heads, matters become more complicated. Because of magnetic stray fields outside the sample, sample shape comes into play, too. It is, for example, energetically more favourable to align the magnetization along the film plane rather than perpendicular to it. Other energies that have their source in the electronic structure can be even more important. The reduced number of nearest neighbours of atoms at the surface of a thin film or at the edge of a nanostructure leads to more atomic-like electronic properties. The most significant changes when going from a free atom to an infinite solid, concern the magnetic moment due to the orbital motion of electrons. This orbital magnetic moment is related to the magnetic anisotropy. Gambardella and co-workers recently reported huge magnetic anisotropies for one-dimensional single atomic chains[2] and single Co atoms and nanoparticles[3] supported on Pt(111) single crystal surfaces.

For many years, researchers have described the way magnetic anisotropies in ultrathin films depend on film thickness by distinguishing between a thickness-dependent contribution from the bulk, and thickness-independent contributions from the two interfaces. Although this phenomenological approach may give an oversimplified picture of the underlying physics, it provides a useful description of the magnetic anisotropy in the absence of more detailed knowledge of the involved mechanisms and parameters. Therefore, assigning different magnetic anisotropy values to perimeter and surface atoms is the result of transferring

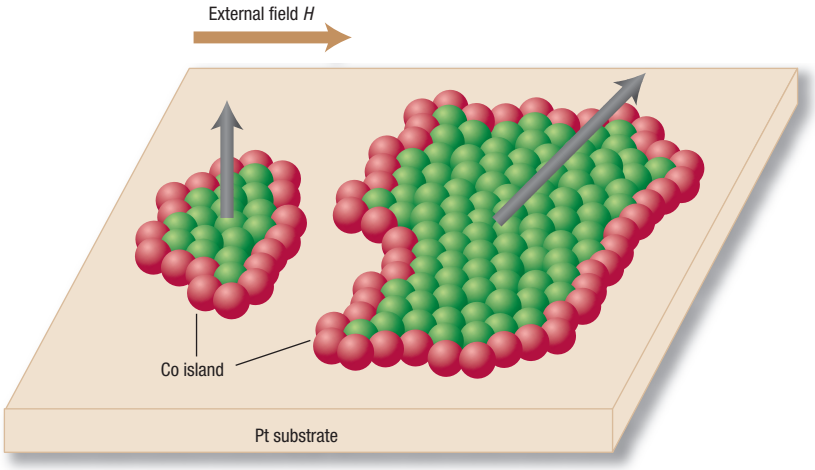

Figure 1 Magnetic anisotropy of two-dimensional magnetic islands formed by a single layer of atoms. If Co atoms at the perimeter of magnetic islands (red) exhibit a much higher magnetic anisotropy than Co atoms from inside the islands (green), as Rusponi *et al.*[1] show, the average magnetic anisotropy per atom of the small island is larger than that of a bigger island. It is therefore easier to tilt the magnetization of a bigger island away from the preferred magnetization direction (perpendicular to the plane of the islands in this example) by applying an external magnetic field, *H*, along the surface plane, than to tilt the magnetization of a smaller island.

such a phenomenological description from thin films to two-dimensional islands. Consequently, the same limitations apply. For example, more than two species of atoms may contribute different amounts of anisotropy to the overall anisotropy of the nanostructure, because atoms at different perimeter sites may exhibit different magnetic anisotropies. As with most cases involving ultrathin films, however, the experimental data presented by Rusponi *et al.*[1] do not allow for the extraction of parameters for more elaborate models.

It will be interesting to see whether the edge atoms at atomic steps at the surface of ultrathin films play a similarly dominant role for their anisotropy as they do for two-dimensional islands. These two cases are not exactly equivalent, because in thin films all atoms (perimeter as well as surface atoms) reside on top of complete layers of the same atomic species, whereas in the system studied by Rusponi and co-workers they sit on a non-magnetic substrate. Transferring their results to thin films would lead to a new view of magnetic anisotropy in ultrathin films: it would mean that the anisotropy of surface atoms sitting in flat regions of the surface is actually not much different from their cousins in the bulk, and that it is only the edge atoms at monoatomic steps that lead to the enhanced anisotropy of the surface atomic layer. This would also have implications for theoretical calculations of thin-film magnetic anisotropies, in which flat surfaces are often considered, whereas real surfaces are never atomically flat. In fact, support for an important role for step atoms comes from several earlier reports that show a correlation between the magnetic anisotropy of thin films and the surface roughness[4], the number of steps at the interface to the underlying substrate[5], or the decoration of monoatomic steps by non-magnetic atoms[6].

With the advent of atomic-scale manipulation of materials and surfaces, investigating and tailoring the magnetic anisotropy of ultrathin films or nanostructures by nanoscale modification of the surface and interface structure seems feasible in the not-too-distant future. The results of Rusponi *et al.* may indicate unprecedented possibilities for tailoring the magnetic anisotropy of materials by assembling two-dimensional nanostructures, and placing different elements at the perimeter and on the inside. The authors already demonstrate this possibility by an example in which they replace the inner part of Co islands by non-magnetic Pt, thereby reducing the magnetic moment per island, but maintaining the same magnetic anisotropy because of having the same number of Co perimeter atoms.

However, the use of magnetic nanostructures of the sizes investigated by Rusponi *et al.* for single-bit magnetic data storage is still at the stage of fundamental research. The measurements by this group were performed at temperatures down to 50 K, which at the moment prohibits commercial use for data storage. The reported remarkable size-dependence of the magnetic anisotropy of two-dimensional Co islands, which points towards a striking difference between the magnetic anisotropy of atoms at different positions of the islands, will undoubtedly stimulate further studies. Advanced magnetic microscopy techniques, such as spin-polarized scanning tunnelling microscopy[7,8], may enable researchers in the near future to directly measure the magnetic anisotropy of individual nano-islands, and to correlate it to their simultaneously determined size and shape. We may yet find ourselves storing our data files on billions of tiny magnetic structures one day.

References

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