Fabrication technology of photonic crystal nanobeams on III-V membranes

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In this article we present a technology process needed for membrane-based butt-joint waveguide-coupled 1D photonic crystal (PC) nanobeams (NBs). We discuss the results of etching experiments through different materials, chemistries and geometrical properties of the slabs to achieve high quality NBs.

The use of membranes allows high density and low power consumption of photonic devices on chip; both needed for optical interconnects [1]. Besides that, active devices such as lasers can be fabricated in III-V materials because of their direct bandgap. However, miniaturization of lasers imposes strict requirements on the reflectivity of the cavity mirrors. In this respect, PC lasers are good candidates since the use of holes as mirrors gives high reflectivity with a small number of periods while having good control of the wavelength [2]. Reflectivity up to 85 % is possible with just 5 holes and Q factors are widely known to be high for PC NBs. However, the advantages of NBs come at a price since fabrication of such structures is challenging [3].

Etch depth (nm)	800	800	800	300	300	2500
Hole diameter (μm)	$0.1-0.35$	$0.1-0.35$	$0.1-0.35$	$0.1-0.35$	$0.1-0.35$	$0.2-1$
Resist type	ZEP520A	ZEP520A	ZEP520A	ZEP520A	ZEPC60	ZEP520A
Material	n-InP/ InGaAs/ p-InP	n-InP/ InGaAs/ p-InP	n-InP/ InGaAs/ p-InP	InP	InP	InP
Chemystry-sccm	CH_4/H_2- $30:10$	Cl_2/N_2- $14:03$	Cl_2/O_2- $15:15$	CH_4/H_2- $30:10$	*CH_4/H_2- $30:10$	*CH_4/H_2- $30:10$
Temperature/ RF power	60/110	200/100	60/10	60/110	150/100	150/100

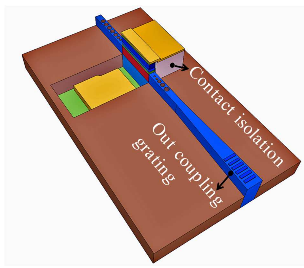

Fig.. 30. Etching parameters (* On an ICP Sentech SI500), and laser schematic.

We consider a butt-joint NB laser design shown in Figure 1. Holes can be located either in the active cavity or the passive waveguide. Simulations by FDTD method show that overall wall-plug efficiency is around 30% with any of those configurations [3]. However, fabrication wise they are not equal: if the holes are in the active region they need to be etched much deeper and through different materials. In order to investigate which configuration is feasible we experimented etching holes of different diameters through representative layer stacks using different chemistries with an ICP 180-oxford and Sentech-SI500. The table in Figure 1 summarizes the different experimental parameters.

There were two test batches. The first test was done in a slab with active and passive material grown on an InP substrate with 800nm thickness and 700nm wide as depicted in Figure 2b). This configuration is a robust test because it comprises different materials and deep etch. We tested CH_4/H_2, Cl_2/N_2 and Cl_2/O_2 chemistries [4]. Figure 2a) shows Scanning Electron Microscope (SEM) pictures of holes with diameters of 0.2 and 1 μm and a targeted etch depth of 1.5μm (col.6 of table). Note 1/3 etch rate between 0.2 and 1 μm holes, which shows the influence of the lag effect. In 2b) hole profiles for different chemistries in an 800 nm thick slab are shown (col.1-3 of the table). Additionally, Figure 3a) depicts how detrimental is for Q factor if the holes are not completely etched trough the slab. Hence, this first batch clearly indicates that the NB structures should avoid etching the holes in thick slabs to reduce lag effect.

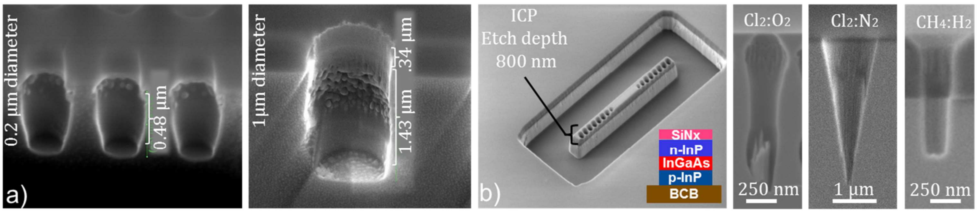

Fig.. 2. Parameters used during the holes etching process.

The second test was done with a 300 nm thick, and 700 nm wide slab of pure InP. We present both, thin and thick resist to point out that the resolution effects of the holes can be controlled accurately using the correct patterning dose. Figure 3b) shows the SEM picture of the top view and Focused Ion Beam cut of the etched holes with different resists (col.4, 5 of the table). Note that even at very high magnification the etched holes are smooth, very well defined and have vertical walls.

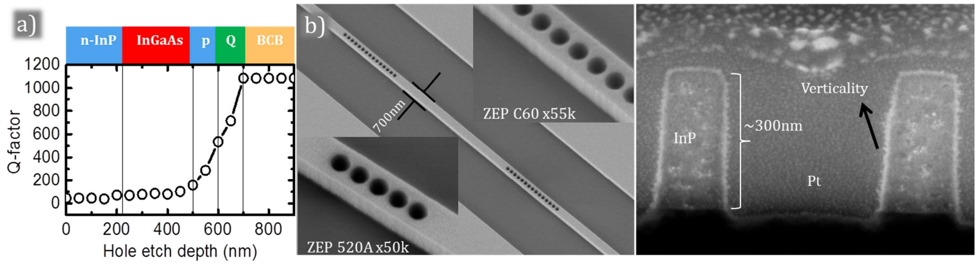

Fig.. 3 . InP etched holes with different resist ZEP 520A and ZEP C60.

Summarizing, to maintain good wall-plug efficiency, reduce surface recombination at the sidewalls of holes in the active material and, to reduce lag effect, lasers with PC mirrors in passive NB butt-joint to an active region is the best choice from a process technology point of view. We obtained high quality holes by using the parameters of columns 5 and 6 of the table in Figure 1, and verified that the resolution of the holes mainly depends on the correct dose and resist thickness (100-300 nm thickness for 100 nm diameter holes).

References

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