R. S. Title

Paramagnetic Resonance of the Shallow Acceptors Zn and Cd in GaAs

The emission observed in GaAs diode injection lasers is believed to be an electronic transition involving acceptor levels.[1] In this Letter the paramagnetic resonance absorptions of the neutral acceptors Zn and Cd in GaAs are reported.

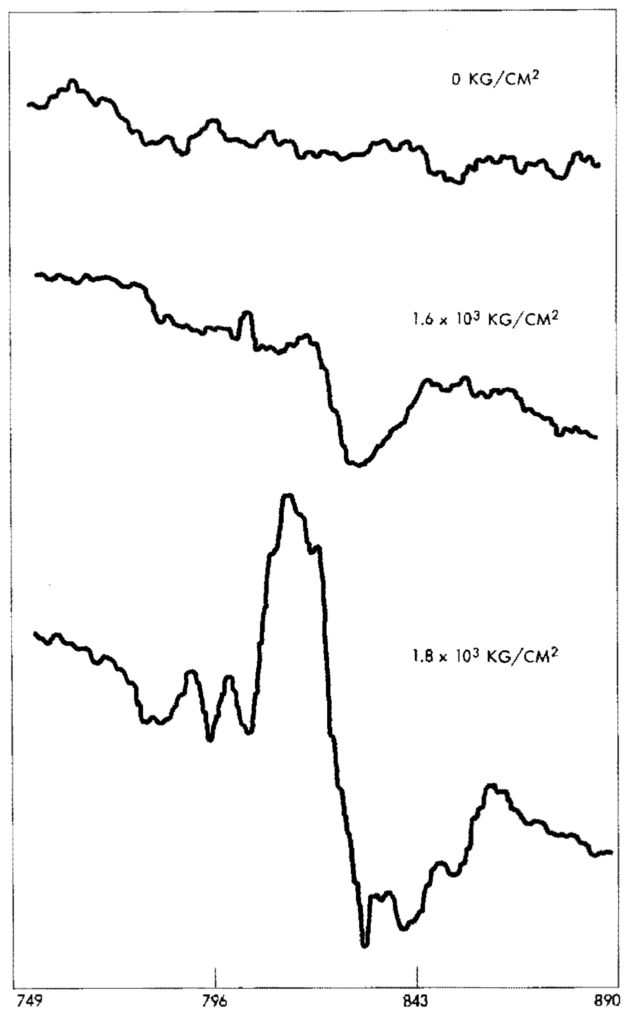
To a first approximation the wave function of the bound hole at the Zn or Cd sites may be considered identical to that of a free hole. The ground state for a free hole at $k=0$ is fourfold degenerate and can be characterized by $J=3/2$. The fourfold degenerate level will split into two doubly degenerate levels when the crystal is strained. The separation between these levels is proportional to the strain. For the strains normally present in the crystal, e.g., those due to dislocations, the separation of the split levels is comparable to that produced by applying a magnetic field of a few thousand gauss. Since the internal strains are random there will be a distribution in the magnitude of the splitting. No paramagnetic resonance absorption between the levels, therefore, is observable. The resonance may, however, be observed by applying a large uniaxial strain to the crystal.[2] The acceptor resonances in silicon have been observed in this way.[2,3]

The nature of the resonance when a large uniaxial stress is applied to the sample has been considered by Kohn[4] and by Pikus and Bir.[5] For large strains the resonance absorption in a direction parallel to the strain direction is characterized by $g_{\parallel} = 2\kappa$, where κ is the valence band parameter introduced by Luttinger.[6] In the perpendicular direction $g_{\perp} = 2g_{\parallel}$. In a general direction $g = (g_{\parallel} \cos^2\theta + g^2_{\perp} \sin^2\theta)^{1/2}$ where θ is the angle between the magnetic field and the stress direction. The above theory is applicable to the case of a free hole. In the case of silicon[2] departures from theory were found, the amount of departure being proportional to the binding energy of the hole at the acceptor. Indium, with the largest binding energy, has the smallest g values in the case of silicon.[2]

Samples of GaAs were mounted along the axis of a TE_{011} cylindrical cavity between two teflon holders. The stress was applied by means of a stainless steel rod pushing against one of the teflon holders. Stresses up to 2.5×10^3 kg/cm^2 were used. All measurements were made at 4.2°K. This method of applying stress allows only $g_{\perp}$ to be measured.

Results for a GaAs sample containing 3×10^{17} Zn atoms/cm^3 are shown in Fig. 1. A resonance at $g_{\perp} = 8.1\pm0.1$ was found at the highest stresses. Stress was applied along the [100] axis. As shown in Fig. 1 the magnitude of the resonance is very sensitive to the

Figure 1 **EPR signal of a Zn acceptor level in GaAs under various stresses.**



amount of stress. There is also an indication of a shift to higher g values as the stress is increased. Similar dependence of the g values on stress had been found for the acceptors in silicon.[2,3]

A resonance was also observed for a GaAs sample containing 5×10^{16} Cd atoms/cm^3. Because of the lower doping level, stresses in excess of 2×10^3 kg/cm^2 were required to bring the level of the resonance above the noise. Stress was applied along the [100] axis. The value of $g_\perp$ was found to be 6.7 ± 0.1. At the higher values of stress the magnitude of the resonance was found to be less stress sensitive than was the case for the heavier Zn-doped GaAs. A similar independence of the relaxation time of boron acceptor levels in silicon with stress for higher stresses had been observed by Ludwig and Woodbury.[3]

The $g_\perp$ value for Cd, 6.7 ± 0.1, is smaller than that for Zn, 8.1 ± 0.1. This would indicate that the hole at the Cd acceptor level is more tightly bound than that of the Zn level.

The value of $g_\perp = 8.1$ for Zn gives a lower limit to the value of κ, the antisymmetric constant for the valence band introduced by Luttinger.[6] For *free* holes $g_\perp$ would be equal to 4κ. The value of $g_\perp$ for Zn indicates that $\kappa > 2.0$. A closer estimate could be obtained from an acceptor level to which the hole is less tightly bound than at the Zn site. No calculation for κ has been made for GaAs. One would expect, however, that κ for GaAs would be similar to κ for Ge, which has been estimated by Kohn[4] to be 3.5 ± 0.2. The value $\kappa > 2.0$ is of the same order of magnitude as this estimate. For silicon a much smaller κ value equal to 0.6 was measured.[2]

Variations in the g values made by applying the stress in other directions and by varying the magnitude of the strain will be studied.

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