Structural and electrical characteristics of metal contacts on n-type GaN/Si(111)

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In this paper, we report on the electrical characteristics and surface morphology of four different metal contacts (Ag, Ti, Pt and Ni) on GaN films grown on silicon substrate. The samples were annealed at different temperatures ranging from 300 °C to 900 °C under flowing nitrogen gas for 15 minutes. The electrical behaviors of the contacts were analyzed by current-voltage (I-V) measurements. Scanning electron microscopy (SEM) measurements and energy dispersive spectroscopy (EDS) were carried out to examine the surface morphology and chemical composition of the metal contacts.

(Received November 12, 2008; accepted November 27, 2008)

Keywords: Thermal stability, Electrical characteristics, Surface morphology, GaN

1. Introduction

The recent emergence of GaN-based devices promises a further revolution in areas such as high speed terrestrial and satellite-based communication system, advanced radar, integrated sensors, high temperature electronics and nonvolatile spintronic memory or signal processing devices [1]. Other devices that have been demonstrated so far include UV/visible light emitting diodes, metal semiconductor field effect transistors, ultraviolet (UV) photoconductive detectors, UV Schottky barrier photodetectors, solar blind Schottky photodiodes and high electron mobility transistors [1–6]. High quality ohmic or Schottky contacts are required for improving the performance of devices. In addition, for

Schottky diodes, good ohmic contacts help in obtaining the actual Schottky characteristics from current–voltage (*I–V)* measurements.

Heat treatment has been widely employed to study the thermal stability in metal semiconductor contacts as well as to improve or optimize the electrical properties of the contacts. For better contact characteristics, a wide variety of metallization schemes, heat treatment, different surface pretreatments, different annealing environments and novel contact layers for GaN have been intensively investigated and developed in order to further improve the contact technology. In this work, we report on the thermal stability, electrical characteristics and surface morphology of different metal contacts (Ti, Ni, Ag and Pt) on n-type GaN films.

2. Experimental

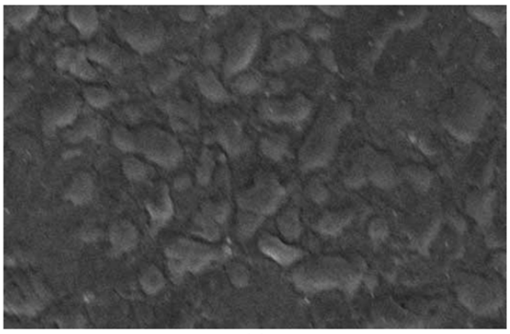
In this work, unintentionally doped n-type GaN films grown on silicon with 0.2 µm thickness and carrier concentration of 2×10^{18} cm^{-3} were used. Different metal contacts (Ag, Pt, Ti and Ni) were coated individually onto the GaN samples via a metal mask by a sputtering system. The metal mask consists of an array of dots with diameter of 250 µm.

Prior to the metal deposition, the samples were cleaned using the standard procedure. Samples were dipped into a mixture of NH_4OH: H_2O: 1: 20 for 5 min, then rinsed with de-ionised (DI) water. Subsequently, the samples were dipped into a mixture of HF: H_2O (1: 50) for 20 seconds then rinsed with de-ionised water. Boiling aqua regia (HCl: HNO_3 = 3:1) was used to chemically etch and clean the samples. The surface cleanliness is important to ensure good quality contact and to minimize surface contamination. After metallization, the samples were annealed in a tube furnace ranging from 300°C to 900°C under flowing nitrogen gas for 15 minutes. Scanning electron microscopy (SEM) measurements and energy dispersive spectroscopy (EDS) were carried out to examine the surface morphology and chemical composition of the metal contacts. The electrical behaviors of the contacts were analyzed by current-voltage (I-V) measurements.

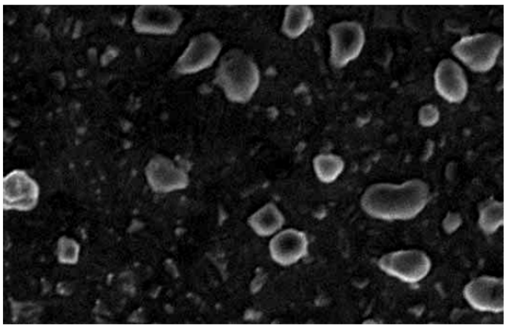
3. Results and discussion

3. 1. Scanning electron microscopy

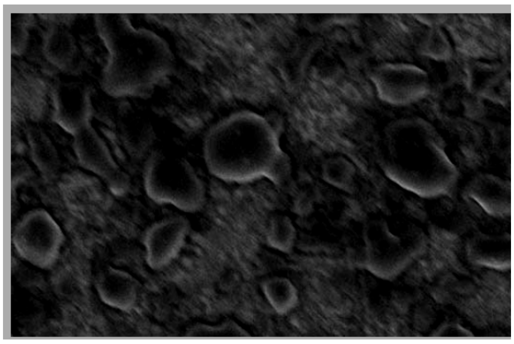
The surface morphology of the contacts is one of the important factors which could affect the device performance significantly. Silver has a low melting point (~961 °C), and islanding normally appears at temperatures in excess of 300 °C. Platinum annealed at elevated temperatures, which are 700 °C and 900 °C exhibit a uniform agglomeration all over the surface. On the other hand, different sizes of islands are found for Ni and Ti samples which were annealed at 800 °C. At low annealing temperatures (below 400 °C), surface morphology for most of the metal contacts except silver were observed to be relatively smooth as revealed by SEM images. However all the samples started experiencing agglomeration at 500 °C, and the agglomeration increased with the annealing temperatures. Fig. 1 shows the SEM images for samples annealed at 700 °C.



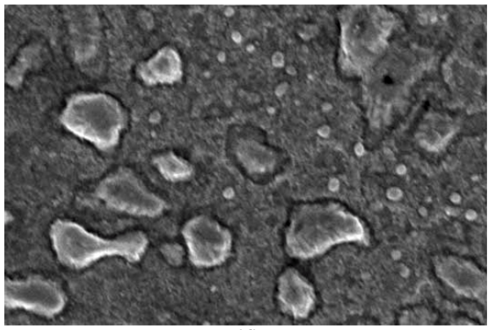
(a)



(b)



(c)



(d)

Fig. 1. SEM images of different samples annealed at 700 °C for 15 minutes: (a) Ni, (b) Ag (c) Pt and (d) Ti.

3. 2. Energy dispersive x-ray spectroscopy

Table 1 shows the EDS analysis results of the oxygen composition for five different metal contacts under different annealing temperatures. Generally, high oxygen content in the contacts is undesirable, since oxygen could influence the characteristics of the samples especially the electrical properties. The formation of oxide layer may reduce the amount of current flowing from contacts to the thin film and eventually the performance of the device may be affected. The EDS data indicate that the amount of oxygen in both Ti and Ni metal contacts increased with the annealing temperatures. On the other hand, oxygen composition in Pt and Ag are found to be stable when the samples were annealed from 300°C to 900°C.

Table 1. EDS analysis data of oxygen for different samples under different annealing temperatures.

Sample	Oxygen Atomic %							
	As dep.	300°C	400°C	500°C	600°C	700°C	800°C	900°C
Ag	1.16	2.35	1.40	0.82	1.54	1.74	0.86	0.47
Pt	3.59	6.09	10.75	12.00	30.21	30.49	30.884	--
Ti	3.01	4.00	2.14	17.34	20.18	30.18	33.17	--
Ni	2.10	3.01	3.04	1.09	1.04	1.91	2.81	3.77

3. 3 Current-voltage measurements

The I-V measurements revealed that ohmic behaviours were observed for as deposited and samples annealed at low annealing temperatures, with the exception of silver. All samples exhibited Schottky characteristic when annealed at higher temperatures. Ni, Pt and Ti started showing Schottky behaviour at 300°C, 500°C, 600°C and 500°C, respectively.

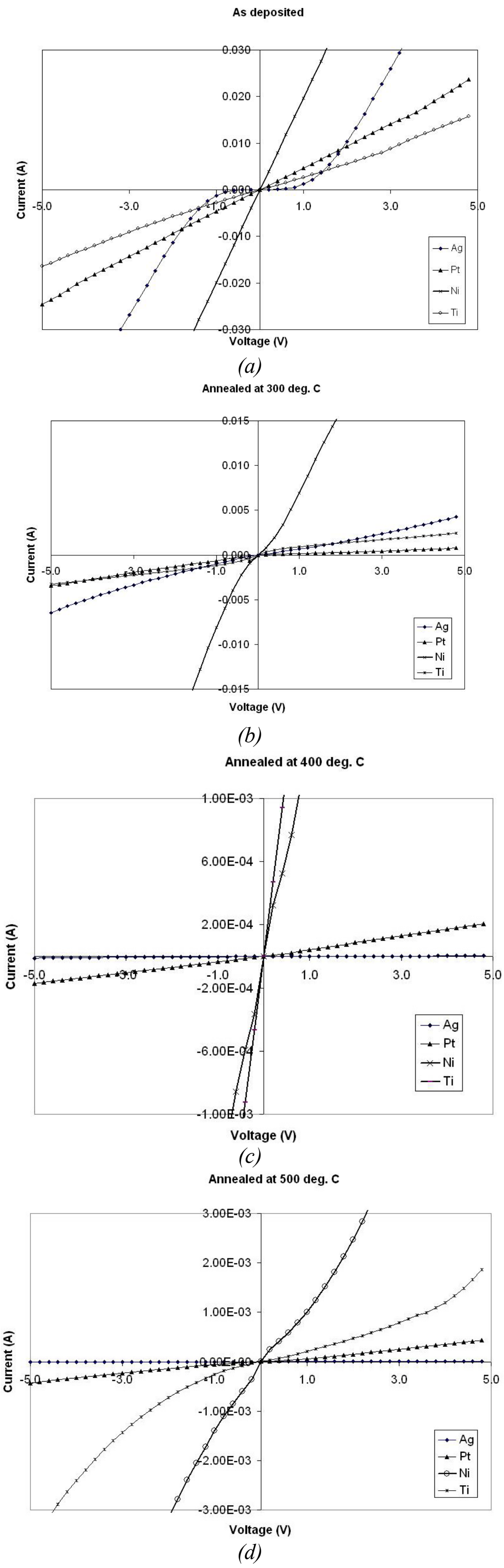


Fig. 2. The I-V characteristics of different samples: (a) as-deposited, (b) annealed at 300°C, (c) annealed at 400°C; and (d) annealed at 500°C.

For silver, the as deposited and 600°C samples showed Schottky behaviour. However ohmic characteristics were observed when annealed from 300 to 500 °C. From the I-V measurements, silver contacts after heat treatment were found to be resistive; this could be attributed to the poor surface morphology. Fig. 2 shows the I-V characteristics of different samples obtained under different post heat treatment conditions. I-V measurements for high annealing temperatures, which above 600°C were not shown in Fig. 2, this is due to the degradation of electrical properties for some of the metal contacts. The degradation could be ascribed to the formation of oxide layers and poor surface morphology of the contacts which reduced the amount of current flow into the thin films. Different metal contacts showed different degree of degradation. Ag, Pt and Ti were found to be deteriorated at the annealing temperatures of 800 °C, 600 °C, 500 °C and 700 °C, respectively. On the other hand, Ni showed little deterioration of the electrical properties. The I-V measurement was obtainable for Ni sample annealed at 900°C.

The electrical characteristics as well as the thermal stability of the metal contacts can be correlated to the structural properties as revealed by SEM and EDS analysis. Ag has low melting point and will experience agglomeration at temperatures in excess of 300 °C, therefore poor surface morphology was observed. The I-V measurements showed that the resistance of Ag increased in a greater degree as compared to other contacts after thermal treatments. EDS analysis indicates that Pt and Ti have strong oxygen affinity. This could be observed from Table 8.2, which shows a sudden tremendous increase of the oxygen composition at annealing temperatures of 500 °C, 600 °C and 600 °C, respectively. This indicates that the formation of oxide layer in the contacts have taken place. The oxide layer is insulating in nature; therefore it could reduce the flow of current into the films significantly.

4. Conclusions

The structural and electrical properties as well as the thermal stability of different metal (Ti, Ni, Ag and Pt) contacts annealed at temperatures ranging from 300 °C to 900 °C have been studied. Nickel appears to be the best candidate among the metals investigated. Excellent electrical properties and thermal stability at elevated temperatures were shown by this metal contact.

Acknowledgements

The support from Universiti Sains Malaysia is gratefully acknowledged. The authors would like to thank Mr Sin Yew Keong for the SEM measurements.

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