Field and Charge Dependence of Radiation Damage in Silicon

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SUMMARY

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By measuring the photovoltaic response of Si with shallow p-n junction as a function of optical wave length, it is possible to determine the depth distribution of damages in Si. Methods for the analysis will be presented.

There is evidence that the radiation damage depends, besides on the mass of the atoms (Si and the impurities), also on (1) the electric charge states of the crystal and the lattice, and (2) the internal field, such as, p-n junction field and the field produced by the concentration gradient in the crystal.

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Introduction

On the problem of the spatial distribution of radiation damage in Si, Spencer [1] and Yurkov [2] have given some theoretical calculations. Vavilov, Patskevich, Yurkov and Glazunov [3], and Flicker and Loferski [4] reported experimental results with 0.5 Mev electron radiation. Vavilov et al., stated a need of further experimental investigation on the interaction of defects and impurities. Flicker and Laferski demonstrated the importance of the energy level of defect centers with respect to the Fermi level. In the present work, by using a somewhat different experimental approach, it becomes possible to ascertain the impurity concentration effect. Essentially, we are using a photovoltaic Si cell with shallow p-n junction subjected to electron radiation. We measure the photovoltaic short circuit current (this will be referred to as current, hereafter), as a function of the photon energy before and after the radiation. By a formula which connects the energy distribution and the spatial distribution of the current, we can calculate a spatial radiation damage function. Such a calculation from our experimental results will be given in the present paper.

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Experiment

Having already described the essential feature of the experimental approach, here we will merely make some comparisons of experimental methods and their implications.

Vavilov *et al.*, measured the radiation damage through the change of the ohmic resistivity of ordinary p-type Si. This method is considerably less sensitive than the method of measuring the current of the photovoltaic cell[5] as used by Flicker and Loferski[4], as well as in the present work. Flicker and Loferski introduced aluminum foils (up to a thickness of 0.75 mm) into the front of the photovoltaic cell. This achieved the purpose of modulating the initial energy of the electrons, and measured the electron-voltaic current due to the different radiation energy. In their analysis, similar to that of Vavilov *et al.*, complicated processes of redistribution, as given in References 1 and 2, had to be introduced.

In our experiment, we measure i_λ, the photovoltaic current per photon of energy hc/λ, thus,

$$i_\lambda = \int_0^d K(\lambda)\ I(\lambda, x)\,dx, \qquad (1)$$

where $I(\lambda, x)$ is the light intensity of λ wave length at depth x from the front surface of the photovoltaic cell, and d is the thickness of the cell. The parameter $K(\lambda)$ can be called a conversion efficiency parameter, but as its usage will be further illustrated, $K(\lambda)$ can also include the dimunition of i_λ due to the local recombinations and trappings. In a homogeneous, isotropic system, we have

$$I(\lambda, x) = I(\lambda, 0)\ e^{-\alpha(\lambda)x}, \qquad (2)$$

here $\alpha(\lambda)$ is optical absorption coefficient. Therefore,

$$i_\lambda = \frac{1}{\alpha(\lambda)}\ K(\lambda)\ I(\lambda, 0) \left\{1 - e^{-\alpha(\lambda)d}\right\}. \qquad (3)$$

The total current generated by a light source $I(\lambda, x)$ through the total cell can be written,

$$i = \int_0^d dx \int_{\lambda_0}^{0} d\lambda\, K(\lambda)\ I(\lambda, x), \qquad (4)$$

where λ_0 is the wave length of the absorption edge which is 1.1μ in Si. From (4), we obtain the current at a place x perpendicular to the surface,

$$i_x = \int_{\lambda_0}^{0} K(\lambda)\ I(\lambda, x)\ d\lambda . \qquad (5)$$

Substituting (3) in to (5),

$$i_x = \int_{\lambda_0}^{0} i_\lambda\ \alpha(\lambda) \left\{1 - e^{-\alpha(\lambda)d}\right\}^{-1} e^{-\alpha(\lambda)x}\ d\lambda . \qquad (6)$$

By using the data of Dash and Newman [6] for $\alpha(\lambda)$, from the the experimental value of d and i_x, we have computed i_x. The difference of i_x for a cell before and after the radiation then indicates a relative spatial distribution of the radiation damage.

Results

Three kinds of photovoltaic cell have been used in the present work:

Specimen 1. p-type surface of about 0.5μ thick, a p-n junction of about 0.5μ wide, and .75mm thick n-type bulk with impurity concentration of the order of 1×10^{18} per c.c.

Specimen 2. The reverse of Specimen 1, i.e., interchange of p and n, with same concentrations.

In Specimens 1 and 2, impurity concentrations are quite constant except near the junction where the p-n compensation occurs.

Specimen 3. Specimen 3 has, besides an n-p junction as in Specimen 2, also a concentration gradient starting at 25μ thick, a steep increase of impurity concentration from 5×10^{17} per c.c. to 5×10^{19} per c.c.

All these cells are subject to 1 Mev 5×10^{14} electrons/cm^2 radiation. The data are normalized to the same initial value and are shown in Figure 1.

We observe in all three samples that there is a small inflection near the location of p-n or n-p junctions, this corresponds to the region of a strong field. Second, there is appreciably less damage in Specimen 3 which has a high impurity concentration.

We are investigating a more quantitative aspect of the problem. There is also some evidence in the dependence of the radiation damage on the time rate of radiation. All these observations can be treated collectively as a quasi-Fermi level effect which was not included in the theoretical Treatment we have referred to.

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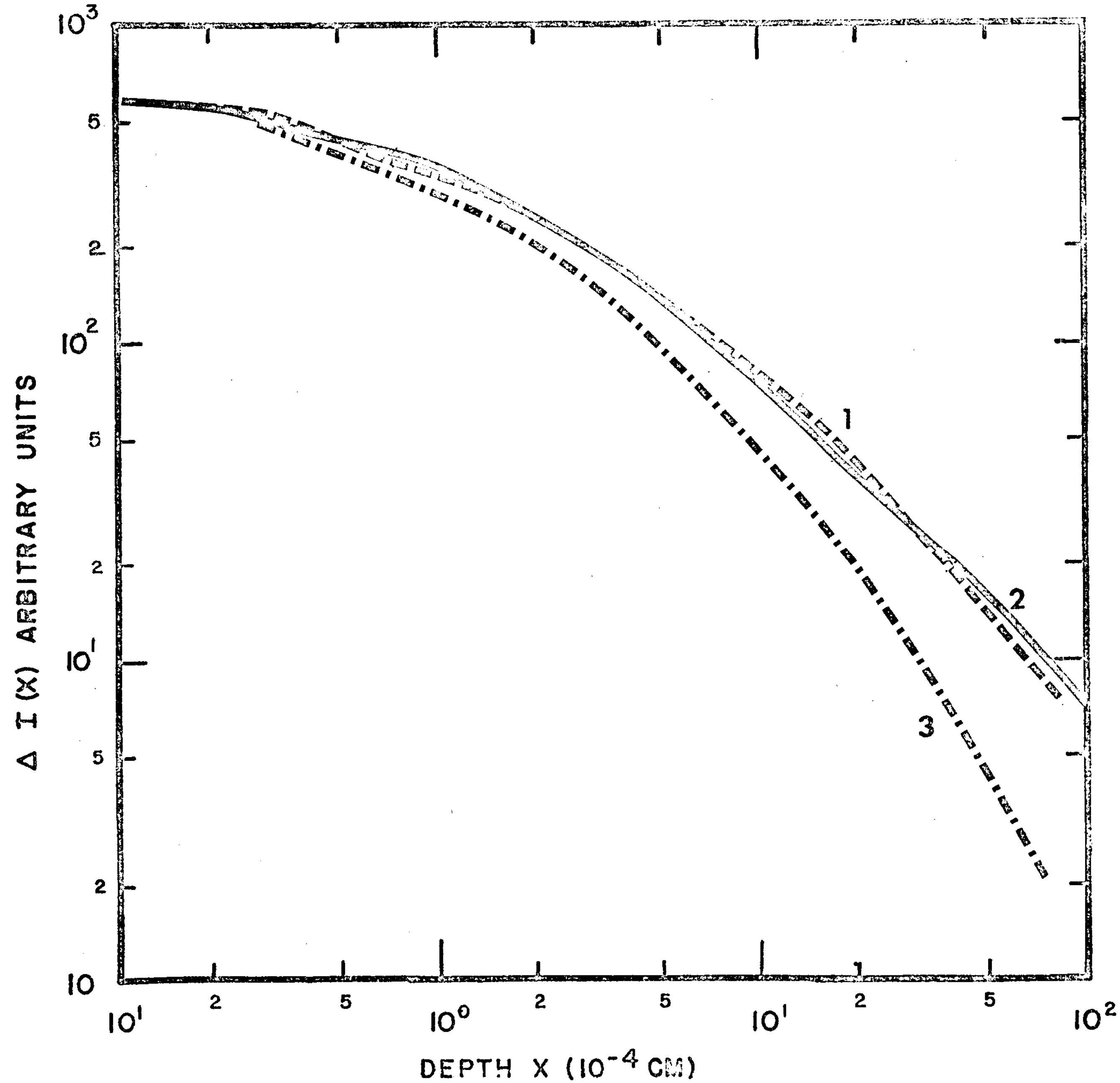

Δ I (X) ARBITRARY UNITS
DEPTH X (10^{-4} CM)
10^3
5
2
10^2
5
2
10^1
5
2
10
10^1
2
5
10^0
2
5
10^1
2
5
10^2
1
2
3