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# *Determination of Ohmic Contact Porosity*

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## *Abstract*

*Ti/Al and Ti/Al/Ni/Au ohmic contacts were deposited by electron beam evaporator on n type GaN and characterized by employing Scanning Electron Microscope. Effect of annealing temperature on the surface morphology of Ti/Al/Ni/Au and Ti/Al ohmic contacts were studied. Image processing techniques were used to study the surface morphology of Ti/Al/Ni/Au and Ti/Al ohmic contacts. Images were preprocessed before finding porosity. Using the MATLAB software, the porosity in the ohmic contact structures was found. The quantitative results were related to the fabrication process.*

***Keywords:*** *Anneal, GaN, ohmic contact, porosity*

## I. INTRODUCTION

GaN based technology is attractive for harsh environment operation because of its physical and chemical stability. GaN-based devices such as diodes, transistors and metal oxide semiconductor field effect transistors are used for many high temperature/high power electronics [1,2]. So, the formation of thermally and electrically stable ohmic contact to the GaN devices plays a crucial role in the multitude of the device performance. Many alloyed and non-alloyed ohmic contact metallization schemes to n-GaN have been reported [3-17]. The conventional rapid thermal annealing (RTA) process after metal evaporation is essential to achieve high quality ohmic contact with low contact resistance and smooth surface morphology for device reliability. This RTA process causes surface roughness due to alloy aggregation under high temperature atmosphere. In this work, the Scanning Electron Microscope (SEM) images of annealed Ti/Al and Ti/Al/Ni/Au ohmic contacts were used to study the metal contacts to n-GaN layer using image processing techniques.

The effect of temperature on the surface morphology of ohmic contacts were studied. Adaptive Wiener filter was used for filtering the ohmic contact images. The porosity in the Ti/Al and Ti/Al/Ni/Au ohmic contacts were obtained using the algorithm.

## 2. IMAGE PROCESSING TECHNIQUES ON OHMIC CONTACT SURFACE

Figure 1 shows the flowchart for finding porosity of ohmic contact surface on GaN. Image acquisition was done using SEM. As porosity is based on minute pores of nano sizes on surface, one has to carefully select filter. Adaptive Wiener filter was used to remove noise from the ohmic contact image [18].. Using the algorithm, the porosity of the structures was computed.

## 3. EXPERIMENTAL WORK

The experimental procedure consists of three important steps: the fabrication of ohmic contact structures, the characterization of the structures using the SEM and analysis of the images through the extraction of the more accurate morphology of the structures.

### *3.1 Fabrication Procedure*

A doped n-type (ND + approximately 3x1018 cm -3 by Hall measurement) GaN layer of 5 µm grown by HVPE on c-plane sapphire substrate was used for the experiment. Prior to metal deposition, a sample was cleaned in trichloroethylene (TCE) to degrease and then treated using acetone for further cleaning. The sample was then immersed in isopropyl alcohol (IPA) for complete removal of organic solvents. The sample was then well rinsed in deionized water (DI) and ready for removal of ionic contaminants and native oxide.

The sample was then immersed in an equally proportioned solution of dilute HCl in deionized water. After this treatment for 5 minutes, the sample was rinsed again in DI water and blow dried using N2 gas. The electron beam (e-beam) evaporator was evacuated to a base pressure of about 5x10-6 mbar prior to deposition.

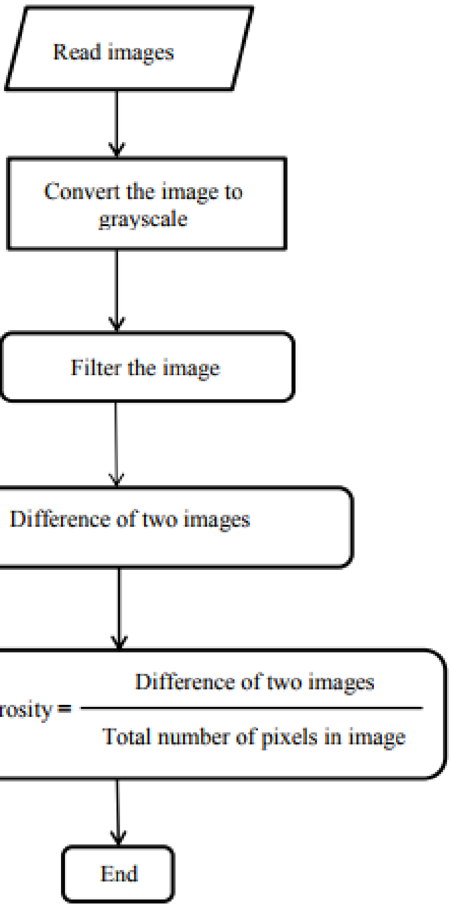


*Figure 1 Flowchart of the MATLAB program*

The composite metal layers were Ti/Al(20 nm/100 nm) and Ti/Al/Ni/Au (20 nm/100 nm/20 nm/100 nm). ºC. The metal contacts were fabricated with standard photolithographic technique with a positive photoresist. The metal lift off was followed by a Rapid Thermal Anneal (RTA) in a N2 ambient. The Ti/Al ohmic contact samples were annealed at 600ºC, 700ºC, 800ºC and 900ºC in an RTA furnace for 1 min in a N2 ambient. The Ti/Al/Ni/Au ohmic metallization samples were annealed at 750ºC, 800ºC, 850ºC, and 900ºC in an RTA furnace for 1 min in a N2 ambient. The influence of the annealing process on the surface morphology of Ti/Al and Ti/Al/Ni/Au ohmic contacts to GaN were examined with the use of a SEM.

### *3.2 Analysis of SEM images using image processing techniques*

SEM image is saved as JPEG format. Later image is input into MATLAB environment using imread function. Images are converted into grayscale for thresholding. The Adaptive Wiener filter was applied on 8 images of Ti/Al and Ti/Al/Ni/Au materials, where four images of each material were taken at different temperature.

## 4. RESULTS AND DISCUSSION

Figure 2 shows the I-V characteristics of Ti/Al contact annealed at different temperatures: as-deposited, 600°C, 700°C, 800°C and 900°C.

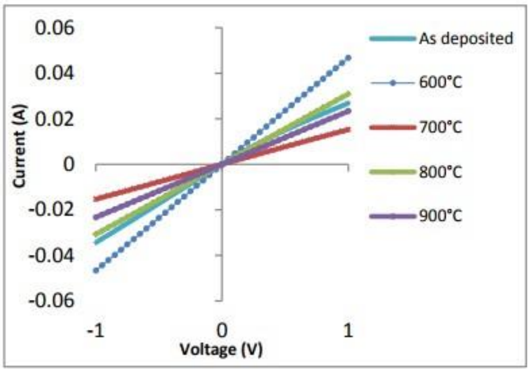


***Figure 2 I-V characteristics of Ti(20 nm)/Al(100 nm) contacts on n-GaN as deposited and after annealing at different temperatures***

Figure 3 shows the I-V characteristics of Ti/Al/Ni/Au contact annealed at different temperatures: as-deposited, 750°C, 800°C, 850°C and 900°C. It is shown that the Ti/Al and Ti/Al/Ni/Au contacts in figures 2 and 3, respectively exhibit ohmic in their as deposited condition. It is noteworthy that the Ti/Al/Ni/Au contacts show better electrical properties than the Ti/Al contacts. All of the contacts showed ohmic characteristics after annealing.

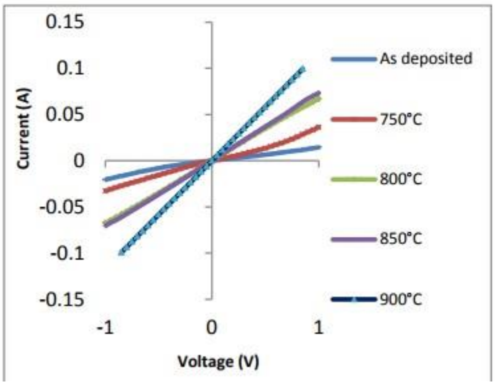


***Figure 3 I-V characteristics of Ti (20 nm)/Al (100 nm)/Ni (20 nm)/Au (100 nm) contacts on n-GaN as deposited and after annealing at different temperatures***

Due to an increase in thermal interdiffusion at the interface between the deposited metals and GaN, there is a decrease in the contact resistance with increasing annealing temperature. After annealing the resistivity of both the Ti/Al and Ti/Al/Ni/Au contacts decreases. The possible cause for decrease in the resistivity is due to the formation of a TiN layer on the GaN surface and associated with its growth, an excess of N vacancies near the TiN-GaN interface. The specific contact resistance was determined from plots of the measured resistance versus the spacing between the CTLM pads. Measurements showed that the specific contact resistances of Ti/Al after anneal

(600 to 900°C) varied in the range of 2x10-4 to 8x10-4 Ω cm2 .

Other research group has also observed similar specific contact resistances for Ti/Al contact [19]. The lowest specific contact resistance was obtained at 600°C. The variation in the contact resistance with increasing annealing temperature is believed to be from an increase in thermal interdiffusion at the interface between the deposited metals and GaN. Measurements showed that the specific contact resistance of Ti/Al/Ni/Au ohmic contact after anneal (750°C to 900°C) varied in the range of 2x10-5 to 8x10-5 Ω cm2 .

Other research groups have also observed similar specific contact resistances for Ti/Al/Ni/Au contact -0.15 -0.1 -0.05 0 0.05 0.1 0.15 -1 0 1 Current (A) Voltage (V) As deposited 750°C 800°C 850°C 900°C [19-21]. It is noteworthy that the Ti/Al/Ni/Au contact show better electrical properties than the Ti/Al contacts.

### *4.1 Ti/Al and Ti/Al/Ni/Au ohmic contacts*

Figure 4 shows the top view SEM images of surface morphology of the Ti/Al ohmic contact after annealing at various temperatures 600ºC, 700ºC, 800ºC and 900ºC for 60s.

Figure 5 shows the top view SEM images of surface morphology of the Ti/Al/Ni/Au ohmic contact after thermal annealing at various temperatures for 60s. An increase in annealing temperature resulted in the decrease in the density of agglomerates and leads to metal interdiffusion and alloying. The sample images studied were of the same magnification (5000). The porosity of all these images are computed for a set of Ti/Al and Ti/Al/Ni/Au ohmic contact annealed at different temperatures.

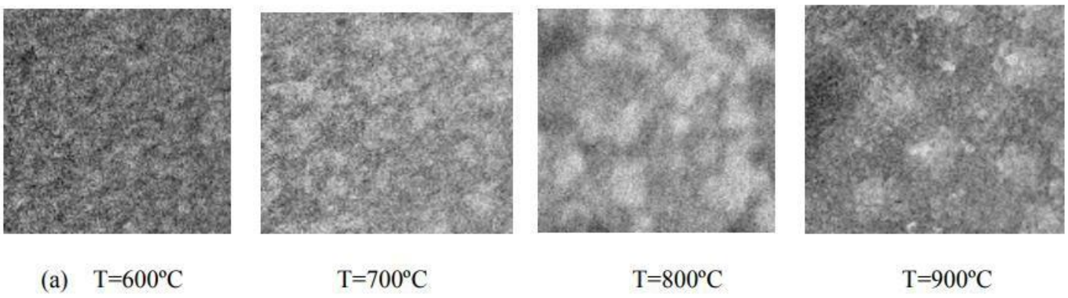


***Figure.4. SEM images of the ohmic contact Ti/Al after thermal annealing at various temperatures for 60s***

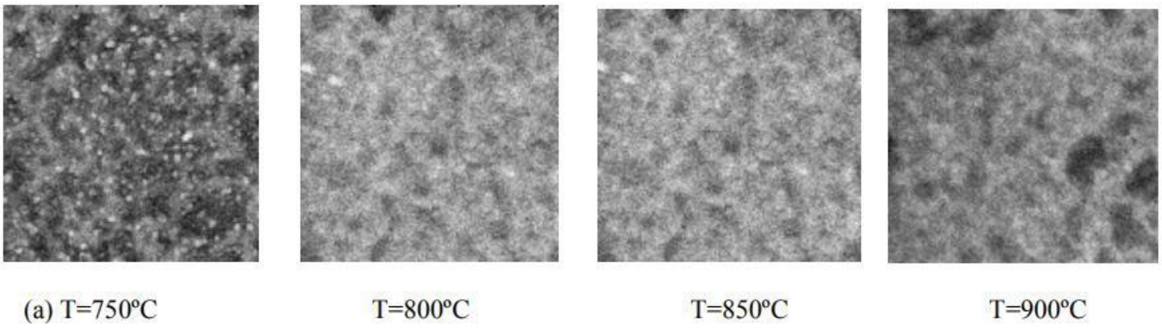


***Figure 5 SEM images of the ohmic contact Ti/Al/Ni/Au after thermal annealing at various temperatures for 60s***

The grains agglomeration appeared at 750ºC to 900ºC in steps of 50ºC, the agglomerates migrated on the surface and coalescence into larger agglomerates. Thus, the thermal annealing process significantly changes the morphology of the ohmic contact and influences the chemical composition of the surface of both Ti/Al and Ti/Al/Ni/Au contacts.

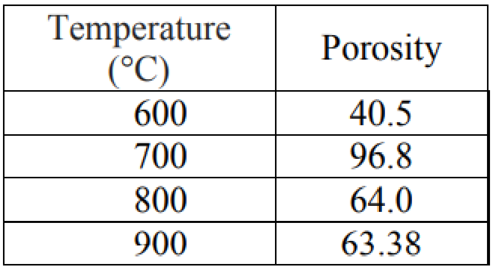
As shown in figures 4 and 5, the surface of the ohmic contacts gets quite rough due to many grooves produced on the surface after annealing at high temperature.

### *4.2 Determination of Ohmic contact porosity on n-GaN using image processing method*

The surface study of Ti/Al and Ti/Al/Ni/Au films deposited by electron beam evaporation on n type GaN were characterized by employing SEM. SEM images of the ohmic contacts were used to determine the porosity. Then various segmentation techniques were used to distinguish pores on the surface image.

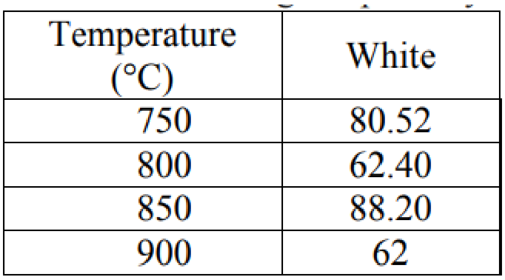
Porosity is defined as the fraction of the bulk sample area A that is not occupied by solid matter. If the area of the solids is denoted by As, and the pore area as Ap= A - As, then porosity = (Ap/A). The pores are in black and the surface of the thin film is in white. The analysis of the binarized image is based on the digitalization of each pore of the thin film surface followed by the measurement of the pore area. The major effects of annealing process are to promote recrystallization leading to grain growth and grain boundary passivation. The effect of annealing under different temperature on the distribution of these thin films pores and the percentage porosity of the white and black pores are as shown in the tables 1 and 2 for Ti/Al and Ti/Al/Ni/Au ohmic contacts, respectively.

***Table 1 Percentage of porosity on Ti/Al ohmic contact***



| Temperature (°C) | Porosity |
|---|---|
| 600 | 40.5 |
| 700 | 96.8 |
| 800 | 64.0 |
| 900 | 63.38 |

***Table 2 Percentage of porosity on Ti/Al/Ni/Au ohmic contact***



| Temperature (°C) | White |
|---|---|
| 750 | 80.52 |
| 800 | 62.40 |
| 850 | 88.20 |
| 900 | 62 |

The porosity of white areas on the surface of Ti/Al film decreases as the annealing temperature increases and the black areas increases as the annealing temperature increases. The porosity of white areas on the surface of Ti/Al/Ni/Au film is highest at 800°C annealing temperature and the porosity of the black areas is lowest at 800°C. The proportion of porosity on the surface of ohmic contact varies with annealing temperature because the annealing works on recrystallized grains of the thin films so the white areas are less and which represents the surface of the ohmic contact. On the other hand, the black areas are growing which represent pores, cracks, and defects on the surface of the ohmic contact.

## CONCLUSION

Ti/Al and Ti/Al/Ni/Au ohmic contacts were deposited on n-type GaN and annealed at various temperatures for 60s have been compared in terms of specific contact resistance and surface morphology. The variations of PSNR of Ti/Al and Ti/Al/Ni/Au ohmic contacts versus annealing temperature for Disk, Gaussian, Motion, Average, Unsharp, Median, Max, Min and Adaptive Wiener in spatial filtering techniques were studied. Gaussian and Adaptive Wiener gives better PSNR for Ti/Al and Ti/Al/Ni/Au ohmic contacts. Adaptive Wiener gives better Temperature (°C) White 750 80.52 800 62.40 850 88.20 900 62 PSNR for Ti/Al/Ni/Au ohmic contact than Ti/Al ohmic contact. The proportion of porosity on the surface of Ti/Al and Ti/Al/Ni/Au films decreases as the annealing temperature increases because the annealing works on the recrystallized grains of the thin films. Thus Ti/Al/Ni/Au ohmic contacts may be preferred for high temperature and high power devices on GaN.

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