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THE INFLUENCE OF PRODUCTION CONDITIONS ON THE MAGNETIC PROPERTIES OF SPUTTERED AND LASER DEPOSITED THIN FILMS

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A comparison between the magnetic properties of iron films deposited by dc sputtering and laser ablation is reported here. Results show that sputtered films generally exhibit isotropic behaviour when deposited on rigid substrates but develop in-plane magnetic anisotropy and greater coercivity when deposited on flexible substrates. Laser ablated films show similar characteristics except for a much weaker induced anisotropy when deposited on flexible substrates.

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1. Introduction

In this study, a novel rotating cryostat (RC) vacuum system originally designed to fabricate organic layers [1,2] has been developed to produce thin iron films. These were then compared with iron films deposited by laser ablation [3]. The magnetic anisotropy of the films was qualitatively studied from plots of magnetisation against applied field obtained using the magneto-optic Kerr effect (MOKE). The film coercivities are also discussed in terms of substrate used and the production techniques employed.

2. Experimental techniques

In this investigation the RC system was configured to use DC sputtering to produce magnetic films. The target material was deposited on to substrates mounted on the circumference of a drum. The drum, which is 13 cm in diameter and liquid nitrogen cooled, can be rapidly rotated up to 2000 rpm. This enables large film strips to be deposited (40 cm × 2 cm). In this investigation however the drum was kept stationary resulting in films with typical dimensions of 2 cm × 2 cm. An important feature of this work is that the Kapton™ substrates were mounted around the circumference of the drum and hence followed the curvature of its surface (see Fig. 1). All depositions were carried out in a background gas of 99.98% purity argon at a pressure of 10^{-2} mbar.

The source material consisted of an iron disk 25 mm in diameter, 0.8 mm thick and 99.8% pure. Silicon and glass substrates were also used in addition to Kapton™.

Iron films were also produced by laser ablation using a Lambda Physik LPX 315I excimer laser, see Fig. 2. The 308 nm wavelength pulsed laser beam was focussed on to a target rotating at 3Hz. The target material was an iron disc from the same source as that used for the sputtered films. The laser beam was focussed on to the target using a 30cm focal length lens to produce a spot size of 1 mm^2. Typical deposition parameters consisted of a laser pulse fluence of 4.5 J/cm^2, a pulse frequency in the range 10 to 40 Hz and a total number of pulses for one deposition of 40,000 to 50,000. Typical deposition rates of 0.03 Å per pulse were achieved which corresponded to a film

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thickness of 100 nm. All depositions were done at a base pressure of 10^{-7} mbar. Silicon, glass and Kapton^{TM} substrates were used for comparative analysis.

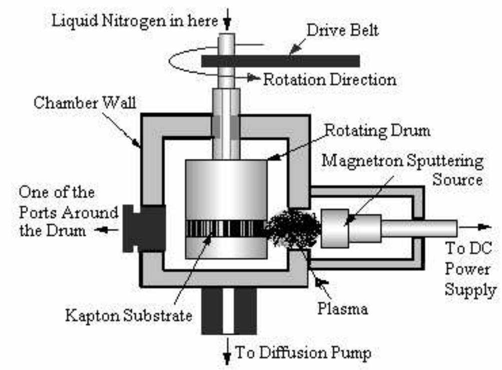

Fig. 1. A schematic diagram of the RC system.

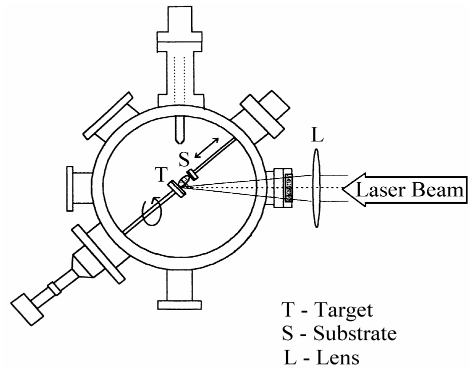

Fig. 2. The laser ablation system

Physical structure was investigated using a thin film x-ray diffractometer. Magnetic characterisation was achieved through the measurement of M-H loops using a magneto-optical Kerr effect plotter (MOKE) and also a commercial vibrating sample magnetometer (VSM) from Molspin Ltd. Unlike the VSM which measures the average bulk magnetisation, the MOKE set-up is essentially a surface technique and therefore only senses the magnetisation to a depth of 10 nm to 20 nm below the surface of the material. It utilises the transverse Kerr effect to measure changes in reflected light intensity proportional to the magnetisation. A magnetising field of ± 50 kA/m was used and the time taken to measure one hysteresis loop was approximately 300 seconds. The MOKE system has a mounting stage that allowed the sample to be rotated through 360 degrees with a precision of 1 degree. The sample could therefore be magnetised in different directions within the film plane enabling an investigation of in-plane anisotropy.

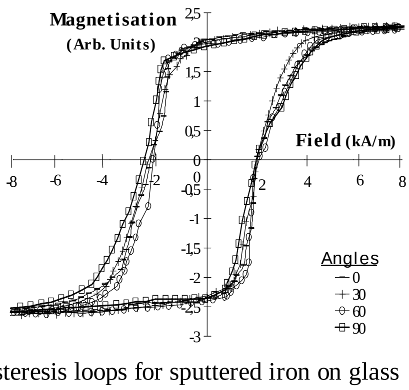

Fig. 3. Hysteresis loops for sputtered iron on glass at various angles within the film plane.

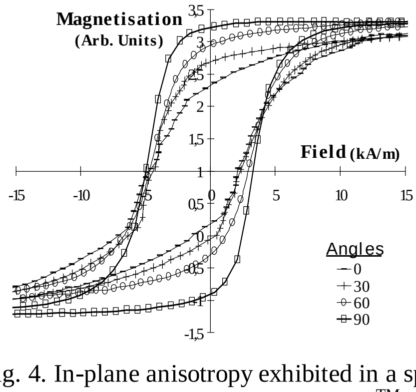

Fig. 4. In-plane anisotropy exhibited in a sputtered iron film deposited on Kapton^{TM}.

3. Results and discussion

Magnetic measurements were made on 100 nm thick iron films in the form of circular discs, approximately 1 cm in diameter, to minimise demagnetising effects. Hysteresis loops for various angles (90^0, 60^0, 30^0 and 0^0) relative to the horizontal direction (during deposition) were measured in the film plane for sputtered iron. All films deposited on silicon and glass from the dc magnetron-sputtering source showed isotropic magnetic behaviour within the film plane. An example of this is shown in Fig. 3 for an iron film on a glass substrate. Fig. 3 shows M-H loops measured in various directions with respect to the horizontal direction during deposition. Although there is a slight variation between each loop with angle, the film does not show any sign of in-plane anisotropy (see also Fig. 5).

The films deposited on flexible Kapton^{TM} substrates exhibited in-plane magnetic anisotropy (see Fig. 4) unlike those deposited on silicon and glass substrates. When the field is applied along the horizontal direction the loop exhibits small coercivity (3.40 kA/m) in comparison to the anisotropy field (18.5 kA/m). When the field is applied at 90^0 to the horizontal direction the loop is almost square with a coercivity of 4.15 kA/m.

Fig. 5 shows the remanence ratio for the isotropic and anisotropic films measured in Fig. 3 and Fig. 4 as a function of angle relative to the horizontal direction. In the case of the anisotropic films, the remanence ratio increases linearly from 0^0 (parallel) to 90^0 (perpendicular) indicating that the magnetic anisotropy results in an easy direction perpendicular to the horizontal direction. One possibility here is that films deposited on Kapton^{TM} are more likely to be subjected to stresses as a result of the flexible nature of the substrate. Stress induced effects are less likely in rigid substrates like silicon or glass unless a significant thermal mismatch between film and substrate occurs. In this work the glass and silicon substrates were mounted on the drum but not subjected to bending stress unlike Kapton^{TM}. Further investigation of stress sensitivity, using the VSM, was conducted by inducing a bending stress in the film sample (Kapton^{TM} substrate used) when taking measurements. A small change in the magnetisation was observed but initial stress bias due to the deposition conditions may have weakened this effect. Further studies are required.

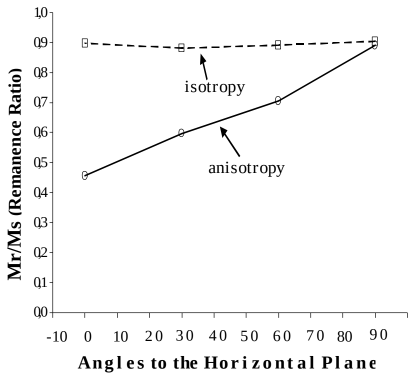

Fig. 5. The directional dependence of the remanence ratio for iron films deposited on glass and Kapton^{TM}.

In general smooth substrates result in magnetically softer films. Silicon and glass have very smooth surfaces compared to Kapton^{TM} and this is reflected in the coercivity values shown in Table 1. Transmission Electron Microscope (TEM) indicates that the films consist of randomly distributed crystallites with sizes 10 nm to 50 nm and higher number of large crystallites on the kapton substrates. Dionisio et al [4] reported bcc α-iron films having coercivity values of around 6 kA/m. The coercivities of the films reported here have similar values to those reported in the literature [4,5].

When the field is applied perpendicular to the film plane using a VSM, the magnetisation becomes more difficult to achieve. This indicates that the hardest axis of the material is perpendicular to the film plane as would be expected due to the demagnetising effect from the film shape. This behaviour was typical for all polycrystalline film specimens studied during the course of this investigation.

X-ray measurements were made with CuK_α radiation in the range of $10^0 < 2\theta < 100^0$, where θ is the Bragg's angle. Bragg reflections were obtained for $2\theta = 45^0, 65^0, 82.5^0$. These angles represent the (110), (200), and (211) planes of body centre cubic (bcc) iron (see Fig. 6).

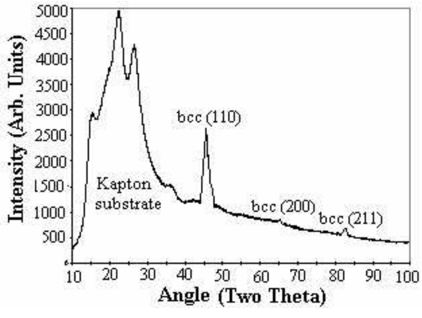

Fig. 6. The x-ray diffraction trace for a sputtered iron film on Kapton substrate.

The emphasis of this work has been placed on the investigation of dc sputtered films produced in the RC system. Measurements were also performed on similar laser-ablated films. All films deposited by laser ablation on glass or silicon substrates exhibited isotropic magnetic behaviour as stated in Table 1.

Table 1. A summary of magnetic characteristics measured for sputtered and laser deposited iron films.

Production technique	Substrate	Coercivity [kA/m]	In-plane Magnetic Anisotropy
sputtering	Kapton	3.40 to 4.15	Yes
	Kapton	3.95 to 4.85	Yes
	Glass	2.20	No
	Silicon	1.60	No
laser ablation	Kapton	2.65 to 2.95	Yes (slight)
	Glass	1.30	No
	Silicon	2.40	No

In the case where Kapton™ substrates were used a slight in-plane magnetic anisotropy was observed but this was small compared to films deposited by sputtering. Since the Kapton™ substrate is not under flexion during laser deposition the resultant film is less likely to be subjected to induced stresses. This is probably why the laser deposited films on Kapton™ are less anisotropic than RC produced films.

4. Conclusions

The effect of the preparation conditions on the magnetic properties of iron films produced from sputtering and laser ablation have been studied. The RC produced films deposited on flexible Kapton substrates were found to exhibit harder magnetic properties and uniaxial magnetic anisotropy compared to those on glass and silicon substrates. Laser ablated films exhibited coercivities of similar magnitude but were not as susceptible to in-plane magnetic anisotropy when used with Kapton. These findings indicate that a RC system with flexible substrates can be used in the future to produce sensing devices for stress detection.

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