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BASIC RADIATION DAMAGE STUDIES

TECHNICAL PROGRESS REPORT

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PROGRESS REPORT

Introduction

Our research is devoted to investigation of the behavior of germanium and silicon under electron irradiation at low temperatures. In spite of the gross differences that are evident in the behavior of these two materials, it now appears that the fundamental processes that govern defect production and annealing may be very similar in both, and that the gross differences in behavior are due to rather subtle differences in the interactions between defects and impurities, or other defects.

Some years ago, Watkins established that the interstitial silicon atom is mobile even at liquid helium temperature. Our recent work on optically induced annealing, radiation annealing and the effects of impurities on the annealing in germanium, have led us to the conclusion that the interstitial is mobile in germanium as well.

The character and amount of damage produced by irradiation at liquid helium temperature depends critically on a competition between 1) trapping of the interstitial by an impurity and, 2) annihilation of the interstitial by an immobile vacancy. This competition is strongly affected by the type and charge state of the impurity and the charge state of both the interstitial and the vacancy.

It appears that both strain-field interactions and Coulomb interactions play important roles in determining how an interstitial interacts with an impurity or a vacancy. Both effects are evident in n-type germanium where the kind of group-V impurity

affects the annealing process in the dark, and the character of the annealing is markedly affected by infrared illumination.

Much of our effort in current experiments and in reinterpretation of earlier work is directed toward the understanding of defect-defect and defect-impurity interactions under various conditions of temperature, illumination and impurity concentration.

Radiation Annealing in Silicon - Optical Absorption Studies

Sivo and Klontz have observed, using electrical measurements, that damage produced in n-type silicon by electron irradiation at temperatures in the range $60^{\circ} \leq T < 250^{\circ}$ K recovers if the specimen is subjected to further irradiation at a lower temperature ($T < 60^{\circ}$). It is known that vacancy-impurity complexes are formed at the higher temperatures. The fate of the interstitial is not known. Our aim in these experiments is to follow the effects of irradiation at high and low temperature on the vacancy-oxygen complex (A-center) by measuring the optical absorption that is associated with this complex at a wavelength of 12 microns.

We find that the 12 micron absorption band grows under irradiation at 80° K, as expected, and that subsequent irradiation at 10° K destroys the absorption band. This indicates that the A-center has been broken up by the low temperature irradiation. Further irradiation at 80° K produces the absorption band again but its growth is at the same rate as in the original irradiation. This suggests that not only was the A-center broken up but that the vacancies produced by the original irradiation were annihilated by the radiation annealing. If the vacancies were simply separated

from the oxygen and remained in the lattice, they would be expected to migrate back to the oxygen atoms as soon as the temperature was raised above 60°K. Annihilation of the vacancies implies that the interstitials are still present, trapped somewhere in the lattice at 80°K and are released during the 10°K radiation annealing.

The sensitivity of our apparatus has been improved by about a factor of five in recent months and we are currently studying the behavior of the twelve micron band in more detail as well as following several other bands that are observed in the range of 6 to 12 microns.

Radiation Annealing in Silicon - Electrical Properties

Actual measurements for this investigation have just begun. A start was delayed by the need to design and construct a new irradiation cryostat with the necessary flexibility of temperature control. The experiments will complement the optical absorption measurements by studying the radiation annealing of the electrical properties for a range of concentrations of various impurities.

Change in Length of Irradiated Germanium

These experiments have been completed, a thesis is nearly written and a paper is in preparation for publication. The important conclusions drawn from this work are: 1) Pure germanium expands under electron irradiation at liquid helium and liquid nitrogen temperatures. The expansion is attributed to a dilation of 0.1 atomic volumes per defect. 2) Doped n-type germanium contracts

under the same irradiation conditions. The contraction is a result of the above dilation being outweighed by an electronic volume effect which produces a contraction of atomic volumes per electron removed from the conduction band.

The electronic volume effect had been directly observed by using the trapping properties of the specimen. The magnitude of this directly measured electronic volume effect is now in good agreement with that deduced from the comparison of the behavior of pure and doped material, provided we attribute the electron trapping only to the defects that anneal at 65°K.

Impurity Effects in n-Type Germanium

This work has also been completed, a thesis is nearly written and a paper is in preparation. The major conclusion is that the interstitial is mobile in germanium at liquid helium temperature and migrates to the neighborhood of a group-V impurity, where it is trapped. A consistent interpretation of the thermal annealing at 65°K in the dark, photo-induced and radiation-induced annealing at liquid helium temperature, and the rapid increase, at 30°K, in the rates of photo- and radiation-induced annealing rates has been achieved.

Radiation Annealing in n-Type Germanium

In continuing this investigation, we have found that the radiation annealing observed at liquid helium temperature in n-type germanium is impurity dependent. As doped material anneals at a significantly faster rate than Sb doped material. The radiation annealing process is observed to be intensity dependent for low

beam intensities, and strongly temperature dependent above 20°K. We now believe that we understand the basic mechanism of the radiation annealing process, however, some aspects such as the conversion of some defects that normally anneal at 65°K into a more permanent form, are still not clear.

Radiation Damage in p-Type Germanium

There is a difficulty in studying the effects of irradiation on the electrical properties of p-type germanium at liquid helium temperature - the presence of defects can be detected only after the specimen is illuminated by infrared light with photon energy less than the band gap. In addition, the number of defects, for a given irradiation appears to be much smaller than in n-type. We have recently discovered that illumination by light with photon energies greater than the band gap quickly eliminates all traces of any defects. This suggests that radiation annealing in p-type may be much more effective than in n-type, and that this is the reason for the much smaller damage rate in p-type. We are presently investigating the radiation annealing in this material. Our observations indicate that it is indeed strong.