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Studies of ferromagnetic resonance line width during electrochemical deposition of Co films on Au(1 1 1)

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Abstract

In situ ferromagnetic resonance (FMR) measurements were performed during and after the electrochemical deposition of Co on Au(1 1 1)/mica substrates using classical three-electrode cell under potential control. The influence of an electrolytically deposited Cu cover layer was investigated by in situ FMR measurements. Prior to the Cu deposition a FMR line width as small as 15 mT was observed. With the Cu covering the crystalline distribution of the Co film is increased and the surface anisotropy is decreased, leading to an enlargement of the FMR line width by a factor of 2 and a change of the FMR line position and shape.

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Keywords: Ferromagnetic resonance; Electrolytic deposition; Surface anisotropy

1. Introduction

Information about magnetic films usually refers to samples prepared by molecular beam epitaxy (MBE) techniques [1]. MBE techniques require a high technical expense and are less suitable for large-scale deposition of magnetic films. On the other hand, electroplating setups offer a similarly high range of adjustable parameters at a much lower experimental costs. Thus with electroplating the engineering of the desired magnetic properties is possible on large deposition areas as well as on nanostructured materials [2,3]. It has been shown that the magnetic properties of Co can be tailored by adjusting the growth condition [4]. In this paper, the lack of in situ magnetic characterization techniques for electrodeposition is overcome by a newly developed combination of ferromagnetic resonance (FMR) setup with an electrochemical cell. Previous in situ magneto-optic Kerr investigations on electrochemically grown Co films were

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unable to provide information about anisotropy and distribution of magnetization [5]. Here we present first in situ FMR measurements, which are compared to ex situ FMR experiments on Cu capped Co films.

2. Experiment

The electrochemical deposition of the Co films with and without Cu cover layer was performed on Au(1 1 1)-films of 30–50 nm thickness. These Au films were prepared by evaporation on freshly cleaved mica substrates and flame annealing to provide 200 nm wide flat terraces with (1 1 1) orientation, verified by scanning tunneling microscopy (STM) [6]. The electrochemical part of the experimental setup consisted of a conventional three-electrode cell with a mercury sulfate reference electrode (MSC) and a Pt counter electrode. The electrolyte was a solution of 0.5 M $CoSO_4$ and 0.5 M $CoCl_2$ and H_3BO_4 at a pH-value of 4. All solutions were prepared with reagent grade chemicals in bidistilled water.

Cyclic voltammograms (cyclic current–voltage curves) [7] between −0.5 and 0.5 V/MSC for the deposition and removal of SO_4 on the Au(1 1 1) surface were performed to enhance the quality of the surface by removing all kinds of adatoms leaving a most perfect surface for the Co deposition. The Co films were deposited by applying a potential below the Nernst potential $U_{Co/Co^{2+}} = -1.02$ V/MSC. By the variation of the overpotential [8] between $\eta = 0.13$ and 0.68 V/MSC different growth conditions were achieved resulting in a different FCC/HCP ratio and different orientation of the magnetization in the Co films [9]. By performing a cyclic voltammogram with Co deposition and removal, the exact deposition rate of Co per η and time can be determined. These cycles were repeated to enhance the accuracy of this calculation before the final Co film is deposited. To investigate the influence of an electrodeposited Cu cover layer, a 0.01 M $CuSO_4$ solution was added to the electrolyte after the final Co layer had been grown. By applying the overpotential $\eta = 0$ V/MSC for the Co to the Co/Cu solution, Cu is deposited on top of the Co layer due to the difference in the growth potentials ($U_{Cu/Cu^{2+}} = -0.3$ V/MSC). For a Cu layer thickness of 7.6 nm no oxidation of Co is observed in the ex situ measurements [4]. Previous investigations [4,10] show that structure and magnetic behavior are comparable to that of MBE grown samples on different substrates.

The ex situ conventional ferromagnetic resonance (FMR) measurements were performed using a FMR-spectrometer in the X-band [11]. The anisotropy parameters were calculated from angle-dependent FMR measurements by fitting the resonance condition self-consistently to the data. The in situ FMR experiments were carried out with the same spectrometer using a self-built TE_{101} cavity in the X-band with a quality factor of 900 and an electrochemical cell connected to this cavity. Thus, the sample was placed between cavity and electrochemical cell. The detection threshold for this in situ FMR setup is around 10^{12} spins. Angle-dependent measurements with the in situ setup are possible in the film plane with an angle variation of maximum $\pm 40^{\circ}$, since the sample-cavity orientation is fixed. Comparing the line width and shape between ex and in situ FMR measurements, information about the anisotropy and magnetization distribution is obtained.

Fig. 1 shows the combined electrochemical and FMR setup. To avoid a leakage of the electrolyte a liquid varnish (Lacomit) was used to seal the connection between the cavity, the sample and the cell. This seal also defines the area of the deposition on the Au surface. The electric contact between sample and potentiostat was the wall of the cavity. To avoid current flow through the FMR spectrometer and to protect the microwave diode the cavity was galvanically decoupled. Angle-dependent in situ FMR measurements are feasible with the experimental setup, but have not been carried out. Angle-dependent measurements were not performed during the growth process, since the time needed for these measurements would lead to a significant pollution of the surface. At overpotential $\eta = 0$ V/MSC remaining impurity ions in the electrolyte will give rise to about one monolayer of adatoms per hour.