Physica B 165&166 (1990) 299-300
North-Holland

CONDUCTION MECHANISM IN GRANULAR RuO_2-BASED THICK-FILM RESISTORS

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The conductivity of a commercial thick-film resistor is measured between 4 K and 15 mK and in magnetic fields up to 7 Tesla. The data can be described by the variable-range hopping mechanism with a Coulomb gap in the density of states. The negative magnetoresistance may be attributed to quantum-interference effects in the strongly localized regime.

Commercial RuO_2-based thick-film resistors are useful low-temperature thermometers because of their excellent stability and small magnetoresistance (1-4). An understanding of the temperature and field dependences of these devices, however, is lacking. Conduction in granular systems may be affected by manufacturing processes. Furthermore, the applicability of theoretical models originally developped for doped semiconductors is still under discussion. The data obtained in this work actually can be described in terms of a hopping conduction which is affected by temperature and magnetic field as expected for a strongly localized semiconductor.

The sample was taken from a batch of commercial 10 kΩ resistors of Siegert GmbH (5). It was mounted inside the mixing chamber of a home-made dilution refrigerator. A magnetic field up to 7 Tesla could be applied either perpendicular or parallel to the conductive layer. Fig. 1 shows that the temperature dependence in zero field follows a $\exp(T_o/T)^{\frac{1}{2}}$ law below 4 K with $T_o = 0.48$ K. (The deviation below 20 mK is due to heating effects even though the measuring current was reduced to 15 pA.) This behaviour is observed rather often in granular systems and may be attributed to variable-range hopping with Coulomb interaction (6). Strictly, the model is valid only for $T \ll T_o$ but no deviation is visible up to 4 K. From $T_o \sim e^2/4\pi\epsilon_o k\epsilon a$ (where ϵ is the dielectric constant and a the radius of localisation) one finds $\epsilon a \sim 3 \cdot 10^{-5}$ m. Assuming $\epsilon \sim 10$ gives $a \sim 3 \cdot 10^{-6}$ m, which corresponds to the size of the metallic grains.

The magnetoresistance is negative at all temperatures and fields, see Fig. 2. This is in striking contrast to the usual case of a large positive magnetoresistance in the strongly localized regime caused by orbital shrinking of the wavefunction in a magnetic field. The absence this effect indicates, that the long-range behaviour of the wavefunction is not relevant for transport in this case.

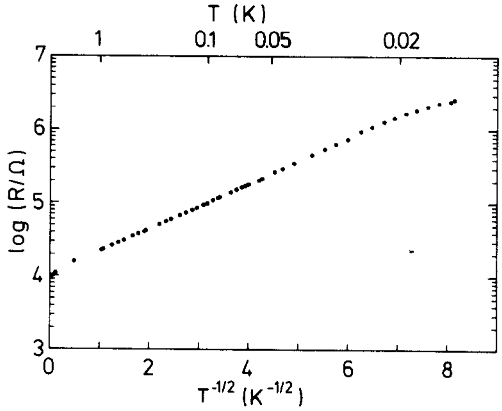

FIGURE 1
Temperature dependence of the resistance in zero field. The straight line behaviour indicates a $\exp(T_o/T)^{\frac{1}{2}}$ law with $T_o = 0.48$ K. The deviation below 20 mK is due to Joule heating by the measuring current of 15 pA.

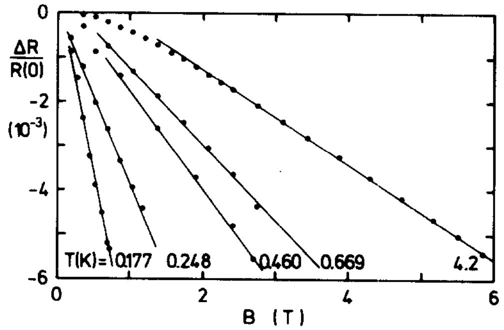

FIGURE 2
Magnetoresistance at various constant temperatures. Except for small fields the magnetoresistance varies linearly as B/B_c.

0921-4526/90/$03.50

A negative magnetoresistance of the hopping mechanism has recently been calculated on the basis of quantum interference effects of the tunneling electron (7-9). The magnetic field dependence is predicted to be linear except for very small fields where it should increase quadratically. This is in agreement with the data of Fig. 2. The temperature dependence of the linear part should scale as $r^{\frac{7}{2}}$, where $r \propto (T_o/T)^{\frac{1}{2}}$ is the temperature dependent hopping length (9). Therefore, the inverse of the slopes of the straight lines should vary as $T^{\frac{7}{4}}$. The experimental results, see Fig. 3, are approximately described by a T^2 law for $T \lesssim T_o$ and tend to saturate above 1 K. This is consistent with the above mechanism. A more detailed analysis requires a calculation of the prefactor which is not yet available.

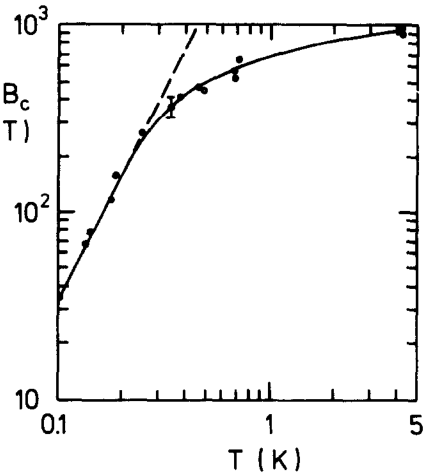

FIGURE 3
The temperature dependence of B_c (i.e. of the inverse of the slopes in Fig. 2).

ACKNOWLEDGEMENTS

It is a pleasure to thank W. Pfab of Siegert GmbH for supplying the sample. I have had very helpful discussions on the theory with W. Schirmacher and B. Shklovskii. Similar experiments were performed simultaneously and independently by K. Neumaier and I am grateful to him for cummunicating his results prior to publication.

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