OHMIC CONTACTS PROPERTIES Pd/Ag METALLIZATION SCHEME ON P-TYPE GaN

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Abstract : In this work, we report on the characteristics of Pd/Ag metallization scheme deposited using thermal evaporation for the formation of ohmic contacts to p-type GaN. The electrical behavior and thermal stability at different annealing temperatures (400°C - 800°C) were investigated. Specific contact resistivity using transmission Line Method (TLM) and current voltage (I-V) measurements were investigated. The minimum specific contact resistivity of 3.9 Ωcm^2 achieved after annealing at 800°C for 6 minutes. Changes in the surface morphology of the contacts were observed using Scanning Electron Microscopy (SEM).

Keywords: Ohmic contact, Specific contact resistivity, Surface morphology, Transmission line method

INTRODUCTION

Studies of the development in GaN with the characteristics of direct wide bandgap of 3.4 eV have been continuously done in the recent years for the applications which involve short wave lengths optical devices and high power/ frequency/ temperature devices [1]. This includes visible and UV LEDs, laser diodes (LDs) and various field effect transistors (FETs) [2]. Contact technology remains a crucial factor for most electronic and optical devices in the field of wide band gap semiconductors. One of the key problems in GaN-based devices is a poor quality of ohmic contacts to p-GaN due to the difficulty in achieving high carrier concentration (~10^{18} cm^{-3} and above). The commonly adopted procedure for making ohmic contacts involves the use of suitable high work function metallization schemes.

It is imperative to obtain a low specific contact resistivity, ρ_c as ohmic contact plays a vital role in the device performance. Bi layered Ni/Au metallization schemes have been extensively used in the commercial blue and green light emitting diodes (LEDs) to obtain ohmic contacts to p-type GaN. However, various groups of researchers are still investigating on different methods in attempting to lower the specific contact resistivity which has a typical value of higher than 10^{-4} Ωcm^2 [3,4].

Only a few studies, however, have been reported for ohmic contacts on p-GaN. To obtain a low ohmic contact resistance, Trexler [5] et al used Ni/Au, Cr/Au and Pd/Au metallization schemes for p-GaN ohmic contacts. In their study, Ni/Au and Pd/Au showed rectifying characteristics irrespective of the thermal annealing treatment. Only Cr/Au metallization showed ohmic properties when the system was annealed.

The development and the fabrication of flip chip GaN based LEDs has prompted the search for high reflectivity metallization, in addition to stable, ohmic and low resistivity contact to GaN. There are few researches that use silver (Ag) as metal contact to p-GaN [6,7] although silver has good electrical resistivity ($1.59x10^{-6}$ Ωcm) and thermal conductivity (1 cal/cm-s-°C)[8]. Moreover, silver can form electrically superior contacts to p-GaN than Ni/Au and has higher reflectivity than Al [9]. In this work, we investigated a new Pd/Ag metallization scheme on moderately doped p-GaN with carrier concentration ranging from 10^{17} to 10^{18} cm^{-3}. Ohmic properties were investigated by annealing samples at temperatures ranging from (400°C - 800°C).

EXPERIMENTAL PROCEDURES

Pd/Ag metallization scheme were fabricated on Mg-doped p-GaN samples grown on sapphire substrates. Firstly, Palladium (Pd) was evaporated onto the GaN through a metal mask, followed by the evaporation of Argentums (Ag) as the capping layer. Prior to the metal deposition, $NH_4OH : H_2O$ = 1:20 solution, followed by $HF:H_2O$ = 1:50 solution were used to remove native oxide on the samples. Boiling aqua regia ($HCl : HNO_3$ = 3:1) was used to chemically etch and clean the samples.

The samples were annealed under flowing nitrogen gas environment in the furnace at 400°C, 500°C, 600°C, 700°C and 800°C for 6 minutes. Identical heat treatments were carried out for additional times of 25 minutes to investigate the thermal stability of the contacts. Changes in the surface morphology of the contacts with different annealing temperatures were examined by using Scanning Electron Microscopy (SEM)

The transmission line method (TLM) pads were designed to be 2mm (W, width) X 1mm (d, length) in size and the spacings, L between the pads were 0.3, 0.4, 0.6, 0.9 and 1.3 mm. The contact resistivities, ρ_c were determined from the plot of the measured resistances against the spacing between the TLM pads. The linear-square method was used to fit a straight line to the experimental data.

RESULTS AND DISCUSSIONS

I-V measurements on TLM patterned samples revealed that all the I-V curves of as-deposited Pd/Ag contacts on p-GaN exhibited nonlinear characteristics, indicating a Schottky behavior between contact and p-GaN.

For samples that were annealed for 6 minutes exhibited ohmic characteristics at temperatures ranging from 400°C to 800°C. The linearity of I-V curves improved with higher annealing temperatures. Figure 1 indicates that the specific contact resistivity decreases as the temperature increases. The I-V characteristics become further near linear after annealing at 800°C for 6 minutes. A minimum value of 3.9 Ωcm^2 for the ρ_c was obtained at 800°C. The improvement of the characteristics of the annealed samples could be related to the increase of the contact areas between the metal scheme and the GaN. The annealing may have activated Mg acceptors by breaking Mg-H complexes and will eventually lead to a higher hole concentration that is vital for tunneling to occur [10].

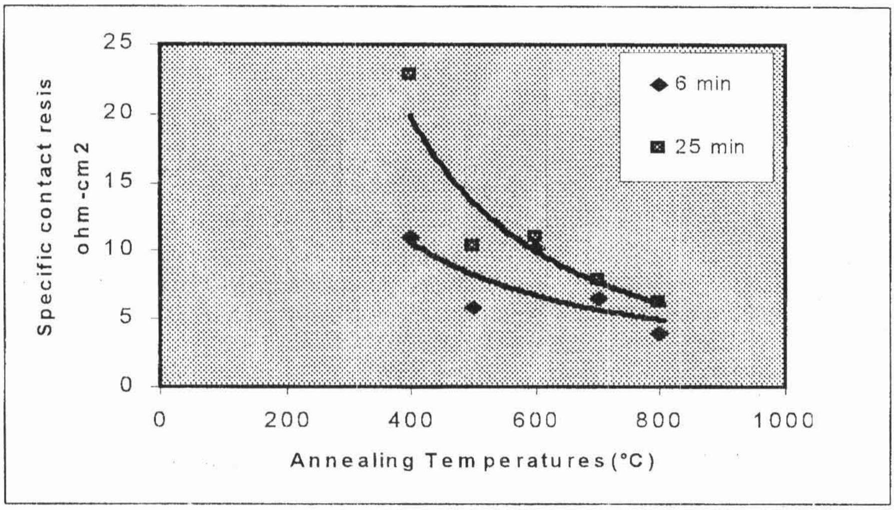


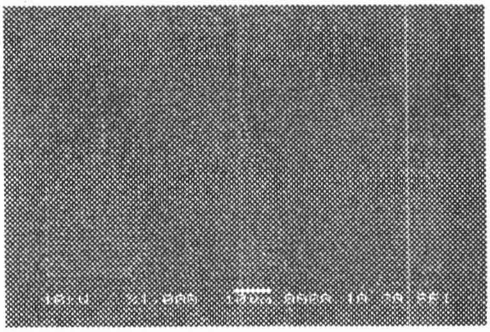
Figure 1: The changes of specific contact resistivities at different annealing temperatures

As for the samples that were annealed for 25 minutes from temperatures of 400°C to 800°C have shown again ohmic characteristics similar to samples annealed for 6 minutes and that the specific contact resistivity decreases as the temperatures increased as seen in Table 1. On the contrary to samples that were annealed for 6 minutes, the specific contact resistivity for samples annealed for 25 minutes degraded to 22.7 Ωcm^2 at 400°C and later improved to 6.256 Ωcm^2 at 800°C. Although we used flowing nitrogen in the tube furnace, there could be a certain amount of oxygen present that will lead to the oxidation of the contacts. Oxidation can occur even with the presence of a very small amount of oxygen [11]. The degradation of the contacts could be attributed to the formation of an oxide layer on the silver surface that was confirmed by energy dispersive spectroscopy (EDS).

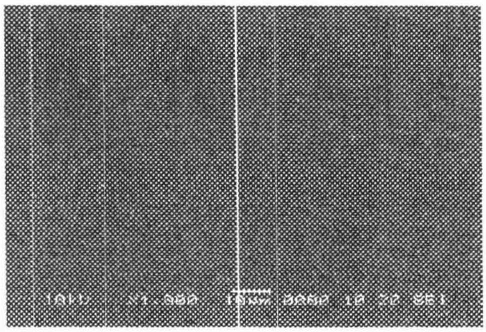
Table 1: The comparison of Pd/Ag specific contact resistivities at different annealing temperatures and annealing times

Sample	Annealing Temperature (°C)	Specific Contact Resistivities (Ωcm^2) Annealing Times/Acumulated annealing Times	
		6 min	25 min/(31 min)
1	400	11.032	22.766
2	500	5.844	10.283
3	600	10.140	10.962
4	700	6.496	7.938
5	800	3.904	6.256

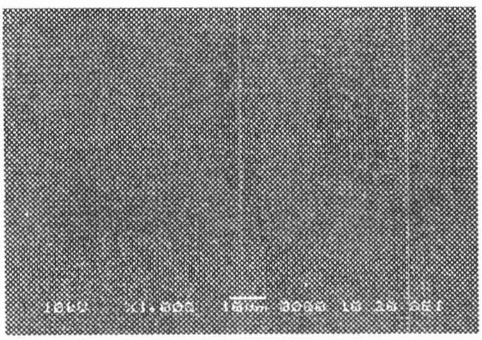
As-deposited contacts exhibited mirror like surface, which was observed using scanning electron microscopy (SEM) shown in Figure 2 (a). When samples were annealed at 400°C, small islands started to appear. When annealing temperature was further increased and the islands became bigger and spread evenly over the surface with regular shape and size. Samples annealed at 700°C and above, "balling up" effect was observed on the surface of the samples. High temperature annealing has the adverse effect on the surface morphology.



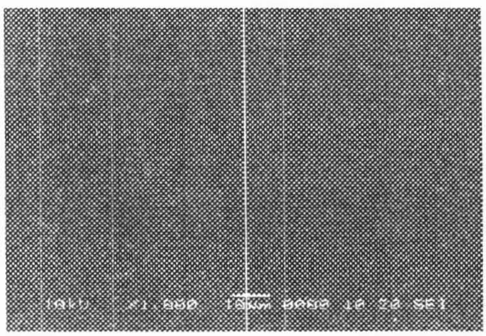
(a) As deposited



(b) 25 min annealed at 400°C



(c) 25 min annealed at 500°C



(d) 25 min annealed 600°C

The samples were annealed under flowing nitrogen gas environment in the furnace at 400°C, 500°C, 600°C, 700°C and 800°C for 6 minutes. Identical heat treatments were carried out for additional times of 25 minutes to investigate the thermal stability of the contacts. Changes in the surface morphology of the contacts with different annealing temperatures were examined by using Scanning Electron Microscopy (SEM)

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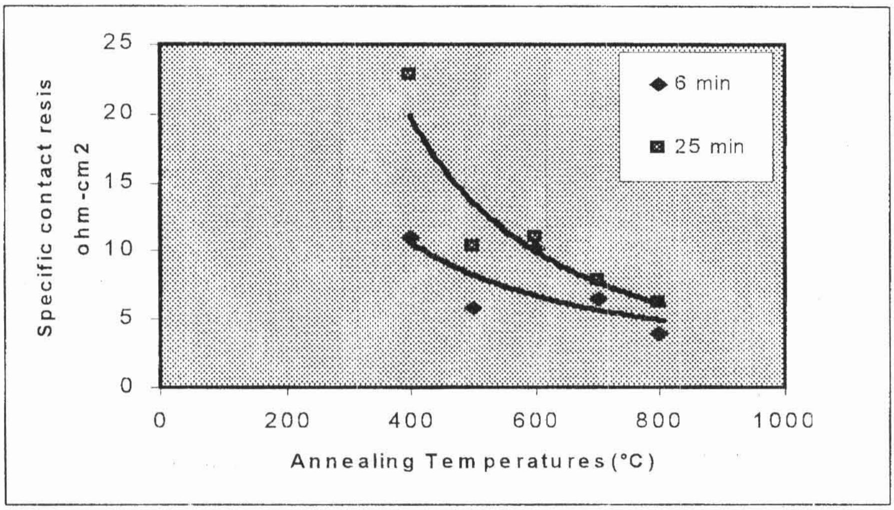

Figure 1: The changes of specific contact resistivities at different annealing temperatures

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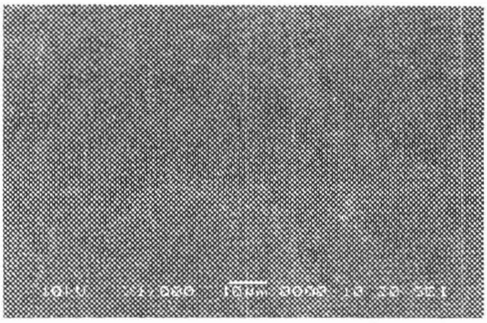
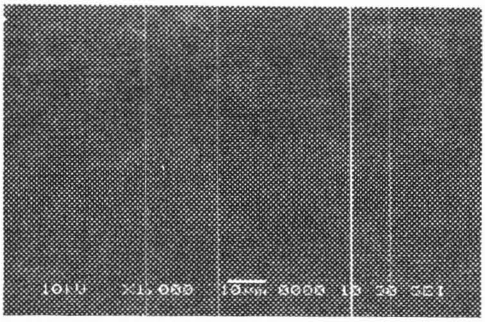


(e) 25 min annealed 700°C



(f) 25 min annealed 800°C

Figure 2: SEM images taken at different annealing temperatures under the same magnification and scale bar indicates 10 microns in length

CONCLUSION

We investigated the properties and characteristics of the Pd/Ag bilayer contacts on p-GaN. The lowest specific contact resistivity achieved was 3.9 Ωcm^2 for annealing temperatures of 800°C for 6 minutes. The specific contact resistivity of this bilayer scheme was sensitive to the change of annealing temperature and durations. Samples that were annealed for 25 minutes exhibited increased SCR compared to samples that were annealed for 6 minutes at 400°C but later decreased as the temperature increased. Changes in the surface morphology of the contacts upon annealing were also examined. "Balling up" effect was observed at high temperature annealing.

ACKNOWLEDGEMENT

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