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COMMUNICATIONS

EFFECT OF ANNEALING ON ELECTRICAL CHARACTERISTICS OF PLATINUM BASED SCHOTTKY CONTACTS TO N–GaN LAYERS

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The wide-bandgap GaN and related materials have been extensively studied for optoelectronic and high-temperature/high power electronic device applications. The key to the advancement of such devices is the understanding of Schottky contacts formation to epitaxial gallium nitride layers.

The paper presents the investigation of Au/Pt/Ti based Schottky contact to n-GaN layers grown by MOVPE technique. Multilayer metallization of Au/Pt/Ti with thicknesses 50/300/1500 A respectively, were evaporated by an electron gun.

The contacts were annealed at RTA (Rapid Thermal Annealing) system in the mixture of hydrogen/nitrogen (1:10) gases over the temperature range from 200C to 700C. The time of annealing process was 20 seconds. The electrical characteristics of gold/platinum/titanium Schottky contacts to n-GaN MOVPE epitaxial layer were studied as a function of the annealing process conditions by current-voltage (I-V) method on dedicated test structures. The barrier heights of the Au/Pt/Ti/n-GaN Schottky junctions were evaluated. The formation and deterioration mechanisms of the Schottky contacts to n-GaN layer were studied.

K e y w o r d s: Schottky barrier height, Au/Pt/Ti Schottky contact, gallium nitride

1 INTRODUCTION

The wide-bandgap GaN and related materials are thermally stable and have been extensively studied for optoelectronic and high-temperature/high power/high frequency electronic devices applications. GaN and its alloys are very promising semiconductor materials also for ultraviolet lasers and photodetectors, light emitting diodes and field effect transistors [1, 2]. Many efforts have been dedicated to the development of fabrication processes of nitrides devices. Wide-bandgap semiconductors could withstand the harsh environment and high temperature. GaN devices could found many applications such as: military, aerospace, automotive, petroleum, engine monitoring, flame detection and solar UV detection [3, 4]. Thermally stable ohmic and Schottky contacts are required in order to continue the improvement of performance of these devices.

Many studies of materials for Schottky contacts to GaN have already been reported, *eg* Au [5], Pd [6], Pt [7], Ni [8], Re [9], Ir [10]. In this paper we present results of measurements of fabricated multilayered Au/Pt/Ti Schottky contact to n-type epitaxial GaN layers.

2 EXPERIMENTAL DETAILS

The GaN layer applied in this study was grown by metalorganic vapour phase epitaxy (MOVPE) on sapphire substrate. Prior to metal deposition, the Ga_2O_3 oxide was removed by applying the $HCl : H_2O$ (1:1) solution, followed by a deionised water rinsing and drying in N_2 flow. The samples were immediately loaded into the vacuum chamber of the evaporation system. The metals stuck and the layers thicknesses of the Au/Pt/Ti multilayer of Schottky contact were selected on the basis of authors previous study. The metallic contact consisting of Ti (50 Å)/Pt (300 Å)/Au (1500 Å) was deposited in sequence on the substrate under a vacuum conditions with a base pressure lower than 10^{-6} mbar. The Ti and Pt layers were deposited by using an electron beam evaporator and Au metallic layer by resistance evaporator. The diameter of the Schottky contact was 2 mm. The Ti layer was introduced to improve the adhesion of the contact to gallium nitride layers, while the Au layer allowed us to reduce the contact resistance. The Pt layer diffused into the semiconductor during annealing step and formed the Schottky contact. The influence of annealing process on the contact properties was studied. The Ti/Pt/Au multilayer Schottky metallization were annealed at various temperatures in rapid thermal annealing (RTA) system in mixture of hydrogen/nitrogen (1:10) gases. The temperature and duration of each annealing process were changed over the range from 200 °C to 750 °C. The annealing time of 20 seconds was selected on the basis of our previous study as the optimal one. The characteristics of Schottky metallization were measured by I–V method.

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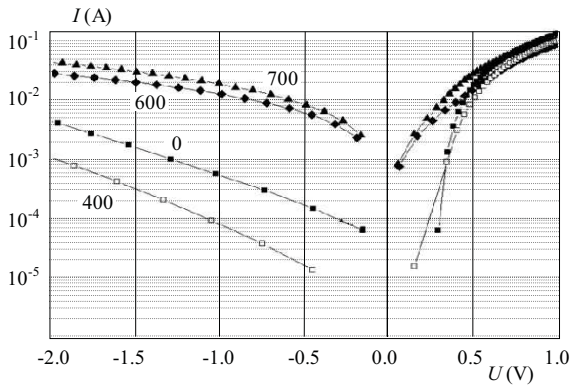

Fig. 1. The I–V characteristics for the Ti/Pt/Au Schottky contact on n-type GaN as a function of annealing temperature.

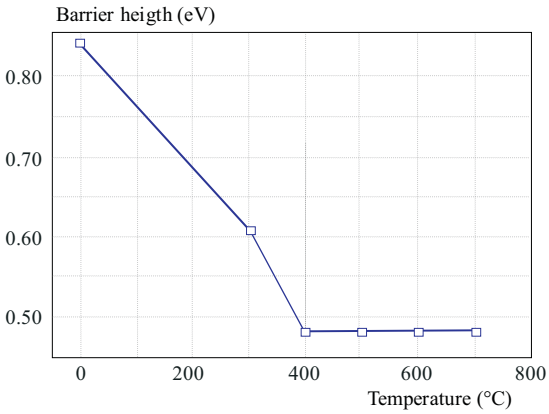

Fig. 2. Plot of barrier heights of Au/Ti/Pt/n-GaN as a function of annealing temperatures.

3 RESULTS AND DISCUSSION

Figure 1 shows the forward and reverse I–V characteristics of Au/Pt/Ti/n-GaN Schottky contacts measured as a function of annealing temperature. It was found that the metallization annealed at temperature above 400 °C revealed fairly large leakage currents.

The leakage current value at -2 V was $4 \times 10^{-3} A$ for the as-deposited structures, whereas structure annealed at 600 °C and 700 °C rectifying metallization leakage currents at -2 V were 0.025 and 0.03 A respectively. The smallest value of leakage current 1.2×10^{-3} A was observed for multilayer metalization annealed at 400 °C. We supposed that at this temperature the diffusion of platinum atoms to gallium nitride surface occurred. It was also observed that the reverse leakage current was increased with the increasing of annealing temperature.

The barrier height is most commonly calculated from the saturation current I_S of I–V characteristic of the Schottky contact, which can be determinate by extrapolating the semilog I versus V curve to $V = 0$. The barrier height Φ_B is calculated from equation (1) as follows

$$\Phi_B = \frac{kT}{q} \ln \frac{AA^* T^2}{I_S} \tag{1}$$

where I_S is the saturation current, q the electron charge, V the applied voltage, A^* the effective Richardson constant, and Φ_B the Schottky barrier height. The value of Φ_B can be deduced directly from the I–V curves if the effective Richardson constant, A^* is known. The theoretical value of A^* is $26.4\,\mathrm{Acm^{-2}K^{-2}}$, evaluated on the basis of the effective mass $m^* = 0.22\,m_0$ of n-GaN [11], was applied to deduce Φ_B. Calculations showed that the Schottky barrier height was 0.84 eV for the as-deposited contact, and 0.61 eV for sample annealed at 300 °C, and 0.48 eV at 400, 500, 600 and 700 °C.

Table 1 shows the values of Schottky barrier height evaluated for Au/Pt/Ti/n-GaN Schottky metallization after annealing in various temperatures. The time of annealing process was 20 seconds. It can be seen that the barrier height of the diode decreases upon annealing temperature extension. Figure 2 shows a plot of barrier heights of multilayer metalization Au/Pt/Ti deposited on n-GaN layers as a function of annealing temperatures.

Table 1. Schottky barrier heights for as-deposited and annealed in various temperatures contacts

Annealing temperature (°C)	Saturation Current I_0 (A)	Schottky barrier height (eV)
as-deposited	1E-10	0.84
300	1.1E-6	0.61
400	1.8E-4	0.48
500	1.5E-4	0.48
600	1.5E-4	0.48
700	1.5E-4	0.48

For the contact annealed at 300 °C, the barrier height was high compared to the barrier height of the contact annealed at 400 °C and higher temperatures. The reverse leakage current increasing for the contact annealed at temperatures above 400 °C.

The reaction of the multilayer metallization with n-GaN surface was not observed after contacts annealing at 400 °C. The metallization morphology was not changed. The decrease of the barrier height with the increasing of temperature of annealing has been also reported previously [12].

According to Duboz *et al* [12] the lower value of the barrier height for sample annealed at higher temperature (in our case at temperatures over 400 °C) can be attributed to reduction in the density of interfacial defects. Also, the scientists have found that the Fermi level at metal/GaN interfaces is pinned by defects. The modification of the defects density by annealing could change the pinning at the Fermi level what could resulted in change of the barrier height.

4 SUMMARY

We have fabricated Au/Pt/Ti Schottky contacts to n-GaN. The electrical characteristics of the metallization

were evaluated by $I-V$ techniques as a function of annealing temperature of the contact formation. The barrier height of the as-deposited Schottky diode was found to be 0.84 eV. The barrier height decreased to 0.61 eV when the contact annealing was performed at 300 °C for 20 seconds, and to 0.48 eV after annealing at the temperature range from 400 °C to 700 °C.

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References

[1] AMANO, H.—KITO, M.—HIRAMATSU, K.—AKASAK, I.: P-Type Conduction in Mg-Doped GaN Treated with Low-Energy Electron Beam Irradiation (LEEBI), Jpn. J. Appl. Phys. 28 No. 12 (1989), L2112–L2114.

[2] NAKAMURA, S.—MUKAI, T.—SENOH, M.: Candela-Class High-Brightness InGaN/AlGaN Double-Heterostructure Blue-Light-Emitting Diodes, Appl. Phys. Lett. **64** No. 13 (1994), 1687–1689.

[3] FERGUSON, I.—TRAN, C. A.—KARLICEK, R. F.—FENG, Z. C.—STALL, R.—LIANG, S. GaN and AlGaN MetalSemiConductorMetal Photodetectors: Mater. Sci. Eng. B **50** (1997), 311–314.

[4] WALKER, D.—ZHANG, X.—KUNG, P.—SAXLER, A.—JAVADPOUR, S.—XU, J.—RAZEGHI, M.: AlGaN Ultraviolet Photoconductors Grown on Sapphire, Appl. Phys. Lett. **68** No. 15 (1996), 2100-2101.

[5] KRIBES, Y.—HARRISON, I.—TUCK, B.—CHENG, T. S.—FOXON, C. T.: Investigation of Au Schottky Contacts on GaN Grown by Molecular Beam Epitaxy, Semicond. Sci. Technol. **12** No. 7 (1997), 913–916.

[6] WANG, L.—NATHAN, M. I.—LIM, T.-H.—KHAN, M. A.—CHEN, Q.: High Barrier Height GaN Schottky Diodes: Pt/GaN and Pd/GaN, Applied Physics Letters **68** (1996), 1267–1269.

[7] SUZUE, K.—MOHAMMAD, S. N.—FAN, Z. F.—KIM, W.—AKTAS, O.—AKTAS, A.—BOTCHKAREY, E.—MORKOC, H.: Electrical Conduction in PlatinumGallium Nitride Schottky Diodes, J. Appl. Phys. **80** (1996), 4467.

[8] ZHANG, B. J.—EGAWA, T.—ZHAO, G. Y.—ISHIKAWA, H.—UMENO, M.: Schottky Diodes of Ni/Au on n-GaN Grown on Sapphire and SiC Substrates, Appl. Phys. Lett. **79** No. 16 (2001), 2567–2569.

[9] VENUGOPALAN, H. S.—MOHNEY, S. E.: Thermally Stable Rhenium Schottky Contacts to n-GaN, Appl. Phys. Lett. **73** (1998), 1242–1244.

[10] JEON, C. M.—JANG, H. W.—LEE, J-L.: Thermally Stable Ir Schottky Contact on AlGaN/GaN Heterostructure, Appl. Phys. Lett **82** (2003), 391–393.

[11] DRECHSLER, M.—HOFMAN, D. M.—MEYER, B. K.—DETCHPROHM, T.—AMANO, H.—AKASAKI, I.: Determination of the Conduction Band Electron Effective Mass in Hexagonal GaN, Jpn. J. Appl. Phys. **34** No. 9B (1995), L1178–1179.

[12] DUBOZ, J. Y.—BINET, F.—LAURENT, N.—ROSENCHER, E.—SCHOLZ, F.—HARLE, V.—BRIOT, O.—GIL, B.—AULOMBARD, R. L.: Influence of Surface Defects on the Characteristics of GaN Schottky Diodes, Mater. Res. Soc, Symp. Proc. **449** (1996), 1085–1091.

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