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Anisotropy of the Sublattice Magnetization and Magnetoresistance in Co/Re Superlattices on $Al_2O(1120)$

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DISCLAIMER

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ANISOTROPY OF THE SUBLATTICE MAGNETIZATION AND MAGNETORESISTANCE IN Co/Re SUPERLATTICES ON $Al_2O_3(11\bar{2}0)$.

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$[Co(20Å)/Re(6Å)]_{20}$ superlattices were grown on a $(11\bar{2}0)$ surface of a Al_2O_3 single crystal, with the [0001] direction of their hcp structure in the plane of the film. The Co layers were found to be antiferromagnetically coupled (AF), with a saturating field of 6 kOe. Polarized neutron reflectivity was used to determine the direction of the sublattice magnetization. In zero applied field, the AF moments are aligned along the Co [0001] axis. In a magnetic field H perpendicular to the Co [0001] axis, the sublattices moments evolve to a canted arrangement, with the AF component always perpendicular to the field. With H along the Co[0001] axis, the AF moments flop in a direction perpendicular to Co[0001] axis. The spin flop transition is not abrupt, but can be described as a gradual rotation that is completed at 2 kOe. The anisotropy of the sublattice magnetization is related to the anisotropy of the magnetoresistance. This has the conventional dumbbell behavior with the field applied perpendicular to the Co[0001] axis, but exhibits an extended plateau near $H = 0$, and a slight increase up to H ~ 2 kOe, when H is parallel to Co[0001] axis.

INTRODUCTION

Recently major computer storage manufactures began to use magnetoresistive read/write heads to increase the bit density in hard disk drives. Even larger gains are possible by taking advantage of both giant magnetoresistance (GMR) and anisotropic magnetoresistance (AMR) effects. GMR was discovered approximately 10 years ago[1] and has been thoroughly studied in several multilayer systems.[2] This effect is driven by the antiferromagnetic arrangement of the magnetization in adjacent magnetic layers of a metallic multilayer system.[3] AMR, on the other hand, has been thoroughly studied since the 1930's.[4] In AMR the resistance with the current applied parallel to the magnetization is greater than the resistance with the current applied perpendicular to the magnetization. For this reason, systems with in-plane anisotropies can be used to exploit AMR in technological devices.

Magnetization and magnetotransport measurements can be used to determine whether antiferromagnetic (AF) coupling exists, but these measurements are indirect. Neutron diffraction and polarization analysis gives a direct way to sense the magnetic ordering of the samples.[5] To study these effects, a system with an in-plane anisotropy and significant AF coupling is needed. For this reason we chose a Co/Re superlattice grown on a $(11\bar{2}0)$ Al_2O_3 substrate. Both Co and Re have hcp crystal structures and their [0001] axis is in the film plane. For small Re thicknesses the superlattice is antiferromagnetically ordered. In addition, a small GMR has been observed previously[6] in (0001) Co/Re multilayers.

EXPERIMENT

The samples were grown on $(11\bar{2}0)$ Al_2O_3 substrates, in a dc magnetron sputtering system with a 3.0×10^{-7} Torr base pressure at West Virginia University.[7] Prior to growth, the substrates were acid-etched and annealed in vacuum at 575 °C. A nominally 50Å Re buffer layer was then deposited at a substrate temperature of 560 °C, followed by the growth of the 20 bilayer Co/Re superlattice at 158 °C. Two nominally identical Co(20Å)/Re(5Å) superlattices were grown for separate neutron diffraction and magnetization measurements. The magnetization measurements were preformed at room temperature using the dc magnetooptic

Kerr effect (MOKE). Transport measurements were carried out on samples cut to approximately 3×3 mm^2 squares at 10 K in a 5.5 Tesla superconducting magnet using a four contact technique. The samples were characterized by low angle and high angle x-ray diffraction using Cu K_α radiation from a rotating anode x-ray source.

RESULTS

Fits of an optical model[8] to the low angle x-ray specular reflectivity gave an actual layer thickness of Co(20Å)/Re(6Å) for the neutron sample and Co(17Å)/Re(8Å) for the magnetization sample. The thickness uncertainties were ±2 Å, the average interface roughness was ~3.4 Å for both samples. High angle x-ray diffraction confirmed the superlattice epitaxy, with the $[10\bar{1}0]$ direction of Co and Re along the direction of growth, and in the plane Co[0001] axis lying parallel to the *c*-axis of the substrate.[7]

MOKE measurement showed *M-H* loops with no remanent magnetization indicating AF alignment (Fig. 1). Notice however, that in the loop corresponding to $H \parallel c$ there is a sudden change in the slope at $\sim \pm 1.1$ kOe. Superlattices of the type [Co(20Å)/Re(15Å)] are uncoupled,[7] with the easy axis along the [0001] direction. On that basis, it is reasonable to surmise that in [Co(17Å)/Re(8Å)] the sublattice magnetization also points along the [0001] direction in zero field, and it spin flops at ±1.1 kOe. Similar results have been recently observed in Fe/Cr[9,10] and Co/Cr[11] multilayers.

Spin dependant neutron reflectivity measurements were carried out on the Co(20Å)/Re(6Å) sample at Argonne National Laboratory on the POSY1 system. Over a momentum range up to the Bragg reflection of the superlattice, the measurements revealed an AF peak position corresponding to twice the superlattice period. Plotted in Fig. 2(a) is the integrated AF peak intensity as a function of *H*. *H* was applied $\perp c$ and $\parallel c$, always in the plane of the sample. The integrated AF peak intensity is proportional to the square of the AF component of the sublattice magnetization (M_{AF}^2). M_{AF} has components parallel ($M_{AF\parallel}$) and perpendicular ($M_{AF\perp}$) to *H*. These two components were separated by analyzing the spin of the neutrons reflected at the AF peak.[12] The scattering associated with $M_{AF\parallel}$ does not change the spin orientation of the neutron, while $M_{AF\perp}$ causes the neutron to flip its spin. From these two components we plot the angle the AF moment makes with respect to H in Fig. 2(b). Notice that when $H \perp c$, the AF moments are always $\perp H$. When $H \parallel c$, the AF moment rotates from being $\parallel c$ to being $\perp c$. Above 2 kOe, M_{AF} is essentially $\perp H$ regardless of the direction of H.

A more detailed picture is obtained assuming that the total magnetic moment per Co atom is M_{tot} = 1.47 μ_B/Co, and a homogeneous model such that $M_{AF\perp}^2 + M_{AF\parallel}^2 + M_F^2 = M_{tot}^2$ when $H \parallel c$, and that $M_{AF\perp}^2 + M_F^2 = M_{tot}^2$ when $H \perp c$. M_F is the ferromagnetic component of the magnetization, which is not measured directly, but is derived from the values of $M_{AF\perp}$ and $M_{AF\parallel}$. Fig. 3 shows $M_{AF\parallel}$, $M_{AF\perp}$, and M_F as a function of H. For the $H \perp c$ case, a continuous transition from $M_{AF\perp}$ at $H = 0$ to M_F as H increases is observed, as expected in a regular antiferromagnet. For the $H \parallel c$ case, the SF transition between $M_{AF\parallel}$ and $M_{AF\perp}$ is gradual. Below 2 kOe, the spins rotate in a canted arrangement while the angle between them decreases, until at 2 kOe no AF component parallel to the field is observed. Above 2 kOe this angle decreases until the spins are parallel to each other at high field. One reason why a smooth rotation is observed, instead of a first order SF transition like in traditional antiferromagnets, is that a surface SF transition occurs and then propagates layer by layer toward the center of the sample as the field is increased.[10] Other possibilities are a small misalignment of the sample's *c*-axis[13] with H and the interface disorder causing a distribution of the antiferromagnetic coupling strengths throughout the sample.

The magnetotransport data shown in Fig. 4 agree well with the neutron diffraction measurements. In the $H \parallel c$, $H \perp I$ configuration, where I is the direction of the current, the resistivity increases as the field is lowered from saturation. This can be associated with the increase in the AF alignment observed via neutron diffraction, resulting in the GMR effect. As H is lowered from 2 kOe to zero, the magnetoresistance dips because of the AMR effect, caused by the rotation of M from being $\perp$ to being $\parallel$ to I. In the $H \perp c, H \perp I$ configuration, the spins start out ferromagnetically aligned and $\parallel I$ at saturation, and then gradually become antiferromagnetically aligned and $\perp I$ as H approaches zero. In this case there is a positive contribution to the magnetoresistance from both the GMR and AMR.

CONCLUSIONS

The magnetic anisotropy in Co/Re $(10\bar{1}0)$ multilayers causes the MOKE hysteresis loop to have a plateau near $H = 0$, and either subtracts from or adds to the magnetoresistance depending on the direction of the c-axis with respect to *I*. This behavior is a result of the gradual SF transition deduced from neutron diffraction measurements. To completely understand this, more detailed measurements are underway to determine the role of the surface magnetization and the sensitivity of the SF transition to the angle between the *c*-axis and *H*. Only then will it be possible to maximize the $d(\Delta\rho/\rho)/dH$ for this kind of anisotropic system

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FIGURE CAPTIONS

Fig. 1. MOKE hysteresis loops preformed at room temperature for the Co(17Å)/Re(8Å) sample with the applied field, H, parallel and perpendicular to the easy axis, denoted by c.

Fig. 2. Integrated antiferromagnetic peak intensity (a) and antiferromagnetic moment angle (b) with respect to H when $H \parallel c$ (•) and $H \perp c$ (○). Inset shows the direction of $\overrightarrow{H}$ with respect to the AF moment $\overrightarrow{M_1} - \overrightarrow{M_2}$.

Fig3. $M_{AF\perp}$ (•), $M_{AF\parallel}$ (○) and M_F (Δ) obtained from neutron diffraction with spin polarization analysis for the cases $H \perp c$ and $H \parallel c$. Lines are guides to the eye.

Fig. 4. Magnetoresistance measurements preformed at 10 K using a four contact technique for the Co(17Å)/Re(8Å) sample in the $H \parallel c$, $H \perp I$ and $H \perp c$, $H \perp I$ configurations. I denotes the direction of the current.

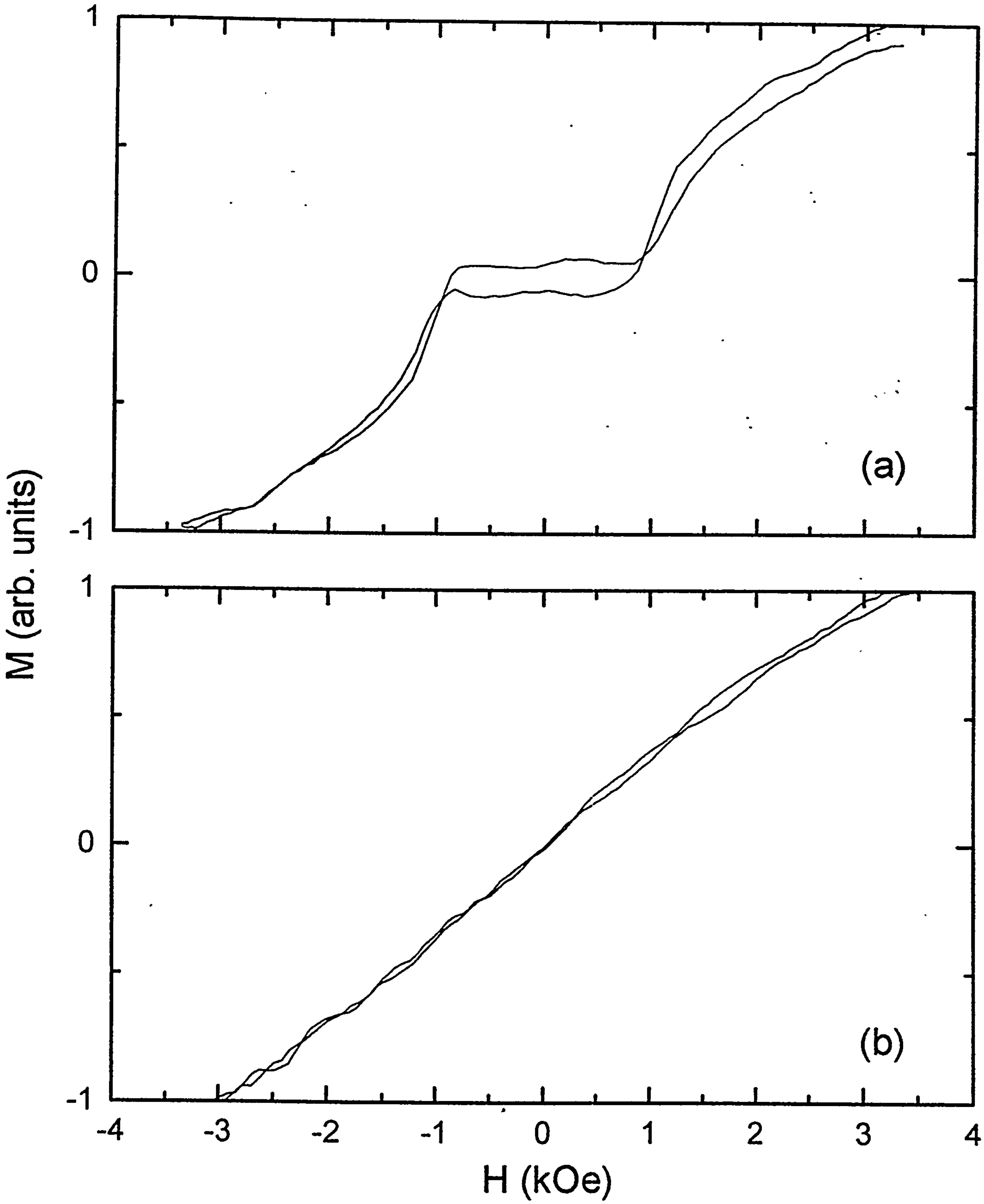

Fig. 1 T. Charlton et al.

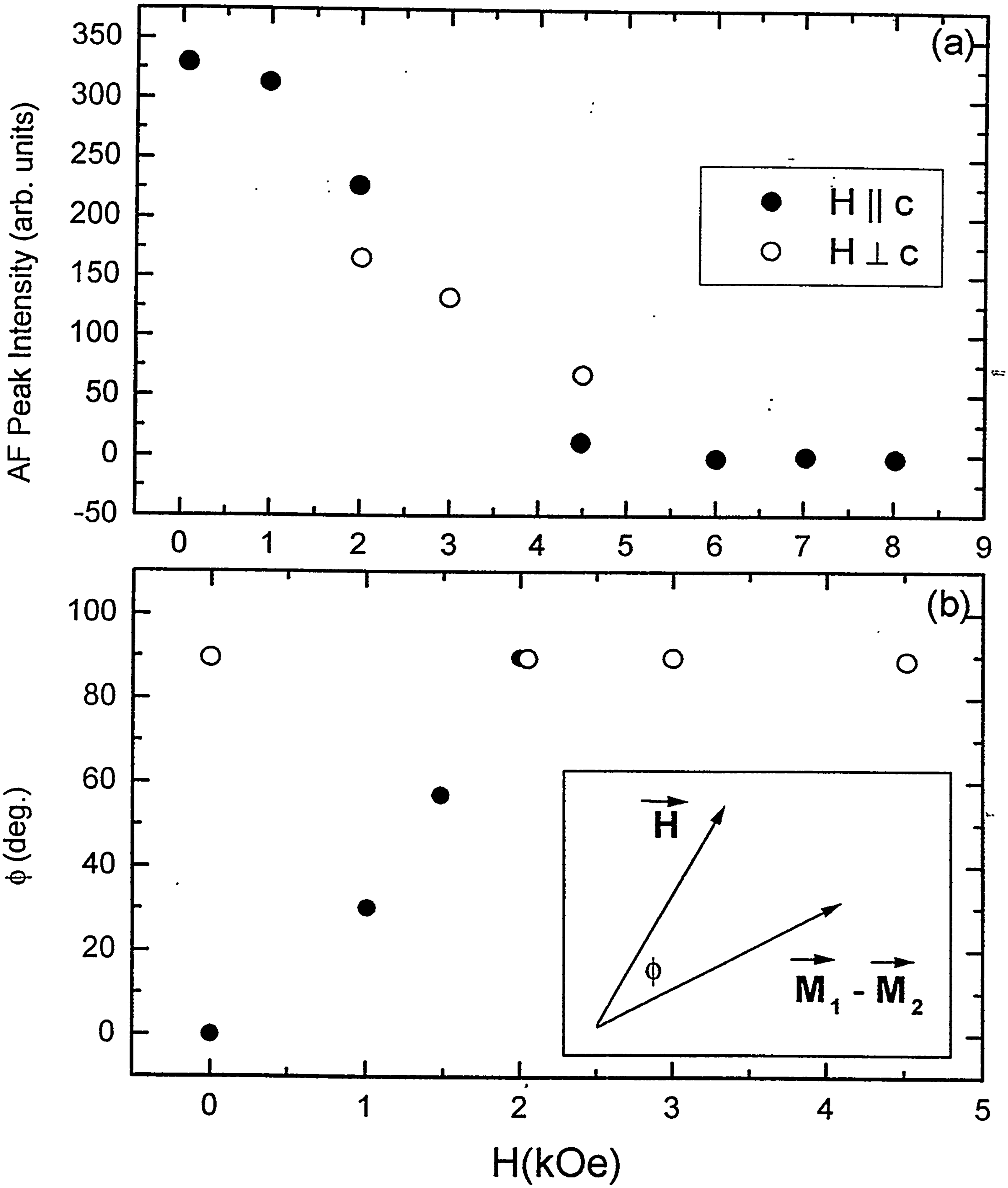

Fig. 2 T. Charlton et al.

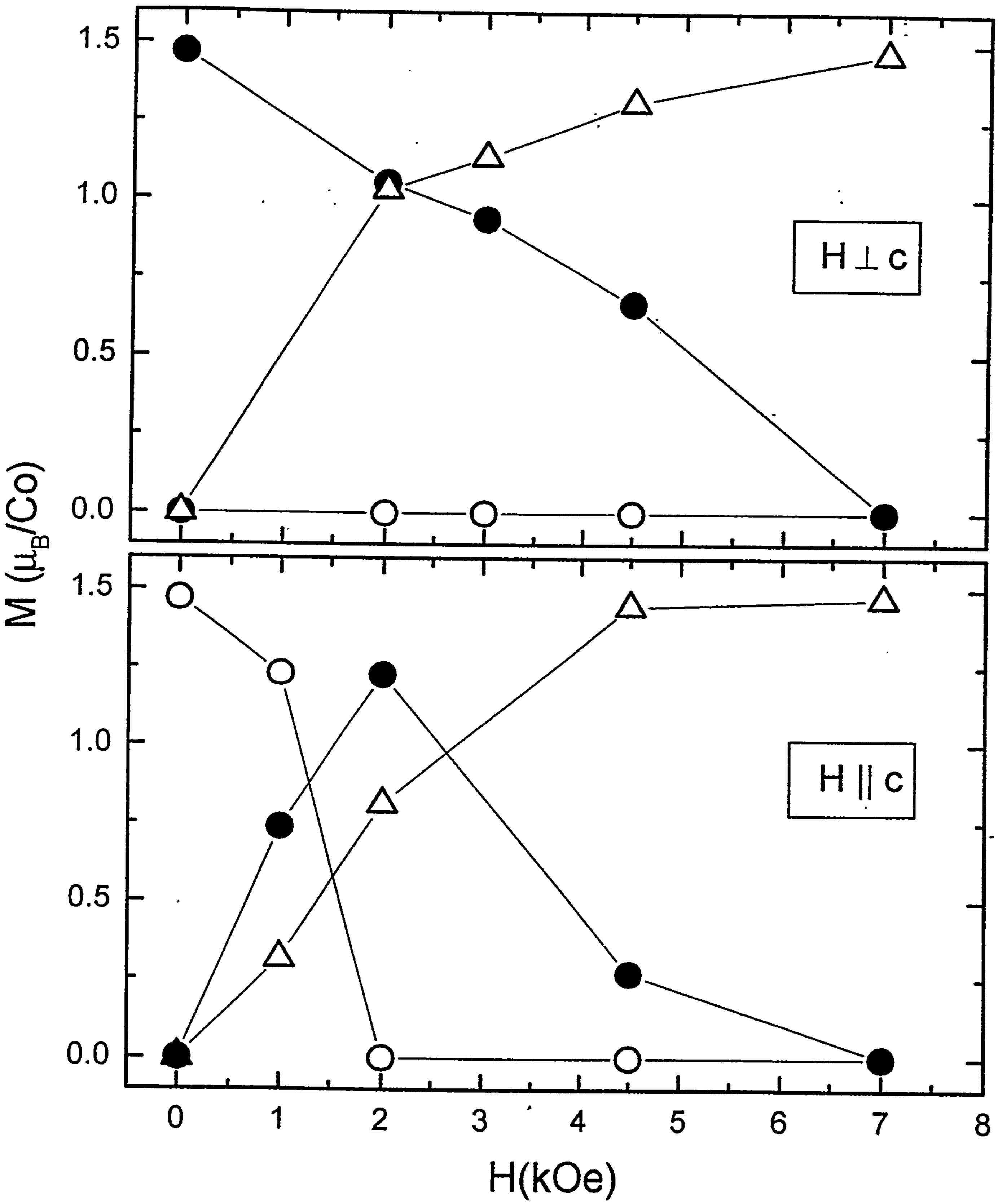

Fig. 3 T. Charlton et al.