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THERMAL ANNEALING BEHAVIOUR ON ELECTRICAL PROPERTIES OF Pd/Ru SCHOTTKY CONTACTS ON n-TYPE GaN

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We have investigated the electrical properties of Pd/Ru *Schottky contacts on n*-GaN *as a function of annealing temperature by current-voltage* (*I-V*) *and capacitance-voltage* (*C-V*) *measurements. The Schottky barrier height of the as-deposited* Pd/Ru *contact is found to be* 0.67 *eV* (*I-V*) *and* 0.79 *eV* (*C-V*), *respectively. Measurements showed that the Schottky barrier height increased from* 0.68 *eV* (*I-V*) *and* 0.80 *eV* (*C-V*) *to* 0.80 *eV* (*I-V*) *and* 0.96 *eV* (*C-V*) *as the annealing temperature is varied from* 200 *°C to* 300 *°C. Upon annealing at* 400 *°C and* 500 *°C, the Schottky barrier height decreased to* 0.73 *eV* (*I-V*) *and* 0.85 *eV* (*C-V*) *and* 0.72 *eV* (*I-V*) *and* 0.84 *eV* (*C-V*), *respectively. It is noted that the barrier height further decreased to* 0.59 *eV* (*I-V*) *and* 0.72 *eV* (*C-V*) *when the contact is annealed at* 600 *°C. The change of Schottky barrier heights and ideality factors with annealing temperature may be due to the formation of interfacial compounds at the* Ru/Pd/*n*-GaN *interface.*

Keywords: *SCHOTTKY BARRIER DIODE, THERMAL ANNEALING TEMPERATURE, I-V AND C-V CHARACTERISTICS, LEAKAGE CURRENT, BARRIER HEIGHT.*

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1. INTRODUCTION

Because of its wide band gap, high electron saturation velocity, large breakdown field and thermal stability, GaN is an attractive candidate for high temperature/high-power electronics [1]. Devices such as metal-semiconductor field effect transistors (MESFETs), high-electron-mobility transistors (HEMTs) and hetrojunction bipolar transistors (HBTs) have been fabricated on GaN [1]. In order to enhance the efficiency of these devices, thermally stable ohmic and Schottky contacts are required. A number of metals have been used as Schottky contacts to GaN by several research groups eg Pt, Au, Ni, Re and Ir. In the present work, we have fabricated and investigated thermal annealing temperature effects on the electrical characteristics of Pd/Ru Schottky contacts to n-type GaN.

2. EXPERIMENTAL DETAILS

In the present work, 2 μm thick Si doped GaN films are used, which are grown by metalorganic chemical vapour deposition (MOCVD) on c-plane Al_2O_3 substrates. The electron concentration obtained by means of Hall measurements is ~ 5.07×10^{17} cm^{-3}. The n-GaN layer is first ultrasonically degreased with warm trichloroethylene followed by acetone and methanol for 5 min each. This degreased layer is then dipped into boiling aqua regia

[HNO_3 : HCL = 1 : 3] for 10 min to remove the surface oxides and rinsed in deionized (DI) water. Ohmic contact is formed by depositing Ti (20 nm)/ Al (100 nm) on a portion of the sample by electron beam evaporation system. Rapid thermal annealing is conducted at 650 °C for 3 min in nitrogen ambient. Subsequently, a Schottky metallization scheme is achieved by depositing Pd (20 nm)/Ru (30 nm) bilayer with a diameter of 0.7 mm through a stainless steel mask in an electron beam evaporation system at a vacuum pressure of 7×10^{-6} mbar. In order to study the thermal annealing effects on Pd/Ru Schottky contacts to n-GaN, samples were annealed at 200 °C, 300 °C, 400 °C, 500 °C and 600 °C for 1 min in N_2 atmosphere in a rapid thermal annealing (RTA) system. Current-voltage (I-V) and capacitance (C-V) characteristics of the Schottky diode were measured at room temperature using Keithley source measuring unit (model No. 2400) and automated DLS - 83D spectrometer (SEMILAB, Hungary), respectively.

3. RESULTS AND DISCUSSION

We analyze the experimental I-V characteristics by the forward bias thermionic emission (TE) theory given as follows [2],

$$I = I_0 \exp(\frac{qV}{nkT})[1 - \exp(\frac{-qV}{kT})] \tag{1}$$

Where

$$I_0 = AA^*T^2 \exp(\frac{-q\Phi_{bo}}{kT}) \tag{2}$$

here I_0 is the saturation current, q is the electronic charge, A^* is the effective Richardson's constant and equals to 26.4 A/cm^2K^2 for n-GaN [3], A is the effective diode area, k is the Boltzmann constant, Φ_{bo} is the Schottky barrier height and n is the ideality factor.

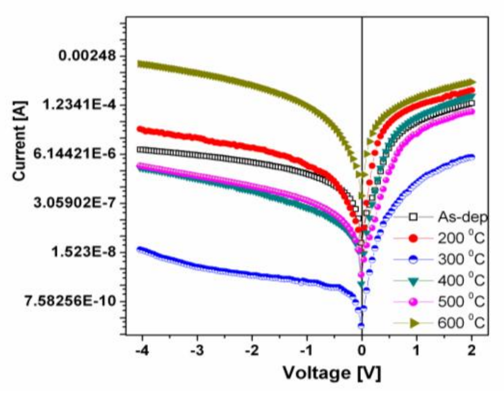

***Fig. 1** – I-V characteristics of* Pd/Ru *Schottky contact on n*-GaN *as a function of annealing temperatures*

The ideality factor is calculated from the slope of the linear region of the forward-bias ln$I$ versus V plots and can be written from equation (1) as,

$$n = \frac{q}{kT}\left(\frac{dV}{d(\ln I)}\right) \tag{3}$$

The Schottky barrier height (Φ_{bo}) is determined from the extrapolated I_0 and is given by,

$$\Phi_{bo} = \frac{kT}{q}\ln\left(\frac{AA^{*}T^{2}}{I_0}\right) \tag{4}$$

Using linear curve fitting for the forward characteristics of ln$I$ versus V data, the barrier height (Φ_{bo}) and ideality factor (n) can be determined from the y-intercept and the slope of the fitted curves respectively.

From Fig. 1, the reverse leakage current value at − 2 V for the as-deposited contact is measured to be 3.79×10^{-6} A. For the samples annealed at 200 °C, 300 °C, 400 °C, 500 °C and 600 °C the reverse leakage current values are 9.32×10^{-6}, 3.76×10^{-9}, 5.60×10^{-7}, 9.29×10^{-7} and 4.02×10^{-4} A, respectively. The smallest value of leakage current 3.76×10^{-9} A is observed for the contact annealed at 300 °C. Calculations yielded a Schottky barrier height of 0.67 eV for the as-deposited Pd/Ru contact. The extracted barrier heights of the annealed Pd/Ru Schottky contacts are 0.68 eV for 200 °C, 0.80 eV for 300 °C, 0.73 eV for 400 °C, 0.72 eV for 500 °C and 0.59 eV for 600 °C. The ideality factor of the as-deposited Ru/Pd/n-GaN Schottky contact is found to be 1.62. However, the ideality factor increased to 2.04 upon annealing at 600 °C. Ideality factors above unity has been attributed to interface states due to thin oxide layer between the metal and the semiconductor, including other contaminants, tunneling currents in highly doped semiconductors, image-force lowering of the Schottky barrier in electric field at the interface and generation-recombination currents with in the depletion region [2].

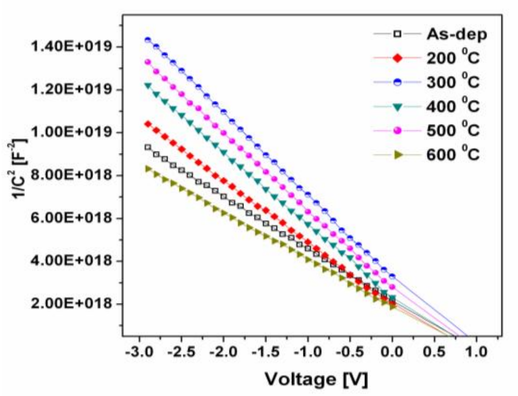

Fig. 2 *– Plot of* $1/C^2$ *versus* V *for the* Pd/Ru *Schottky contacts annealed at different temperatures*

A plot of $1/C^2$ as a function of bias voltage for the as-deposited and annealed Pd/Ru Schottky contacts is shown in Fig. 2. Capacitance-voltage

(C-V) measurements are performed at a frequency of 1 MHz. The C-V relationship for Schottky diode is given by [4],

$$\frac{1}{C^2} = \frac{2}{\varepsilon_S q N_d A^2} - (V_{bi} - \frac{kT}{q} - V) \tag{5}$$

where ε_s is the permittivity of the semiconductor ($\varepsilon_s = 9.5\ \varepsilon_0$), V is the applied voltage and A is the area of the diode. The x-intercept of the plot of ($1/C^2$) versus V gives V_0 and it is related to the built-in potential V_{bi} by the equation $V_{bi} = V_0 + kT/q$, where T is the absolute temperature. The barrier height is given by the equation $\Phi_{CV} = V_0 + V_n + kT/q$, here $V_n = (kT/q)\ \ln(N_c/N_d)$. The density of states in the conduction band edge is given by $N_c = 2(2\pi m{\cdot}kT/h^2)^{3/2}$, where $m^* = 0.22\ m_0$ and its value is 2.6×10^{18} cm^{-3} for n-GaN at room temperature [5]. The carrier concentration (N_d) can be extracted from the slope of $1/C^2$ versus V plot and the corresponding values are 3.84×10^{17} cm^{-3} for the as-deposited, 3.44×10^{17} cm^{-3} for 200 °C, 2.59×10^{17} cm^{-3} for 300 °C, 2.94×10^{17} cm^{-3} for 400 °C, 2.77×10^{17} cm^{-3} for 500 °C and 3.92×10^{17} cm^{-3} for 600 °C annealed samples. The measured Schottky barrier height of the as-deposited Pd/Ru Schottky contact is found to be 0.79 eV. For the samples annealed at 200, 300, 400, 500 and 600 °C the Schottky barrier heights are 0.80 eV, 0.96 eV, 0.85 eV, 0.84 eV and 0.72 eV, respectively.

Fig. 3 shows a plot of barrier heights and ideality factors of Ru/Pd/n-GaN Schottky diode as a function of annealing temperature. From Fig. 3, it is also evident that the barrier heights ($\Phi_{\text{I-V}}$) determined from I-V measurements are significantly lower than those obtained from C-V measurements ($\Phi_{\text{C-V}}$). The difference in barrier heights obtained from I-V and C-V measurements may arise from the presence of a native oxide layer [6] or spatial inhomogeneity at the Ru/Pd/n-GaN interface [7].

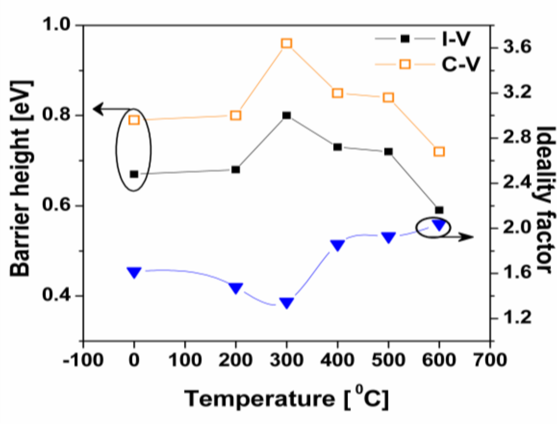

Fig. 3 *– Variation of the barrier heights and ideality factors with annealing temperature for the* Pd/Ru *Schottky contacts on n-type* GaN

4. CONCLUSIONS

Rapid thermal annealing effects on the electrical properties of Ru/Pd/n-GaN Schottky contacts have been investigated by current-voltage (I - V) and capacitance-voltage (C-V) techniques. As-deposited Ru/Pd/n-GaN Schottky diode exhibits barrier height of 0.67 eV (I-V) and 0.79 eV (C-V), respectively. Experimental results indicated that the Schottky barrier height increased from 0.68 eV (I-V) and 0.80 eV (C-V) to 0.80 eV (I-V) and 0.96 eV (C-V) as the annealing temperature is varied from 200 °C to 300 °C and decreased to 0.59 eV (I-V) and 0.72 eV (I-V) after annealing at 600 °C. The variation of Schottky barrier heights with different annealing temperatures may be attributed to the interfacial reactions of Pd/Ru with GaN.

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