Low-energy spectroscopy of SmB_6

M. Dressel[a,b,*], B. Gorshunov[a,b,c], N. Sluchanko[c], A. Volkov[c], G. Knebel[b], A. Loidl[b], S. Kunii[d]

[a] 1, Physikalisches Institut, Universität Stuttgart, Germany
[b] Experimentalphysik V, Universität Augsburg, Germany
[c] General Physics Institute, Russian Academy of Sciences, Moscow, Russia
[d] Department of Physics, Tohoku University, Sendai, Japan

Despite three decades of research, many fundamental properties of the intermediate valence semiconductor SmB_6 are not fully understood [1,2]. The results of determining the hybridization gap can be divided into small (3–5 meV) and large (10–15 meV) values [1]. From optical experiments the gap was estimated to lie in the range 3–10 meV [1,3] with a large uncertainty due to the low-frequency extrapolation necessary for the Kramers-Kronig analysis. Utilizing a Mach–Zehnder interferometer we measured the optical transmission and phase shift of a prepared 28 μm thick SmB_6 crystal in the energy range of 0.6–4.5 meV at low temperatures $T < 20$ K; DC resistivity, Hall effect, and infrared reflectivity experiments were also conducted on these single crystals [4].

* Correspondence address: 1, Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany. Fax: + 49-711-685-4886; e-mail: dressel@pil.physik.uni-stuttgart.de.

The conductivity and dielectric constant displayed in Fig. 1, are directly calculated from the measured transmission spectra and phase shifts using Fresnel's equations. Above 13 K we find a Drude-like behavior typical for the response of free charge carriers. At $T \approx 8$ K and lower the spectrum becomes dispersionless as characteristic for a dielectric material, with a value $\varepsilon(0) \approx 600$. The absorption peak at $24\,\mathrm{cm}^{-1}$ in the 3 K conductivity spectrum corresponds to the step in $\varepsilon(\nu)$. Fig. 2 gives an overview of the conductivity in a large spectral range. The low-temperature electrodynamic response can be well described by $\sigma(\nu) = \sigma_{\mathrm{Drude}}(\nu) + \sigma_{\mathrm{osc}}(\nu) + \sigma_{\mathrm{IRose}}(\nu) + \sigma_{\min}$ where σ_{Drude} is the free carrier response, σ_{osc} describes the $24\,\mathrm{cm}^{-1}$ peak, σ_{IRose} is the IR conductivity, and $\sigma_{\min} \approx 10\,(\Omega\,\mathrm{cm})^{-1}$ denotes the minimum conductivity. Using this model we determine the scattering range and plasma frequency of the free charge carriers of concentration N. From $N \propto \exp\{-E_g/2k_BT\}$ at $15\,\mathrm{K} < T < 20\,\mathrm{K}$, we find an hybridization gap $E_g = 19$ meV. Below 15 K, $N \propto \exp\{-E_d/k_BT\}$ gives evidence for a narrow donor-type band inside the gap located $E_d = 3$ meV below the bottom of the upper band.

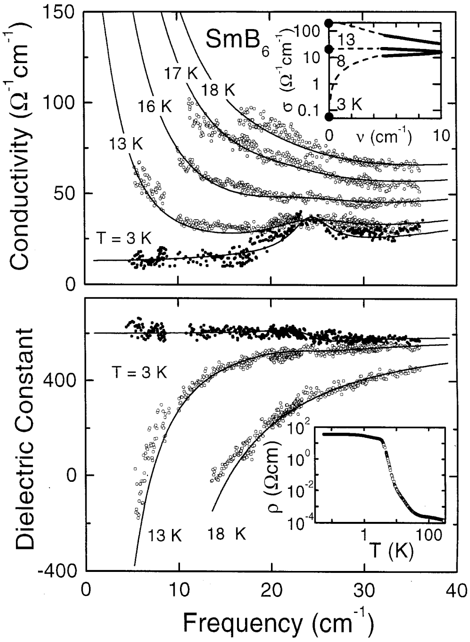

Fig. 1. Spectra of the conductivity and the dielectric constant of SmB_6. The solid lines show the fits by our model. The inset in the upper panel compares these data with the DC conductivity (large solid dots). The interpolation (dashed lines) is done by a Drude term, by a constant value, and by $\sigma(\nu) \propto \nu$ for 13, 8, and 3 K, respectively. The inset of the lower panel shows the temperature dependence of the DC resistivity.

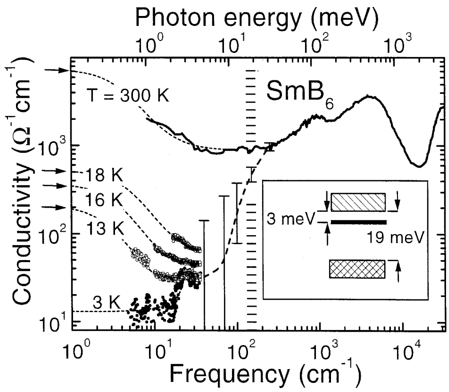

Fig. 2. Frequency dependent conductivity of SmB_6. The small dots correspond to the sub-mm data; the arrows to the DC conductivity. The solid lines are obtained by the Kramers–Kronig analysis of the reflectivity spectra. The thick dashed line interpolating the 3 K data sets is a guide to the eye. The error bars give the upper and lower boundary of the IR conductivity obtained by the Kramers–Kronig analysis of the 3 K reflectivity spectrum. The thin dashed lines are calculated by our model. The shaded area corresponds to the energy gap value (19 ± 2) meV. The inset gives a simplified view of the band scheme of SmB_6.

At the same energy we observe the 24 cm^{-1} peak which can be associated with the direct excitation of charge carriers from the narrow band to the conduction band. Assuming only electrons participating in the transport, we can evaluate the effective mass $m^* \approx 100 m_0$ indicating the importance of correlations in the enhanced density of states at the bottom of the conduction band [4].

For $T \leqslant 5$ K the Drude-like dispersion has disappeared and the sub-mm response is dominated by σ_{min}. The low-frequency (below a few cm^{-1}) conductivity exhibits a strong dispersion $\sigma(\nu) \propto \nu$ which we attribute to the localization of carriers and hopping transport. In the range $4\,K < T < 10\,K$ we find $\sigma_{dc}(T) \propto \exp\{T_0/T^{1/4}\}$ with $T_0 = 54$ K as predicted for variable range hopping.

References

[1] P. Wachter, in: K.A. Gschneider Jr., L. Eyring (Eds.), Handbook on the Physics and Chemistry of Rare Earths, Vol. 19, North-Holland, Amsterdam, 1994, p. 177 and references therein.

[2] G. Aeppli, Z. Fisk, Comm. Condens. Matter. Phys. 16 (1992) 155.

[3] H. Ohta et al., J. Phys. Soc. Japan 60 (1991) 1361 and references therein.

[4] B. Gorshunov et al., Phys. Rev. B 59 (1999), to appear.