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Improvement of Luminous Efficiency of Micro Ultraviolet Light-Emitting Diodes with Photonic Crystals

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ABSTRACT

This study investigates the luminous efficiency on 385nm AlInGaN-based Micro UltravioletLight-emitting Diodes (uUV-LEDs) with Photonic Crystals (PhCs). The PhC lattice constant of 385 nm, and hole depth of 250 nm on the pGaN layer increase the output power extraction efficiency by 1.74timescompared with pGaN non-PhCuUV-LED.

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Introduction

As several research groups have already reported, GaN based ultrathin microcavity light-emitting diodes (uMCLEDs) with photonic crystals (PhCs) increase the output power extraction efficiency by approximately 150% compared with GaN non-PhC uMCLED, and obtained a directional far-field emission pattern at half intensity of nearly ±15° [1,2].

Our group has developed micro-LED display that micro-UV-LED excite red green and blue phosphor. We have already reported that our micro-UV-LED method is superior than other methods that apply red, green and blue LEDs, or that blue LED excite red and green phosphor [3].

As the mass production period approached, it became necessary to further increase the luminous efficiency of micro-UV-LEDs. Therefore, we fabricated PhCs structure on pGaN layer of 385nm LED wafer and evaluated it.

Materials and Methods

First, a UV-LED wafer with a peak wavelength of 385 nm was grown on a 4-inch sapphire substrate using a Metal Organic Chemical Vapor Deposition method (MOCVD), then PhC was patterned on the p-layer by using an EB lithography, and then PhCs was fabricated by Ionized Inductively Coupled Plasma(ICP) etching. The formation area was 2 mm x 2 mm, and it was formed in five places on the 4-inch wafer surface. After that, the chip process was performed to create a flip chip with a light-emitting area of 90 um x 90 um. Figure 1 shows the flip chip process procedure, and Figure 2 shows the structure of the fabricated flip chip.

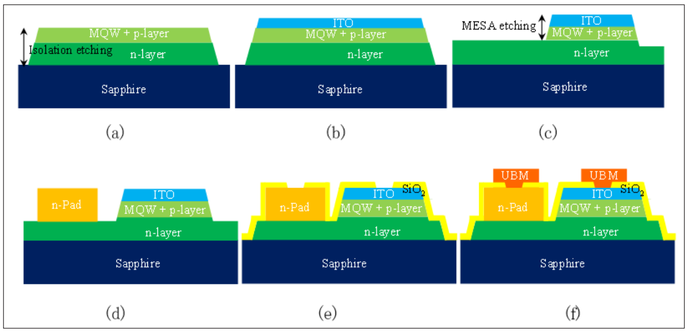

Figure 1: Fabrication Steps for the UV µLED Chip.
(a): Each chip size is formed by Isolation Etching on the p-layer, multi quantum well (MQW), and n-layer; (b): ITO is deposited on the p-layer; (c): n-layer is exposed by Mesa Etching; (d): n-pad is deposited on the n-layer; (e): Partially etched SiO2passivation; (f): UBM deposition

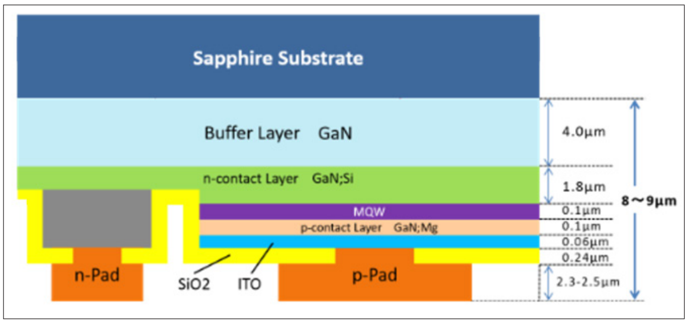

Figure 2: Flip Chip Structure

Regarding evaluation, the wavelength (nm) and intensity (a.u.) were measured by photoluminescence (PL) on the wafer. Next, after fabricated a flip chip on the sapphire substrate, and

- The voltage transition against the input current (I-V characteristics),
- The emission intensity transition against the input current (I-L characteristics), and
- The emission spectrum was measured by a manual prober to verify the difference in characteristics with and without PhCs.

Results and Discussion

Wafer Evaluation

Figure 3 shows an image of the SEM observation of the PhCs fabricated on the wafer surface after dry ICP etching. The color of the wafer surface changed where the PhCs were fabricated, and the SEM observation confirmed that the hole shape was tapered, with a surface diameter of 270-300 nm and a bottom diameter of 200-230 nm.

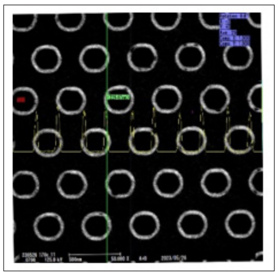

Figure 3: SEM Image of PhCs (bottom: 226.67 nm, top: 285.33 nm)

Next, Figure 4 shows the results of the PL wavelength and intensity. The areas with PhCs had a tendency for the wavelength to shift 0.5-1.0 nm toward the longer wavelength side and the PL. intensity was improved by about 1.5 to 1.6 times compared to areas without PhCs.

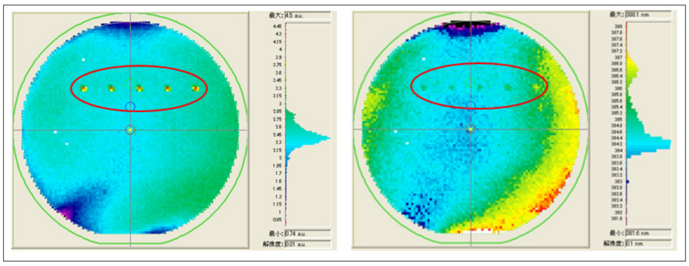

Figure 4: PL Measurement Results
(Left: Emission Intensity (a.u.), Right: Peak Wavelength (nm))

Chip Evaluation

Photos of flip chips with and without PhCs are shown in Figure 5, and a light emission photo is shown in Figure 6. It was confirmed that the flip chip with PhCs had improved light emission intensity. Electrical characteristics were evaluated by a manual prober for chips between PhCs and non-PhCs.

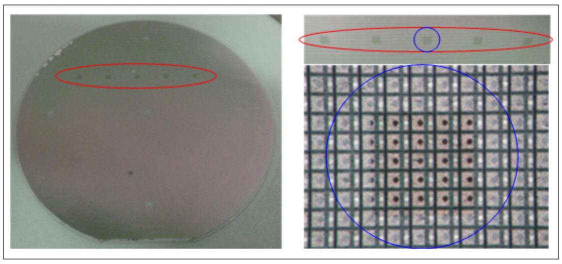

Figure 5: Photo of Flip Chip with PhCs (Forming Area: 2mm x 2mm, 5 locations)

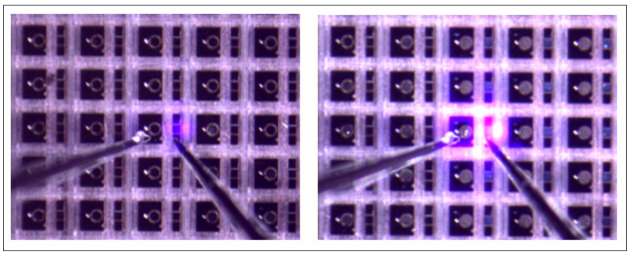

Figure 6: Flip Chip Light Emission (Left: Non-PhCs, Right: PhCs)

Figure 7 shows the I-V characteristic measurement results. Both chips showed good characteristics, with almost no difference between PhCs and non-PhCs. By fabricating PhCs on the p-layer surface, the resistance value was slightly higher, but the forward voltage (VF) was within a usable range. In addition, there was concern about short circuit failure due to an increase in crystal defects, but there was no leakage current in the low current region and good characteristics were obtained.

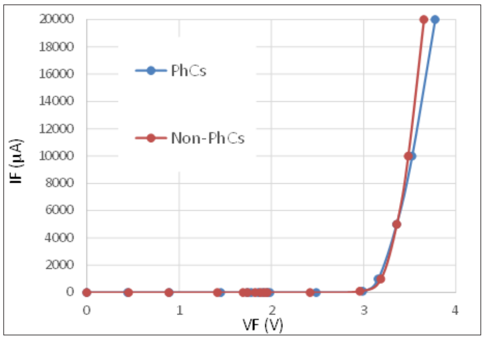

Figure 7: I-V Characteristic Measurement Results

Figure 8 shows the results of the I-L characteristic measurements. The chip with PhCs had intensity that was approximately 1.74 times higher than the chip without PhCs. Since the active layer is located 250 nm from the surface of the p-GaN layer, there was concern that the heat from dry etching might damage the crystal, but there was no bad influence and we confirmed the effect of PhCs.

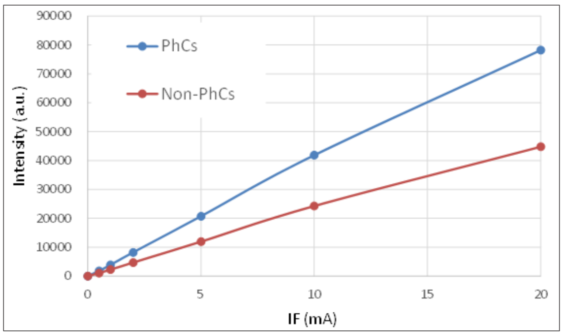

Figure 8: I-L Characteristic Measurement Results

Figure 9 shows the emission spectra. The peak wavelength of the chip with PhCs was 386.26 nm, with a half-width of 11.78 nm, while the peak wavelength of the chip without PhCs was 385.74 nm, with a half-width of 11.79 nm. There was almost no difference between PhCs and non-PhCs, and favorable results were obtained.

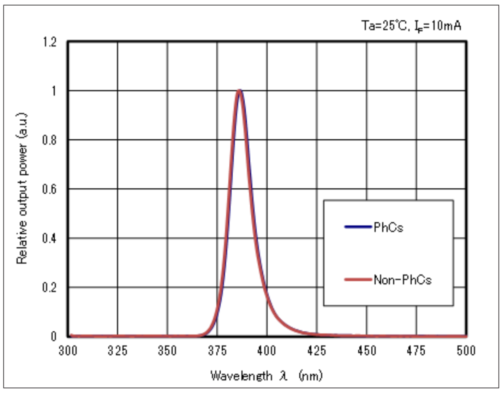

Figure 9: Emission Spectrum

Conclusions

In order to increase the luminous efficiency of uUV-LEDs, PhCs was fabricated on the p-layer surface of a 385nm LED structure, and the effect of PhCs was verified using a flip chip with a luminous area of 90um x 90um. As a result, no abnormalities were found in the electrical characteristics and emission spectrum, and the luminous intensity was improved by approximately 1.74 times. PhCs is considered to be an effective method for realizing micro-UV-LEDs displays.

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