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# Exchange Bias in fcc-CoPt/CoO/Si films as a function of annealing treatment

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ABSTRACT

The investigation on the interface properties of fcc-CoPt/CoO thin films grown by Pulsed Laser Deposition is presented. The structural and microstructural properties of the CoO antiferromagnetic layer have been modulated by thermal treatments in order to investigate their influence on the magnetic behavior of the system.



## 1. Introduction

The Exchange Bias (EB) phenomenon discovered by Meiklejohn and Bean in 1956 [1] has been extensively investigated during the last decades, due to the large interest in both fundamental studies and technological applications [2]. One piece of evidence for the presence of EB is the observation of a shift in the hysteresis loop ($H_{ex}$) in systems characterized by an interface between a ferromagnetic (FM) and an antiferromagnetic (AFM) material. The shift of the hysteresis loop has been attributed to the unidirectional (exchange) anisotropy that arises from a direct exchange coupling at the FM/AFM interface when the sample is cooled across the Néel temperature $T_N$ of the AFM material [1] under an applied magnetic field. The exchange coupling usually also leads to an increase of coercivity, as observed in many EB systems characterized by low anisotropic AFM materials [2].

The chemically ordered $L1_0$ CoPt alloy is well known for its high magnetocrystalline anisotropy that gives the system the great stability (high coercivity) required for applications as a medium in high density magneto-recording [3,4]. Such a phase can be obtained from the chemically disordered fcc phase, but to overcome the energy barriers for inducing the long-range chemical ordering, a high temperature treatment is necessary.

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In principle, a coercivity enhancement of the low anisotropy and low coercivity fcc-CoPt phase could be obtained by exploiting the exchange coupling of this soft ferromagnetic phase with an antiferromagnetic layer.

As the Exchange Bias is an interface effect strictly dependent on the layers thickness and the interface quality [5], the control of the growth mechanism and deposition parameters is of crucial importance. For this reason, we have prepared a bilayer, composed of an fcc CoPt film deposited on top of a CoO underlayer ($T_N = 293$ K, $K_a = 10^7$ erg/cm$^3$) and, prior to CoPt deposition, different thermal treatments of the underlayer have been performed, in order to correlate the corresponding microstructural features to the observed interface coupling effects.

The bilayers were deposited by Pulsed Laser Deposition; by this technique, many different deposition parameters, such as deposition temperature, gas pressure and deposition rate can be easily varied in an independent way.

## 2. Experimental

Samples were prepared by sequential deposition of CoO and CoPt on a Si (100) substrate in a PLD high vacuum chamber. CoO layers (30 nm thick) were grown ablating a metallic Co target at 400 °C in an oxygen pressure of $10^{-3}$ mbar, following the procedure illustrated in [6]. In order to study the modifications of the magnetic properties related to the annealing process, a CoPt/$CoO_{as-dep}$/Si bilayer was prepared without any annealing procedure ($t_{ann} = 0$, sample A), while for the other samples, after the deposition of the antiferromagnetic CoO layer, the substrate temperature was increased up to 600 °C in vacuum condition ($P = 10^{-6}$ mbar) for 1 h (sample B) and 2 h (sample C); then, a thin film (about 15 nm thick) of fcc-CoPt was deposited on top, at 600 °C.

Structural studies were carried out by the Energy Dispersive X-ray Diffraction (EDXD), the measurements being performed by a non-commercial equipment, fully described elsewhere [6]. In this unconventional mode, the reciprocal space scan ($q$-scan, where $q$ is the normalized momentum transfer magnitude), necessary to collect the diffraction pattern, is carried out electronically, rather than mechanically, as in the conventional X-ray diffraction [7]. Moreover, ED X-ray Reflectometry [8] measurements were performed to obtain information on the film thickness and roughness, this technique being sensitive to surface and interface morphology at the angstrom resolution [9].

A commercial SQUID magnetometer (Quantum Design, $H_{max} = 5.5$ T) has been used for magnetization measurements at variable temperature (5 K–300 K).

## 3. Results and discussion

EDXD measurements on sample A ($t_{ann} = 0$) showed the presence of the CoO phase, the (311) reflection being identified at $q = 4.92$ Å$^{-1}$ (Fig. 1(a)). However, the polycrystalline $Co_3O_4$ phase was also observed, probably produced on top of CoO surface during the waiting time (5′) necessary to raise the substrate temperature prior to the CoPt layer deposition (CoPt (111), $q = 2.85$ Å$^{-1}$). As previously reported, the formation of the $Co_3O_4$ phase is hard to avoid and a pure CoO film could be obtained only when a Pt cap-layer was deposited immediately after the CoO growth [10].

To study the EB properties, the samples were cooled from room temperature down to 5 K under an applied field $H_{cool} = 2$ T, parallel to the film surface. The hysteresis loop was then measured between $\pm 2$ T along the $H_{cool}$ direction.

The presence of exchange coupling between CoPt and CoO layers (sample A) was evidenced by the horizontal shift of the hysteresis loop, with $H_{ex} = 16$ mT at $T = 5$ K (Fig. 2(b)). The coercivity value $H_c = 130$ mT resulted to be higher than what expected for the unbiased CoPt layer, as confirmed by the measurements on the reference fcc-CoPt/Si single layer deposited in the same conditions ($H_c = 88$ mT) reported in Fig. 2(a), where the two zero field cooling hysteresis loops at 10 K are compared for the two systems. Thus, the observed coercivity enhancement can be reasonably attributed to the exchange coupling at the AFM/FM interface (exchange anisotropy). When CoO was heated up to 600 °C for different annealing times ($t_{ann} = 60'$ and $120'$ for sample B and C, respectively) before CoPt deposition, both $H_{ex}$ and $H_c$ after field cooling sensibly changed, depending on the thermal treatment (Fig. 2(c), (d)).