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Factors affecting magnetic properties of evaporated iron films

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Abstract

The factors determining the magnetic properties of iron films evaporated from an evaporation source positioned around a novel rotating cryostat (RC) system have been discussed. Results show all films exhibit isotropic behaviour when the RC system is stationary irrespective of the types of substrates used. However, when the RC is rotated, the films produced on kapton™ generally show a slight in-plane anisotropy. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Thin films; Uniaxial anisotropy; Rotating cryostat

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1. Introduction

During the preparation process, magnetic anisotropy is frequently induced in ferromagnetic thin films. Roughly speaking, the main results reported up to now can be classified in three different categories following the direction of the anisotropy field with respect to film plane: thin films which exhibit an anisotropy axis perpendicular to the film plane, thin film possessing an in-plane uniaxial anisotropy, and thin films deposited at oblique incidence angle [1]. In this study, a novel rotating cryostat (RC) evaporation system has been developed for the first time to produce magnetic iron thin films on various substrates in order to investigate the factors affecting the properties of the evaporated iron thin films and therefore characterise the RC system. The films deposited on kapton™(polyimide) had an in-plane uniaxial magnetic anisotropy and have been investigated in detail.

2. Experimental details

The RC system uses a mobile physical deposition method to produce films. In contrast to static deposition systems, the target material can be deposited onto the circumference of a rapidly rotating (up to 2000 rpm) liquid nitrogen-cooled substrate (13 cm diameter) in an evacuated chamber ($\sim 10^{-6}$ mbar), see Fig. 1. The system has a large deposition area of 80 cm^2 (2 cm wide) compared to a few cm^2 in static techniques; up to ten target sources. Therefore, making use of multiple target sources can produce multilayers. Before each experiment started, the substrate was placed to the drum of the RC at room temperature, and then the RC was pumped down to a pressure of $\sim 10^{-6}$ mbar. After the inner drum and outer drum were filled with liquid nitrogen, the inner drum was rotated and brought up to a speed of 1300 rpm. Deposition was then started. The target material used in this study was 99.0% pure and 1–40 μm diameter powdered iron. Approximately, 100 nm thick films have been successfully produced using a resistive heated furnace positioned around the drum of the RC system. The RC system was run under two conditions: (1) stationary (2) rotated at 1300 rpm, and also the films produced on to rigid glass and silicon or plastic kapton substrates.

The magnetic investigations were carried out primarily using a magneto-optical kerr effect instrument (MOKE) but comparative measurements were also made using a commercial vibrating sample magnetometer (VSM). The MOKE system is illustrated in Fig. 2 and utilises the transverse kerr effect to measure loops proportional to the M–H loops. The system consists of a diode laser of wavelength 670 nm that is

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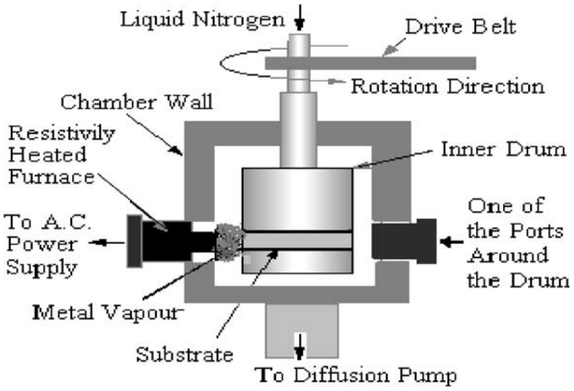

Fig. 1. A schematic diagram of RC evaporation system.

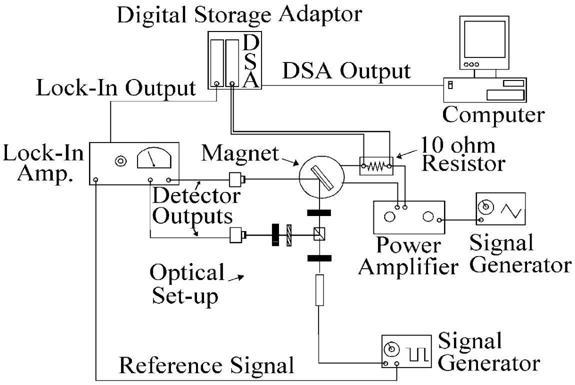

Fig. 2. The MOKE loop plotter.

modulated at 500 Hz. The laser beam is split into two separate beams one of which is reflected off the film surface and the other is used as a reference. The intensity of the two beams are equalised prior to taking measurements and fed into a lock-in amplifier. The output from the lock-in amplifier is digitised and sent to a computer together with a voltage signal, which is related to the applied magnetising field. The data can then be interpreted in the form of a magnetic hysteresis loop. The MOKE system has a sample mounting stage that allows the sample to be rotated about a horizontal axis with an accuracy of 1°. The sample can therefore be magnetised in the range of ±60 kA/m in different directions within the film plane enabling an investigation of in-plane anisotropy The MOKE set-up is essentially a surface technique that examines only the top 10–20 nm of the film surface. By using the VSM, which is a bulk measurement technique, it is possible to determine if the surface magnetisation is similar to the bulk of the film. The sample was vibrated at 75 Hz in fields up to 1 T.

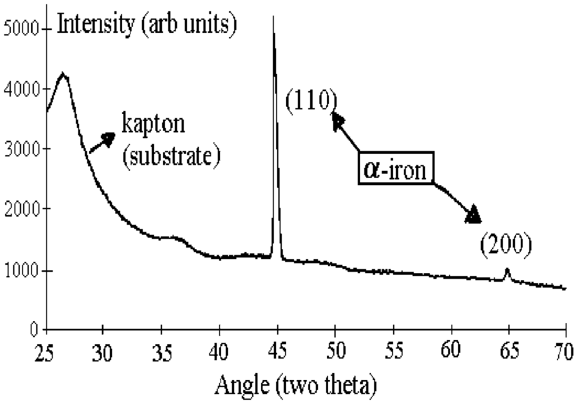

Fig. 3. X-ray diffactogram for an evaporated iron film.

3. Results and discussion

Magnetic measurements were made on evaporated iron thin films in the form of circular discs approximately 1 cm diameter to minimise demagnetising effects reflective and mirror-like in appearance.

The physical structure was investigated using the standard technique of X-ray diffraction. The X-ray measurements were made with CuK$_\alpha$ radiation in the range of $25° < 2\theta < 70°$, where θ is the Bragg's angle. Fig. 3 represents the intensity of diffracted X-rays plotted against twice the Bragg's angle. Bragg reflections of the samples were obtained for $2\theta = 45°$, 65°. These angles represent the (1 1 0) and (2 0 0) reflections of a BCC α-iron structure. The films have a polycrystalline structure consisting of small randomly distributed crystallites in the range of 5–50 nm with a higher number of large crystals. Transmission electron microscopy analysis also confirms this finding.

All films deposited on silicon and glass substrates from a resistive heated furnace positioned adjacent to the outer drum of the RC system showed isotropic magnetic behaviour within the film plane irrespective of which running conditions of RC (stationary or rotated at the speed of 1300 rpm) have been used. An example of this is shown in Fig. 4 for a film produced on glass substrate. This figure shows a number of M–H loops measured in various directions within the film plane. The total angular range of measurement was 90° with the 0° directions to the rotation direction of the drum of the RC normally rotated. Although there is slight variations between each loop with angle, the film does not show any sign of in-plane anisotropy. The loops indicate that the film is isotropic in the directions in which the measurement took place, see Fig. 1.

This is also seen for films deposited on kapton when the RC is run under the stationary condition. In the case where RC is rotated at the speed of 1300 rpm, it has been

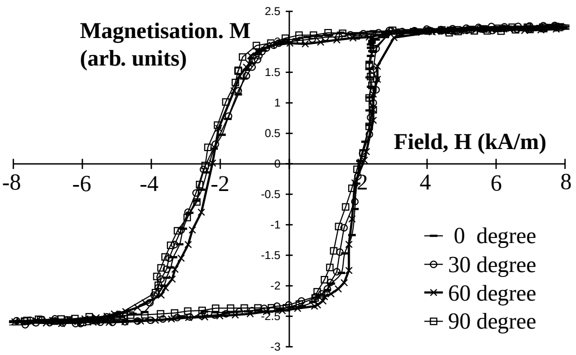

Fig. 4. An example of isotropic hysteresis loops of evaporated iron thin films on glass.

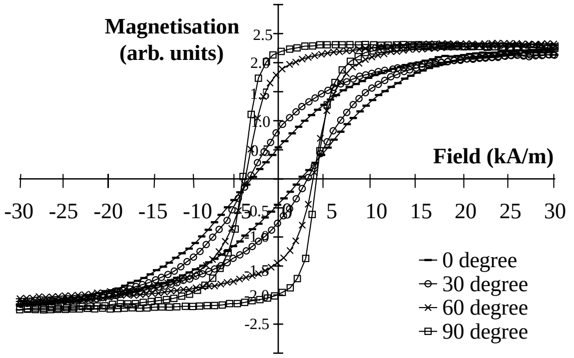

Fig. 5. In-plane anisotropy exhibited in a magnetic iron film evaporated on kapton.

found that the films exhibit an in-plane magnetic anisotropy as shown in Fig. 5. This figure shows the hyteresis loops obtained at various angles relative to the rotation direction of the kapton substrate placed on the inner drum of the RC. When the field is applied along the rotation direction, the loop exhibits a smaller coercivity, 2.85 kA/m, in comparison to anisotropy field, H_a, 18.8 kA/m. When the field is applied at 90° to the rotation direction, the loop is almost square with a coercivity field H_c, 4.25 kA/m. H_c is different from H_a which means that when the field is applied along the easy axis, the magnetisation does not rotate uniformly but there is a nucleation and propagation of domain walls.

Dionisio et al. [2] reported that BCC α-iron films has the coercivity values of around 6 kA/m. The coercivities of the evaporated films reported here have similar coercivity values to those found in the literature [2,3]. The implication here is that the rotation of the substrate during the deposition causes stress effects in the plane of film produced in flexible substrates such as kapton. Stress effects are less likely to appear in rigid substrates like silicon or glass unless a significant thermal mismatch between film and substrates occurs. A number of mechanisms for in-plane anisotropy have been previously proposed [4]. Stress effects have been convincingly put forward as a cause of in-plane anisotropy in magnetic film media and it seems the most likely explanation for the observations made in this investigation.

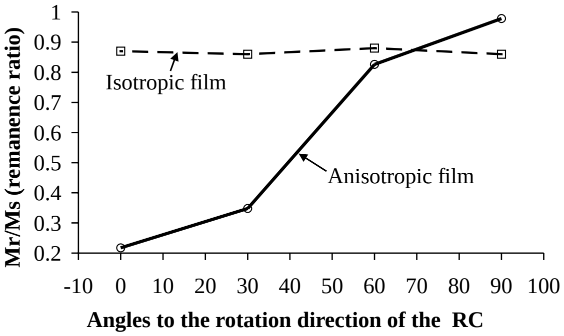

Fig. 6. The remanence ratio of magnetic isotropy (Fig. 4) and anisotropy (Fig. 5) of the films versus angles to the rotation direction.

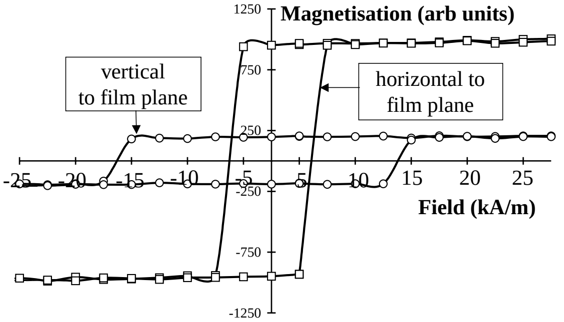

Fig. 7. Vertical anisotropy of evaporated film on kapton measured by using VSM.

Fig. 6 shows the remanence ratio for isotropic and anistropic films reported in Figs. 4 and 5 as a function of angle to the rotation direction. Remanence ratio for isotropic films is stable, whereas in anisotropic films, it increases monotonically from the parallel (0°) to perpendicular (90°) direction in horizontal plane of the film, indicating magnetic anisotropy with an easy direction perpendicular to the horizontal plane of the RC system.

Using VSM, when the field is applied vertical to the film plane, vertical anisotropy was found not to exist. This indicates that the hardest axis of the M–H loops is vertical direction to the film plane as shown in Fig. 7. As a result of demagnetising effect, the film shape anisotropy dictates that specimens must have planar easy axis. This shows the planar magnetisation loops, typical of all polycrystalline film specimens studied during this investigation.

Hysteresis loops obtained by VSM and MOKE are very similar inferring that the surface magnetisation measured by the MOKE system is representative of the whole film. Furthermore, the investigation of stress sensitivity was conducted using VSM. A film sample produced on kapton was bent and put in the VSM. Small changes in the measured hysteresis loops were observed. The reason for the small amount of changes is that the initial inherent stress in the sample could already be available and the sample is supposed to be stress-induced by the rotation of the drum.

4. Conclusions

For the first time, thin iron films were produced using a rotating cryostat evaporation technique. The factors affecting the in-plane anisotropy induced in the films were related to the frozen stress in the flexible substrates during the rotation of the RC drum at the speed of 1300 rpm. Further measurements indicate that the films evaporated on rigid substrates have isotropic magnetic behaviour irrespective of the running conditions. It is proposed to produce films with various compositions and targets like hence paving the way to fully investigate the magnetoelastic properties of magnetic materials with respect to their prospective use as sensing elements for stress detection devices.

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