Optical Properties of Plastically Deformed Germanium

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(Received March 15, 1955)

N-type germanium specimens of 1 ohm-cm resistivity were plastically deformed from 3 to 15 percent at about 700°C. The more strongly deformed specimens were found to be converted to *p*-type. All of the deformed specimens exhibited a shift in the intrinsic absorption edge as well as an extended tail. Those samples which were converted to *p*-type also exhibit the characteristic absorption bands due to free holes. These results differ from those obtained for neutron-bombarded germanium which exhibits no shift of the absorption band and a tail of somewhat different character from that found in the plastically deformed material.

DISLOCATIONS produced in germanium by plastic deformation at elevated temperatures have been shown to affect the electrical conductivity and the lifetime of the minority carriers. These changes in the properties are considered to be due to the formation of acceptor centers which have energy levels 0.2 ev below the conduction band.[1] It was of interest to carry out optical studies on plastically deformed germanium in order to see what further information could be obtained about the effects of dislocations. Samples of 1-ohm-cm *n*-type germanium were given deformations ranging from 3 to 15 percent by compression at approximately 700°C. The deformation was accomplished in a stainless steel furnace by pressing the samples in a helium atmosphere between cylinders of Burundum.* Resistivity and thermoelectric power measurements indicated that the larger deformations converted the originally *n*-type germanium to *p*-type. Heating without deformation was found to increase the resistivity from 1-ohm-cm *n*-type to 3-ohm-cm *n*-type. The material remained *n*-type after a 3 percent deformation, changing from 1-ohm-cm to 15-ohm-cm. On the other hand, a 15 percent deformation converted the material to 16-ohm-cm *p*-type.

Optical transmission measurements were carried out from 1 to 15 microns by means of a Perkin-Elmer spectrometer with LiF and NaCl prisms. Measurements were made on the original material and on the heated, but undeformed, control samples as well as on the deformed samples. Typical room temperature transmission and absorption curves are given in Figs. 1 and 2.

Transmission measurements out to 15 microns are in agreement with the resistivity data. The original material, the heated control, and the 3 percent deformed samples have high transmissions in this range corresponding to relatively pure *n*-type germanium. The

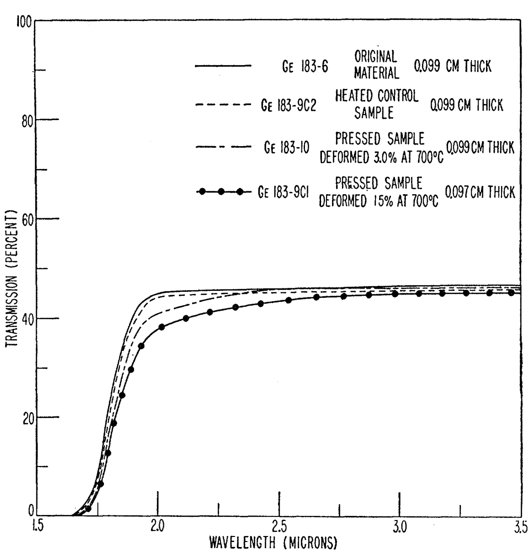

Fig. 1. Transmission of germanium specimens before and after heat treatment and deformation.

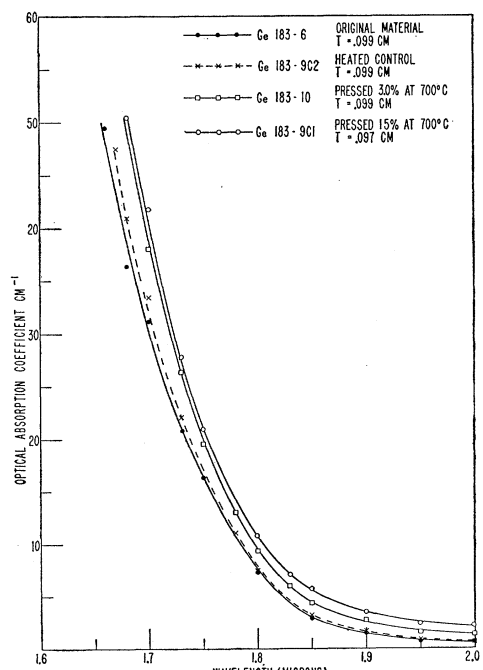

Fig. 2. Optical absorption coefficients for same specimens whose transmissions are shown in Fig. 1.

[1] Pearson, Read, and Morin, Phys. Rev. **93**, 666 (1954).
* Trade name for Al_2O_3 ceramic made by U. S. Stoneware Company.

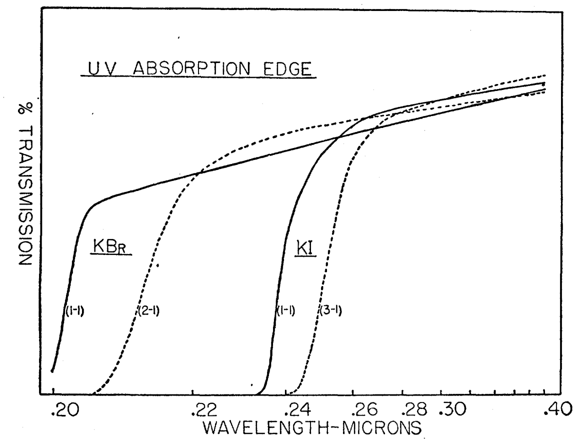

FIG. 3. Transmission of KBr and KI specimens before and after plastic deformation. The numbers in parentheses indicate the change from the initial final thickness in mm.

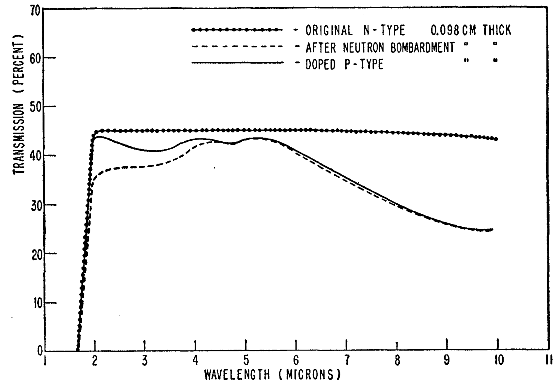

FIG. 4. Transmission of germanium specimens converted from n- to p-type by neutron irradiation compared with the original n-type material and with an unirradiated p-type specimen of the same final charge carrier concentration.

strongly deformed germanium samples also exhibited characteristic absorption bands due to free holes[2] which further confirms the change to p-type character.

All of the deformed samples are found to exhibit an extended tail and a shift in the intrinsic optical absorption edge toward longer wavelengths which increased with the amount of deformation. This shift is similar to one previously observed in plastically deformed KBr and KI as shown in Fig. 3.[3] At liquid nitrogen temperature the strongly deformed samples have a high resistance and exhibit photoconductivity to approximately 6 microns.

It has long been recognized that lattice imperfections affect the long wavelength edge of the fundamental "electronic" absorption band of insulators.[4] Seitz, for example,[5] has suggested that the long-wavelength tail observed in the silver halides is due to the presence of dislocations which cause a relaxation of the selection rules affecting nonvertical transitions. More recently Blakney and Dexter[6] investigated theoretically two additional mechanisms by which dislocations affect optical properties (a) the effect of local density variations on the energy gap and (b) the effect of defect centers which introduce discrete levels in the forbidden band. Their calculations indicate that phonon interactions[7] are more effective than dislocations in breaking down selection rules. In addition they point out that the dislocations will influence the absorption only near the edge and therefore cannot account for the extended tail.

We may accordingly attribute the shift of the absorption edge observed in plastically deformed germanium to the effect of local changes in density on the energy gap and the tail to defect centers and their associated energy levels. The long-wavelength tail observed in germanium seems to have a break at 2.5 microns corresponding to an energy gap of 0.5 ev. It is tempting to attribute the absorption associated with this tail to transitions from the dislocation acceptor levels to the valence band. The extended tail beyond 2.5 microns is presumably associated with other simple lattice defects. The photoconductivity observed at liquid nitrogen temperatures is probably also due to such centers. An extended tail has also been observed in neutron bombarded germanium[8] as shown in Fig. 4 by the difference in transmission between a sample converted from n-type by neutron bombardment and a doped p-type sample of the same final charge carrier concentration. This tail is attributed to a distribution of centers associated with simple lattice defects.

[2] H. B. Briggs and R. C. Fletcher, Phys. Rev. **87**, 1130 (1952).
[3] Burstein, Smith, and Davisson, Phys. Rev. **86**, 615 (1952), and unpublished data.
[4] N. F. Mott and R. W. Gurney, *Electronic Processes in Ionic Crystals* (Oxford University Press, London, 1940), second edition; F. Seitz, Phys. Rev. **80**, 239 (1950).
[5] F. Seitz, Revs. Modern Phys. **23**, 328 (1951).
[6] R. M. Blakney and D. L. Dexter, Phys. Rev. **96**, 227 (1954); D. L. Dexter, paper presented at Atlantic City Photoconductivity Conference, November, 1954 (unpublished).
[7] Hall, Bardeen, and Blatt, Phys. Rev. **95**, 559 (1954).
[8] Unpublished data from work at Naval Research Laboratory in collaboration with J. H. Crawford and J. W. Cleland of Oak Ridge National Laboratory.