Fabrication of Line Electrodes on Oblique Surface of Micro-LED Pixels and Impact on Their Characteristics

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ABSTRACT

Blue color micro-LEDs were fabricated by monolithic integration method, and line electrodes were fabricated on oblique surface. Their current-voltage and emission characteristics are discussed for further improvement in device performance.

1 Introduction

Micro-LED (μ-LED) displays are considered as promising technologies for developments of next generation displays [1]. In the prototype, flip chip LEDs are integrated on a circuit board. However, there still exists critical issues on cost-effective mass-transfer techniques to precisely handle huge numbers of μ-LED chips. A monolithic integration method realizes simultaneous miniaturization and mounting the μ-LEDs by etching the LED wafer. The use of phosphors makes it possible to produce full-color μ-LED display with low time costs. In this study, blue μ-LED pixels are fabricated using a monolithic integration method.

2 Experiment

The blue LED structure was grown on (0001) sapphire substrate by metalorganic vapor phase epitaxy. It consists of a 2.5-μm-thick unintentionally-doped (UID) GaN, 1.0-μm-thick Si-doped n-type GaN, a total of 100-nm-thick five periods of GaInN/GaN multiple quantum-well emission layer, and a 100-nm-thick Mg-doped p-type GaN. The fabrication processes for μ-LED pixels are schematically shown in Fig. 1. After annealing the LED wafer in a nitrogen atmosphere to activate acceptors in the p-type GaN, a 5-nm-thick Ni metal and 100-nm-thick ITO were deposited by an electron beam (EB) evaporation method. ITO was annealed in an oxygen atmosphere to make it transparent. After patterning the Ni metal and ITO by photolithography and wet chemical etching, the LED wafer was selectively etched for 1 min. by the inductively-coupled-plasma reactive-ion-etching (ICP-RIE). Then, to make n-GaN contacting layer, the LED wafer was patterned by photolithography and Ni metal and ITO was selectively wet etched followed by the ICP-RIE etching for 16 sec. To form the n-type electrode, the LED wafer was patterned by photolithography and a total of 80-nm-thick Ti/Al/Ni/Au metal were deposited by the EB evaporation. After that, to from the isolation layer, the LED wafer was patterned by photolithography and a 200-nm-thick SiO_2 was deposited by the EB evaporation. Finally, to form the p-type electrode, the LED wafer was patterned by photolithography and a 5-nm-thick Ni metal and 100-nm-thick ITO were deposited by the EB evaporation. ITO was annealed in an oxygen atmosphere to make it transparent. The μ-LED mesa structure was evaluated by field emission-scanning electron microscope (FE-SEM), current-voltage (I-V) characteristics, and emission spectrum. The crosstalk was evaluated using the free software imageJ and photographs.

3 Results

Approximately 100×70 μm^2 square blue μ-LED mesa structure was fabricated as shown in Fig. 2. As shown in Figs. 3 and 4, the μ-LED showed a vivid blue light with a peak wavelength at 466 nm. The current-voltage characteristics showed a rectifying property with a threshold voltage of 0.5 V as shown in Fig. 5, though the leakage current was recognized.

4 Discussion

The unevenness of the luminescence in Fig. 3(a) is thought to be caused by the improvement of light extraction efficiency by pit. As for the leakage current in Fig. 5, thinning the SiO_2 isolation layer at side was confirmed from the bird's-eye view SEM observation, and was attributed to the possible origin. Therefore, it is necessary to increase the thickness of the SiO_2 film.

5 Conclusions

To realize appropriate method for micro-LED displays at low cost, approximately 100×70 μm^2 square blue μ-LED pixels were fabricated using a monolithic integration method. The μ-LED showed a vivid blue light with a peak wavelength at 466 nm though the leakage current was recognized. The bird's-eye view SEM observation assured us that thinning the SiO_2 isolation layer at side is possible origin. Further improvement will be possible by optimizing the isolation layer. The results suggest that low-cost micro-LED displays can be realized.

Acknowledgment

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References

[1] G. Biwa, The Institute of Image Information and Television Engineers, Vol. 73, pp.939-942 (2019).

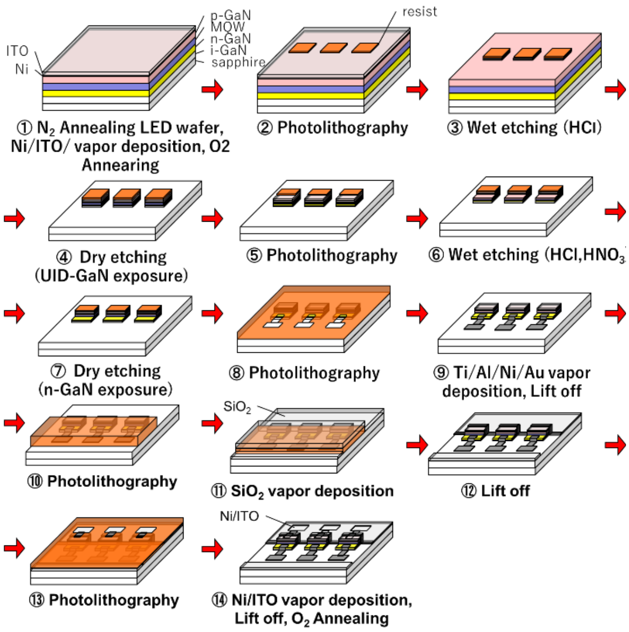


Fig.1 Schematic diagram of fabrication processes for micro-LED pixcels

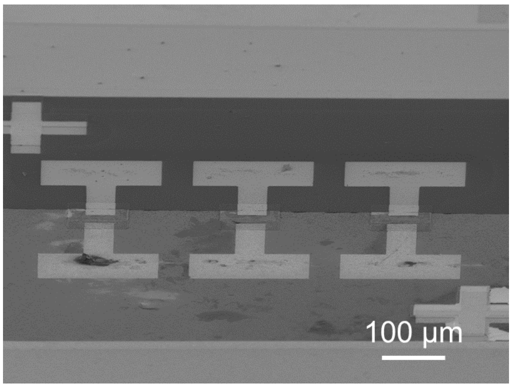
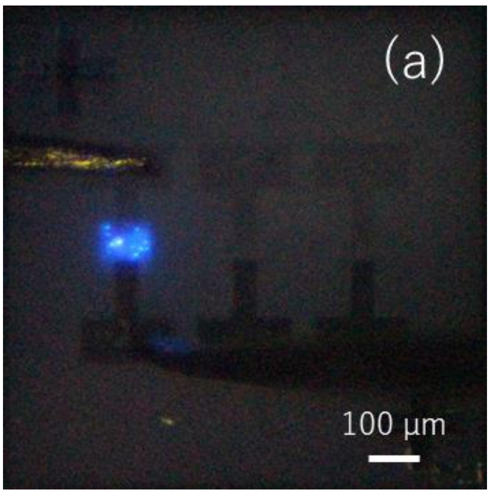


Fig. 2 Bird's-eye view SEM image.



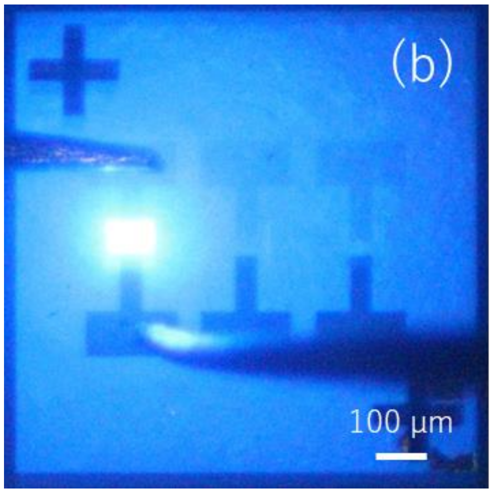


Fig. 3 Emission image operated at (a) 4.5 V and 0.4 mA, (b) 5.5 V and 0.65 mA.

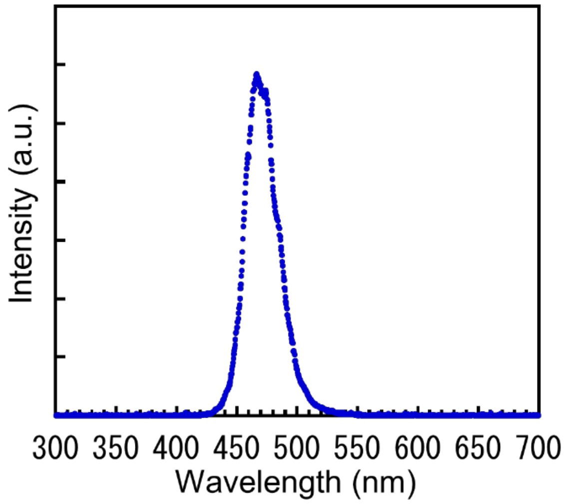


Fig. 4 Emission spectrum operated at 5.5 V and 0.65 mA.

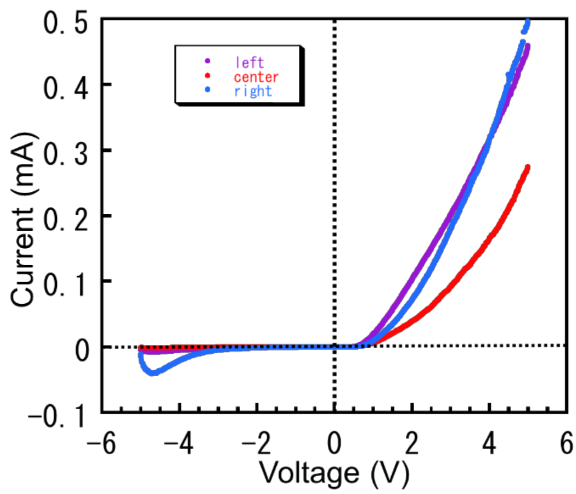


Fig. 5 Current-voltage characteristics of micro-LED.