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Far infrared transmission of SmTe under high pressure

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Abstract

We measured the transmission spectra of SmTe under several pressures in the energy region between 40 and 320 cm^{-1} at 300 and 110 K. At $P = 0$ GPa a strong absorption appears from 90 to 190 cm^{-1} at 300 K and 100 to 165 cm^{-1} at 110 K. This indicates that ω_{TO} increases with temperature and ω_{LO} decreases with increasing temperature. Another absorption appears at around 290 cm^{-1} with the half width of 20 cm^{-1}. The possibility for its origin is considered as two methods. One seems to be due to the two phonon process. The other seems to be due to a magnetic quasi-particle such as a magnetic polaron. We found that the semiconductor–metal transition in SmTe occurs at 3.5 GPa.

Since 1960 the Sm monochalcogenides have greatly attracted many scientists' attention because of their varied physical properties. It was recognized by Picon et al. [1] that these firstly show semiconducting properties. In 1964 Zhuze et al. [2] reported that the black surface of SmS changes into the golden colored surface after polishing, which today can be taken as the first hint of a pressure-induced semiconductor–metal transition. The researches for the pressure-induced phase transition in the Sm monochalcogenides, thereafter, have been achieved. Jayaraman et al. reported that it is first order in SmS at a critical pressure of only 6.5 kbar [3]. Bucher et al. also reported that it occurs at 35 and 53 kbar in SmSe and SmTe, respectively [4]. In spite of the fact that the semiconductor–metal transition of Sm monochalcogenides might play a important role in many modern physical theories, experiments on the stoichiometric Sm-monochalcogenides are scarce due to the experimental difficulties under high pressure and the growing difficulties of their single crystals. Especially, optical properties under high pressure have been almost reported, besides SmS.

Hence, experimentally, the discovery of the pressure-induced semiconductor–metal transition in SmTe using optical measurements appears to be a significant achievement in modern physics. In this paper, we report the results on the optical transmission measured under high pressure for single crystal SmTe.

We measured the transmission spectra of SmTe under several pressures in the energy region between 40 and 320 cm^{-1} at 300 and 110 K. The measurement was done using synchrotron radiation (SR) as a light source at the SR facility of the Institute for Molecular Science (UVSOR). At the beam line, BL6A1 of UVSOR, the SR light was led to a Martin–Puplett type Fourier-spectrometer and the interferogram was recorded by a liquid helium cooled bolometer. The pressure system was a lever-arm type diamond anvil cell (DAC). The measurement of the pressure was done by using the shift of two fluorescence line spectra, R_1 (694.3 nm at $P = 0$ GPa) and R_2

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(692.9 nm at $P = 0$ GPa) of a small piece ruby, which was put into the DAC together with the sample.

The single crystals of SmTe have been grown by the Bridgeman method using the high-frequency induction furnace in an evacuated and sealed tungsten crucible. Its lattice constant is estimated to be 6.602 Å. Its gap is evaluated to be 0.635 eV from its electrical resistivity. The resistivity at 130 K is about 2×10^4 times larger than that at 300 K. This indicates that SmTe has a good purity.

Fig. 1 shows the wave number dependence of reflectivities at 300, 78 and 10 K for SmTe at $P = 0$ GPa. A peak and a weak dip appear at about 120 and 270 cm^{-1}, respectively. The former seems to be due to the optical phonon. The peak decreases as increasing temperature. This is due to the increase of damping energy, which represents a force always opposed to the ionic motions, with increasing temperature. The latter is an interesting one, the origin of which will be mentioned below.

Figs. 2 and 3 show the wave number dependence of transmission under several pressures at 300 and 110 K, respectively. At $P = 0$ GPa a strong absorption appears in both temperatures. The wave number region of the absorption is from 90 to 190 cm^{-1} at 300 K and 100 to 165 cm^{-1} at 110 K. This indicates that ω_{TO}, which denotes the natural frequency of the transverse oscillator for phonon, increases with temperature and ω_{LO}, which denotes the natural frequency of the longitudinal oscillator, decreases with increasing temperature. In the wave number region, the transmission at 300 K is slightly higher than that at 110 K. This is due to the increase of the damping energy, which

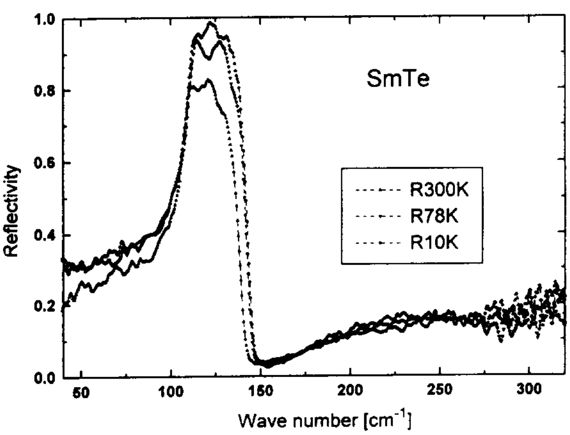

Fig. 1. The wave number dependence of reflectivities at 300, 78 and 10 K at $P = 0$ GPa for SmTe.

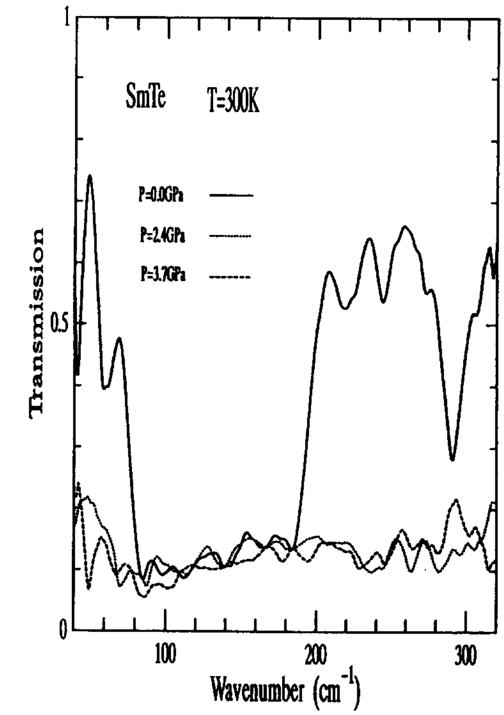

Fig. 2. The wave number dependence of transmissions under several pressures at 300 K for SmTe.

represents a force opposed to the ionic motions, with increasing temperature. Another absorption appears at around 290 cm^{-1} with a half width of 20 cm^{-1}. The possibility for its origin is considered as two methods. One seems to be due to the two phonon process, TO + LO, because the absorption energy is similar to the energy of LO + TO. Although the temperature dependence of the ω_{TO} and ω_{LO} are strong, however, the energy of the absorption is almost independent of temperature. Thus, this possibility is not yet certain. The other seems to be due to the magnetic quasi-particle such as a magnetic polaron. The 4f-electrons (f^6) in SmTe lie between a valence and a conduction band [5]. The magnetic interaction (magnetic polaron) between $4f^5$, which has a magnetic moment, and the magnetic moment of the conduction electron being originated from $4f^6$–5d transition reduces the energy. This is, also, not certain yet. More detailed experimental and theoretical studies are needed.

The transmission in regions below 100 cm^{-1} and around 240 cm^{-1} suddenly decreases above $P = 2$ GPa. At last, the light wave may not almost transmit the sample above 2.4 GPa at 300 K and 3.5 GPa at 110 K, at which we failed the transmission measure-

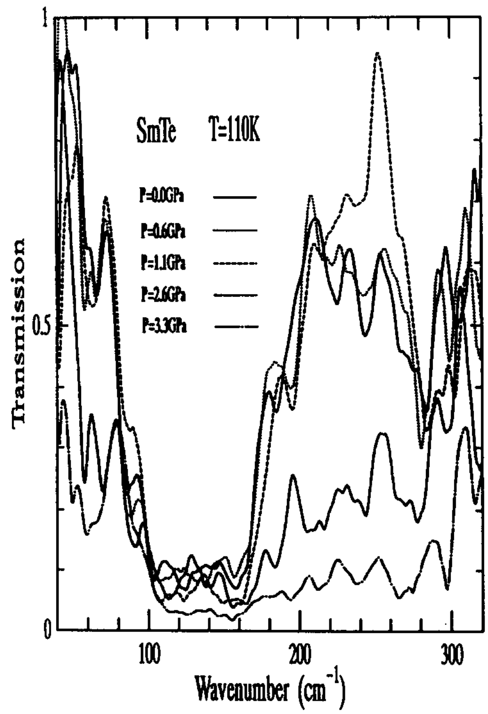

Fig. 3. The wave number dependence of transmissions under several pressures at 110 K for SmTe.

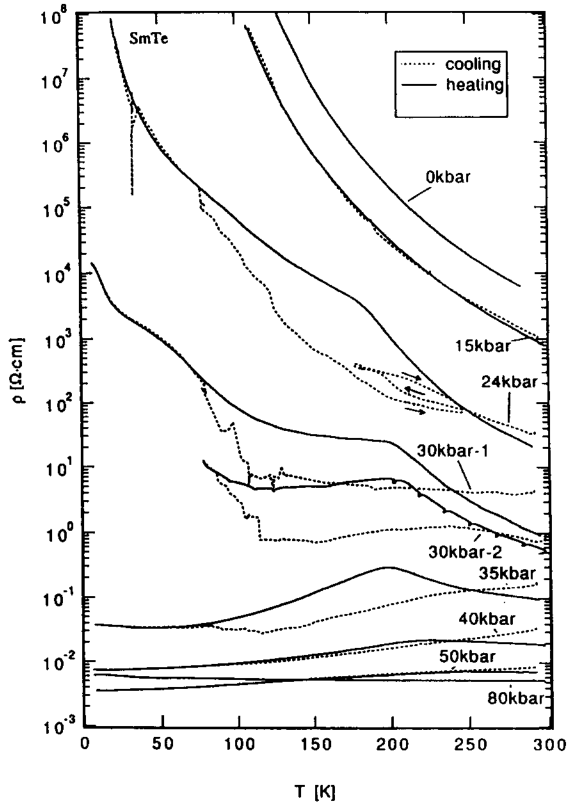

Fig. 4. The temperature dependence of electrical resistivities under several pressures for SmTe.

ment because the light did not transmit. These facts indicate that the Drude reflection by carriers occurs. As shown in Fig. 4, however, the resistivity at 2.4 GPa shows the temperature dependence of a semiconductor. The fact that the light do not transmit the sample at 300 K seems to be due to the carriers created through thermal excitations. From the results of 110 K almost without the thermal excitation, we conclude that the semiconductor–metal transition in SmTe occurs at 3.5 GPa. This is consistent with the results of resistivity.

We achieved success on the measurement of the optical transmission under high pressures for rare-earth compounds. This experiment is expected to give much information to modern physics and is, thus, considered a valuable one. To get more detailed information, we are planning the measurement of reflectivity, which will give the information of the created carriers, under high pressure.

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