Pramāṇa, Vol. 11, No. 2, August 1978, pp. 145-147, © printed in India

Electrical conduction and size effect in bismuth films†

A RAHMAN* and P C MAHANTA
Department of Physics, Gauhati University, Gauhati 781 014
*Department of Physics, B. Barooah College, Gauhati 781 007

MS received 7 October 1977; revised 18 February 1978

Abstract. The size effect on electrical conduction is observed in bismuth films in the region of film thickness above 2000 Å. Applying Fuchs-Sondheimer theory and assuming specularity parameter $p=0{\cdot}8$, the value of bulk resistivity and mean free path are obtained as $6{\cdot}692\times10^4$ ohm-cm and 6000 Å respectively.

Keywords. Size effect; ellipsoidal surface; diffuse scattering.

1. Introduction

In the present investigation electrical size effect has been studied for polycrystalline Bi films. The details of the size effect theory and experimental arrangements for studying the same have been given elsewhere (Rahman 1977). The semi-metal Bi has ellipsoidal Fermi surfaces and it has been pointed out that the use of ellipsoidal energy surfaces in the size effect theory leads to the differences that are small compared with the probable experimental uncertainties, so that the Fuchs-Sondheimer theory (Campbell and Morley 1971), based on spherical model can be used quite satisfactorily (Ham and Mattis 1960). The Fuchs-Sondheimer theory connecting bulk resistivity ρ_0 and bulk mean free path λ can be written for thick film region as,

$$\rho d = \rho_0 \left[d + \frac{3\lambda}{8}(1-p) \right] \tag{1}$$

where ρ is the resistivity of the film of thickness d, and p is the specularity parameter.

The relation (1) indicates that if ρd is plotted as a function of d, the result should be a straight line with slope equal to ρ_0 and intercept on the d axis equal to $-(3\lambda/8)(1-p)$.

In the present case, the resistances of evaporated films were measured *in situ* at about 10^{-4} torr pressure and the resistivities were calculated from the known dimensions of the films. The resistances were measured using a Marconi Universal Bridge type TF 2700. The basic accuracy of the bridge was $\pm1\%$ of reading $\pm0{\cdot}1\%$ of range full scale. The film thickness was measured by a quartz crystal thickness monitor placed near the substrate. The sensitivity of the monitor was ±10 Hz at 1 kHz range.

†Part of a thesis submitted by senior author in partial fulfilment of the requirements for the Ph. D. degree of Gauhati University.

2. Results and discussion

X-ray studies showed that bismuth films deposited on glass substrates were polycrystalline. A typical resistivity vs thickness curve obtained from the results of the present investigation on polycrystalline bismuth films is shown in figure 1. It is seen that the resistivity values for thicknesses above 2000 Å decrease continuously showing the expected size effect. Due to long mean free paths of the carriers, the resistivity has not reached a constant value even after 5000 Å. Plot of ρd as a function of d (figure 2) shows excellent straight line as is indicated by the relation (1). The value of bulk resistivity ρ_0 obtained from the slope is $6{\cdot}692\times 10^{-4}$ ohm-cm and that of the mean free path λ, obtained from the intercept assuming $p=0{\cdot}8$ (partial diffuse scattering) is 6000 Å. The reported value of ρ_0 is $1{\cdot}16\times 10^{-4}$ ohm-cm at 295 °K (Kittel 1974) and that of λ in bulk single crystal is of the order of microns at room temperature (Pippard and Chambers 1952). Thus the values obtained in the present case applying Fuchs-Sondheimer theory for polycrystalline bismuth films are in good agreement with the reported values. A little higher value of resistivity and consequently the low value of mean free path obtained in the present case may be attributed to the frozen-in structural defects. Thus the thickness variation of resistivity above 2000 Å clearly demonstrates the expected size effect and the application of Fuchs-Sondheimer theory gives nearly the correct values of bulk resistivity and mean free path.

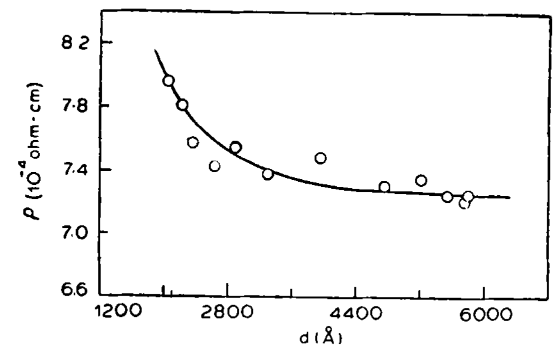

Figure 1. Variation of electrical resistivity of bismuth films with film thickness 300°K.

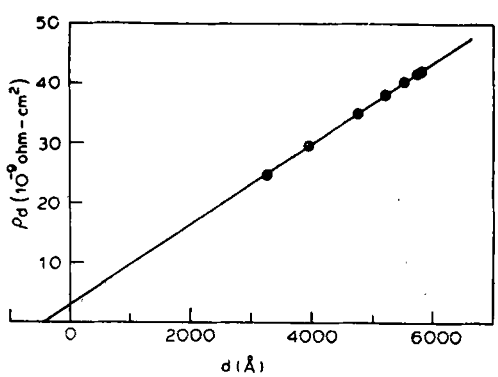

Figure 2. ρd vs d plot for bismuth film

Below 2000 Å thickness, the carrier wavelength becomes comparable with the thickness (Hoffman and Frankl 1971) and quantum size effect as predict edby Sondomirskii (1967) becomes observable under very controlled conditions at lower temperatures. At higher temperatures including room temperature the oscillatory behaviour of resistivity in the quantum size effect region is likely to be damped out as the relaxation time is shortened and the uncertainty in the energy levels becomes comparable with the spacing between them. The region of quantum size effect was not investigated in the present case.

References

Campbell D S and Morley A R 1971 *Rep. Progr. Phys.* **34** 289
Ham F S and Mattis D C 1960 *IBM J. Res. Develop.* **4** 143
Hoffman R A and Frankl D R 1971 *Phys. Rev.* **B3** 1825
Kittel C 1974 *Introduction to Solid State Physics* (New Delhi: Wiley Eastern) 4th ed. p. 260
Pippard A B and Chambers R G 1952 *Proc. Phys. Soc.* **A65** 955
Rahman A 1971 Ph.D. Thesis submitted to the Gauhati University
Sondomirskii V B 1967 *Sov. Phys. JETP* **25** 101