Highly Reflective and Low Resistance Indium Oxide/Ag Ohmic Contacts to p-GaN for Flip-Chip Light Emitting Diodes

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GaN-based semiconductors are significantly important for the applications in high-brightness light emitting diodes (LEDs) for solid-state lighting. To realize solid-state lighting, the achievement of high extraction efficiency is vital. Flip-chip LED configuration was shown to be very effective in increasing extraction efficiency in GaN-based LEDs.[1,2] For flip-chip LEDs (FCLEDs), the formation of low resistance and high reflective p-GaN contact is essential.

In this work, we have investigated low resistance and highly reflective various doped In_2O_3(DIO)/Ag ohmic contacts to *p*-type GaN for FCLEDs by means of current-voltage (I-V) measurements, x-ray photoemission spectroscopy (XPS), transmission electron microscopy (TEM), and Auger electron spectroscopy (AES). It is shown that the DIO/Ag contacts show excellent ohmic behaviours with specific contact resistances in the range ~10^{-4}-~10^{-5} Ωcm^2, when annealed at temperatures of 330-530 °C for 1 min in air ambient. For example, Fig. 1 shows the annealing temperature dependence of the I-V characteristics of the Cu-doped In_2O_3/Ag contacts. The as-deposited sample reveals nonlinear I-V behavior. However, their I-V characteristics are significantly improved when annealed in air. Both the annealed samples show somewhat similar electrical behaviors. Measurements showed that the samples yield specific contact resistance of 2.67×10^{-5} and 1.28×10^{-5} Ωcm^2 for 330 and 530 °C, respectively. It was further shown that the annealed samples produce reflectivity higher than ~90 % at 460 nm, which is superior to those of the annealed Ni/Au and Ni/ITO-based contacts. Furthermore, the I-V characteristics of the LEDs fabricated with the DIO p-contact layers exhibit a forward-bias voltage of within 3.0-3.6.0 V at injection current of 20 mA, which is comparable to (and much better than) that of the LEDs with the annealed Ni/Au, (Ni)/ITO, Ag single contact layers.

The output power of the LEDs is also characterized. Based on I-V, AES, and XPS results, interfacial reactions and their ohmic formation mechanisms are described and discussed. The results strongly indicate that the DIO/Ag scheme can present a highly promising p-type contact for high power GaN-based FCLEDs for solid-state lighting.

References

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2. F. Sunada, and A. Heller, *Environ. Sci. Technol.* **32**, 282 (1998).

Figure 1 The I-V characteristics of Cu-doped In_2O_3/Ag contacts as a function of the annealing temperature.