The role of overlayer on the formation of Ni-based transparent ohmic contacts to p-GaN

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INTRODUCTION

Gallium nitride and the related III-V nitrides have attracted great attention as optoelectronic devices in the blue and ultra-violet wavelengths because of the success in commercialization of blue light emitting diodes (LEDs). In order to improve the performance of LEDs, highly transparent, low-resistance ohmic contacts to p-GaN are essential. Recently, low-resistance ohmic contacts with high transparency were realized using Ni/Au ohmic contacts annealed in O_2 ambient. However, little work has been performed to elucidate the role of Au layer on the formation of the Ni/Au ohmic contacts to p-GaN. In this study, we investigate the role of overlayer on the formation of highly transparent, low-resistance ohmic contacts to p-GaN. For this purpose, various metals were deposited on Ni layer and annealed in O_2 ambient. The results show that that thermodynamic properties and work function of the overlayer greatly influence the performance of the Ni-based ohmic contacts to p-GaN.

EXPERIMENTAL

In this study, the InGaN-MQW-LED structures grown by metalorganic chemical vapor deposition on sapphire were used. The LED structure consists of a 30 nm low temperature GaN buffer layer followed by 4μm GaN:Si. The MQW consists of five 2 nm thick well layers of $In_{0.2}Ga_{0.8}N$ and 10 nm thick barrier layers of GaN layer, followed by 150 nm thick p-GaN layer. Ohmic contact resistivity was determined using transmission line method (TLM). An active region was defined by chemically assisted ion beam etching using Cl_2. The TLM test structures were patterned by photoresist. Two types of samples were prepared. One set of specimen is the deposition of Ni(5 nm) and Pt, Au, or Pd metals in sequence on the p-GaN. The other set of specimen is the deposition of Ni(5nm), followed by annealing in O_2 ambient and deposition of Al, Ti, Au, Pt metal. For the fabrication of LEDs, Ti/Al ohmic contact was used as n-electrode.

RESULTS AND DISCUSSION

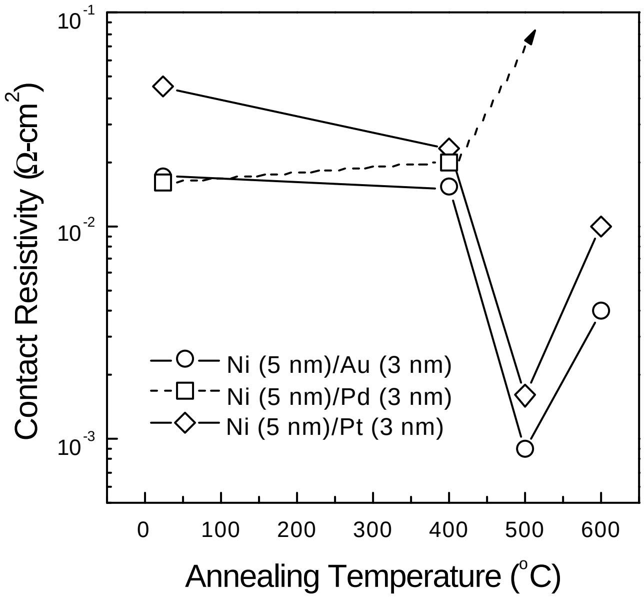
Figure 1 shows the variation of contact resistivities as a function of annealing temperature for Ni-based ohmic contacts with three different overlayers. For the Ni/Au and Ni/Pt contacts, contact resistivities drastically decreased after annealing at 500℃ for 10 min. The minimum contact resistivities of the Ni/Au and Ni/Pt contacts were 9×10^{-4} Ωcm^2 and 1×10^{-3} Ωcm^2, respectively. The rapid decrease of the contact resistivity is attributed to the formation of NiO as well as reduction of sheet resistance of p-GaN. However, the contact resistivity of the Ni/Pd contact increased rapidly after annealing at 500℃. The oxidation of Pd overlayer as well as Ni layer during O_2 annealing is responsible to the increase of the contact resistivity.

Figure 2 shows the transparency spectra for the three contacts after annealing at 500℃ in O_2 ambient. The light transmittance for the Ni/Au contact was as high as 90%. Meanwhile, that for the Ni/Pt contact was lower than 60%. In order to investigate the influence of the transparency on the performance of LEDs, we fabricated LEDs with Ni/Au and Ni/Pt contacts as a p-electrode. As shown in Fig. 3, the operation voltage of the fabricated LEDs were ~4 V at 20 mA for both Ni/Au and Ni/Pt contacts. However, the Ni/Au contact was much transparent than the Ni/Pt contact. This resulted in much higher luminous intensity of the LEDs with Ni/Au contact (1.1cd) than those with Ni/Pt contact (0.7 cd). Thermodynamic properties of the overlayer determined the transparency of the contacts. The positive heat of formation for Ni-Au alloy allows the segregation of Au in the grain boundaries of NiO, which results in highly transparent contacts. However, large negative heat of formation for Ni-Pt alloy results in the formation of Ni-Pt layer, followed by reduction of transparency of the contact.

Figure 4 shows the I-V curves of LEDs with NiO/metal contacts. This clearly indicates that higher the work function of overlayer, lower the operation voltage. This implies that the work function of the overlayer should be high enough.

CONCLUSIONS

We investigated the role of overlayer in the Ni-based ohmic contacts on the performance of LEDs. From these study, we concluded that the overlayer in the Ni-based transparent ohmic contacts should satisfy the following conditions, that is, (1) positive heat of formation for the Ni-overlayer alloy, (2) much higher oxidation resistance than Ni, and (3) high work function.



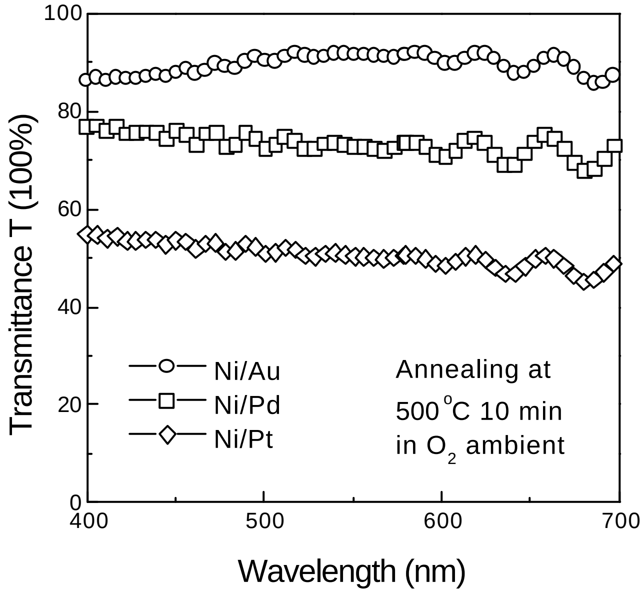


Fig. 1. Variation of contact resistivity as a function of annealing temperature. Annealing time was 10 min

Fig. 2. The transmission spectra of Ni-based ohmic contacts to p-GaN

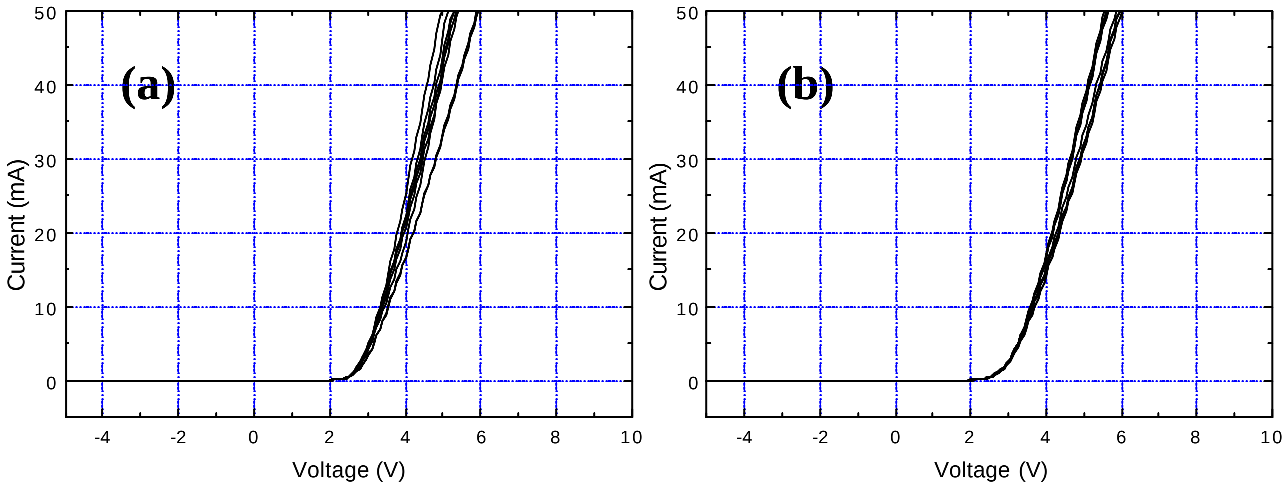


Fig. 3. I-V characteristics of fabricated LED using (a) Ni/Au and (b) Ni/Pt ohmic contacts as a p-electrode

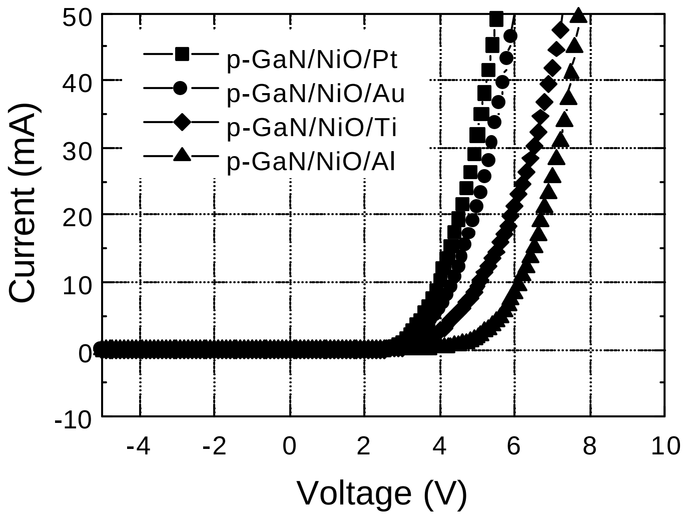


Fig. 4. I-V characteristics of fabricated LED using NiO/metal Ohmic contacts as a p-electrode

Overlayer Metal	Interaction With Ni ($H_{formation}$) (kJ/mole of atoms)	Oxidation ($G_{formation}$) (kJ/mole of atoms)	Work Function (eV)
Au	Ni50Au50 +8	+15	5.1
Pt	Ni50Pt50 -9.3	.	5.65
Pd	Ni50Pd50 -0.5	-41	5.12

Table 1. Selected properties of overlayers