Physical Properties of SmS Metallic Phase at Low temperature

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The resistivity of SmS single crystal has been measured under pressure up to 8 GPa. As an applied pressure is increased, the electrical resistivity changes drastically. In particular it shows a kink at T_M in the ρ vs T curve above 2 GPa. We found that the electrical resistivity shows the $\rho = \rho_0 + AT^2$ dependence with a large coefficient A below T_M . If we ascribe this term to the electron-electron scattering, the electron correlation effect plays a dominant role in the high pressure region, which may correspond to the large γ value.

[SmS, resistivity, electron correlation, intermediate valent state, semiconductor-metal transition]

1. Introduction

The compound SmS has been studied by a large variety of experimental methods. Application of high pressures induces the well known semiconductor-metal transition. The magnetic susceptibility of the collapsed phase of SmS lead Maple and Wohleben[1] to the conclusion that SmS in the metallic phase, like SmB₆ at atmospheric pressure, could be described by a system of ions showing intermediate valent state. The heat capacity measurements were reported to have a large T -linear term coefficient, $\gamma = 145 \text{ mJ/molK}^2$ at almost 1.5 GPa[2]. If we assume that it is due to the conduction-electron contribution, this may be an evidence of a strong electron correlation effect. Although many investigations have been performed so far, it may not be clear yet whether the electron correlation effect plays a dominant role in the metallic phase. Thus we have made the electrical resistivity measurements to study the electron correlation effect in SmS under high pressure.

2. Experimental

We prepared single crystals of SmS by the bridgman method in a sealed tungsten tube, under high vacuum. X-ray powder photographs confirmed both the NaCl structure and the lattice constant (5.925 Å) corresponding to the earlier data of SmS (5.97 Å)[3]. At ambient pressure, the electrical resistivity is 28 mΩ cm at room temperature, and increases down to about 25 K by 260,000 times, below which the electrical resistivity was too large to be measured.

The resistivity of SmS has been measured up to 8 GPa. The sample of millimeter size is set up in a teflon cell containing a 1:1 mixture of fluorinate FC-70 and FC-77. The electrical contacts are Au-paste and Au-wire. Pressures have been applied using piston-cylinder ($p < 1.5 \text{ GPa}$, $1.5 \text{ K} < T < 300 \text{ K}$) and cubic anvil press ($p > 1.5 \text{ GPa}$, $2.5 \text{ K} < T < 300 \text{ K}$)[4], in which pressure load is kept constant during the measurements.

3. Results

Fig.1. represents the data at $p < 1.2 \text{ GPa}$. Below room temperature the activation energy is estimated to be about 100 meV at ambient pressure when using a plot with $\rho = \rho_0 \exp(-\Delta/2k_B T)$.

Fig.1. ρ vs T curve at $p < 1.2 \text{ GPa}$.

Fig.2. shows the electrical resistivity as a function of pressure is increased at room temperature. From Figs.1. and 2. it is clear that the transition is not a semiconductor-metal transition but a

semiconductor-semiconductor transition takes place discontinuously at about 0.68 GPa. In addition, under 1.2 GPa, a small hump is observed on the ρ vs T curve at about 13 K, and the ρ increases with decreasing temperature down to the temperature where the hump takes place with $\Delta=4.5$ meV (Fig.1.). For $T < 2$ K, however, the ρ is found to decrease with decreasing temperature, while the resistivity at 0.5 K is found to be a very large value of $1180 \mu\Omega\text{cm}$.

Fig.2. Electrical resistivity as a function of increasing pressure at room temperature.

As an applied pressure is increased furthermore, the electrical resistivity changes drastically as seen in Fig.3. Above 1.5 GPa, the electrical resistivity increases with decreasing temperature, while it does not obey an activation law. Moreover, an anomaly at T_M appears above 2 GPa. T_M is plotted as a function of pressure in fig.4.

3. Discussion

The new result is that a kink at T_M under pressure in the ρ vs T curve is observed systematically, which is not shown in recent measurements[2][5]. Fig.4. shows the T_M vs pressure curve, which suggests the presence of a magnetic ordering phase. However, no evidence of a magnetic ordering temperature has been reported so far.

It is evidenced that the electrical resistivity shows the $\rho=\rho_0+AT^2$ dependence under pressure more than 2 GPa with a large coefficient A below T_M . Fig.5. shows ρ as a function of T^2 . ρ_0 and the coefficient A rapidly decreases with increasing pressure as seen in Fig.6. A large coefficient A seems to reflect a strong electron correlation effect. The large γ value was found in heat capacity at

Fig.3. ρ vs T curve at various pressure.

Fig.4. T_M (circles), and activation energy (triangles) as a function of pressure.

1.5 GPa [1]. If we assume that both A and γ are caused by the same origin, the large γ suggests the coefficient A to be $0.2 \mu\Omega\text{cm}/\text{K}^2$

under 1.5 GPa [6], which seems to correspond well to the value obtained by an extrapolation in this study. However, it is difficult to find whether electrical resistivity shows $\rho = \rho_0 + AT^2$ dependence under 1.5 GPa because of the pressure near the phase transition boundary. Moreover, the recent electrical resistivity and Hall coefficient measurements [5][7] suggested the existence of "Semiconducting Intermediate Valence State" at $p < 2$ GPa. In order to make clear this point, the heat capacity in the metallic state and the pressure dependence of the γ value should be measured.

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Fig.5. ρ vs T^2 curve under high pressure.

Fig.6. The pressure dependence on the ρ_0 (circles) and A (triangles).