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Electrical and structural properties of low-resistance Pt/Ag/Au ohmic contacts to p-type GaN

V. Rajagopal Reddy [a,*], N. Ramesha Reddy [a], Chel-Jong Choi [b]

[a] *Department of Electronics, University of Mysore, Post-Graduate Centre, Hemagangotri 573 220, Hassan, India*
[b] *Analytical Engineering Center, Samsung Advanced Institute of Technology (SAIT), P.O. Box 111, Suwon 440-600, South Korea*

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Abstract

A Pt (20 nm)/Ag (50 nm)/Au (30 nm) metallization scheme has been investigated for producing low-resistance ohmic contacts to moderately doped p-type GaN (1.3×10^{17} cm^{-3}). It is shown that the as-deposited contacts exhibit a linear I–V characteristic with a specific contact resistance of $4.43 \times 10^{-3}\ \Omega\,\text{cm}^2$. The Pt/Ag/Au contact produced a specific contact resistance as low as $1.70 \times 10^{-4}\ \Omega\,\text{cm}^2$ after annealing at 800 °C for 1 min in a N_2 atmosphere. It is further shown that the surface morphology of the contact annealed at 800 °C (RMS roughness of 19.9 nm) became somewhat degraded compared with that of the as-deposited one (RMS roughness of 3.3 nm). Based on the Auger electron microscopy and X-ray diffraction results, possible explanations for the improvement of the ohmic behavior are described.

Keywords: Electrical and structural properties; Pt/Ag/Au ohmic contacts; Spectroscopy; X-ray diffraction; p-GaN

1. Introduction

GaN-based III-nitride semiconductors are highly attractive materials for optoelectronic devices such as light emitting diodes and laser diodes in the blue and ultraviolet wavelength ranges [1–3]. One of the serious problems in these devices is a large voltage drop across the p-type GaN/metal interfaces, namely, poor ohmic contact, which leads to poor device performance. Extensive studies have been carried out to find a way of lowering the contact resistance of p-type GaN material.

High quality ohmic contact with low-resistance is still relatively difficult to obtain for p-type GaN, because of the difficulty in achieving high carrier concentrations and the absence of suitable metals with high work function. A number of Pt- and Pd-based ohmic contacts such as Pt, Pt/Ni/Au, Pt/Ru, Pt/Au, Ti/Pt/Au, Pd/Au, Pd/Ni, Pd/Pt/Au, Pd/Ag/Au/Ti/Au, Pt/Pd/Au and Pt/Re/Au have been reported as promising metallization schemes for p-GaN [4–15]. The Pt-based ohmic contacts showed specific contact resistivity typically in the range of low 10^{-3} to low $10^{-5}\ \Omega\,\text{cm}^2$. It has been reported that the reduction of the specific contact resistivity for the Pt-based ohmic contacts was related to the formation of gallides during thermal annealing. Kim et al. [14] investigating Pt/Pd/Au ohmic contact to p-GaN reported that the formation of Pt– and Pd–Ga phases leads to reduction of the contact resistivity by the formation of a highly doped surface region. Reddy et al. [15] also reported that the ohmic contact characteristics of Pt/Re/Au are associated with the formation of Pt–Ga phases and that they play an important role in reducing contact resistivity. In this work, we have investigated the

* Corresponding author. Tel.: +91 8172240968; fax: +91 8172240674.
E-mail address: reddy_vrg@rediffmail.com (V. Rajagopal Reddy).

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electrical and structural properties of Pt/Ag/Au ohmic contacts on moderately doped p-type GaN as a function of annealing temperature. It is shown that the Pt/Ag/Au ohmic contacts produce specific contact resistivity as low as $1.70 \times 10^{-4}\ \Omega\,cm^2$, when annealed at 800 °C for 1 min in nitrogen ambient.

2. Experimental details

The Mg-doped p-type GaN samples were grown by metalorganic chemical vapor deposition on *c*-plane sapphire substrate. A 1.5 μm thick p-type GaN layer was grown on 2 μm thick undoped GaN buffer layer. The carrier concentration was determined to be $1.13 \times 10^{17}\ cm^{-3}$ by means of Hall effect measurements with the van der Pauw geometry at room temperature. The GaN layer was first ultrasonically degreased with trichloroethylene, acetone and methanol for 5 min in each step and then the surface oxides were removed in buffered oxide etch (BOE) solution for 10 min followed by a deionized water rinse and a dry N_2 blow. The circular transmission line (CTLM) pads were patterned on the p-type GaN layer by a standard photolithography technique. The inner dot radius was 25 μm and the spacing between the inner and the outer radii were varied from 3 to 18 μm. Prior to metal deposition, the CTLM-patterned layers were dipped in BOE solution for 30 s. The Pt/Ag/Au (20 nm/50 nm/30 nm) films were then deposited on the surface treated p-type GaN by electron beam evaporation under a pressure of 1×10^{-6} Torr. Some of the samples were rapid thermal annealed at temperatures in the range of 550–800 °C for 1 min under N_2 ambient. Current–voltage characteristics (*I*–*V*) of the contacts were measured using a four-probe arrangement at room temperature. Depth profiles of elements were obtained from Auger electron spectroscopy (AES: VG: Microlab 350) measurements. The microstructures of the interfaces between metal contacts and p-GaN were analyzed by X-ray diffractometer (Siefert XRD PW 3710) using Cu k_α radiation ($\lambda = 1.5418$ Å).

3. Results and discussion

The typical current–voltage characteristics of Pt/Ag/Au contacts on p-GaN as a function of annealing temperature, measured between pads with a spacing of 6 μm are shown in Fig. 1. The as-deposited contacts exhibit near linear *I*–*V* behavior, with the *I*–*V* behavior becomes increasingly linear as the annealing temperature is increased. The specific contact resistances determined from plots of the measured total resistance versus the spacing between the CTLM pads are shown in Fig. 2. Measurements showed that the specific contact resistivity is $4.43 \times 10^{-3}\ \Omega\,cm^2$ for the as-deposited samples and

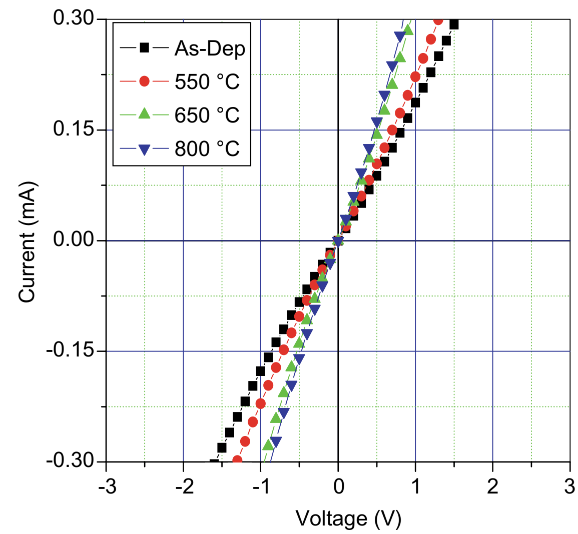

Fig. 1. The typical *I*–*V* characteristics of Pt/Ag/Au contacts on p-type GaN as a function of annealing temperature, measured between the CTLM pads with a spacing of 6 μm.

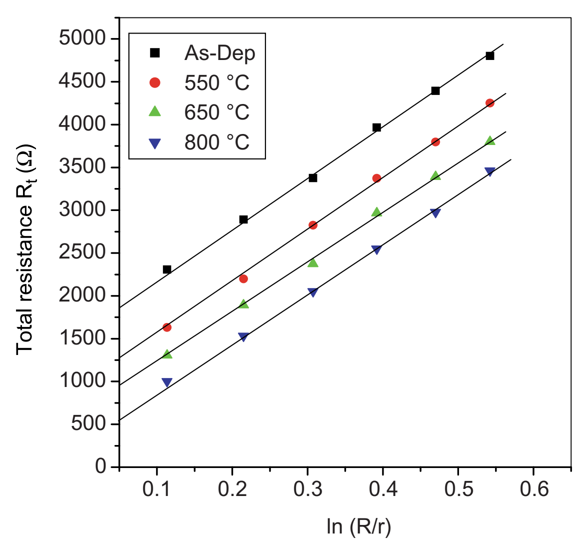

Fig. 2. Plots of the measured total resistance (R_t) versus the spacing between the CTLM pads as a function of temperature.

$1.02 \times 10^{-3}\ \Omega\,cm^2$, $6.61 \times 10^{-4}\ \Omega\,cm^2$ and $1.70 \times 10^{-4}\ \Omega\,cm^2$ for the samples annealed at 550, 650 and 800 °C, respectively. It is shown that annealing at 800 °C results in the lowest resistivity, as evident from the *I*–*V* characteristics of Fig. 1. In this work, thus, the as-deposited and 800 °C samples were mainly characterized.

To characterize interfacial reactions between the metal layers and the GaN, AES analysis was employed. For the as-deposited sample, AES depth profile showed no significant intermixing between the metal layers and the GaN, as shown in Fig. 3(a). It was also shown that a small amount of Ga was out-diffused into the Pt layer, which is indicative of possible reaction between Pt and