# PHONON SCATTERING DUE TO DEEP ACCEPTORS IN SEMICONDUCTORS

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We have measured the magnetothermal conductivity in GaAs(Mn) [$3.8 \times 10^{18}$ $cm^{-3}$] and Si(In) [$5 \times 10^{15}$ $cm^{-3}$] for temperatures between 1.4 K and 90 K at magnetic fields up to 8 T. In both cases the dopants are deep acceptors with binding energy much larger (110 meV and 165 meV respectively) than given by the effective mass theory (~35 meV). There is a double interest in such systems: First, an excited level 3 meV (4.2 meV) above the acceptor ground state has been concluded from ultrasonic measurements /1/ /2/. Such an excited state might be connected with a Jahn-Teller effect of these deeper acceptors and should be seen by resonant phonon scattering in thermal conductivity. Second, an anomalous behavior of the magnetothermal conductivity has been found for shallow acceptors in Ge (but not in Si) /3/ making comparison with systems with different g-factors desirable. The g-factors of acceptors in GaAs are roughly three times, the g-factor of Si(In) about 0.6 times that of Si(B).

In zero magnetic field in both cases we see a strong reduction of the thermal conductivity at low temperatures as compared to the pure material scaling well in concentration with the reduction found for shallow acceptors; furthermore, a distinct dip is seen at about 23 K for Si(In) (Fig. 1) and at about 12 K for GaAs(Mn) (Fig. 2). The same dip has been found for GaAs(Mn) by Holland /4/ at concentrations lower than ours. The maximum thermal conductivity for Si(In) is reduced due to about $10^{18}$ $cm^3$ oxygen contained in the sample /2//5/. The dependence on magnetic field is analogous to that found by Challis and Halbo /3/ for Si(B): The relative thermal conductivity $\varkappa_B/\varkappa_0$ for GaAs(Mn) first falls to a minimum value of about 0.6 (due to an enlarged resonant scattering) and then rises rapidly (Fig. 3). However, this rise tends to saturate at the highest fields to a value about ten times below that of the pure crystal, which may be due to

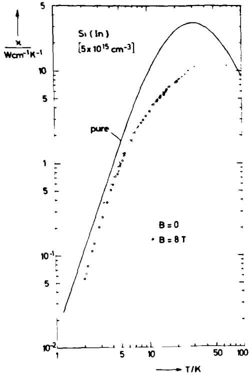


Fig.1 Thermal conductivity in Si(In).

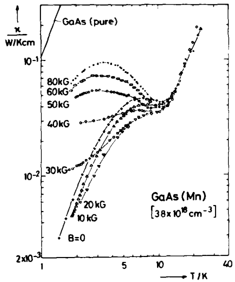


Fig.2 Thermal conductivity in GaAs(Mn) at several magnetic field strengths.

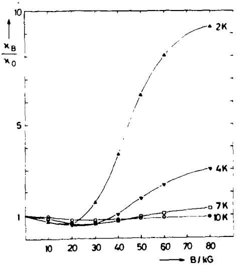


Fig.3 Relative thermal conductivity $\kappa_B/\kappa_0$ in GaAs(Mn) as a function of magnetic field at various temperatures.

the low frequency part of the resonance scattering associated with the dip at 12 K. As is expected from the small g-factor, the variation of $\varkappa_B/\varkappa_0$ for Si(In) is slow; that is, only a reduction is seen attaining a minimum value of 0.8 at 2 K and 8 T. Thus, in both cases the magnetic field dependence does not show the "anomaly" found for shallow acceptors in Ge. However, the variation of $\varkappa_B/\varkappa_0$ for Si(In) seems to be somewhat slower than can be accounted for by the g-factor and, in the case of GaAs(Mn), the minima of $\varkappa_B/\varkappa_0$ at different temperatures do not scale very well with B/T, but there is a part $\propto (B/T)^2$.

For an analysis of $\varkappa_0$ we applied a modified model for the acceptor ground state: A distribution of small splittings $\delta$ (determining the low temperature part of the scattering) and an excited level $\Delta$ above these split levels. The extended nature of the acceptor wave function, reducing the interaction with short wavelength phonons, was taken into account (Bohr-radius 10 Å for GaAs(Mn) and 7.4 Å for Si(In)). The formula for resonance fluorescence scattering in the form given by Suzuki and Mikoshiba /6/ was applied. The assumption $\delta \ll kT$ made for ease of calculation underestimates the scattering at the lowest temperatures. A good fit following the acute variation of $\varkappa_0$ in the dip region especially for GaAs(Mn) was not possible. In both cases it was necessary to take a smaller Bohr radius for the excited level (3 Å for GaAs(Mn)). The best values for $\varkappa_0$ thus obtained are 5 meV for Si(In) and 3 meV for GaAs(Mn). This has to be compared with the values analyzed from ultrasonic measurements. A more direct determination of these energies with quasimonochromatic phonons /7/ is desirable.

One of us (K. L.) gratefully appreciates the cordial hospitality of the group of Service Basses Températures, CEN Grenoble.

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