Mobility in Zinc Blende and Indium Antimonide

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CRYSTALS of the sphalerite structure are piezoelectric.[1] Therefore, there will be an electric polarization associated with the acoustical modes of vibration in zinc blende and indium antimonide. This polarization may lead to local charge accumulation and a periodic electrical potential. The contribution to the electronic scattering by this potential has been calculated for these two cases. It can be shown that there is a phase difference of 90° between the matrix element for scattering by this mechanism and the matrix element found by deformation potential theory; hence it is valid to consider the mechanisms independently.

Normal modes of vibration are developed in the form of traveling waves, assuming the crystal to be elastically isotropic as a working approximation. From the strain associated with each of the modes, the electric polarization is found by using the form of the piezoelectric tensor determined by the crystal symmetry.[1] Use of the measured piezoelectric constant, however, gives the polarization in the absence of an electric field, and an induced polarization equal to $(k_s-1)/4\pi\mathbf{E}$ must be added, where $\mathbf{E}$ is the internal electric field and k_s is the static dielectric constant. By making this correction and using Poisson's equation, the electrical potential is calculated. From this potential the matrix elements for scattering an electron of wave number $\mathbf{k}$ into a state of wave number $\mathbf{k}'$ by longitudinal waves and by each of the transverse waves are found, assuming that the lattice vibrations of importance are fully excited and that an effective mass approximation is valid. The squares of the three matrix elements are then added. In the determination of the relaxation time for electron scattering, τ, the integral over $\mathbf{k}'$ depends upon the choice of initial electron wave number $\mathbf{k}$. The integration has been carried out for $\mathbf{k}$ lying along the three directions [001], [011], and [111]. The results are

$$\frac{1}{\tau}=\frac{\alpha\pi m e^2 C^2}{\rho c_l^2\hbar^3 k_s^2}\cdot\frac{KT}{k},$$

where C is the measured piezoelectric constant, ρ is the density, c_l is the acoustic velocity for longitudinal waves, and α equals 15.8, 15.6, and 15.1 for the three directions, respectively. An average value of α equal to 15.5 was used. In the evaluation of α, the ratio of longitudinal to transverse acoustical velocities is determined from Poisson's ratio which is assumed to be 0.3. Finally an average value of k appropriate for drift mobility is found[2] for low temperatures where the conduction electrons are not degenerate, giving $k=8(2mKT)^{\frac{1}{2}}/3\pi^{\frac{1}{2}}\hbar$. The resulting expression for mobility is

$$\mu=\frac{0.044\rho c_l^2\hbar^2 k_s^2}{eC^2 m^{\frac{3}{2}}(KT)^{\frac{1}{2}}}.$$

The temperature dependence will be modified if the electrons are degenerate; further, other parameters may vary with temperature, notably m and C.

In zinc blende, $\rho c_l^2=1.14\times10^{12}$ dynes/cm^2,[3] $k_s=8.3$,[4] $C=4.2\times10^4$ statcoul/cm^2,[5] and m is taken equal to the electron mass. At 300°K, these values give 2700 cm^2/volt-sec. The data of Lenz[6] indicates a mobility of about 300 cm^2/volt-sec, but corrections for polarization suggested by Klick and Maurer[7] might raise this considerably. Further, the importance of impurity scattering in the measurement by Lenz is not known.

Neither C nor k_s is known for indium antimonide. Since m is very small and k_s is presumably quite large, an anomalously large piezoelectric constant would be required if this mechanism is to be important in indium antimonide.

If the optical dielectric constant, equal to 14,[8] is taken as the lower limit for k_s, $m=0.013m_e$,[9] and $\rho c_l^2=0.75\times10^{12}$ dynes/cm^2,[10] then a piezoelectric constant of $C=2.4\times10^5$ statcoul/cm^2 is required for a mobility of 10^5 cm^2/volt-sec at 300°K.

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[1] W. Voigt, *Lehrbuch der Kristallphysik* (B. G. Teubner, Leipzig and Berlin, 1910), p. 832.
[2] The author is indebted to Dr. Conyers Herring for critical comments on the averaging procedure.
[3] Averaged from the elastic constants measured by W. Voigt, given in Walter G. Cady, *Piezoelectricity* (McGraw-Hill Book Company, Inc., New York, 1946), p. 159.
[4] K. Höjendahl, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **16**, No. 2, 91 (1938).
[5] Reference 3, p. 229.
[6] H. Lenz, Ann. Physik **382**, 449 (1925).
[7] C. C. Klick and R. Maurer, Phys. Rev. **81**, 124 (1951).
[8] Avery, Goodwin, Lawson, and Moss, Proc. Phys. Soc. (London) **B67**, 761 (1954).
[9] Dresselhaus, Kip, Kittel, and Wagoner, Phys. Rev. **98**, 556 (1955).
[10] Estimate by R. W. Keyes, Phys. Rev. **99**, 490 (1955).

Possible Source of Line Width in Ferromagnetic Resonance

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THE dissipation of power in ferromagnetic resonance is considered to be a two-stage process.[1] The spin wave state with wave number, k, equal to zero