ELECTRON SPIN RESONANCE IN NTD SILICON

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ABSTRACT

Neutron transmutation doped silicon has been studied and characterized by electron spin resonance. Two samples were irradiated for the same final target resistivity (25 ohm-cm) in the University of Missouri Research Reactor. One was in a position with high flux, and the second was exposed to a lower flux. The room temperature ESR spectrum as a function of anneal temperature for both samples has been obtained from the irradiation temperature up to 600°C. A number of ESR centers have been found. The lattice defect configuration corresponding to some of these centers has previously been identified and is discussed. The data indicates that ESR measurements are a non-destructive and convenient way to obtain the sample's temperature during irradiation.

1. INTRODUCTION

When silicon is irradiated with neutrons, a variety of point defect structures are produced in the crystal. The microscopic structure of these defects can be determined by electron spin resonance\(^1\) (ESR). (ESR has been an essential technique for understanding many important radiation damage centers and processes in silicon.\(^2\)\(^-\)\(^5\)) Although ESR can only measure defects containing one or more electron(s) with an unpaired spin, such defects are rather common in silicon. In fact, the detailed analysis of ESR data has permitted the assignment of lattice configurational models to a variety of rather complex defects, several of which will be discussed in Section 4.1. In this paper, the ESR signals observed from NTD silicon are reported both after irradiation and after various
annealing stages. Signals from a number of different defect centers have been found, and previously reported models for these centers are discussed. In addition, of special interest to several attendees at this conference was the discussion (Section 4.2) on how ESR measurements can be used to determine the irradiation temperature variations at various positions and under various conditions in a reactor.

2. EXPERIMENTAL DETAILS

Two irradiated samples were kindly provided by Dr. Jon Meese of the University of Missouri Research Reactor Facility. Both samples were float zone silicon, grown by Topsil. Each was placed in an aluminum can during irradiation and exposed to both thermal and fast neutrons. Both were irradiated to a total fluence of $1.05 \times 10^{18}$ n/cm$^2$, corresponding to a target (high temperature) resistivity of 25 ohm-cm. The difference between the samples was in their irradiation positions.

Sample #1 was exposed to a higher flux in the reactor.
Sample #2 was exposed to a lower flux just out beyond the reflector in the pool (S-basket position).

The flux on Sample #1 was about $3 \times 10^{13}$ n/cm$^2$/sec with a Cd ratio of thermal to fast neutrons of about 10:1. The flux on Sample #2 was about $10^{12}$ n/cm$^2$/sec with a Cd ratio a factor of two or three higher.

Several days after irradiation ESR samples were cut from the boules. They had approximate dimensions of 3 mm x 3 mm x 10 mm. ESR measurements were made at room temperature using a standard X-band Varian Associates EPR spectrometer. The samples were rotated about the long dimension which was cut as the [110] axis so that the [001], [111], and [110] axes could all be aligned along the magnetic field which was perpendicular to the [110] rotation axis. The signal intensity at each anneal temperature was normalized to a ruby standard in the ESR cavity.

Anneals were carried out in a quartz tube with flowing argon. All anneals were for ten minutes at the specified temperature, which does not include the five minute warm-up time or the cool-down time.

3. RESULTS

As the magnetic field was swept, numerous ESR lines of various intensities were seen. In addition, the position of these lines in the spectra changed substantially with small changes in the sample orientation. Often, many lines belong to one particular defect