APPENDIX B

DIRECT HEATING OF NiFe TAPES

Theoretical calculation

The equation governing emission of thermal radiation by a body with surface area A and emissivity ε at a temperature T is

$$P/A = \sigma \varepsilon T^4 \tag{B1}$$

where σ is Stefan's constant, equal to $5.67 \times 10^{-8} \text{Wm}^{-2} \text{K}^{-1}$.

When a body is in thermal equilibrium with its surroundings, for example a NiFe at room temperature, it absorbs energy from its surroundings at the same rate that it emits the energy. This power absorbed, P_0 is given by

$$P_0 = \sigma \varepsilon A T_0^4 \tag{B2}$$

where T_0 is the ambient temperature.

If we then add extra energy to the tape by dissipative current flow, and assume that the power being absorbed from the surroundings is unchanged, the total power which the tape must emit is $P_0 + I^2 R$, where I and R represent the current and resistance respectively. The temperature, T, of the tape is now given by

$$I^2 R + P_0 = \sigma \varepsilon A T^4 \tag{B3}$$

Substituting this in equation B2 gives

$$I^2 R = \sigma \varepsilon A (T^4 - T_0^4) \tag{B4}$$

hence

$$T^{4} - T_{0}^{4} = (\rho/2w^{2}\sigma\varepsilon t)I^{2}$$
(B5)

where ρ is the resistivity of the tape, w the width and t the thickness, and the contributions to the area *A*, from the sides of the tape are neglected.

Comparison with measured values

The difficulty which arises when trying to measure the temperature is that it is not uniform across the tape. For a 55 mm long tape, the temperature is highest in the centre and there is a significant gradient, so that within 1 cm of the contact block, the temperature measured by the infra-red pyrometer may be 100°C lower than in the centre. This indicates that there is significant conduction of heat which affects at least the edges of the tape. The temperature recorded is that measured in the centre of the tape.

Figure B1 shows how data measured of two typical tapes compares with the theoretical prediction of equation B5. There is a very good fit, but it is noticeable that the gradients for the two tapes are slightly different. The most likely cause of this is slight differences in the thicknesses of the samples.



Figure B1 Comparison of theoretical prediction of Stefan's Law (line) with the actual temperatures measured on two tapes indicated by the symbols.

The data is replotted in figure B2 as temperature vs current to provide a calibration curve in cases where the temperature cannot be measured directly. This figure shows that there appears to be a slight systematic discrepancy between the measurements and predicted curve at temperatures below around 300°C.

There are a number of factors which could change the temperature during a deposition process, one such factor being a change in the resistance of the tape. One instance in which this is likely to occur is when a thick metal film with a low resistivity is deposited onto a thin substrate. For example, if 1 μ m of Ag (r=16 n Ω m) is deposited onto a 34 μ m Ni tape (r=590 n Ω m), the resistance of the film is approximately equal to that of the tape. Thus the total resistance of the substrate/film couple falls by 50% over the course of the deposition run. For a constant heating current, the temperature is related to the fourth root of the resistance hence for a heating current of 6 A, the temperature is predicted to fall from 500°C to 380°C through this effect.

The resistance of a tape may also be reduced if the tape is oxidised – this is explored in detail in Chapter 5. One other factor which may be relevant in some situations is the fact that the resistivity of the tape may actually change. For example when annealing a cold worked tape to induce primary recrystallisation, the process of recovery will cause the resistivity to decrease.

Another factor which can drastically change the substrate temperature is the emmisivity of the surface. For deposition of a film, only one surface of the tape is affected, but still the effect is significant as shown by the light line in figure B3, where the temperature is seen to change from 720°C to 500°C is a film an emmisivity of 0.7 is deposited on one side of a Ni tape which is carrying 10 A. The change is even more significant if both sides of the tape are affected, as occurs during an oxidation process for example. The dark line shows that a change of emmisivity to 0.7 causes the temperature to fall to 400°C.



Figure B3 The effect on temperature of a change in emmisivity of either one or both sides of a tape carrying a 10 A resistive heating current

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