phys. stat. sol. (c) **1**, No. 2, 219–222 (2004) / **DOI** 10.1002/pssc.200303920

Study of long-term stability of ohmic contacts to GaN

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Received 15 September 2003, accepted 27 October 2003
Published online 22 December 2003

PACS 68.60.Dv, 73.40.–c, 81.05.Ea, 81.70.Pg, 85.30.–z

We report on low-resistivity thermally stable ohmic contacts to p-GaN using ZrN/ZrB_2 metallisation. Transport properties, thermal conductivity and long-term stability of contacts were examined. p-GaN/ZrN/ZrB_2 contacts show excellent stability upon aging in air, indicating their suitability for long-term operation at temperatures up to 150 °C.

1 Introduction GaN's intrinsic properties such as wide bandgap, high thermal conductivity, high melting temperature, high breakdown voltage and high saturation velocity make it a material of choice for high temperature and high power electronic devices [1]. During the last decade, significant progress in both material and processing technologies as well as in the design of new device structures has been made. Now the most important and challenging problem is to master the reliability of GaN-based devices.

In this paper we address the issue of long-term stability of ohmic contacts to GaN. Electrical contacts that are structurally stable at high temperature are the prerequisite for reliable operation of GaN electronic devices. Zr-based metallisation was chosen as a contact material because of high electrical conductivity, superior thermal stability and chemical resistance against corrosion, making it compatible with GaN. Zr/ZrN metallisation was reported effective in providing low-resistivity contacts to n-type GaN by depleting its superficial film from nitrogen, creating thus a highly doped subcontact region and a stable ZrN compound at the contact interface [2]. In our previous studies, ZrN/ZrB_2 metallisation was used for p-type GaN contacting purposes. The presence of Zr in the metallisation was a key factor for the formation of the ohmic contact by removal hydrogen from the subcontact layer and creation thereby a highly doped p^+ region [3]. Moreover, structural stability of ZrN/ZrB_2 metallisation deposited on GaN upon annealing up to 1100 °C in N_2 has been proven [4]. In the present study we have investigated the thermal conductivity of p-GaN/ZrN/ZrB_2 ohmic contacts and performed accelerated lifetime testing of these contacts. It is well established that efficient heat removal is critical to the performance of semiconductor devices. Thus for thermal management of the device, it is important to know accurately the value of the thermal conductivity of metallisation and semiconductor subcontact region. Thermal conductivity investigations were performed using Scanning Thermal Microscopy (SThM), enabling to couple the topographic image with the thermal conductivity information [5]. To age the contacts they were annealed in air at temperatures up to 150 °C over a period of 300 hours. The aging process was monitored by specific contact resistance measurements and compositional depth profiling of the contacts.

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2 Experimental details The substrate materials for this study were 2 µm thick Mg doped to ~3×10^{19} at.cm^{-3} GaN epilayers grown by MOCVD on a sapphire substrate. The concentration of holes from Hall effect measurements was $p = 5\times10^{17}$ cm^{-3}. Zr-based metallisation, consisting of ZrN(50nm)/ZrB_2(50nm) bilayer was deposited by sequential DC magnetron sputtering in Ar discharge from ZrN and ZrB_2 targets, respectively. The microstructure of both ZrN and ZrB_2 films was amorphous. Their resistivity, as determined from four point probe measurements, was 200 µΩcm and 150 µΩcm, respectively.

The patterns for contact resistivity evaluation were formed using photolithography and lift-off techniques. Contacts were annealed in a RTP system at 800 °C for 60 s. in flowing N_2. Subsequent to annealing, 100 nm thick Ag or Au overlayer was deposited for bonding.

Contact resistivity (r_c) was evaluated by circular transmission line method (cTLM) using test pattern with contact pads separation varying from 10 to 60 µm. Aging experiments were done using a Keithley 2400 source-meter equipped with a microprobe and hot-plate enabling thermal measurements in air. Depth profiling by secondary ion mass spectrometry (SIMS) was performed with a Cameca 6F instrument, using cesium primary ion beam and detection of CsX^+ secondary cluster ions.

Thermal conductivity (κ) measurements were done using a combined SThM/AFM system [6]. The calibration procedure made it possible to evaluate absolute values of local thermal conductivity coefficient with submicron spatial/depth resolution [7]. The system allowed measuring local temperature with thermal resolution of 5 mK and thermal conductivity with a resolution of 10^{-2} Wm^{-1}K^{-1}.

3 Results and discussion The electrical characteristics of p-GaN/ZrN/ZrB_2/Ag ohmic contacts are shown in Fig. 1. Contact resistivities of 7×10^{-5} Ωcm^2 were obtained. The temperature dependence of r_c was also evaluated. As shown in Fig. 2, contact resistivity remains unaltered by temperature changes, which is indicative that tunnelling via metal/semiconductor interface is responsible for ohmic behaviour.

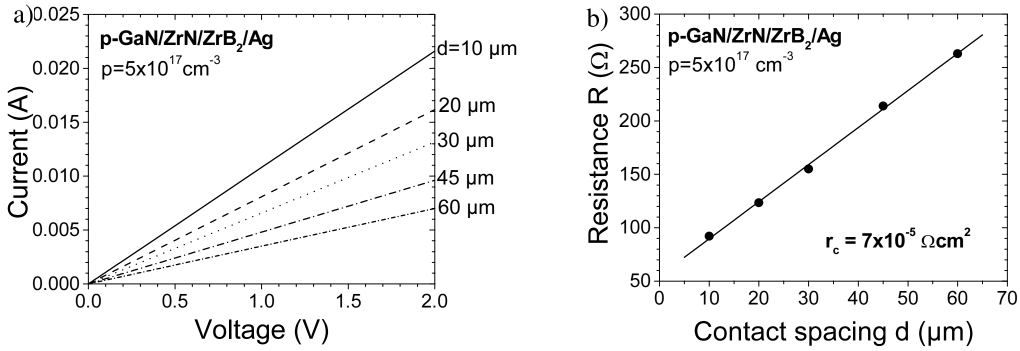

Fig. 1 a) I-V characteristics of p-GaN/ZrN/ZrB_2/Ag ohmic contacts as measured on five c-TLM pads, b) c-TLM results of contact resistivity measurements.

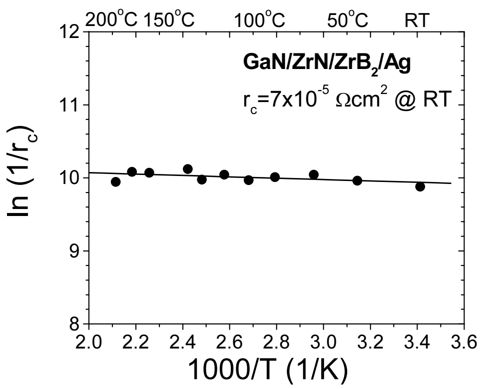

Fig. 2 The temperature dependence of contact resistivity for p-GaN/ZrN/ZrB_2/Ag ohmic contacts.

The topographic and the thermal conductivity images of a fragment of ZrN/ZrB_2 contact pad on p-GaN acquired simultaneously are juxtaposed in Figures 3a and 3b. In both images the area corresponding to p-GaN appears much darker than that of the Zr-based metallisation indicating that the thermal conductivity of 100 nm thick ZrN/ZrB_2 metallisation is significantly higher than that of p-GaN. The thermal conductivity of p-GaN was measured to be 118 $Wm^{-1}K^{-1}$. For comparison purposes, reported values of κ for GaN vary from 130 $Wm^{-1}K^{-1}$ (400 mm thick HVPE grown GaN) [8] to 220 $Wm^{-1}K^{-1}$ (bulk n-GaN crystals) [9]. The relatively low thermal conductivity of p-GaN can be attributed to extremely high concentration of Mg and high concentration of hydrogen [3]. As for ZrN/ZrB_2 metallisation, it is not thick enough to determine the absolute thermal conductivity. Nevertheless very good uniformity of the thermal conductivity should be noted. Thermal aging did not cause changes in the thermal conductivity image of $p\text{-}GaN/ZrN/ZrB_2$ contacts.

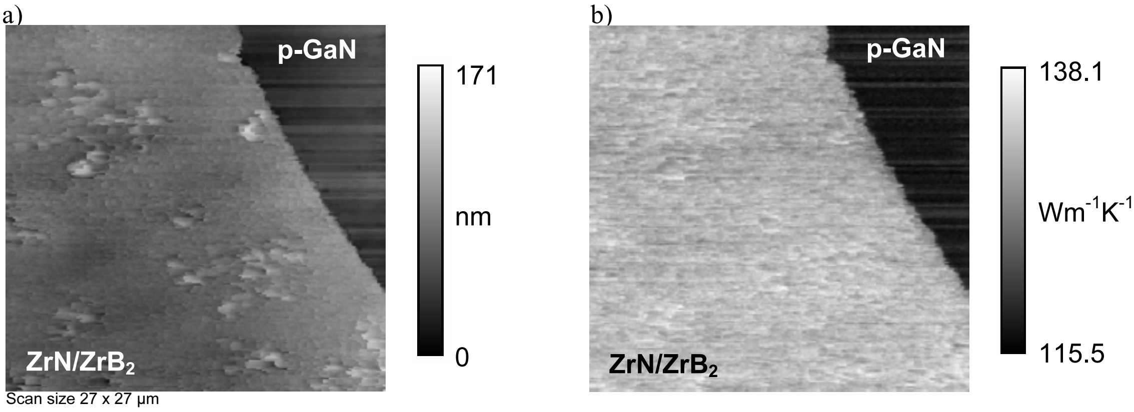

Fig. 3 Topographic (a) and thermal conductivity (b) images of a fragment of ZrN/ZrB_2 contact pad on p-GaN substrate.

To evaluate their long-term stability, $p\text{-}GaN/ZrN/ZrB_2/Ag$ ohmic contacts were aged during two consecutive cycles: at 125 °C and next at 150 °C for 300 hours each. The contact resistivity was measured after each aging step. The results from aging experiments and compositional SIMS profiling of $p\text{-}GaN/ZrN/ZrB_2/Ag$ contact performed subsequent to aging, are shown in Figures 4 and 5, respectively. The contact resistivity remains unchanged upon these two aging cycles. SIMS analysis confirms the stability of the contact system. Here, particularly significant is the sharpness of the Ag/ZrB_2 interface (Ag signal at this interface decreases by 4 orders of magnitude) testifying for the excellent behaviour of Zr-based metallisation as a diffusion barrier.

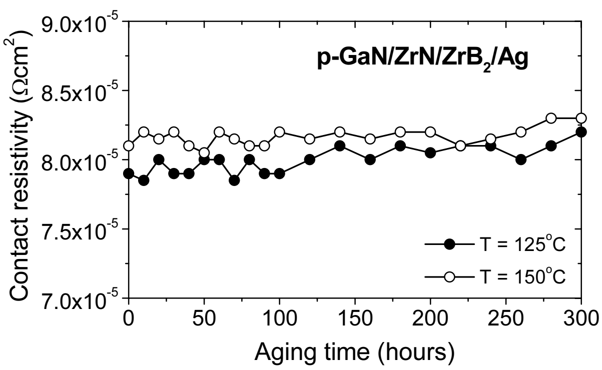

Fig. 4 The resistivity of $p\text{-}GaN/ZrN/ZrB_2$ ohmic contacts as a function of aging time.

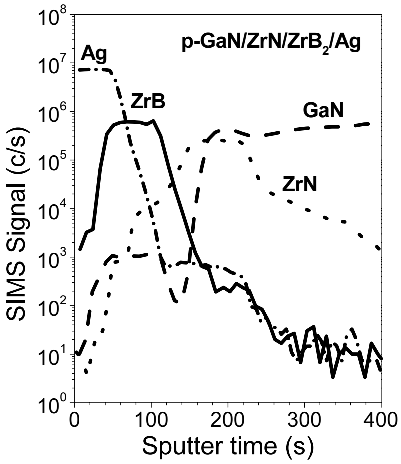

Fig. 5 SIMS profiles for p-GaN/ZrN/ZrB_2 ohmic contacts after aging.

3 Conclusions We have fabricated low-resistivity ohmic contacts to p-GaN using ZrN/ZrB_2 metallisation and evaluated their transport and thermal properties, as well as their long-term stability. It has been found that the current transport across the contact interface is dominated by tunnelling of holes. This confirms our previous suggestions regarding the mechanism of the ohmic contact formation by enhanced activation of Mg and creation of a p^+-GaN superficial film [3]. Furthermore, we have proven the applicability of SThM method to assess the thermal conductivity of metal/semiconductor contacts. Finally we have demonstrated excellent electrical and thermal stability of Zr-based contacts upon aging in air over a period of 300 hours, indicating their suitability for long-term operation at temperatures up to 150 °C.

Acknowledgements Research is partially supported by grants from European Commission G5RD-CT-2001-00566-DENIS and the State Committee for Scientific Research 7T11B 009 20.

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