# Selective-area femtosecond laser lift-off processing of GaN LED chips

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**Abstract**

Gallium nitride (GaN) is a promising semiconductor material for creating versatile LED devices in various applications, including solid-state lighting, augmented reality, and sensors. By transferring the nanostructured GaN LEDs onto flexible substrates, they could even exhibit enhanced performance compared to flexible organic LEDs in terms of their flexibility, longevity, and external quantum efficiency. To release GaN LED chips from their original sapphire substrates to other substrates, laser lift-off (LLO) has been regularly utilized in production of power LEDs as a reliable and reproducible technology. For the normal LLO process, photons with energies above the band gap of GaN are used, so that the energy is dissipated at the sapphire/GaN interface. These LLO processes are based on expensive excimer laser technology, and due to limitations in available wavelengths, not transferable to

AlGaN LLO with higher band gaps. In this work, a femtosecond LLO technology is proposed and demonstrated to realize free-standing GaN LED chips. The used laser has a wavelength of 520 nm, a pulse length of 350 fs, and a repetition rate of 200 kHz. Even though the impinging photons have lower energy than the GaN bandgap (3.4 eV), the directed laser pulse is transmitted through the sapphire and reaches the interface to the n-GaN layer, where it is absorbed by non-linear two-photon excitation. Consequently, the GaN is decomposed resulting in lift-off from the sapphire. The LED selective-area transfer is performed using a two-step LLO process with different laser energies (Figure 1). From the experiments, InGaN/GaN LED chips with a total area of 1 × 1 $mm^2$ were successfully separated from the sapphire substrate (Figure 2), which exhibited an emission spectrum with peak wavelengths of ~465 nm in cathodoluminescence and electroluminescence measurements. Transmission electron microscopy was also used to verify the condition of InGaN/GaN multi-quantum wells (MQWs).

**Keywords**: laser lift-off, LED, GaN, femtosecond laser

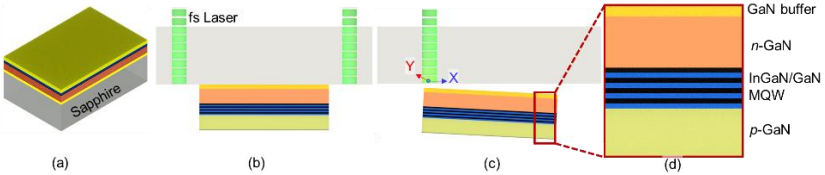


*Figure 1: (a) Sketch of InGaN/GaN LED wafer, (b) and (c) LLO process flow using two-step laser ablation from backside showing (b) higher energy ablation for selectively creating the outer frame surrounding the to be lifted-off GaN chip,(c) scanning with lower energy ablation for releasing the GaN chip from the sapphire substrate (d) investigating the GaN chip epilayers after LLO.*

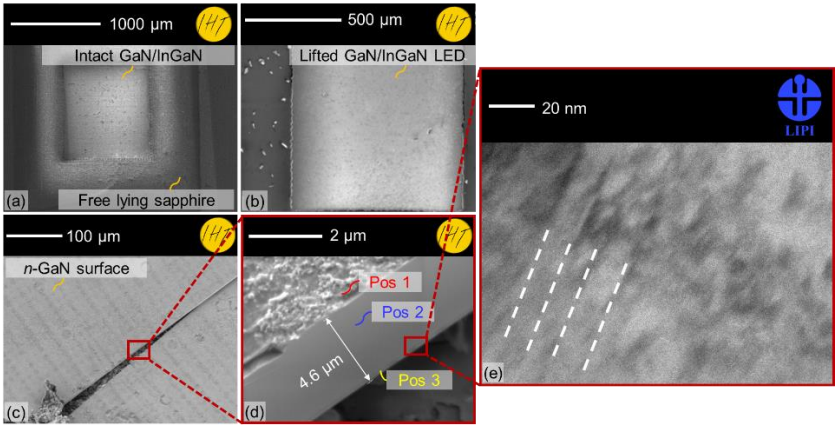


*Figure 2: SEM images of a lifted LED chip. (a) After selective outer frame removal of the GaN layer at high pulse energy, (b) lifted free-standing InGaN/GaN LED chip, (c) closer view at the n-GaN surface condition, (d) cross-section at a cut through the chip. (e) TEM image of the multi-quantum wells (MQWs).*