The importance of sidewall conditions on the performance of micro-LEDs

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III–Nitride-based micro light-emitting diodes (μLEDs), the alternative, ultimate, and recent rising technology for the next-generation display, can realize the ultra-small pixel size that is necessary for augmented reality and virtual reality. Dry etching using inductive coupled plasma-reactive ion etching (ICP-RIE) can easily define the size of μLEDs less than a 10 μm scale with lithography technology. However, ICP-RIE unintentionally produces sidewall damage, resulting in an efficiency loss of μLEDs.

In this study, we shed light on that the sidewall conditions of μLEDs changes both internal quantum efficiency (IQE) and light extraction efficiency (LEE), which are the production of external quantum efficiency (EQE). To reveal the effect of sidewall condition, an equilateral triangle μLEDs with m-planar sidewalls on the scales of 100 μm^2 and 400 μm^2 were intentionally designed. ITO was used as a p electrode and mesa size were identically etched using ICP-RIE. After ICP-RIE, we eliminated the sidewall damage using tetramethylammonium hydroxide (TMAH) that etches non-polar III-nitride surface as shown in Fig. 1. Subsequently, n-electrode (Cr/Au) was deposited. To form the p-electrode, the samples were covered by SiO_2 layer using plasma-enhanced chemical vapor deposition. Then, via hole was formed by a RIE. Finally, Al/Ni/Au p-electrode was deposited. The Al layer was served as a reflection layer to lead the light reflection to downward. Fig. 2 shows the size and TMAH-dependent relative EQE as a function of current density. It was shown that for 400 μm^2 μLEDs, TMAH effectively enhanced EQE by around 10% in low current operation, whereas for 100 μm^2 μLEDs, EQE was slightly reduced by around 3%. Although TMAH could remove the sidewall damage induced by ICP-RIE, the sidewall morphology simultaneously changed (Fig. 1), resulting in decreasing LEE. Interestingly, at a high current regime (Inset of Fig. 2), EQE of 400 μm^2 μLEDs decreased after TMAH. This different behavior at the low and high current regime indicates that TMAH affects both IQE and LEE. For detail, we will discuss through photoluminescence, X-ray photoemission spectroscopy, and transmission electron microscopy.

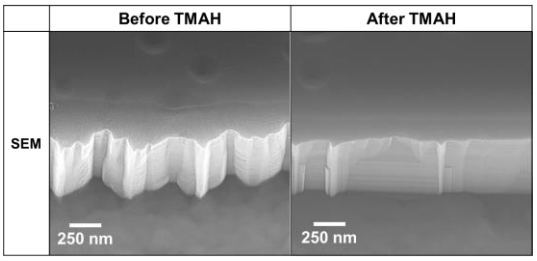

Fig. 1 Sidewall morphology of before and after TMAH.

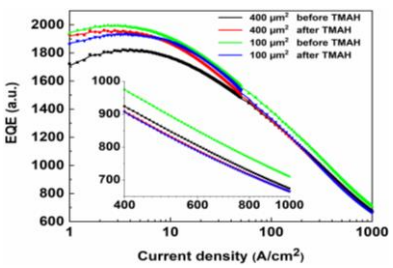

Fig. 2 Size and TMAH dependent EQE of triangular μLEDs.

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