ELECTRICAL RESISTIVITY OF ARSENIC FROM 7 K DOWN TO 50 mK

C. Uher

To cite this version:
C. Uher. ELECTRICAL RESISTIVITY OF ARSENIC FROM 7 K DOWN TO 50 mK. Journal de Physique Colloques, 1978, 39 (C6), pp.C6-1054-C6-1055. <10.1051/jphyscol:19786466>. <jpa-00217946>

HAL Id: jpa-00217946
https://hal.archives-ouvertes.fr/jpa-00217946
Submitted on 1 Jan 1978
ELECTRICAL RESISTIVITY OF ARSENIC FROM 7 K DOWN TO 50 mK

C. Uher
Department of Physics, Michigan State University, East Lansing, Michigan 48824, USA

Résumé.—Nous avons mesuré la résistivité électrique de l'arsenic dans la direction de l'axe binaire, entre 50 mK et 7 K en utilisant un SQUID comme détecteur de zéro. Au-dessous d'environ 5 K, les résultats peuvent être représentés par l'équation $10^{8} \rho_{0} = 6.636 + 6.9 \times 10^{-3} \frac{T_{1}}{\Omega \cdot \text{cm}}$. Une décroissance brutale de $\rho$, qui est possible d'associer à une transition supraconductrice large, a été observée au-dessous de 100 mK.

Abstract.—We have measured the electrical resistivity of arsenic in the binary direction between 50 mK and 7 K using a SQUID null detector. Below about 5 K the data can be represented by equation $10^{8} \rho_{0} = 6.636 + 6.9 \times 10^{-3} \frac{T_{1}}{\Omega \cdot \text{cm}}$. A sudden decrease, possibly associated with a broad superconducting transition, was observed below 100 mK.

We report on our preliminary electrical resistivity measurements of arsenic in the binary direction and extending from about 7 K down to 50 mK. Measurements were performed in a dilution refrigerator and high precision (5 parts in $10^{5}$) was achieved using a SQUID null detector, described previously /1/. The single crystal sample (18x4x1.7 mm, long dimension along binary axis) was grown by Jeavons and Saunders /2/ using a vapor transport technique and was kindly lent to us by Professor Saunders. Heremans et al. /3/ had previously measured the transport properties of this sample from 300 K to 2 K.

A good thermal contact to the sample was made by spot welding a copper strip to one end and then applying a layer of Wood's metal over the joint. The other end of the copper strip was welded to the mixing chamber of the dilution refrigerator. Despite great care the sample suffered damage and its resistivity ratio was only 283 compared to 586 reported by Heremans et al. /3/. The temperature of the sample was monitored by a pair of calibrated germanium thermometers inserted in a copper holder soldered close to the free end of the sample. Tests were made to ensure that the electrical contacts were ohmic and the resistivity was current independent. A measuring current of 200 μA was used to keep the Joule heating and the self-magnetic field negligible.

Several layers of mu-metal reduced the external magnetic field to a few milligauss. Our measurements of the thermopower made on the same sample indicated that the error arising from the Peltier effect could be neglected. The absolute value of the resistivity is limited by the uncertainty in the geometrical factor which estimate to be about 5%.

The data are shown in figure 1 plotted against $T^{3}$. The straight lines indicate that a cubic power law can describe the ideal resistivity down to 0.1-0.3 K. Below about 5 K the data can be represented by the equation

$$10^{8} \rho_{0} = (8.636 \pm 0.0005)(6.9 \pm 0.05) \times 10^{-3} \frac{T_{1}}{\Omega \cdot \text{cm}}$$

above 5 K the coefficient of the $T^{3}$ term is somewhat smaller, $6.1 \times 10^{-3} \frac{\Omega \cdot \text{cm}}{\text{K}^{3}}$. Heremans et al. /3/ have also observed a cubic temperature dependence in the higher temperature range, 8-30 K, but their data indicate a much smaller coefficient $1.7 \times 10^{-3} \frac{\Omega \cdot \text{cm}}{\text{K}^{3}}$. Such a large difference between the slopes of the ideal resistivity may indicate a substantial deviation from Matthiessen's rule (DMR) associated with the damage to the arsenic sample in present measurements.

Below 100 mK the resistivity of the sample began to decrease rapidly (see inset in figure 1). A similar decrease in resistivity at these temperatures has been observed recently in Bi doped with Sn or Te (Uher and Pfohl /4/), and has been attributed to the onset of superconductivity. This may also be happening in As.

The $T^{3}$ dependence of the resistivity is puzzling. It is unlikely that carrier-carrier scattering

*Work was supported by NSF grant DMR-75-01584

**Present address : CSIRO, National Measurement Laboratory, P.O. Box 218, Lindfield N.S.W. 2070, Australia
Fig. 1: Temperature dependence of the resistivity in the binary direction of arsenic. Left and bottom scales apply to full dots, upper and right-hand scales to open circles.

could be responsible on its own as this invariably leads to a quadratic temperature dependence, e.g. Baber /5/, Appel /6/ and Kukkonen and Maldague /7/. On the other hand, carrier-phonon scattering in the Bloch-Grüneisen formulation predicts a $T^2$ law at the lowest temperatures, i.e. $T \ll \Theta_D$. Arsenic has a low carrier density ($2 \times 10^{24} \text{cm}^{-3}$), and its Fermi surface consists of 3 small pockets of electrons at the L-points and equal densities of holes in a multiply connected surface around the T point (Lin and Falicov /8/ and Priestley et al. /9/).

Although the Debye temperature $\Theta_D$ of arsenic is 282 K, Sondheimer /10/ has suggested that, in the case of semimetals with very small Fermi surface dimensions, $\Theta_D$ for carrier-phonon interaction should be replaced by an effective Debye temperature

$$\Theta_{D}^{*} = \frac{2k_{F}v_{s}}{k_{B}}$$

(2)

where $v_{s}$ is the speed of sound and $2k_{F}$ is the maximum dimension of the Fermi surface. For the highly mobile $\alpha$ holes in As /11/ the effective Debye temperatures in the binary direction have been estimated by Heremans et al /3/ as $\sim 20$ K (transverse phonons) or $\sim 50$ K (longitudinal phonons). The effective Debye temperatures for the lower density $\gamma$-holes located in narrow necks connecting six $\alpha$-holes pockets are at least a factor of three lower for the binary direction /8,9/. With such low effective Debye temperatures, it may not be surprising that we have not observed a higher power law than $T^2$ in the temperature dependence of $\rho$ down to 0.1-0.3 K.

Measurements at lower temperatures and on higher quality crystals (resistance ratio approaching $10^6$) are needed to clarify the question of the carrier scattering in As and the likely limiting exponent of the temperature dependence of the ideal resistivity as $T \rightarrow 0$. Further investigation is also required of the decrease in the total resistivity below 100 mK.

Acknowledgements. - The author would like to thank Professor G.A. Saunders for making available the sample of arsenic, to Professor W.P. Pratt, Jr. for use of his dilution refrigerator and to Dr. J.G. Collins for a critical reading of the manuscript.

References

/6/ Appel, J., Phys.Rev. 125 (1962) 1815