LETTERS TO THE EDITOR

PHYSICS

Magnetic Anisotropy in Evaporated Thin Films containing Aluminium

SINGLE metal and alloy ferromagnetic films prepared by vapour deposition at normal[1] or oblique[2] incidence are known to possess a magnetic anisotropy in the film plane.

Published work has been confined chiefly to the main ferromagnetic elements and to alloys near the 80/20 nickel–iron composition. At this composition the observed anisotropy is thought to be due in part to directional ordering of the solute atoms as described by the Néel–Taniguchi theory[3]. To examine further the influence of directional ordering on the anisotropy of films, and particularly the behaviour of alloys containing small amounts of non-magnetic solute atoms, the system aluminium–iron was investigated. The induced anisotropies of bulk materials of the alloy range considered have been examined[4], and show evidence of the influence of directional ordering.

Evaporations were carried out at pressures near 10^{-4} mm mercury on to glass substrates held at 200° C. The source-substrate distance was 15 cm and films were deposited at a rate near 900 Å/min to thicknesses near 2000 Å. Because of the differing vapour pressures of aluminium and iron at temperatures at which iron begins to evaporate at a convenient rate, the film composition is increased in aluminium relative to that of the alloy charge. Using a single alloy charge it is thus difficult to obtain films containing controlled low quantities of aluminium. The alloy composition of the film may be more closely controlled by evaporating the two materials simultaneously from two different sources. This technique was used in the investigation reported here, the iron being held in a magnesia crucible and heated by high-frequency induction and the aluminium was placed on a loop of tungsten wire through which a high current could be passed. The geometry of the arrangement was such that for the film substrate position where the iron was deposited at normal incidence, the aluminium was incident at an angle near 30°.

Films prepared according to this arrangement had an induced easy axis direction in the film plane, orthogonal to the line joining the film to the aluminium source. The influence of the aluminium beam on the induced anisotropy was confirmed by depositing some films after moving the aluminium source by an angle of 90° about an axis normal to the substrate plane, when the easy axis direction was again observed to form orthogonal to the line joining the film to the aluminium source.

The magnitude of the aluminium beam induced anisotropy increased with aluminium content in the film, with a specimen containing an averaged chemical composition of 22·0 atomic per cent aluminium having an anisotropy energy density of $1{\cdot}5 \times 10^5$ ergs cm^{-3}. This compares with a maximum induced anisotropy of less than $1{\cdot}8 \times 10^4$ ergs cm^{-3} in bulk aluminium–iron, which occurs at a composition of near 22·0 atomic per cent aluminium[4].

Where the iron itself was deposited at oblique incidence the anisotropy so induced[2] could be removed in favour of an anisotropy with an easy axis direction defined by an oblique incidence aluminium beam. The anisotropy of permalloy films could be governed by the aluminium beam and the easy axis so formed could be made to lie orthogonal to the direction of an applied annealing field. In a typical example, a permalloy film containing near 3 atomic per cent aluminium had an equivalent anisotropy field, aligned by the aluminium beam, of 22·0 œ. with an easy axis direction cœrcive force of 0·9 œ.

The origin of the aluminium beam induced anisotropy was not confined to behaviour at the film-glass substrate interface as films of iron–aluminium, formed in such a way that the iron began depositing after the aluminium had finished, showed little trace of any replication anisotropy[5]. In addition, films the substrates of which were coated with iron to a thickness of a few hundred Å before depositing the alloy, still possessed an anisotropy governed by the aluminium beam.

The presence of an aluminium beam induced anisotropy may be associated with the fact that during film growth the aluminium is incident chiefly on those surfaces of the growing crystallites which face the aluminium source. Diffusion within the film is thought to be insufficient to produce a homogeneous alloy, so that the film consists of alternate regions, lying orthogonal to the line joining the film to the aluminium source, which are relatively high and low in aluminium content. This anisotropic distribution of aluminium within the film is then assumed to establish an effective aligned shape anisotropy in the magnetic structure of the film which causes the magnetic anisotropy. The anisotropic distribution of aluminium, a material having a high affinity for oxygen, may have the effect of aligning the oxygen atoms present in films deposited at pressures used in the present investigation[6]. The aligned oxygen could then contribute to the induced anisotropy according to the models considered by Heidenreich *et al.*[7] and Prosen *et al.*[8].

The ability to govern easy axis direction in evaporated films using an oblique incidence aluminium beam suggests that the easy axis dispersion found in large-area films due to the geometry of the deposition[2] could be reduced by the application of suitably orientated aluminium beams incident over the film area during its deposition. In this manner it should be possible to produce a film the easy axis direction of which remained sensibly constant over a large area.

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An Optical-radiation Quenching Effect following a Current Pulse superimposed on a Background Arc Plasma in a Low-pressure Mercury Vapour Valve

AN experimental single-anode mercury pool valve with a saturated-vapour pressure of about 5 μm mercury was operated in a single-phase single-way rectifier circuit with resistance load to pass at a frequency of 50 c/s half-sinusoidal current pulses with a crest value of 20 amp. and superimposed on each of these basic pulses was a further pulse of half-sinusoidal wave-shape with a