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semiconductors by measuring reflection and transmission in the region 1 to 30 μ. The effect of free carriers on the optical constants was determined from these measurements. With sufficiently high carrier concentrations, the reflectivity shows a pronounced minimum, rising to high values at long wavelengths. The contribution of free carriers to the electric susceptibility was obtained. In all cases, the susceptibility is proportional to the wavelength squared as expected for free carriers when the radiation frequency is high compared to the collision frequency. Knowing the carrier concentration from electrical measurements, the conductivity effective mass can be obtained from the susceptibility. The effective mass results are 0.15 for *n*-type germanium, 0.27 for *n*-type silicon, 0.37 for *p*-type silicon, 0.029 for *n*-type InSb, 0.20 for *p*-type InSb, and 0.033 for *n*-type InAs. The values for germanium and silicon are in reasonable agreement with values expected from cyclotron resonance. The *n*-type InSb result agrees with the value obtained from the shift of the intrinsic absorption edge with electron concentration but not with the cyclotron resonance value. The electron carrier concentration of the sample used here is relatively high, $n_e = 6.3 \times 10^{17}$ cm^{-3}.

* Work supported by an Office of Naval Research Contract.

K7. Combination of Scattering by Optical Modes and by Acoustical Modes in a Degenerate Semiconductor.* V. A. JOHNSON, *Purdue University.*—If conduction electrons are subject to two simultaneous scattering processes characterized by different energy dependences of the mean free paths, a combined mean free path must be used in the calculation of electrical properties. Previous calculations have been made only for classical semiconductors. The present computation is made for impurity semiconductors with positive values of the Fermi level under the assumption that both lattice scattering (l independent of carrier energy) and polar scattering (l approximately proportional to carrier energy) are present. In the classical semiconductor the combined resistivity is up to 11% greater than the sum of the two components, but, as the degree of degeneracy increases, this difference decreases, and the separate resistivity components are simply additive in a highly degenerate sample. The mean-free-path term in the thermoelectric power increases with increasing degeneracy and also increases about linearly as the scattering varies in nature from pure lattice scattering to pure polar scattering. For all positions of the Fermi level, the dimensionless factor in the Hall coefficient shows a U-shaped curve when plotted against the fraction of polar scattering present. With increasing degeneracy, there is little change in the position of the minimum, but the end values become lower.

* Work assisted by a U. S. Signal Corps contract.

K8. Electron Bombardment of Indium Antimonide.* L. W. AUKERMAN AND K. LARK-HOROVITZ, *Purdue University.*—Bombardment of single crystal specimens of InSb with 4.5-Mev electrons decreases the carrier mobility and changes the carrier concentration, depending on the initial Fermi level and the temperature of the bombardment. At approximately 230°K or lower temperatures *n* type is converted to *p* type with sufficient bombardment. Annealing experiments indicate that four types of defects are produced which anneal at different temperature regions: at 80–85°, 120–150°, 250–330°, and the fourth does not anneal below 373°K. The defects which anneal below 250°K are complicated and cannot be explained in terms of simple vacancy-interstitial recombination. The defects which anneal at 250–330°K are donors and acceptors and are assumed to be vacancies and interstitials. Analyses of bombardments carried out at 200–240°K indicate that these acceptor and donor levels lie at approximately 0.035 and 0.082 ev above the valence band, respectively. From the magnitude of the changes in mobility it is inferred that there are doubly ionized levels. The defects which remain at 373°K are mostly donors with an activation energy greater than 0.03 ev below the conduction band.

* Work supported by a U. S. Atomic Energy Commission contract.

K9. Electron Scattering in InSb. H. EHRENREICH, *General Electric Research Laboratory.*—The electron mobility and thermoelectric power of InSb have been calculated in the temperature range 200 to 500°K assuming scattering by acoustical and optical phonons and holes. The nonparabolic conduction band theory of Kane[1] and the cyclotron resonance mass 0.013 m were used. A systematic treatment of acoustic mode scattering, neglecting small piezoelectric effects,[2] shows deformation potential scattering dominant, but too small to explain the observed mobility. Only the polar interaction couples electrons to optical modes in InSb. Transport theory developed to treat this interaction[3] has been extended to apply to nonparabolic bands. The calculated mobility agrees closely with experiment[4] over the specified temperature range for a reasonable choice of the effective ionic charge e^*. Excellent agreement between the theoretical thermoelectric power, which is independent of e^*, and experiment[5] is also obtained for the 0.013 effective mass. Electron-hole scattering is significant at temperatures above 500°K.

[1] E. O. Kane, Bull. Am. Phys. Soc. Ser. II, 1, 285 (1956).
[2] W. A. Harrison, Phys. Rev. 100, 903 (1955).
[3] D. J. Howarth and E. H. Sondheimer, Proc. Roy. Soc. (London) A219, 53 (1953).
[4] Hrostowski, Morin, Geballe, and Wheatley, Phys. Rev. 100, 1672 (1955).
[5] H. Weiss, Z. Naturforsch. 11a, 131 (1956).

K10. Temperature Dependence of Electron Localization in InSb. R. J. SLADEK, *Westinghouse Research Laboratories.*—Application of a strong magnetic field to *n*-InSb at 4.2°K reduces the number of mobile electrons,[1] presumably due to the shrinking of the electronic wave functions with an accompanying increase in the energy of binding between a donor ion and an electron.[2] To obtain quantitative information on this effect we have measured the Hall coefficient and resistivity at several temperatures in the liquid helium range, in fields up to 30 000 gauss, on *n*-InSb samples kindly provided by Dr. A. Beer of the Battelle Memorial Institute. Using a crude model consisting of a band responsible for conduction and localized bound states, we have obtained values for the donor-electron binding energy between 10 000 and 30 000 gauss. Measurements of the Hall coefficient as a function of electric field indicate that electrons localized by the magnetic field can be re-excited into conducting states.

[1] R. W. Keyes and R. J. Sladek, Phys. Rev. 100, 1262(A) (1955); H. P. R. Frederikse and W. R. Hosler, Bull. Am. Phys. Soc. Ser. II, 1, 298 (1956).
[2] Yafet, Keyes, and Adams, Internatl. J. Phys. Chem. Solids (to be published).

K11. Measurement of Resistivity and Mobility of Silicon and Indium Antimonide Ingots.* J. J. DUGA, A. C. BEER, AND R. K. WILLARDSON, *Battelle Memorial Institute.*—Various methods used to obtain a profile of the resistivity, mobility, and Hall coefficients of silicon and indium antimonide ingots at 80 and 300°K are described and the results compared. The standard two- or four-probe arrangements have been modified to incorporate easily interchangeable probes of different metals. Contact resistance and rectification were reduced by electroforming probes containing donor or acceptor materials for *n*- or *p*-type silicon, respectively.[1] Four probes in a diamond shape gave a direct measurement of the carrier mobility from the ratio of the transverse and longitudinal potential gradients. Low resistance contacts are obtained by using rhodium-plated dots. Approximate determinations of resistivity were also done without the use of contacts by noting the change of the Q of a small test coil in close proximity to the ingot.[2] The relative precision of these methods was determined by cutting specimens from the ingots and accurately measuring their properties.

* Supported in part by the A. F. Cambridge Research Center.
[1] R. H. Creamer, Brit. J. Appl. Phys. 7, 149 (1956).
[2] H. K. Henisch and J. Zucker, Rev. Sci. Instr. 27, 409 (1956).

K12. Donor Defect Control in Polycrystalline PbTe. R. W. FRITTS AND S. KARRER, *Milwaukee Gas Specialty Company.*—Annealed polycrystalline ingots of PbTe containing a slight lead excess exhibit *N*-type carrier concentrations limited to less than 10^{18}/cc. Additions of Bi, Ta, Mn, Zr, Ti, Al, Ga, Cl, Br, I, or *U* can be incorporated into the melt to increase the carrier concentration beyond 10^{19} electrons/cc. Resistivity-temperature plots and Seebeck emf data are given for a range of bismuth additions to slightly lead-rich PbTe. All of these third element additions form compounds with lead or tellurium that can be represented by the formula A_xB_y, in which A is the more metallic component. For each compound that induces donor levels the ratio x/y is found to be less than unity. These donor forming species have a sufficiently high heat of formation to be expected to exist in equilibrium with liquid PbTe and the slight lead excess. It is proposed[1] that upon freezing an appropriate number of PbTe molecules is substitutionally replaced by a molecule of the additive species plus an uncharged Schottky-type lead vacancy. The donor defect is established when an excess lead atom migrates into this vacancy and releases an electron to ionization.

[1] C. Wagner, J. Chem. Phys. 18, 62 (1950).

FRIDAY AFTERNOON AT 2:30

Oriental 272

(C. S. BARRETT presiding)

Metals

L1. Mechanical Strength of Thin Films of Silver and Gold.* W. K. FORD, JR., A. L. STAMPER, AND J. W. BEAMS, *University of Virginia.*—The tensile strengths of thin evaporated films of silver and gold have been determined as a function of film thickness by the "bulge" method. The metal film is mounted over the open end of a cylindrical tube and its bulge measured at various air pressures inside the tube until the film bursts. From these data the tensile strength can be determined.[1] The tensile strengths are sensible constant (1.1×10^9 dynes/cm^2 for silver and 0.9×10^9 dynes/cm^2 for gold) at thicknesses greater than 2.5×10^{-5} cm for silver and 2×10^{-5} cm for gold. At thicknesses below 2×10^{-5} cm for silver and 1.5×10^{-5} cm for gold, there is a marked increase in tensile strength. These results are in good qualitative agreement with those found with electrodeposited silver films by the centrifugal method.[2] The quantitative differences are believed to be due to variations in the stress patterns, differences in methods of deposition, and possible slight adhesion in the case of the centrifugal experiments.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] A. G. Gleyzal, Trans. Am. Soc. Mining Met. Engrs. 70, 288 (1948).
[2] Beams, Breazeale, and Bart, Phys. Rev. 100, 1675 (1955).

L2. Torsional Strain and the Screw Dislocation in Whisker Crystals. R. G. TREUTING, *Bell Telephone Laboratories* (introduced by R. D. Heidenreich).—It has been shown theoretically by J. D. Eshelby that the presence of a screw dislocation in a fine whisker crystal should result in a torsional strain of appreciable magnitude. Theoretical opinion has been divided as to whether a spontaneously grown whisker should contain a screw dislocation. The Weissenberg x-ray pattern of a crystal oscillated about a twist axis reveals such strain by elongation of the reflection spots to extended streaks. The effect has been found in the patterns of three spontaneously grown tin whiskers. From the strain in each, determined from the pattern, the whisker diameter is calculated and compared with the optically measured value. Agreement is within a factor of three; the torsional strain is of the order required by the presence of a screw dislocation in the whisker. The method will also show evidence of plastic strain, in particular the presence of dislocation twist boundaries, found in one of the specimens and considered the result of handling and mounting.

L3. Torsion Induced Recrystallization of Highly Refractory Filaments.* F. GIFFORD AND E. COOMES, *University of Notre Dame.*—Single crystals up to 15 cm length were grown repeatedly in 2 to 5-mil Mo and W filaments, after twisting these filaments from 2 to 10 turns per inch. The moving gradient method with 2000°K for Mo and 2800°K for W was used. Observations with an electron projection microscope showed a uniform screw-like pattern of high electron emission superimposed upon the projection pattern of the single crystal. This is apparently due to impurities in an otherwise perfect crystal.

* Work supported in part by the Office of Naval Research and U. S. Atomic Energy Commission.

L4. The Influence of Torsion on Crystal Growth in Molybdenum Filaments by the Robinson Method.* J. SHILTS AND E. COOMES, *University of Notre Dame.*—Recrystallization of previously twisted Mo filaments has been carried out by the Robinson method.[1] Variation of the parameters twist strain and temperature indicate that (1) there is an optimum twist for a given temperature, and (2) there is a limit to the temperature range for a given twist. For the particular wires used, the longest crystals were obtained for a twist of about 4 turns per inch and a temperature of about 1650°K.

* Work supported in part by the Office of Naval Research and U. S. Atomic Energy Commission.
[1] C. S. Robinson, J. Appl. Phys. 13, 647 (1942).

L5. Calculation of the Elastic Shear Constants of Magnesium Alloys.* C. S. SMITH AND J. R. REITZ, *Case Institute of Technology.*—Leigh's[1] calculation of the shear constants of aluminum are extended to crystals of lower symmetry, i.e., to magnesium and dilute magnesium alloys. The requirement that pure magnesium be in equilibrium with respect to shears that change its c/a ratio is consistent only with electron overlap having already occurred across the Brillouin zone faces perpendicular to the c axis, a result at variance with the usual assumptions for this metal. Assuming c overlap and one other overlap in the pure metal, it is found that the total number of overlap electrons is 1.70×10^{21} cm^{-3}, i.e., 2% of the valence electrons. The overlap appearing at 2.01 electrons/atom is assumed to be in the equatorial plane of the Brillouin zone; it produces an abrupt change in one of the shear constants as