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ELECTRICAL CHARACTERIZATION OF NICHROME/4H-SiC SCHOTTKY DIODES

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ABSTRACT

Schottky barriers have been made by evaporation of Nichrome at a pressure of 1×10^{-6} Torr onto n-type 4H-SiC. Electrical characteristics of the fabricated diodes were analyzed by current-voltage (I-V) and capacitance-voltage (C-V) techniques initially at the room temperature. Electronic parameters such as barrier height, ideality factor, donor concentration were determined. The barrier height of 0.88eV obtained from C-V measurements and 0.83eV obtained from the I-V measurements with ideality factor of 1.98 for as-deposited diodes at room temperature. Diodes showed non-ideal behavior like high ideality factor and lower barrier height at room temperature. These diodes therefore were annealed for the improvement of the Schottky parameters in the temperature range from 25^0C-400^0C. The consequently calculated Schottky barrier height (SBH) and ideality factors are found to be temperature dependent. After rapid thermal annealing (RTA) up to 400^0C barrier height of 1.38 eV from C-V measurements and the value of 1.34 eV were obtained from I-V measurements with ideality factor of 1.11. We believe that improvement in electrical parameters result from the improvement in the quality of interfacial layer.

Keywords: Nichrome - Schottky barrier - Diodes - Rapid Thermal Annealing - Ideality factor.

I. INTRODUCTION

Silicon Carbide (SiC) is one of the wide band gap semiconductors, most promising material for imminent generation of power devices. This is primarily due to the intrinsic properties such as high breakdown field strength, a high saturated electron drift velocity, reasonable electron mobility and very high thermal conductivity [1-3]. In recent years, significant progress has been accomplished in SiC power devices. Significant works have been done in the improvement of SiC electronic devices, mainly Schottky diode due to their technological importance. Although SiC Schottky diodes are now easily available in the market, still studies related to their properties and applications remain important topic in today's research. Many investigators have investigated the properties of SiC Schottky diodes on both 6H-SiC [4-9] and 4HSiC [10-16]. Recently people have shown their interest in 4H-SiC mainly due to its superior electrical properties namely bandgap, high electron mobility and more isotropic nature. [17].

Several studies related to SiC Schottky contacts have been carried out during the last two decades. The current transport and the temperature dependence of the barrier height in 4H-SiC Schottky diode remains an issue of research. SiC SBD mostly found to illustrate non-ideal I-V-T characteristics and as a result exhibit anomalous deviations in barrier height (ϕ_B) and ideality factor(n) with respect to change in temperature

[18].Several publications on 4H-SiC Schottky barrier diodes fabricated using Ni, Ti, Au, Cr, Pt, Al, W, Mo, Cu, etc are available [5-20]. However, to our knowledge there is little information available onNichrome/4H-SiC Schottky contacts. Since ohmic contact on 4H and 6H-SiC using Nichrome shows more stability [21] than the nickel contacts, we have planned to investigate the 4H-SiC SBD contacts using Nichrome in this paper.

II. FABRICATION AND CHARACTERIZATION

The starting material used for the fabrication of Schottky diodes was n-type 4H-SiC (0001), 8^0 off Si face epiwafer purchased from Cree Inc. The substrate was n+-type with a donor concentration of 1×10^{18}cm-3 with lightly doped ($N_D=9\times10^{14}$ cm-3) n-type epi-layer having specific resistivity of 0.020Ωcm. Prior to metal deposition for making Schottky and ohmic contacts the samples were degreased in organic solvents like acetone, trichloroethylene and methanol successively. Immediately prior to placing the samples in a vacuum chamber, they were immersed in 10% HF for 20 s at room temperature followed by rinsing in DI water and blow drying. Then, Nickel back-side ohmic contact was deposited and annealed in N_2 atmosphere at 900°C for 10 min. Guard ring was realized by standard lithography processes. Schottky contact was formed using Nichrome on 4H–SiC epilayer was done by e-beam metallization process at a pressure ranging between10^{-6} to 10^{-7} Torr having thickness of 1500A^0. The contact metal had circular geometry with diameter of 1mm. Structure of the diode is shown in fig.1 The electrical forward I–V characterization of the diodes were performed on a probe station equipped with Keithley 236, both before (as deposited) and after a rapid thermal annealing of the devices in the temperature range 100-400^{0}C. Capacitance voltage (C-V) characteristics were measured using Agilent LCR meter at frequencies of 1 MHz and 100 kHz.

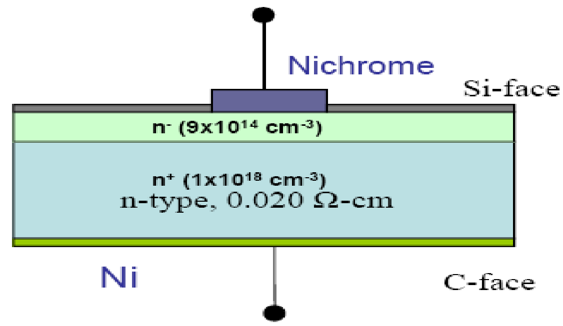

Fig.1: Schematic cross-section of Nichrome/4H-SiC Schottky diodes.

III. RESULTS AND DISCUSSION

According to thermionic-emission theory, the current-voltage (I-V) relationship for Schottky diode can be expressed as [20]

$$J = J_s[\exp(\frac{qV}{kT}) - 1] \quad (1)$$

where $J_s = A^* T^2 \exp(\frac{-q\phi_B}{kT})$

represents the reverse saturation current density, q is the electronic charge, A^* is the Richardson's constant (146A/cm^{2}K^2) for 4H-SiC [21], ϕ_B is the barrier height, k is the Boltzmann constant, T is temperature in K and V is the forward voltage. However the measured devices were found to follow the I-V relationship given in equ. (2).

$$J = J_s[\exp(\frac{qV}{nkT}) - 1] \quad (2)$$

where n is ideality factor.

If the applied voltage V is larger than 3kT/q, exponential term dominates and J can be approximated as:

$$J = J_s \exp(\frac{qV}{nkT}) \quad (3)$$

and, n=1 for thermionic emission theory.

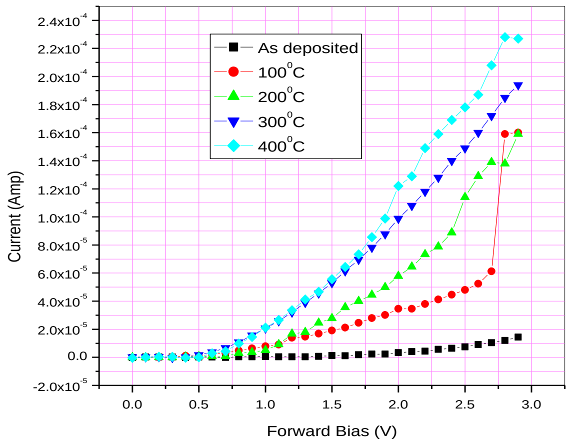

Fig.2: Experimental forward I-V characteristics of Nichrome/4H-SiC SBD's measured at different temperature values.

Fig.2 shows the forward I-V characteristics of a typical device for as deposited as well as devices annealed at four different temperatures. The ideality factor calculated from the slope of the linear region of the forward bias J-V characteristics using the relation:

$$n = \frac{q}{kT}\frac{dV}{d(\ln J)} \quad (4)$$

The extrapolated value of the current density to zero voltage was used to obtain the reverse saturation current density J_s. The barrier height was obtained from the relation

$$\phi_B = \frac{kT}{q}\ln(\frac{A^*T^2}{J_s}) \quad (5)$$

A barrier height of 0.83eV and ideality factor of 1.98 was calculated for as-deposited Nichrome/4HSiC SBDs. For an ideal Schottky barrier the ideality factor is unity and the barrier height is independent of the bias voltage, current flows only due to the thermionic emission. Higher values of n can be attributed to the presence of thin oxide interfacial layer, bias dependence of the barrier height, electron tunneling through the barrier and series resistance. The departure of n from unity in Schottky barriers is mainly because of the field dependence of the barrier height. This field dependence takes place either due to the presence of insulating interfacial layer or due to the barrier lowering. I-V measurement is one of the commonly used techniques to find out the transport mechanism in diodes. In order to get clear understanding of the current transport mechanism through Nichrome/4H-SiC system, I-V characteristics were carried out after every thermal anneal process in temperature range from 25 ^{0}C-400 ^{0}C. RTA process was done up to 400 ^{0}C for 20 min in nitrogen ambience. I-V barrier height and ideality factor for Nichrome/4H-SiC Schottky diodes for as deposited as well as after each RTA process step were tabulated in table (1). These values showed the improvement in barrier height and ideality factor after RTA.

Temperature in ^{0}C	I-V (eV) Barrier Height (e	C-V (eV) Barrier Height (e	Ideality Factor
As-deposited	0.83	0.88	1.98
100	0.91	0.97	1.77
200	0.97	1.00	1.47
300	1.14	1.19	1.20
400	1.34	1.38	1.11

Table 1: Electrical parameters of Nichrome /4H-SiC Schottky diodes extracted from I-V and C-V characteristics.

Fig.3. shows current density-voltage (J-V) plots of typical Nichrome/4H-SiC Schottky diode for as-deposited and thermally annealed upto 400^{0}C. Figure.4. shows the variation in barrier height and ideality factor of Nichrome/4H-SiC Schottky with respect to annealing temperature measured through I-V characteristics. This plot illustrates that barrier height increases and ideality factor decreases with the increase in annealing temperature.

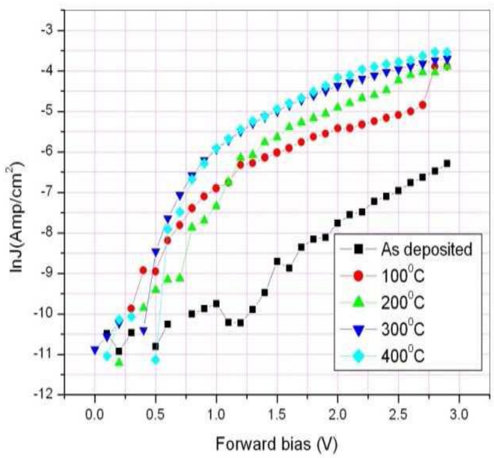

Fig.3: J-V characteristics of Schottky diodes after different annealing temperature values.

We believe that increase in Schottky barrier height from a value of 0.83 eV for as-deposited phase to 1.34 eV for high temperature anneal phase is due to the metallurgical reactions taking place at the interface which probably reduces the interfacial oxide layer and causes the increase in the Schottky barrier height.

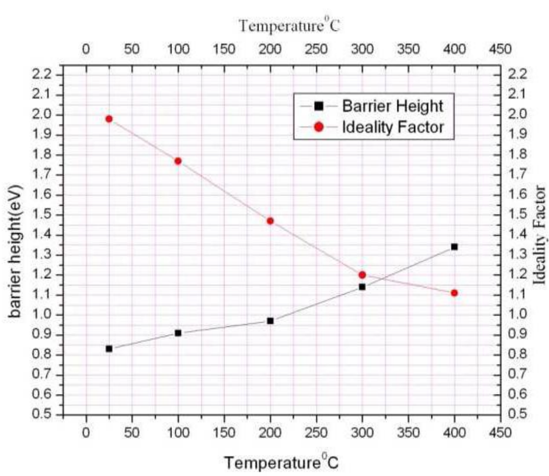

Fig.4: Dependence of I-V Barrier height and Ideality factor on Temperature.

Moreover figure 5 shows a linear relationship between the temperature dependent barrier heights and ideality factors obtained from the experimental forward bias I–V characteristics. This may be attributed to lateral barrier inhomogeneities in Schottky diodes [24-30]. The straight line drawn in plot was the least squares fit to the experimental data. From the plot in Figure 5 for n=1 barrier height value of 1.29 eV for Nichrome/4H-SiC SBDs was obtained from the linear relationship. As can be seen, the barrier height of 1.29 eV is rather close to the barrier height values at high temperatures. This has been attributed to the fact that the barrier height increases with increasing temperature, and thus it can be said that the barrier heights appear more uniform at higher temperatures in the Schottky diodes [31-33].

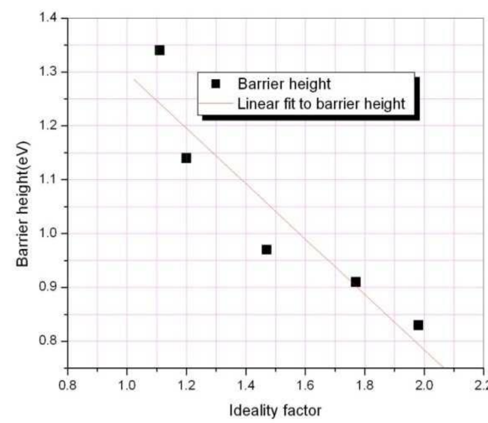

Fig.5: Experimental barrier eight and ideality factor plot.

Capacitance-voltage (C-V) measurement method was also used for the extraction of SBH and doping concentration. When a small a.c. signal is superimposed upon a d.c. bias, charges of one type are induced on metal surface and charges of other type on semiconductor. The relationship between capacitance and voltage is given by

$$C = \sqrt{\frac{q\varepsilon_0\varepsilon_s N_D}{2[V_{bi} - V_R - (kT/q)]}} \qquad (6)$$

where N_D is the donor concentration; q, is the electronic charge; k, the Boltzmann's constant; ε_s, is the permittivity of the semiconductor: V_{bi}, the built in voltage; and V_R the applied voltage. The slope of the $1/C^2$ vs. V plot is given by

$$\frac{d(1/C^2)}{dV_R} = \frac{-2}{A^2 N_D \varepsilon_s \varepsilon_0} \qquad (7)$$

The donor concentration can be calculated from the measured slope and the barrier height from the intercept on the voltage axis [23]. Thus we obtain

$$\phi_B = V_i + V_n + \frac{kT}{q} - \Delta\phi \qquad (8)$$

where V_i is the voltage axis intercept; !ϕ, the image force barrier lowering; and V_n is the depth of the Fermi level below the conduction band. Plots of capacitance versus reverse bias usually gave good straight lines which when extrapolated to the voltage axis, gave the diffusion voltage Vi = (kT/q). A typical plot for as-deposited diode is shown in Fig.6. Similar plots were obtained for thermally annealed diodes. From the slope of these curves donor concentration N_D was calculated which is in good agreement with the value provided by the manufacturer. The calculated values are tabulated in Table (1). The barrier height values are also tabulated in the table. Image force barrier lowering !ϕ has been neglected while calculating the barrier height. The barrier heights calculated from C-V measurement of Nichrome/4H-SiC Schottky diode deviate in the range from 0.88 eV to 1.38 eV. It has also been found that C-V barrier heights are larger than I-V derived barrier heights. This is expected as I-V characteristics would depend to a certain extent on the surface preparation method of the SiC.

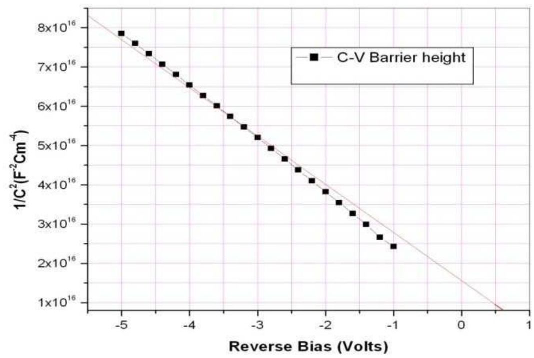

Fig.6: $1/C^2$ vs. voltage plot of the Nichrome/4HSiC Schottky barrier diode.

IV. CONCLUSION;-

Electrical characteristics of Nichrome/4H-SiC Schottky contacts with different thermal anneal in temperature range from 25^0C-400^0C have been reported in this paper. Nichrome/4H-SiC Schottky diodes were characterized by I-V and C-V measurement techniques to extract Schottky parameters like barrier height, ideality factor and doping concentration of the epilayer. Barrier height calculated on as-deposited contacts was 0.83 eV and 0.88 eV from I-V and C-V techniques respectively. Diodes showed non-ideal behavior at room temperature having ideality factor of 1.98 which improves to 1.11 after annealing at 400^0C. Rapid Thermal annealing appears to be an essential step to reduce the non-ideality.

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