Effects of thermal annealing of Pt Schottky contacts on quaternary n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film

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Schottky behavior of Pt contacts on nanostructure $Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film grown by molecular beam epitaxy (MBE) technique on sapphire substrate were investigated extensively at annealing temperatures range of 300-600 ºC. The temperature dependence and structural properties of the Schottky barrier heights (SBH) of Pt contacts were characterized using X-ray diffraction (XRD), atomic force microscopy (AFM) and current-voltage (I-V) measurements. XRD result showed there is no phase change observed on Pt contact with change the annealing temperature. The temperature dependence of the SBH is attributed to the change of the surface morphology of Pt films and variation of the interface of the samples. The results revealed that the high quality Schottky contact with a SBH and ideality factor of 0.76 and 1.03 respectively can be obtained under 30 minutes annealing at 400 ºC in N_2 ambience.

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1. Introduction

Group III-nitride semiconductors, particularly AlInGaN received a great deal of attention in the past decade due to its possible integration with current electronic and optoelectronic devices [1]. These materials have wide band gap, high breakdown field, and high electron saturation velocity which make it an attractive candidate for the development of electronic devices operation at high temperature, high power and high frequency [2].

There are many reports regarding the effect of the thermal annealing of Pt contact on binary GaN and ternary AlGaN [3-5]. However, the literature on Pt contacts to n-GaN is very limited and there are no reports regarding study of thermal annealing effect on quaternary AlInGaN.

Several research groups reported the use of metal contact such as Pt contact on GaN [3] to investigate the temperature-dependence of Schottky diodes. They attributed the SBH dependent on temperature to the changes of surface morphology of Pt films on the n-GaN [4]. Yu et al. investigated Ir/Pt contact electrode to GaN and reported a barrier height of 0.79 eV [5]. The thermally treated Nickel (Ni) contact on GaN-based UV photodetectors was studied by Lee et al. (2005). [6]

The choice of Pt contact in this work is based on its high work function (about 5.65 eV) and high resistance to oxidation and corrosion. As far as our acknowledge is concern, this paper is the first report on the effects of thermal annealing of Pt Schottky contacts on n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ grown on sapphire substrate.

2. Experiments part

Nanostructure $Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film with thickness of 100 nm grown by using molecular beam epitaxy (MBE) on sapphire substrate was employed. RCA cleaning method carried out at room temperature before any fabrication process to remove any contaminations on the wafers such as thin oxide or residual organic residues. The procedure includes using $NH_4OH:H_2O=1:50$ solution for 10 minutes, then washed with deionised water. Subsequently, the samples were dipped into HF: $H_2O=1:50$ for 10 seconds then, washed again with deionised water. The cleaned sample was then chemically etched in boiling aqua regia of HCl: HNO3=3:1 for 10 minutes to reduce the amount of oxygen and carbon contamination of quaternary AlInGaN surface. Wafer was then blown dry with compressed air after cleaning.

Then, Schottky metals contact were deposited on n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ films using suitable metal mask with thickness of 250 nm and target purity of 99.99% using Edwards A500 RF-sputtering system. I-V characteristics were carried out on n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film which grown on sapphire substrate using LIV characteristic system Model optronic spectroradiometer Lab OL 770-LED, and then the Schottky barrier heights (SBH) calculated for these samples.

Fig. 1 shows the schematic diagram of Pt contacts on n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film grown on sapphire (Al_2O_3) substrate.

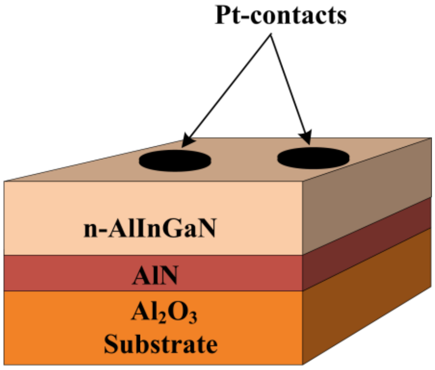

Fig. 1. Pt contacts on n-$Al_xIn_yGa_{1-x-y}N$ film grown on sapphire substrate.

High resolution X-ray diffraction (HRXRD) PANalytical X' pert Pro MRD with a Cu-kα_1 radiation source of wavelength equal to 1.5406 Å has been used to indentify, structures, and crystalline quality for the samples.

3. Results and discussions

Fig. 2 shows the 2θ XRD spectrum of Pt contact on n-$Al_xIn_yGa_{1-x-y}N$ thin film grown on sapphire substrate after annealing treatment at 400 °C for 30 minutes respectively. The results peaks related to quaternary AlInGaN (0002) and buffer layer AlN (0002) at 34.5° and 36°, respectively, while peaks of Pt (111), Pt (200) and Pt (220) are at 40°, 44.5°, and 64.8°, respectively.

In spite of the various annealing temperature ranged 300- 600 °C however, there is no new phases observed therefore the spectrum of annealing treatment at 400 °C only included. These results confirm that the high quality of Pt contacts on the quaternary n-$Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film, as shown by the values of their grain size d, which are summarized in Table 1.

Fig. 3 shows the AFM measurement of the sample as which at annealing temperature of 400 °C, the high root mean square (RMS) and better surface morphology was obviously obtained which indicates that the surface morphology of the sample has been enhanced.

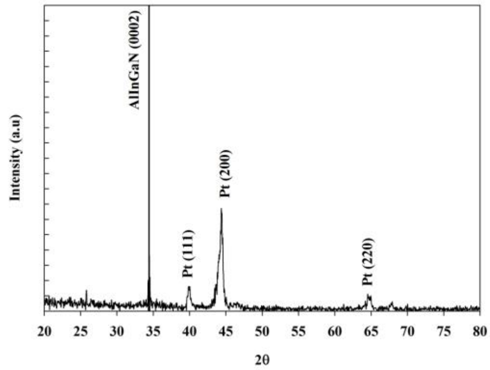

Fig. 2. The 2θ XRD spectrum of Pt Schottky contact on quaternary n-$Al_xIn_yGa_{1-x-y}N$ thin film grown on sapphire substrate at annealing temperatures of 400 °C.

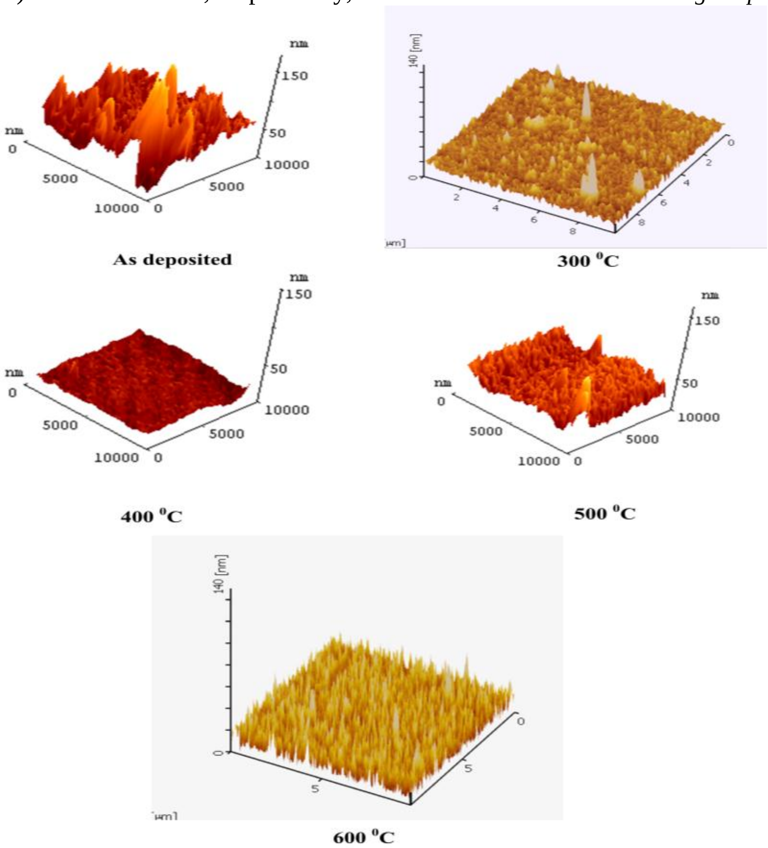

Fig. 3. AFM measurement of Pt Schottky contact on quaternary n- $Al_{0.08}In_{0.08}Ga_{0.84}N$ film grown on sapphire substrate under different annealing temperatures.

This may attribute to oxide free and the rearrangement of the Pt atoms with the increasing of temperature until 400 ºC which lead to create good metal-semiconductor interface. In addition, the annealing at 400 ºC minimizes the effect of compressive stress and strain induced in the metal-semiconductor contact resulting from the normal heating process [6]. While, a high temperature annealing treatment leads to the degradation of the metal–semiconductor contacts.The root mean square (RMS) gives an idea of the surface morphology and its values summarized in Table 1.

Table 1. Grain size, RMS, SBH, and ideality factor n for Pt contact on $Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film.

Sample	d (nm)	RMS (nm)	SBH (eV)	n
As-deposited	27	12	0.67	1.38
300	11	3.8	0.65	1.4
400	8	18	0.76	1.03
500	22	7	0.69	1.48
600	-	4.8	0.66	1.51

Fig. 4 shows the I-V characteristics of Pt Schottky contacts measured as a function of annealing temperature. It is observed that the properties of all Pt Schottky contact are uniform over different temperatures. The I-V characteristics were analyzed using standard thermionic emission relation for electron transport from a metal-semiconductor given by [7] as

$$I_d = I_s \exp\left(\frac{qV_d}{nkT}\right)\left[1-\exp\left(\frac{-qV_d}{kT}\right)\right] \qquad (1)$$

where V_d is the voltage across the diode $V_d=V-IR$, R is the series resistance, n is the ideality factor and I_s is the saturation current given by

$$I_s = AA^{**}T^2 \exp\left(\frac{-q\phi_b}{kT}\right) \qquad (2)$$

where A^{**}, A and $Ø_b$ are the effective Richardson constant, the area of the diode and the Schottky barrier height respectively. The value of SBH can be deduced directly from the I–V curves if the effective Richardson constant is known. The theoretical value of this factor is 25 A cm^{-2} K^{-2} based on the effective masses $m^*=0.2\ m_o$ for GaN, $m^*=0.11\ m_o$ for InN and $m^*=0.4\ m_o$ for AlN [7, 8], and is used here to deduce $Ø_b$ from Eq. (1). A plot of $ln\ \{I_d/\ [1-exp\ (-qV/KT)]\}$ versus V_d yields I_s as the intercept and once it is determined the barrier height $Ø_b$ is estimated from it.

Calculations for sample annealed at 400 ^{0}C yield that the SBH and ideality factor (n) at the Pt/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ interface was 0.76 eV and 1.03 which has been shown that a high barrier height of Pt contact occurred. This means a contact which can produce good electrical conductivity and a high work function.

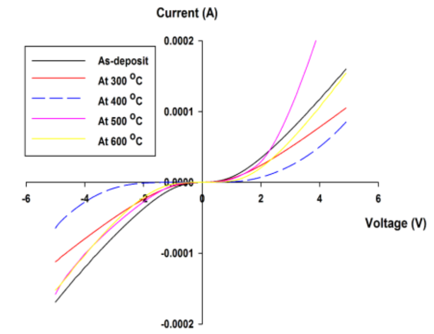

Fig. 4. I-V measurement of various annealing temperature of Pt Schottky contacts deposited on quaternary $Al_{0.08}In_{0.08}Ga_{0.84}N$ thin film grown on sapphire substrate.

4. Conclusions

The application of thermal annealing treatment to Pt/ $Al_{0.08}In_{0.08}Ga_{0.84}N$ metal-semiconductor contact at various annealing temperatures (300-600 ºC) was investigated. High root mean square (RMS), better surface morphology and high Schottky barrier heights have been obtained for Pt/$Al_{0.08}In_{0.08}Ga_{0.84}N$ contacts annealed at 400 ^{o}C. This relatively high temperature makes the samples is promising to optoelectronic devices operating in this temperature. High temperature annealing treatment leads to the degradation of the metal-semiconductor contacts therefore, it is not recommended.

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