Effects Of the $\gamma$-radiation on the electrical characteristics of the Au/n-Si/Au-Sb Schottky diode

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Abstract. In this study is investigated of effects of the $\gamma$-radiation on current-voltage ($I-V$) and capacitance-voltage ($C-V$) characteristics of Au/n-Si/Au-Sb Schottky diode at room temperature. Initially, the ohmic contact has been made on n-Si crystal with Au-Sb alloy. Then, the rectifier contact is made by evaporation Au metal diameter of about 1.0 mm to the other surface of n-Si in turbo molecular pump at about $10^{-7}$ Torr. The $I-V$ measurements of this diode performed by the use of a KEITLEY 487 Picoummeter/Voltage Source and the $C-V$ measurements were performed with HP 4192A (50–13 MHz) LF Impedance Analyzer at room temperature and in dark. Then, this diode was subjected to $\gamma$-radiation, and $I-V$ and $C-V$ measurements were taken again. Consequently, examines the difference between these two measurements.

1. Introduction
The metal–semiconductor (MS) contact in the semiconductor device technology is still investigated and has attracted much attention during recent years [1–3]. The performance and stability of MS is of great importance to the electronic devices. MS contacts have an important role in the development of semiconductor devices due to their applications in various electronic and optoelectronic devices [4]. The parameters which characterize such a contact depend on the method used during the fabrication [5]. The semiconductor crystal surfaces are usually covered with thin layer of native oxide and organic contaminants in the laboratory environment [6,7]. In many cases, the Schottky barrier height on chemically prepared semiconductor surfaces indicates the presence of interfacial layer whose thickness is dependent on exposure time of the semiconductor surface in the chemically cleaned substrates [2,8]. Recently, the studies of the radiation damage of the semiconductor-based devices have increasingly demanded the attention of researchers. Although the impact of the radiation on the performance of the devices has clearly been known as various deformations, there is yet no convenient explanation to all types of crystals or devices. There are two types of basic radiation-damage mechanisms for devices: ionization damage and displacement lattice damage. Ionizations of the material create free charge, which can move in the material. This damage is generally harmless for the device operation. But displacement lattice damage in semiconductor based devices can have a significant impact on their electrical properties, through the creation of stable radiation defects, which have one and/or more levels in the bandgap [9]. Well-known examples for silicon are the creation of group V donor–vacancy pairs or the creation of interstitial [10–13].

In many cases, the charge of the shallow dopants is compensated by the radiation levels, resulting in a lowering of the free carrier density and an increase in resistivity [14]. Therefore, it is important to determine how the Schottky contact parameters give a response to the $\gamma$-irradiation, since all semiconductor-based devices communicate one another over the MS contacts in an electronic circuit. The Effects Of the $\gamma$-radiation on the I–V and C–V characteristics of Au/n-Si/Au-Sb Schottky contact has been studied and reported in this article.
2. Experimental

n-Si wafer pieces of (100) orientation and one side polished were used in this study. Firstly, the wafer was sequentially cleaned with trichloroethylene, acetone and methanol ultrasonically for 3 min respectively and then rinsed in deionized water of 18 MΩ and dried with high purity N₂. The Si wafer were chemically cleaned using the RCA cleaning procedure (i.e., 10 min boiling in NH₃+H₂O₂+6H₂O followed by 10 minutes in HCl+H₂O₂+6H₂O at 60°C) before making contacts. Preceding each cleaning step, the samples were rinsed thoroughly in deionized water with ultrasonic vibration for 5 min and were finally dried by high purity nitrogen (N₂) atmosphere. After the cleaning process, the wafer is immediately inserted into the vacuum room. Extensive alloys such as Au–Sb are used for n-Si ohmic contact. We have used Au–Sb alloy for ohmic contacts are made by evaporating on the non-polished side of the n-Si wafer pieces when vacuum was decreased by 10⁻⁶ Torr and then by thermal annealing at 300 °C for 3 min inflowing nitrogen in a quartz tube furnace. One of them was immediately inserted into the evaporation chamber to form the Au Schottky contacts. The metal gate, Au, was then deposited through a mask by thermal evaporation in dots of the shape of approximately 1mm diameter. Schottky contacts were formed when vacuum was decreased by 10⁻⁶ Torr. In this way, the Au/p–Si/Au-Sb Schottky diode was obtained. The I–V and C–V characteristics of the diode were measured using a Keithley 487 Pico-amperometer/voltage source and HP model 4192 ALF impedance analyzer under dark conditions. And then, this sample was subjected to γ-radiation, and then I-V and C-V measurements were taken again.

3. Results and discussion

Fig. 1 shows the forward and reverse bias I–V characteristics of the diode before and after irradiation. The effect of γ-radiation is clearly shown. It is seen that after γ-radiation in the diode, leakage current has been decreased. The other effect of irradiation is a reduction in a forward bias current.

According to Thermionic emission theory, forward bias current of a Schottky diode depending on the applied potential given by equations (1). The values of ideality factor (n) and barrier height (eΦ₀) are obtained from these equalities (equations (2) and (3)).

\[
\begin{align*}
I &= I_0 \left[ \exp\left(\frac{eV}{nkT}\right) - 1 \right] & (1) \\
n &= \frac{e}{kT} \frac{dV}{d(\ln I)} & (2) \\
e\Phi_0 &= kT \ln\left(\frac{AA^*T^2}{I_0}\right) & (3)
\end{align*}
\]

Where

\[
I_0 = AA^*T^2\exp\left(-\frac{q\Phi_0}{kT}\right) & (4)
\]

is the saturation current, A is the diode area, A* is the Richardson constant and equals 112 A/cm² K² for n type Si, T is the temperature in Kelvin, Φ₀ is the effective barrier height at zero bias, where q is the electron charge, V is the applied voltage, k is the Boltzmann constant, n is the ideality factor, and it is determined from the slope of the linear region of the forward bias ln–V characteristic through the relation (2), where n equals unity for an ideal diode. However, n has usually a value greater than unity [9].
The I–V characteristics of the Au/n-Si/Au-Sb Schottky diode before and after irradiation.

The values of the barrier heights for before and after irradiation are calculated as 0.86 and 1.54 eV, respectively. Furthermore, the values of the ideality factors for before and after irradiation are calculated as 1.44 and 1.82, respectively. It is seen that the values of the ideality factor has increased after irradiation. Due to γ- radiation, the defects can be created in the crystal lattice and this causes an increase in the ideality factor. The increase in the barrier height is mainly responsible for the decrease in the reverse bias current of the diode. The radiation-induced degradation observed in the reverse I–V characteristics could be attributed to an increase in the interfacial defect density [15]. An increase in the ideality factor also indicates that for the diode, the current transport mechanism cannot be a thermionic emission type and it may be a tunneling type transport [16].
Figure 2. The rectifying ratio versus applied voltage characteristics of the Au/n-Si/Au-Sb Schottky diode before and after γ-radiation.

Figs. 3 and 4 show the typical C–V characteristics for unirradiated and irradiated situations of the diode at various frequencies. It is seen from these figures that the values of the capacitance decrease with the irradiation and increasing frequency [9]. This irradiation effect can be attributed to the change in dielectric constant at the metal semiconductor interface or to the decrease in the net ionized dopant concentration with irradiation [17–19]. Furthermore, the acceptor-like defects can be used to explain the decrease in the C–V properties of the Au/n-Si/Au-Sb diode after γ-radiation.

Figure 3. The forward and reverse bias C–V characteristics of the Au/n-Si/Au-Sb Schottky diode before γ-radiation at various frequencies.
**Figure 4.** The forward and reverse bias C–V characteristics of the Au/n-Si/Au-Sb Schottky diode after γ-radiation at various frequencies.

Fig. 5 depicts the reverse bias C²–V characteristics of the unirradiated diode, at various frequencies. It is seen that the C²–V are linear. This can be explained by the absence of the excess capacitance [9].

**Figure 5.** The reverse bias C²–V characteristics of the Au/n-Si/Au-Sb diode before γ-radiation at various frequencies.

Fig. 6 shows the reverse bias C²–V characteristics of the irradiated diode at various frequencies. The lateral shift in the C²–V characteristics is due to an increase in diffusion potential, which results in an increase in the barrier height [9].
Figure 6. The reverse bias $C^2$–$V$ characteristics of the Au/n-Si/Au-Sb diode after $\gamma$-radiation at various frequencies.

Table 1 The characteristic parameters of the Au/n-Si/Au-Sb diode obtained from I-V and C-V characteristics before and after $\gamma$-radiation.

| Radiation situation | $I-V$ | $C^2$–$V$ |
|---------------------|-------|----------|
|                     | $n$   | $I_0 (A)$ | $\Phi_b (eV)$ | $V_d (eV)$ | $E_f (eV)$ | $N_d (cm^{-3})$ | $\Phi_b (eV)$ |
| Unirradiation       | 1.44  | $2.78 \times 10^{-7}$ | 0.68 | 100 kHz | 0.68 | 2.38 $\times 10^{16}$ | 0.18 | 0.86 |
|                     |       |           |      | 500 kHz | 0.71 | 2.33 $\times 10^{16}$ | 0.18 | 0.89 |
| Irradiation         | 1.82  | $5.54 \times 10^{-9}$ | 0.78 | 100 kHz | 0.85 | 69.37 $\times 10^{6}$ | 0.69 | 1.54 |
|                     |       |           |      | 500 kHz | 1.03 | 66.98 $\times 10^{6}$ | 0.69 | 1.72 |

4. Conclusion

It was found that the electrical characteristics of the Au/n-Si/Au-Sb Schottky diode are very sensitive to $\gamma$-radiation. It was found that the values of Schottky barrier height and the ideality factor showed an increase after $\gamma$-radiation. The degradation in the Au/n-Si/Au-Sb diode properties may be due to the introduction of radiation-induced interfacial defects (between Au and n-Si), and lattice defects via displacement damage.
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