FABRICATION AND CHARACTERISATION of InGaAs/InGaAsP/InP LONG WAVELENGTH SEMICONDUCTOR LASERS

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Key words: Optoelectronics, semiconductor lasers

ABSTRACT

This paper presents the fabrication and characterisation of wet and reactive ion etched ridge waveguide InGaAs/InGaAsP/InP lasers with an operating wavelength of 1.5µm. Characterisation results of InGaAs/InGaAsP/InP lasers are given of two etching methods, namely wet chemical etching and reactive ion etching. Relative advantages and disadvantages of these two methods are also discussed comparatively.

I. INTRODUCTION

The future demand for broadband services requires telecommunication networks to operate with faster, more efficient and higher capacity. Data links with higher bandwidth are needed for increasing telephone traffic, upcoming services such as internet, video telephones, high definition television (HDTV), computer and other multimedia services [1]. After the invention of semiconductor lasers- which are utilised as light sources in optical communication systems- in 1962, the past 30 years have witnessed fast developing fibre optic communication system. Thus, the optical systems with high bandwidth and low attenuation have been an ideal replacement for copper (coaxial) based communication systems.

For use in long haul optic communication systems, semiconductor lasers are required to operate in low loss silica window around the 1.5µm wavelength region where attenuation is about 0.2dB/km. Since oxide stripe lasers are have less efficiency and lifetime, different etching methods such as wet, reactive ion and ion beam etching are used widely to fabricate ridge waveguide semiconductor lasers. Here, we present the experimental results of long wavelength (1.5µm) semiconductor lasers fabricated from InGaAs/InGaAsP/InP material system.

II. MATERIAL STRUCTURE

The wafer was grown by metal organic vapour phase epitaxy (MOVPE) at the EPSRC III-V central facility at the University of Sheffield. The epitaxial layers were grown on an n^+ Si doped, doping density $2x10^{18}$ cm^{-3} InP substrate. From the substrate, the layer specifications are as follows: a 1µm n-type Si doped ($5x10^{17}$ cm^{-3}) lower cladding layer, a 295nm waveguide core, a 1.2µm p-type Zn doped ($7x10^{17}cm^{-3}$) upper cladding layer, a 50nm InGaAsP transition layer (bandgap with a wavelength value, λ_g=1.18µm) with Zn doping at $2x10^{18}cm^{-3}$, and finally an $In_{0.53}Ga_{0.47}As$ contact layer with Zn doping at a concentration of $4.5x10^{18}cm^{-3}$.

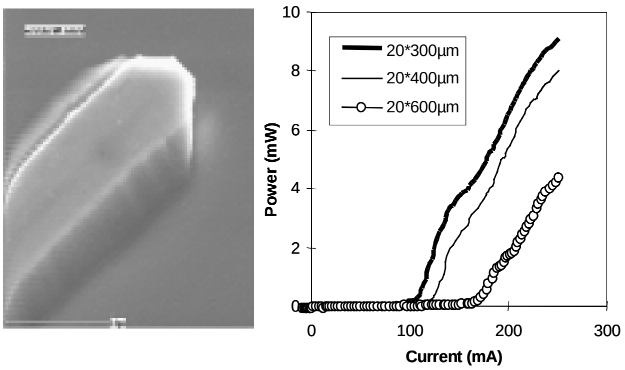
The active layer contains five 60Å $In_{0.53}Ga_{0.47}As$ quantum wells with six 120Å InGaAsP (λ_g=1.26µm) barriers. By using the barrier region in the structure, the overflow electrons from the active layer to the p-cladding layer are reflected by the effect of electron interference [2]. The wells are surrounded in both directions with a step graded index region, consisting of a 50nm InGaAsP (λ_g= 1.18µm) and an 80nm InGaAsP (λ_g= 1.1µm) quaternary layers. All the layers are lattice matched to InP.

III. FABRICATION AND CHARACTERISATION OF WET ETCHED RIDGE WAVEGUIDE LASER

Wet chemical etching, when compared with dry etching methods, is simple and offers high selectivity where the undesired removal of the mask is prevented. It also avoids potential drawbacks associated with standard methane/hydrogen (CH_4/H_2) dry etching such as deep damage to the quantum well layers and passivation due to hydrogen incorporation. However, since wet etching rates can be the same in all directions, i.e. the etching is isotropic, a good rate of reproducibility and the transfer of patterns smaller than 3µm to the semiconductor surface are difficult to accomplish.

Before accomplishing wet etching process, samples were coated with S1805 photoresist and then baked in an oven at 90°C for 30 minutes. After 5-50µm wide waveguides were aligned on the samples, wet chemical etching was applied in two steps. In the first step, a mixture of 40 parts Acetic acid (Glacia), 20 parts Hydrochloric acid (HCl), 3 parts Hydrogen peroxide (H_2O_2) and 15 parts RO water was used to remove the InGaAs cap layer. The second step etch involved 3 parts Orthophosphoric acid (H_3PO_4) and 1 part Hydrochloric acid (HCl) that etched the upper InP cladding layer. Then, to create a dielectric on the unetched region, Al_2O_3 of 300nm was deposited on the sample by using e-beam evaporator, followed by lift-off the resist in acetone. Finally, the fabrication process was finished with p-side (20nm Titanium/150nm gold) and n-side (14nm gold/14nm germanium/14nm titanium/200nm gold) metal deposition.

After annealing the samples at 330°C for 1 minute, individual lasers were produced from the wafer by scribing and cleaving. Light-current (L-I) characteristics of the cleaved lasers were plotted by means of a computerised system. An etch profile and the L-I curve of the laser device, cleaved at 300µm, 400µm and 600µm long cavity lengths, are given in Figure 1.



(a) (b)

Figure 1. (a) Scanning electron microscopy (SEM) picture and (b) L-I curve of the wet etched laser.

An increase in the threshold current and a decrease in slope efficiency were recorded as the cavity length was increased. Some semiconductor material parameters such as threshold current density, internal loss and quantum efficiency are very useful to determine the optical quality of lasers fabricated. The external quantum efficiency is defined by [3]

$$\eta_{ex} = \frac{\eta_{in}}{1+\dfrac{\alpha_i L}{\ln(1/R)}} \tag{1}$$

where η_{ex} is the external quantum efficiency, η_{in} is the internal quantum efficiency, α_i is the internal loss, L is the cavity length and R is the mirror reflectivity.

Internal quantum efficiency (η_{in}) is found from the characterisation of inverse quantum efficiency against cavity length. The characterised material parameters are given in Table 1.

Width (µm)	**η_{in} (%)**	**α_i (cm^{-1})**	**J_{th} (A/cm^2)**
20	18.4	10.4	1375-1750

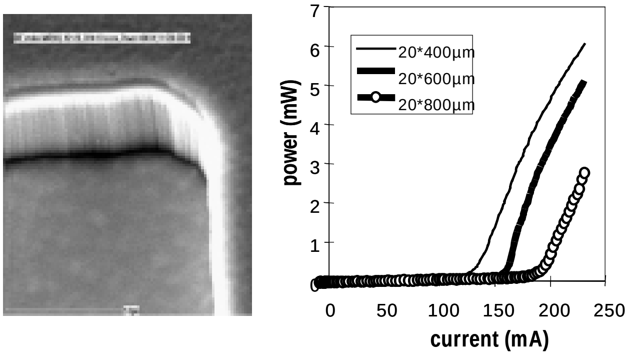
Table 1. Material parameters of the wet etched sample

The 20µm wide devices fabricated had a low internal quantum efficiency of 18.4 and an internal loss (α_i) of $10.4cm^{-1}$, which led to the high values of threshold current densities (J_{th}) in the range of 1375 to $1750A/cm^2$.

IV. FABRICATION AND CHARACTERISATION OF REACTIVE ION ETCHED (RIE) RIDGE WAVEGUIDE LASERS

Reactive ion etching (RIE) that is a method of dry etching overcomes certain disadvantages of wet etching such as undercut and nonuniformity. Features with dimensions less than 3µm are patterned using dry etching techniques because they are hard to achieve with wet etching. However, dry etching processes may damage wafers due to physical and chemical bombardment during etching. This section describes fabrication and characterisation of reactive ion etched lasers.

Following the preparation of the mask (SiO_2/Ni), the samples were etched in a mixture of methane/hydrogen (CH_4/H_2) chemistry by using a reactive ion etching machine. The etching conditions are as follows: Power is 400W, DC self-bias voltage is 500V, CH_4/H_2 is 10/20sccm and base pressure is 0.5mTorr. The same metal deposition materials utilised in the fabrication of wet etched lasers were also used on p and n-side of the RIE etched wafers. Figure 2 shows an etched structure and the L-I curve of the laser device, which were cleaved at 400µm, 600µm and 800µm long cavity lengths.



(a) (b)

Figure 2. (a) SEM image and (b) L-I curve of the etched laser.

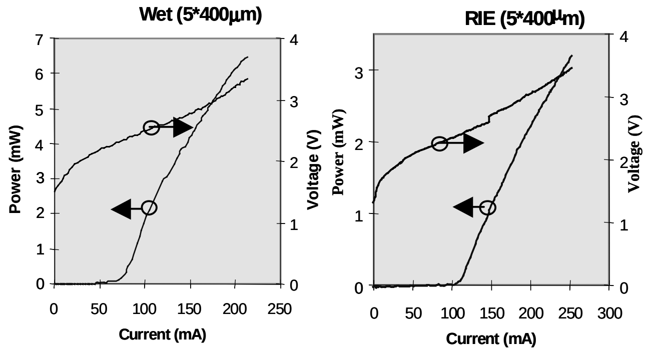
SEM picture illustrates totally smooth structure of the RIE etched laser. As observed in the case of wet etching, the threshold current increased with increasing cavity lengths (Figure 2(b)). Using equation (1), the material parameters were obtained and tabulated in Table 2.

Width (μm)	η_{in} (%)	α_i (cm^{-1})	J_{th} (A/cm^2)
20	26	14	1156-1625

Table 2. Material parameters of the RIE etched sample.

V. COMPARISON OF WET AND REACTIVE ION ETCHED (RIE) RIDGE WAVEGUIDE LASERS

A comparison is given in Figure 3 for the two best 5μm wide ridge waveguide lasers.



(a) (b)

Figure 3. L-I-V characteristics of 5μm wide and 400μm long (a) wet etched and (b) RIE etched lasers.

As seen in the above figures, the RIE etched laser had a threshold current of 105mA while the wet etched device yielded a threshold current of 75mA. The forward bias characteristics (I-V) of the wet and RIE etched lasers were almost identical. This implies that either the optimised RIE etch did not cause the hydrogen passivation effect (the passivation of electrical activity) on the sidewalls or it was removed by the annealing process [4]. By using Tables 1 and 2, the values of internal quantum efficiency and internal loss for wet and dry etched devices are shown in Table 3.

	Width (μm)	η_{in} (%)	α_i (cm^{-1})	J_{th} (A/cm^2) (20μm*400μm)
Wet etched	20	18.4	10.4	1450
RIE etched	20	26	14	1625

Table 3. Material parameters of wet and RIE etched devices.

Table 3 demonstrates that an increase in both the internal loss and the threshold current density was observed in the case of reactive ion etching. This indicates that reactive ion etching caused a slight damage, which was not removed totally by the post etch annealing process. Another possibility deteriorating the performance of RIE etched devices can be an asymmetry in the current injection window. However, internal quantum efficiency in RIE etched lasers is higher than that of wet etched ones.

VI. CONCLUSIONS

Wet and RIE etched lasers were fabricated and characterised to compare their performance. Although current-voltage characteristics of the devices were almost identical, which showed that the hydrogen passivation effect was very low on the RIE etched lasers, the performance of the wet etched devices were slightly better than the RIE etched ones. This is likely due to the damage caused by dry etching. This can be improved by reducing bias voltage levels in the case of reactive ion etching. It should be noted that if highly vertical structures is required for an application such as corner mirrors in optical crosspoint switches, the advantage of using reactive ion etching largely outweighs the risk of damaging the material.

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