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Fast Neutron Irradiation Effects on Threshold Voltage of Si Diode

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1. Introduction

A diode composed of p-n junction is fundamental to the performance of functions such as rectification, amplification, switching, and other operations in electronic circuits [1][2]. A p-n junction diode is that current flows quite freely when the positive applied voltage is higher than the threshold voltage, whereas no current flows when the applied voltage is lower than the threshold voltage. This asymmetry of current flow makes the p-n junction diode very useful as a rectifier. Fast neutron irradiation incurs lattice damages on the bulk of Si diodes [3][4]. The electrical characteristics of Si diodes are altered by the fast neutron irradiation. This study will investigate the characteristics of threshold voltage of Si diode for the fast neutron irradiation.

2. Experimental Studies

2.1 p-n diode

The total current crossing the junction is composed of the sum of the diffusion and drift components in p-n diodes [1][2]. The diffusion current is composed of majority carrier electrons on the n side surmounting the potential energy barrier to diffuse to from n to p over the smaller barrier, and holes surmounting their barrier from p to n. With forward bias, the barrier is lowered and many more electrons in the n-side conduction band have sufficient energy to diffuse from n to p over the smaller barrier. Therefore, the electron diffusion current can be quite large with forward bias. Similarly, more holes can diffuse from p to n under forward bias because of the lowered barrier. For the reverse bias the barrier becomes so large that virtually no electrons in the n-side conduction band or holes in the p-side valance band have enough energy to surmount it. Therefore, the diffusion current is usually negligible for reverse bias.

The drift current is relatively insensitive to the height of the potential barrier. Therefore the drift current is simply proportional to the applied field. The reason is the fact that the drift current is limited not by how fast carriers are swept down the barrier, but rather how often. The electron and hole drift currents at the junction are independent of the applied voltage. The supply of minority carriers on each side of the junction required to participate in the drift component of current is generated by thermal excitation of electron-hole pairs. If the electron-hole pair is generated within a diffusion length of the transition region, the electron can diffuse to the junction and swept down the barrier to the n-side. The resulting current due to drift of generated carriers across the junction is commonly called the generation current since its magnitude depends entirely on the rate of generation electron-hole pairs.

The total current can be described as the diffusion current minus the absolute value of the generation current, and is given by (1),

$$\mathrm{I} = I_0\left(e^{qV/_{kT}} - 1\right), \qquad (1)$$

where I_0 is the absolute value of the generation current, V is applied voltage, q is magnitude of the electronic charge, k is Boltzmann's constant, and T is temperature [1]. When V is positive and greater than a few kT/q, the exponential term is much greater than unity. Therefore, the current is increases exponentially with forward bias. When V is negative (reverse bias), the exponential term approaches zero and the current is $-I_o$, which is in the n to p (negative) direction. When V greater than and opposite to the built-in voltage of p-n junction is applied, a current will flow and the diode will be turn-on. The diode have a forward threshold voltage, above which it conducts and below which conduction stops. The threshold voltage of Si diode is approximately 0.7V.

Fast neutron irradiation incurs lattice damages on the bulk of Si diodes [3][4]. The lattice damage arises from the displacement of Si atoms because of the bombardment by fast neutron irradiation. The lattice damages that remain after irradiation are composed of complexes of vacancy with impurity atoms and two adjacent vacancy sites in the lattice. The resistivity of the Si after fast neutron irradiation is increased due to the lattice damages. In this study, the current characteristics of the diode are investigated through the fast neutron irradiation on a Si diode.

2.2 Experimental Results

A Si p-n diode, generally used for switching application, is applied in this experiment. Fast neutron irradiation is performed using the MC-50 cyclotron in KIRAMS (Korea Institute of Radiological & Medical Sciences). The irradiated fast neutron fluence is 1 x 10^{10} n/cm^2.

Figure 1 shows the experimental result of the diode currents versus the applied external voltage for before and after fast neutron irradiation. The diode current is decreased in the case of after fast neutron irradiation compared with the case of before irradiation. And the threshold voltage is increased in the case of after fast neutron irradiation compared with the case of before irradiation.

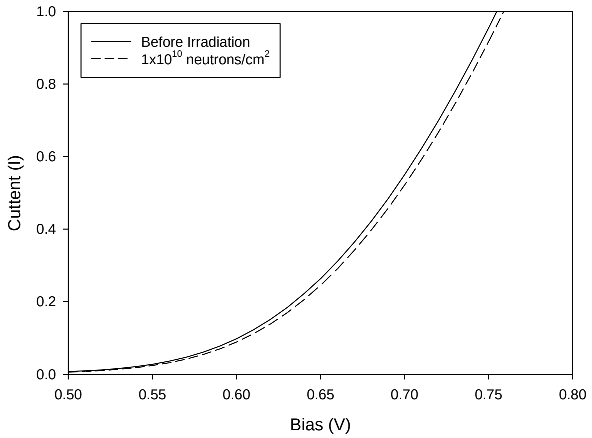

Fig. 1. Current versus applied voltage.

Figure 2 shows the deviation of diode current between after and before irradiation cases. I_a is the measured diode current after fast neutron irradiation, and I_b is the measured diode current before irradiation. It is shown in Figure 2 that the current deviation between after and before irradiation is rapidly increased at near the threshold voltage.

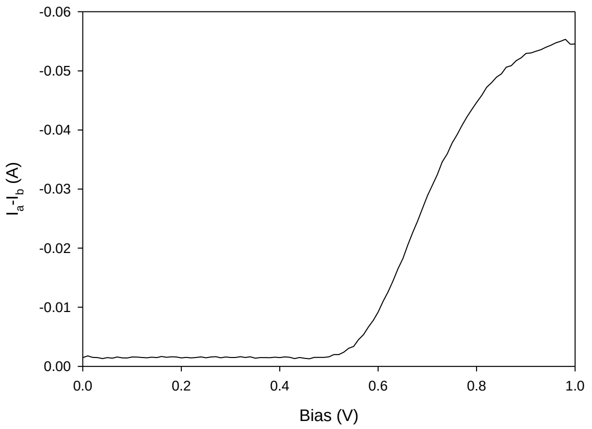

Fig. 2. Current deviation between after and before fast neutron irradiation.

Figure 3 shows the deviation of applied voltage versus diode current between after and before irradiation cases. V_a and V_b are the applied voltage for the cases of after and before fast neutron irradiation respectively. It is shown in Figure 3 that a higher external voltage should be applied to achieve same current in the case of after fast neutron irradiation compared with the case of before irradiation.

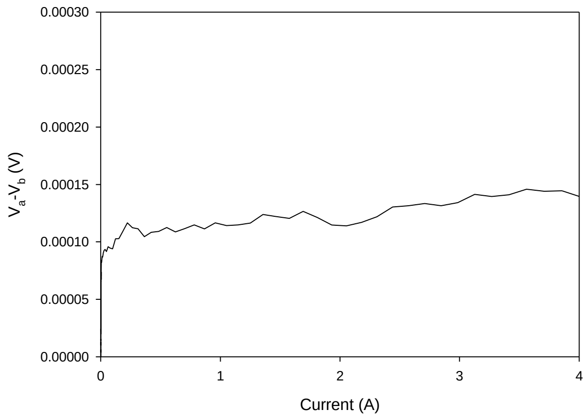

Fig. 3. Voltage deviation between after and before fast neutron irradiation.

3. Conclusions

In p-n junction diode, current flows quite freely when the applied positive voltage is higher than the threshold voltage, but current flow approaches zero when the applied voltage is lower than the threshold voltage. Fast neutron irradiation incurs lattice damages on the bulk of Si diodes. The lattice damages that remain after irradiation are composed of complexes of vacancy with impurity atoms and two adjacent vacancy sites in the lattice. In this paper, the characteristics of threshold voltage of Si p-n diode is investigated through the fast neutron irradiation experiment. The experimental results show that the threshold voltage is increased in the case of fast neutron irradiation compared with the case of before irradiation.

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