Conduction mechanism in electron beam irradiated Al/n-Si Schottky diode

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Introduction

In the high energy physics experiments, silicon based diodes are used to fabricate radiation detector to detect the charged particles.[1] The Schottky barrier diodes have been studied extensively to understand the behavior of metal-semiconductor interface, since such interfaces have been utilized as typical contacts in silicon devices.[2] Because of surface states, interfacial layer, microscopic clusters of metal-semiconductor phases and other effects, it is difficult to fabricate junctions with barriers near the ideal values predicted from the work functions of the two isolated materials, therefore measured barrier heights are used in the device design.[2] In this work, the Al/n-Si Schottky contacts are employed to study the diode parameters (Schottky barrier height and ideality factor), where the Schottky contacts were fabricated on electron beam irradiated silicon wafers.. The interface behavior between electron irradiated Si wafer and post metal deposition is so far not reported. This method could be an alternative way to tailor the Schottky barrier height (SBH) without subjecting semiconductor sample to pre chemical and/or post heat treatments during fabrication.

Experimental Details

The n-type silicon (100) wafer doped with phosphorous is procured from Sigma Aldrich®, Bangalore. The wafer is diced into pieces of 1×1 *cm* and the thickness is 0.5 *mm*. The samples are then subjected to electron beam irradiation (EBI) using LINAC, RRCAT, India. The beam energy and dose rate during EBI was 7.5 *MeV* and 6.5 *kGy/s* respectively. The samples were irradiated at different doses (500, 1000, 1500 *kGy*) at room temperature. The Schottky contacts are fabricated on the irradiated surface of n-Si wafer. Al is used as metal contact since it is chemically inactive and make no silicide bonds. [2] Thermal evaporation technique is employed to deposit Al on n-Si. The area and thickness of the deposited Al film on n-Si are 0.4 cm^2 and 20 *nm* respectively. I-V characterization was done using Keithly 2450 source meter at room temperature.

Results and Discussions

The rectifying behaviour of Al/n-Si is shown in Fig.1. The current conduction mechanism of a rectifying metal-semiconductor or Schottky junction under forward bias is explained by thermionic emission model for which n=1 in eqn. (1), called the ideal Schottky diode behaviour.

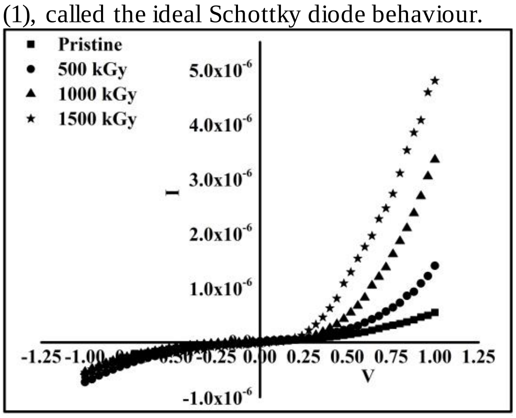

Fig.1. Rectifying behaviour of electron beam irradiated n-Si wafer

Most practical Schottky diodes show deviations from ideal behaviour, a parameter *n*, called ideality factor is introduced to take into account of the non-ideal behaviour of the Schottky diode. The deviation from the ideal behaviour are due to several reasons: (i) surface treatment before metal deposition, (ii) interface states at thin oxide between metal and semiconductor, (iii) image force lowering of the Schottky barrier in the electric field at the interface, (iv) generation-recombination currents within the space-charge region.[4] For V>>3kT/q, the thermionic approximation takes the form:

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

Where $I_s = AA^{**}T^2 \exp\left(-\frac{q\Phi_B}{kT}\right)$ called the reverse saturation current, A is the effective area of the diode, A^{**} is the Richardson constant (For n-Si, A^{**}=112 A cm^{-2} K^{-2}), q is charge of the electron, Φ_B is barrier height and k is Boltzmann constant. Semi-log plot of the eqn (1) is shown in the Fig.2. The slope and intercept gives ideality factor and Schottky barrier height respectively. Changes in the ideality factor and Schottky barrier height after EBI are reported in Table.1. We can see that, at lower and higher voltages the thermionic emission and recombination in the space-charge region are the dominating transport mechanisms respectively.

Table.1. Schottky diode parameters of electron beam irradiated n-Si wafer

Electron Beam Irradiation Dose (*kGy*)	Schottky Barrier Height, Φ_B (*eV*)	Ideality Factor, *n*
0	0.863	5.433
500	0.849	6.997
1000	0.837	8.743
1500	0.862	3.579

Since the oxide layers are inevitable; the metal deposition on such a Si surface leaves a glassy interfacial layer at the junction. The electron can tunnel through this thin layer, and affect the barrier to current transport through the junction. [2]. This is because, changes in the surface states of Si are possible after EBI. This is because the triply periodic potential in the crystal abruptly terminates at its surface, and this introduces departures from energy band scheme appropriate in the crystal. When the foreign atoms, particles and/ or an oxide layer adsorbed on the surface can give rise to discrete energy levels which influence the properties of the solid in a region near surface. This results in a large density of localized quantum states at the surface whose energy levels are distributed in the forbidden gap.[5] Therefore, the electrical properties of the semiconductor are influenced to a considerable depth in the crystal by electrons occupying surface states and gives rise to charges at the metal-semiconductor interface. This overall causes the inhomogeneity in the Schottky barrier height due to Fermi level pinning at different positions. [1]

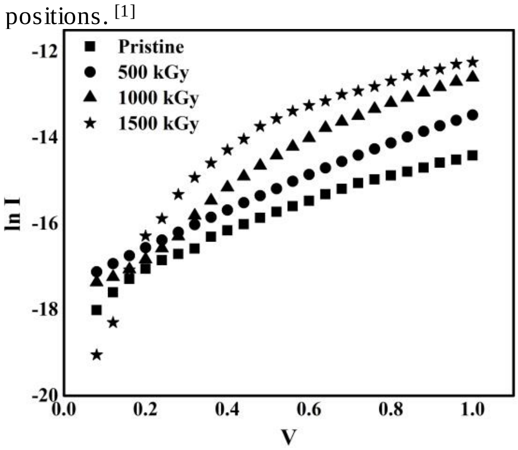

Fig.2 Semi-log plot of post Al deposition on electron beam irradiated n-Si wafer

Summary

Conduction mechanism of electron beam irradiated Al/n-Si Schottky diode may be explained using thermionic emission model. The electron irradiation modifies the surface states and the introduced bulk defects near the surface causes inhomogeneity in SBH. modifications in SBH and n are dose dependent.

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