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FMR studies on ultrathin metallic films grown on Al_2O_3 surfaces

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Abstract

We investigated the ferromagnetic resonance of cobalt and iron films consisting of small islands deposited on a sapphire single crystal (Al_2O_3(0 0 0 1)) under UHV conditions. STM measurements performed on similar deposits on a thin alumina film (Al_2O_3/NiAl(1 1 0)) revealed a three-dimensional growth mode. On the basis of these structural data we investigated the magnetic anistotropy via angular-dependent ferromagnetic resonance measurements. Cobalt islands exhibit a uniaxial out-of-plane anisotropy which alignes the magnetization parallel to the substrate. This in-plane magnetization is due to the demagnetizing field which is calculated as the dipole sum atom by atom. Furthermore, the influence of adsorbates like O_2 or CO on the magnetism of thin films was investigated revealing a partial reduction in intensity. The adsorbates only influence the outer atoms and a magnetic core still remains.

Keywords: Ultrathin films; Ferromagnetic resonance

A lot of research has been done in the field of magnetism of ultrathin films and small particles due to a great interest in the physics of systems with reduced dimensions as well as to many potential technological applications [1,2]. Depositing metals on oxide surfaces leads generally to a formation of small islands [3]. Therefore, it would be interesting to characterize the magnetic properties of such a collection of particles, especially the anisotropy constants, which determine the dynamic behaviour of the magnetic moment caused by thermal activation. Furthermore, the surface magnetism of small particles can be investigated by adsorption of gases due to the large surface to volume ratio. In this work we characterized the magnetic properties of ensembles of cobalt and iron islands by ferromagnetic resonance (FMR) spectroscopy carried out under UHV conditions. These metals were deposited on the reconstructed basal plane of single crystalline sapphire ($(\sqrt{31}\times\sqrt{31})R \pm 9^\circ$ Al_2O_3(0 0 0 1)). On the other hand, we used a thin, well-ordered, epitaxial aluminium oxide film (Al_2O_3/NiAl(1 1 0) [4]) as the substrate for the same metals to perform STM measurements which are shown in Fig. 1. Image (a) shows a coverage of 0.3 Å of Co deposited at room temperature. The decoration of step edges can be observed as well as the nucleation on the terraces. Even in this regime of small coverages the particles exhibit heights of two to three atomic layers indicating a Volmer–Weber growth mode. The upper STM image (b) has been taken from a Co film with an average film thickness of 6.5 Å as measured with a quartz balance and shows again three-dimensional particles but no underlying oxide substrate. This is a result of the tip function which overestimates the particle diameter due to the finite dimensions of the tip. We know from TEM measurements that there is nearly no difference between the growth mode of metal particles (Pt, Pd) on the thin metal supported alumina film and unsupported, bulk-like Al_2O_3 [5]. Therefore, we conclude from these STM measurements that also cobalt grows in a three-dimensional way on the reconstructed sapphire surface.

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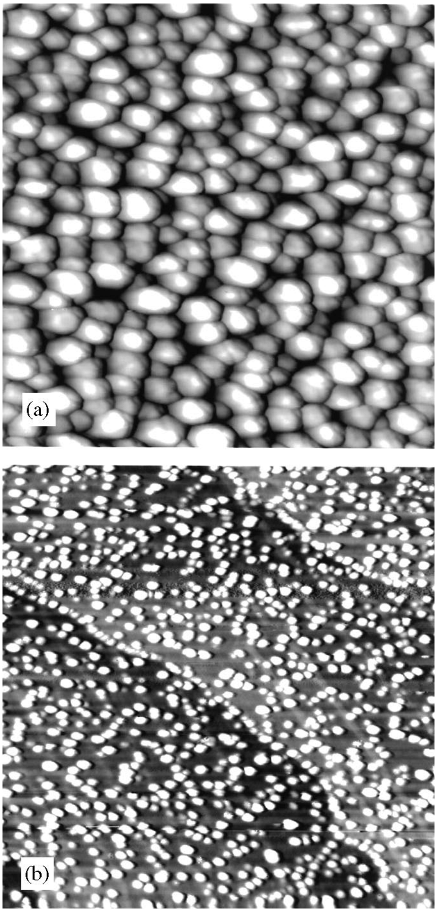

Fig. 1. (a) 0.3 Å $Co/Al_2O_3/NiAl(1\,1\,0)$, $200\times200\ nm^2$/ 5.1 V/ 0.5 nA; (b) 6.5 Å $Co/Al_2O_3/NiAl(1\,1\,0)$, $100\times100\ nm^2$/ 1.0 V/ 0.56 nA. At both coverages STM shows three-dimensional particles indicating that Volmer–Weber growth mode is present.

The angular dependence of the resonance field of several cobalt films is shown in Fig. 2. With the present sample holder it is only possible to detect the out-of-plane-anisotropy as depicted in the inset (with θ as out-of-plane angle). For all coverages the highest field is observed for $\theta = -90°$, i.e. when the outer magnetic field is perpendicular to the substrate surface. The resonance field decreases monotonically and reaches its minimum at $\theta = 0°$. All curves are symmetric with respect to 0° and therefore, only one half of the data is shown here. From these results we conclude that cobalt exhibits a uniaxial out-of-plane anisotropy and the magnetization lies parallel to the substrate surface, i.e. in plane. Assuming that Co grows epitaxially as HCP crystallites on the sapphire surface (the lattice parameters do not differ much) the axis perpendicular to the substrate is the easy axis. Then the shape anisotropy is responsible for the in-plane magnetization. In order to extract further results

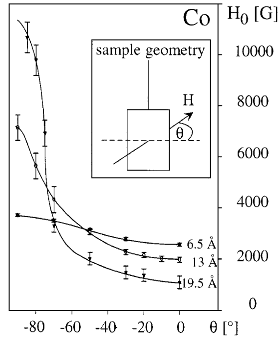

Fig. 2. Resonance field H_0 as a function of the out-of-plane angle θ for different amounts of cobalt on sapphire exhibiting a uniaxial out-of-plane anisotropy and an in-plane magnetization.

we developed a model concerning the present anisotropies. Firstly, the magnetocrystalline anisotropy constants are size dependent in the case of superparamagnetic (SPM) aggregates and therefore smaller as compared to the bulk-values because of the thermal fluctuation of the magnetic moment [6]. Secondly, the demagnetizing field was calculated evaluating the dipole sum atom by atom within small half ellipsoidal particles revealing much lower values than in the thin disk approach within the model of continuous matter. The dipole field depends on the size and the aspect ratio of the particle and exhibit values between a few hundred and a few thousand Gauss.

The influence of crystal structure on the resonance line can be observed after annealing the samples for 10 min to 873 K due to a temperature triggered crystallization (spectra cannot be shown here due to the limited space). While the Co signal only becomes more asymmetric due to coalescence the Fe resonance splits into several lines with different intensity and different angular dependences. This can be attributed to the three possible orientations of a BCC metal grown with the quasi hexagonal (1 1 0)-plane on a hexagonal substrate exhibiting different internal fields due to the different positions of the easy axis [7].

Finally, we investigated the influence of adsorbed gases on the magnetism of cobalt islands. Adsorption of CO which is not shown here reduces but does not completely quench the FMR signal [8]. Therefore, CO molecules only influence the magnetism of the outer atoms and a magnetic core is still left which is compatible with three-dimensional particles. Oxidation of annealed cobalt particles leads to similar results. Fig. 3 shows the successive reduction of FMR intensity during an oxidation series. The particles were oxidized in the outer range and a smaller metallic core remains giving rise to an FMR signal which tends to reveal isotropic SPM behaviour. This is shown in the upper diagram of Fig. 3: the

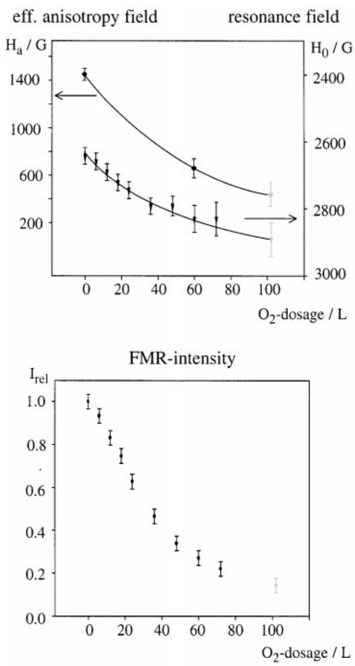

Fig. 3. FMR data of an oxidation series of 6.5 Å Co (annealed) showing incrasing tendency towards isotropic SPM: the FMR-intensity decreases with increasing oxygen dosage (lower part); the effective anisotropy field decreases and the resonance field tends towards 3035 G (upper part).

effective anisotropy field H_a decreases with increasing oxygen dosage and the resonance field H_0 tends towards 3035 G corresponding to the resonance position determined only by the g-value ($g = 2.18$, bulk) and by no other anisotropy fields.

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