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Sub-Milliwatt Operation of 308 nm Deep UV LED using quaternary InAlGaN

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1. Introduction

For the realization of 250-350 nm band ultraviolet (UV) emitters using III-nitride materials, it is required to obtain high-efficiency emission of wide bandgap (In)AlGaN and hole conductivity. We have demonstrated that high-efficiency UV emission is obtained from quaternary InAlGaN with In segregation effect in the wavelength of 280-380 nm at room temperature [1-2]. 330 nm light-emitting diodes (LEDs) using InAlGaN emitting layers have been already demonstrated [3]. We have also demonstrated 230 nm band high-efficiency emission from AlN/AlGaN QWs [4]. However, it was difficult to fabricate short wavelength LEDs because of the lack of wide bandgap p-type AlGaN. In this work, We achieved sub-milliwatt operation of 308-314 nm deep UV-LEDs using quaternary $In_xAl_yGa_{1-x-y}N$ active region. High-Al-content Mg-doped $Al_xGa_{1-x}N$ (x=0.53) was used as p-type region. Hole conductivity for high Al content Mg-doped AlGaN was obtained by growing with alternative gas flow growth process in metalorganic vapor phase epitaxy (MOVPE). The maximum output power of fabricated UV-LEDs were 0.4 and 0.8 mW for the emission wavelength of 308 and 314 nm, respectively, under pulsed current injection.

2. Experiments and Discussions

Structures were grown on sapphire substrate by low-pressure (76 Torr) metalorganic vapor phase epitaxy (MOVPE). Figure 1 shows photoluminescence (PL) spectra measured at room temperature (R.T.) from 0.06 μm-thick quaternary $In_xAl_yGa_{1-x-y}N$ grown on 1.2 μm-thick $Al_{0.5}Ga_{0.5}N$ buffer layer with various growth conditions. We obtained strong PL with the wavelength range at 290-360 nm from quaternary InAlGaN. The PL intensity of InAlGaN was as high as that of InGaN emitting at 430 nm at room temperature.

We fabricated two types of LED sample with quaternary InAlGaN emitting layer. Figure 2 shows the schematic LED structure. The layer structure consists of low temperature (LT)-AlN layer, Si-doped $Al_xGa_{1-x}N$ (x=0.47) buffer layer, undoped $In_xAl_yGa_{1-x-y}N$ emitting layer, Mg-doped $Al_xGa_{1-x}N$ (x=0.53) layer and Mg-doped GaN capping layer. For the growth of Mg-doped AlGaN, alternative gas flow sequence is used. Crystal quality of high Al content AlGaN was improved by migration enhancement of precursors by using alternative gas flow sequence. We observed the reduction of full-width at half maximum (FWHM) and intensity enhancement of AlGaN PL emission grown with alternative gas flow. We achieved hole conductivity for Mg-doped $Al_{0.53}Ga_{0.47}N$ layer without using superlattice (SL) structures. The UV output can be taken out from the backside of sapphire substrate through n-$Al_{0.47}Ga_{0.53}N$ layer below InAlGaN emitting layer as shown in Fig. 2.

Figures 3 (a) and (b) shows integrated output power of LED I and II, respectively, measured under pulsed current injection at room temperature. We obtained single-peaked emission spectra both for 308 and 314nm LEDs. The emission peak was confirmed to be from quaternary InAlGaN emitting layer, since the electroluminescence (EL) peak was just matched to photoluminescence (PL) peak. The output power of 308 and 314 nm emission was 0.4 and 0.8mW when the injection current is 130 and 260 mA, respectively.

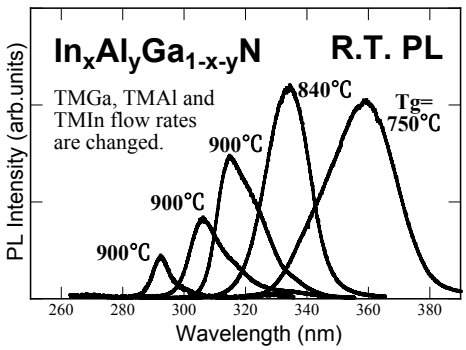


Fig. 1 Photoluminescence (PL) spectra measured at room temperature from quaternary $In_xAl_yGa_{1-x-y}N$ grown with various growth conditions.

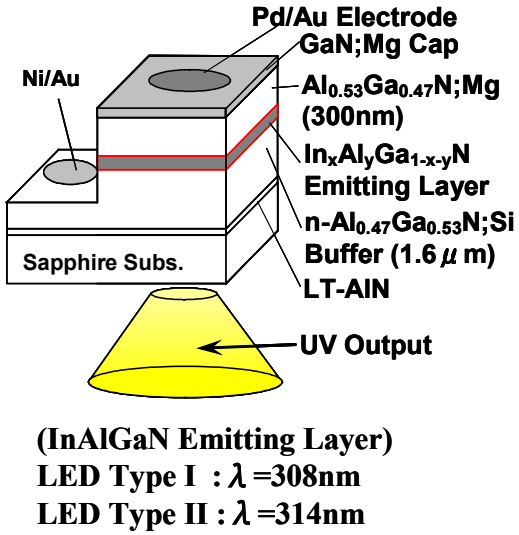
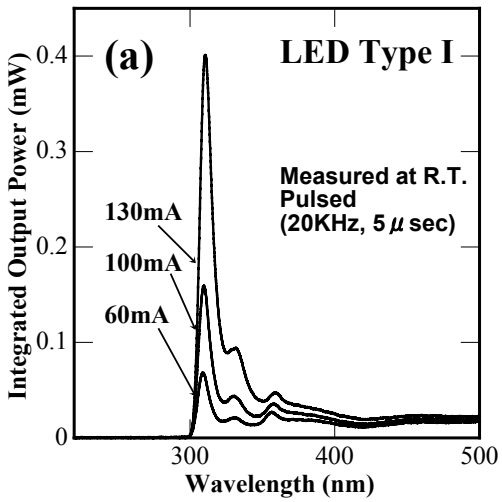


Fig. 2 Schematic structure of UV-LED with quaternary InAlGaN emitting region.



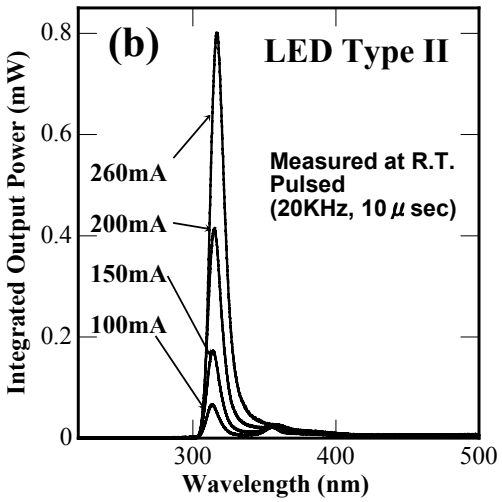


Fig. 3 Integrated output power for (a) LED I and (b) LED II measured under pulsed current injection at room temperature.

3. Conclusions

In conclusion, We achieved 308-316 nm deep ultraviolet (UV) light-emitting diodes (LEDs) using quaternary $In_xAl_yGa_{1-x-y}N$ active region. We used high-Al-content Mg-doped $Al_xGa_{1-x}N$ (x=0.53) as p-type region. Hole conductivity for high Al content Mg-doped AlGaN was obtained by growing with alternative gas flow growth process in MOVPE. The maximum output power of UV-LEDs were 0.4 and 0.8 mW for the emission wavelength of 308 and 314 nm, respectively.

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