Case II: $4\Delta_c/kT \gg 1$

The level scheme for $\Delta_c \neq 0$ is shown in Fig. 11(b). In order to find ϵ_F one has to solve the Fermi level equation (A8) using the effective donor-state energy (A9) in which $E_d^{(l)}$ is given by (A7). This leads to a complicated expression for ϵ_F which can be solved numerically when the quantities Δ_c and E_2 are known.

One can find, however, a simple expression for the limiting case $4\Delta_c/kT \gg 1$. This condition will always be satisfied at low enough temperatures. The influence of the upper three states of the donor multiplet can then be neglected. At low enough temperatures, i.e., when the total electron concentration $n \ll N_d - N_a$ and $n \ll N_a$, the Fermi energy shifts parallel to the donor ground state energy when stress is applied so that

$$\epsilon_F = 2\Delta_c - (4\Delta_c^2 + \epsilon^2)^{\frac{1}{2}}. \quad \text{(A15)}$$

Substituting (A15) into (A6) yields the final result for the respective conductivity changes:

$$\frac{\Delta\sigma}{\sigma_0} = \left[\pm \frac{K-1}{2K+1} \sinh(\epsilon/kT) + \cosh(\epsilon/kT) \right] \times \exp\{[2\Delta_c - (4\Delta_c^2 + \epsilon^2)^{\frac{1}{2}}]/kT\} - 1, \quad \text{(A16)}$$

with ϵ given by (A5). The plus sign applies to arrangement C, the minus sign to arrangement D.

The case of finite Δ_c differs from the case $\Delta_c = 0$ considered previously in that the total carrier concentration in the conduction band is changed by the stress. This change in n is reflected in a change of the Hall coefficient R:

$$\frac{R - R_0}{R} = 1 - \cosh(\epsilon/kT) \times \exp\{[2\Delta_c - (4\Delta_c^2 + \epsilon^2)]/kT\}. \quad \text{(A17)}$$

In deriving this result, the condition $4\Delta_c \gg kT$ was assumed to hold and the effect of stress on the ratio of Hall mobility to drift mobility was neglected.

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Electron Damage Thresholds in InSb†

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Measurements of carrier removal rate and isochronal recovery in electron-irradiated InSb indicate that displacements are produced at electron energies as low as 240 kev. Two recovery stages have been found and the activation energies for recovery determined. The conductivity recovery in the low-temperature stage was found to be first order.

THE rate at which carriers are removed from the conduction band in InSb by electron bombardment has been measured as a function of energy in an effort to determine the threshold electron energy for the production of atomic displacements. The results are shown in Fig. 1. The irradiation and electrical conductivity measurements, from which the carrier removal rates, $d\bar{n}/dN_e$, were derived, were carried out at liquid nitrogen temperature. The sample was n-type with 1.4×10^{14} carriers/cm$_e$ and a mobility of 3.5×10^5 cm^2/volt sec at liquid nitrogen temperature. The sample thickness was 0.017 cm.

Figure 1 may be separated into an energy region in which $d\bar{n}/dN_e$ changes rapidly with energy and a "tail" region in which $d\bar{n}/dN_e$ changes very slowly with energy, suggesting that two different processes may be responsible for the observed conductivity changes. This possibility was investigated by studying the isochronal recovery of damage produced at different electron energies. Figure 2 shows the data for samples annealed after bombardment at 240 kev and 400 kev. The 240-kev damage recovers in two stages labeled I and II in the diagram. The 400-kev damage recovers entirely in Stage II and the annealing of a sample irradiated at 700 kev shows nearly all the recovery occurring in Stage II (with the rest of the recovery occurring at higher temperatures). The absence of recovery in Stage I after irradiation at these energies may be due to heating of the sample during the irradiation. The conductivity change produced in the 700-kev irradiation is too large to be due to a surface effect, indicating that the damage which recovers in Stage II is due to displacements in the bulk of the sample. Since Stage II recovery is observed at 240 kev, the threshold energy must be less than or equal to 240 kev (this corresponds to a maximum energy transfer of 5.7 ev to an indium atom). The recovery of damage produced by 200-kev electrons was observed to occur entirely in Stage I indicating that the threshold for production of the damage recovering in Stage II is above 200 kev. The nature of the damage recovering in Stage I is not clear at the present; surface effects cannot be ruled out as they were in Stage II.

Isothermal recovery data were obtained after 240-kev and 400-kev irradiations and were combined with the

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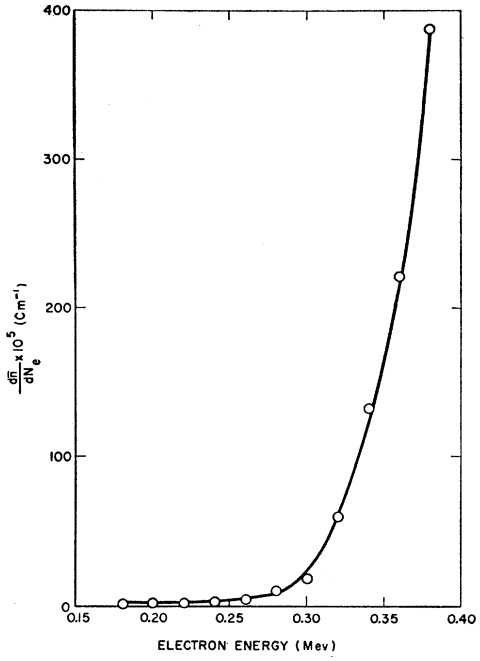

FIG. 1. (Carriers removed per cm³)/(bombarding electrons per cm³), $d\bar{n}/dN_e$, as a function of the energy of the bombarding electrons.

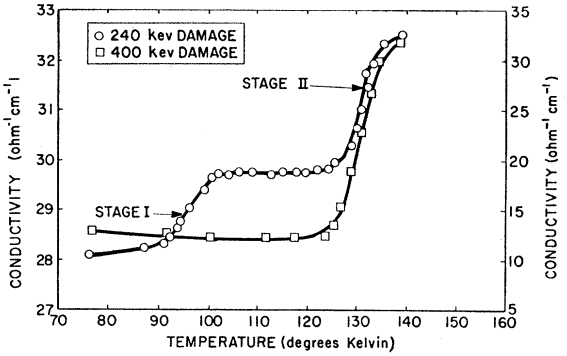

FIG. 2. Isochronal recovery of electron damage produced at 240 kev and 400 kev. The scale on the left is for the 240-kev damage.

isochronal data to obtain activation energies for the recovery of damage,[1] yielding 0.23 ev for Stage I and 0.56 ev for Stage II. The conductivity recovery in Stage I obeyed first-order kinetics and may be due to the recombination of close vacancy-interstitial pairs. Satisfactory interpretation of the isothermal data for Stage II and the unexpectedly large relative difference in the two activation energies has not yet been achieved. Further work is in progress to clarify these points.

[1] For a discussion of the method, see C. J. Meechan and J. A. Brinkman, Phys. Rev. **103**, 1193 (1956).

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d Bands in the Body-Centered Cubic Lattice

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A model of a crystal, consisting of positive point charges neutralized by a uniform distribution of negative charge, is employed to study the form of the *d* bands in a body-centered cubic lattice as a function of the lattice spacing. The wave functions are expressed as linear combinations of plane waves and the potential treated as a perturbation. It is shown that the perturbation series for the energy is a power series in Za, where Z is the atomic number and a is the lattice parameter. The leading term in the series is of the order $(1/a)^2$, and the coefficients of successive terms in the series decrease rapidly. The first three terms are evaluated for the states of predominantly *d* symmetry at the center of the Brillouin zone, and the corner H.

INTRODUCTION

ALTHOUGH there have been many calculations of energy bands in the transition elements,[1] the band structures of these elements are not well understood. Recently it has been proposed that the *d*-band structure of the body-centered cubic transition elements, iron and chromium, is radically different from that of the face-centered cubic elements, nickel and copper.[2] Experimental information adequate to resolve the problem does not exist. In view of the complexities of careful theoretical computation for these elements, it remains interesting to study a model whose simplicity permits more exact calculation.

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[1] A review of band calculation has been given by J. Callaway, in *Solid State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, Inc., New York, 1958), Vol. 7, p. 99.

[2] N. F. Mott and K. W. H. Stevens, Phil. Mag. **2**, 1364 (1957).