Buffer Structure Optimization of Monolithically Integrated HEMT-LED Using a Metal-Interconnection-Free Integration Scheme

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Monolithic integration of InGaN/GaN light emitting diodes (LEDs) and AlGaN/GaN high electron mobility transistors (HEMTs) is attracting growing interest due to its advantages in reducing device footprint, simplifying process complexity and enhancing system reliability. In all previously reported works [1-4], the electrical connection between the HEMTs and the LEDs was implemented by metal wire interconnection, which could introduce extra parasitics and degrade the performance of the integrated device. Recently, we demonstrate a metal-interconnection-free scheme for integrated HEMT-LED. The impact of buffer quality on the optical performance of the HEMT-LED device has been investigated. It was found that a specially designed GaN/AlN buffer on sapphire substrates can satisfy both the high crystalline quality and high resistivity requirements for the HEMT-LED integration.

The device fabrication started with selective removal of as-grown AlGaN/GaN HEMT epi-layers on a sapphire substrate by ICP. Subsequently, an LED structure was regrown on the exposed GaN buffer of the HEMT in the etched openings. The overgrown LED epi was initiated with a 1.6 μm thick n-type GaN, serving as the cathode of the LED and the drain connection of the HEMT, enabling a three-terminal HEMT-LED device without metal-interconnection in between. There is negligible interface resistance between the regrown n-type GaN, connecting the vertical LED structure and the 2DEG channel of the HEMT. Comparable on-resistance was observed for the discrete HEMTs and the integrated HEMT-LED devices, indicating good contact between the n-type GaN (cathode) of the LEDs and the 2DEG channel of the HEMTs.

PL spectra from the LEDs grown on high resistivity HEMT buffer exhibited a 40% reduction in the peak intensity as compared to a standard LED on sapphire substrates. We attribute the degradation to the compromised crystalline quality of the high resistivity HEMT buffer. To find an alternative buffer structure suitable for both the HEMTs and the regrown LEDs, a GaN/AlN buffer has been developed. By optimizing the growth condition of the AlN layer, the crystalline quality can be as good as the commonly-used LED buffer on sapphire while maintaining high resistivity. Raman spectra indicated that the LEDs grown on the high resistivity HEMT buffer showed tensile stress of around 0.41 GPa. Using the GaN/AlN buffer, the stress condition was tuned to compressive stress, which can effectively eliminate the possibility of cracking in the regrown LED epi. As a result, this kind of GaN/AlN is promising to serve as a common platform for HEMT-LED integration to achieve high-power light output and high breakdown voltage simultaneously.

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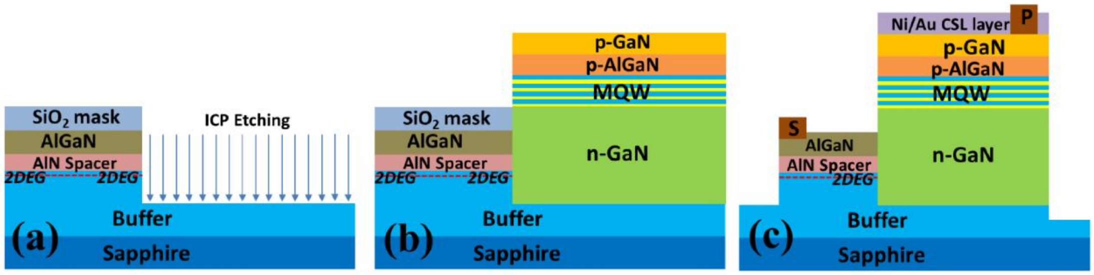


Fig. 1 Simplified process flow for HEMT-LED integration: (a) Selective epi removal of AlGaN/GaN stack to expose GaN buffer, (b) Selective epitaxial growth of LED epi (c) Mesa etching and electrode deposition.

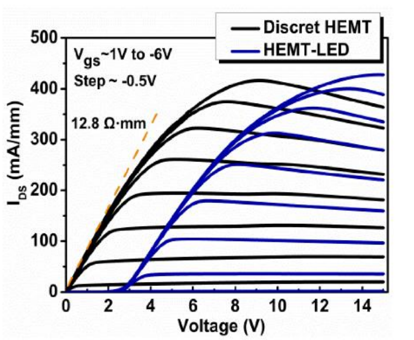


Fig. 2 Output characteristics of the discrete HEMT and integrated HEMT-LED devices, respectively.

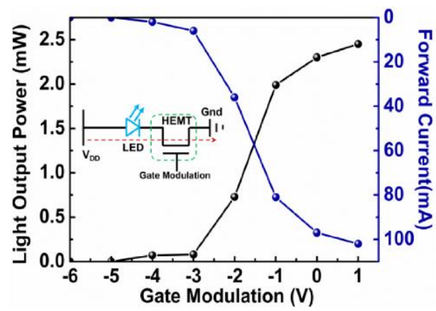


Fig. 3 Light output power and I-V characteristics of the HEMT-LED device modulated by V_{gs} at V_{dd} = 8V

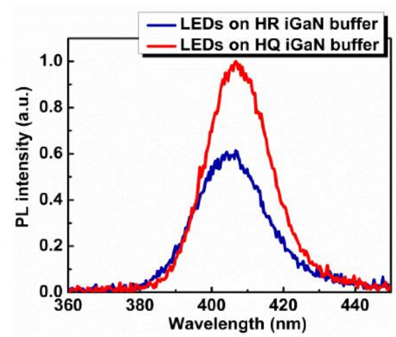
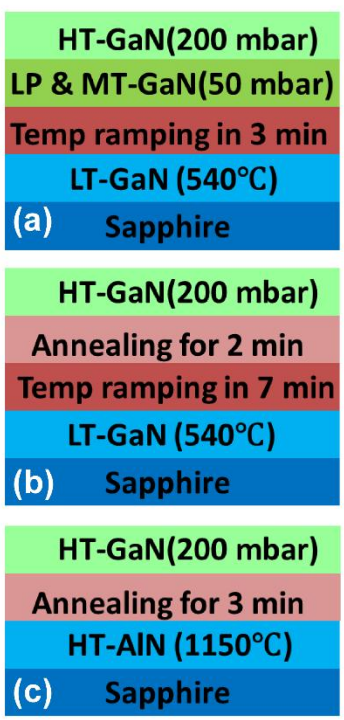


Fig. 4 Photoluminescence spectra for LEDs grown using high resistance (HR) HEMT buffer and high quality (HQ) LED buffer, respectively.



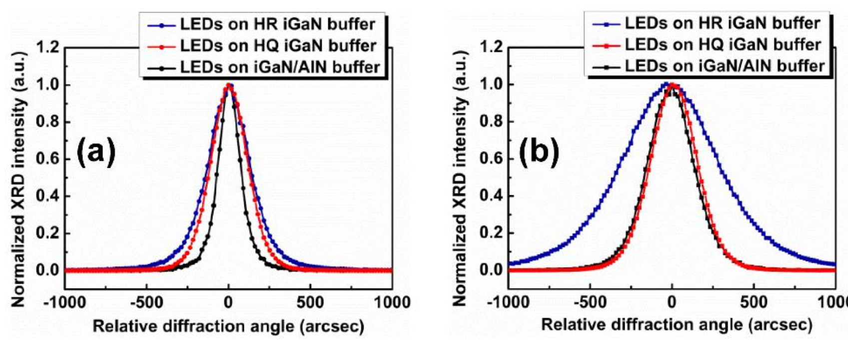
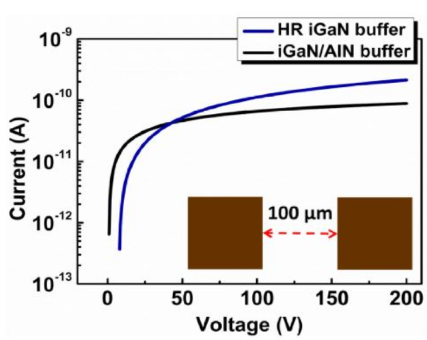


Fig. 6 HRXRD omega rocking scans of (a) GaN (002) and (b) GaN (102) for high resistance (HR) iGaN buffer , high quality (HQ) iGaN buffer and iGaN/AlN buffer, respectively.



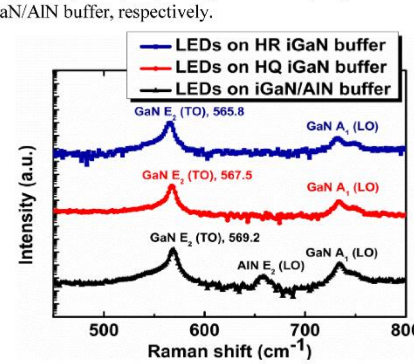


Fig. 5 Schematic of (a) high resistance (HR) iGaN buffer, (b) high quality (HQ) iGaN buffer, and (c) iGaN/AlN buffer on sapphire.

Fig. 7 Breakdown characteristics for the high resistance (HR) iGaN buffer, and iGaN/AlN buffer on sapphire.

Fig. 8 Micro-Raman spectra of the LEDs using high resistance (HR) iGaN buffer, high quality (HQ) iGaN buffer, and iGaN/AlN buffer, respectively.