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BASIC RADIATION DAMAGE STUDIES

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Impurity Effects in N-Type Germanium

In this investigation we are examining the effect of different doping impurities on the annealing of lightly doped n-type Ge following electron irradiation at liquid helium temperature. The index of damage is the pulsed field (hot carrier) conductivity, measured with the specimen at 4.2° K.

We find that the species of impurity has an influence on the central temperature of the 65° K annealing stage for isochronal annealing and, on the rate of annealing, at a given temperature, for isothermal annealing. Defects anneal at lower temperature in specimens doped with As than they do in specimens doped with the same number of Sb impurities. The shift in the isochronal annealing peak is about 3° K. Isothermal annealing studies confirm that the activation energy for the process is lower in As doped specimens.

This influence of impurity type on the annealing appears to rule out the possibility that the process is one of recombination of close vacancy-interstitial pairs. It is clear that since both Sb and As impurities are completely ionized at 60° K, the influence of the impurity type cannot be due to an electronic effect related to differences in ionization energy. The most reasonable explanation is that the defects must probe the sites of impurities which implies long range migration of the defects. It is not yet clear whether the defects migrate to impurity sites during irradiation at low temperature or whether they "see" the doping impurities only during the anneal. However, the optically induced annealing that we reported last year appears to be most easily explained if we assume that the doping impurities can trap interstitial atoms during irradiation at helium temperature.

Change in Length of Irradiated Germanium

It was established some time ago by North and Buschert that degenerate n-type Ge decreases in length when irradiated by electrons at liquid helium temperature. To account for the decrease they invoked an electronic volume effect - suggesting that the removal of electrons from the conduction band to defect states produces a larger decrease in volume than the increase expected from the production of vacancies and interstitials. As we reported last year, we are able to observe an increase in length when we excite carriers from defect states to impurity states (after a specimen has been irradiated far enough to make it non-degenerate) but the magnitude of the length change per carrier transferred is about a factor of three too small to account for the observed length change upon irradiation. We have now examined the change in length resulting from carrier excitation in several irradiated specimens and have verified our previously reported result.

We have now investigated how the length change under irradiation depends on impurity concentration. There is a transition in behavior which occurs between 5×10^{16} and 10^{17} impurities per cm^3 . Specimens containing more than 10^{17} per cm^3 show a decrease in length under irradiation, below 5×10^{16} little or no length change is observed, although electrical measurements indicate that defects are still produced at the same rate.

We think that it is perhaps significant that the transition in behavior of the length change occurs at the impurity concentration range that marks the transition from degenerate to impurity band conduction in Ge. It may be that the electronic volume effect is not as large for transfer of a carrier from an impurity band to a defect state as it is from a merged band to impurity state.

Radiation Annealing in N-Type Germanium

During electron irradiation of Ge at liquid helium temperature two competing processes occur: 1) Defects are produced by a displacement process when electrons collide with lattice atoms and the resulting vacancies and interstitials come to rest at some suitable sites in the lattice; 2) Defects are removed and altered by a radiation annealing process that appears to be connected with ionization in the crystal. The two processes have opposite dependence on the irradiation energy. We are attempting to separate these two processes and determine the dependence of each on irradiation energy, beam intensity and specimen temperature. At this point we have a considerable amount of experimental information but have not yet completed our analysis.

Radiation Damage in P-Type Germanium

Photo-induced decay of conductivity and carrier concentration of p-type Ge that has been irradiated at liquid helium temperature is under investigation. We are attempting to determine whether the two observed decay constants are indicative of two separate defect rearrangement processes or if they are two components of a single process. We find that this decay is influenced by heating to 80° K before illumination although no changes are observed during heating. Heating prior to illumination alters the time constants of the decay and also the magnitude of the change resulting from illumination. This light induced decay is also found to depend on the type of doping impurity.

Radiation Annealing in Silicon - Optical Absorption Studies

In this investigation we plan to use optical absorption studies to determine whether known defect complexes are broken up in the radiation annealing process discovered by Sivo and Klontz in n-type Si.

We have had difficulties in obtaining vacuum tight seals for infrared windows on our cryostat that must stand cycling to liquid helium temperature. These difficulties have now been solved and the irradiation for the first experiments is about to begin.

Ph.D. Thesis Completed

"An X-Ray Study of the Lattice Parameter of Silicon" - N. M. Moyer, Purdue University, 1968.

Publications

"Effects of Carbon on the Lattice Parameter of Silicon" - J. A. Baker, T. N. Tucker, N. E. Moyer and R. C. Buschert, J. Appl. Phys. 39, 4365 (1968)

"Stored Energy Release in Electron Irradiated Germanium" - M. P. Singh and J. W. MacKay, Phys. Rev. 175, 985 (1968)

"Studies of Radiation Damage in Degenerate Silicon Irradiated at Low Temperatures" - L. L. Sivo and E. E. Klontz (Accepted for publication in Phys. Rev.)