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InGaN/GaN pyramidal quantum structures for microLED applications

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Abstract – We grew and characterized InGaN/GaN pyramidal quantum structures, InGaN nanostructures grown on top of micro-sized GaN pyramids by means of an in-house technique, hot-wall metal-organic chemical vapor deposition. Arrays of InGaN/GaN pyramidal structures exhibited micro-sized pyramids possessing high uniformity, excellent hexagonal base, and multi-layer InGaN/GaN structures with clearly-determined interfaces. Moreover, the pyramidal structures revealed strong and well-defined emission from InGaN nanostructures in the deep blue regime at low temperatures, elucidating the rewards for development of these novel light-emitting systems, and their potential for microLED applications.

1 Introduction

Micro-sized light-emitting diodes (microLEDs) have been emerging as a promising technology for high-performance photonic applications such as high-resolution compact displays [1]. However, the microLED devices of today are mainly fabricated by top-down etching processes of conventional planar InGaN/GaN structures, inevitably resulting in emission efficiency drops as the wavelengths extended beyond blue regimes and/or the device sizes scaled down to micrometer orders [2]. Pyramidal structures with e.g. InGaN quantum structures grown on the top of GaN micro-sized pyramids [3, 4] have a promising potential for development of high-efficiency microLEDs. Since small-size pyramids are advantageous to relax the strain and pyramidal semi-polar facets are effective to reduce the electric field, consequently lowering the quantum confined Stark effects; the micro-sized pyramids are excellent building-blocks for micro-size device structures without need of etching processes, accordingly exhibiting a minimum of sidewall defects. However, there are very few reports on microLED materials and devices based on pyramidal structures [5]. In this work, we report on InGaN/GaN pyramidal structures obtained by hot-wall metal-organic chemical vapor deposition (MOCVD), and characterized by scanning-electron microscope (SEM), high-angle annular dark-field scanning transmission electron microscope (HAADF-STEM), and micro photoluminescence (μ-PL).

2 Sample fabrication

A thin (30 nm) silicon-nitride film was employed as mask layer covering an n-type doped GaN epitaxial layer grown on a silicon-carbide substrate, in which micro-sized openings were obtained by lithography and plasma etching. N-type doped GaN pyramids were grown in the openings by selective-area growth by means of a horizontal hot-wall MOCVD, followed by the growth of InGaN/GaN multiple quantum well (QW) structures, and finally capped by p-type doped GaN on top. The hot-wall MOCVD, an in-house technique developed so far, has been chosen due to its merits of efficient heating and high temperature honogeneity [6], beneficial for growth of wide energy-gap semiconductors including III-nitride systems.

3 Structural characterization

An SEM image shown in Fig. 1 (a) displays an array of InGaN/GaN pyramidal quantum structures grown in circular openings of 1.5 μm diameter, exhibiting a high uniformity throughout the pattern. Besides, a single pyramid (top view and side view) is shown in Fig. 1 (b), revealing an excellent hexagonal base and well-defined facets on top. We did not observe significant parasitic deposition on unpatterned areas, suggesting high selectivity of the growth process. In addition, the HAADF-STEM exhibits multilayer InGaN/GaN structures possessing well-defined interfaces (Fig. 2), with InGaN QWs having uniform thicknesses of 3 nm on the pyramid facets. Moreover, energy dispersive X-ray (EDX) mapping images reveal intense signals of In in the InGaN layers (Fig. 3).

4 Optical characterization

μ-PL measurements were performed, showing clear emission of GaN at room temperature and 5 K (Fig. 4), attributed to the n-type doped GaN. Moreover, in addition to the "yellow" GaN-related emission at long wavelength regimes, which are suppressed at low temperatures, we observed strong and well-defined emission in deep blue regime at low temperatures. Such blue emission is not seen for scans in the areas without pyramids, shown in the inset of Fig. 4, and can be ascribed to the emission from InGaN QW structures. The fabrication of micro-LED devices employing the InGaN/GaN pyramidal quantum structures will be carried out in order to explore merits of the hot-wall MOCVD as well as the structures for development of state-of-the-art LEDs.

5 Summary

We fabricated and characterized InGaN/GaN pyramidal quantum structures obtained by horizontal hot-wall MOCVD. From spectroscopy characterization by means of SEM, STEM and μ-PL, we demonstrated structures with uniform micro-sized InGaN/GaN pyramids, which exhibited multi-layer InGaN/GaN structures with well-defined interfaces on the facets and strong deep-blue emission from InGaN QWs. The results also exemplify the benefits of hot-wall MOCVD for development of novel light-emitting devices, potential for microLED applications.

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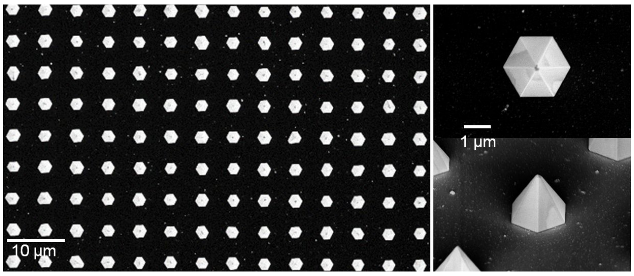

Fig. 1: SEM images of InGaN/GaN pyramidal quantum structures.

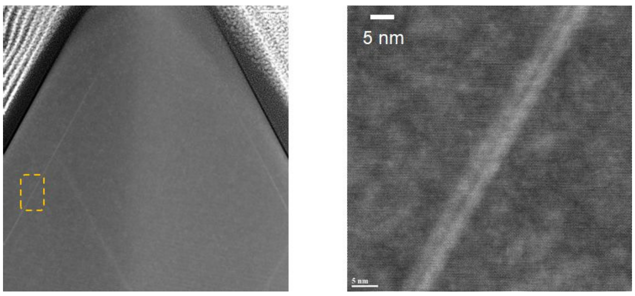

Fig. 2: TEM images of InGaN/GaN pyramidal quantum structures.

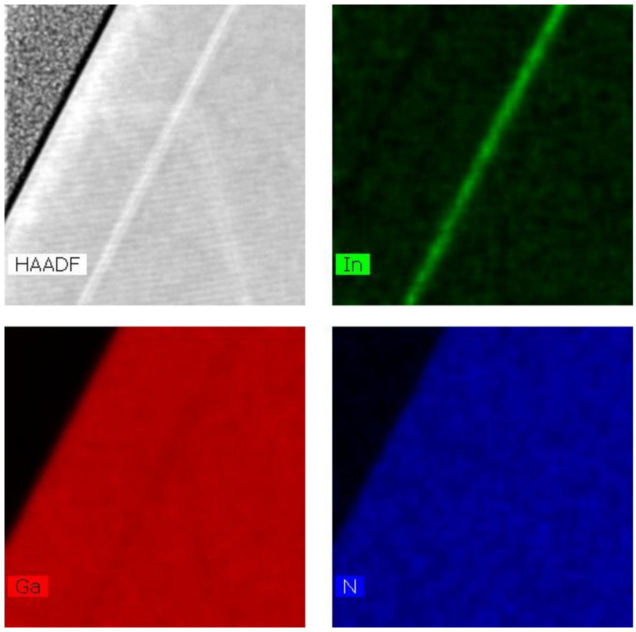

Fig. 3: EDX maps of InGaN/GaN pyramidal quantum structures.

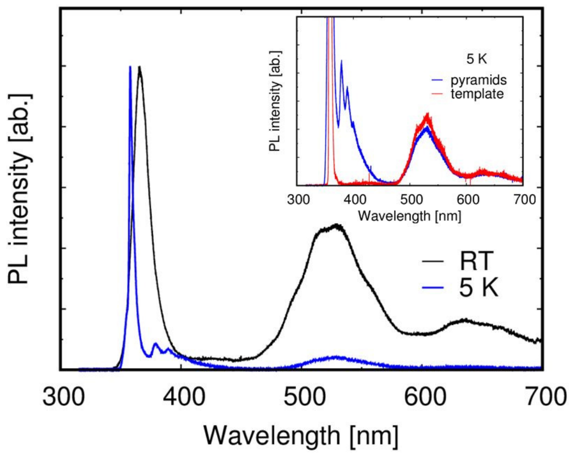

Fig. 4: μ-PL spectra of InGaN/GaN pyramidal quantum structures.