Effects of Pre-annealed Nickel Contact Layer on LED Device Performance using Ni/Ag-based p-type Contacts

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Abstract: Effects of pre-annealed Ni contact layer on the blue LED device characteristics using Ni/Ag-based p-type contacts were investigated. It can effectively suppress reverse leakage current without affecting the forward voltage of LEDs.

OCIS codes: (230.0230) Optical devices; (220.0220) Optical design and fabrication; (250.0250) Optoelectronics

1. Introduction

Highly reflective ohmic contacts are crucial in vertical LEDs and flip-chip LEDs. Much research has been conducted in improving light reflectance or reducing contact resistance using different metal schemes and annealing conditions [1-5]. Among different metal schemes, Ni/Ag-based p-type ohmic contact is known to be one of the most desirable candidates for high performance LEDs because Ag provides the highest reflectance at blue wavelengths and forms ohmic contact on p-type GaN [3-5].

Ni/Ag-based contacts are typically deposited via one-step evaporation followed by annealing in an oxygen ambience to form ohmic contacts. After oxyen annealing, the nickel contact layer is converted to NiO which is commonly expected to reduce contact resistance like nickel in Ni/Au contact for top-emitting LEDs. In addition, it has been mentioned that NiO can enhance thermal stability of the contact, improve Ag adhesion, and prevent Ag agglomeration [5, 6]. Some publications proposed single or multiple metal overlayers on Ni/Ag to further prevent Ag agglomeration and improve reflectance, but metal inter-diffusion may degrade contact resistance and reflectance [7]. Furthermore, effect of Ni/Ag-based contact on LED's reverse leakage has seldom been discussed in prior publications.

In this paper, effects of pre-annealed Ni contact layer on the device performance of gallium nitride-based blue LED device characteristics using Ni/Ag-based p-type contacts were investigated. A proposed mechanism of ohmic contact formation was also discussed.

2. Experiment

Blue LED GaN epi grown on planar sapphire substrate by metalorganic chemical vapor deposition (MOCVD) with peak emission wavelength of 450nm were used in this study. A plasma-enhanced CVD (PECVD) grown SiO2 mask was used for inductively coupled plasma (ICP) etching. 300μm × 300μm MESAs were patterned by standard photolithography and etched down to the n-type GaN. Then a Ni(8Å) contact layer was e-beam evaporated and RTA annealed at 650℃ for 30 seconds in N_2 ambience. Afterwards, Ni(2Å)/Ag(150nm) or Ni(2Å)/Ag(150nm)/Pt(10nm) were deposited and followed by post-deposition annealing at 400℃ for 3 minutes in an O_2 ambience. LEDs with conventional one-step Ni(10Å)/Ag(150nm) contacts annealed at 400℃ for 3 minutes in O_2 ambience were also separately fabricated for comparison. To finish the device fabrication, Ti/Al/Ti/Au (300/120/50/50 nm) metal layers were finally evaporated to form the p and n- electrodes. The electrical and optical properties of FCLEDs were measured using a semiconductor parameter analyzer (HP 4155A) and LED auto-prober with spectrometer.

3. Results and Discussion

From the test results, the forward voltage of Ni/Ag-based LEDs with N_2 pre-annealed Ni contact layer (2.86V to 2.88V at 20mA) was similar to the one with one-step Ni/Ag contact (2.89V at 20mA). However, as shown in Fig. 3(Left), the reverse leakage of the former one (<50nA at -10V) is significantly lower than the latter (10μA at -10V). It demonstrated that the N_2 pre-annealed Ni contact layer can effectively suppress Ag in-diffusion without affecting the forward voltage of LEDs, as depicted in Fig. 2(Left). Surface morphology of the contacts was also retained after annealing, preserving its reflectance. In this experiment, we also observed that the Ni/Ag-based LEDs with Pt overlayer have lower optical output power than LEDs with Ni/Ag contact, which indicates that in-diffusion of Pt causes degradation of contact reflectance as shown by SIMS depth profiling in Fig. 2(Right). In addition, both forward voltage and reverse leakage of LEDs using Ni/Ag contact with O_2 pre-annealed Ni contact layer are much higher, which implied that NiO is unexpectedly not a key aspect of the ohmic contact formation in the Ag-based contacts and high oxygen incorporation in Ni contact layer enhances Ag in-diffusion and cause higher reverse leakage/contact resistance instead.

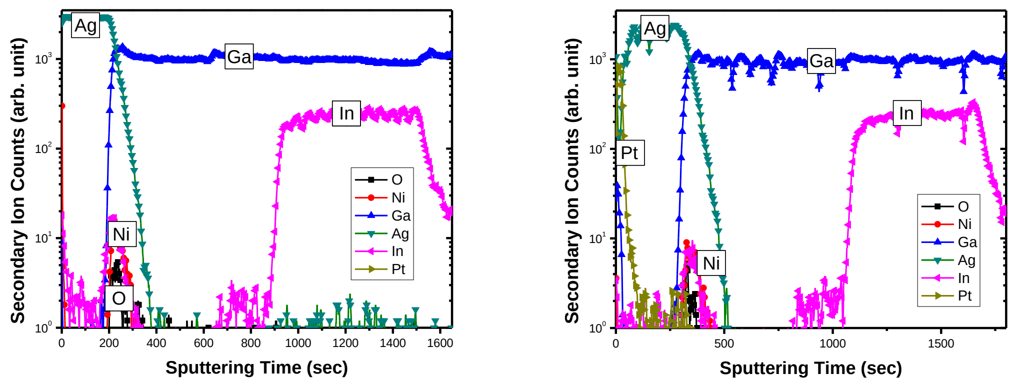

Fig. 1. SIMS of (left) Ni/Ag and (right) Ni/Ag/Pt contact after N_2 annealing at 400°C for 3 minutes. Except the out-diffusion of indium, no significant in-diffusion of Ag and Pt were observed.

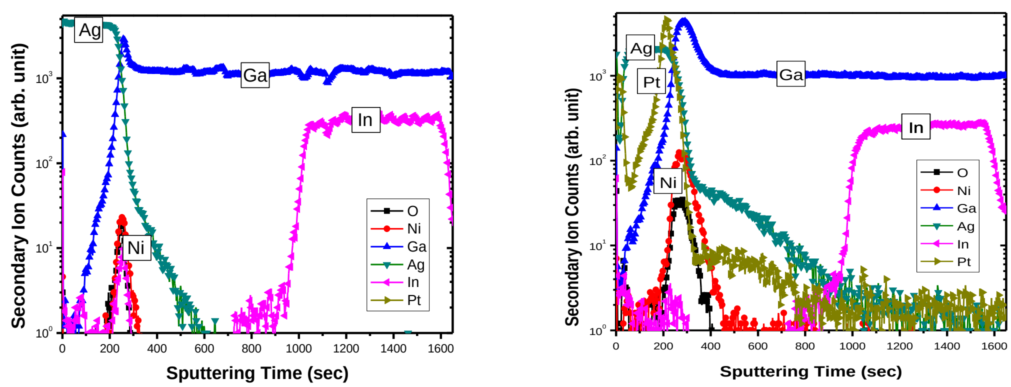

Fig. 2. SIMS of (left) Ni/Ag contact with N_2 pre-annealed Ni contact layer after O_2 annealing at 400°C for 3 minutes; and (right) Ni/Ag/Pt contact with O2 pre-annealed Ni contact layer after O2 annealing at 400°C for 3 minutes. Fig. 2(left) shows in-diffusion of Ag was prohibited by N_2 pre-annealed Ni contact layer. Meanwhile the in-diffusion of Ag is significant on the contact shown in Fig. 2(right). It is suspected that in-diffusion of Pt caused degradation of contact reflectance.

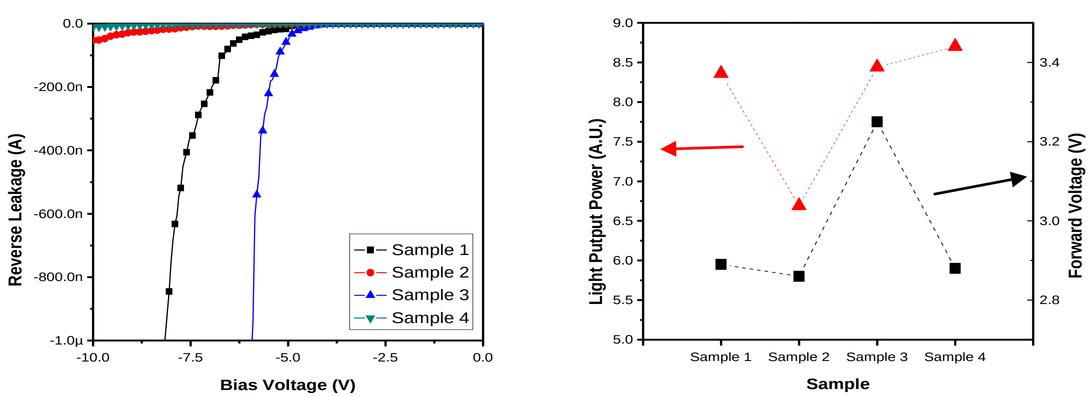

Fig. 3. (left) Reverse leakage of LED sample 1 (one-step Ni/Ag), sample 2 (Ni/Ag/Pt with N_2 pre-annealed Ni Contact layer), sample 3 (Ni/Ag contact with O_2 pre-annealed Ni Contact layer), and sample 4 (Ni/Ag contact with N_2 pre-annealed Ni Contact layer), all annealed at 400°C for 3 minutes at O_2 ambience. Fig. 3(right) LED sample 2 has lower optical output power, which is attributed to the in-diffusion of Pt, as indicated in Fig. 2(right).

4. Conclusion

Effects of pre-annealed Ni contact layer on the blue LED device characteristics using Ni/Ag-based p-type contacts were investigated. The results show N_2 pre-annealed Ni contact layer can effectively suppress reverse leakage current without affecting the forward voltage and light output power of LEDs. In contrast, O_2 pre-annealed Ni contact layer significantly degrades the electrical performance of LEDs. It is suspected that high oxygen incorporation in Ni contact layer enhances Ag in-diffusion and cause higher reverse leakage/contact resistance instead.

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6. References

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