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Analysis of the current–voltage characteristics of the Pd/Au Schottky structure on n-type GaN in a wide temperature range

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Abstract

We report on the temperature-dependent electrical characteristics of the Au/Pd/n-GaN Schottky diode in the temperature range of 90–410 K. The barrier heights and ideality factors of Schottky diodes were found in the range 0.23 eV and 3.5 at 90 K to 0.97 eV and 1.9 at 410 K, respectively. It was observed that the zero bias barrier height Φ_{bo} decreases and the ideality factor n increases with a decrease in temperature. Such behavior is attributed to barrier inhomogeneities by assuming a Gaussian distribution of barrier heights at the interface. The estimated values of series resistance (R_S) are in the range of 636 Ω at 90 K to 220 Ω at 410 K using Cheung's method. Based on the above observations, the Φ_{bo}, n and R_S values are seen to be strongly temperature dependent. The flat-band barrier height $\Phi_{bf}(T = 0\text{ K})$ and temperature coefficient α were found to be 0.67 eV and 2.81×10^{-3} eV K^{-1}, respectively. Further, the homogeneous barrier height is estimated from the linear relationship between temperature-dependent experimental effective barrier heights and ideality factors and the value is approximately 1.31 eV. The effective Richardson constant is determined to be 20.43 A cm^{-2} K^{-2} and is in good agreement with the theoretical value. It is concluded that the temperature-dependent *I–V* characteristics of the Au/Pd/n-GaN Schottky diode can be successfully explained on the basis of thermionic emission (TE) mechanism with the Gaussian distribution of the barrier heights.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Rapid progress in the fabrication of electronic and optoelectronic devices with III–V group nitrides, particularly gallium nitride (GaN), is a highly promising semiconductor material for high temperature, high frequency and high power applications. The applications include high electron mobility transistors (HEMTs) [1], metal oxide semiconductor field effect transistors (MOSFETs) [2], metal semiconductor metal (MSM) photo detectors [3], light emitting diodes (LEDs) [4] and laser diodes (LDs) [5]. In order to realize such novel devices or to improve device performance, it is important to study the electrical properties of metal/GaN Schottky interfaces at below (low) and above (high) room temperature.

It is of great importance to study temperature-dependent electrical characteristics if the current transport mechanism of the Schottky diode is to be elucidated. Some of the researchers have studied the electrical properties of Schottky contacts with different metal schemes on *n*-type GaN in a wide temperature range [6–11]. Osvald *et al* [7] investigated the temperature dependence of the electrical characteristics of GaN Schottky diodes with two crystal polarities (Ga- and N-face). They reported a decrease in the barrier heights

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with a decrease in temperature and an increase in ideality factors for both polarities. Arehart *et al* [8] studied the impact of threading dislocation density on the Ni/n-GaN Schottky diode using forward current–voltage–temperature (*I–V–T*) measurements. Ping *et al* [9] reported the Schottky barrier height (SBH) 0.94 eV and 1.07 eV by *I–V* and *C–V* methods, and the effective Richardson constant was $\sim$3.24 A cm^{-2} K^{-2} of the Pd Schottky barrier on n-GaN by the modified Norde method. Akkal *et al* [10] investigated the current–voltage characteristics of Au/n-GaN Schottky diodes in the temperature range 80–300 K, and reported the saturation current ($I_s = 1.9 \times 10^{-11}$ A) and ideality factor ($n = 1.18$) at room temperature. Recently, Zhou *et al* [11] studied the electrical characteristics of Schottky rectifier with a SiO_2 field plate on a freestanding n-GaN in the temperature range of 298–473 K and reported that the barrier height increases and ideality factors decreases with temperature. They found that the value of A^* determined by a modified Richardson's plot is close to the theoretical value. In the present work, a detailed analysis of the temperature dependence of the electrical characteristics of the Pd/Au Schottky barrier on *n*-type GaN has been carried out to clarify the origin of the anomalous behavior of the barrier height and of the ideality factor and the significant underestimation of Richardson's constant. The temperature-dependent barrier characteristics of the Au/Pd/n-GaN Schottky contacts are interpreted on the basis of existence of the Gaussian distribution of the barrier heights around a mean value due to barrier height inhomogeneities prevailing at the metal/semiconductor (MS) interface.

2. Experimental details

The gallium nitride (GaN, N-face) wafer used in this study was grown by metalorganic chemical vapor deposition on the c-plane Al_2O_3 sapphire substrate with the thickness of 2 μm and doped with Si. The electron concentration obtained by means of Hall measurement was $\sim 4.07 \times 10^{17}$ cm^{-3}. The n-GaN layer was first ultrasonically degreased with warm trichloroethylene, acetone and methanol for 5 min in each. This degreased layer was dipped into boiling aqua regia [HNO_3:HCl = 1:3] for 10 min to remove the surface oxide and the sample was rinsed in deionized water. A Ti (30 nm)/Al (30 nm) ohmic contact was deposited on a portion of the sample by the electron beam evaporation system under the vacuum of 4×10^{-6} mbar. Then the sample was annealed at 600 °C for 2 min in N_2 ambient. The Schottky contacts were formed by evaporation of Pd (30 nm) as the first layer and Au (30 nm) as the second layer (Pd, 99.999%; Au, 99.999%) with a diameter of 1 mm through a stainless steel mask. The current–voltage characteristics of Pd/Au Schottky contacts were measured in the temperature range 90–410 K by steps of 40 K in the dark using a temperature controller DLS-83D-1 cryostat with a sensitivity of ±1 K. The *I–V* measurements were performed by using a Keithly source measure unit (model no 230).

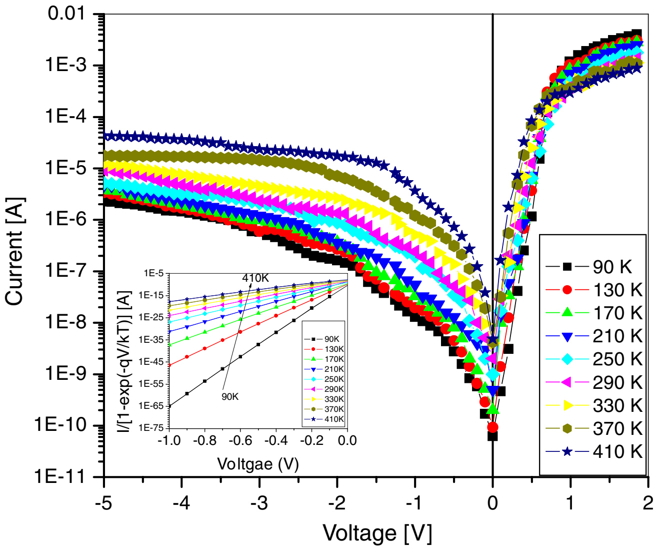

Figure 1. The reverse and forward current–voltage characteristics of the Pd/Au Schottky contact to n-GaN in temperature range 90–410 K. The inset shows the plot of $I/[1-\exp(-qV/kT)]$ versus V for the Pd/Au Schottky contacts in the wide temperature range.

3. Results and discussion

The forward and reverse current–voltage (*I–V*) characteristics of the Au/Pd/n-GaN Schottky barrier diode in the wide temperature range 90–410 K are shown in figure 1. Twelve Schottky contacts on the n-GaN surface were performed for Pd/Au Schottky barrier diodes. The variation of calculated parameters is almost the same in all the cases. Only one diode is used for measurements at different temperatures in this paper. It is clear from figure 1 that the curves intersect at a point, implying that at such a point current (*I*) and bias (*V*) have unique values. The slope of the ln(*I*)–*V* curves at this point is independent of temperature, so the derivative of ln(*I*) with respect to temperature will be zero. Some of the authors [12, 13] discussed the intersection behavior of the current–voltage characteristics of inhomogeneous Schottky contacts. According to Chand [12], the intersection of ln(*I*)–*V* curves may occur because of decreasing apparent barrier height with decreasing temperature, which was also supported by Osvald [13]. Osvald [13] reported that the intersection behavior of *I–V* curves for the inhomogeneous diodes may be due to series resistance distribution, and it is assumed that for small diodes the series resistance is completely independent, each having its own series resistance. The realistic scheme assumes that every diode has its own series resistance connected with the limited current spreading and there is also some common series resistance. On the other hand, it is possible that the intersection has to occur here because of the saturation effects of series resistance in each elementary barrier [12].

The *I–V* relation for the Schottky diode based on the thermioinic emission theory is given by [14]

$$I = I_0 \exp\left(\frac{qV}{nkT}\right)\left[1 - \exp\left(\frac{-qV}{kT}\right)\right], \qquad (1)$$

Table 1. The leakage currents, zero-bias barrier heights Φ_{bo}, ideality factors n and series resistance R_S of the Pd/Au Schottky contact on n-type GaN in the temperature range 90–410 K

T (K)	Leakage current at –1 V (A)	Φ_{bo} (eV)	n	R_S (Ω)
90	1.28×10^{-8}	0.23 (±0.03)	3.5 (±0.03)	636 (±0.6)
130	1.95×10^{-8}	0.34 (±0.02)	3.1 (±0.02)	491 (±0.7)
170	3.27×10^{-8}	0.46 (±0.02)	2.7 (±0.04)	416 (±0.4)
210	5.50×10^{-8}	0.56 (±0.02)	2.5 (±0.03)	348 (±0.5)
250	1.96×10^{-7}	0.66 (±0.03)	2.3 (±0.04)	330 (±0.4)
290	2.42×10^{-7}	0.73 (±0.03)	2.2 (±0.03)	304 (±0.5)
330	5.12×10^{-7}	0.82 (±0.04)	2.1 (±0.02)	298 (±0.6)
370	1.21×10^{-6}	0.89 (±0.03)	2.0 (±0.02)	285 (±0.5)
410	3.64×10^{-6}	0.97 (±0.02)	1.9 (±0.03)	220 (±0.4)

where

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

Here, I_0 is the saturation current, n is the ideality factor, V is the applied voltage, T is the absolute temperature, q is the electron charge, k is the Boltzmann constant, Φ_{bo} is the SBH, A is the effective diode area and A^* is the effective Richardson constant for n-GaN, assumed to be 26.4 A cm^{-2} K^{-2} [15] The I–V measurement were made to determine the saturation current I_0 from which the barrier height was defined in terms of thermionic emission theory:

$$\Phi_{bo} = \frac{kT}{q} \ln\left(\frac{AA^*T^2}{I_0}\right). \quad (3)$$

Equation (1) shows that the logarithmic plot of $I/[1-\exp(-qV/kT)]$ against V (inset in figure 1) is linear and I_0 is obtained from the y-axis intercept at zero voltage at each temperature. Using these I_0 values in equation (3), the SBHs are calculated and given in table 1. The ideality factor n is a measure of conformity of the diode to thermionic emission, and it is determined from the slope of linear region of forward bias ln I versus V characteristics through the relation

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

for an ideal diode $n = 1$, nevertheless the ideality factor n has usually greater than unity. The values of barrier heights and ideality factor of the Schottky diode at different temperatures are calculated using equations (3) and (4). Calculations showed that the SBH and ideality factor values of the Pd/Au contact are 0.23 eV and 3.5 at 90 K and 0.97 eV and 1.9 at 410 K, respectively. It is observed that the barrier height is increased linearly from 0.23 eV to 0.97 eV with the increase in temperature from 90 K to 410 K, accompanied by a significant improvement of the ideality factor n from 3.5 to 1.9. It is observed that the leakage current increase with the increase in temperature is in the range 1.28×10^{-8} A (at 90 K) to 3.64×10^{-6} A (at 410 K) at –1 V. The experimentally observed leakage current is consistent with SBH inhomogeneity. The presence of a few large low-SBH regions (large ideality factor) at the Schottky barrier interface can certainly lead to the observation of a leaky component in the junction current.

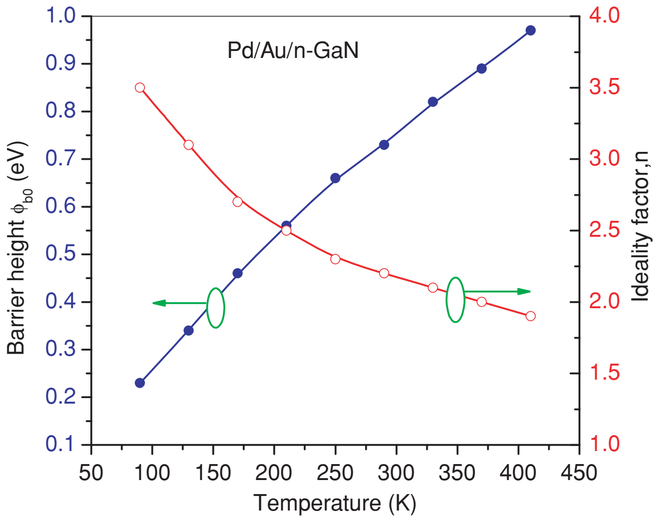

Figure 2. The variation of barrier heights and ideality factor with temperature for the Pd/Au Schottky contact on n-GaN.

Because of a lower effective SBH, the presence of even a single low-SBH region can lead to the observation of leakage current. The leakage currents, zero-bias barrier heights Φ_{bo} and ideality factors n values are given in table 1.

The temperature dependence characteristics of the Pd/Au SBH and ideality factor n are shown in figure 2. Interestingly, it is noted that the SBH Φ_{bo} was found to increases with temperature while the ideality factor n was found to decrease with temperature. A similar phenomenon was also found in silicon-based Schottky diodes [16, 17] and bulk GaN Schottky rectifier [11]. The existence of SBH inhomogeneity was often used to explain such a temperature dependence of Φ_{bo} and n [18]. Assuming that a diode consists of parallel segments of different barrier heights and each contributes to the current independently (parallel conduction model), the current of the diode will preferentially flows through the lower barriers. As a result, the current conduction is dominated by patches of lower barrier height with a large ideality factor at lower temperatures. However, as the temperature increases, the patches with higher barrier heights take effect due to the fact that electrons gain sufficient thermal energy to surmount them [18]. Thus, both the barrier height and ideality factor observed from the temperature-dependent characteristics are consistent with SBH inhomogeneity.

The ideality factor of the Schottky barrier diode with a distribution of low SBH may increase with a decrease in temperature. According to [16, 19–21], the plot of the experimental effective barrier heights versus the ideality factor n of the Au/Pd/n-GaN Schottky diodes is shown in figure 3. Based on Tung's theoretical approach, Schmitsdorf *et al* [21] found a linear correlation between the zero-bias SBHs and ideality factors. As can be seen from figure 3, there is a linear relationship between the experimental effective barrier heights and ideality factor of the Schottky contacts and is attributed to lateral inhomogeneities of the barrier heights in the Schottky diodes. The extrapolation of the barrier heights versus ideality factor $n = 1$ has given a homogeneous barrier height of approximately 1.31 eV. Thus, it is noticed that the

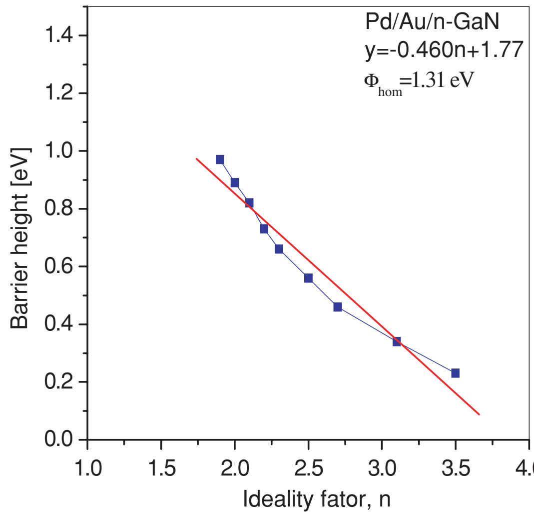

Figure 3. Plot of the Schottky barrier height versus ideality factors of the Au/Pd/n-GaN Schottky diode at various temperatures.

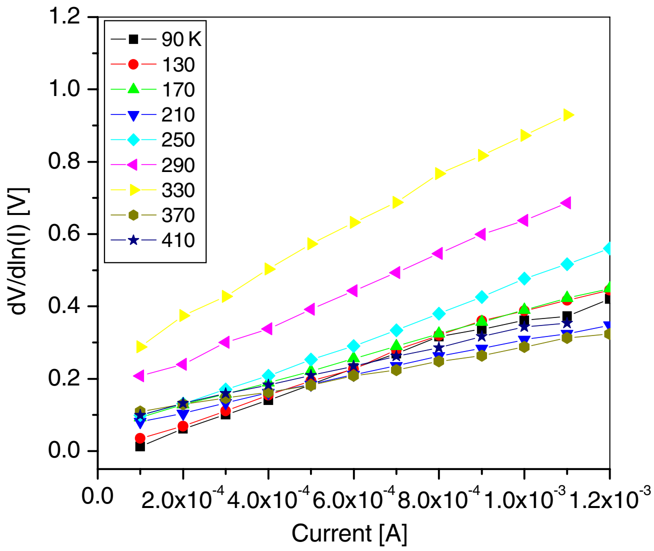

Figure 4. Experimental $\mathrm{d}V/\mathrm{d}(\ln I)$ versus I curves for the Au/Pd/n-GaN Schottky diode at different temperatures (90–410 K).

significant decrease of the zero-bias barrier height and increase of the ideality factor especially at low temperature may be due to barrier inhomogeneities.

Usually, the forward bias of *I–V* characteristics is linear in a semi-logarithmic scale at low forward bias voltage but deviates considerably from the ideality due to the effect of series resistance. The series resistance is a very important parameter of the Schottky diode. The series resistance of the Pd/Au Schottky diode is investigated in the temperature range 90–410 K. The current–voltage characteristics of the Au/Pd/n-type GaN Schottky diode show a rectification behavior as shown in figure 1. Here, the series resistance was evaluated from forward bias *I–V* data using the method developed by Cheung [22]. One can also obtain the series resistance of the Schottky diode using approaches described in [23–27]. The forward bias *I–V* characteristics due to thermionic emission of a Schottky contact with series resistance can be Cheung's function which is defined as

$$\frac{\mathrm{d}V}{\mathrm{d}\,(\ln I)} = IR_{\mathrm{S}} + n\left(\frac{kT}{q}\right). \tag{5}$$

Figure 4 shows the experimental plot of $\mathrm{d}V/\mathrm{d}(\ln I)$ versus I for different temperatures for the Au/Pd/n-GaN Schottky diode. Equation (5) should give a straight line for the data of the downward region in the forward bias *I–V* characteristics. Thus, a plot of $\mathrm{d}V/\mathrm{d}(\ln I)$ versus I will give R_{S} as a slope and $n(kT/q)$ as the y-axis intercept. Thus, the series resistance (R_{S}) values are calculated from equation (5) for each temperature given in table 1. As shown in table 1, the increase of R_{S} with fall in temperature is believed to result due to factors responsible for the increase of ideality factor and lack of free carrier concentration at low temperatures [16].

Another way to correlate the derived parameters ideality factor n and barrier height Φ_{bo} is to calculate the flat-band barrier height Φ_{bf}. Unlike the case of zero-bias barrier height, the electric field in the semiconductors is zero under the flat-band conditions and thus the semiconductor bands are flat, which precludes tunneling and image force lowering from affecting the *I–V* characteristics. The flat-band barrier height Φ_{bf} can be calculated from the experimental ideality factor and zero-bias barrier height Φ_{bo} according to [28, 29]

$$\Phi_{\mathrm{bf}} = n\Phi_{\mathrm{bo}} - (n-1)(E_{\mathrm{C}} - E_{\mathrm{F}}), \tag{6}$$

where E_{F} is the Fermi energy and E_{C} is the conduction band energy. The energy difference between the conduction band and the Fermi level is given by

$$E_{\mathrm{C}} - E_{\mathrm{F}} = \frac{kT}{q}\ln\frac{N_{\mathrm{C}}}{N_{\mathrm{d}}}, \tag{7}$$

where N_{C} effective density of states in the conduction band edge, and N_{d} is the donor concentration. Assuming that the effective mass m^*_{e} and the donor concentration N_{d} do not change with temperature, the effective density of states in the conduction band N_{C} will change with temperature according to the relation [30].

$$N_{\mathrm{C}}\ (\mathrm{cm}^{-3}) = 2.6\times 10^{18}\left(\frac{T}{300}\right)^{3/2}. \tag{8}$$

The flat-band barrier height of the Au/Pd/n-GaN Schottky barrier diode is calculated from the *I–V* barrier heights and corresponding ideality factor at each temperature using equation (6). Figure 5 shows the variation of the flat-band height Φ_{bf} as a function of the temperature. As can be seen from figure 5, the flat-band barrier height is invariably larger than the zero-bias barrier height at low temperature. Furthermore, the temperature dependence of the flat-band barrier height can be described as

$$\Phi_{\mathrm{bf}}(T) = \Phi_{\mathrm{bf}}(T=0) + \alpha T, \tag{9}$$

where $\Phi_{\mathrm{bf}}(T = 0\ \mathrm{K})$ is the flat-band barrier extrapolated to zero and α is the temperature coefficient. In figure 5**,** a linear fit is used to determine the slope and the y-axis intercept which give the value of α and the value $\Phi_{\mathrm{bf}}(T = 0\ \mathrm{K})$, respectively. The fitting of the $\Phi_{\mathrm{bf}}(T)$ data in equation (9) yields $\Phi_{\mathrm{bf}}\ (T = 0\ \mathrm{K}) = 0.67$ eV and $\alpha = 2.81\times 10^{-3}$ eV K^{-1}.

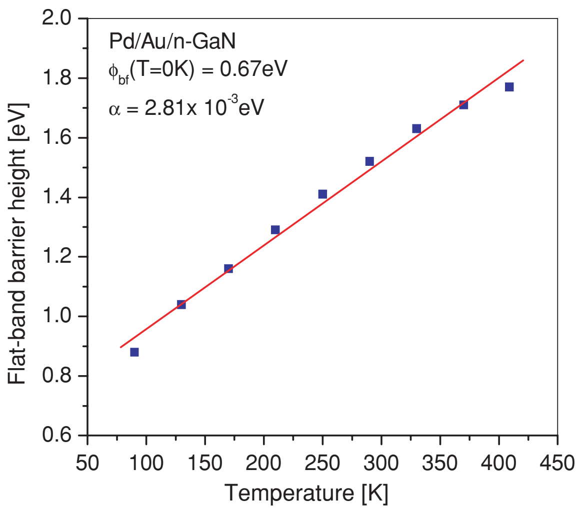

Figure 5. Plot of variation of the flat-band barrier height with temperature.

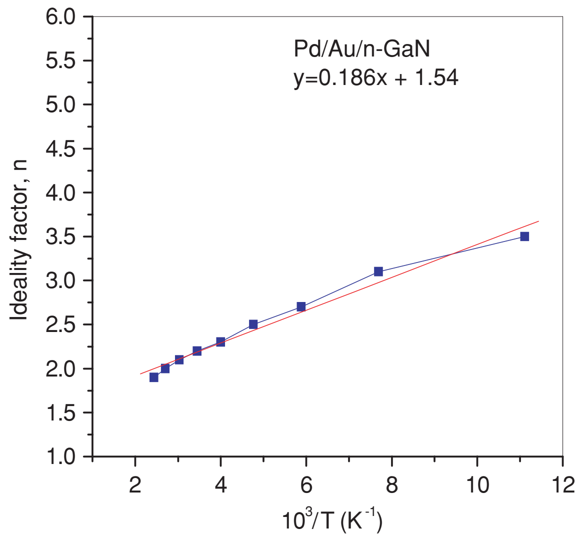

Figure 6. Temperature dependence of the ideality factor for the Au/Pd/n-GaN Schottky diode in the temperature range 90–410 K.

The variation in the ideality factor with temperature is shown in figure 6. In fact, the higher values of the ideality factor show that there is a deviation from TE theory for the current mechanism. The values of the ideality factor n are not constant with temperature as seen from figure 6. Such behavior of the diode ideality factor has been attributed to particular distribution of surface states [17]. The ideality factor n was found to be inversely proportional to temperature as shown in figure 6 as $n(T) = n_0 + T_0/T$, where n_0 and T_0 are constants which were found to be 1.54 and 186 K, respectively. The increase in the ideality factor with decreasing temperature is known as the T_0 effect. The possible explanation of origin of such a case has been proposed taking into account the interface state density distribution, quantum mechanical tunneling and image force lowering [30].

The explanation of the abnormal behavior of the *I–V* characteristics of the Schottky barrier diode has been attributed to the spatial variation of barrier heights. The spatial barrier inhomogeneities in Schottky diodes are described mainly by the Gaussian distribution function [31, 32]:

$$P(\Phi_b) = \frac{1}{\sigma_S\sqrt{2\pi}}\exp\left[-\frac{(\Phi_b - \overline{\Phi}_b)^2}{2\sigma_S^2}\right]. \tag{10}$$

The total current at the forward bias V is given by

$$I(V) = \int_{-\infty}^{\infty} I(\Phi_b, V)P(\Phi_b)\,d\Phi, \tag{11}$$

where $I(\Phi_b, V)$ is the current at a bias V for a barrier of Φ_b based on the thetmionic emission model. Substituting equations (1) and (10) into equation (11), and performing the integration it becomes

$$I(V) = I_0 \exp\left(\frac{qV}{kTn_{ap}}\right)\left[1 - \exp\left(\frac{-qV}{kT}\right)\right] \tag{12}$$

with

$$I_0 = AA^*T^2 \exp\left(\frac{-q\Phi_{ap}}{kT}\right), \tag{13}$$

where Φ_{ap} and n_{ap} are the apparent barrier height and apparent ideality factor, respectively and are given by

$$\Phi_{ap} = \bar{\Phi}_{bo}(T = 0) - \frac{q\sigma_0^2}{2kT} \tag{14}$$

$$\left(\frac{1}{n_{ap}} - 1\right) = \rho_2 - \frac{q\rho_3}{2kT}, \tag{15}$$

where $\overline{\Phi}_{bo}$ is the mean barrier height and σ_S is linearly bias dependent on Gaussian parameters, such as $\overline{\Phi}_b = \overline{\Phi}_{bo} + \rho_2$ eV and standard deviation $\sigma_S = \sigma_{S0} + \rho_3$ eV, where ρ_2 and ρ_3 are voltage coefficients which may be dependent on T and they quantify the voltage deformation of the barrier height distribution. The temperature dependence of σ_S is usually small and can be neglected [17].

Fitting the experimental data in equation (2) and (4) gives Φ_{ap} and n_{ap}, respectively, which should obey equations (14) and (15). Thus, the plot of Φ_{ap} versus $1/2kT$ (figure 7(*a*)) should be a straight line which gives $\overline{\Phi}_{bo}$ and σ_0 from the intercept and slope, respectively. In figure 7(*a*), the values of $\overline{\Phi}_{bo}(T = 0) = 1.03$ eV and $\sigma_0 = 0.118$ eV were obtained from the experimental Φ_{ap} versus $1/2kT$ plot. In figure 7(*a*), the plot of n_{ap} versus $1/2kT$ should be a straight line that gives the voltage coefficients ρ_2 and ρ_3 from the intercept and slope, respectively. The obtained values of $\rho_2 = 0.447$ eV and $\rho_3 = 0.0045$ eV from the experimental n_{ap} versus $1/2kT$ plot. The standard deviation is a measure of the barrier homogeneity. The lower value of σ_0 corresponds to more homogenous barrier height. It is seen that the value of $\sigma_0 = 0.118$ eV is not small compared to the mean value of $\overline{\Phi}_{bo} = 1.03$ eV, and it indicates greater inhomogeneities at the interface. Further, the observed value of standard deviation is 0.118 eV, which index to decide the magnitude of the barrier height inhomogeneity in a Schottky diode. These values indicated that a Au/Pd/n-GaN Schottky diode had relatively more inhomogeneous barrier heights. This could be due to the interface oxide layer (Ga_2O_3) at the junction region of the Au/Pd/n-GaN Schottky diode [33]. According to Forment *et al* [34], the possible explanation is that the larger standard

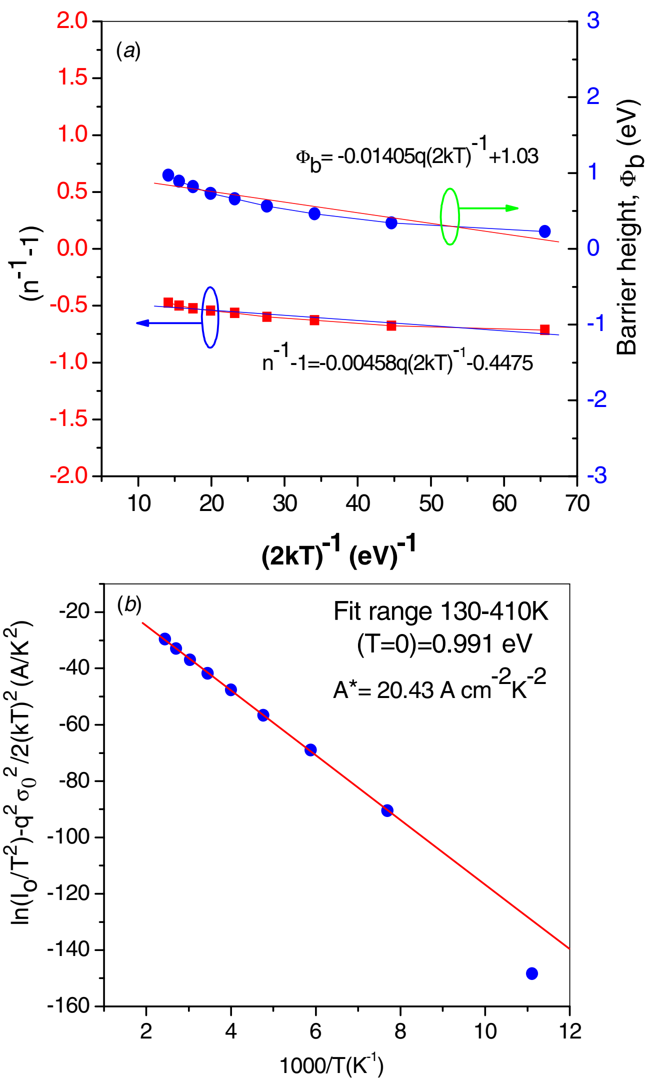

Figure 7. (a) The zero-bias apparent barrier height and ideality factor versus $1/2kT$ curves of the Au/Pd/n-GaN Schottky diode according to Gaussian distribution. (b) Linear fit of the $\ln(I_0/T^2) - q^2\sigma_0^2/2(kT)^2$ versus $1000/T$ (K^{-1}) plot for the modified Richardson at the temperature between 130 K and 410 K.

deviation may be due to the spreading of interfacial dipoles at the metal–semiconductor interface, caused by local differences in the morphology at the interface. Further, they observed that the standard deviation can also strongly be influenced by surface treatments. Moreover, Calvet *et al* [35] have shown experimentally that the barrier inhomogeneities become less important in devices with smaller contact areas.

A combination of equations (2) and (14) gives the following expression [36]:

$$\ln\left(\frac{I_0}{T^2}\right) - \frac{q^2\sigma_0^2}{2(kT)^2} = \ln(AA^*) - \frac{q\overline{\Phi}_{bo}}{kT}. \qquad (16)$$

The modified $\ln(I_0/T^2) - q^2\sigma_0^2/2(kT)^2$ versus $1000/T$ plot is shown in figure 7(b). It can be seen that the modified Richardson plot has quite good linearity over the whole temperature range. Linear fitting of the curve gives the mean barrier height $\overline{\Phi}_{bo}$ and effective Richardson constant A^*, and the values are 0.991 eV and 20.43 A cm^{-2} K^{-2}, respectively. As can be seen, the mean barrier height is in close agreement with the value of $\overline{\Phi}_{bo} = 1.03$ eV from the plot of Φ_{ap} versus $1/2kT$ given in figure 7(a), while the modified Richardson constant $A^* = 20.43$ A cm^{-2} K^{-2} is closer to the theoretical value of 26.4 A cm^{-2} K^{-2} [15]. This is another important proof of the model of Gaussian distribution of barrier heights in Au/Pd/n-GaN Schottky diodes.

4. Conclusion

The current–voltage (I–V) characteristics of the Au/Pd/n-GaN Schottky diode has been measured in the temperature range of 90–410 K. The estimated I–V barrier heights are in the range of 0.23–0.97 eV with the ideality factor of 3.5–1.9 (90–410 K). The effect of the temperature on the SBH (Φ_{bo}), ideality factor (n) and series resistance (R_S) extracted from I–V characteristics was investigated. It was noted that the zero-bias barrier height Φ_{bo} increased and the ideality factor n and series resistance R_S decreased with increasing temperature. The calculated values of series resistance (R_S) of Au/Pd/n-GaN are in the range 636 Ω at 90 K and 220 Ω at 410 K using Cheung's method. From the above observations, the $\Phi_{bo,}$ n and R_S values are seen to be strongly temperature dependent. The flat-band height and temperature coefficient α were calculated to be $\Phi_{bf}(T = 0\ \text{K}) = 0.67$ eV and $\alpha = 2.81 \times 10^{-3}$ eV K^{-1} by the I–V method. The effective Richardson constant was found to be 20.43 A cm^{-2} K^{-2}, which is much closer to theoretical value of 26.4 A cm^{-2} K^{-2}. The homogeneous SBH value of approximately 1.31 eV for Au/Pd/n-GaN Schottky diodes was estimated from the linear relationship between the experimental barrier heights and ideality factors. The origin and nature of the decrease in the ideality factor and increase in the barrier height with increasing temperature in the Au/Pd/n-GaN Schottky barrier diodes has been successfully explained on the basis of thermionic emission with the Gaussian distribution of the barrier heights. This behavior is attributed to spatial variations of the barrier heights.

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References

[1] Moon J S, Micovic M, Kudoghlian A, Janke P, Hashimoto P, Wong W S, McCray L and Nguyen C 2002 *IEEE Electron. Device Lett.* **23** 637
[2] Mistele D 2002 *Mater. Sci. Eng.* B **93** 107
[3] Flannery L B, Harrison I, Lacklison D E, Dykeman R I, Cheng T S and Foxon C T 1997 *Mater. Sci. Eng.* B **50** 307
[4] Chen L C, Hsu C Y, Lan W H and Teng S Y 2003 *Solid-State Electron.* **47** 1843
[5] Werner R, Reinhardt M, Emmerling M, Forchel A, Harle V and Bazhenov A 2000 *Physica* E **7** 915
[6] Yu L S, Liu Q Z, Xing Q J, Qiao D J and Lau S S 1998 *J. Appl. Phys.* **84** 2099

[7] Osvald J, Kuzmik J, Konstantinidis G, Lobotka P and Georgakilas A 2005 *Microelectron. Eng.* **81** 181
[8] Arehart A R, Moran B, Speck J S, Mishra U K, Den Baars S P and Ringel S A 2006 *J. Appl. Phys.* **100** 023709
[9] Ping A T, Schmitz A C, Asif Khan M and Adesida I 1996 *Electron. Lett.* **32** 68
[10] Akkal B, Benamara Z, Abid H, Talbi A and Gruzza B 2004 *Mater. Chem. Phys.* **85** 27
[11] Zhou Y, Wang D, Ahyi C, Tin C C, Williams J, Park M, Mark Williams N, Hanser A and Preble Edward A 2007 *J. Appl. Phys.* **101** 024506
[12] Chand S 2004 *Semicond. Sci. Technol.* **19** 82
[13] Osvald 2006 *J. Solid-State Electron.* **50** 228
[14] Rhoderick E H and Williams T H 1988 *Metal Semiconductor Contacts* (Oxford: Clarendan)
[15] Drechsler M, Hofman D M, Meyer B K, Detchprohm T, Amano H and Akasaki I 1995 *Japan J. Appl. Phys.* **34** L1178
[16] Chand S and Kumar J 1996 *J. Appl. Phys.* **80** 288
[17] Zhu S, Van Meirhaeghe R L, Detavernier C, Cardon F, Ru G P, Qu X P and Li B Z 2000 *Solid-State Electron.* **44** 663
[18] Karadeniz S, Sahin M, Tugluoglu N and Safak H 2004 *Semicond. Sci. Technol.* **19** 1098
[19] Sullivan J P, Tung R T, Pinto M R and Graham W R 1991 *J. Appl. Phys.* **70** 7403
[20] Tung R T 1992 *Phys. Rev.* B **45** 13509
[21] Schmitsdorf R F, Kampen T U and Monch W 1995 *Surf. Sci.* **324** 249
[22] Cheung S K and Cheung N W 1986 *Appl. Phys. Lett.* **49** 85
[23] Cibils R M and Buitrago R H 1986 *J. Appl. Phys.* **581** 1075
[24] Norde H 1979 *J. Appl. Phys.* **50** 5052
[25] Bohlin K E 1986 *J. Appl. Phys.* **60** 1223
[26] Sato K and Yasumura Y 1985 *J. Appl. Phys.* **58** 3655
[27] Lee T C, Fung S, Beling C D and Au H L 1992 *J. Appl. Phys.* **72** 4739
[28] Kribes Y, Harrisson I, Tuck B, Cheng T S and Foxon C T 1997 *Semicond. Sci. Technol.* **12** 913
[29] Wagner L F, Young R W and Sugerman S 1983 *IEEE Electron Device Lett.* **4** 320
[30] Sze S M 1981 *Physics of Semiconductor Devices* 2nd edn (New York: Wiley)
[31] Singh A 1993 *Solid-State Electron.* **28** 223
[32] McCafferty P G, Sellai A, Dawson P and Elabd H 1996 *Solid-State Electron.* **39** 583
[33] Lee S-Y, Jang C-O, Hyung J-H, Kim T-H and Lee S-K 2008 *Physica* E **40** 3092
[34] Forment S, Van Meirhaeghe R L, De Vrieze A, Strubbe K and Gomes W P 2001 *Semicond. Sci. Technol.* **16** 975
[35] Calvet L E, Wheeler R G and Reed M A 2002 *Appl. Phys. Lett.* **80** 1761
[36] Karatas S, Altindal S, Turut A and Ozmen A 2003 *Appl. Surf. Sci.* **217** 250