IN-SITU ETCHING TECHNIQUE, INSIDE MOCVD REACTOR, FOR FABRICATION OF III-V OPTOELECTRONIC DEVICES

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ABSTRACT

The challenge of the mass production of optoelectronic devices is to develop new technological process in order to reduce the number of steps and to improve the process yield. In particular, for the realisation of integrated photonic devices, the etching and the following (eventually selective) regrowth represent the most crucial technological steps.

This paper overviews the recent technological advances in obtaining vertical and oblique sidewalls in both InP and GaInAsP/InP MQW laser structures partially masked with SiN into the MOCVD deposition chamber, by using chlorinated compounds.

The optimized experimental conditions were applied to etch mesa stripes in a SCH-MQW laser structure, followed by lateral InP:Fe regrowth in the same step. Threshold current as low as 6 mA and differential quantum efficiency higher than 25% for SI-BH MQW laser have been achieved.

INTRODUCTION

The development of emerging optical access network systems relies on cost reduction, high volume production and high reliability of optical components. At the same time both access and transport network systems require devices with high integration level and increased dimensions.

The realization of buried active stripe for high speed lasers (i.e. SI-BH Semi Insulating - Buried Heterostructure lasers), the butt-coupling between active and passive waveguide for tunable lasers, the etching of Fabry-Perot laser facets, directly performed on the wafer, for low cost application, are only a few of possible applications.

Usually the etching step is performed using RIE (Reactive Ion Etching) technique. This etching is based on a plasma effect, which can damage the quality of the interfaces. In all previous case a damaged interface can promote interdiffusion of the doping species and can affect the process yield and the device characteristics.

It is highly desirable to have a process in which simple dry chemical selective etch (without plasma effect) immediately followed (without air exposure) by a selective regrowth step burying the active region of the device (if the regrowth is required) is.

Up to now, lots of works done using HCl gas as etching agent have been published on the gas phase etching of GaAs-based alloys, leading to devices realization, Shimoyama et al (1) Inoue et al (2). However only a few reports on etching experiments on InP have been accomplished, Caneau et al (3). In some cases it has been pointed out that, in spite of its simplicity of use, HCl gas offers a series of disadvantages related to the difficult control of the etch rate of the Al-containing materials. Moreover, the relatively high etch rate on InP-based compounds leads to surface morphology and etch rate control, incompatible with device realization.

To overcome these problems, some Cl-containing compounds have been used to etch both GaAs-based alloys, Ikawa and Ogura (4) and InP-based materials, Knight et al (5) Bertone et al (6).

In this work, in-situ etching (ISE) technique is performed using 2-chloropropane (C_3H_7Cl) and dichloromethane (CH_2Cl_2) in a MOCVD reactor. Both compounds are non corrosive liquid at room temperature: they can be stocked in a conventional stainless steel bubbler and they can be introduced into the reaction chamber by a standard metalorganic source line of the MOCVD reactor. In this way, we also avoid the presence of a further compressed gas cylinder containing dangerous substance.

ETCHING RESULTS

The etching experiments were performed in a home-made MOCVD reactor at a constant pressure of 76 torr with Argon as carrier gas, using either 2-chloropropane or dichloromethane as chlorinated compounds and a group V-precursor (As,P) flow, to prevent the thermal decomposition of the surface. Conventional Arsine or Phosphine has been used during the etching process but also their less dangerous and promising substitutes Tertiarybutylarsine (TBAs) and Tertiarybutylphosphine (TBP) were tested, as an attempt to increase the safety of the process.

At first the etching experiments were done on InP and GaAs to verify the different behavior in terms of etch rate and resulting morphology. The etching runs were carried out by loading InP substrates or GaAs substrates, both patterned with SiN stripes along the (011) and (0-11) directions. The operating temperature was varied in the range 500-600 °C, as we are mostly interested in etching InP-based materials. Best conditions were found around 550 °C (limited by the presence of InP). Under these conditions it is relatively easy to etch InP while it is very difficult to etch GaAs (best results were obtained at higher etching temperature as reported in Ref. [4]). Figure 1 and Figure 2 show the strong difference in etching behavior, even if the etching conditions were the same. The result will be useful to understand etching evidences of the next set of experiments.

In the second part of the work, etching experiments were done on (100) InP substrates and on laser structures (previously grown by MOCVD on InP), patterned with SiN stripes along the (011) and (0-11) directions.

The laser structure we considered for both experimental runs and device realizations is a 9 wells partially strain compensated InGaAsP/InGaAsP SCH-MQW (Separated Confinement Heterostructure-MQW) having λ_{em} = 1.55 μm. Before loading into the MOCVD reactor, the samples were dipped in concentrated sulphuric acid to remove the surface oxides, then rinsed in deionized water and dried.

Etching results obtained on InP substrates are shown in Figure 3, whereas Figure 4 shows the etching behavior obtained on laser structure. In both cases we can observe the development of the well defined (111) planes when SiN stripes are oriented along the (011) direction and the nearly vertical (88°) facets by using SiN stripes oriented along the (0-11) direction. Moreover the vertical walls etching seems to be a promising way for the realization of Fabry-Perot laser facets directly on wafer. We didn't observe any bumps or steps in correspondence of the MQW stack, both for the oblique and for the vertical side-walls of the laser structure.

According to the different etching results between GaAs and InP, the laser structure containing GaInAsP alloy shows a lower etch rate with respect InP as well evidenced in Figure 3 and Figure 4.

FABRY-PEROT LASER REALIZATION

SI- BH Fabry-Perot laser diodes have been realized to test the process yield and the devices characteristics. After etching the active stripe, the surface was ready for selective regrowth of the semi-insulating Fe-doped InP, without air exposure of the active region of the device.

After SiN chemical removal, in a second regrowth step, Zn-doped InP and Zn-doped GaInAs contact layer were deposited by conventional MOCVD procedure. Then, conventional technological steps were adopted to finish the device process (Figure 5).

The devices were cleaved at different length, leaving the facets as cleaved. Figure 6 (left) reports the histogram of the threshold current obtained with a device length of 250 μm. The graph shows a very high uniformity in threshold current, since more than 85% of the devices tested exhibited a threshold current of less than 6 mA at 20 °C; the threshold current at 60 °C was about 25 mA. Similar results have been obtained in terms of quantum efficiency, close to 25%.

This excellent uniformity as well as the low threshold current, are the result of the precise active etching and the good quality of the interfaces obtained by using the in-situ technique.

Dynamic measurements on the laser devices have shown a modulation bandwidth of 10 GHz, obtained at only 20 mA of bias current (four times the threshold current). At higher injection the device was limited by the parasitic capacitance; the maximum bandwidth, that could be obtained reducing the contact area, can be estimated in 15 GHz.

The right side of Figure 4 reports some results of the preliminary aging tests performed on 6 laser samples, biased at 100 mA and 60 °C. The devices were found to be highly stable, operating for 1000 h without any degradation. The devices are being currently tested, to deeply investigate the reliability of such lasers.

APPENDIX

From the above considerations, we would like to make a simple model of the process chemistry. We believe that we have firstly to consider the reaction:

$$H_2 + Cl_2 \leftrightarrow 2\,HCl \qquad (1)$$

then the reaction considered as responsible for the etching of InP:

$$HCl + InP \rightarrow InCl + 1/2H_2 + 1/2P_2 \qquad (2)$$

Reaction (1) indicates that the composition of the etching gas is a mixture of Cl_2 + HCl, with a variable percentage ratio, depending not only on the temperature, but also strongly on the concentration of active hydrogen and active chlorine, probably in radical forms. The presence of free chlorine in the etching mixture may also explain the relative easiness to etch the InGaAsP alloys and the GaAs at higher temperature.

CONCLUSIONS

New ISE technique, suitable for mass production of integrated photonic devices has been developed. Avoiding the plasma damage of a conventional etching technique and also avoiding the air exposure of the sample between etching and regrowth steps, the process yield and device reliability are improved.

SI-BH Fabry-Perot lasers have been realized to confirm the validity of this technique.

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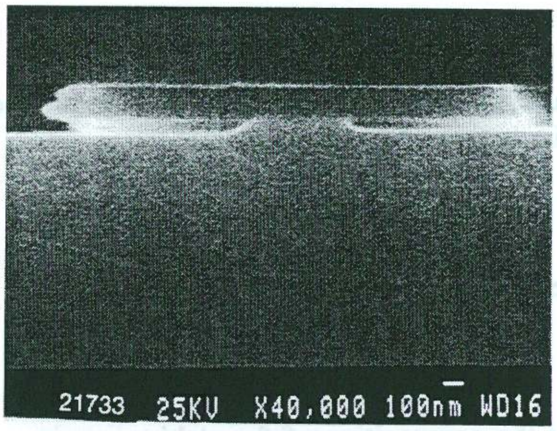

Figure 1: Etching behavior obtained on GaAs substrate when SiN stripes are oriented parallel to the (011) direction. (CH$_2$Cl$_2$+TBAs)

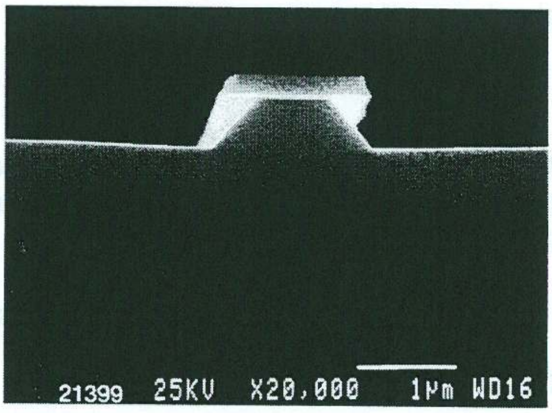

Figure 2: Etching behavior obtained on InP substrate when SiN stripes are oriented parallel to the (011)direction.(CH$_2$Cl$_2$+TBP)

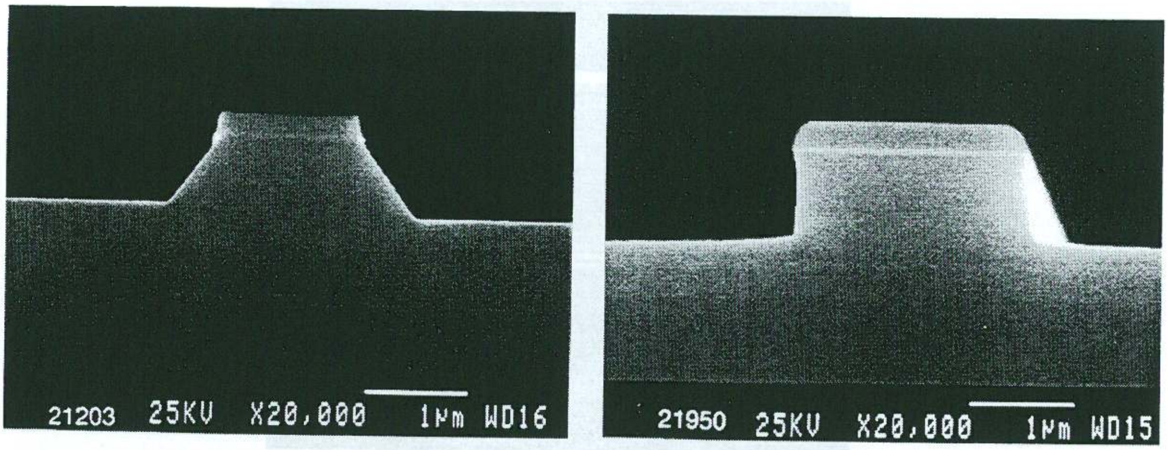

Figure 3: Etching behavior obtained on InP substrate when SiN stripes are oriented parallel to the (011) direction (left) and parallel to the (0-11) direction (right). Etching time = 30 min.

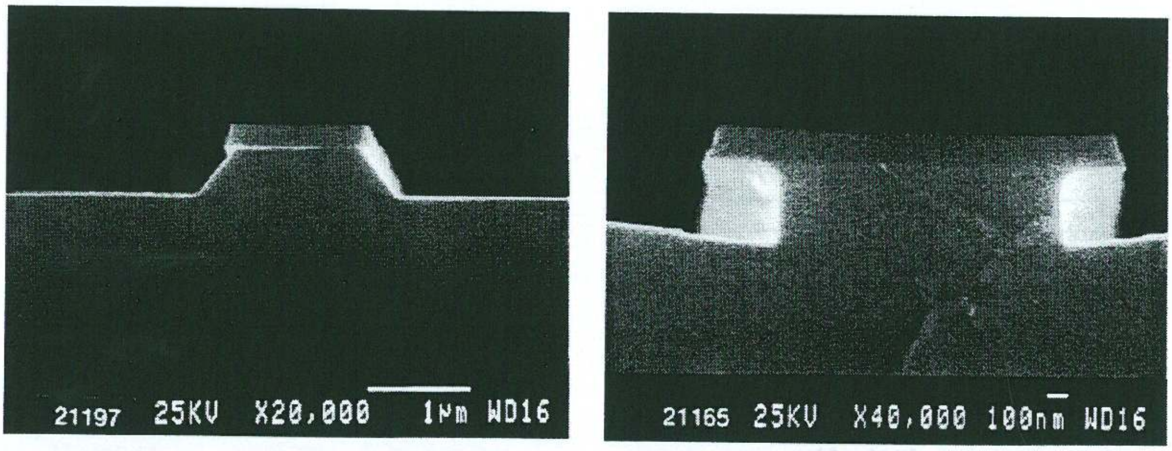

Figure 4: Etching behavior obtained on laser structure when SiN stripes are oriented parallel to the (011) direction (left) and parallel to the (0-11) direction (right). Etching time = 30 min.

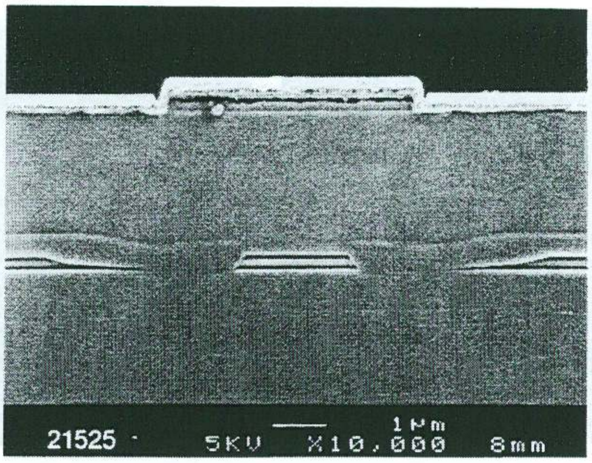

Figure 5: Scanning electron micrograph of the device

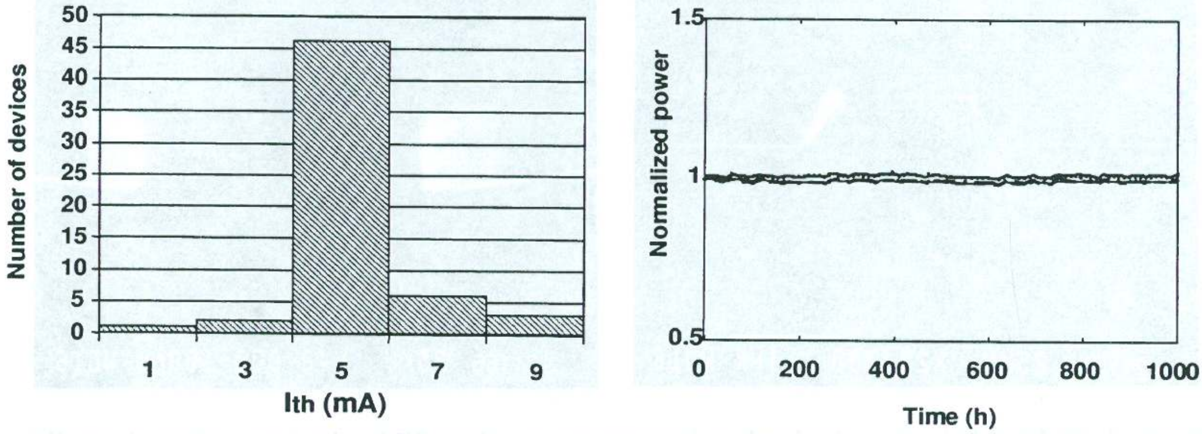

Figure 6: Histogram of the threshold current obtained with a device length of 250 µm (left); preliminary aging tests performed on 6 laser samples, biased at 100 mA and 60 °C (right)