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# 650 nm-AlGaInP Visible Light-LD with Dry-Etched Mesa Stripe

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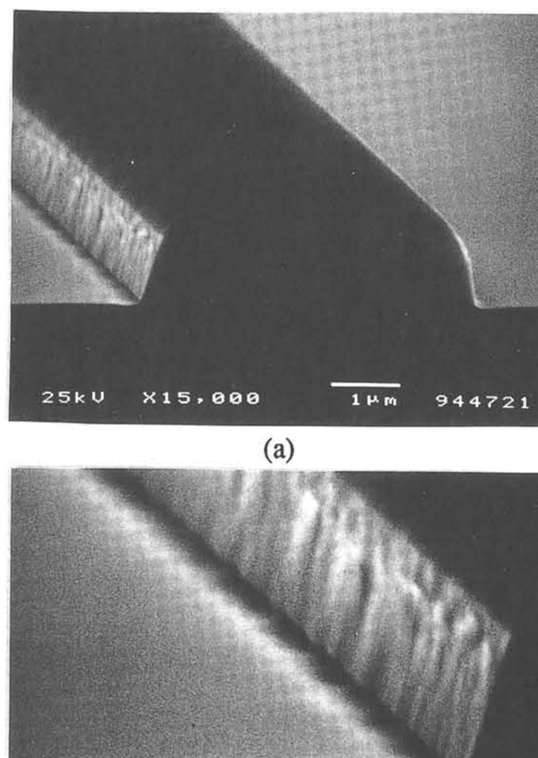
650 nm GaInP/AlGaInP index waveguide-type visible light laser diodes with dry-etched mesa stripes have been fabricated by $Cl_2$-reactive ion beam etching for the first time. Etching depth was accurately controlled by *in situ* laser reflectometry and a symmetrical mesa shape was obtained even on a 6°-misoriented substrate. Dry-etched LDs have characteristics almost the same as those of wet-etched mesa LDs. Ageing tests showed that these LDs have an operating time of at least 1500 hours.

## *1. Introduction*

The uniformity of etching depth and width attainable by dry etching make this a potentially useful technique for mass production of laser diodes (LDs). Controllability of etching depth and anisotropy of etching profile are especially attractive for making AlGaInP visible-light LDs, because the etching depth has a great influence on the optical confinement and waveguide loss of LDs, and because anisotropic etching can make a symmetrical mesa stripe even on the oriented substrates often used to obtain shorter wavelength emission from AlGaInP LDs[1]. The dry etching of AlGaInP, however, is very difficult because of low volatility of In and the oxidation of Al. Previously, we reported the first smooth and vertical etching of AlGaInP materials[2]. In that letter, it was pointed out that the aluminum-containing surface had been protected from oxidation during the etching process by reducing the amount of water in the etching chamber, and that high temperature, low gas pressure and high ion energy etching condition had promoted the desorption of indium and its reaction products.

Here we report the first 650-nm AlGaInP LD that has a dry-etched mesa stripe and that has characteristics as good as those of wet-etched LDs even in ageing test.




(b)

Fig.1 SEM photograph of dry etched AlGaInP LD wafer. (a)stripe (b)bottom. No roughness is seen

## 2. Experimental

A GaInP/AlGaInP-10QW-SCH structure was grown by metalorganic vapor phase epitaxy (MOVPE) on a 6°-misoriented GaAs (001) substrate[3]. The etching mask was a layer of $SiO_2$ patterned by $CF_4$ reactive ion etching using a photoresist mask. The mesa stripe was fabricated by $Cl_2$ reactive ion beam etching (RIBE) at the condition of high temperature (~200°C), low gas pressure (~$10^{-5}$ Torr) and high ion energy (600 eV). Etching depth was monitored by *in situ* laser reflectometry with accuracy of 10 nm. Then an n-GaAs current blocking layer and a p-GaAs cap layer were grown by MOVPE.

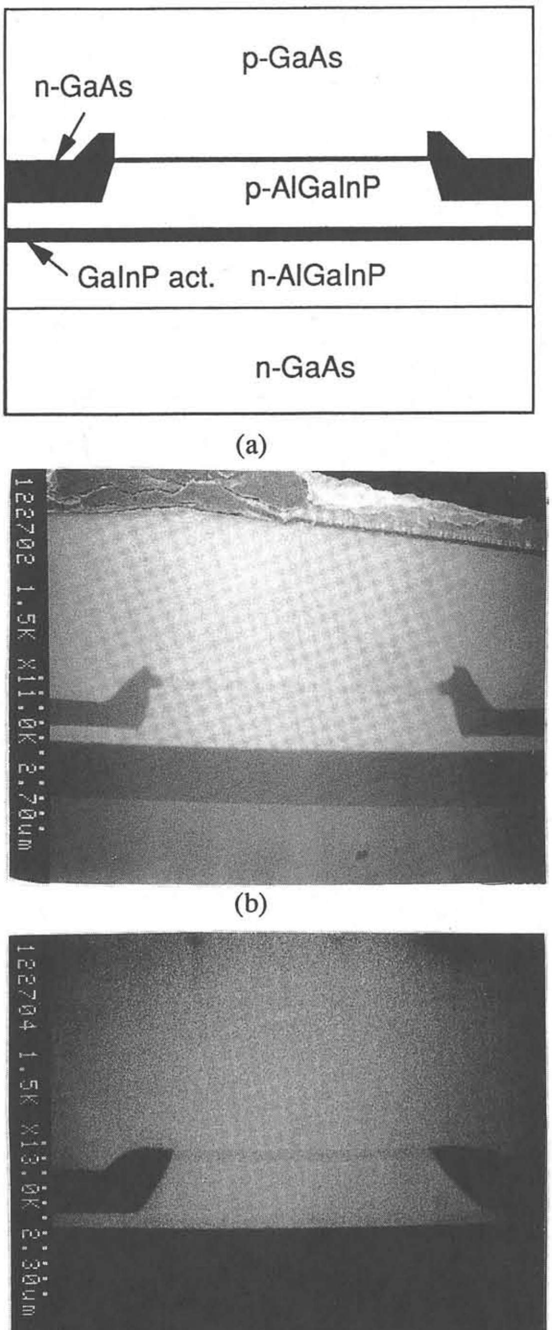



Fig.2 Crosssectional view of regrown mesa stripe.
(a) structure (b) dry-etched mesa (c) wet-etched mesa

## 3. Result and Discussion

Figure 1 shows an etched stripe of AlGaInP. Because no roughness on the etched bottom is observed by scanning electron microscopy (SEM),

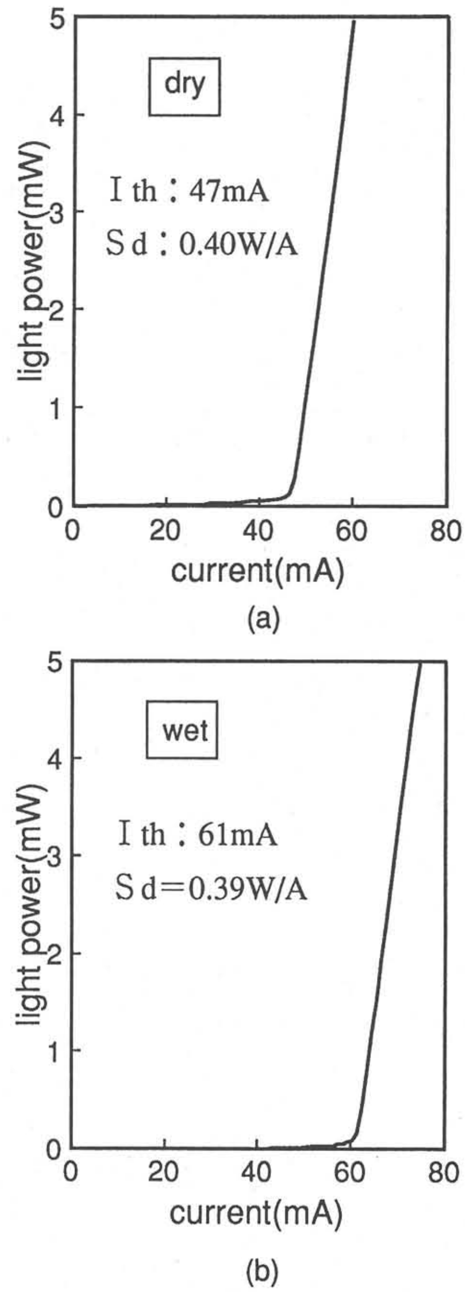



Fig.3 I-L charactteristic of (a) dry etched LD.
(b) wet etched LD. 25℃ CW L=500 $\mu$m

the surface roughness must be less than 10 nm. This smooth etching important for following regrowth process, was achieved by high-temperature (200°C), high-ion-energy (600 eV), and low-$Cl_2$-pressure conditions, promoting the evaporation of unvolatile $InCl_x$. Additionally, the oxidation of Al was prevented by keeping base pressure of the etching chamber below $4\times10^{-8}$ Torr[2]. During this etching, *in situ* laser reflectometry was used to control the etched depth to within 10 nm.

Figure 2 shows laser structure and a cross-sectional SEM view of the buried mesa stripe. The vertical and symmetrical mesa shape was obtained on this 6°-misoriented wafer in comparison with asymmetrical and sloped mesa shape of wet etched stripe. The vertical and symmetrical mesa shape probably has such advantages as small spot size and stable transverse mode operation. The SEM photograph shows that the quality of the overgrown layer is good even on the dry-etched surface.

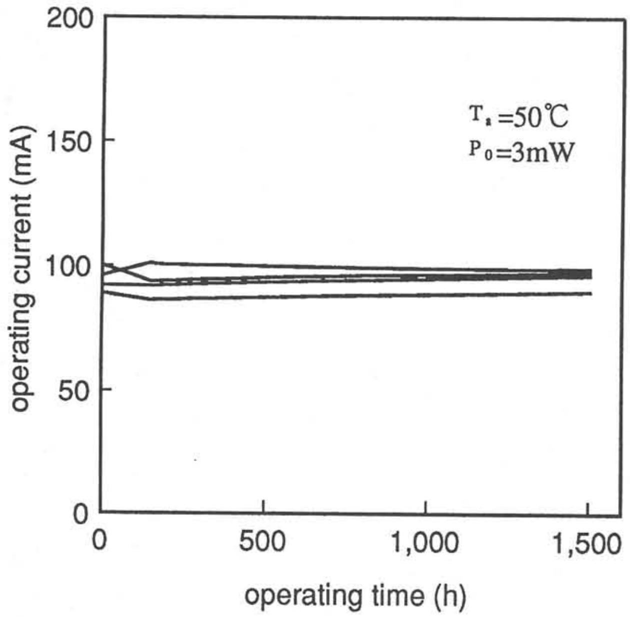



Fig. 4 Aging test of dry etched LDs.

Figure 3 shows I-L characteristic of a dry-etched and wet-etched LD during CW operation at 25°C. The cavity length here is 500 μm and the mesa width is 6 μm. The threshold current is 47 mA and slope efficiency is 0.40 W/A, values almost same as those of wet-etched LDs. The dispersion of the threshold current is about 4 %.

Figure 4 shows the results of aging tests for 4 pellets at 50°C. The operating power was kept at 3 mW. These LDs operated stably for over 1500 hours.

## *4. Summary*

In summary, we fabricated the first 650-nm AlGaInP LD with a dry-etched mesa stripe. Etching depth was accurately controlled by *in situ* laser reflectometry and a symmetrical mesa shape was obtained even on a 6°-misoriented substrate. Dry-etched LDs have characteristics almost the same as those of wet-etched mesa LDs. Ageing tests showed that these LDs have an operating time of at least 1500 hours. These results indicate that the dry-etching process is potentially valuable for fabricating AlGaInP visible-light LDs.

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