



The influence of high energy electron irradiation on the Schottky barrier height and the Richardson constant of Ni/4H-SiC Schottky diodes

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ABSTRACT

The influence of high energy electron (HEE) irradiation from a Sr-90 radio-nuclide on *n*-type Ni/4H-SiC samples of doping density $7.1 \times 10^{15} \text{ cm}^{-3}$ has been investigated over the temperature range 40–300 K. Current–voltage (*I*–*V*), capacitance–voltage (*C*–*V*) and deep level transient spectroscopy (DLTS) were used to characterize the devices before and after irradiation at a fluence of $6 \times 10^{14} \text{ electrons-cm}^{-2}$. For both devices, the *I*–*V* characteristics were well described by thermionic emission (TE) in the temperature range 120–300 K, but deviated from TE theory at temperature below 120 K. The current flowing through the interface at a bias of 2.0 V from pure thermionic emission to thermionic field emission within the depletion region with the free carrier concentrations of the devices decreased from 7.8×10^{15} to $6.8 \times 10^{15} \text{ cm}^{-3}$ after HEE irradiation. The modified Richardson constants were determined from the Gaussian distribution of the barrier height across the contact and found to be 133 and $163 \text{ A cm}^{-2} \text{ K}^{-2}$ for as-deposited and irradiated diodes, respectively. Three new defects with energies 0.22, 0.40 and 0.71 eV appeared after HEE irradiation. Richardson constants were significantly less than the theoretical value which was ascribed to a small active device area.

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1. Introduction

Metal-semiconductor (MS) Schottky barrier diodes (SBDs) are widely used where diodes with low forward voltage drop, junction capacitance and high switching speed are required [1]. This makes them ideal as rectifiers in photovoltaic systems, high-efficiency power supplies and high frequency oscillators [2]. SBDs also have important uses in optoelectronics, high frequency and bipolar integrated circuits applications [3,4]. The reliability of SBDs is influenced significantly by

the quality of the MS junction [5]. The performance of the devices can be quantified experimentally study in terms of their ideality factor, Schottky barrier height (SBH), saturation current, series resistance and free carrier concentration. Among these properties of the MS interface, SBH plays a major role in the successful operation of many devices in transporting electrons across the MS junction [6].

Since room temperature (300 K) measurements of *I*–*V* and *C*–*V* characteristics alone cannot provide detailed information about the mechanisms responsible for the formation of barrier at the interface of the MS and electrical properties of devices [7], additional insight is gained by characterising the diodes over a wide temperature range (40–300 K). Conclusions may be drawn from the deviation of *I*–*V*–*T* characteristics from the

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ideal thermionic emission current model at lower temperature for many SBDs. The I - V - T characteristics of SBDs based on TE theory reveals an abnormal increase in the ideality factor and a decrease in the SBH with decreasing temperature [8–11]. The abnormal behaviour has been attributed to be a function of the atomic structure, and atomic or barrier inhomogeneities at the MS interface, which are caused by defects, multiple phases and grain boundaries. The barrier inhomogeneities in MS SBDs are often modelled as a Gaussian distribution function and used to provide better understanding to experimental I - V characteristics [12–15].

SiC is a promising semiconductor with a wide bandgap of 3.26 eV [16]. Because of its wide bandgap and chemical stability, it can be used to produce electronic devices that are capable of operating at high temperature, high frequency and high power semiconductor devices, as well as in harsh radiation fields [17–20]. Effects of radiation and temperature on semiconductors are technologically important for radiation to sensing applications, as well as manufacturing processes and high temperature and high power applications [21]. Deep level transient spectroscopy (DLTS) on SBDs is often used to investigate the properties of defects in semiconductors.

Many researchers have reported that some wide bandgap semiconductors such as SiC, ZnO and GaN are radiation hard which makes them suitable for use in harsh radiation environments [18]. Effects of proton, fast electron and fast neutron irradiation on SiC have been investigated by different researchers [18,22–24]. To the best of our knowledge, the effect of high energy electron (HEE) irradiations at fluence of $6 \times 10^{14} \text{ cm}^{-2}$ on Ni/4H-SiC has not been reported.

In this work, we present the effect of HEE irradiations on the electrical characteristics of nickel SBDs fabricated on 4H-SiC SBDs measured over wide temperature range (40–300 K). The major aim of this work is to determine the extent to which the characteristics of nickel on n -type 4H-SiC Schottky diodes would be affected by HEE irradiations.

2. Experimental procedure

The samples used for this work were cut from a nitrogen-doped n -type 4H-SiC wafer, polished on both sides with the Si face epi ready, resistivity of $0.02 \Omega\text{-cm}$ and doping density of $7.1 \times 10^{15} \text{ cm}^{-3}$. The wafers were supplied by CREE Res. Inc. The samples were cut into smaller pieces with dimension of roughly $2 \times 3 \text{ mm}^2$ and degreased by boiling for 5 min each in trichloroethylene, acetone, methanol and followed by 1 min rinse in de-ionized water. They were etched in 40% hydrogen fluoride for 30 s in order to remove the native oxide layer on the samples, then rinsed in de-ionized water, followed by blow drying with nitrogen gas prior to thermally fabrication of nickel ohmic contact on the back surface ($1.0 \times 10^{18} \text{ cm}^{-3}$ doped side) of the samples.

Resistive evaporation was employed for the fabrication of nickel ohmic and Schottky contacts because it is known to neither introduce defects nor contaminate the samples. The ohmic contact with a thickness of 3000 Å was deposited at a rate of 0.4 Å s^{-1} . For ohmic contact formation, the

samples were annealed in a tube furnace under flowing argon gas at 950°C for 10 min to form nickel silicides [25].

Before deposition of the Schottky contact, the samples were cleaned in an ultrasonic water bath for 3 min each in trichloroethylene, acetone and methanol, followed by 1 min rinsed in de-ionized H_2O after the annealing of the ohmic contact. Nickel Schottky contacts were resistively evaporated through a metal contact mask and had an area of $2.4 \times 10^{-3} \text{ cm}^2$ and a thickness of 1000 Å deposited at a rate of 0.2 Å s^{-1} under a vacuum of approximately 10^{-5} Torr .

The sample was irradiated through the Schottky contacts by HEE from a strontium-90 radioactive source at a fluence rate of $7 \times 10^9 \text{ electrons-cm}^{-2} \text{ s}^{-1}$. The irradiation was carried out at room temperature and lasted for 24 h, which resulted in a fluence of $6 \times 10^{14} \text{ electrons-cm}^{-2}$. The energy distribution of electron emitted by strontium-90 radionuclide has been reported by Auret et al. [26]. The sample was characterized at room temperature and in the dark using I - V and C - V station, consisting of a HP 4140 B pA metre/DC voltage source and HP 4192 A LF Impedance Analyser, respectively. Hereafter, the sample was placed in a closed cycle helium cryostat and characterised by conventional DLTS, I - V - T and C - V - T measurements in wide temperature range. This procedure was performed before and after HEE irradiation.

3. Results and discussion

3.1. C - V characteristics

The fabricated devices were subjected to irradiation at room temperature. Both as-deposited and irradiated devices were examined by the C - V method at different temperatures. Fig. 1 shows the plot of capacitance as a function of reverse bias voltage. The capacitance decreased with a decrease in temperature. The capacitance increased with decreasing reverse voltage for both, but the capacitance after irradiation was lower, as also be reported [27,28]. The C^{-2} (pF^{-2}) as a function of reverse bias voltage, V (V) before and after HEE irradiation measured at 1 MHz with the samples at temperatures range

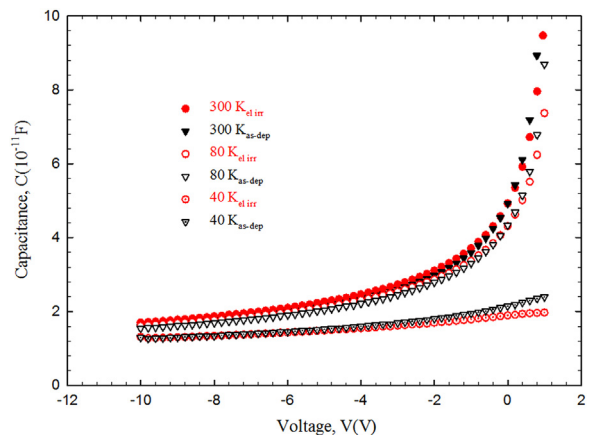


Fig. 1. The C - V characteristics of Schottky barrier diodes of Ni/ n -4H-SiC before and electron irradiation in temperature range 40–300 K.

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