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Electron irradiation effects on the Schottky diode characteristics of p-Si

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Abstract

Particle irradiation can induce transient and permanent changes in the electrical properties of semiconductor devices in radiation environments. The effects of electron irradiation on the device properties of Al/p-Si Schottky diodes are reported here. Schottky diodes were exposed to a maximum cumulative dose of 100 kGy at room temperature. Their forward and reverse current–voltage (*I*–*V*) characteristics were studied at room temperature. The diode parameters such as ideality factor, reverse saturation current, barrier height and series resistance were calculated from the forward *I*–*V* characteristics. An increase in the values of the ideality factor and a decrease in the barrier height values were observed over this dose range. Also, the reverse current was found to increase with increasing dose.

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Keywords: Si; Schottky diodes; *I*–*V*; Electron irradiation

1. Introduction

Metal–semiconductor (MS) contacts play an important role in all semiconductor electronic and opto-electronic devices [1,2]. All metal–semiconductor contact-based devices are very sensitive to the properties of the MS interface [3] and hence any mechanism that affects it will also influence the performance of these devices. The Schottky diode has the advantage of lower turn-on voltage over a p–n junction diode, permitting their use in very high frequency applications [4]. These devices appear promising for both space and terrestrial applications, but irradiation hardness is a prerequisite for these applications. Therefore, it is necessary to understand the response of these devices to ionizing radiation.

Exposure of semiconductor devices to energetic radiation has been employed as a tool to controllably introduce point defects to tailor the properties, to gain insight into the nature of intrinsic defects and to study the radiation damage effects on their electrical properties. Exposure of semiconductor devices to energetic radiation may result in the degradation of their properties or in functional failure [5]. Electron irradiation can introduce point defects in a crystal lattice. Minority carrier life time is the most sensitive electronic property of semiconductors in a radiation environment. The degradation of minority carrier life time results in changes in device properties. In this paper, results of the investigations on the effect of 8 MeV electron irradiation on the *I*–*V* characteristics of Al/p-Si Schottky diodes are presented.

2. Experimental

Silicon wafers (p-type) used in the present work were grown by the Czochralski (CZ) technique. Al/p-Si Schottky barrier diodes were prepared using boron-doped Silicon wafers of (1 0 0) orientation, 300 μm thickness and 1 Ω cm resistivity. The wafers were cleaned with organic solvents, trichloroethylene, acetone and methanol in

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succession and rinsed in deionised water. The wafers were then etched in dilute hydrofluoric acid (1:10) to remove the native SiO_2 layer, rinsed with deionised water and dried. Ohmic contacts were made on the back side of Silicon wafer by gold evaporation. Schottky contacts were made on the front side of the wafers by depositing aluminium films of 1.5 mm diameter and 200 nm thicknesses by vacuum evaporation. The metal depositions were carried out using a HINDHIVAC Vacuum coating unit-Model 12A4D evacuated through a rotary backed oil diffusion pump, at a pressure of 8×10^{-6} Torr.

The Schottky diodes were irradiated at room temperature from the ohmic side of the device with 8 MeV electrons at various doses up to 100 kGy (equivalent to a fluence of $3.02 \times 10^{14}\ \mathrm{cm}^{-2}$) using a Microtron Accelerator. The delivered doses were measured using a Fricke dosimeter. Current–voltage (I–V) characteristics of the diodes were measured at room temperature, both before and shortly after irradiation, using a computer interfaced Keithley 236 source-measure unit.

3. Results and discussion

Fig. 1 shows the forward (semi-logarithmic) and reverse I–V characteristics of electron irradiated Al/p-Si Schottky diodes at various doses. Both the forward and reverse current have increased after irradiation.

The current through a Schottky diode according to thermionic emission theory is given by [6]

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

with

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

where I_s is the saturation current, q is the electronic charge, V is the junction voltage, n is the diode ideality factor, k is the Boltzmann constant, T is the temperature, A_d is the diode area, A^{**} is the effective Richardson constant and ϕ_B is the barrier height.

The diode ideality factor, 'n' and the reverse saturation current I_s were determined [7] from the slope and the intercept of semi-logarithmic forward biased I–V plot at $V > 3kT/q$ using Eqs. (1) and (2). The Schottky barrier height of the diodes was calculated from the saturation current I_s using [8]

$$\Phi_B = \frac{kT}{q}\ln\left(\frac{A_d A^{**} T^2}{I_s}\right) \tag{3}$$

The theoretical value of the Richardson constant $A^{**} = 32\ \mathrm{A\,cm^{-2}\,K^{-2}}$ was used for the calculation of the barrier height.

The values of the ideality factor and barrier height obtained for the unirradiated Al/p-Si Schottky diodes were 1.784 and 0.72 eV, respectively. The higher value of the ideality factor (>1) may be due to the presence of interface states between the metal and the semiconductor since an interfacial film of atomic dimensions always exists between a metal contact and silicon [9].

The variation in saturation current of Al/p-Si Schottky diodes with electron dose is shown in Fig. 2. The diode ideality factor and barrier height of the devices as a function of dose are shown in Fig. 3. With increasing dose, a decrease in the values of ϕ_B and an increase in the values of 'n' are observed up to a dose of about 25 kGy, above which the variation is small. The defects are created in the crystal lattice due to irradiation and the defect concentration increases with increasing dose. The defect concentration tends to saturate beyond 25 kGy, giving rise to a reduced variation in the electrical parameters.

The variations in the Schottky diode parameters with electron dose are given in Table 1. The increase in reverse saturation current with dose (Fig. 2 and Table 1) may be due to the presence of radiation-induced crystal lattice defects which act as trapping or recombination centers,

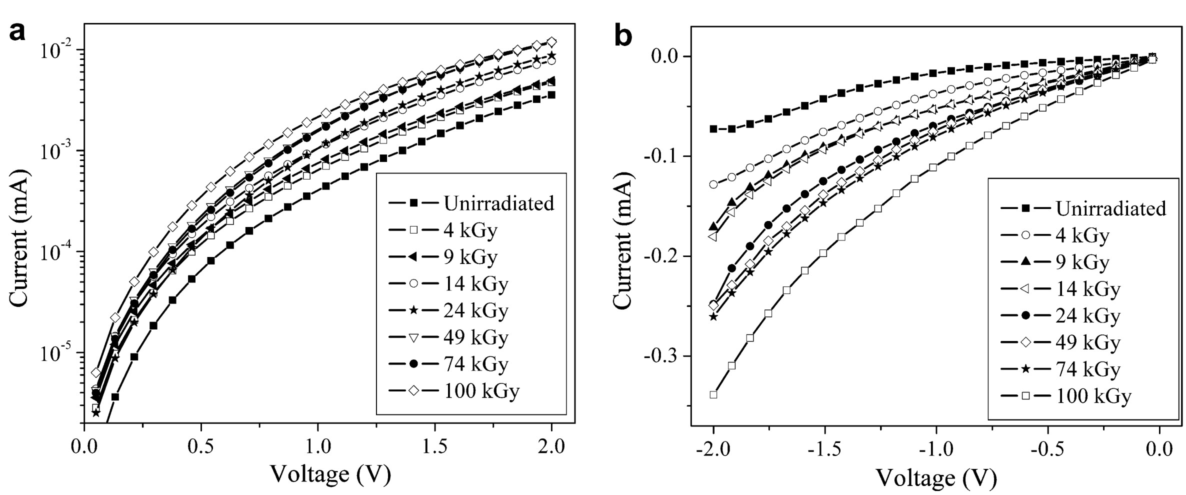

Fig. 1. (a) Forward I–V characteristics of electron irradiated Al/p-Si Schottky diodes at various doses. (b) Reverse I–V characteristics of electron irradiated Al/p-Si Schottky diodes at various doses.

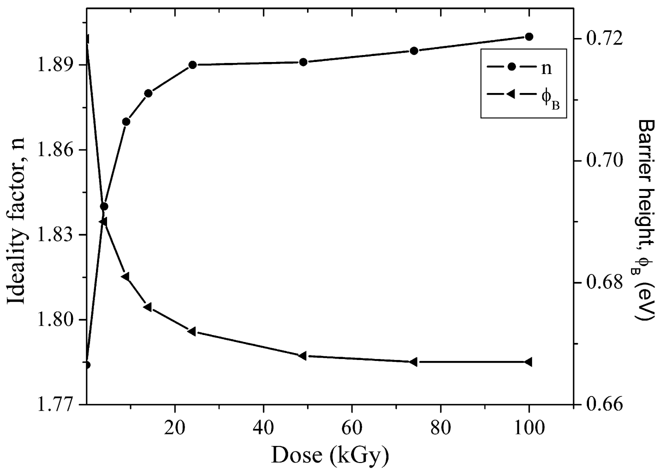

Fig. 2. Saturation current of electron irradiated Al/p-Si Schottky diodes as a function of electron dose.

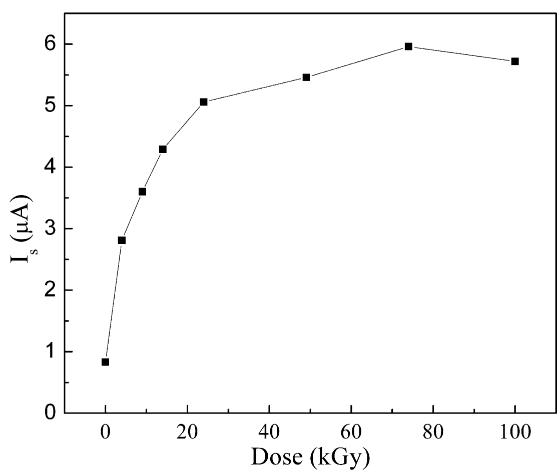

Fig. 3. Ideality factor and barrier height of electron irradiated Al/p-Si Schottky diodes as a function of electron dose.

shortening the life time of the minority carriers. As the life time decreases, the diffusion length decreases, resulting in an increase in the reverse current [10,11].

The decrease in barrier height with dose (Fig. 3) indicates a change in the electrical properties of the interface. Irradiation might have introduced defects in the Al/Si interface leading to the reduction in Schottky barrier height. The interface states act as recombination centers or traps and affect the I–V behavior. The increase in the density of interface states can result in an increase in the ideality factor and lowering of the barrier height with dose [12,13].

The increase in reverse current with dose may be due to the generation of carriers in the bulk depletion region due to radiation-induced lattice defects, as the reverse current is proportional to the concentration of minority carriers near the junction [14,15].

Electron irradiation creates primarily displacement damage in the silicon lattice, which causes the generation of deep traps and hence a reduction of the carrier generation and recombination life time, followed by an increase in the reverse current. The displaced atom leaves vacancy positions which may migrate until they form stable configurations with impurity atoms [19].

Therefore, the degradation characteristics of semiconductor devices can also be correlated with the displacement damage and subsequently to the non-ionization energy loss (NIEL) deposited in the device. Displacement damage dose is the product of the particle fluence, ϕ and the NIEL associated with the energy, E, of the incident particles [16] given as

$$D = \phi \times \text{NIEL} \tag{4}$$

NIEL is the rate at which energy is transferred from the irradiating particle to the target lattice through non-ionizing events. NIEL values for a given energy can be obtained from the literature [17].

In situations where the displacement damage dose changes with incident energy, the concept of equivalent displacement damage dose is used, which is given by [18]

$$D_{\text{eq}} = D \times \frac{\text{NIEL}(E)}{\text{NIEL}(E_{\text{ref}})} \tag{5}$$

where NIEL (E) is non-ionization energy loss at the energy of interest and NIEL (E_{ref}) is the non-ionization energy loss at a reference energy, normally taken as 1 MeV.

The displacement damage dose and equivalent displacement damage dose corresponding to the electron irradiation dose in kGy are also given in Table 1 for comparison of the degradation of the device parameters.

Table 1
Changes in the Schottky diode parameters with the corresponding doses in kGy, electron fluence, displacement damage dose and equivalent displacement damage dose

Dose (kGy)	Fluence (cm^{-2})	Displacement damage dose, D (Gy)	Equivalent displacement damage dose, D_{eq} (Gy)	Saturation current, I_s (μA)	Ideality factor, n	Barrier height, ϕ_B (eV)
0	0	0	0	0.83	1.78	0.72
4	1.21×10^{13}	0.20	0.63	2.81	1.84	0.69
9	2.72×10^{13}	0.45	1.43	3.60	1.87	0.68
14	4.23×10^{13}	0.70	2.22	4.29	1.88	0.68
24	7.25×10^{13}	1.20	3.81	5.06	1.89	0.67
49	1.48×10^{14}	2.45	7.78	5.46	1.89	0.67
74	2.23×10^{14}	3.70	11.73	5.96	1.90	0.67
100	3.02×10^{14}	5.00	15.86	5.72	1.90	0.67

4. Conclusions

The conclusions drawn from the studies of 8 MeV electron irradiation effects on the *I–V* characteristics of Al/p-Si Schottky diodes are as follows. The ideality factor and the saturation current of the Schottky diodes were found to increase with dose. A decrease in the Schottky barrier height and a significant increase in the reverse current of the diodes with dose were also observed. The degradation in the diode properties may be due to the introduction of radiation-induced interfacial defects via displacement damage. The defect concentration seems to tend towards saturation beyond 25 kGy, resulting in a reduced variation of these parameters.

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