Measurement of heat flow by means of the Nernst effect

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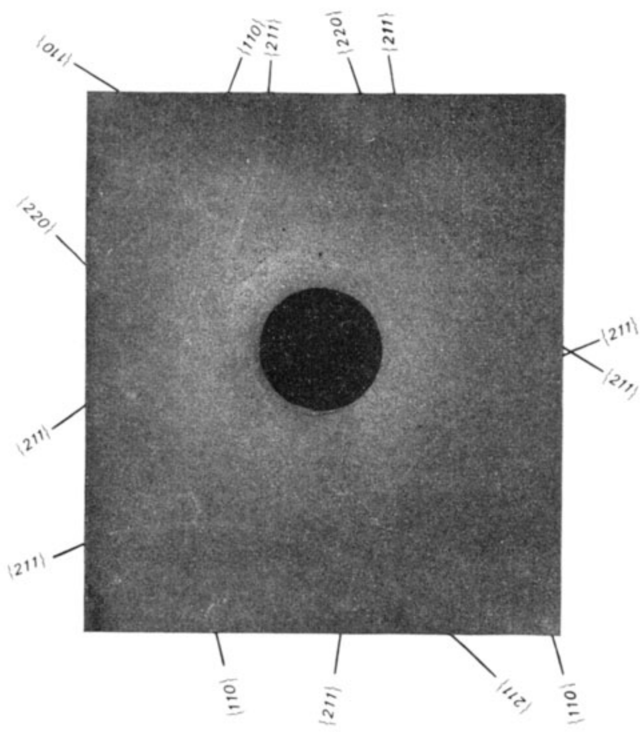

Figure 2 Kossel pattern from a grain of mild steel

We use the back reflection Kossel technique at present to study orientation relationships of grains of mild steel. This necessitates making a large number of Kossel prints of one specimen, but an inaccuracy of a few degrees in each single orientation determination can be tolerated. As an example of the method one print is presented (figure 2). The exposure time was 20 s and the film spacing 52 mm, but this can be varied from 0 to 80 mm continuously. The spot size for normal microprobe work is better than 1 μm. When lowering the specimen for Kossel work this spot size may grow to about 2 μm which can be checked by measuring the diameter of the contamination mark on the specimen. In figure 2 the Kossel lines have been indexed according to the lattice planes they correspond with. This information is sufficient to decide upon the orientation of the observed grain relative to a fixed coordinate system. Presently we hope to publish the results of our investigation on orientation relationships of grains in mild steel in correlation with x ray diffraction measurements on the same material.

Our experiences prove this method of back reflection Kossel patterns to be well suited for this kind of orientation study.

References

Openshaw I R and Swindells N 1966 *Proc. 4th Congr. X-ray Optics and Microanalysis* (Paris: Hermann) p 555

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Abstract A comparison is made between the Seebeck and Nernst effects in semiconductors for the measurement of heat flow. The latter effect would seem to be superior since the Nernst EMF is proportional to temperature gradient rather than temperature difference. This means that devices for measuring the flow of heat based on the Nernst effect may have a very small thermal resistance. A device, incorporating InSb–NiSb eutectic as the active material, has been tested successfully.

1 Introduction

It is our present purpose to consider the development of an instrument that plays the same role in thermal measurements that the ammeter plays in electrical measurements. In other words, we deal with the problem of measuring the flow of heat without offering appreciable resistance to that flow.

In principle, rate of heat flow may be determined by incorporating some resistance in the thermal path and by observing the temperature difference developed across that resistance. We consider how this may best be done employing either the Seebeck effect or the Nernst effect and we show that the use of the latter has certain inherent advantages.

2 Comparison of the Seebeck and Nernst effects

It would seem that a good way of utilising the Seebeck effect in measuring heat flow is to adopt the arrangement shown in figure 1(*a*) (Stafford Hatfield and Wilkins 1950). The thermal resistance consists of a block of semiconductor. The temperature difference across this block gives rise to a thermoelectric EMF which is then an indication of the rate of heat flow. Advantage is taken of the large absolute Seebeck coefficient of a semiconductor compared with that of a metal or metallic alloy. Thus, whereas the differential Seebeck coefficient of a Chromel–Alumel couple is about 40 μV K^{-1}, that for a semiconductor–metal couple may be 1 mV K^{-1}. Even higher Seebeck coefficients could, in fact, be achieved but the semiconductor would then have such a high electrical resistivity that measurement of the thermoelectric EMF would prove difficult. For a given heat flow, the output EMF is proportional

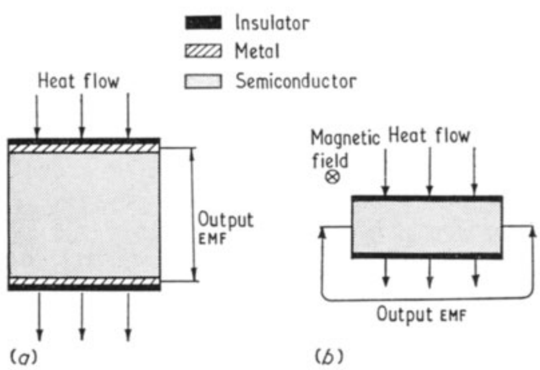

Figure 1 Devices for measuring heat flow based on (*a*) Seebeck effect and (*b*) Nernst effect

to the thermal resistance. Thus, if it is desirable that the thermal resistance be minimized, a low sensitivity (ratio of output EMF to rate of heat flow) must be tolerated.

An alternative arrangement that makes use of the Nernst (transverse thermomagnetic) effect is shown in figure 1(*b*). Again the material would be a semiconductor (but a different material from that shown in figure 1(*a*)). The advantage of using the Nernst effect is that the output EMF is proportional not to the *temperature difference* across the semiconductor but to the *temperature gradient*. For a given rate of heat flow the temperature gradient is independent of the thickness, so it would seem that the thermal resistance could be reduced to negligible proportions without the output being affected. This is not quite true in practice since there will always be some thermal resistance at the contacts between the device and the rest of the thermal circuit. Nevertheless, our observations indicate that the Nernst effect is superior to the Seebeck effect for the determination of heat flow with the introduction of the minimum thermal resistance.

3 Selection of materials

The selection of materials for the *thermoelectric* device is simple. One merely chooses the semiconductor with the highest Seebeck coefficient that is compatible with a reasonable electrical resistivity. The ratio of the sensitivity σ to the thermal resistance R is given by

$$\left(\frac{\sigma}{R}\right)_{\text{Seebeck}}=\frac{V}{WR}=\alpha \qquad (1)$$

where V is the output EMF, W is the rate of heat flow and α is the Seebeck coefficient which we assume to be about 1 mV K^{-1}. The thermal resistance at the contacts can always be made negligible, at least in principle, by appropriate choice of dimensions of the semiconductor.

For the *Nernst* device, we expect the major part of the thermal resistance to be due to the contacts and, in fact, we shall neglect the contribution from the semiconductor. The temperature gradient in the semiconductor is equal to $W/\kappa A$, where κ is the thermal conductivity and A the cross-sectional area. Thus, if l is the length of the detecting element between the output leads, the Nernst EMF is equal to $lBQW/\kappa A$ where B is the magnetic field and Q the Nernst coefficient. In this case, then, the ratio of sensitivity to thermal resistance is

$$\left(\frac{\sigma}{R}\right)_{\text{Nernst}}=\frac{V}{WR_c}=\frac{lBQ}{\kappa AR_c} \qquad (2)$$

where R_c is the thermal contact resistance.

If it is assumed that the contact resistance is independent of the choice of semiconductor, we see that the material for the Nernst element should have the highest value of the ratio Q/κ. It is likely that the device would have to be operated at or near room temperature in the rather modest field provided by a permanent magnet. Under these conditions by far the most suitable material is the InSb–NiSb eutectic (Wagini and Weiss 1965). Materials such as Bi and Cd_3As_2–NiAs that have been shown to be suitable for other devices (Washwell *et al.* 1970, Goldsmid and Sydney 1971) are definitely inferior for this particular application.

We have examined a sample of InSb–NiSb in a field of 0·5 T and found it to have a Nernst coefficient of $7{\cdot}67\times10^{-4}$ V K^{-1} T^{-1} and a thermal conductivity of 14·9 W K^{-1} m^{-1}. Typically the length of the element might be 10 mm. The thermal resistance at each contact might be no more than 5 K W^{-1} for an area of 10 mm^2; bearing in mind that there are two interfaces, AR_c should not exceed 10^{-4} K m^2 W^{-1}. Thence, we expect $(\sigma/R)_{\text{Nernst}}$ to be not less than about 2·6 mV K^{-1}. This seems to be definitely superior to what can be achieved using the Seebeck effect.

4 Experimental observations

In order to test the validity of the above predictions we have made a heat-flow measuring device based on the Nernst effect in InSb–NiSb.† The sample, of 35 mm^2 cross-sectional area in the heat flow direction, was permanently bonded to anodized aluminium heat-exchange plates with Araldite epoxy resin. The outer surfaces of the aluminium plates were coated with indium. The overall thermal contact resistance of the device was found to be 1·9 K W^{-1} which is appreciably less than the value of 2·9 K W^{-1} that corresponds to the resistance of 5 K W^{-1} for a 10 mm^2 area postulated in §3. Actually, in the device that was made the thermal resistance of the sample was not negligible since its thickness was relatively large, i.e. about 1·6 mm. Thus, in a field of 0·5 T the ratio σ/R turned out to be only 1·5 mV K^{-1}. However, for a sample an order of magnitude thinner the ratio σ/R would have risen to about 4 mV K^{-1}. A still higher value of this ratio would result from any improvement in techniques for making thermal contact whilst maintaining electrical insulation between the surfaces.

References

Goldsmid H J and Sydney K R 1971 *J. Phys.* D: *Appl. Phys.* **4** 869–75

Stafford Hatfield H and Wilkins F J 1950 *J. Sci. Instrum.* **27** 1–3

Wagini H and Weiss H 1965 *Solid St. Electron.* **8** 241–54

Washwell E R, Hawkins S R and Cuff K F 1970 *Appl. Phys. Lett.* **17** 164–6

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An automatic Zimm–Crothers type viscometer

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Abstract An automatic Zimm–Crothers type viscometer is described which permits very accurate measurements at various values of the shear stress, using only one rotor.

1 Introduction

For investigation of the viscosity of solution of DNA of high molecular weight it is important to measure at extraordinary low shear stress, as these solutions exhibit large deviations from Newtonian behaviour (e.g. Bloomfield 1968). To meet these conditions a rotating cylinder viscometer was designed by Zimm and Crothers (1962) which proved to be accurate and versatile. In the instrument the rotating cylinder (the rotor) just floats in the solution contained in a larger cylinder; this ensures that both cylinders remain coaxial. The rotation

† Sample kindly supplied by Dr H Weiss of Siemens AG.