Thermal conductivity of gallium sulfide

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(Submitted May 22, 1998)
Fiz. Tverd. Tela (St. Petersburg) **41**, 24–25 (January 1999)

The results of investigating of the thermal conducitivity of a GaS single crystal in directions parallel and perpendicular to the *c* axis in the temperature interval 5–300 K are reported. The investigations show that the degree of anisotropy of the thermal conductivity of GaS decreases with temperature. © *1999 American Institute of Physics.* [S1063-7834(99)00601-2]

The strong anisotropy of interatomic interactions in lamellar crystals gives rise to a variety of specific properties. The phonon spectrum of strongly anisotropic materials has been repeatedly investigated theoretically, but there is no unequivocal interpretation of the experimental data. The specific features of the phonon spectra of such crystals are reflected in the behavior of the heat capacity, thermal expansion, and thermal conductivity.

In the present work we investigated the thermal conductivity of a lamellar GaS crystal in the temperature interval 5–300 K. In Ref. 1, where the specific heat of gallium monosulfide is studied at low temperature, it is shown that flexural waves with a quadratic dispersion law play the main role in the behavior of $C_p(T)$ at low temperatures. A quasiflexural mode was later observed in the phonon spectrum of GaS by neutron diffraction.[2] Thus it is doubtless of scientific interest to study the influence of structural anisotropy on the thermal conductivity of this compound.

The thermal conductivity was measured by the steady-state method.[3] The temperature gradient was measured with copper–constantan and Cu–Cu+Fe thermocouples. The thermocouples were calibrated with respect to platinum and germanium resistance thermometers. The thermocouples were indium-soldered to the sample. Adiabatic screens, whose temperature was regulated automatically, were used to prevent any heat losses by lateral radiation. The error in the measurements of the thermal conductivity did not exceed 5%. Reference measurements of the thermal conductivity in crystal quartz cut parallel to the *c* axis agree with published data. Single-crystal GaS samples were cut in the form of a 0.10–0.15 cm^2 and 2–2.5 cm long parallelepiped.

Figure 1 shows the temperature dependences of the thermal conductivity in directions perpendicular ($\varkappa_\perp$) and parallel ($\varkappa_\parallel$) to the principal axis *c* of a hexagonal GaS crystal. The thermal conductivity of GaS above 100 K has been studied in Ref. 4. Our room-temperature data agree satisfactorily with the results obtained in Ref. 4. As one can see from the figure, the temperature dependences $\varkappa_\perp(T)$ and $\varkappa_\parallel(T)$ have a maximum at 24 and 20 K, respectively. We note that the electronic part can be neglected, i.e. in the experimental temperature interval heat is transferred by phonons. At room temperature the degree of thermal conductivity anisotropy reaches $\varkappa_\perp/\varkappa_\parallel \sim 9$. the degree of anisotropy decreases with temperature, and is approximately 3 at 20 K and ~ 1.7 at liquid-helium temperatures. At low temperatures (below the maximum in the region of boundary scattering) the temperature dependence of $\varkappa$ in gallium sulfide satisfies the power law $\varkappa_\perp \sim T^{2.4\pm0.1}$ and $\varkappa_\parallel \sim T^{2.1\pm0.1}$. In the same temperature range the temperature dependence of the heat capacity has the form given in Ref. 1 for GaS. Above the maximum the thermal conductivity of GaS can be expressed as $\varkappa_\perp \sim T^{-0.7}$ and $\varkappa_\parallel \sim T^{-1.1}$ in a wide temperature interval 60–300 K.

We note that the temperature variation of $\varkappa_\parallel$ is somewhat different in different samples. This is probably due to the difficulty of cutting out and orienting the samples in the [001] direction. The $\varkappa_\parallel$ data were obtained by averaging measurements for two samples.

It is known[5] that in lamellar crystals, including GaS, the acoustic phonons can be treated approximately as if they belong to three separate frequency branches $\omega_l \sim k, \omega_t \sim k$, and $\omega_c \sim k^2$. The phonons belonging to the *l* and *t* branches correspond to longitudinal and transverse in-plane atomic displacements. The *c* branch pertains to out-of-plane modes.

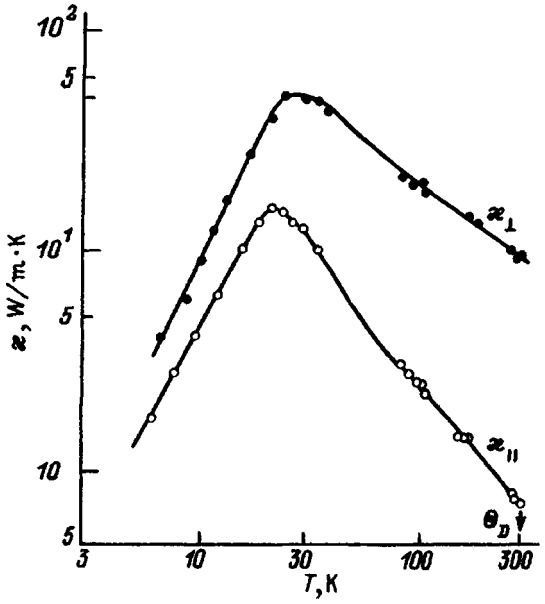

FIG. 1. Temperature dependence of the thermal conductivity of gallium sulfide parallel ($\varkappa_\parallel$) and perpendicular ($\varkappa_\perp$) to the *c* axis. The arrow marks the Debye temperature.

The difference between $\varkappa(T)$ and $C_p(T)$ at low temperatures (below 20 K) for GaS is probably due to the difference in the contributions of *c*, *l*, and *t* phonons to the thermal conductivity and heat capacity.

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Translated by M. E. Alferieff