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A New High Radiance LED Structure with Circular 45° Corner Reflector

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1. Introduction

Up to now, many kinds of LED structures have been suggested to improve performance. First of all, the increase of output power of LED is the most important issue because the incoherent optical power that can be coupled into optical fiber depends directly upon the radiance of the source, and display systems need brighter radiance source for efficient display in the daylight.

In this paper, we newly propose and fabricate high radiance surface emitting LED with 45° corner reflector and microlens using UV curing method. The improvement of output power of the proposed LED structure is calculated and compared with the conventional surface emitting LED type. $HBr-H_3PO_4-K_2Cr_2O_7$ chemical etchant is newly developed for fabrication of circular 45° corner reflector.

2. Experiment

Although SE-LED is a excellent optical source, it is easily saturated at high current density. The radiation saturation is due to many processes such as carrier leakage over the heterojunction barrier, auger recombination and in-plane superluminescence. But it is already suggested that in-plane superlumenescence is the dominant mechanism in LED saturation [1]. So we propose a new type of surface emitting LED with circular 45° corner reflector. Because the light of in-plane radiation can be extracted to the emission surface by circular 45° corner reflector, the saturation phenomenon that comes from the in-plane superluminescence can be dramatically improved. Fig. 1 shows the simulation results of the output power ratio between the proposed SE-LED with 45° corner reflector and the conventional SE-LED as a function of optical gain (g). Because the guided light experiences an optical amplification when it travels in the active layer, the power ratio increases as current injection increases. From the simulation result, we can conclude that the output power of the proposed new LED increases by a factor of 4 compared to that of a conventional surface emitting LED, and linearity of the output power can be improved by extraction of increase of in-plane radiation as the current increases.

a. Fabrication of corner reflector

For the fabrication of 45° corner reflector, chemical etchant must have several special etching properties such as exact circular shape etching for circular corner reflector, 45° side wall angle in all crystal directions to reflect the light guided in the active layer to bottom surface where the emission region is, and high quality of etched surfaces. Also, the etching rates of InP and InGaAsP must be the same to minimize light scattering at corner reflector that comes from the discontinuity between cladding layer (InP) and active layer(InGaAsP).

We newly developed chemical etching solution for fabrication of circular 45° corner reflector. The etching solution is prepared by mixing HBr, H_3PO_4 and 0.5 mole $K_2Cr_2O_7$ aqueous solution. AZ5214 photoresist is used as an etching mask. When the composition of HBr :H_3PO_4 : (0.5M)$K_2Cr_2O_7$ etchant becomes 1:1:1, InP and InGaAsP etching rates are almost the same (~2μm/min at 20°C). The rms roughness of the etched surface measured with Atomic Force Microscope(AFM) is 4.9Å.

b. Device fabrication

Grown LED epitaxial layers using MOCVD are 2×10^{18} n-doped InP cladding layer(1.5μm) on (100) InP substrate, unintentional doped $In_{0.39}Ga_{0.61}As_{0.847}P_{0.153}$ active layer(0.2μm), unintentional doped InP(0.1μm) to prevent the Zn diffusion into the active region, 2×10^{18} p-doped InP cladding layer(2μm) and highly p-doped $In_{0.53}Ga_{0.47}As$ contact layer(0.1μm). Fig. 2(a) shows the schematic structure of the fabricated LED with circular 45° corner reflector. Fig. 2(b) is a photograph of the p-metal side. The bright circle region is p-metal, and dark black circle at the edge of p-metal region is the circular corner reflector. Fig. 2(c) is a SEM picture of the n-metal side with a microlens fabricated using UV curing method [2][3]. The height of microlens is about 30μm.

3. Measurements and Discussions

a. Light–Current Characteristics – Fig. 3 shows the light output power versus current curves of a conventional SE-LED without corner reflector and the proposed SE-LED with circular 45° corner reflector. Compared with a conventional SE-LED, the output power of the new LED increases several times(~4 times at 400mA), and the linearity is improved dramatically. Although the light output power of a conventional SE-LED is saturated near 100mA injection current, the new LED does not show significant saturation phenomena. When the injection current increases, the emission in the plane of the active layer is enhanced by stimulated emission. This enhancement will take place at the expense of the emission into other directions. So, in the conventional surface emitting LED structure, the output power is easily saturated at high current level by the in-plane superluminescence effect [1]. We think that the improvements of linearity and output power of proposed LED come from the extraction of the in-plane radiation by the circular 45° corner reflector. Also the improvement of output power ratio between LED's with and without corner relfector is well matched with the calculation result in Fig. 1 at high current levels.

b. Spectra Characteristics – Fig. 4 is the spectra of proposed surface emitting LED's with 45° corner reflector at various current levels. Although the spectrum envelope of the proposed LED is the same as that of a conventional SE-LED at low current level, the spectrum envelope shows significant change when the injection current level increases as shown in Fig. 4. As the current increases, a dominant main peak appears. We think that this main peak comes from the extraction of the in-plane radiation by the 45° corner reflector. Because the in-plane radiation is enhanced by optical gain (g) in the active layer as current injection increases, the amplitude of main peak clearly becomes larger as injection current increases. Also, because the spectrum of edge emitting LED is narrower than that of surface emitting LED, we can confirm that the main peak comes from the reflected in-plane radiation by the 45° corner reflector. For the first time, this phenomena is observed experimentally since saturation of SE-LED by in-plane superluminescence effect was theoretically suggested [1], and the proposed LED suggests a method to overcome the saturation. This result means that proposed LED structure combines the characteristics of conventional edge emitting and surface emitting LED.

4. Conclusions

In this paper, we have newly proposed and fabricated high radiance surface emitting LED with 45° corner reflector and microlens. For fabrication of corner reflector, we developed $HBr\text{-}H_3PO_4\text{-}K_2Cr_2O_7$ chemical etchant and characterized the etching properties. Compared with conventional surface emitting LED, the output power of proposed LED increased several times at high current level and the linearity is dramatically improved. In the spectra characteristics, we could observe a new main peak that came from the extraction of in-plane radiation by the 45° corner reflector as injection current increased. This result means that saturation by in-plane superluminescence is an important factor in surface emitting LED.

References

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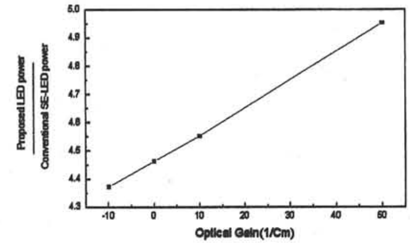

Fig. 1 Calculated output ratio between a conventional surface emitting LED and the proposed LED with circular 45° corner reflector.

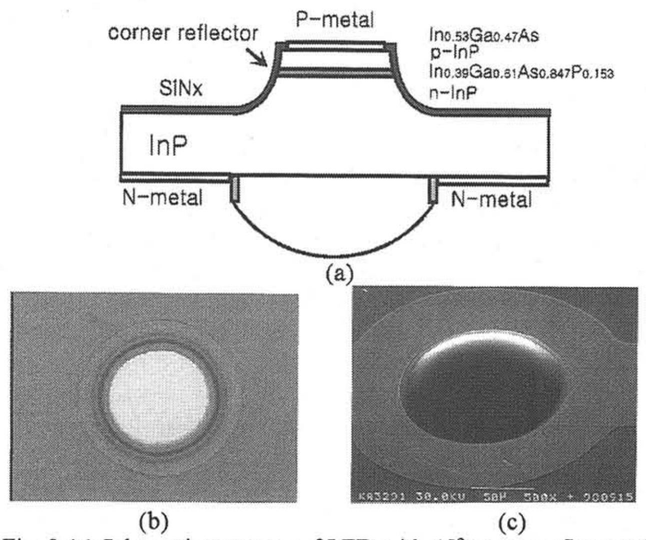

Fig. 2 (a) Schematic structure of LED with 45° corner reflector, (b) photograph of p-metal side with corner reflector, (c) SEM picture of n-metal side with microlens fabricated using UV curing method.

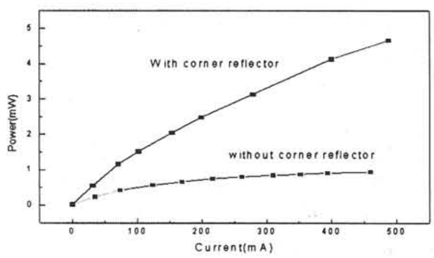

Fig. 3 Light output power versus current curve of SE-LED with circular 45° corner reflector.

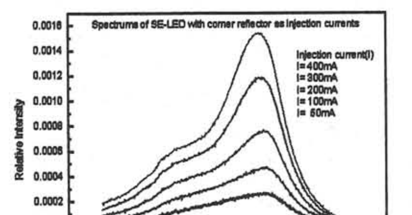

Fig. 4 spectrum characteristics of SE-LED with circular 45° corner reflector.