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Realization of 340nm-band high-power (>7mW) InAlGaN quantum well UV-LED with p-type InAlGaN

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1. Introduction

(In)AlGaN alloys are attracting much attention as candidate materials for realizing deep ultraviolet (UV) light-emitting diodes (LEDs) or laser diodes (LDs)[1-3]. However, the efficiency of UV-LEDs with wavelengths shorter than 360 nm is still low. The crucial issue on emission efficiency of UV-LED is considered to be low current injection efficiency. The injected electron is easily overflowed into p-type layer in UV region. Furthermore, high-quality AlN or AlGaN buffer layer is also very important for realizing high internal quantum efficiency (IQE) of AlGaN-based quantum well (QW) and for realizing high hole concentration of p-type layers. In this study, we realized high-power operation of quaternary InAlGaN-based UV-LEDs with p-type InAlGaN layers. We revealed that Mg-doped InAlGaN layer is superior to Mg-doped AlGaN layer for use as p-type layers of UV-LEDs. We obtained output power of 7.1mW from 346 nm InAlGaN-based UV-LED by optimizing electron injection into QWs and by improving the crystal quality of AlN/AlGaN template.

2. Experiments and Discussions

340nm-band UV-LED structures were grown on the sapphire substrate by low-pressure metal-organic chemical vapor deposition (LP-MOCVD).

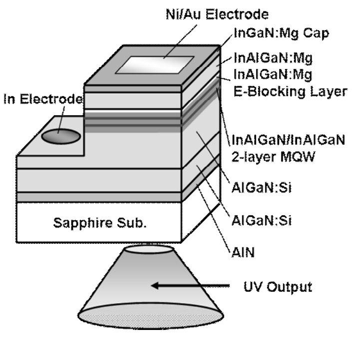

Fig.1. Schematic structure of 340nm-band InAlGaN-based UV-LED.

Figure 1 shows a schematic structure of fabricated UV-LED. Layer structure consisting of undoped InAlGaN/InAlGaN 2-layer multi-quantum well (MQW), Mg-doped InAlGaN electron blocking layer (EBL) and Mg-doped InAlGaN layer was grown on sapphire/AlN/AlGaN template. The typical layer structure of an AlN/AlGaN template consists of an approximately 3.1μm-thick high-temperature (HT)-AlN layer directly deposited on a sapphire substrate, a 0.5μm-thick Si-doped $Al_{0.4}Ga_{0.82}N$ buffer layer, and a 5.5um-thick Si-doped $Al_{0.2}Ga_{0.8}N$ n-type layer.

Figure 2 shows the comparison of output power of the UV-LEDs between using p-InAlGaN and p-AlGaN. The output power of UV-LED with p-InAlGaN layers (6.6mW) was approximately 4.7 times larger than that with p-AlGaN layers (1.4mW). From this result, the advantages of the p-InAlGaN in comparison with the p-AlGaN for 340 nm-band UV emitters were revealed.

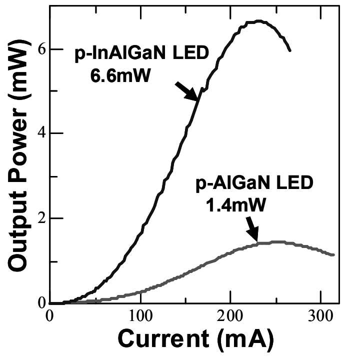

Fig.2. Comparison of output power of InAlGaN-QW UV-LEDs with p-InAlGaN and p-AlGaN under RT CW operation.

Figure 3 shows the output power as a function of electron blocking height for three series of well depth of the InAlGaN QWs, i.e., 130, 200 and 300meV. Well composition was fixed for keeping emission wavelength constant on each sample. The output power was dramatically improved by increasing electron blocking height and by increasing quantum well depth. However, the output power was decreased by further increase of electron blocking height, which may be caused by the reduction of hole concentration due to using higher Al composition for p-InAlGaN layers. We also found that the output power was dramatically increased by increasing well width. These tendencies agree well with the theoretical calculations using device simulator.

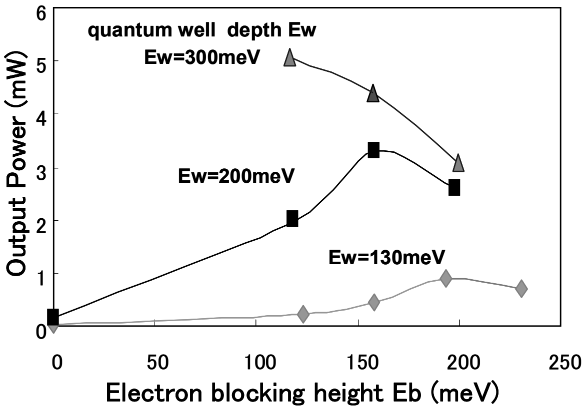

Fig.3. Relationship between the electron blocking height and output power of InAlGaN-based UV-LED.

Figure 4 shows the cross-sectional transmission electron microscope (TEM) image (g=[11-20]) for InAlGaN based UV-LED structures with AlN/AlGaN template. We confirmed that high-quality AlN/AlGaN template was successfully grown on sapphire substrate, from the TEM images. The threading dislocation density (TDD) for edge-type and screw-type were estimated to be $1.1\times10^{9}cm^{-2}$ and $1.3\times10^{8}cm^{-2}$, respectively, measured by using the TME images.

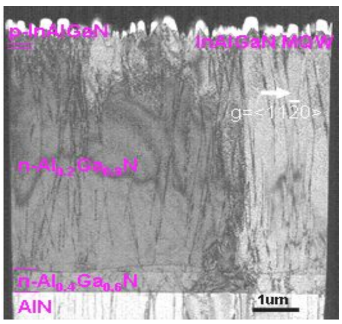

Fig.4. Cross section TEM image of InAlGaN based UV-LED (g=[11-20]).

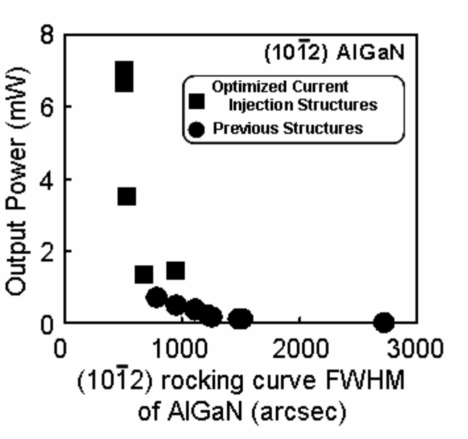

Fig.5. The maximum output power as a function of XRC (10-12) FWHM of $Al_{0.2}Ga_{0.8}N$.

Figure 5 shows the maximum output power as a function of (10-12) x-ray ω-scan rocking curve (XRC) FWHM for $Al_{0.2}Ga_{0.8}N$. In the case of FWHM over 1000arcsec region, output power is less than 1mW. The output power was dramatically improved by reducing the FWHM of AlGaN. The output power of the 340 nm-band UV-LED was increased by approximately 7 times by reducing the FWHM of XRC (10-12) from around 800 to 510 arcsec.

Figure 6 shows (a) current versus light-output (I-L) characteristic and a spectrum, and (b) external quantum efficiency (EQE) of InAlGaN-QW UV-LED with p-InAlGaN layers under room temperature (RT) CW operation. We obtained the maximum output power of 7.1mW from the quaternary InAlGaN-based UV-LED with the wavelength at 346nm. The maximum EQE was approximately 0.86%.

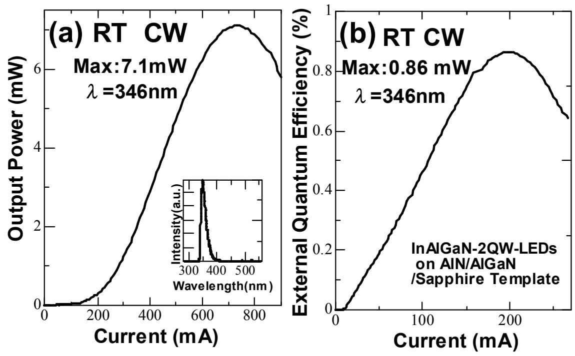

Fig.6. (a) The I-L characteristic and the spectrum and (b) max EQE characteristic of an InAlGaN-QW UV-LEDs with p-InAlGaN under RT CW operation.

3. Conclusions

We demonstrated high-power quaternary InAlGaN-based UV-LEDs. The output power was dramatically increased by using p-type InAlGaN layers and by improving electron injection structures and the crystal quality AlN/AlGaN template. The maximum output power of UV-LED with p-InAlGaN (6.6mW) is about 4.7 times higher than that with p-AlGaN (1.4mW). The high quality AlN/AlGaN template was successfully grown on sapphire substrate. The TDD for edge and screw type dislocation is $1.1\times10^{9}cm^{-2}$ and $1.3\times10^{8}cm^{-2}$, respectively. The output power was improved by approximately 7 times by reducing the FWHM of XRC (10-12) from around 800 to 510 arcsec. The maximum output power and EQE of fabricated InAlGaN based UV-LED were 7.1mW and 0.86%, respectively, under DC current injection at RT.

References

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