Therefore, it seems possible that the elastic strain calculation previously invoked[3] to explain the relation $dr/dt=Mr^2$,[5] may be, at least in part, a gratuitous complication. In any case, the effect due to lowering of the energy barriers by elastic strains would simply aggravate that which would normally be expected from the inhomogeneity itself. For if ΔG is a diminishing function of c, the factor $\exp(-\Delta G/RT)$ must be inserted into the integrand of Eq. (1) or its counterpart, and this would have the effect of heavily weighting the inhomogeneity contribution.

For illustrative purposes nucleon damage and recovery have been considered here solely in terms of the formation and annihilation of $i-v$ pairs. The existence of residual defects that persist at high temperatures shows that this model can be only partly correct. Either other defects are produced along with the $i-v$ pairs during irradiation, or the coalescence of vacancies and/or interstitials competes with the annihilation process to produce stable aggregates.

The writer would like to extend thanks to Professor J. S. Koehler for detailed information concerning particle ranges, and to Dr. C. E. Dixon for the privilege of seeing the manuscript previously referred to,[7] prior to its publication. This critique was incidental to the work sponsored by the U. S. Atomic Energy Commission.

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Antiparallel Dipole Arrangement in Tungsten Trioxide

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ALTHOUGH tungsten trioxide WO_3 is reported to have ferroelectric or antiferroelectric properties,[1] no definite structural mechanism has been proposed to account for this behavior. The detailed crystal structure analysis of WO_3 has been carried out from a study of its Patterson function. The structure given by Braekken[2] is shown to be incorrect in dipole arrangement.

The single crystal used ($0.1\times0.2\times0.01$ mm) is composed of two domains, twinned on the (110) plane.[3] Each domain contains a number of repeated twins (180° domains) of submicroscopic dimensions. We have successfully completed the structure determination at room temperature by using only reflections from a similar kind of twin component. The unit cell is monoclinic with the lattice constants: $a=7.274\pm0.002$A, $b=7.501\pm0.001$A, $c=3.824\pm0.003$A, and $\beta=89°56'$. The space group is $P\,2_1/a$, and $Z=4$. The atomic coordinates and interatomic W−O distances are as follows:

W: $\frac{1}{4}+x,\ \frac{1}{4}+y,\ z.\quad x=0.006,\ y=-0.021,\ z=0.053.$
O_{I}: $\frac{1}{4},\ y,\ 0.\quad y=0.03.$
O_{II}: $0,\ \frac{1}{4},\ 0.$
O_{III}: $\frac{1}{4},\ \frac{1}{4}+y,\ \frac{1}{2}.\quad y=0.03,$

and

$$\mathrm{W-O_{I}}=1.87\mathrm{A},\quad \mathrm{W-O_{III}}\ (\text{above})=1.71\mathrm{A},$$
$$\mathrm{W-O_{II}}=1.83\mathrm{A},\quad \mathrm{W-O_{III}}\ (\text{below})=2.11\mathrm{A}.$$

The angle $\mathrm{W-O_{II}-W}$ differs from 180° by about 12°, which will be important in connection with the dielectric properties of this substance.[4] The sites of the oxygen atoms, which are too light to give considerable contributions to the x-ray reflections, have been derived mainly from spatial considerations.[5]

It is to be stressed from the above results that the dipole arrangement in WO_3 is very similar to that of $NaNbO_3$ which has recently been analyzed by Vousden.[6] In both structures, the dipoles parallel to the x direction are arranged in alternate senses, while the ones perpendicular to it are put in the same sense (Fig. 1). The dipoles in Braekken's structure, however, are arranged alternately in both directions. The dipole orientations obtained above will also give WO_3 antiferroelectric properties, similar to those of $NaNbO_3$.

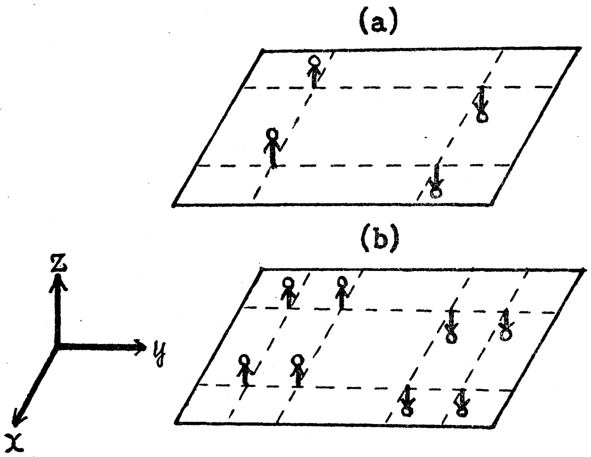

FIG. 1. The dipole arrangement in WO_3 and $NaNbO_3$. The arrows show the directions of displacement of the metal ions. (a) WO_3 (present work), (b) $NaNbO_3$ (Vousden). The axes are referred to the original perovskite structure.

A detailed description of the work will be published elsewhere shortly.

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Microwave Observation of the Collision Frequency of Holes in Germanium

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IT has been shown in a previous letter[1] that the inertial effects of the electrons in n-type germanium may be studied through a microwave measurement of the dielectric constant as a function of temperature. The working equations[2] for the dielectric constant and conductivity, based on a free carrier model with relaxation time independent of energy, derived in reference 1 are

$$\kappa=\kappa_0-\frac{Ne^2\tau^2}{\epsilon_0 m^*[1+(\omega\tau)^2]}\tag{1}$$

and

$$\sigma=\frac{Ne^2\tau}{m^*[1+(\omega\tau)^2]},\tag{2}$$

where κ_0 is the dielectric constant associated with carrier free germanium, N is the number of carriers per unit volume, m^* is the effective mass, τ is the relaxation time, and ω the microwave angular frequency.

Measurements of the dielectric constant and conductivity have now been made in p-type germanium in order to determine m^* and τ for the holes.

The samples were prepared by doping intrinsic germanium with sufficient gallium to make the carrier contribution to the dielectric constant appreciable. Measurements were made of the attenuation and phase shift due to transverse slabs 0.016 and 0.032 in. thick with 1.24 cm microwaves. The results for the hole contribution to the dielectric constant $\Delta\kappa$ are given in Fig. 1. The value used for κ_0 was 16.[1] The solid curves are the theoretical curves based on Eq. (1) plotted for various values of m^*.

Some recent calculations[3] of Herring of the hole contribution to the dielectric constant assume a Maxwellian distribution of velocities for the holes, an energy dependent relaxation time, and energy surfaces of the type suggested by Herman and Callaway,[4,5] and by Shockley.[6] These calculations give for $\omega\tau<1$ the following simple formula:

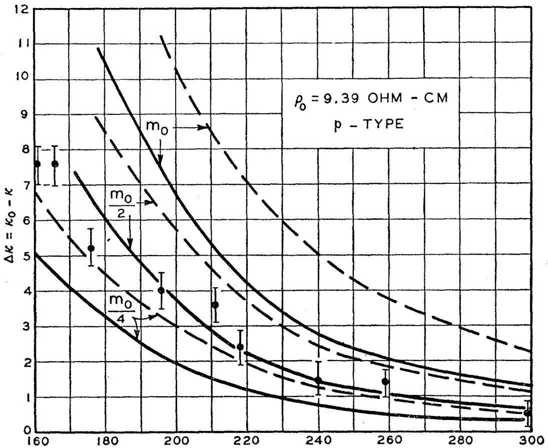

FIG. 1. Plot of $\Delta\kappa=\kappa_0-\kappa$ vs absolute temperature for germanium ($\rho_0=9.39$ ohm-cm).

$$\kappa=\kappa_0-\frac{Ne^2}{m^*\epsilon_0}\Big/\left[\left(\frac{e}{m^*}\right)^2\frac{1}{\mu_0\mu_H}+\omega^2\right].$$

It is seen that this formula is essentially the same as that used in the previous work[1] for electrons except that the square of the drift mobility has been replaced by the product of the drift mobility (μ_0) and Hall mobility (μ_H). This change if applied to electrons makes very little difference in the effective mass since $\mu_H/\mu_0\cong 1.03$; however, for holes[7] the value of μ_H/μ_0 varies from 1.30 to 1.70 giving a large variation from the energy independent τ theory. The dashed curves shown in Fig. 1 are those predicted by Herring's theory and it is seen that a good fit to the theory can be obtained by setting m^* equal to about $(0.30\pm0.13)m_0$.

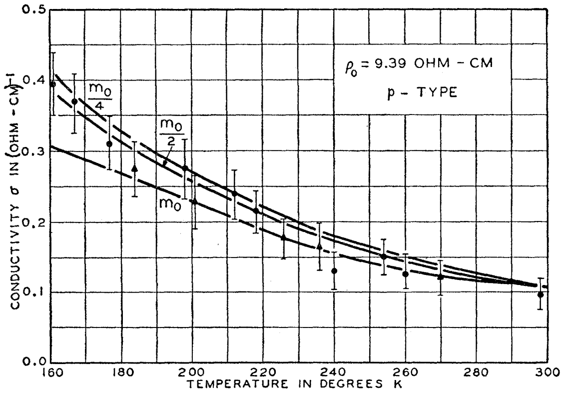

FIG. 2. Plot of σ vs absolute temperature for germanium ($\rho_0=9.39$ ohm-cm).

The conductivity data are shown in Fig. 2. It is seen that they also are consistent with the theoretical curves based on Eq. (2), further indicating that the free carrier model is adequate in the present case. The conductivity data are consistent with the mass deduced from the dielectric measurements but are not in themselves good enough to yield an effective mass.

The measurements were carried out for samples whose room temperature resistivities varied from 5 ohm-cm to 15 ohm-cm and the measurements are consistent with the effective mass given above independent of resistivity and temperature over the regions described. The relaxation time based on Eqs. (1) and (2) is then given by $\tau=3.6\times10^{-7}T^{-2.3}$ sec.

The author wishes to thank W. Shockley for many helpful discussions concerning this work, M. B. Prince for furnishing the drift mobility data required in calculating the theoretical curves, and Herring for allowing the author to use his results in the analysis of the data priort o publication.

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Electrical Conductivity of Mechanically Disturbed Germanium Surfaces

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THE mechanically disturbed germanium surface has been of interest in the study of surface electron-hole recombination,[1] in the study of contact potentials,[2] and in the study of rectification and thermoelectric effects.[3,4]

If the germanium surface is mechanically disturbed as by grinding, polishing, or sandblasting, we have, in effect, a surface

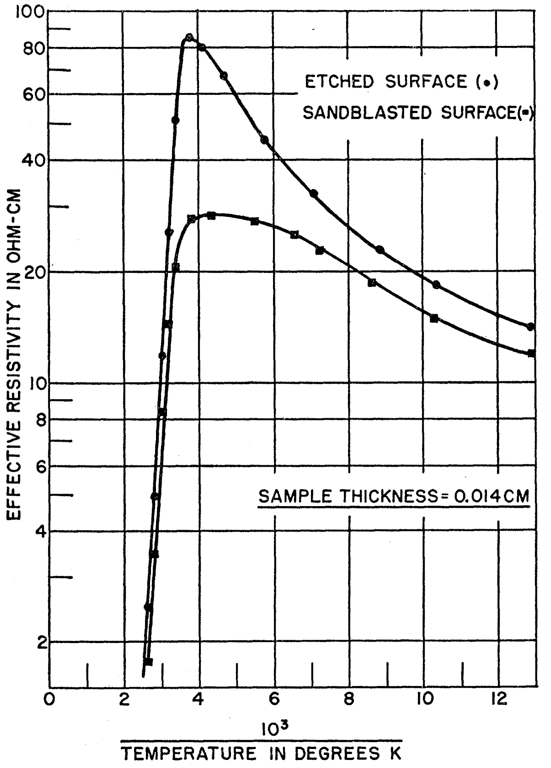

FIG. 1. Resistivity of a thin single crystal before and after sandblasting.