ENHANCED OPTICAL PERFORMANCE OF MONOLITHICALLY INTEGRATED HEMT-LED BY BUFFER OPTIMIZATION

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Monolithic integration of III-nitride light emitting diodes (LEDs) and high electron mobility transistors (HEMTs) on a common material platform is challenging but advantageous in eliminating parasitic components of interconnects.[1-4] Recently, we demonstrated a metal-interconnection-free integration scheme for HEMT-LED integration by combining selective epi removal and selective epitaxial growth procedures. These metal-interconnection-free HEMT-LED devices exhibit good characteristics in the modulation of the LED brightness by gate control of the injected driving current through the HEMT with excellent off-state characteristics. Besides this, with a seamless contact between the GaN channel of the HEMTs and the n-type layer of the LEDs (Fig. 1), the interconnection related parasitic components can be effectively minimized and eliminated. However, due to the differences in material requirements for LED and HEMT, it is not trivial to achieve high brightness in the LED and high breakdown in the HEMT simultaneously, which impedes further development of the integrated HEMT-LED device.

In optimizing the integration scheme, we have designed a GaN/AlN buffer on sapphire, offering good crystalline quality and high buffer resistivity for the integrated HEMT-LED devices. The influence of the AlN growth conditions (e. g. temperature, pressure, and V/III) on the crystalline quality of the upper GaN buffer has been investigated, as illustrated in Fig. 2. Under optimal growth conditions, the full-width-at-half-maximum value of the GaN buffer can be as small as 173 arcsec and 337 arcsec for (002) and (102) planes, respectively. In the meantime, a low buffer leakage was achieved. Based on this high-quality GaN/AlN buffer, AlGaN/GaN HEMT epi was grown on sapphire substrate, which showed an RMS roughness value of 0.3 nm and a sheet resistance of 280 Ω/□, with a 2DEG mobility over 1700 $cm^2/V \cdot s$. In addition, another two AlGaN/GaN HEMT structures based on high resistance HEMT buffer and high quality LED buffer have been grown for reference. Atomic force microscope was used to compare the surface morphology of the HEMTs grown on different kinds of buffers (Fig. 3). The HEMTs grown on the high resistance HEMT buffer showed disordered step-flow surface morphology, accompanied by a large density of line-shaped defects. By using the GaN/AlN buffer, the AlGaN HEMT surface exhibited well-aligned atomic steps, similar to that on the high quality LED buffer. Afterwards, ICP etching was performed to selectively remove part of the HEMT epi and InGaN/GaN LED epi regrowth was performed on the exposed region. Photoluminescence measurement showed significantly enhanced peak intensity of the LEDs grown on the GaN/AlN buffer, compared to that on the high resistance HEMT buffer (Fig. 4 (a)). The improvement is mainly due to the reduced dislocation density, as reflected by the reduced XRD linewidth (Fig. 4 (b)). Besides this, red-shift of the peak wavelength can be observed in the LEDs grown on the high resistance HEMT buffer, which is caused by the residual tensile stress originated from the high resistance HEMT buffer and further built up during the subsequent n-type GaN growth, as is shown in the micro-Raman results in Fig. 4 (c). Using the GaN/AlN buffer, the tensile stress can be tuned to compressive stress, attributed to the smaller lattice constant of the underlying AlN layer. This can effectively eliminate the possibility of crack for the overgrown LED epi and improve the yield of the integrated HEMT-LED device. As a result, this kind of GaN/AlN buffer can serve as a common platform for HEMT-LED integration to achieve an enhanced optical performance of the LEDs without degrading the high breakdown performance of the HEMTs.

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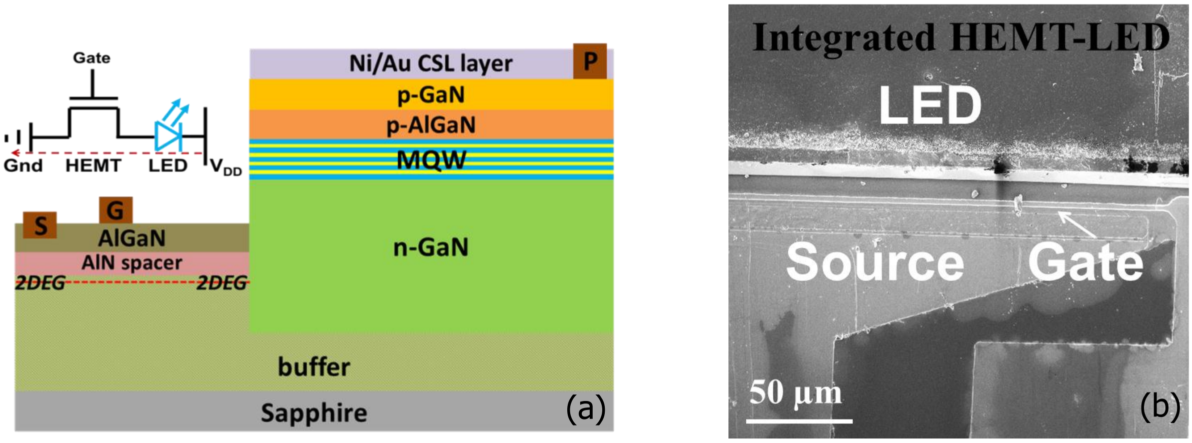

Fig. 1 (a) Schematic of the metal-interconnection-free HEMT-LED device. The inset shows the equivalent circuit diagram of the integrated HEMT-LED device and (b) Top view SEM image of the fabricated HEMT-LED device.

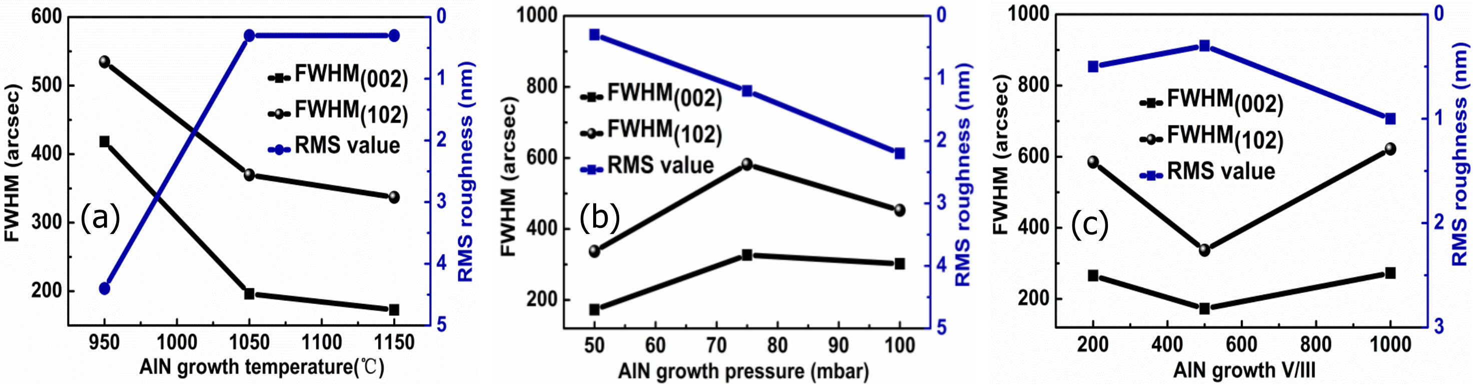

Fig. 2 Influence of (a) AlN growth temperature, (b) AlN growth pressure, and (c) AlN growth V/III on the crystalline quality of GaN as well as the surface roughness value of the AlGaN/GaN HEMTs using the GaN/AlN buffer.

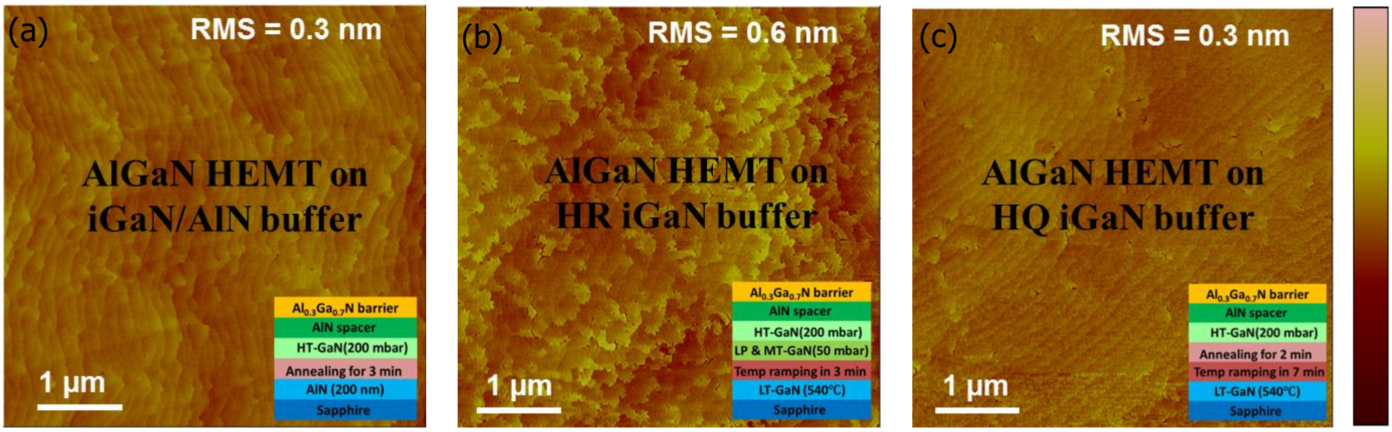

Fig. 3 Surface morphology of AlGaN/GaN HEMTs using (a) GaN/AlN buffer, (b) high resistance (HR) HEMT buffer, and (c) high quality (HQ) LED buffer. Vertical scale bar is 10 nm.

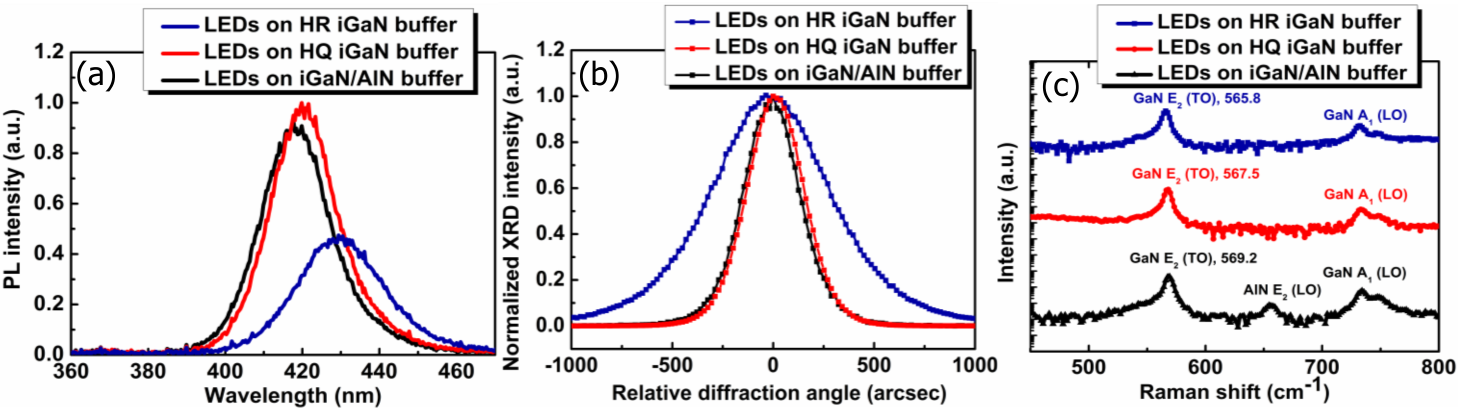

Fig. 4 (a) PL spectra from LEDs overgrown on different buffers, (b) XRD omega rocking curve from (102) planes, and (c) Micro-Raman spectra from of the LEDs using different buffers.