Double heterostructure lasers with facets formed by a hybrid wet and reactive-ion-etching technique

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Double heterostructure lasers were fabricated in which one of the laser facets was produced by a hybrid wet and reactive-ion-etching technique. This technique is suitable for GaAs/GaAlAs heterostructure lasers and utilizes the selectivity of the plasma in preferentially etching GaAs over GaAlAs. Lasers fabricated by this technique are compatible with optoelectronic integration and have threshold currents and quantum efficiency comparable to lasers with both mirrors formed by cleaving. The technique enables the use of relatively higher pressures of noncorrosive gases in the etch plasma resulting in smoother mirror surfaces and further eliminates the nonreproducibility inherent in the etching of GaAlAs layers.

The desirability of providing lasers on large-area substrates,[1–3] which contain both optical and electronic components require the development of batch processing techniques. To make use of a large-area chip, the laser feedback must be provided by techniques other than cleaving. Distributed feedback structures have been explored[4,5] and wet chemical etching[6–9] has also been used to define laser mirrors, but undercutting and orientation selectivity are inherent constraints. Recently reactive-ion-etching (RIE) techniques have been successfully used to fabricate[10–13] feedback facets in quaternary lasers. Because of the recognized technological importance of the GaAs/GaAlAs system it would be desirable to extend these ideas to this system as well. GaAs has been etched by RIE,[14,15] but there has been no report of similar work in GaAs/GaAlAs lasers, presumably because of the difficulty involved in the etching of GaAlAs. A gas mixture of BCl_3 and Cl_2 has been used[16] to etch GaAlAs though the oxidation of GaAlAs makes the etching process difficult to reproduce. Recently, reactive ion assisted chemical etching of GaAs/GaAlAs was demonstrated[17] but reproducible etching required ultra-high-vacuum conditions ($< 10^{-9}$ Torr base pressure). In this paper we describe a novel hybrid wet and dry etching technique which enables high aspect ratio structures in GaAs/GaAlAs heterostructures which form good feedback structures for laser devices. The technique utilizes noncorrosive gases in the plasma, is reproducible and yields surfaces which are smoother than those produced by conventional RIE of GaAs/GaAlAs layers.

In the case of GaAs/GaAlAs high selectivity in the etching using a freon-12 plasma has been demonstrated.[18] Further, using a mixture of freon-12 (CCl_2F_2), helium and oxygen we have obtained good etch rates ($\sim$0.1–0.5 μm/min) with vertical walls in GaAs even at pressures as high as 15–20 μm. At these pressures the GaAlAs on the surface is etched at a rate which is more than one order of magnitude smaller than that of GaAs. The high-pressure etching has a further advantage—generally increasing gas pressures and the lowering of substrate temperatures leads to smoother etching.

We have made use of this selectivity in making laser facets, by first wet etching grooves (with orientational preference) in the heterostructures and then using the edges of the etched GaAlAs layers as masks in the dry etching of the GaAs active layer. As illustrated in Fig. 1(a), to the double heterostructure (DH) grown by liquid-phase epitaxy a thin $Ga_{0.5}Al_{0.5}As$ layer is added at the top for protecting the GaAs(p^+) contact layer during the RIE. The layers are wet etched using a mixture of H_2SO_4, H_2O_2 and H_2O, resulting in orientation dependent profiles. When the (100) plane of GaAs is etched with mask openings oriented along the [011] or [01$\bar{1}$] directions, the groove profiles are determined by the preferential etching of (111) and (1$\bar{1}\bar{1}$) planes (V groove) or of the (1$\bar{1}$1) and ($\bar{1}1\bar{1}$) planes (dovetail groove), respectively.[19] We found that when a DH is etched in the H_2SO_4-H_2O_2-H_2O system, the angle of the groove sidewalls changes with Al

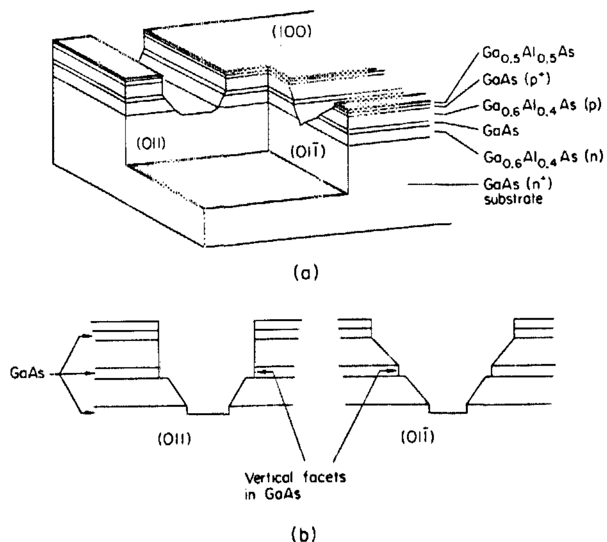

FIG. 1. General scheme of the hybrid wet and dry etching scheme: (a) Groove profiles that can be obtained when the (100) face of a DH is preferentially etched with a H_2SO_4-H_2O_2-H_2O solution. Note that the GaAs is not etched vertically either in the (011) or the (01$\bar{1}$) direction (b) Groove profiles after RIE, showing vertical walls in GaAs.

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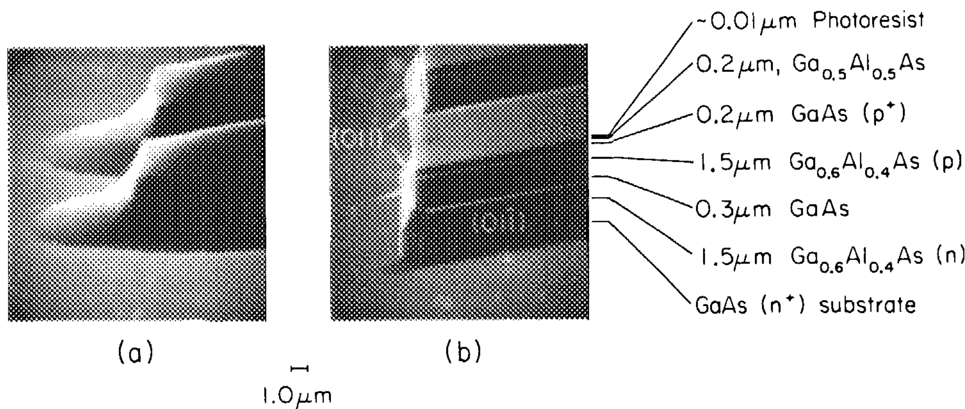

FIG. 2. Cross-sectioned SEM views of the wet-etched facets: (a) before, (b) after RIE.

concentration, the etchant composition and the etching temperature. For $Ga_{0.6}Al_{0.4}As$ etched with H_2SO_4:H_2O_2 (30% by weight): H_2O (1:8:10) at 25 °C we obtained near vertical profiles along the $(01\bar{1})$ direction in the GaAlAs upper cladding layer. The GaAs active layer is etched with a positive slope[20] as shown in Fig. 1(a). The sample is then etched in a plasma under the conditions described above. The GaAlAs layers act as masks and the GaAs layers are etched with a vertical profile [Fig. 1(b)]. Because of the higher pressures under which the layer is etched, we expect the facet to have a smoother surface. This technique is most suitable when the active layer is thick (> 0.3 μm) so that a significant portion of the lasing mode is confined in the active layer. With the perpendicularly wet etched top cladding layer the effective reflectivity of the facet is further improved.

After the DH layer is grown by LPE, the wafers are patterned with AZ1350J photoresist with openings for the mirrors. The resist is hard baked to prevent significant undercutting and to promote adhesion. The mirror groove is wet etched by using the 1:8:10 etch solution, and the sample is then reactive ion etched in a diode plasma etch station. The top and bottom electrodes were covered with 6-in. diam silicon wafers. An etch gas consisting of freon-12:He:O_2 was used at a pressure of 15–20 μm at a plasma power density of 0.15 W/cm^2. The GaAs etch rate was 0.2 μm/min under these conditions. We found that by utilizing a 1/16 in. thick quartz plate over the bottom electrode, the etch rate increased by over a factor of two under identical conditions.

In Fig. 2 are shown the scanning electron microscope cross sections of some devices before and after the reactive ion etching. In this case, etching in both the (011) and the $(01\bar{1})$ directions are shown. In the $(01\bar{1})$ plane the GaAlAs is nearly vertically wet etched (Fig. 2a). After the plasma etching, good vertical facets are obtained near the contact layer, active layer and the substrate. In all these regions the GaAlAs upper layers act as a plasma etch mask. In Fig. 3(a) magnified image of the etched GaAs region is shown indicating nonuniformities on the scale of < 500 Å. At lower pressures (~ 5 mTorr), required to etch GaAlAs, the etched surfaces would be significantly rougher illustrating the advantage of this higher pressure technique. After etching vertical walls in the GaAs (active) layer by RIE, a further chemical polishing was done by a dip etch in H_2SO_4:H_2O_2:H_2O (4:1:1). Oxide stripe lasers were then fabricated from wafers prepared in this way.

Figure 4 shows the light intensity of the cleaved facet of comparable devices, where some lasers had both mirrors cleaved and some had one of the facets reactive ion etched.

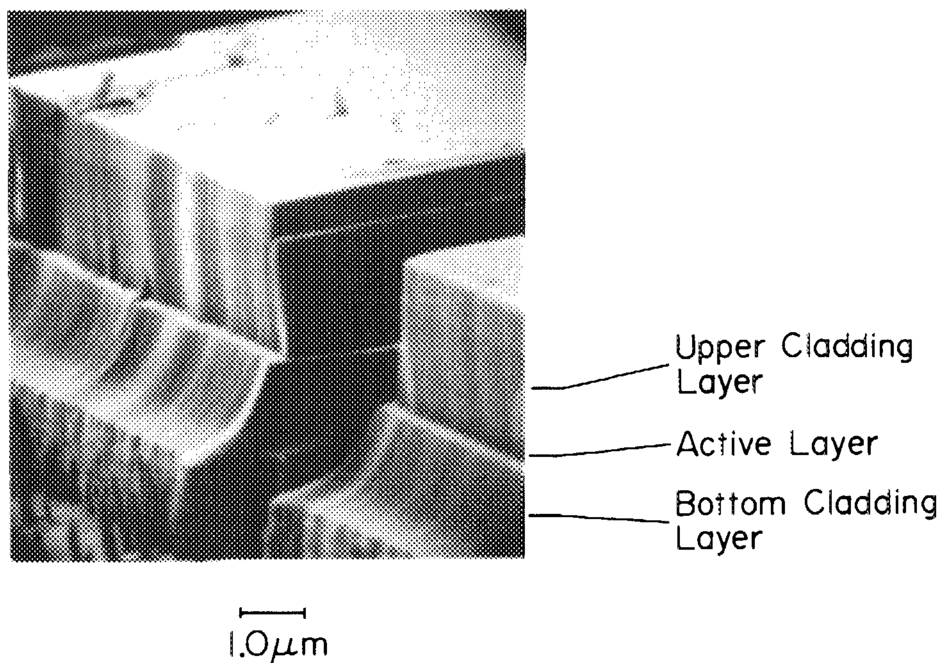

FIG. 3. A magnified view of the facet surface revealing nonuniformities of < 500 Å.

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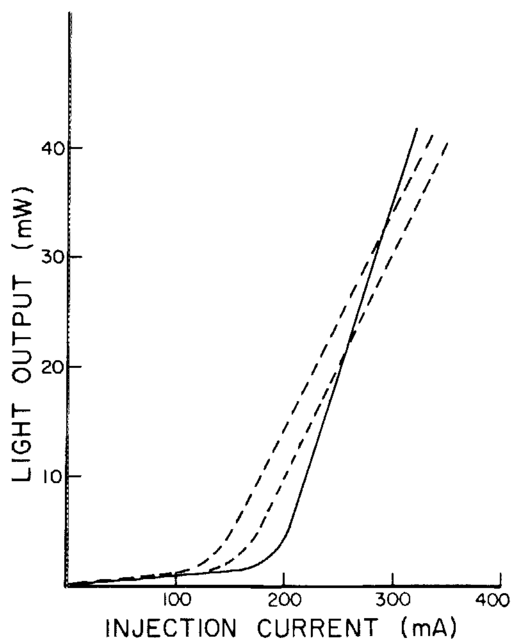

FIG. 4. Light intensity vs laser current for various lasers (—)with both cleaved facets (----) with one facet etched.

The threshold currents in lasers with both mirrors cleaved and those with one of the facets reactive ion etched were comparable (within 10%), and were reasonable on account of the thick active layers used in these devices. The quantum efficiency of these lasers were comparable as well, indicating an adequately well-etched mirror. These results were obtained in a large number of devices fabricated from different wafers, indicating a high degree of reproducibility. The mirrors produced by this method provide for laser feedback with lower reflectivity at the cladding layers than that of the active layer so that highly confined fields would be the preferred lasing modes. Therefore, the fundamental transverse mode is favored even for very thick active layers. In this case, the slopes in the GaAlAs cladding layers have a minor influence in the laser operation, allowing for use orientations other than that of the (011) for the laser mirrors. By this technique, mirrorlike facets with different curvatures can be fabricated as well. In fact, unstable resonator cavity lasers with both curved mirrors formed by etching were also demonstrated.[21] These lasers had threshold current and external quantum efficiency in good agreement with theoretical predictions in which the mirror reflectivity was assumed to be the same as that of cleaved facets.

In summary, we have described the successful operation of a simple DH laser fabricated using a hybrid wet- and dry-etching technique. This technique may prove useful in the fabrication of other laser device geometries, the integration of the lasers with other electronic, or optical devices and components on the same wafer.

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