Insulator-metal transition studied by heat capacity measurements on SmS

Kazuyuki Matsubayashi [a], Hitoshi Mukai [a,1], Takashi Tsuzuki [a], Takashi Nishioka [a], Noriaki K. Sato [a,2]

[a] *Department of Physics, Graduate School of Science, Nagoya University, Nagoya 464-8602, Japan*

Abstract

We have measured the specific heat of SmS at pressures up to $\sim$ 7.5 kbar. We have observed that the electronic specific heat coefficient γ shows a steep increase at around $P_c \sim 3.5$ kbar, which corresponds to an insulator-metal phase transition. In the metal phase above P_c, we have found that γ reaches 100 mJ/mole K^2, indicating a strongly correlated metallic state. In the insulator phase, on the other hand, we have observed an anomaly in the temperature dependence of the specific heat around 1 K, which seems to survive in the metal phase.

Key words: SmS; high pressure; specific heat; insulator-metal transition

It is well known that samarium sulfide exhibits the first-order insulator-metal transition at 6.5 kbar[1]. Although the electrical resistivity indicates a steep decrease around 6.5 kbar at 473 K, it shows only quite a broad decrease at 4.2 K[2]. This transition was also observed in heat capacity measurements under pressure [2]. The electronic specific heat coefficient γ is zero at ambient pressure, while that at 15 kbar was observerd to be 145 mJ/mole K^2 [2]. On the other hand, it seems that the metal phase is not a single phase but consists of a couple of phases [3–5]. Therefore, it is not clear to which phase the aforementioned pressure of 15 kbar corresponds. In order to reveal the nature of the insulator-metal transition and each phase in SmS, we carried out the specific heat measurements.

First we synthesized a powdered material by reacting high purity sulfur with samarium in a quartz tube. Then we grew a single crystal in a tungsten tube by the Bridgman method. We have measured the heat capacity by the heat pulse method at pressures of up to $\sim$ 7.5 kbar. The pressure was generated by a beryllium-copper piston-cylinder clamp device using Fluorinert as a pressure transmitting medium.

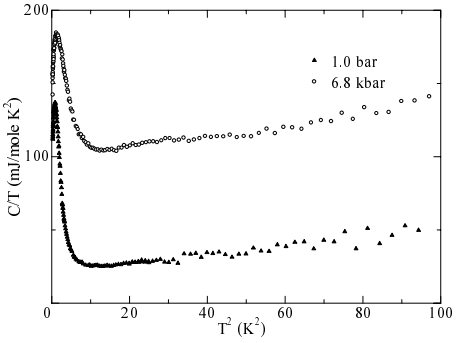

Fig. 1. Plot of C/T versus T^2 at ambient pressure and 6.8 kbar.

Figure 1 shows a plot of C/T versus T^2 at ambient pressure and 6.8 kbar. We estimated the γ-coefficient by linear extrapolation to 0 K using data from 5 to 10 K. We give in figure 2 this γ-value as a function of external pressure. The insulator-metal transition is evidently observed around $P_c \sim 3.5$ kbar. One may no-

[1] Present address: NEC Soft Ltd. Tokyo, Japan
[2] E-mail: kensho@edu3.phys.nagoya-u.ac.jp

tice that this value of P_c is smaller than that in the literature. This is explained as follows; the insulator-metal transition is the first-order, therefore the transition pressure P_c in the process of decresing pressure is smaller than that of incresing pressure [6]. Furthermore, the pressure applied at room temperature is usually reduced during lowering temperature of the sample and the pressure cell, due to the difference in the temperature dependence of their thermal expansion coefficients. Because of these reasons, the present value of P_c is smaller than that in the literature.

In the metal phase above P_c, we found the large γ-value reaching 100 mJ/mole K^2. This means that the metal phase is a strongly correlated metallic state. Comparing with $\gamma \sim 145$ mJ/mole K^2 at 15 kbar reported by Bader *et al.*, the present value measured at 7.5 kbar is small. In order to study the P-dependence of the correlation effect and reveal the existence of the phase transitions in the metal phase, we need to extend our measurements to higher pressures.

In the insulator phase below P_c, on the other hand, the aforementioned extrapolation yields non zero γ-value. This is clearly due to the existence of an anomaly in the specific heat around 1 K. In order to characterize this anomaly, we have studied sample dependence. Plots of C/T versus T for several samples are shown in figure 3. The magnitude of the anomaly varies from sample to sample, even though all of the samples investigated here were cut from one mother single crystal ♯1. In particular, sample ♯1-2 exhibits a huge C/T value that amounts to ~ 200 mJ/mole K^2, implying the existence of huge density of states near the Fermi energy enhanced by the many body effect. In conjunction with the strong sample dependence, this anomaly is probably ascribed to an impurity (including defect) effect. It is unclear if this effect is related to a magnetic polaron formation [7].

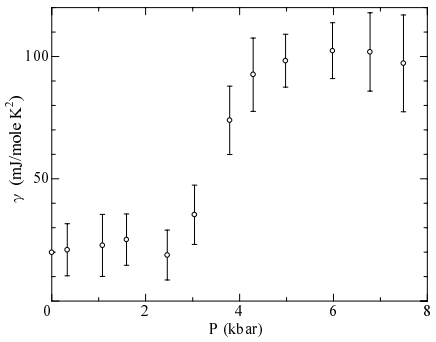

Fig. 2. γ-value as a function of pressure. γ shows a steep increase at around $P_c \sim 3.5$ kbar.

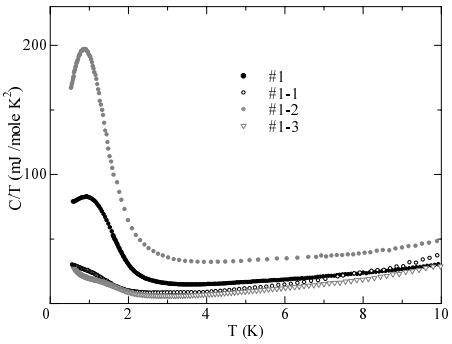

Fig. 3. Plot of C/T versus T for several samples at ambient pressure. The magnitude of the anomaly around 1 K exhibits a strong sample dependence.

To conclude, we have studied the pressure dependence of γ-value, and found its steep increase at around $P_c \sim 3.5$ kbar, corresponding to the insulator-metal transition. We observed that there appears an anomaly with a huge C/T value around 1 K. We also revealed that the metal phase is a strongly correlated metallic state.

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