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High Efficiency GaAs LED with a Meltback Micro-Lens

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AlGaAs micro-lens was fabricated for LED applications using the LPE meltback technique. The lenses can be used to enhance the efficiency of AlGaAs/GaAs LED's. The meltback technique using the LPE provides simple fabrication procedures and reproducibility which are not easily achieved in the conventional lensed structure.

I. Introduction

In semicondutor optical devices and systems, the hemispherical micro-structure has been studied for the micro-lens to enhance the efficiency of the optical device.

The meltback etch is adopted as a method to fabricate a micro-lens and to integrate it with a GaAs single hetero-structure LED. Meltback is a characteristic phenomenon pertaining only to LPE. However, it is not so easy to control compared to the widely-used wet or dry etching processes.

The internal quantum efficiency of LED's can approach 100 percent at room temperature[1]. However, the external quantum efficiency is generally much lower. The principal factor limiting the efficiency is the external reflection at the semiconductor-air interface due to the difference in the refractive indices. The refractive index of GaAs is 3.6, while that of air is 1.0. Total internal reflection occurs for all rays incident on the semiconductor-air interface at angles greater than a critical angle of 16.1^{o} from the normal. Only 2 percent of the generated radiation can be emitted directly through the top surface of a flat-geometry emitter. External quantum efficiencies of 14 and 28 percent have been achieved with GaAlAs homo-structure hemispherical emitters[2] and GaAlAs hetero-structure hemispherical emitters[3], respectively. The primary disadvantage in the GaAlAs hemispherical emitter is that growing very thick GaAlAs epitaxial layer is required. By adopting the meltback hemispherical emitter, however, it is not difficult to obtain the thick AlGaAs layer .

An LED with cylindrical lens structure was successfully fabricated using the meltback technology.[4]

In this paper, we report the first successful LED with a hemispherical lens structure made with the meltback technology.

II. Design and Experiments

The integration of the meltback micro-lens in the AlGaAs LED let the photons generated by the electro-luminescence emit with lower external loss by the increment of the total reflection angle.

There are many design considerations in the high efficiency LED such as the epitaxial conditions, the location of the ohmic contacts and the current spreading structures. It is important to carefully control the epitaxial conditions such as the meltback time, the degree of under-saturation and the regrowth times for each layer.

The location and the doping concentration of the active layer will affect the characteristics of the LED. It is possible to control the location of active layer in the AlGaAs hemispheric micro-lens by controlling the growth time of the p-clad layer as shown in figure 1.

Another parameter related with the current spreading is the doping concentration of the p-type cladding layer. The appropriate current spreading will enhance the light emission. Large current spreading is generally resulted in the case of low doping. Also the good crystal quality with no significant optical scattering loss is obtained with lower doping concentration.

Fabrication process of the LED is as follows. First SiO_2 is sputtered on the p-substrate and circular windows are opened using conventional photolithography and oxide etching. Then selective meltback is performed and single-hetero structure is grown immediately after meltback process. AuGe/Ni is evaporated and alloyed to make an ohmic contact on the n GaAs. The p-substrate is etched selectively using the $NH_4OH:H_2O_2=1:20$ solution until the AlGaAs lens shape is exposed. To ensure the selective etching, Al composition of the p-type clad layer is chosen to be greater than 0.3. AuZn/Au is selectively evaporated around the lens using the liftoff process.

III. Result and Discussions

Fig.2 shows the scanning electron micrograph of the micro-lens array after etching of the p-substrate . The hemispherical AlGaAs lenses are regrown on the melted back regions. It shows the anisotropic plane at the side of the micro-lens parallel to the <110> direction. It is obvious that there occurs not only isotropic but also some anisotropic process in the meltback etching. The anisotropic meltback is found to be independent with the wiping off direction. Scanning electron micrographs of the three different etch and regrowth lens shapes are shown in figure 3. The anisotropic side is observed in all the photographs of figure 3. Symmetrical melt-etched areas with 2 edges were found, which shows the characteristic two or four fold symmetry of (100) oriented GaAs substrate with respect to the aluminum addition. It is believed that after the initial wetting, the etching proceed dominantly around the edge of the mask opening. This results in the appearance of the (111) surfaces as meltback progresses.

We have observed that at the beginning, the side meltback etch is quite significant. Then hemispherical lens shape is growing as the melt time increases. And finally inverse-pyramid etch shape is resulted similar to the anisotropic wet etch. It is possible to control the hemispherical lens shape by the time of meltback .

The forward cut-in voltage of the fabricated LED is 1.3V for 100μA and the reverse breakdown voltage is 3V. Figure 4 shows the light output versus current characteristics of the fabricated LED. From figure 4, we find that the defect density around the active layer is rather high so that space charge region recombination is the dominant factor in the injected current. It is found that the SiO_2 film becomes unstable after the high temperature selective epitaxy. In order to reduce the leakage current, the followings are suggested.

a) locating the ring contacts on the AlGaAs micro-lens and b) reducing the LPE temperature to prevent the oxide damage.

IV. Conclusion

Micro-lenses with different diameters are fabricated using meltback and regrowth technique in LPE. By regrowing the single-hetero structure, an LED is fabricated. Slight deviations from the ideal hemispheric structures are observed because of the anisotropic meltback pheomena.

References

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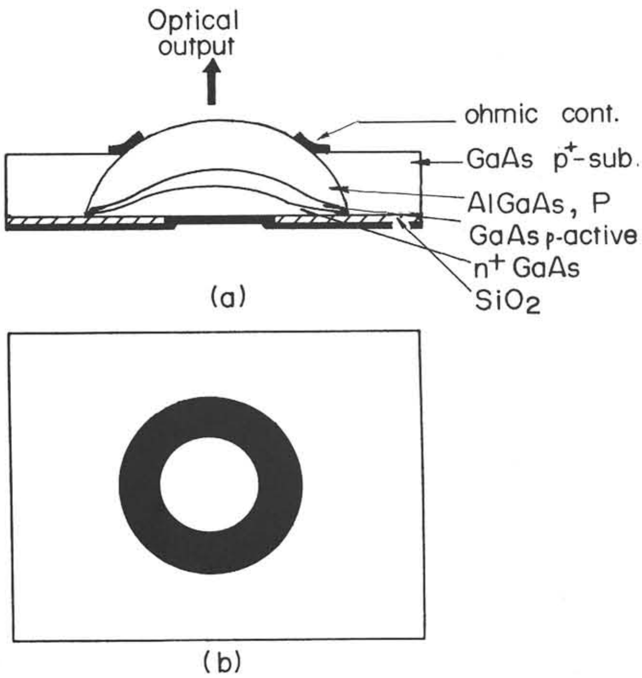


Fig.1 A schematic diagram of an LED with a meltback micro-lens.
(a) Cross-sectional view, (b) Top view.

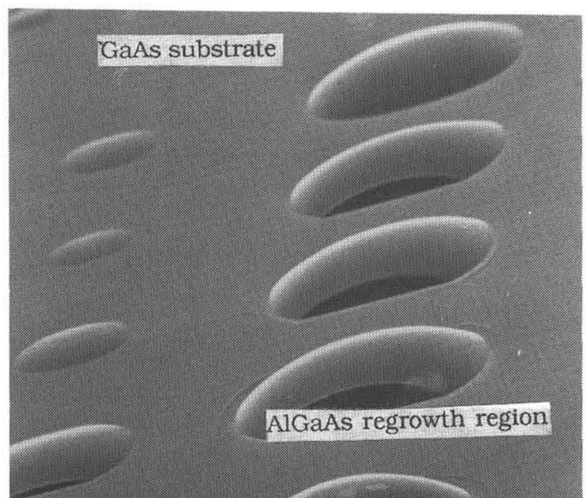
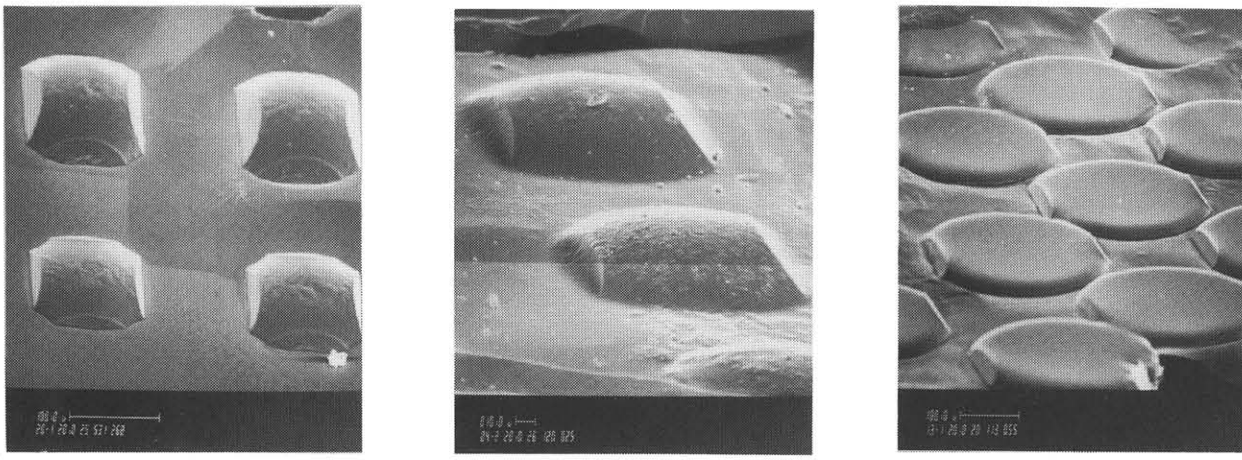


Fig.2 Scanning electron micrograph of the meltback micro-lens array with different window sizes.



(a) (b) (c)

Fig.3 Scanning electron micrographs of the meltback and regrown structures with different conditions.
(a) no aluminum, meltback time:4 sec (b) aluminum (1.4mg/1g gallium), meltback time:4 sec (c) aluminum(1.4mg/1g gallium), meltback time:15 sec.

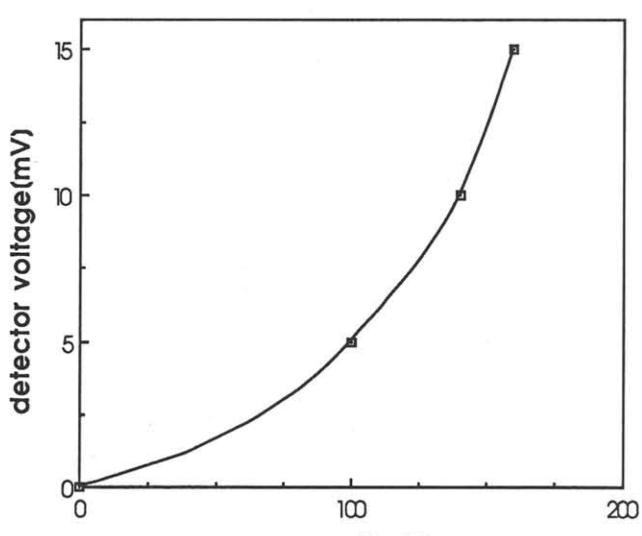


Fig.4 Light output versus current characteristics.