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In-situ current–voltage analysis of Au/GaAs Schottky diode under nitrogen ion irradiation

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ABSTRACT

The effect of irradiation by 650 keV $^{14}N^{5+}$ ions on the electrical characteristics of a Au/GaAs Schottky diode is analyzed with an *in-situ* current–voltage characterization technique. The Schottky barrier height (SBH) is found to be 0.55 ± 0.01 eV for an un-irradiated diode and remains practically unchanged (0.54 ± 0.01 eV) at the highest ion irradiation fluence of 1×10^{14} ions cm^{-2}. The ideality factor is found as 2.5 for the as-prepared diode and increases to 3.1 at the highest ion irradiation fluence. The results are discussed with reference to the energy loss mechanism of a swift heavy ion as it passes through the metal-semiconductor interface.

1. Introduction

The physics of the metal–semiconductor (M–S) interface remains a subject of considerable research interest due to the technological applications involving such interfaces. Such interfaces form integral parts of any semiconductor device structure. The SBH controls the electrical transport across the M–S interface and is very significant for successful device operation. The performance of these devices depends on the properties of the M–S interface to a large extent. The density of the interface states and their energy distribution greatly influence device characteristics.

The irradiation by energetic ions modifies the properties of an M–S interface and can alter the current transport properties of the diode. The interaction with energetic ions leads to creation of interfacial states inside the semiconductor band gap. The swift heavy ion loses energy inside the solid and can introduce several types of defects, leading to changes in the microscopic structure at the M–S interface. Such defects can alter the electronic states at the M–S interface resulting in modification of device properties.

There are some previous studies on the effects of swift heavy ion (SHI) irradiation on metal–semiconductor interfaces [1–5]. The modification of the M–S interface due to irradiation by ions at such high energies is found to be largely due to the electronic energy loss phenomenon. There are also some studies on irradiation of M–S interfaces by ions with energy of few MeV, which result in near-interface deposition [6,7] leading to creation of ion irradiation induced defects, and modification of electrical characteristics of the diode. Reports are also available on the experiments with such systems by ion irradiation at lower energies [8–12]. The present work studies the effect on the M–S Schottky structure due to irradiation by ions in the energy range of a few 100 keV. The effect of irradiation by a 650 keV $^{14}N^{5+}$ ion beam on the current–voltage (*I–V*) characteristics of Au/n-GaAs Schottky barrier diodes is studied. The *in-situ I–V* technique allows a systematic study of the effect of ion irradiation on the same sample under identical experimental conditions.

2. Experimental

The Schottky diode was fabricated on a single-side-polished n-type GaAs (Si-doped) wafer of doping concentration 5×10^{15} atoms cm^{-3}. Both Ohmic and Schottky contacts were deposited on the polished side. Prior to deposition, the wafer was cleaned chemically by treating in trichloroethylene, acetone and methanol sequentially for 10 min each. Then the wafer was deoxidized by etching in 10% HCl solution for 1 min, and rinsed in de-ionized water. Au–Ge (88:12) eutectic alloy was used for making Ohmic contact. A circular film (200 nm thick, 2 mm diameter) was deposited in high vacuum (10^{-7} Torr) by resistive heating, and annealed in Ar ambient at 430 °C for 5 min. After chemical cleaning, a Au Schottky contact (150 nm thick, 2 mm diameter) was deposited by electron gun evaporation in ultra high vacuum (10^{-8} Torr), at a deposition rate of 0.1 Å s^{-1}, monitored by quartz crystal thickness monitor.

The irradiation experiment was performed with $^{14}N^{5+}$ ions of energy 650 keV in the Low Energy Ion Beam Facility (LEIBF) at Inter University Accelerator Centre, New Delhi [13]. The irradiation was performed at room temperature in high vacuum (1×10^{-7} Torr) from the Au-side at a beam current of 15 nA. The current–voltage (*I–V*) characteristics were measured at various ion fluences from 1×10^{10} to 1×10^{14} ions cm^{-2}. The electrical contacts from the diode were taken outside the chamber by using vacuum feed-throughs for shielded coaxial cables. *I–V* characterization was performed using a programmable Keithley 2400 source meter.

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3. Results and discussion

There exist various mechanisms of electrical transport across the M–S Schottky barrier like thermionic emission, thermionic field emission, field emission, and recombination-generation. For a moderately doped semiconductor and normal temperature at which the experiment was performed, thermionic emission is the dominant phenomenon of current transport across the barrier [14], which follows the equation,

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

where, I_s is the saturation current and n is ideality factor of the diode; q is the electronic charge and k is Boltzmann's constant.

Saturation current I_s is given by

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

where, A is the contact area of the diode, A^* is the Richardson constant (8.16 A/cm^2 K^2 for GaAs), Φ_B is the apparent Schottky barrier height. Using non-linear curve fitting techniques to fit Eq. (1), diode parameters I_s and n were extracted from experimental I–V data. From I_s, Φ_B is determined using Eq. (2).

Fig. 1) shows the I–V characteristics for pristine and irradiated Au/n-GaAs diodes with irradiation fluence up to 1×10^{14} ions cm^{-2}. The values of SBH and ideality factor are calculated by fitting these data to the thermionic emission model for forward bias, as plotted in Fig. 2). The SBH for the as-prepared diode is found as 0.55 ± 0.01 eV, which remains practically unchanged up to the highest fluence of 1×10^{14} ions cm^{-2} (0.54 ± 0.01 eV). The ideality factor is found to be 2.5 for the as-prepared diode, which increases to 3.1 at the highest ion irradiation fluence.

To understand the modification of the M–S barrier by swift heavy ion irradiation, the basic phenomena associated with energy loss of the ion as it passes through the M–S interface should be considered. The energetic ion loses its energy inside the solid by (1) nuclear energy loss (S_n) due to elastic scattering by the target nuclei, and (2) electronic energy loss (S_e) due to inelastic interaction with the target electrons. The electronic loss dominates at high energies whereas the nuclear loss becomes dominant at low energies. The energy loss of the 650 keV $^{14}N^{5+}$ ions inside the target is shown in Fig. 3. The energetic ion crosses the M–S interface and moves to a depth of about 0.6 μm into the GaAs substrate. According to calculations performed with the standard Monte Carlo Simulation program SRIM 2006 [15], after passing through a depth of 150 nm in gold, the energy of the ion is 376 keV. At this energy the values of S_n and S_e in gold are respectively, 7.6 and 96.5 eV/Å. The corresponding values in GaAs are 3.8 and 62.3 eV/Å. Thus the mean values of S_n and S_e at the interface are 5.7 and 79.4 eV/Å respectively. Thus the value of electronic energy loss is nearly 14 times that of the nuclear energy loss at the M–S interface. As well known, the nuclear energy loss causes displacement of target atoms leading to defects like vacancies and interstitials, which can increase the density of states at the M–S interface. The electronic energy loss causes excitation of target electrons, and during relaxation of these electrons various types of defects may be created [16,17]. Thus the interaction with a swift heavy ion beam leads to formation of electronic states at the M–S interface, which modifies the current transport properties across the barrier.

In the present experiment it is observed that the SBH remains practically unchanged (0.55 ± 0.01 eV) throughout the range of irradiation fluence, and ideality factor increases from 2.5 for as-deposited diode to 3.1 at the highest fluence. As the ion traverses inside the solid, it loses energy by elastic nuclear interaction and excitation of the target electrons. This leads to creation of defects at the M–S interface, and modification of the interface electronic states and apparent changes in the electrical characteristics of the diode.

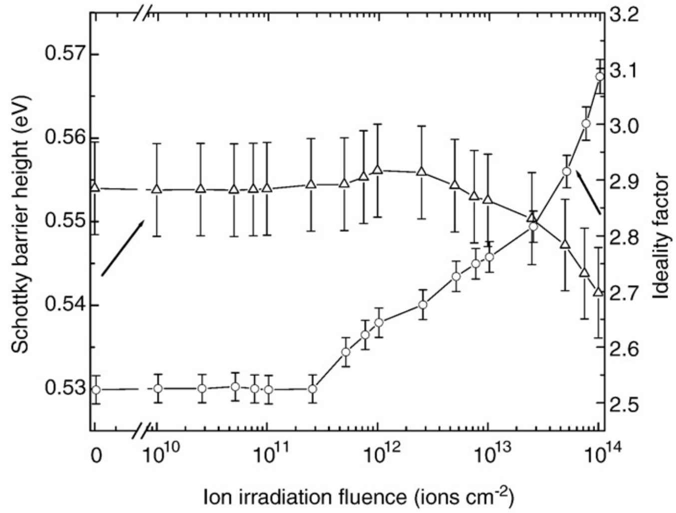

Fig. 2. Variation of SBH and ideality factor with irradiation fluence.

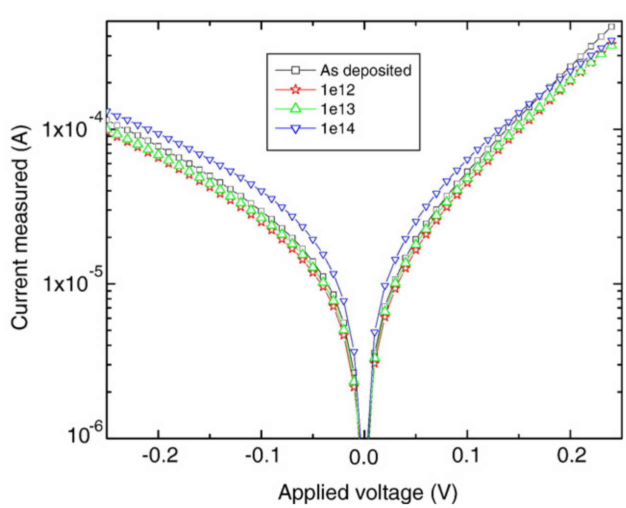

Fig. 1. I–V characteristics of as-deposited and N-ion-irradiated diode as a function of ion fluence.

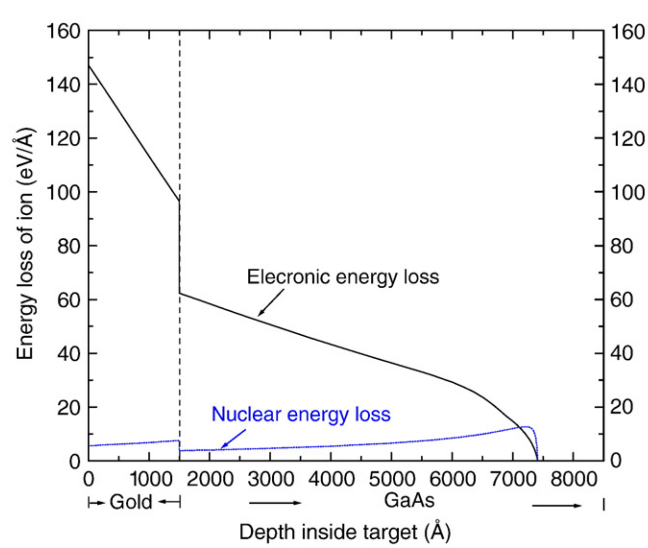

Fig. 3. Energy loss of the ion inside the target.

However, the effect of such modification on the effective density of electronic states at the M–S interface remains non-apparent up to some level of irradiation fluence if a large density of states is already present at the M–S interface. Thus the SBH of the diode is found to remain almost unchanged. This is expected because of the presence of a large density of states at the M–S interface, which accounts for the slightly lower barrier height of the as-deposited diode as compared to ideal contact on n-GaAs [18].

The ideality factor for the as-deposited diode is found as 2.5. The value of ideality factor of the diode shows the deviation of the current transport behavior from that of an ideal thermionic conduction model. The increase in value of 'n' shows increase in the contribution of field emission, thermionic field emission, and recombination-generation currents. The irradiation by the swift heavy ion beam leads to the creation of defects at the M–S interface, which increases the possibility of types of current transport process other than thermionic emission. Thus the value of n is found to increase with ion irradiation to 3.1 at the highest fluence.

4. Conclusion

Au/n-GaAs Schottky diode was irradiated with a 650 keV N-ion beam at various fluences ranging from 1×10^{10} to 1×10^{14} ions cm^{-2}. The SBH remains practically unchanged (0.55 ± 0.01 eV) in the range of irradiation fluence. The ideality factor is found as 2.5 for the pristine diode, which increases to 3.1 at the highest fluence. Due to the presence of a large density of interface states in the as-prepared diode, the effect of ion irradiation on the SBH remains non-apparent in the range of fluence of the experiment. The defect creation due to ion irradiation leads to increase in the ideality factor of the diode.

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