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InGaAsP-InP planar-stripe lasers fabricated by wet chemical etching

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InGaAsP-InP planar-stripe lasers are fabricated monolithically, in which cavity mirrors are formed by wet chemical etching and planar stripes are aligned along the [100] direction. The lasers emit light at $\sim 1.5\ \mu$m. The lowest threshold current density of these lasers is almost the same as that of conventionally fabricated cleaved-mirror lasers.

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The 1.4–1.7 μm spectral region is currently of great interest because of the recent development of low-loss optical fibers in this spectral region.[1] InGaAsP-InP double-heterostructure (DH) lasers emitting in the 1.4–1.7 μm wavelength range thus become a promising candidate for the light source of an optical fiber communication system. There are several reports on such lasers.

Realization of a monolithic integrated optical circuit is a current topic in the field of injection laser technology. Most of the injection lasers have been fabricated to form the mirror resonators by breaking the crystal along the (110) cleavage planes. The cleaved-mirror fabrication process, however, provides many undesirable disadvantages for monolithic integration of the optical circuits arising from the loss of the batch-process ability on the one wafer. There have been many reports on the monolithic fabrication of etched-mirror lasers in the GaAlAs-GaAs system.[2] Such etched-mirror formation enable making short-cavity lasers and also fabricating integrated lasers on the same wafer with other optical and/or electronic components such as monitoring detectors, modulators, waveguides, and laser-driving transistors.

Wright, Nelson, and Cella[3] have recently fabricated InGaAsP-InP DH lasers ($\lambda = 1.3\ \mu$m) by a batch process which incorporates chemically etched mirrors aligned along the $[0\bar{1}1]$ direction. More recently, Miller and Iga[4] have reported the successful fabrication of a monolithically etched-mirror laser ($\lambda = 1.3\ \mu$m) aligned along the $[01\bar{1}]$ direction with one chemically etched mirror and one cleaved mirror. The threshold current densities of such lasers have been about 40% above that of the cleaved mirror fabricated from the same wafer.

This paper reports an attempt at monolithic fabrication of planar-stripe InGaAsP-InP DH lasers ($\lambda \sim 1.5\ \mu$m) by wet chemical etching. The mirror cavity is aligned along the [100] direction and Br_2 in the methanol system is used for fabrication of the etched-facet (100) mirrors.

Figure 1 shows a diagram of the etched-mirror laser used in the present work. The InGaAsP-InP wafers used were grown in a specially designed carbon boat by low-temperature liquid phase epitaxy.[5] The four-layer double heterostructure, *n*I-InP, InGaAsP, *p*-InP, and *n*-InGaAsP, was grown on a (001) *n*-InP substrate. To prepare the planar-stripe laser, a SiO_2 film was sputtered onto the n-InGaAsP cap layer and 10-μm wide stripe windows were opened by standard photolithography technique. The stripes were aligned along the [100] direction. The Zn diffusion was then

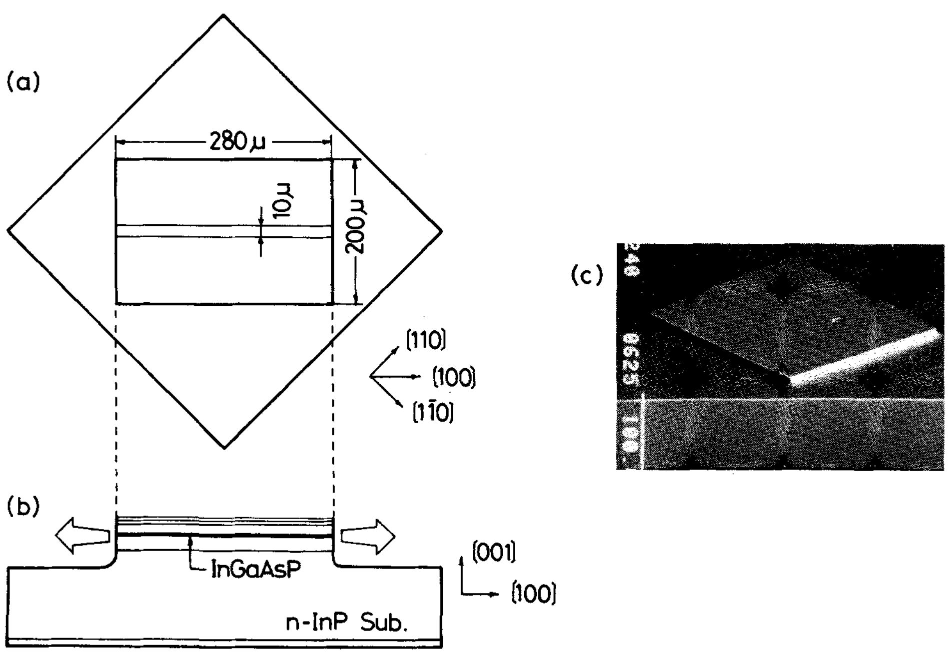

FIG. 1. Geometrical structure of an etched-mirror InGaAsP-InP planar-stripe laser: (a) top view, (b) cross-sectional view, and (c) SEM photograph of an etched-mirror laser.

performed through the windows to a depth sufficient to reach the p-InP layer. After removing the SiO_2 film, the n-InP substrate was lapped to a thickness of 60–100 μm, and Au-Zn and Au-Ge-Ni Ohmic contacts were applied to the p side and substrate side, respectively. The rectangular Au-Zn contact was then defined by photolithographic processing using Shipley AZ-1350 as a photoresist mask and a KI-I_2-H_2O solution as an etchant of the Au-Zn metal.

After definition of the Au-Zn Ohmic contacts, a SiO_2 film about 2000 Å thick was deposited on the p side of the wafer over the Au-Zn contacts. Subsequent photolithographic steps were employed to define SiO_2 masks 280 μm long and 200 μm wide directly over the Au-Zn contact for making the etched-cavity mirror, where the defined Au-Zn contact receded slightly from this SiO_2 mask to prevent contact by the subsequent etched-mirror fabrication procedure. A 0.3 vol % Br_2 in methanol solution was used in the present study for the etch-mirror fabrication. To fabricate good-quality etched mirrors on the DH wafer, it is necessary to employ etching solution which provides vertical-mirror walls on the etching profile and gives almost the same etching rates for the individual DH layers; in the present case for InP and for InGaAsP. It is well known that, in a zinc-blende crystal such as InP, the two [110] directions are not exactly equivalent, while all the [100] directions are identical and offer vertical walls on the etching profile by various etching solutions.[6] The Br_2-methanol system also exhibits clear preferential etching characteristics for InP.[6] Channels aligned along the [$\bar{1}$10] and [110] directions give etching profiles of V-shaped and reverse mesa-shaped structures, respectively, defined predominantly by the (111) In slow etching faces. However, this system has almost equal etching rates for InP and InGaAsP and thus is widely used to fabricate buried-heterostructure lasers as the mesa-etching solution.[7] In order to obtain vertical etched mirrors, the stripes were aligned in the present study along the [100] direction. The (100) faces of InP, in principle, consist either of In or P atoms. However, neither is preferred, since both atoms are doubly bonded to the crystal lattice at the surface, and real (100) faces consist of a mixture of the In and P atoms. This feature provides the vertical walls, i.e., (100) walls, on the etching profile of the stripes aligned along the [100] crystallographic direction. After fabrication of the mirrors by etching, the lasers were separated into individual units by cleaving [see Fig. 1(a) and 1(c)].

Figure 2 shows a scanning electron microscope (SEM) photograph of the chemically etched (100) mirror plane. It can be seen that the etched mirror tends to be vertical and smooth with a small tail at the bottom. The etching rates, however, differ slightly between that for the InGaAsP active layer and that for InP confining layers, i.e., the InGaAsP active layer is more deeply etched than its surrounding InP confining layers. The (110) etched-mirror lasers were also fabricated from the same wafer by chemical etching with the

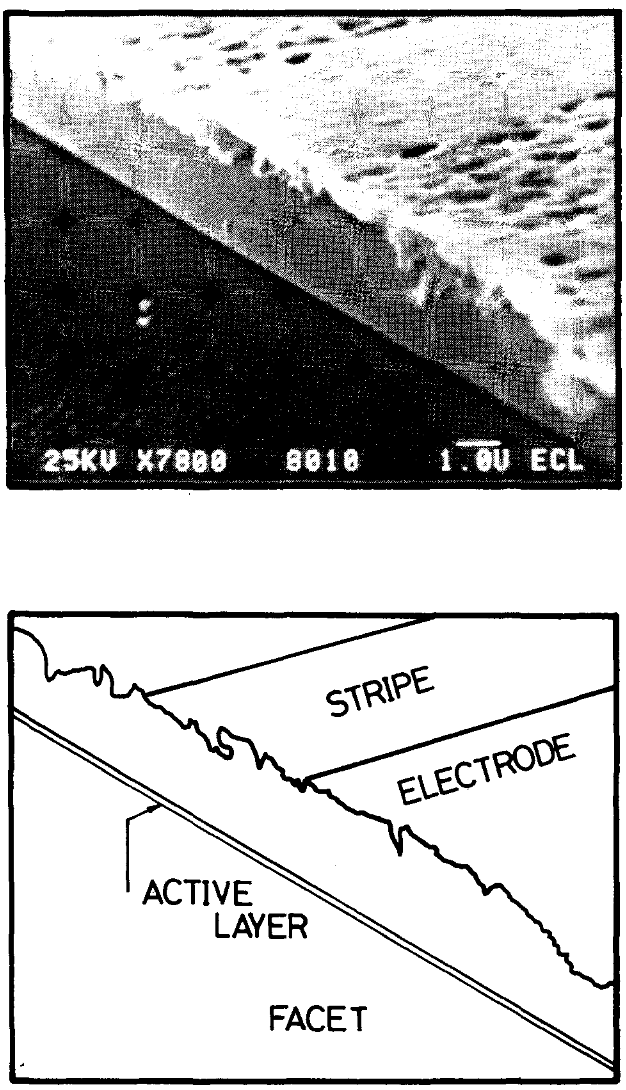

FIG. 2. SEM view of an etched-mirror plane.

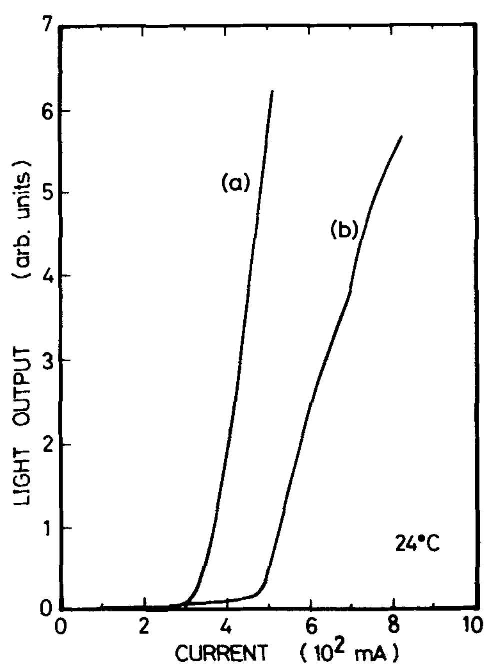

FIG. 3. Room-temperature light-current characteristics for (a) a conventionally fabricated cleaved-mirror laser ($L = 200\ \mu$m) and (b) an etched-mirror laser ($L = 280\ \mu$m).

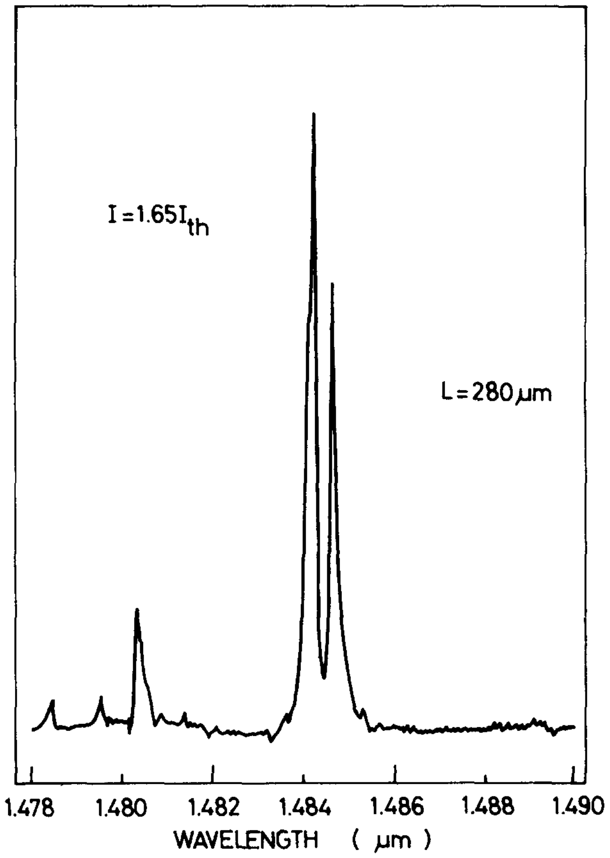

FIG. 4. Lasing spectrum of an etched-mirror InGaAsP-InP planar-stripe laser at room temperature under pulse operation with a current level of 1.65 I_{th}.

Br_2 in methanol solution, but no lasing was observed from these lasers. It might seem that this would be due to the mirror profile, since the reflectivity is greater for the vertical (100) mirror than for the tapered (110) mirror.[2]

To evaluate the performance of the etched-mirror lasers, planar-stripe lasers were also fabricated from the same wafer using conventional cleaving technique. These had 200-μm cavity length (L) and 10-μm stripe width. Figure 3 shows typical light versus injection current characteristics for (a) InGaAsP-InP cleaved-mirror laser [$L = 200 \mu$m] and (b) etched-mirror laser [$L = 280\ \mu$m]. The lasers were driven under pulse operation at 24 °C. The threshold current (I_{th}) of the cleaved-mirror laser was 330 mA, and that of the etched-mirror laser was 470 mA. These lasers, thus, have almost the same threshold current density of about 16.5 kA/cm^2. Wright *et al.*[3] have recently reported that the threshold current density for the $(1\bar{1}0)$ etched-mirror lasers with Br_2 in the methanol solution is approximately 40% higher than for standard cleaved-mirror lasers fabricated from the same wafer.

Figure 4 shows an example of the room-temperature lasing spectrum for an InGaAsP etched-mirror laser with a current level of 1.65 I_{th}. The lasing wavelength was in the range of 1.47–1.49 μm.

In conclusion, planar-stripe InGaAsP-InP lasers have been fabricated monolithically by wet chemical etching. The lowest threshold current density of these lasers is almost the same as that of conventionally fabricated cleaved-mirror lasers. The fabrication process described here provides not only the capabilitiy of making short-cavity lasers, but also of fabricating integrated optical circuits on the same substrate.

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