Hall Coefficient in Tin-Bismuth Alloys*

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The Hall coefficient in a series of tin-bismuth alloys has been measured at 75°K as a function of composition. The results are compared with previous results on the band structure in these alloys. They indicate that hole conduction is present though not always dominant throughout the range of alloys studied.

I. INTRODUCTION

PREVIOUS studies[1] of superconductivity in tin-bismuth alloys were used to construct a picture of the density of states curve for the tin structure. The resulting curve showed the typical structure of a metal which conducts by virtue of an overlap between two bands. A study of the variation of the Hall coefficient seemed desirable since changes in sign of the Hall coefficient should occur as the region of overlapping bands is filled.

II. PREPARATION OF SAMPLES

The samples were prepared from high purity tin and bismuth from the Vulcan Detinning Company and Cerro de Pasco Corporation, respectively. In both cases the purity was greater than 99.99%. The component metals were weighed on an analytical balance and melted over a torch in a high purity graphite mold, shaken vigorously to homogenize the melt, and then quenched in cold water. The resulting slug was then recast into strips of dimensions 2 cm×0.75 cm×0.02 to 0.06 cm. These strips were annealed at just below the eutectic point for a few days for the lower percent alloys, and up to two months for the higher percent bismuth alloys. The range of composition of the samples covered the range of solid solubility of bismuth in tin at the eutectic temperature. After removal of the samples from the annealing furnace, the current and Hall leads were soldered to the sample, and it was immediately immersed in liquid nitrogen to prevent any precipitation of the bismuth from solid solution. All data were taken at 75°K.

III. EXPERIMENTAL TECHNIQUE

The apparatus used for determining the Hall coefficient is practically identical to that used by Teutsch and Love.[2] All data were taken at a magnetic field strength of about 9500 gauss. This was the maximum field available with the electromagnet, and it was used to obtain maximum Hall voltages for reasonable accuracy of the results. No systematic study of the possible field or temperature dependence of the Hall coefficient was made. However, the Hall coefficient in the three atomic percent bismuth sample was found to be independent of the field strength within the experimental errors. Reversal of sample current and magnetic field was used to eliminate undesirable emf's. Because of the small values of the Hall voltage observed, a total of about 30 readings were taken for each sample and the results averaged. The results are shown in Fig. 1, where the Hall coefficient in volt-cm per ampere-gauss is plotted versus atomic percent of bismuth in tin. Mean deviations were calculated to give the limits of error shown. For comparison the values of the density of states at the Fermi surface taken from reference 1 are also shown.

IV. DISCUSSION

No adequate theory of the Hall effect in metals with complicated band structures exists. The theory commonly used[3] assumes conduction in two bands containing electrons and holes, respectively. The resulting

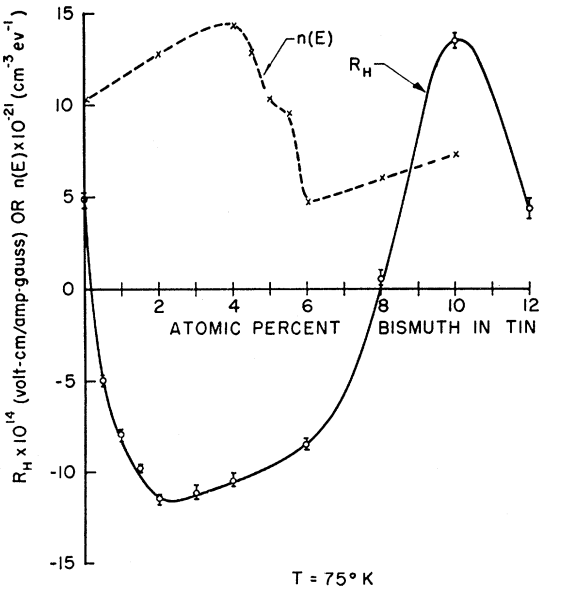

FIG. 1. Plot of Hall coefficient and density of states versus atomic percent of bismuth in tin at 75°K. All data were taken at 9500 gauss.

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[2] W. B. Teutsch and W. F. Love, Phys. Rev. **105**, 487 (1957).

[3] A. H. Wilson, *The Theory of Metals* (University Press, Cambridge, 1953), 2nd ed., p. 213.

expression for the Hall coefficient

$$R=\frac{R_1\sigma_1^2+R_2\sigma_2^2}{(\sigma_1+\sigma_2)^2}, \quad (1)$$

depends on the Hall coefficients R_1, R_2 and conductivities σ_1, σ_2 of the two bands, and therefore has too many unknown quantities for a quantitative comparison with experiment. However it does allow for the presence of either sign of Hall coefficient depending upon whether electron or hole conduction predominates in the sense of Eq. (1), and is useful for a qualitative interpretation of the results. The Hall coefficient in pure tin is very small and negative at room temperature. This would indicate not a large number of conduction electrons but rather a delicate balance between electron and hole conduction. The fact that at 75°K the Hall coefficient is positive indicates that the temperature dependence of the conductivities in the two bands is sufficiently different to swing the balance in favor of hole conduction at the lower temperature. However, even a small percentage of bismuth added, corresponding to an increase of the electron-atom ratio, is sufficient to reverse the sign of the Hall coefficient. The Hall coefficient, however, reverses sign again at about 8 at. % bismuth, reaches a peak positive value at 10 at. % bismuth, and is rapidly dropping toward negative values again at the highest atomic percent bismuth sample studied. On the basis of the density of states curve shown one would not expect quite the same behavior. The sharp drop in density of states between 4 and 6 at. % bismuth, and the rising portion beyond 6 at. % indicate that complete filling of the lower band is taking place around 6 at. % bismuth, beyond which electron conduction predominates. Because of the behavior of the Hall coefficient one can only conclude that the lower band (holes) does not drop sharply to zero just beyond 6 at. % as the extrapolation of the density of states indicates, but rather tails off in such a way that holes are present even out to 12 at. % bismuth. Their density however must be small, and since the Hall coefficient is positive in the presence of higher density of electrons in the upper band, one can only conclude that the holes have a much higher mobility than the electrons. Upon complete filling of the lower band the Hall coefficient must become negative again, and it is gratifying to note a strong tendency in this direction beyond 10 at. % bismuth.

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Thermal Resistance due to Point Defects at High Temperatures

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An expression is obtained for the lattice thermal conductivity at high temperatures in the limit when the scattering of phonons by point defects is stronger than by umklapp processes. The latter limit the phonon mean free path at low frequencies and most of the heat is transported at frequencies such that the point defect and umklapp mean free paths are equal. The conductivity varies as $(AT)^{-\frac{1}{2}}$, where A is proportional to the strength of the point defect scattering, T is the temperature. The theory is in rough agreement with the thermal conductivity of Ge-Si alloys, measured by Steele and Rosi.

I. INTRODUCTION

THE lattice thermal conductivity is given by

$$\kappa=\frac{1}{3}\int S(\omega)v^2\tau(\omega)d\omega, \quad (1)$$

where $S(\omega)d\omega$ is the specific heat per unit volume due to lattice modes of frequency ω, $d\omega$, v is the velocity of the lattice waves, and $\tau(\omega)$ their effective relaxation time. If the phonons are scattered by various interaction processes, each process contributes additively to $1/\tau$, except that anharmonic three-phonon processes which conserve the total wave vector (N processes) do not contribute directly to the thermal resistance, but require special consideration.[1]

Point defects scatter phonons and contribute to the inverse relaxation time as

$$1/\tau'=A\omega^4. \quad (2)$$

They thus increase the thermal resistance. In the present paper we shall discuss their effect on the thermal resistance at temperatures at and above the Debye temperature θ in the limit when the point defect resistance is larger than the intrinsic resistance. Previous authors[1–3] have discussed the low-temperature point defect resistance in terms of τ', but relatively little attention has been paid to the high-temperature case; Ambegaokar[4] has, however, considered the high-temperature point

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