Origin of Hypersonic Attenuation in Germanium at Low Temperatures

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Hypersonic attenuation in germanium at different temperatures is calculated and compared with the recent low-temperature measurements by Truell and his associates. The excellent agreement between the theory and experiment for the temperature dependence shows that Umklapp processes are responsible for the attenuation at low temperatures.

HYPERSONIC attenuation in germanium at low temperatures has been recently studied by Truell and his associates.[1] They found a sharp rise in attenuation beginning at about 20°K, similar to thermal resistivity measurements in dielectric crystals at low temperatures where phonon-phonon scattering associated with Umklapp process is considered to be responsible for the sharp rise in thermal resistivity with the increase in temperature. The very fact that acoustic wavelengths are roughly of the same order as the mean free path for Umklapp processes supports our expectation that Umklapp processes are also present here.

According to Akhiezer[2] sound waves on passing through a crystal disturb the equilibrium distribution of thermal phonons. The re-establishment of equilibrium in the phonon gas requires an increase of entropy and leads to absorption of sound. Introducing a few simplifying assumptions Bömmel and Dransfeld[3] have obtained the following expression for the absorption coefficient:

$$\alpha(\text{db/inch})=1.1\frac{cT\gamma_{\text{av}}^2}{\rho v^3}\frac{\omega^2\theta}{1+(\omega\theta)^2},$$

where c is the specific heat per cc, v is the longitudinal sound velocity, ρ is the density, γ_{av} is the average Grüneisen constant, ω is the angular frequency of the sound wave, and θ is the relaxation time for phonon-phonon Umklapp processes.

This expression has been shown to be in qualitative agreement with experiment in quartz where a similar rise in hypersonic attenuation was reported earlier by Bömmel and Dransfeld.[4] No attempt, however, was made to calculate the attenuation at different temperatures (except when $\omega\theta=1$) and compare it with experiment. We have calculated hypersonic attenuation at different temperatures in the case of germanium and have compared it with experiment. The small apparent attenuation below 20°K, which is independent of temperature and is largely due to the reflection losses, has been subtracted from the observed attenuation at other temperatures. The solid curve in Fig. 1 is the theoretical curve and the circles represent the experimentally observed attenuation at 508 Mc/sec after making the correction for reflection losses. The relaxation time at these low temperatures has been calculated with the help of the relation $K=\frac{1}{3}cv^2\theta$, where K is the thermal conductivity, c is the specific heat, and v is the velocity of sound waves. Values of thermal conductivity, specific heat, and elastic constant c_{11} at low temperatures used in the calculation are from the measurements of Rosenberg,[5] Hill and Parkinson,[6] and Fine,[7] respectively. A value of the average Grüneisen constant was obtained by choosing it such that the theoretical value of the hypersonic attenuation was equal to the experimental value, say, at 70°K. This value was used for all subsequent calculations.

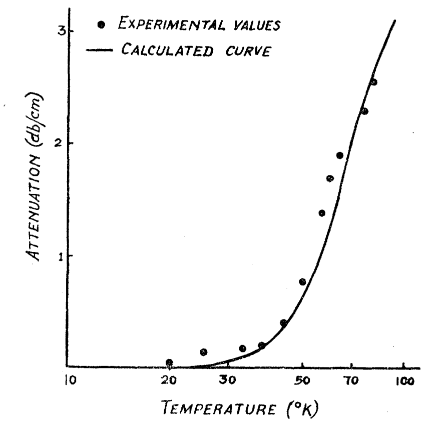

FIG. 1. Hypersonic attenuation in germanium at low temperatures.

The excellent agreement between the theory and experiment for the temperature dependence of hypersonic attenuation in germanium, as shown in Fig. 1, shows unmistakably that phonon-phonon Umklapp processes are responsible for the observed hypersonic attenuation at low temperatures.

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