Effects of thermal annealing of Pt Schottky contacts on n-GaN

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Abstract

In this paper, the Schottky behavior of Pt contact on n-GaN grown by RF-plasma assisted molecular beam epitaxy was investigated under different annealing temperatures. The temperature dependence and structural evolution of the Schottky barrier heights of Pt contacts were characterized by using current- voltage (I-V) measurements and scanning electron microscopy (SEM). The results revealed that the Schottky barrier heights of the samples change with annealing temperature. The high quality Schottky contact with a barrier height and ideality factor of 1.107 eV and 1.234 respectively can be obtained under 30 min annealing at 800^{o}C in N_2 ambience.

1. Introduction

Gallium nitride (GaN) has a wide band gap of 3.4 eV which is useful for of UV/blue light emitting diodes and high temperature electronics applications. GaN based electronic and optoelectronic devices including visible light emitting diode (LED) [1], ultraviolet photoconductive detectors [2], ultraviolet Schottky barrier photodetector [3], metal-semiconductor field effect transistors (MESFETs) [4], high electron mobility transistors (HEMTs) [5] and heterojunction bipolar transistors (HBTs) [6] have been reported. In order to optimize the electrical behavior of these devices, it is crucial to develop stable and reliable ohmic and Schottky contacts.

Pt has a high work function that makes it ideal for use as Schottky contacts on n-type GaN and it also resistance to oxidation and corrosion [7]. The Schottky barrier height of Pt/n-GaN has been reported by several groups with value between 0.89 eV and 1.27 eV [8-10]. According to the Schottky-Mott model, the Schottky barrier height is dependent on the metal work function and electron affinity of semiconductor χ (GaN χ = 4.1eV) [11]. Metals with low functions are used in many ohmic contacts to n-GaN, while metals with high metal work functions have received the most attention in Schottky barrier contacts to n-GaN. The work function of Pt metal is 5.65 eV and consequently expects to form a good Schottky contact on n-GaN [12].

In this paper, we report the experimental results of thermal annealing of Pt Schottky contacts on n-type GaN. The structural and temperature dependence of the Schottky barriers heights of Pt contacts on n-GaN epilayer at different annealing temperature have been studied.

2. Experiment details

The n-type GaN thin film used in this study was grown on sapphire substrate by using RF plasma-assisted molecular beam epitaxy (RF-MBE). Active nitrogen was supplied by nitrogen plasma source while effusions cell were used for Ga and Si. Prior to the expitaxial growth, the sapphire substrate was nitridated for 45 min at 200^{o}C. This process consequently results in the formation of a relaxed AlN thin buffer layer [13]. After nitridation, a thin AlN buffer layer was grown at the substrate temperature of 780^{o}C, and then GaN epilayer was grown at 760^{o}C, followed by *in situ* doping using Si. During the growth of n-type GaN, streaky reflection high energy electron diffraction (RHEED) patterns were observed.

In this experiment, only one wafer was used and it was divided into several small pieces to minimize possible variability between different growth runs. The characteristics of Schottky barrier contacts are strongly influenced by the condition of the semiconductor surface prior to the metallization. For III-V semiconductors, a few nanometers thin oxide layer grows rapidly on the surface when it exposed to air. Hence, prior to the metal deposition, the n-type GaN film was cleaned by aqua regia solution to remove the native oxide on the surface. Pt contacts with thickness of about 150nm are first deposited on the samples by using sputtering system. To study the thermal annealing effects of Pt contacts on n-type GaN, samples were annealed in N_2 atmosphere at temperature of 200^{o}C, 400 ^{o}C, 600 ^{o}C, 800 ^{o}C for 30 min in tube furnace. The current-voltage (*I-V)* measurements were performed with a Kiethley High-voltage-source-measure-unit model 237. Scanning electron microscopy (SEM) was employed to investigate the surface morphology of the sample.

3. Results and discussion

Fig. 1 shows the I-V characteristics for Pt Schottky contacts on n-GaN. As-deposited, Pt contact shows ohmic characteristic, however after annealing at 200^{o}C, a Schottky behavior is observed. The metal contacts become more rectifying with increase in the annealing temperature.

The electrical parameters, i.e., Schottky barrier heights (SBHs), Φ_B, saturation current, I_o, and ideality factor, η can be determined from the I-V measurements. For thermionic emission and $V > 3kT/q$, the general diode equations are [14]:

$$I = I_o exp\{qV/(\eta kT)\} \qquad (1)$$

$$I_o = AA^*T^2 exp\{-q\Phi_B/(kT)\} \qquad (2)$$

Where I_o is the saturation current density, η is the ideality factor, q is the electron charge, k is Boltzmann's constant, T is the absolute temperature, A^* is the effective Richardson coefficient, A is the contact area, and Φ_B is the barrier height. The theoretical value of A^* can calculated using

$$A^* = 4\pi m^* q k^2/h^3 \qquad (3)$$

where h is plank's constant. For n-type GaN, $m^* = 0.20m_o$ is the effective electron mass for GaN and the value of A^* is determined to be 26.4 $Acm^{-2}K^{-2}$ [15].

The extrapolated value of current to zero voltage for the straight line portion of the plot of ln*I* vs *V* gives the saturation current I_o and give a straight line with a slope of $q/(\eta kT)$. The barrier height of the Schottky contact was determined from the Eq. (2).

For sample involving two Schottky contacts, representing two diodes connected back-to-back, the I-V characteristics of the Schottky contact are more appropriate to be analyzed in the more general form of equation, where it can be used under reverse bias conditions [16,17]

$$I = I_o exp\{qV/(\eta kT)\}[1-exp\{-qV/(kT)\}] \qquad (4)$$

The equation can be written as

$$\frac{I\exp(qV/kT)}{\exp(qV/kT)-1} = I_o\exp(qV/\eta kT) \qquad (5)$$

The y-intercept of a linear curve fits yields the saturation current, I_o which is then plotted as $ln\{Iexp\{qV/kT\}/[exp\{qV/kT\}-1]\}$ versus V. From this plot, Φ_B the barrier height can be extracted by using Eq. (2).

The results of the Schottky barrier height and ideality factor of the Pt Schottky contacts at different annealing temperatures are summarized in Table 1. It can be seen clearly from Table 1 that the ideality factor and Schottky barrier height of the samples change with annealing temperature. A slight increase of Schottky barrier height of Pt contacts were observed for 400°C annealed and increased greatly after annealing above 800°C. At 800°C annealing temperature, the Schottky barrier height and the ideality factor of the Pt contact are 1.107 eV and 1.234 eV respectively. The increase of the Schottky barrier height can be correlated with the reduction of nonstoichiometric defects in the metallurgical interface [18,19].

Table 1 The comparison of SBH and ideality factor of Pt Scottky contact for various annealing temperature and duration

Sample	Annealing temperature	Schottky barrier height (eV)	Ideality factor,n
1	As deposited	N.A	N.A
2	200°C	0.451	1.030
3	400°C	0.677	1.050
4	600°C	0.876	1.156
5	800°C	1.107	1.234

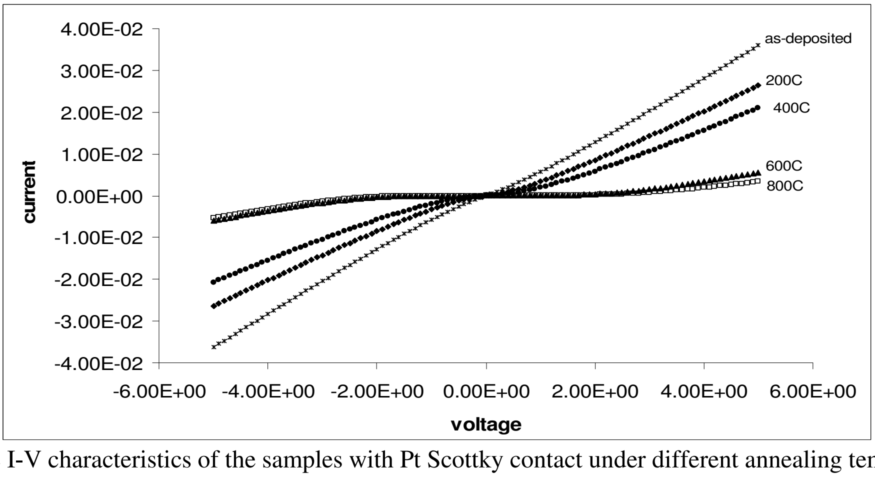
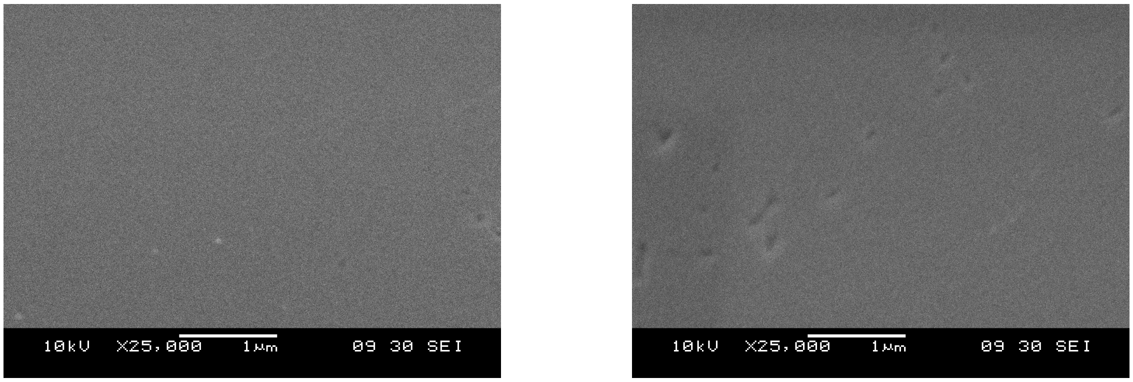
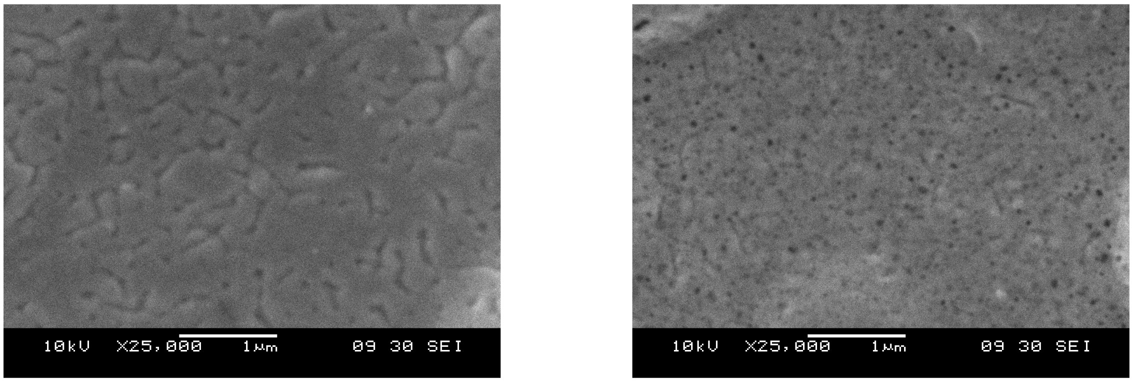


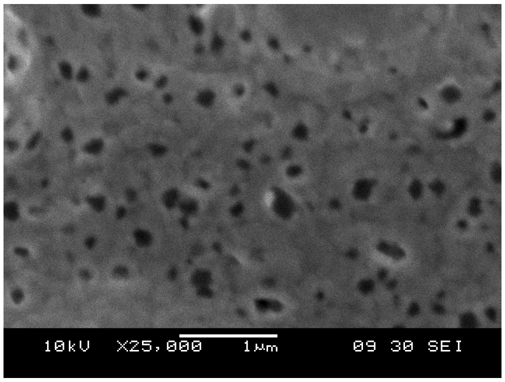
Fig. 1. The I-V characteristics of the samples with Pt Scottky contact under different annealing temperatures.



(a) as grown (b) 200^{o}C



(c) 400^{o}C (d) 600^{o}C



(e) 800^{o}C

Fig. 2. SEM observation of the metal surfaces after annealing at different temperatures.

The morphology of the surface of Pt contacts after annealing was observed by using SEM. The results of SEM are shown in Fig. 2. As seen in the figure, the as-deposited and annealed samples (200^{o}C) show a smooth and featureless surface. However, the rough surfaces were observed at annealing temperature of 400^{o}C. Increasing the annealing temperature at 600^{o}C brings more dramatic changes. The rough surfaces become more obvious. When the annealing temperature reached 800^{o}C, the particles of Pt become larger and reveal dark areas of the surface. Metal island formation was observed at high temperatures. Island formation during the high annealing of thin metal contacts on n-GaN is due to the difference of surface energies between thin metal films and GaN that causes dewetting [20].

4. Conclusion

Thermal annealing effects of Pt Schottky contact on n-GaN were studied by annealing samples in N_2 ambience for 30 min at various temperatures. The Schottky barrier height and the surface of Pt contact change with various annealing temperatures. The behavior of Pt on n-GaN shows that they are suitable Schottky contacts at temperature as high as 800^{o}C.

Acknowledgement

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