Infrared Spectroscopy under Multiextreme Conditions: Direct Observation of Pseudogap Formation and Collapse in CeSb

Cerium monoantimonide (CeSb) has many magnetic phases with complex magnetic structures at low temperatures, high pressures and high magnetic fields [1]. The magnetic structure affects the transport property through the hybridization between Ce 4*f* and Sb 5*p* orbitals, referred to as *pf* mixing [2]. One of the characteristic properties is that at pressures (*P*) of several GPa [3] the electrical resistivity at a temperature (*T*) of around 30 K increases by one full order over that at ambient pressure. Then, we investigated the origin of this enhancement of the electric resistivity using the infrared spectroscopy under multiextreme conditions of low temperatures, high pressures and high magnetic fields.

The experiment was performed at the infrared magneto-optical imaging beamline **BL43IR**. To perform infrared spectroscopy under multiextreme conditions, a diamond anvil pressure cell with a sample was set at the sample position located at the center of a superconducting magnet. The sample conditions were $T \geq 4$ K, $P = 4$ GPa and magnetic fields of $B \leq 14$T.

The temperature dependence of the optical conductivity [σ(ω)] spectrum derived from the Kramers-Kronig analysis of the reflectivity spectrum at P = 4 GPa and B = 0 T is shown in Fig. 1. Below $T = 30$ K and above 60 K, the spectra are typically metallic because σ(ω) increases with decreasing photon energy. At intermediate temperatures, the σ(ω) spectrum displays a strong temperature dependence. At 30 K, the spectrum changes drastically. In particular, σ(ω) below 0.1 eV decreases with decreasing photon energy. This means that the metallic character is suppressed at intermediate temperatures. The σ(ω) spectrum at 35 K has a peak with a center energy of 65 meV. The peak structure indicates the pseudogap appears under the given condition.

The pseudogap collapses not only by increasing temperature but also by applying magnetic field higher than 6.5±0.5 T. The magnetic field - temperature (*B*-*T*) phase diagram at 4 GPa resulting from changes in the σ(ω) spectrum is shown in Fig. 2. In the phase named AF-1, an antiferromagnetic spin aligns directly along the magnetic field. The Sb 5*p*

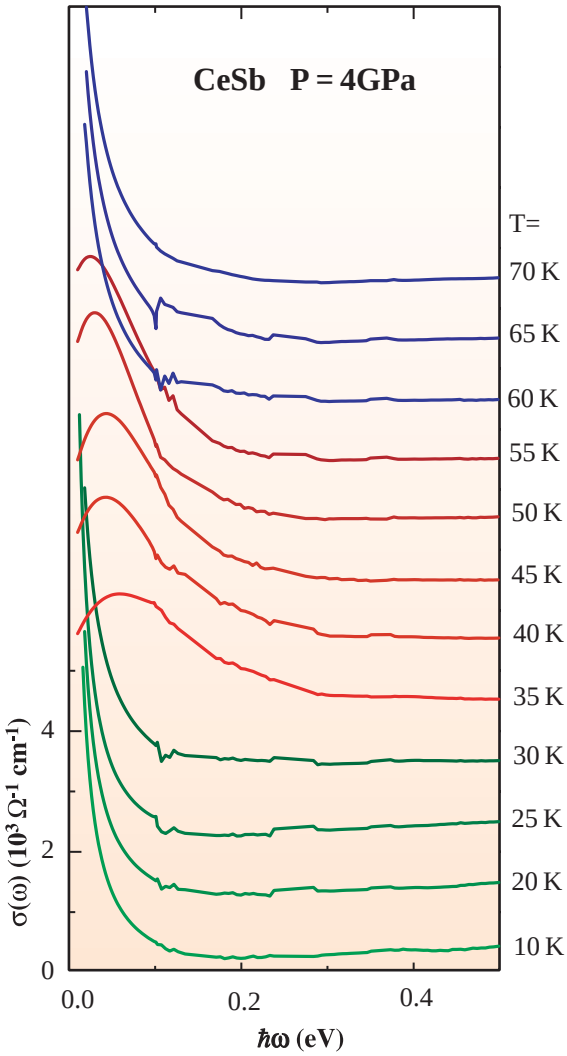

Fig. 1. Temperature dependence of optical conductivity (σ(ω)) spectrum of CeSb at $P = 4$ GPa and $B = 0$ T. Successive curves are offset by 10^3 for clarity. Same phases are shown by the same colors.

band is modulated by the magnetic structure and then the energy gap opens at the Fermi level. In the figure, two phase diagrams of *P*-*T* at B = 0 T [1] and *B*-*T* at ambient pressure [4] are also plotted. The phase diagram at 4 GPa is simpler than that at ambient pressure. In particular, the complex magnetic structure at ambient pressure disappears at 4 GPa. At ambient pressure, since the *pf* mixing competes with other magnetic interactions and crystal field splitting, such complex magnetic phases and structures appear. With increasing pressure, the *pf* mixing is enhanced and then predominates among these interactions. The enhancement of *pf* mixing also results in a simpler magnetic phase diagram at 4 GPa. This is the plausible result of the *pf* mixing enhancement due to applied pressure. This is the first optical observation of the magnetic field induced nonmetal-metal phase transition at high pressures [5].

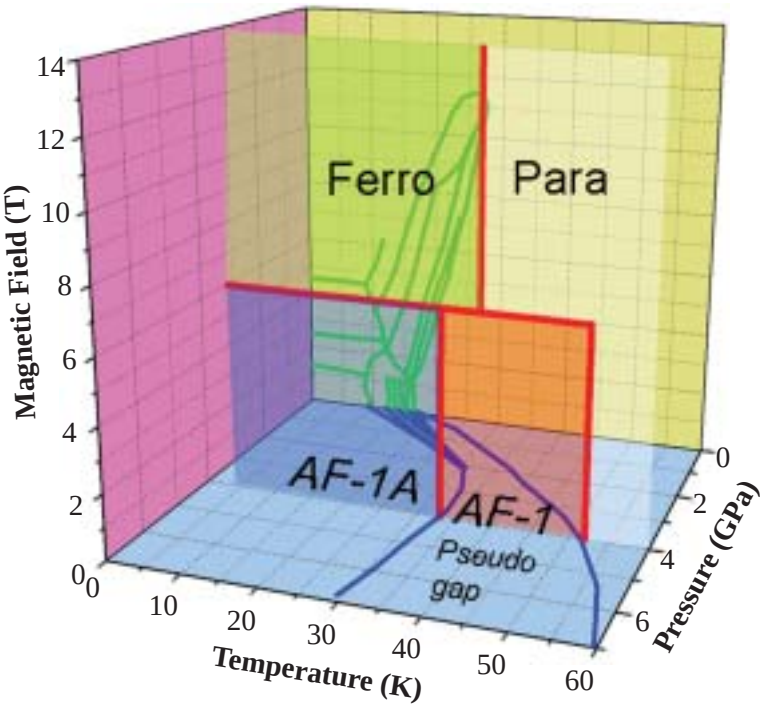

Fig. 2. Magnetic field - temperature (*B*-*T*) phase diagram of CeSb at *P* = 4 GPa derived from σ(ω) spectra under multiextreme conditions. The phase diagrams of *P*-*T* at 0 T (blue lines) [1] and *B*-*T* at ambient pressure (green lines) [5] are also plotted for reference. AF-1 and AF-1A are the names of the phases. Only AF-1 phase has a pseudogap structure.

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