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THE ELECTRICAL RESISTIVITY OF $Bi_{1-x}Sb_x$ ALLOYS

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The electrical resistivity of some $Bi_{1-x}Sb_x$ alloys containing 2-20% of antimony was measured in the temperature range 300-500 K. The measurements suggest that the behaviour of the electrical resistivity for all samples throughout the temperature range studied is semimetallic.

Bismuth is a semimetal with a carrier concentration of about 10^{18} cm^{-3}. The addition of group V elements such as antimony is expected to modify the band structure of bismuth as well as change the carrier concentration. The electrical properties of bismuth-antimony alloys have been investigated by many workers.

Jain [1] made the first systematic and detailed study of a large number of bismuth-antimony alloys. He found that alloys containing less than 5% antimony exhibit overlapping between valence and conduction bands and are therefore semimetals. In alloys containing between 5% and 40% antimony, the resistivity increases as the temperature is lowered below 100 K, and Jain deduced that these alloys are intrinsic semiconductors with small energy gaps. This behaviour was attributed to the removal of the overlap between the conduction and the valence bands in bismuth due to antimony addition. The findings of Goldsmid [2] are consistent with those of Jain.

Shoenberg and Uddin [3] suggest that the Fermi energy decreases on the addition of antimony. Heine [4] has pointed out that a decreased Fermi energy implies a decreased overlap and that, consequently, bismuth-antimony alloys may become semiconducting at concentrations of antimony greater than 4%.

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Das and Meena [5] studied the properties of bismuth-antimony alloy containing 60% antimony, in the form of thin films, in the temperature range 100-500 K. They observed semimetallic behaviour for large thicknesses (1625-5050 Å) and semiconducting behaviour for small thickness (340 and 830 Å).

Studies on the electrical properties of bismuth-antimony alloys in the temperature range 100-300 K have also been carried out by Malabika and Ramendranarayan [6]. They observed semimetallic behaviour for a sample containing 5.7% antimony and semiconductor behaviour for a sample containing 8.5% antimony. The observed properties of these alloys could be explained on the basis of the presence of antimony impurity levels between the conduction and valence bands.

Though the difference in the limit of percentage of antimony for the transition from semimetal to semiconductor is not large, the difference in the nature of the free carriers appears to be a considerable one, and necessitates further investigations.

All the previous studies were carried out in the low-temperature range (4-300 K) except for the work of Das and Meena [5], so the aim of the present work is to study the behaviour of the electrical resistivity of some bismuth-antimony alloys in the temperature range 300-500 K as a function of the antimony composition up to 20%.

Experimental

Bismuth and antimony were purchased from May and Baker Ltd., Dagenham, England, with a label purity of better than 99%.

Initially, a known amount of antimony was allowed to dissolve in a known amount of molten bismuth in a fused quartz boat. The melting process was carried out in a nitrogen atmosphere to avoid any oxidation on the surface. Ten bismuth-antimony alloys were prepared by this method in the range from 2% to 20% antimony.

The samples were prepared in the form of cylindrical rods by remelting the crushed alloys in pyrex tubes with an internal diameter of about 4 mm, again in a nitrogen atmosphere. After annealing, the samples were reduced to the proper length by grinding with a silicon carbide paper. A part of each sample was analysed in the chemical department before measurement of its resistivity.

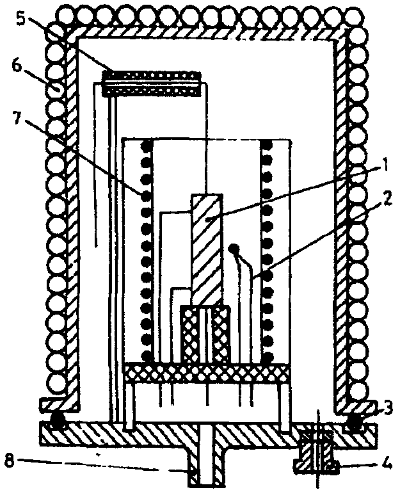

Fig. 1 The electrical resistivity apparatus. 1 - sample; 2 - thermocouple; 3 - O -ring; 4 - eight teflon isolated holes; 5 - ceramic tube; 6 - water tubing; 7 - heater wire; 8 - to vacuum

For determination of the electrical resistivity, the sample was held in the electrical resistivity apparatus shown in Fig. 1 and connected with the

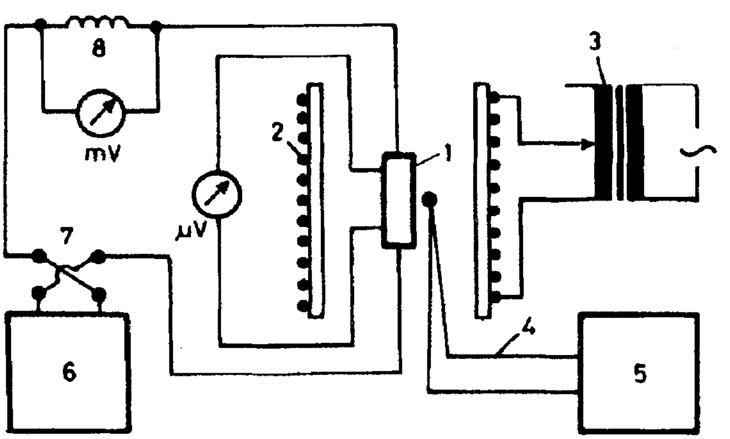

Fig. 2 The electrical circuit used for determination the electrical resistivity. 1 - sample; 2 - furnace; 3 - variable transformer; 4 - copper - constantan thermocouple; 5 - digital thermometer; 6 - stabilized D - C power supply; 7 - reversing switch; 8 - standard

electrical circuit shown in Fig. 2. Through the use of a well-stabilized direct current power supply, a current of about 0.2 A was allowed to pass through the sample. The current was determined by measuring the potential difference across a standard resistance of 0.1 ohm in series with the sample. The potential difference across the sample was measured with a sensitive microvoltmeter. Readings were correct up to 1 ±μV. To avoid any thermoelectric effects, the potential difference was always measured for direct and reversed current.

The temperature variation was carried out by adjusting the current passing in the heating wire of a furnace especially designed for this purpose by using a variable transformer. The temperature was measured by means of a digital thermometer with a copper-constantan thermocouple. During the measurements, the pressure in the chamber was about 10^{-3} Torr. The measured resistivity was accurate within about 5%.

Results and discussion

The electrical resistivity was measured for samples containing different

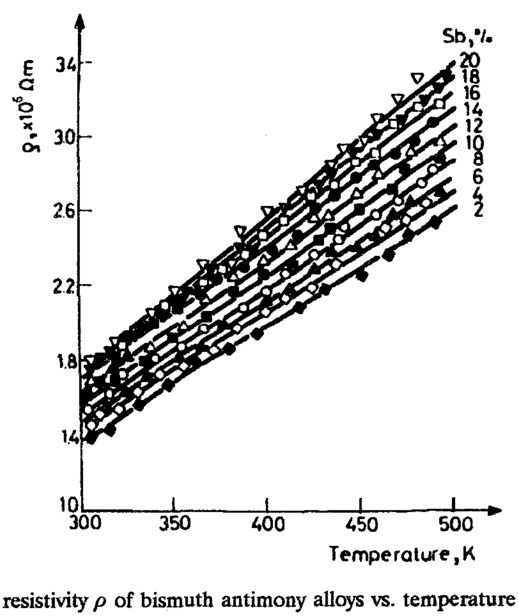

Fig. 3 The electrical resistivity ρ of bismuth antimony alloys vs. temperature T

concentrations of antimony, from 2% to 20%, in the temperature range from

300 K to 500 K. Plots of the electrical resistivity measurements *vs*. temperature for all the samples are shown in Fig. 3. These measurements indicate a linear dependence of the electrical resistivity on temperature for all concentrations of antimony.

Table 1 Temperature coefficient of resistance (TCR) of bismuth-antimony alloys

Sb, %	TCR, deg^{-1}
2	0.00515
4	0.00515
6	0.00517
8	0.00521
10	0.00525
12	0.00532
14	0.00540
16	0.00543
18	0.00549
20	0.00554

The calculated temperature coefficient of resistivity (TCR) is shown in Table 1. It can be seen that TCR increases with increasing antimony concentration.

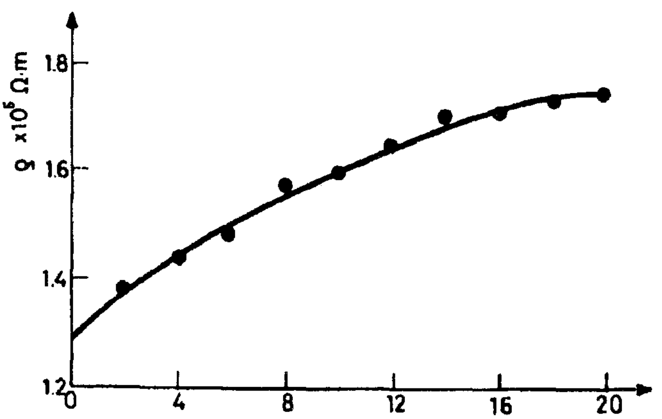

Fig 4 The electrical resistivity ρ of bismuth antimony alloys vs. concentration of antimony at 300 K

The dependence of the electrical resistivity on the concentration of antimony at 300 K is shown in Fig. 4, which indicates that the electrical resistivity of bismuth-antimony alloy increases with increasing antimony concentration.

The increasing electrical resistivity of bismuth-antimony alloys with increasing temperature indicates that for all antimony concentrations these alloys are semimetals above room temperature. This behaviour can be attributed to the presence of overlapping between the conduction and valence bands in the model of this alloy.

It can also be concluded that the transition to the semiconducting behaviour for this alloy appears only at temperatures less than 300 K.

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Zusammenfassung -Es wurde der elektrische Widerstand einiger $Bi_{1-x}Sb_x$-Legierungen mit einem Antimongehalt von 2-20% für den Temperaturbereich 300-500 K ausgemessen. Die Messungen zeigen, daß das Verhalten des elektrischen Widerstandes für alle Proben und im gesamten Temperaturbereich halbmetallisch ist.