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Strain-induced enhancement of thermal stability of Ag metallization with Ni/Ag multi-layer structure

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Vertical-structure light-emitting diodes (V-LEDs) by laser lift-off (LLO) have been exploited for high-efficiency GaN-based LEDs of solid-state lightings. In V-LEDs, emitted light from active regions is reflected-up from reflective ohmic contacts on p-GaN. Therefore, silver (Ag) is very suitable for reflective contacts due to its high reflectance (>95%) and surface plasmon coupling to visible light emissions. In addition, low contact resistivity has been obtained from Ag-based ohmic contacts annealed in oxygen ambient. However, annealing in oxygen ambient causes Ag to be oxidized and/or agglomerated, leading to degradation in both electrical and optical properties. Therefore, preventing Ag from oxidation and/or agglomeration is a key aspect for high-performance V-LEDs.

In this work, we demonstrate the enhanced thermal stability of Ag-based Ohmic contact to p-GaN by reducing the thermal compressive stress. The thermal compressive stress due to the large difference in CTE between GaN ($5.6 \times 10^{-6}/^{o}C$) and Ag ($18.9 \times 10^{-6}/^{o}C$) accelerate the diffusion of Ag atoms, leading to Ag agglomeration. Therefore, by increasing the additional residual tensile stress in Ag film, the thermal compressive stress could be reduced, resulting in the enhancement of Ag agglomeration resistance. We employ the thin Ni layer in Ag film to form Ni/Ag mutli-layer structure, because the lattice constant of NiO (4.176 Å is larger than that of Ag (4.086 Å). High-resolution symmetric and asymmetric X-ray diffraction was used to measure the in-plane strain of Ag films. Due to the expansion of lattice constant by oxidation of Ni into NiO layer, Ag layer in Ni/Ag multi-layer structure was tensilely strained after annealing. Based on experimental results, it could be concluded that the reduction of thermal compressive stress by additional tensile stress in Ag film plays a critical role to enhance the thermal stability of Ag-based Ohmic contact to p-GaN.