PHYSICS

Magnetic Anisotropy in Single Crystal Films of β-Cobalt

PREVIOUSLY we have reported[1] that single crystal films of face-centred cubic β-cobalt (normally stable at temperatures in excess of 425° C) may be prepared at room temperature by electrodeposition on to copper single crystal substrates. These films may be grown in parallel orientation with the substrate to thicknesses of approximately 1μ using a bath consisting of 300 g/l. $CoSO_4.7H_2O$, 6 g/l. boric acid and 3 g/l. sodium chloride with the pH set at 2·3 and the current density ~ 12 m.amp/cm². The magnetic anisotropy contents of these films have now been determined using a torque magnetometer having a sensitivity of $(2{\cdot}56 \pm 0{\cdot}02) \times 10^{-2}$ dyne cm/deg. rotation of the torsion head, the actual torque being measured by a null method. With the suspension system in position between the poles of the 4-in. Newport electromagnet, the maximum field H was ~ 8 kœ applied in the plane of the film.

The torque, L, of the thin β-cobalt film on the copper disk may be expressed in terms of the magnetocrystalline anisotropy constants K_1 and K_2 by the equations:

$$-L_{\{110\}} = \frac{K_1}{8}(2\sin 2\beta + 3\sin 4\beta) + \frac{K_2}{64}(\sin 2\beta + 4\sin 4\beta - 3\sin 6\beta) + K_u \sin 2\theta$$

for a f.c.c. Co {110} film; and

$$-L_{\{001\}} = \frac{K_1}{2}(\sin 4\beta) + K_u \sin 2\theta$$

for a f.c.c. {001} film.

Here K_u is the uniaxial anisotropy constant representing induced anisotropy, θ the angle between the magnetization vector, M, and the 'easy' direction of the component of induced anisotropy and β the angle between M and the < 100 > direction. As it is not possible to align a particular crystal direction accurately with respect to the initial field direction, the angle β may be expressed as $(T + \delta)$, where T is the measured angle (for example, on the magnet turntable) and δ is a constant phase angle between T and β due to this misalignment. Similarly θ may be expressed as $(T + \delta')$.

Both expressions, therefore, may be expressed as a Fourier series $-L = A_2 \sin 2T + A_4 \sin 4T + A_6 \sin 6T + B_2 \cos 2T + B_4 \cos 4T + B_6 \cos 6T$.

The experimental curves were analysed using the Pegasus computer of Northampton College of Advanced Technology with a 36 ordinate programme, and the coefficients K_1, K_2, K_u, δ and δ′ extracted from the appropriate coefficients. The following results were obtained:

(1) *Magnetocrystalline anisotropy constants* K_1 *and* K_2. The coefficients of sin $4T$ and cos $4T$ from the analysed torque curves for the cobalt films with a {110} plane parallel to the surface of the disk gave $(K_1 + K_2/6) = -(8{\cdot}1 \pm 0{\cdot}1) \times 10^5$ ergs/c.c. (for a field of 8 kœ), which is comparable (6 per cent smaller) with results obtained from precipitated particles[2]. For the films with a {001} plane parallel to the disk surface K_1 was obtained again from the coefficients of cos $4T$ and sin $4T$. The mean value was found to be $K_1 = -(6{\cdot}3 \pm 0{\cdot}1) \times 10^5$ ergs/c.c. and hence $K_2 = -(10{\cdot}8 \pm 1{\cdot}2) \times 10^5$ ergs/c.c. Extrapolation of K_1 and $(K_1 + K_2/6)$ to $H = \infty$ gives a variation ~ 2 per cent in the foregoing results. These results thus extend the work of Sucksmith and Thompson[3], who measured K_1 and K_2 for β-cobalt from a bulk sample over the temperature-range 500°–1,000° C and showed that in this range K_1 is a function of temperature given by $K_1 = K_0 e^{-aT^2}$, where K_0 and a are constants. Fig. 1 shows the results of Sucksmith and Thompson together with our results. It can be seen that the simple temperature dependence does not appear to hold if the results are extended to room temperature. A better fit appears to be $K_1 = K'/(e^{aT^2} + A)$, where K', a and A are empirical constants (full line in Fig. 1).

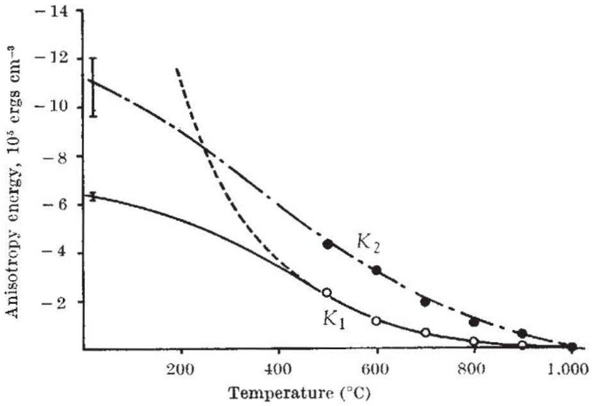

Fig. 1. Variation of K_1 and K_2 with temperature for β-cobalt. ○ and ●, data from Sucksmith and Thompson (ref. 3); ⌶, room temperature values; – – –, $K_1 = K_0 \exp -aT^2$

(2) *The uniaxial anisotropy constant* K_u. The results indicated that K_u decreased with increasing thickness, becoming less than 2 per cent of K_1 for films thicker than 1000 Å. In agreement with previous work[4], however, no systematic variation of K_u with thickness was found in these unannealed films. Typical results for K_u in ergs/c.c. are: {110} β-cobalt surface, $3{\cdot}3 \times 10^5$ for 100 Å thick film; {001} β-cobalt surface $2{\cdot}2 \times 10^5$ for a 100 Å thick film and 0·6 for a 850 Å thick film. It would, therefore, appear that K_u arises from an inter-surface phenomenon at the copper/cobalt interface and one of the most important processes to be considered is oxygen ordering[5]. If it were an inter-surface phenomenon one would indeed expect the effect to decrease as the thickness increased.

The angle, ψ, between a $<1\bar{1}0>$ lattice row and the 'easy' direction of the uniaxial component was found to be approximately 0° in the case of films prepared on a Cu {110} surface, that is, the 'easy' direction of K_u was the $<1\bar{1}0>$ direction. For films deposited on to a Cu {001} surface, however, such a definite relation was not observed, although in general ψ was less than 15°.

J. GODDARD
J. G. WRIGHT

Department of Physics,
Sir John Cass College,
London, E.C.3.

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GEOLOGY

Delayed Isostatic Response and High Sea-levels

RISE of previously loaded areas as a result of delayed isostatic response is well established in Fennoscandia[4], the Great Lakes[3] and Lake Bonneville[1]. Irrespective of minor short-period fluctuations in level it is generally accepted that sea-level rose at the rapid average rate of about 8 m/1,000 years, 17000–7,000 years ago, and that it has since dropped by about 4 m (ref. 2).

It is proposed here that the 4-m drop in sea-level is the delayed isostatic response to the loading of the sea bed caused by the previous rapid rise. Land areas are thought to have risen and most coasts to have been near the hinge lines between the sinking sea bed and the rising land. Observations are confined to the coasts, and, if delayed