MASTER

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Progress Report

Introduction

Our program is restricted to study of the behavior of defects introduced into germanium and silicon by electron irradiation at low temperatures. We are particularly interested in the nature of the primary defects produced by irradiation at liquid helium temperature and the way these defects move to recombine or form associations with impurities under various conditions of crystal excitation. The effect of irradiation itself on primary defects after they have been produced is a key factor in understanding radiation effects in these materials, since any modification of the defects during irradiation leads to a mixture of primary and secondary defects. For this reason most of our current work involves the study of radiation annealing. We have established that radiation annealing produces significant alterations in defects for both germanium and silicon at low temperatures.

Radiation Annealing in n-Type Germanium

When n-type germanium that has been previously damaged by 1 MeV electron irradiation at helium temperature is subjected to further irradiation by lower energy electrons, recovery of damage is produced. We have been studying this process using a pulsed conductivity (hot carrier) technique to make measurements of the electrical properties. In the past year we have been able to exploit some of the special properties of this technique to

label and follow the concentrations of two important defects.

Both of these defects are acceptor centers and each is capable of capturing two electrons. We have established that these centers are neutral immediately following irradiation or exposure of the specimen to X-rays. When carriers are excited from the chemical impurity donor states to the conduction band, by application of a voltage pulse to the specimen, these defects capture their first electron with a characteristic time of the order of a microsecond. The second electron is captured in a characteristic time that is 10^3 times longer. We can readily distinguish the two types of centers by virtue of the fact that each has a different characteristic time for capture of electrons.

Type I has the larger capture cross section. It accounts for 90% of the carriers removed by 0.7 MeV irradiation and disappears completely under irradiation annealing at helium temperature or thermal annealing at 65°K . Type II has the smaller capture cross section and accounts for only 10% of the damage at 0.7 MeV but rises to 50% at 4.5 MeV . Type II is unaltered by radiation annealing and is not affected by thermal annealing up to 120°K .

We believe that type I may be the isolated vacancy since it is the dominant species for irradiation energies less than 0.7 MeV, while type II may be the di-vacancy whose threshold energy for production should be about 0.7 MeV.

If the identification given above is correct, the di-vacancy in germanium is very resistant to annihilation by interstitials.

p-Type Germanium

This work is now almost complete. We have examined the dependence of defect production on temperature, impurity type and concentration and on irradiation energy, as well as the thermal annealing and radiation annealing processes. The behavior of p-type germanium is most complex and the studies are complicated by very strong trapping effects that result in non-equilibrium carrier distributions. We believe that we have now unravelled most of the complexities.

Radiation Annealing in n-Type Silicon - Optical Absorption

For n-type silicon, production of damage by electron irradiation is strongly temperature dependent. Irradiation at temperatures below 60°K produces little or no damage. Above 60° the efficiency of damage production rises rapidly. On the other hand, if a specimen is damaged at a temperature above 60°, further irradiation at a lower temperature produces recovery of damage. We have been using the optical absorption bands of known defects in silicon to determine which defects are involved in this temperature dependent radiation annealing process.

Last year, in our progress report, we stated that the vacancy-oxygen complex (A-center) disappears under radiation annealing. This report was in error. Later, more careful studies with improved techniques show that the A-center is not affected by radiation annealing. We have also established that the defects involving carbon (presumably association of an interstitial Si atom with a substitutional carbon atom) are also not affected in specimens containing both oxygen and carbon.

By going to higher irradiation energy (4.5 MeV) we have been able to introduce sufficient divacancy concentrations to observe that this defect is removed by radiation annealing at temperatures below 60°K. We are presently engaged in studying the temperature dependence of divacancy production and the temperature dependence of the irradiation annealing of this defect.

Radiation Annealing in Silicon - Electrical Measurements.

It is not possible to observe the optical absorption band due to the E-center (vacancy-phosphorus association) in n-type silicon. Therefore as a companion to the work described above we are using electrical properties measurements on moderately doped silicon in an effort to determine the effect of radiation annealing on the E-center. Here we make measurements of carrier concentration over a wide range of temperature to obtain a measure of the number of electronic states at 0.4 eV below the conduction band. This level is characteristic of the E-center but a complication arises because the divacancy has a level in the same region. Our measurements up to this time indicate that the E-center is probably removed by radiation annealing, but careful correlation with the optical absorption measurements on the divacancy will be necessary before this becomes a firm conclusion.

Principal Investigator's Effort

The principal investigator's time is devoted, on an annual basis among the following activities: Teaching, 25%; Departmental and University Committees, 5%; Research and Administration connected with this contract, 70%.

Publications

The following papers were presented at the 1970 International Conference on Radiation Effects in Semiconductors, Albany, N.Y. August 1970. They are in Press and will appear in the journal Radiation Effects.

"Defects Induced by Electron Irradiation of p-Type Germanium"
R. A. Matula and E. E. Klontz.

"Impurity Dependence of the Low Temperature Annealing in n-Type Germanium", Jon M. Meese and J. W. MacKay.

"Review of Radiation Effects in Germanium", J. W. MacKay and E. E. Klontz.