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Enhanced light intensity of InGaN-based LEDs grown on molybdenum patterned sapphire substrates

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Abstract

We report enhanced light intensity of InGaN-based light-emitting diodes (LEDs) grown on molybdenum patterned sapphire substrates (MOPSS). The InGaN-based LEDs grown on the MOPSS has lower quantum-confined Stark effect (QCSE) within multiple quantum wells and better GaN crystal quality than on the conventional sapphire substrates (CSS). The light intensity was increased by 43% at an injection current of 350 mA compared with that of conventional LEDs. The enhancement of light intensity is attributed to improve internal quantum efficiency and light extraction efficiency by MOPSS.

1. Introduction

In recent years, InGaN-based LEDs are useful for wide applications in backlight of flat-panel displays, and solid state lighting. In order to compete with conventional lighting sources and realize the ultimate lamp, the external quantum efficiency (EQE) of InGaN-based LEDs has to be further increased. The EQE of InGaN-based LEDs is determined by internal quantum efficiency (IQE) and light-extraction efficiency (LEE). Many significant methods have been utilized in the literatures to improve the EQE of InGaN-based LEDs, such as PSSs [1], epitaxial lateral overgrowth (ELOG) [2], and so on. Among these technologies, the PSSs method is currently being used in manufacturing industries because of its high production yield. The PSSs technique can improve both IQE and LEE by decreasing threading dislocations and enhancing light scattering. Although the PSSs technique already have significant improved the EQE, the devices operated at high driving currents inevitably generate amounts of heat. It has been reported that the optical power is degraded with heat due to the thermal activation of non-radiative electron–hole recombination [3]. Various techniques have been developed to o overcome the thermal issues [4].

In this work, we report the high performance of the InGaN-based LEDs grown on molybdenum patterned sapphire substrates (MOPSS). It is known that metal molybdenum (Mo), as well as metal W, is a high melting point material with good chemical stability which could avoid reaction with chemical species in the growth ambient. Therefore, metal Mo not only offers heat dissipation but also enhances light reflection inside the LEDs.

2. Experiments and results

The MOPSS were fabricated with photolithography and sputter deposition. The fabrication started with photoresist (PR) on the 2 inch c-plane sapphire substrate and circle-shaped PR mask array patterns was formed by the photolithography method. Then, the 100-nm Mo film was grown by DC magnetron sputter deposition. After removal of resistance, the MOPSS was obtained. The MOPSS patterns having the diameter of 3.5μm, height of 100nm and periodicity of 6μm were fabricated on the 2 inch c-plane sapphire substrate. The surface morphology, periodicity, height and diameter of the accomplished PSSs were examined by FEI Dual-Beam NOVA 600i Focused Ion Beam and optical microscope (OM) as shown in Figure 1. The energy-dispersive X-ray spectroscopy (EDS or EDX) analysis shows in the inset of fig. 1 (a), and it indicated that molybdenum-circle shaped patterns deposited on the sapphire (Al_2O_3) substrates.

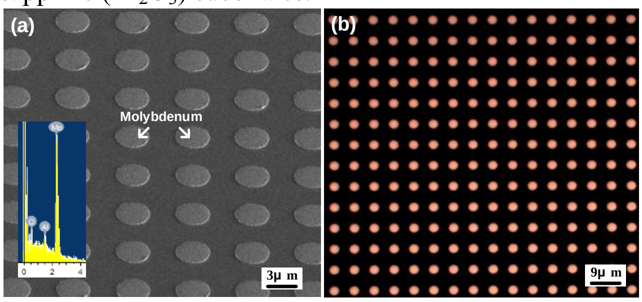

Fig. 1 (a) Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS or EDX) analysis, and (b) optical microscope (OM) analysis for MOPSS.

After the cleaning process, the InGaN-based LED samples were grown on the PSSs with Taiyo Nippon Sanso SR2000 atmospheric-pressure metal organic chemical vapor deposition (AP-MOCVD) under three-flow gas injection. The InGaN-based LED structures, which consist of a 25 nm-thick low-temperature GaN nucleation layer, a

2.5-μm-thick unintentionally doped GaN buffer layer (grown at 1180°C), and a 3-μm-thick n-GaN layer, using SiH_4 as the n-type dopant, were firstly grown on the PSSs. Then, five pairs of InGaN/GaN multiple-quantum wells (MQWs) having a 2.9-nm-thick InGaN well and a 11-nm-thick GaN barrier (grown at 800°C and 850°C, respectively) were deposited, followed by a 20-nm-thick p-AlGaN electron blocking layer, and a 120-nm-thick p-GaN layer, using Cp_2Mg as p-type dopant. The InGaN-based LEDs with a conventional sapphire substrate (CSS) and MOPSS were grown under the same growth conditions.

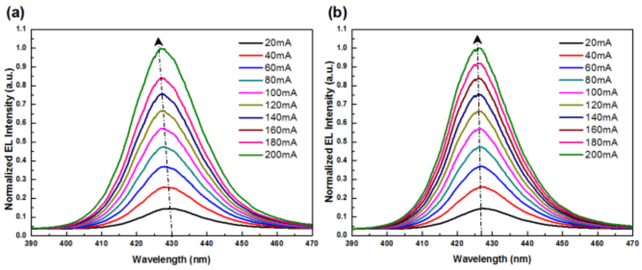

Fig. 2 Blue shifts phenomenon of the InGaN-based LEDs having the (a) CSS and (b) MOPSS.

Utilizing the excitation current dependent electroluminescence (EL) measurement was used to examine the quantum-confined Stark effect (QCSE). Figure 2 (a) and (b) show the peak wavelength shifts of EL spectrum under different injection current for the InGaN-based LEDs having the CSS, and MOPSS, respectively. As show in the figure, the EL spectra of InGaN-based LEDs having the CSS, and MOPSS at the injected currents from 20mA to 200mA. The shifts in EL peak wavelength between 20-mA and 200-mA forward current for the InGaN-based LEDs with CSS and MOPSS are 1.8 nm and 1 nm, respectively. Therefore, the InGaN-based LED grown on the MOPSS has the weaker QCSE than that grown on the CSS. The abatement of QCSE within the MQWs elevates the overlap between electron and hole wave functions and reduces the nonradiative recombination rate.

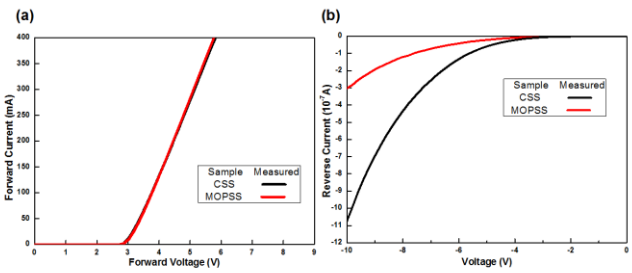

Fig. 3 (a) Forward I-V characteristics and (b) reversed I-V characteristics, of InGaN-based LEDs having the CSS and MOPSS.

Figure 3 shows the current-voltage (I-V) characteristics of the InGaN-based LEDs, fabricated with the standard 1×1 mm^2 LED die processed in the industry. The forward voltages of the InGaN-based LEDs grown on the CSS and MOPSS at an injection current of 350mA were 5.48 and 5.43 V, respectively. The behavior of forward current versus voltage curves for the InGaN-based LEDs grown on the CSS and MOPSS are very similar even under high injection current. The reverse leakage current of InGaN-based LEDs is shown in the figure 3 (b). The reverse currents at a voltage of -10V for the InGaN-based LEDs grown on the CSS and MOPSS are -11×10^{-7} and -3×10^{-7} A, respectively. As compared with the InGaN-based LED grown on the CSS, the samples grown on the MOPSS have lower leakage current due to the better crystalline quality of GaN epitaxial layers.

Figure 4 shows light intensity (light emitted toward the upward direction measured by placing the detector on the top of LEDs) of the devices as the function of injection current. It was observed that the InGaN-based LEDs with the MOPSS have higher intensity than that with the CSS. Compared with the InGaN-based LED grown on the CSS at an injection current of 350mA, the enhanced ELintensity values of the samples grown on the MOPSS are by up to 43%. According to the above experimental results, the stronger LOP of the sample with MOPSS can also be contributed from the lower QCSE in the InGaN/GaN MQWs and larger light reflection by metal Mo arrays patterns..

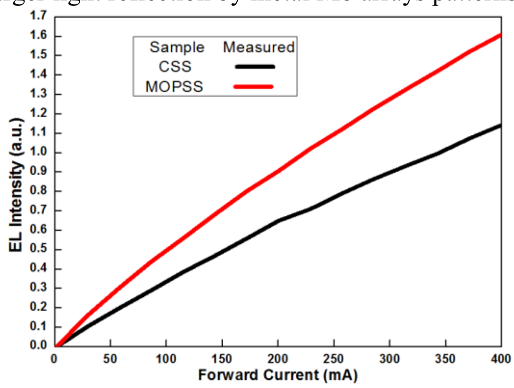

Fig. 4 EL characteristics of InGaN-based LEDs having the CSS and MOPSS.

3. Conclusions

This paper reports that the growth of InGaN-based LEDs on the MOPSS can have better crystal quality and extract more light than on the CSS. Furthermore, reduction of QCSE in the InGaN/GaN MQWs is observed. Compared with the InGaN-based LED grown on the CSS at an injection current of 350mA, the enhanced ELintensity values of the samples grown on the MOPSS are by up to 43%.

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