

Improved electrical parameters of vacuum annealed Ni/4H-SiC (0 0 0 1) Schottky barrier diode

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ABSTRACT

The reported work has been focused on the improvement of electrical parameters of Schottky diode using vacuum annealing at mild temperature in Ar gas ambient. Nickel Schottky barrier diodes were fabricated on 50 μm epitaxial layer of *n*-type 4H-SiC (0 0 0 1) substrate. The values of leakage current, Schottky barrier height (ϕ_B), ideality factor (η) and density of interface states (N_{SS}) were obtained from experimentally measured current–voltage (*I*–*V*) and capacitance–voltage (*C*–*V*) characteristics before and after vacuum annealing treatment. The data revealed that ϕ_B , η and reverse leakage current for the as-processed diodes are 1.25 eV, 1.6 and 1.2 nA (at -100 V), respectively, while for vacuum annealed diodes these parameters are 1.36 eV, 1.3 and 900 pA (at same reverse voltage). Improved characteristics have been resulted under the influence of vacuum annealing because of lesser number of minority carrier generation due to incessant reduction of number of available discrete energy levels in the bandgap of 4H-SiC substrate and lesser number of interface states density at Ni/4H-SiC (0 0 0 1) interface.

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1. Introduction

Silicon Carbide (SiC) based power devices receive increasing attention in the area of high temperature engineering and harsh environment applications. The continuous development of SiC Schottky diode technology is believed to replace the traditional Si diodes in converters and other applications with better performance and excellent characteristics. Due to physical properties like wider bandgap energy (> 3 eV) of about three times larger than that of Si, heat conductivity better than copper, large saturation velocities of electron and holes and a critical breakdown electric field, which is higher than Si—SiC offers best material for high power device applications [1–5]. To improve the device parameters for the family of SiC Schottky diodes, a large amount of research has been conducted for various applications [6–9,17]. Most of the studies are focused on the development of basic material properties and processing; however, very little efforts [10–15] have been directed towards quantifying and understanding the effect of annealing on the

electrical properties of the Schottky diode structure. In most of the devices processing it is essential to control the metal–semiconductor (MS) interface in order to obtain reproducible characteristics. Among all power devices, 4H-SiC based Schottky barrier diodes are the most mature semiconductor device technology, and many novel conceptions have been implemented to improve its inherent properties like low reverse leakage current and lower forward voltage drop and so on [7,16,17].

In Schottky diode technology it is well known that metalization annealing treatments terminate the dangling bonds of SiC at the interface of metal/SiC and reduce the surface states of the structure. The reproducibility of metal in the realization of Schottky contacts is not well controlled because of the reaction at the interface of the metal and SiC. The interface material plays the key role for barrier height and leakage current. The characteristics of the devices could be suppressed or eliminated with the selection of stable metal contact materials. Ni is extensively explored as a Schottky contact material [18–20] in the fabrication of such type of diodes. The low electrical resistivity at room temperature and thermodynamic stability are certainly interesting properties of Ni metal. Therefore the annealing at mild temperature in suitable ambient may be one of the miraculous methods to improve its interface properties.

Vacuum annealing is the most radical method to reduce hydrogen dangling bonds, surface oxidation and gas impregnation at metal–semiconductor interface. However, high-temperature

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vacuum annealing in Ar gas ambient as the final production operation has a negative influence on the service properties of metal and its possible alloys at metal–semiconductor (MS) interface. This is because of vacuum corrosion of the metal surface and the formation of a surface layer with a changed composition and structure, which substantially reduces the fatigue properties.

In this paper the influence of vacuum annealing at mild temperature in Ar gas ambient on the electrical performance has been experimentally examined by I – V and C – V characterization methods for the fabricated Ni/4H-SiC (0 0 0 1) Schottky barrier diodes. Experimental details for the fabrication of Schottky barrier diodes and I – V and C – V measurement techniques are given in the next section. The adopted methodology and the measurement of electrical parameters are mentioned in the section thereafter. Finally, the technical discussions are given, which are followed by conclusions.

2. Experimental details

A device grade n/n^+ -type 4H-SiC substrate of 50 μm epitaxial layer (nitrogen doped concentration of $9 \times 10^{14} \text{ cm}^{-3}$) on Si-face, 8° off axis (0 0 0 1) oriented, was used. Prior to loading in a horizontal quartz furnace for the oxidation, a thorough chemical cleaning treatment (Degreasing, RCA and Piranha) was given to all the wafers. Wafers were loaded for oxidation at 800°C with a flow of nitrogen. Wet thermal oxidation has been performed at 1110°C for 3 h and wafers were unloaded at 800°C in nitrogen flow. Oxide thickness of sample was recorded using Ellipsometer, which is again verified by the surface profiler. The thermal oxide on Si-face (400 Å) of substrate was retained by photoresist for field plate realization while the oxide layer from C-face was fully removed using buffer oxide etchant (BOE). Ohmic contact was realized on the C-face by the deposition of thin layers of Ti (300 Å), Pt (300 Å) and Au (2000 Å) using e-Beam evaporation system in vacuum range of 10^{-7} Torr. A thickness of 2000 Å of nickel was deposited on Si-face of substrate using e-Beam evaporation method in ultra high vacuum (UHV) after pattern recognition (for Schottky metal contact, field plate delineation and guard ring formation) using photolithography. In this process Schottky diodes with diameter 1.2, 1.6 and 2.0 mm were fabricated. The same metal (Ni) was extended on the thermal oxide for the field plate termination of the edge effect. In the similar sequence, guard ring was realized using the similar metal without edge coverage. Fig. 1 shows the schematic representation of fabricated Schottky barrier diode having field plate and guard ring edge termination techniques.

In this paper, one set of diodes was fabricated by above described methods and is termed as the “as-processed diodes” while another set is called “vacuum annealed diodes” for which the sequential process are briefly described below.

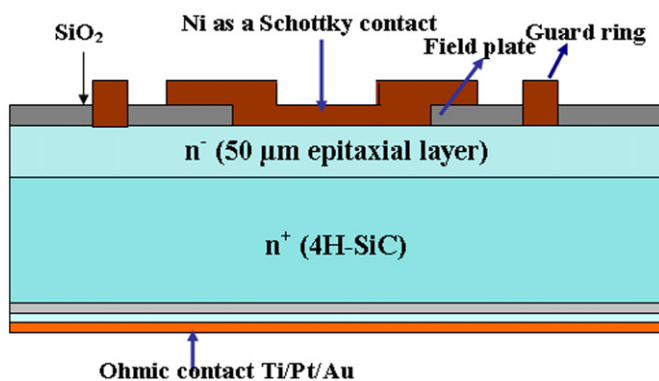


Fig. 1. Schematic diagram of fabricated Schottky diode structure employing field plate and guard ring edge terminations.

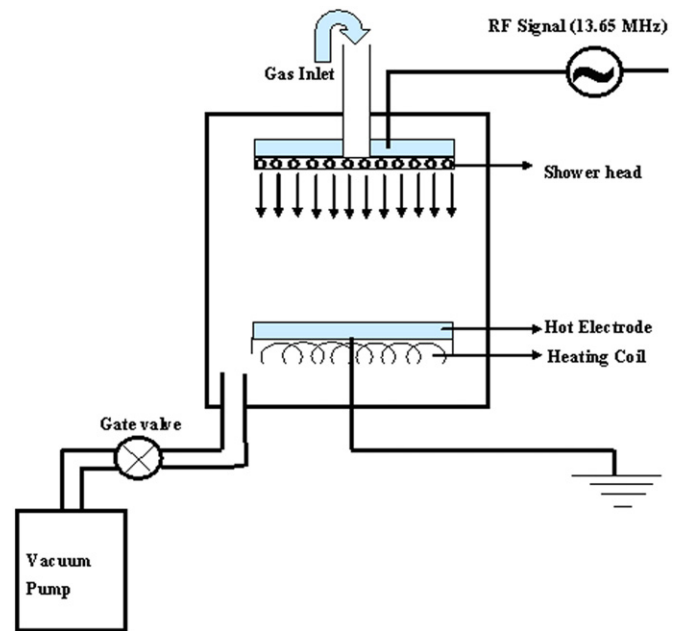


Fig. 2. Schematic representation of vacuum annealing setup.

The vacuum annealing was performed at mild temperature (350°C) in the ambient of Ar gas using a seal proof chamber. Fig. 2 shows the schematic representation of used vacuum annealing experimental setup. The details of the adopted process are as follows:

1. base pressure of chamber was maintained at 0.02 Torr.
2. Gate valve was closed and dry N_2 was introduced in the chamber to break the vacuum.
3. Wafers were placed on the hot electrode.
4. Gate valve was again opened to create the desired vacuum.
5. Wait till the pressure of 0.02 Torr is obtained.
6. The wafers were heated to the temperature of 350°C .
7. Ar gas was introduced in the vacuum chamber through shower head with the flow of 365 cc/min for 30 mins.

Individual chips of Schottky diode were diced and bonded on TO-8 header using West Bond's ball to wedge bonder. HP 4140B pA meter/ DC voltage source was used for I – V measurement while Agilent 4284 A LCR meter was used for C – V measurement. The experimental data were acquired using indigenously developed LabVIEW based computer aided measurement platform. Forward I – V measurement was performed by sweeping the DC bias from 0 to 1 V with 0.1 V step voltage, while for reverse I – V measurement the voltage has been swiped from 0 to -100 V with 1 V step. The measurement frequency and signal level for C – V characteristics were fixed at 1 MHz and 1.0 V. The whole C – V measurements were performed by sweeping the DC bias from -40 to 1 V.

3. Methodology and measurement of electrical parameters

The forward and reverse current–voltage (I – V) characteristics of Ni/4H-SiC (0 0 0 1) Schottky contact for the as-processed and vacuum annealed samples are shown in Figs. 3 and 4, respectively. Current transport in Schottky contacts is due to majority carriers and it may be described by thermionic emission [21] over the interface barrier. The experimentally measured data is fitted by the conventional thermionic emission equation. The characteristic parameters such as ON voltage (it is the minimum voltage at which the forward current increases rapidly from its leakage value), ϕ_B , reverse

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