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Effect of 8 MeV Electrons on Au/n-Si Schottky diodes

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Abstract

This paper presents the results of 8MeV electron irradiation effects on the electrical characteristics of Au/n-Si Schottky diodes. The diode parameters were calculated from the I-V and C-V characteristics. It is found that both forward and reverse current increases after irradiation. A decrease in the value of barrier height and increase in the ideality factor are observed with increase in electron dose. Capacitance – Voltage measurements indicate that there is a slight reduction in the carrier concentration due to electron irradiation.

Keywords: Au/ n-Si, Schottky diode, electron irradiation, Current- Voltage, Capacitance- Voltage characteristics, carrier concentration, depletion layer width.

Introduction

Radiation causes ionization and atomic displacement in semiconductors. Electron irradiation is known to have less degradation effect than neutron irradiation of similar energy and dose, but have higher damage coefficient than for gamma rays [1]. Semiconductor devices which operate in space are often subjected to various types of radiations. The permanent and transient changes in the electrical properties of semiconductor devices induced by radiation may cause device degradation. An understanding of the degradation mechanism is therefore necessary to improve the device performance in radiation environment [2]. Studies on the effect of electron irradiation on the Schottky barrier diodes are also important for fundamental understanding of the phenomenon of interaction at the interface. In some fields such as the testing of radiation hardness of semiconductor devices for the aerospace industry and the development of particle detectors it is extremely important to correlate the effects of irradiation on the material/device properties with the modification of the electrical characteristics of Schottky barriers . Moreover, these studies shed light on the basic interaction processes, and their influence on various properties of semiconductors. Stable defects in silicon created by electron irradiation can be divided into three categories, 1) defects created directly by collision such as divacancies 2) defects created by the interaction among radiation induced intrinsic defects such as di-interstitials and 3) defects created by the interaction between an intrinsic defect and an impurity originally present in the crystal like vacancy- oxygen complex [3]. Radiation induced deep levels in silicon have been studied by many researchers including several studies on degradation of Si devices at fluences less than $1x10^{16}$ electrons/cm^2, where minority carrier effects dominate. Therefore studies on response of 8 MeV electron irradiation and defects responsible for the degradation of device performance of Au/n-Si Schottky diodes can be very useful for understanding the effects in Si solar cells also. Here the effect of 8 MeV electron irradiation on the electrical characteristics of Au/n-Si Schottky diodes over a range of doses is investigated.

Experimental

Au/Si Schottky barrier diodes were prepared using phosphorous doped <100> Silicon wafers of 4” in diameter, 545µm thickness and 4-11 Ωcm resistivity. The wafer was etched in dilute hydrofluoric acid (1:10) to remove the SiO_2 layer which is generally formed on silicon, rinsed with distilled water and dried. Schottky contacts were prepared by depositing gold dots of area 0.01766 cm^2 and thickness 2000 Å by vacuum evaporation on Si. Ohmic contacts were made on the back side of Silicon by depositing aluminum. Both forward and reverse Current-Voltage (I-V) characterization of the diodes were carried out using a computer interfaced Keithley 236 Source-Measure Unit in the voltage range 0-2V and -1V to 0V respectively with a step voltage of 0.1V. Capacitance –Voltage measurements were carried out at 1MHz using a computer interfaced DLS-2000 system. The Au/n-Si Schottky barrier diodes were exposed to 8MeV electrons from the Microtron at room temperature for doses from 1 kGy to 75 kGy. The salient features of the Microtron accelerator are detailed elsewhere [4]. The devices were placed at a distance of 30 cm from the titanium window under normal ambient conditions. The electrical characterizations of the Schottky diodes were also carried out after irradiation.

Theoretical Background

The electrical properties of the Schottky barrier contacts are generally very sensitive to the properties of metal- semiconductor interface. Thus the I-V characteristics of the contact are useful monitors of the properties of the interface. For a Schottky barrier diode, the thermionic emission theory predicts that the I-V characteristics at forward bias V are expressed by [5]

$$I = I_s\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \tag{1}$$

where I_s is the reverse saturation current given by

$$I_s = A_d A^{**} T^2 \exp\left(\frac{-q\phi_b}{kT}\right) \tag{2}$$

Here A^{**} =1.122x10^6 Am^{-2}K^{-2} is the effective Richardson constant for n-silicon, [5,6] A_d is the diode area, k is the Boltzmann constant, q is the electronic charge, T is the temperature, 'n' is the ideality factor and ϕ_b is the barrier height (in eV).

The ideality factor, 'n' can be obtained from Eq. (1) as

$$n = \frac{q}{kT}\frac{dV}{d(\ln I)} \tag{3}$$

The barrier height ϕ_b can be calculated using the equations

$$\phi_b = \frac{kT}{q}\ln\left(A_d A^{**} T^2 / I_S\right) \tag{4}$$

$$\ln\left(\frac{I_S}{T^2}\right) = \ln(A_d A^{**}) - \frac{q\phi_b}{kT} \tag{5}$$

The barrier height (ϕ_b) and the Richardson constant (A^{**}) can be calculated from the equations (4) and (5).

The neutral region of the semiconductor (between depletion region and the back contact) offers a high resistance and significant voltage drop occurs in this region which results in the reduction of the voltage across the barrier region. The series resistance (R_S) can be determined from the I-V plot in the high forward bias region. The capacitance of the device can be measured as a function of voltage in order to characterize the junction properties of the diodes. The depletion layer capacitance of a junction at a voltage V is given by [5].

$$C = A\left[\frac{q\varepsilon_0\varepsilon_r N_D}{2\left(V_{bi} + V\right)}\right]^{\frac{1}{2}} \tag{6}$$

Where A is the effective diode area, N_D is the carrier concentration, ε_r the dielectric constant of silicon, ε_0 the absolute permittivity and V_{bi} is the built in potential. The total thickness of the depletion layer W of the junction can be given by

$$W = \frac{\varepsilon_0 \varepsilon_r A}{C} \tag{7}$$

Results and discussion

Current – Voltage Characteristics

The diode ideality factor, 'n' was calculated from the I-V characteristics in the region 0.02V to 0.3V, and the reverse saturation current I_s was obtained by extrapolating the straight line portion of I-V curve to V=0 using Eq. (2) and (3). The barrier height Φ_b can be calculated using the equation (4).

Figs.1 (a) and 1(b) represent the forward and reverse I-V characteristics of the Au/n-Si Schottky diode before and after irradiation with different electron doses. It is found that both forward and reverse current increases after irradiation. The increase in reverse current with dose may be due to the generation of carriers in the bulk depletion region as a result of the radiation induced lattice defects as reverse current is proportional to the concentration of minority carriers near the junction [7]. Variations in saturation current with dose for the diodes are shown in Fig. 2.The increase in reverse saturation current with dose may be due to the presence of radiation induced crystal lattice defects which act as trapping or recombination centers shortening the life time of the minority carriers [8]. The ideality factor n, reverse saturation current I_s, series resistance R_s and barrier height ϕ_b calculated from the pre- irradiated forward characteristics were 2.716, $1.5x10^{-9}$A, 9.2kΩ, and 0.84eV respectively.

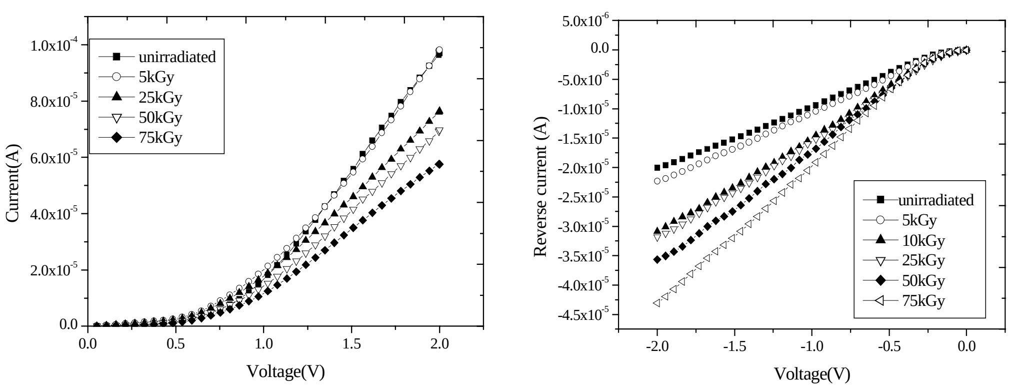

Figure 1: (a) Forward I-V (b) Reverse I-V characteristics of electron irradiated Au/n-Si Schottky diodes at various doses.

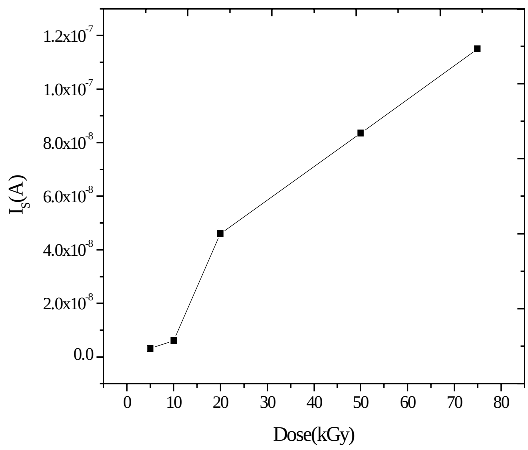

Figure 2: Variation of Saturation current as a function of dose.

The diode ideality factor of the junctions was larger than unity in the present work. An ideality factor greater than unity is generally attributed to the presence of a bias dependent schottky barrier height. Generation–recombination, tunneling, interface impurities and interfacial oxide layer are the possible factors for the higher value of ideality factor [9]. The variation of diode parameters calculated from I-V characteristics with electron dose are summarized in Table 1.

Table 1: The diode parameters as a function of electron dose calculated from I-V characteristics.

Dose (kGy)	**n**	**R_S (kΩ)**	**I_S (A)**	**ϕ_b (eV)**
0	2.716	9.2	1.5×10^{-9}	0.84
5	2.85	10.72	3.14×10^{-9}	0.812
25	2.92	13.2	6.15×10^{-9}	0.745
50	2.98	16.05	4.6×10^{-8}	0.729
75	3.06	17.15	1.15×10^{-7}	0.721

Fig. 3 shows the ideality factor and barrier height as function of electron dose. A decrease in the values of barrier height and increase in the ideality factor are observed with increase in electron dose. Irradiation might have introduced defects at the Au/n-Si interface leading to the reduction in schottky barrier height. Increase in the density of interface states can result in an increase in the ideality factor and lowering of the barrier height with dose [10]. An increase in the series resistance was found for all the doses indicating that product of mobility and free carrier concentration has reduced. The reduction in the mobility may be due to the introduction of defect centers on irradiation which act as scattering centers. Introduction of the deep traps result in decrease in carrier concentration will be reduced [9].

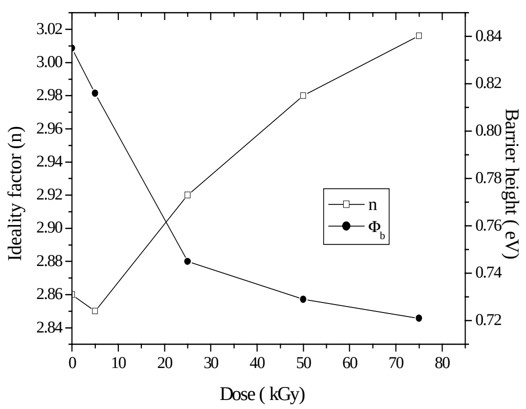

Figure 3: Variation of ideality factor and barrier height of Au/n-Si Schottky diodes irradiated with 8MeV electrons of various doses.

Capacitance –Voltage Measurements

Fig. 4 shows the dependence of $1/C^2$ on applied voltage of an electron irradiated Au/ n-Si Schottky diodes at room temperature. $1/C^2$ –V plots are linear for the diodes before as well as after irradiation to various electrons doses. This suggests that the abrupt junction is not altered much after irradiation.

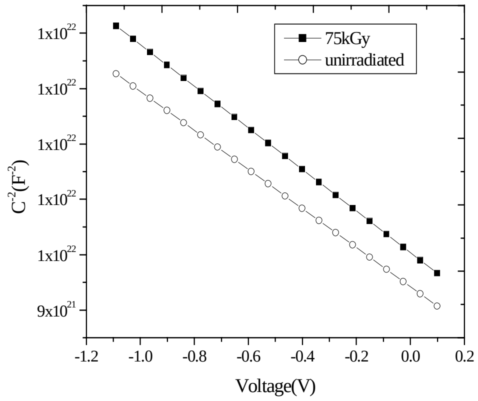

Figure 4: Plot of $1/C^2$ versus V for an electron irradiated Au/ n-Si Schottky diode.

Carrier concentration and Built in potential are estimated from Eq. (6), and is found to be $8.11 \times 10^{20}/m^3$ and 0.99 V respectively. The depletion layer width for the diode is calculated using equation (7). The depletion layer width for the unirradiated diode is 1.97µm at zero bias and 2.23 µm at -1V bias. At 75kGy the depletion layer width has increased to 2.0 µm at zero bias and 2.28 µm at -1V bias.

Fig.5 shows the variation of carrier concentration N_D with dose. A slight reduction in the carrier concentration is observed due to electron irradiation. The diffusion potential remains the same for all the doses. So it can be concluded that no major change has taken place in the depletion region of the device which indicates that the vacancies and the interstitials produced by irradiation might have recombined before they can form stable complex defects, as the defects are very mobile at room temperature [11].

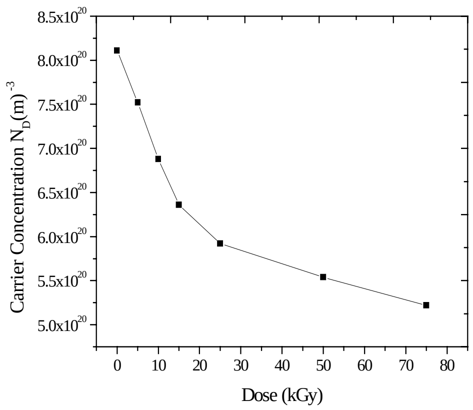

Figure 5: Carrier Concentration of the Au/n-Si Schottky diode as a function of dose.

Conclusions

Following conclusions may be drawn from the study of electron irradiation effects on the electrical characteristics of Au/n-Si Schottky diodes.

1. Both forward and reverse current increases after irradiation. The increase in reverse current with dose may be due to the generation of carriers in the bulk depletion region as a result of the radiation induced lattice defects.
2. A decrease in the value of barrier height and increase in the ideality factor are observed with increase in electron dose. Irradiation might have introduced defects at the Au/n-Si interface leading to the reduction in Schottky barrier height.
3. Capacitance – Voltage measurements indicate that there is a slight reduction in the carrier concentration due to electron irradiation. The diffusion potential remains the same for all the doses indicating that no major change has taken place in the depletion region of the device.

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