

LETTER TO THE EDITOR

Exchange anisotropy in CoCr films

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Received 27 October 1987

Abstract. Exchange anisotropy was first discovered in oxidised cobalt particles (Co–CoO) by Meiklejohn and Bean. They observed a shift in the hysteresis curve along the field axis, a non-vanishing rotational hysteresis, and a unidirectional component in torque curves, after the sample was cooled in a saturating magnetic field. Later the effect was also found in other ferro–antiferromagnetic systems by Meiklejohn.

In this Letter a shift in the hysteresis curve of CoCr films is presented. RF-sputtered CoCr films were cooled in a magnetic field of 17 kOe from room temperature to liquid-nitrogen and helium temperatures. The shift is approximately 100 Oe in the direction opposite to the cooling field. The antiferromagnetic regions that are thought to be concentrated on the column boundaries offer a new opening in the discussion on the reversal mechanism of CoCr films.

CoCr layers have been proposed as suitable media for perpendicular magnetic recording (Iwasaki 1980). The layers are either sputtered or evaporated and in most cases a columnar morphology is revealed by SEM observations. The magnetic reversal mechanism is still a subject of discussion. Two principal models have been proposed for the magnetic behaviour of CoCr and the difference between them is the influence of the column boundaries upon the ferromagnetic exchange force. If this force acts across the column boundaries, the film is more or less continuous and the reversal mechanism is thought to be the displacement of vertical (Bloch) domain walls (Wielinga 1983). If it does not, the columns are magnetic particles with only magnetostatic interaction. Hence, the magnetic reversal is either a coherent or an incoherent particle reversal mechanism. Most authors propose the incoherent ‘curling’ mode (e.g. Ouchi and Iwasaki 1987). In a third intermediate model the formation of spike domains is considered, and a reversal mechanism of (spike-)domain-wall motions within the columns is proposed (Hemmes 1986). The nature of the column boundaries is of secondary importance here. One of the arguments for the particulate model is the evidence of Cr segregation to the column boundaries as reported by several authors (e.g. Chapman *et al* 1986 and references therein). Segregation was also predicted theoretically by Chelikowsky (1984) who based his predictions on the Mie-

dema model. However, the conclusion generally drawn from this evidence, namely that the Cr-rich boundaries are ‘non-magnetic’, seems to be premature. It is well known that homogeneous bulk CoCr with more than 25 at.% Cr is no longer ferromagnetic (that is what is really meant by ‘non-magnetic’), but in (small) regions with a large Cr concentration the antiferromagnetic nature of Cr might dominate. Also, many of the possible oxides and compounds that might be formed due to oxide gettering during the preparation process are antiferro- or ferri-magnetic. The possibility of an antiferromagnetic column boundary and its influence on the magnetic properties of CoCr have already been discussed by Danan and Andrä (1983). As we proposed earlier (Hemmes 1986), Meiklejohn’s experiment (Meiklejohn 1962) is a suitable way to detect the possible existence of antiferromagnetic regions in CoCr layers.

If a ferro–antiferro system is cooled from a temperature T between the Neél temperature T_N and the Curie temperature T_C , to a temperature below T_N , in a magnetic field large enough to saturate the ferromagnetic part, the antiferromagnetic part is ordered by the saturated ferromagnet. In reverse, the ordered antiferromagnet induces a unidirectional anisotropy in the ferromagnet as long as the temperature remains below the Neél temperature. The exchange anisotropy can be detected as a shift of the hysteresis

curve along the field axis, opposite to the direction of the cooling field, by a non-vanishing rotational hysteresis at higher external fields, or by a unidirectional ($\sin \theta$) component in torque curves. These phenomena were first found in the Co-CoO system (oxidised Co particles) by Meiklejohn and Bean (1956), and explained as 'exchange anisotropy'. This anisotropy is unidirectional rather than uniaxial. Ohkoshi *et al* (1984, 1985) succeeded in preparing Co-CoO films with perpendicular anisotropy, suitable for perpendicular recording, in which they also found exchange anisotropy, while Takahashi *et al* (1980) extensively studied the 'Meiklejohn-Bean effect' in Co-CoO films with in-plane anisotropy. The shift is of the order of 1 kOe as reported by Meiklejohn and Ohkoshi, but only of the order of 50 Oe in Takahashi's films.

Here a shift of approximately 100 Oe in the hysteresis curve of CoCr films is presented. Hysteresis curves with the external field perpendicular to the sample surface were measured using a PAR Vibrating Sample Magnetometer supplied with superconductive coils and sample cooling facilities to liquid-helium temperatures. The samples were cooled from 308 K to 9 or 77 K either in a zero external field or in a field of 17 kOe approximately perpendicular to the sample surface. The hysteresis curve at room temperature was also measured. Three films were investigated: a Magnetron and an RF-sputtered CoCr(81/19 at.%) sample on Si with thicknesses of 1.5 and 0.9 μm respectively, and a 2 μm thick RF-sputtered CoCr(79/21 at.%) film deposited on a polyimide foil covered with an amorphous 350 nm thick Ge underlayer. Preparation conditions have been given previously (Hemmes 1986), and for those of the last film see Schrauwen *et al* (1987). Systematically, a shift opposite to the cooling field was found for the hysteresis curves that were taken after the sample was cooled in the external field of 17 kOe. However, since the sample holder could only contain three small ($3 \times 5 \times 0.3 \text{ mm}^3$) pieces of the samples sputtered on Si, the hysteresis curves of these samples were too noisy to show a decisive shift. Therefore, 20 samples were cut from the polyimide foil, covered with a Ge underlayer and 2 μm thick CoCr, and stacked together in the sample holder. Five hysteresis curves were taken of this sample, one slightly above room temperature at 308 K. The sample was then cooled in a field of -17 kOe to 9 K and measured. After heating the sample to 77 K the hysteresis curve was again measured. The reproducibility was found to be good when repeating this last measurement. Finally, the sample was heated to 308 K and cooled again to 9 K but now in zero external field. Little difference was found between the hysteresis curves taken at 9 and 77 K, after the sample was cooled in the external field, the latter showing only a slightly lower coercivity H_c and saturation magnetisation M_s , but both curves were shifted approximately 100 Oe along the field axis. As an

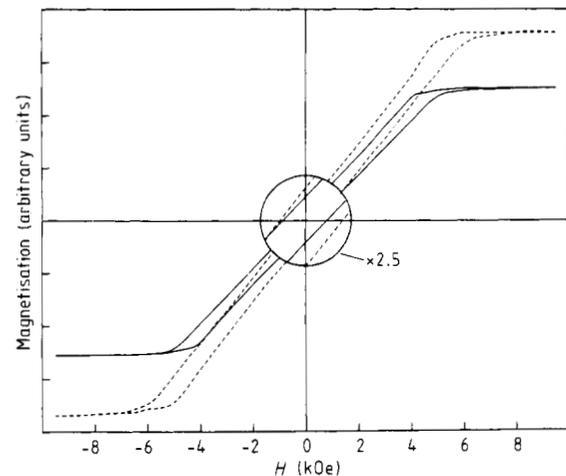


Figure 1. Hysteresis curves of a 2 μm thick CoCr (79/21 at.%) film sputtered on a polyimide foil with Ge underlayer at 308 K (full curve), and at 9 K after cooling in an external field of -17 kOe (broken curve). At the origin the curves are magnified 2.5 \times to discern the shift of the second curve. The vertical (magnetisation) scale, although in arbitrary units, is the same for both curves.

example, in figure 1 the curve with no shift obtained at room temperature (full curve) is compared with the one after cooling the sample to 9 K in the external field. The shift is opposite to the cooling field (-17 kOe in this case), hence providing evidence for the existence of antiferromagnetic regions in the CoCr sample. It should not go unnoticed that, although it occurred almost within the error of measurement, a systematic tendency was observed for all the curves that were shifted towards the positive field to be also shifted down along the vertical magnetisation axis, as if a ferrimagnet with a very small net magnetisation (and very large coercivity) were present instead of a true antiferromagnet. Close examination of the figures in the original paper of Meiklejohn and Bean (1956) and in the work of Tamari *et al* (1985) and Ohkoshi *et al* (1984) confirm this observation.

The existence of antiferromagnetic regions in CoCr offers a new opening in the discussion on the reversal mechanism of CoCr films. They are perhaps responsible for the contradicting experimental results found in CoCr layers. The regions are probably located at the column boundaries (Danan and Andr a 1983), however Maeda and Asahi (1987) propose a dissolution of Co into six radial oriented regions within each column, based on TEM observations and energy dispersive x-ray microanalyses of selectively wet-etched thin CoCr samples. Depending on the Neel temperature(s) of the antiferromagnet(s) they are either paramagnetic at room temperature and unable to pass the exchange force or they are antiferromagnetic and induce a unidirectional anisotropy locally, which depends on the direction of the magnetisation in the neighbouring ferromagnet during

film deposition. Spike-domain formation, especially in the 'Maeda-type' of films, is energetically more favourable than in continuous films, since no or considerably less domain-wall energy is needed. The Neèl temperature is determined by the nature of the antiferromagnet, but possibly, also, size effects may be of importance e.g., the Neèl temperature of bulk Cr is 475 K, but very thin layers of Cr are predicted to be ferromagnetic. Systematic research has to be done on various types of CoCr layers, analogous to the study of Takahashi *et al* (1980) on evaporated Co-CoO thin films, to reveal the exact nature of the antiferromagnetic regions and their influence on the magnetic reversal mechanism of CoCr films.

The authors would like to thank Philips Research Laboratories for providing the vsm measuring facilities, JPC Bernards for providing the CoCr sample on polyimide and G Poedt for performing the measurements.

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