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Long Term Instability in the Defect Assembly in Irradiated High Resistivity Silicon Detectors*

V. Eremin, A. Ivanov, E. Verbitskaya
Ioffe-Physico-Technical Institute of Russian Academy of Sciences
194021 St. Petersburg, Russia

Z. Li
Brookhaven National Laboratory
Upton, NY 11973-5000

B. Schmidt
Institute for Ion Beams and Material Research
Research Center Rossendorf, D-01314 Dresden, Germany

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V.Eremin, A.Ivanov, and E.Verbitskaya
Ioffe Physico-Technical Institute of Russian Academy of Sciences, 194021 St-Petersburg, Russia

Z.Li
Brookhaven National Laboratory, Upton, New York 11973, USA

B.Schmidt
Institute for Ion Beams and Material Research, Research Center Rossendorf, D-01314 Dresden, Germany

Abstract

Different kinetic behavior has been revealed for the two types of irradiated high resistivity silicon detectors in the reactions of the interstitial carbon (C_i) annealing and the formation of the C_i-O_i complex. In the detectors with an increased oxygen contents prolonged growth of the C_i-O_i complex concentration obeyed the second order reaction due to an additional source of C_i atoms which were not detected by DLTS measurements. Transformation of carbon related defects has been analyzed concerning the long term instability of irradiated silicon detectors.

1. Introduction

The problem of reverse annealing of irradiated silicon detectors has been studied in details in its macroscopic evolution [1,2]. The data showed accumulation of the negative charge in the space charge region which resulted in the increase of the net effective concentration N_{eff} [3]. Hypotheses available to explain this phenomenon are based on microscopic reactions with various dominant defects. This paper presents the results concerning instability of radiation induced defects in high resistivity silicon detectors which originates from the reactions with carbon related defects.

2. Experimental procedure

Detectors used in the study were made from n-type FZ Si with resistivities of ρ = 1-2 kΩ-cm (Freiberger Elektronikwerkstoffe GmbH) and of 5kΩ-cm (Wacker Chemitronic). Irradiation was made by α-particles or neutrons followed by annealing at RT or elevated temperatures. The spectra of radiation induced defects were measured by C-DLTS technique.

3. Kinetic behavior of carbon related defects

The investigation was concentrated on the processes with carbon related defects: annealing of the interstitial carbon C_i, H1 = E_V + 0.33eV, and simulteneous formation of the C_i-O_i complex, H2 = E_V + 0.40eV, Annealing of the C_i atoms with a concentration $n_x(t)$ obeyed the first order reaction:

$$n_x(t) = n_{x0}\exp(-t/\tau) \qquad (1)$$

where τ is the time constant. The kinetic parameters of this reaction have been revealed to depend on the oxygen contents introduced during thermal oxidation [4]. According to these parameters the detectors were devided into two groups: 1) "fast" samples with an increased oxygen contents (τ was found to be several hours at RT); 2) "slow" samples with a lower oxygen contents (similar values of τ were achieved at ~50°C). In defect studies [5], the concentration of neutron induced defect level with an activation energy E_a = 0.39eV correlated with the reverse annealing of N_{eff}. One of the possible candidates for this level can be the C_i-O_i complex.

Formation of the C_i-O_i complex with a concentration $N_x(t)$ may be described as the first order reaction:

$$N_x(t) = n_{x0}\left[1-\exp(-t/\tau)\right] \qquad (2)$$

if it is controlled by the C_i concentration solely, or may obey the second order reaction of the two components C_i and O_i with similar concentrations:

$$N_x(t) = n_{x0}\left(1-\frac{1}{1+kn_{x0}t}\right) \qquad (3)$$

where k is the rate constant of the reaction.

The isothermal annealing data for the H1 and H2 centers for "fast" sample (Wacker Si) showed that even after the total exhaustion of the interstitial

carbon (during ~15 hours) the concentration of the C_i-O_i center has been observed to its trend of increase even at RT (Fig.1). Under prolonged annealing (~40 days) the best fit of the data could be obtained using the second order reaction. The constant k ~10^{-17} cm^3s^{-1} was similar to the rate constant of N_{eff} reverse annealing in [2].

The difference in the kinetic behavior of the C_i defect and the C_i-O_i complex implies that the C_i-O_i complex formation may be controlled by an additional process of carbon and oxygen atom interaction. An "excessive" concentration of the C_i-O_i complex N_{exc} was defined as:

$$N_{exc} = N_x - N^1_{sim} \quad (4)$$

where N^1_{sim} is the concentration simulated according eq.(1) with the parameters n_{x0} and τ corresponding to the C_i annealing. The best fit of the excessive concentration can be obtained with the second order reaction (Fig.2), similar to the total concentration of the C_i-O_i complex. After the second irradiation the concentration increase of the C_i-O_i complex showed two stages: an initial fast concentration increase during the first 25 hours of RT anneal fitted by the second order reaction, and afterwards the saturation of the concentration.

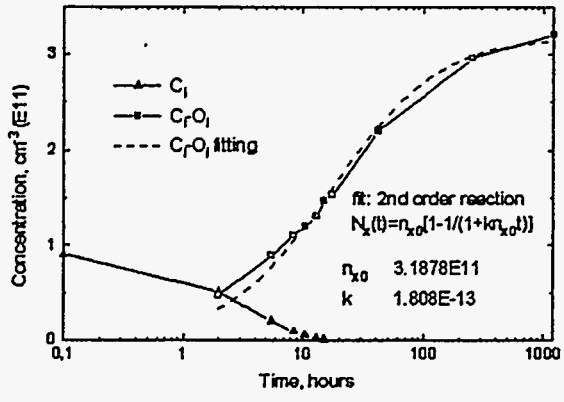

Fig.1. Isothermal RT annealing of the interstitial carbon and the C_i-O_i complex.

For "slow" samples, the increase of the concentration of the C_i-O_i complex correlated well with the C_i decay which occurred during ~30 hours at T=50°C.

4. Discussion

For both types of the detectors the second order reaction for the formation of the C_i-O_i complex is observed at least after the first irradiation-annealing cycle. Hence, the two components C_i and O_i with similar concentrations are assumed to combine in the defect formation.

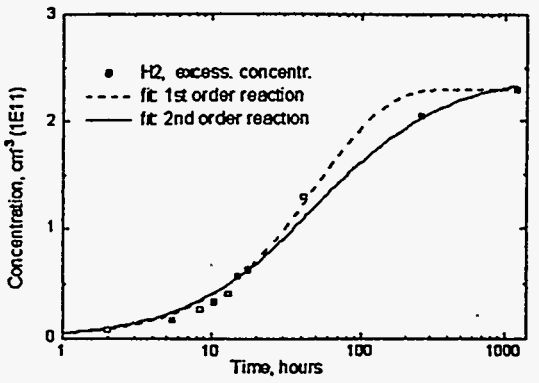

Fig.2. RT annealing of the "excessive" concentration of the C_i-O_i complex.

Further, significant increase of the concentration of the C_i-O_i complex after the exhaustion of the interstitial carbon implies an additional source of this constituent in the C_i-O_i complex generation. This additional source may also explain the fact that, after the second irradiation-annealing cycle the saturation concentration of the C_i-O_i complex exceeded that after the first irradiation-annealing cycle. These atoms together with electrically active C_i centers measured by DLTS may have participated in the generation of the C_i-O_i complex and presumbly dominate in the "fast" samples.

We assume that accumulation of the C_i-O_i complex may affect the reverse annealing only in the very early stage of the N_{eff} change. Still, the data on isochronous elevated temperature annealing show concentration increase only for carbon related defects. Thus, the results give rise to suggest that instability in the defect assembly in irradiated silicon detector can arise from the complexes including carbon and oxygen.

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