

anomalous region. Since most of the mirrors we coat are curved, we usually place a standard size flat sample in the vacuum plant with the mirror and use this to measure the spectral reflectance of the coating.

In order to check the accuracy of the device, measurements were carried out on freshly evaporated silver and aluminium. Results are shown in figure 3. The solid lines are our measurements and the dotted lines are published values derived theoretically (Kingslake 1965). The results for silver agree to better than $\pm 0.25\%$, and the values for aluminium come close to the theoretical optimum known to be achieved only with very high rate deposition in UHV conditions. Our coating was carried out at 4.10^{-6} Torr at a rate of 3 nm s^{-1} .

3. Conclusion

We have described a purpose built accessory for a standard commercial instrument which makes it possible to perform accurate and meaningful reflectance measurements in the wavelength range 185–950 nm. The device is seen to have several significant advantages over commercially available reflectance measuring systems.

Acknowledgments

We would like to record our appreciation of the skilful efforts of the late David Mayhew in constructing this device from the minimum of graphical and verbal instructions.

The paper is published by kind permission of the Director of the Royal Greenwich Observatory.

References

- Bennett and Koehler 1960
J. Opt. Soc. Am. **50** 1
- Strong J 1938 *Procedures in Experimental Physics* (Englewood Cliffs, New Jersey: Prentice-Hall) p 376
- Kingslake R (ed.) 1965 *App. Optics and Optical Engineering* Vol III (New York: Academic Press)

Hall effect measurement techniques in metallic thin films

A Palevski and A Fried

Department of Physics and Astronomy, Tel Aviv University,
69978 Tel Aviv, Israel

Received 12 May 1983, in final form 20 June 1983

Abstract. A modification of Hall effect measurement for thin films by the so-called three-terminal network is described. It is based on a special geometrical arrangement of Hall electrodes using photolithography and lift-off techniques.

1. Introduction

The three-terminal method, where a single Hall electrode faces two electrodes connected by a shunt with a variable tap, has been known for a long time and is successfully used for measuring Hall effect in highly resistive materials, such as semiconductors (Putley 1960). However, for metallic samples (especially dirty ones), where the ohmic voltage is large compared with the Hall voltage, a large value of the shunt resistance with high stability and resolution is required. The use of the high resistive shunt increases the time constant of the circuit, and also might increase the noise of the measuring instrument such as nanovoltmeter.

In the present paper we present a new geometrical arrangement of terminals which can be realised using photolithography and which allows us to solve the misalignment problem by using a relatively low resistive shunt.

2. Description of the method

In order to use a small shunt resistor, we have to achieve a situation where the smallest possible ohmic voltage appears across the two terminals from the same side. That means that the distance between them should be as small as possible and that the single terminal which faces them should also be roughly symmetrically located between them.

The basic idea which allows us to minimise the voltage between terminals of the same side is the following: we connect these terminals at the same point; the width of the contact point is the same as the width of the opposite terminal; misalignment between centres of contact point and single terminal is small compared to the width of the terminal (figure 1). Considering such a geometrical arrangement, one can notice that the voltage between A and B, V_{AB} , is smaller than the ohmic voltage between the dashed lines. V_{AB} is not zero, because there is always a finite current flowing between A' and B' as shown by Durand (1953). By varying the angle between terminals one can adjust V_{AB} to be of the order of the misalignment voltage. A relatively low resistive shunt will now be sufficient to balance the potentials between the tap of the shunt and point C.

3. Experimental realisation

A small electrode width as well as a small misalignment can be achieved using photolithography. First the mask is drawn very accurately and then reduced by a factor of 5 by photography. Then five pictures of the mask are photographed on a transparency and the final mask is obtained as seen in figure 2(a) (five samples are produced by one photolithographic procedure).

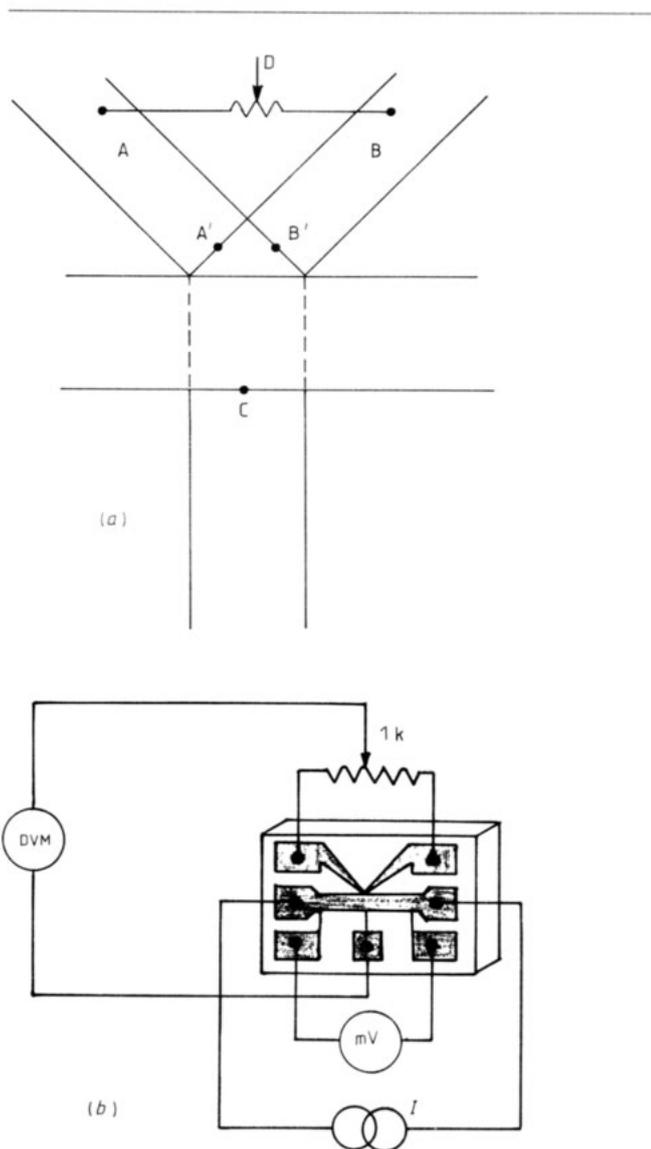


Figure 1. (a), Schematic geometrical arrangement of the electrodes; (b), schematic drawing of the electrical circuit.

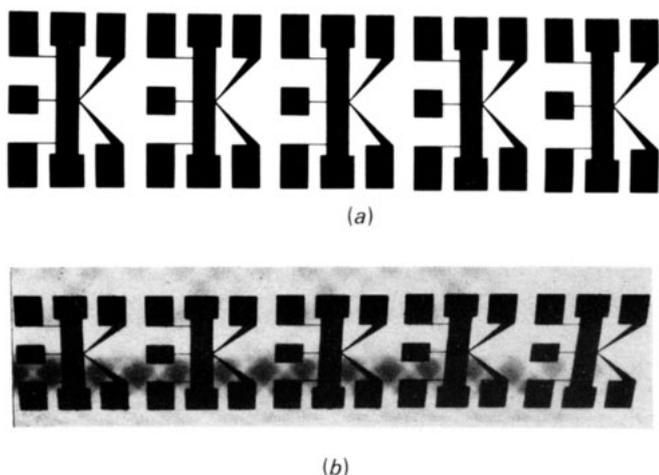


Figure 2. (a), A mask for producing five samples for Hall effect measurement; (b), a glass with five metallic samples. (Shaded areas are due to reflection from the bottom of the glass.)

A standard glass substrate covered with positive photoresist (Shipley AZ 1305) is exposed to light with the mask contacting the substrate. After the developing process, the metallic film is deposited by vacuum evaporation onto the substrate and finally the metal covering the photoresist is lifted off by dissolving the photoresist in acetone. As a result of this procedure, one gets a metallic film of the form of the mask on the glass substrate (figure 2(b)). The width of the electrode is about $200 \mu\text{m}$ and the accuracy of alignment is about $10 \mu\text{m}$. (Of course, both parameters could be much improved if necessary.)

4. Electrical measurements

Measuring V_{AB} , V_{AC} , V_{BC} and the voltage along the sample we calculated the value of misalignment ($\sim 2 \mu\text{m}$) and the effective distance between points A and B ($\sim 50 \mu\text{m}$). Note that in order to achieve this distance using the conventional three-terminal method one should make two terminals of $\sim 25 \mu\text{m}$ width separated by no more than $25 \mu\text{m}$. That means that for electrodes of the same width in both methods one gets a voltage V_{AB} lower by one order of magnitude for the geometry we propose. It is clear that this voltage could be reduced even more with a sharper angle between electrodes.

5. Hall effect measurement

100 nm Al and 10 nm Au films were measured at room temperatures. First, the tap D is located at the point where $V_{CD} = 0$ at zero magnetic field. This is checked for different currents (position of the tap should be independent on the value of the current, when the circuit is balanced properly). Then a magnetic field is applied at constant current perpendicularly to the sample. After that, the current is changed in the presence of a constant magnetic field. Both effects are found to be linear and Hall coefficients for Al ($R_{Al} \times 10^{11} = -3.4 \pm 0.2 \text{ (m}^3 \text{ A}^{-1} \text{ s}^{-1}\text{)}$) and Au ($R_{Au} \times 10^{11} = -6.5 \pm 0.2 \text{ (m}^3 \text{ A}^{-1} \text{ s}^{-1}\text{)}$) are established. One verifies that the value of the Hall coefficients remains the same, under reversal of the magnetic field and current. The absolute accuracy of the measurement is limited, not by the accuracy of the measuring Hall voltage, but by the precision of the film thickness determination. The accuracy of the measured ratio V_{CD}/IH is about 0.5%. For a $100 \mu\text{A}$ current at 10 kG magnetic field the value of the Hall voltage for the Au film $V_{CD} = 0.65 \pm 0.01 \mu\text{V}$. The voltage along the sample of 10 mm length is 4 mV and the measured $V_{AB} = 24 \mu\text{V}$, $V_{AC} = 11 \mu\text{V}$, $V_{BC} = 13 \mu\text{V}$ at $B = 0$.

4. Conclusion

The modification of the conventional three-terminal method used with modern photolithographic techniques is a very convenient method for measuring the Hall effect in metallic films. It may become very useful for the study of the Hall effect in alloy or disordered films in which the Hall constant is small but the resistivity is high.

Acknowledgments

We wish to thank Guy Deutscher, Michael Rappaport, Yacov Kantor, David Bergman and Aharon Kapitulnik for helpful discussions about the method. We also thank Herman Leibowitz for assistance in mask preparation.

References

- Durand E 1953 *Electrostatique et Magnetostatique* (Paris: Masson)
- Putley E H 1960 *Hall Effect and Related Phenomena* (London: Butterworth)