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Transparent low resistance ohmic contact to *p*-type GaN and its application to GaN based light emitting diodes

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Abstract

A novel method to fabricate low resistance ohmic contacts to *p*-GaN of high transparency was developed by oxidation of bi-layer metallic films. In this paper, the results of Ni(5 nm)/Au(5 nm), Ni(5 nm)/Pt(5 nm) and Co(5 nm)/Au(5 nm) contacts were reported. The minimum specific contact resistance (ρ_c) as low as 4.0×10^{-6} Ω cm^2 was obtained for the oxidized Ni/Au contact at 500 °C, which had a NiO/Au composite structure. In contrast to the oxidized Ni/Au contact, the oxidized Ni/Pt and Co/Au contacts exhibited higher ρ_c. The diversified results were attributed to different microstructure for the oxidized Ni/Pt contact and different oxide Co_3O_4 formation for the oxidized Co/Au contact. Due to the transformation of Ni and Co to NiO and Co_3O_4, respectively, the transparency of the three contacts increased. The oxidized Ni/Au contact display transparency (T) higher than about 70% in visible range, which was the highest among the three contacts. Due to the oxidized Ni/Au contact having low ρ_c and high T, it was applied to GaN based blue LEDs as *p*-contact to increase light output. The output power of the blue LED with the oxidized Ni/Au transparent contact (TC) increased 4.5 times higher than that one without the TC.

Ho et al. recently reported a low-resistance ohmic contact to *p*-GaN by oxidizing Ni/Au thin films.[1-4] The minimum ρ_c of $4x10^{-6}$ Ω cm^2 was achieved for the oxidized Ni(5nm)/Au(5nm) contact. At the same time, Koide et al.[5] performed similar experiments, but less striking results were reported. Not only the excellent contact performance, the oxidized Ni/Au contact also exhibited high transparency. The unique characteristics were related to the transformation of Ni to NiO. Thereupon, an energy band model based on the Au/*p*-NiO/*p*-GaN heterostructure was proposed to explain the low-resistance ohmic characteristic. The barrier heights at Au/*p*-NiO and *p*-NiO/*p*-GaN junctions were estimated to be 0.3 and 0.185 eV, respectively. As a result of the significant reduction of ρ_c by the oxidization process, it is reasonable to expect that a metal with higher work function than that of Au (5.1 eV) can further decrease or eliminate the barrier at the metal/*p*-GaN interface. Therefore, In this study, Pt with work function of 5.65eV was tentatively used to substitute Au to investigate the effect of the metallic phase in the metal/oxide composite contact. Besides, Co was also used to replace Ni to evaluate the role of oxide phase.

Ni(5 nm)/Au(5 nm), Ni(5 nm)/Pt(5 nm) and Co(5 nm)/Au(5 nm) metal contacts were deposited on MOCVD grown *p*-GaN with hole concentration of $2x10^{17}$ cm^{-3}. The as-deposited Ni/Au, Ni/Pt and Co/Au samples were further heat treated in air for 10 minutes to accomplish the metal/oxide composite contacts. The detailed experimental procedures were published elsewhere.[1-4]

The three as-deposited metal contacts are Schoktty-type, while they all convert into ohmic after oxidation heat treatment. Fig. 1 shows the dependence of ρ_c upon heat treatment temperature of the Ni/Au, Ni/Pt and Co/Au contacts. ρ_c of oxidized Ni/Au is always lower than the oxidized Ni/Pt and Co/Au contacts. X-ray diffraction and cross-sectional transmission electron microscopy (XTEM) analyses indicated that the oxidized metal contacts mainly consisted of a metallic phase of Au or Pt, and an oxide phase of NiO or Co_3O_4. The XTEM micrographs are shown in Fig. 2. The transformation of Ni and Co into NiO and Co_3O_4, respectively, increases transparency of the contacts,

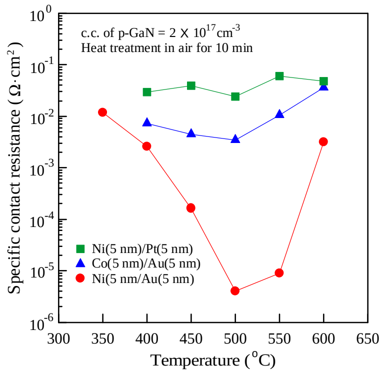

Fig. 1 ρ_c of the Ni/Au, Ni/Pt and Co/Au contacts heat treated at different temperature in air.

as shown in Fig. 3. The transparency of the oxidized Ni/Au contact is higher than the other two contacts. Owing to the unique properties of the oxidized Ni/Au contact, it is applied to a multi-quantum well blue LED as a transparent *p*-contact. The light emitting pattern of the blue LED with such TC is shown in Fig. 4. The light uniformly emits from the area with the TC. Therefore, the light output power is higher than the LED without TC, which only employs Ni/Au metal contact. For this example, 4.5 times increase of light output power is obtained. In the meanwhile, the forward voltage at 20 mA decreases from 7.14 V to 3.43 V when TC is applied. The voltage difference is in agreement with the calculation results when ρ_c and contact area of TC and metallic Ni/Au contacts, respectively, are taken into account. The operation voltage can be further decreased when the *p*-GaN quality is improved.

Reference

1. J.-K. Ho, C.-S. Jong, C.-N. Huang, C.-Y. Chen, C. C. Chiu, and K.-K. Shih, Appl. Phys. Lett. **74,** 1275 (1999).
2. J.-K. Ho, C.-S. Jong, C.-N. Huang, C. C. Chiu, K.-K. Shih, L.-C. Chen, F.-R. Chen, and J. J. Kai, J. Appl. Phys. **86,** 4491 (1999).
3. L.-C. Chen, F.-R. Chen, J. J. Kai, L, Chang, J.-K. Ho, C.-S. Jong, C.-N. Huang, C.-Y. Chen, C. C. Chiu, and K.-K. Shih, J. Appl. Phys. **86,** 3826 (1999).
4. L.-C. Chen, J.-K. Ho, F.-R. Chen, J. J. Kai, L, Chang, C.-S. Jong, C.-N. Huang, C.-Y. Chen, C. C. Chiu, and K.-K. Shih, Phys. Stat. Sol. A **176**, 773 (1999).
5. Y. Koide, T. Maeda, T. Kawakami, S. Fujita, T. Uemura, N. Shibata, and M. Murakami, J. Elecron. Mater. **28**, 341 (1999).

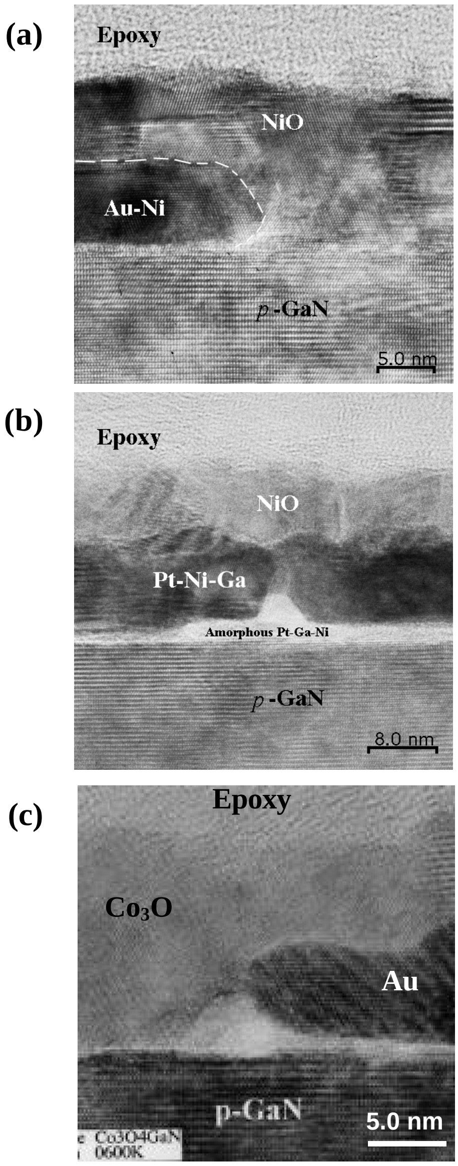

Fig.2 The XTEM micrographs of (a) Ni/Au, (b) Ni/Pt and (c) Co/Au contacts, heat treated at 500 °C for 10 minutes in air.

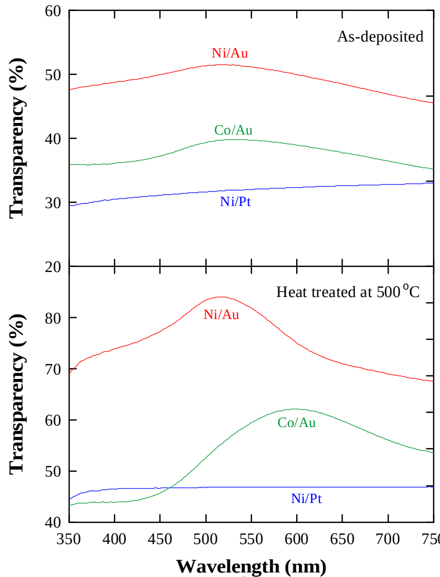

Fig. 3 Transparency of the as-deposited and oxidization heat treated metal contacts.

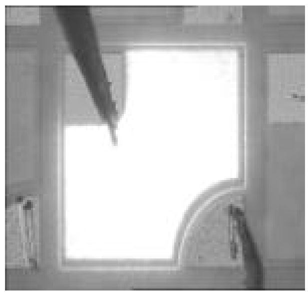

Fig.4 Light emitting pattern of a blue LED with oxidized Ni/Au transparent contact.

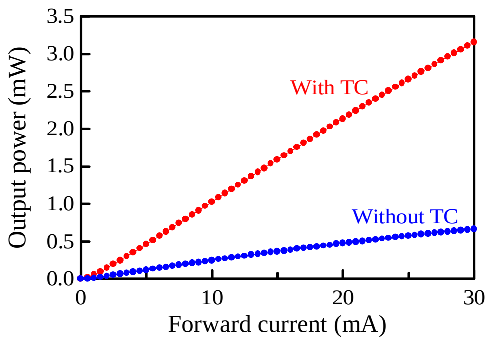

Fig.5 The effect of the oxidized Ni/Au contact on the light output power of blue LED lamps.