



## Dry Etching of High [Al] AlGaAsSb Compounds Using Cl<sub>2</sub> /N<sub>2</sub> /Ar ICP RIE

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Brice Adelin, Quentin Gaimard, Alexandre Larrue, Aurélie Lecestre, Pascal Dubreuil, et al.. Dry Etching of High [Al] AlGaAsSb Compounds Using Cl<sub>2</sub> /N<sub>2</sub> /Ar ICP RIE. International Conference on Micro and Nano Engineering ( MNE ) 2014, Sep 2014, Lausanne, Switzerland. hal-01102417

**HAL Id: hal-01102417**

**<https://hal.science/hal-01102417>**

Submitted on 12 Jan 2015

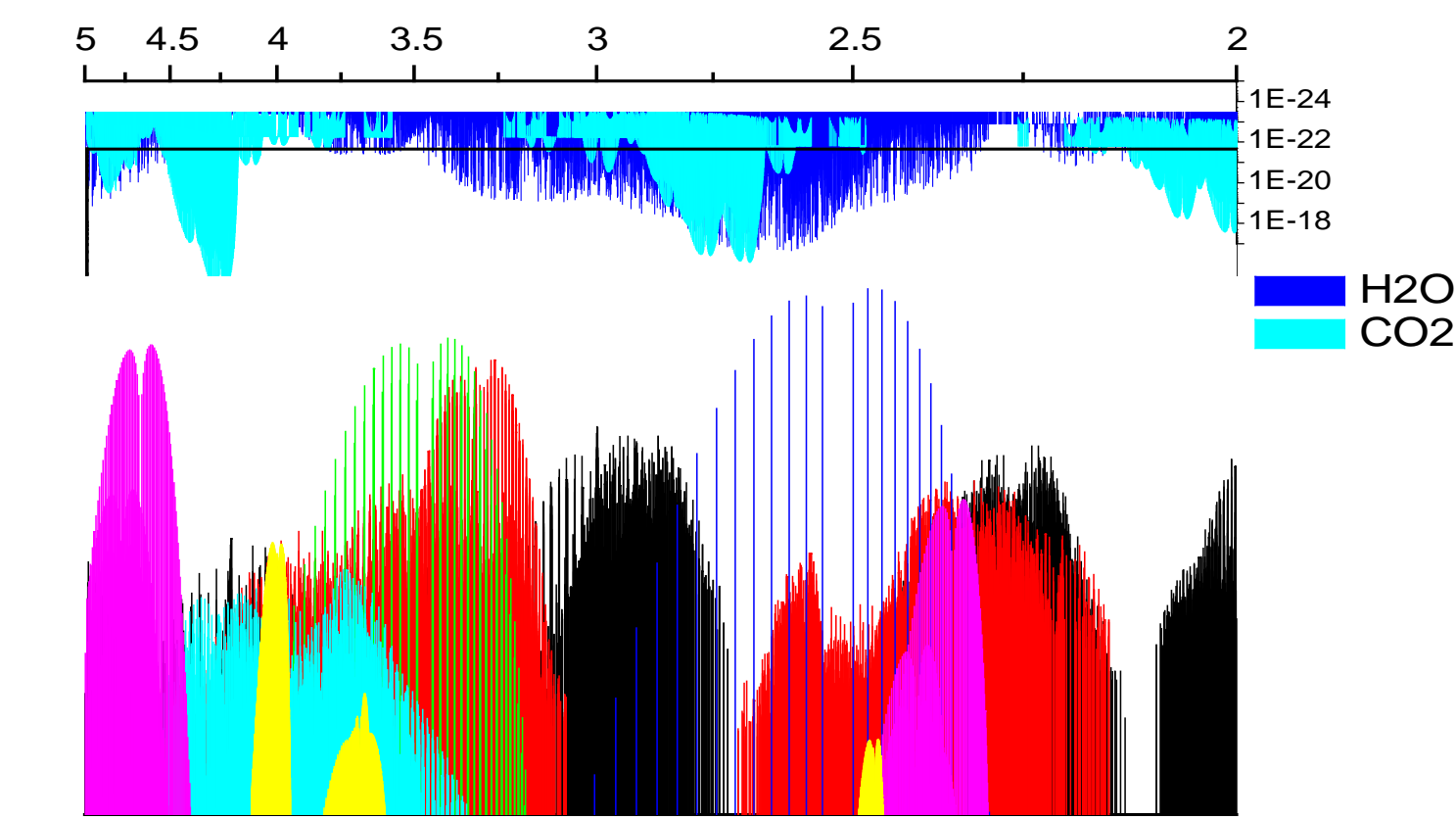
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Dry Etching of High [Al] AlGaAsSb Compounds Using  $\text{Cl}_2/\text{N}_2/\text{Ar}$  ICP RIEB. Adelin<sup>a,b,\*</sup>, Q. Gaimard<sup>c</sup>, A. Larrue<sup>a,b</sup>, A. Lecestre<sup>a,b</sup>, P. Dubreuil<sup>a,b</sup>, Y. Rouillard<sup>c</sup>, G. Boissier<sup>c</sup>, A. Vicet<sup>c</sup>,  
A. Monmayrant<sup>a,b</sup>, and O. Gauthier-Lafaye<sup>a,b</sup><sup>a</sup>LAAS-CNRS, 7 avenue du Colonel Roche, BP 54200, 31031 Toulouse cedex 4, France<sup>b</sup>Université de Toulouse ; UPS, INSA, INP, ISAE ; LAAS ; BP 54200, 31031 Toulouse cedex 4, France<sup>c</sup>Institut d'Electronique du Sud (IES), Université Montpellier 2, Place Eugene Bataillon, 34095 Montpellier, France

## Context



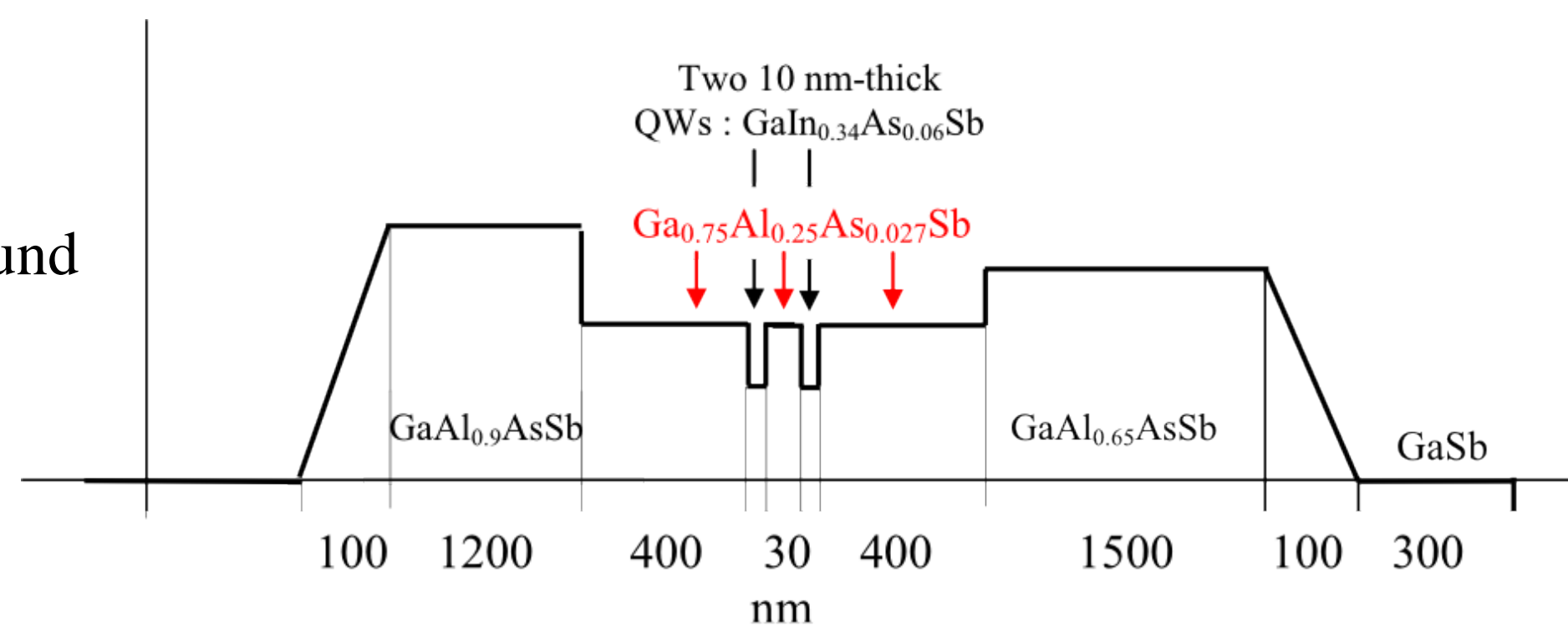
GaSb based compound semiconductors emit in the mid-infrared range and present extremely good optoelectronic properties, with demonstrated bipolar laser diodes emitting from 2 to 3.5  $\mu\text{m}$  with good performances. One key challenge remaining is the realization of high performance single mode emitters to enable the realization of efficient trace gas detection systems. Such diodes are often made with a core waveguide embedded in claddings made of AlGaAsSb with high Al content. Deep etching of high Al content claddings is known to be a particular challenge for deep etching with high aspect ratio, and restricts the designs achievable for laser diodes fabrication.

We present our work on deep etching of sub-micron 1D and 2D periodic structures designed to achieve DFB effect in edge emitting mid infrared lasers. DFB cavities can be realized using several geometries. We investigated two thoroughly opposite ones. The first studied geometry relies on periodic modulation of a waveguide width, and requires smooth etching of narrow 1D trenches with a mostly open etch mask. The other investigated geometry relies on 2D photonic crystal cavities, and requires deep etching of sub-micron diameter holes with high aspect ratios, in a mostly closed mask.

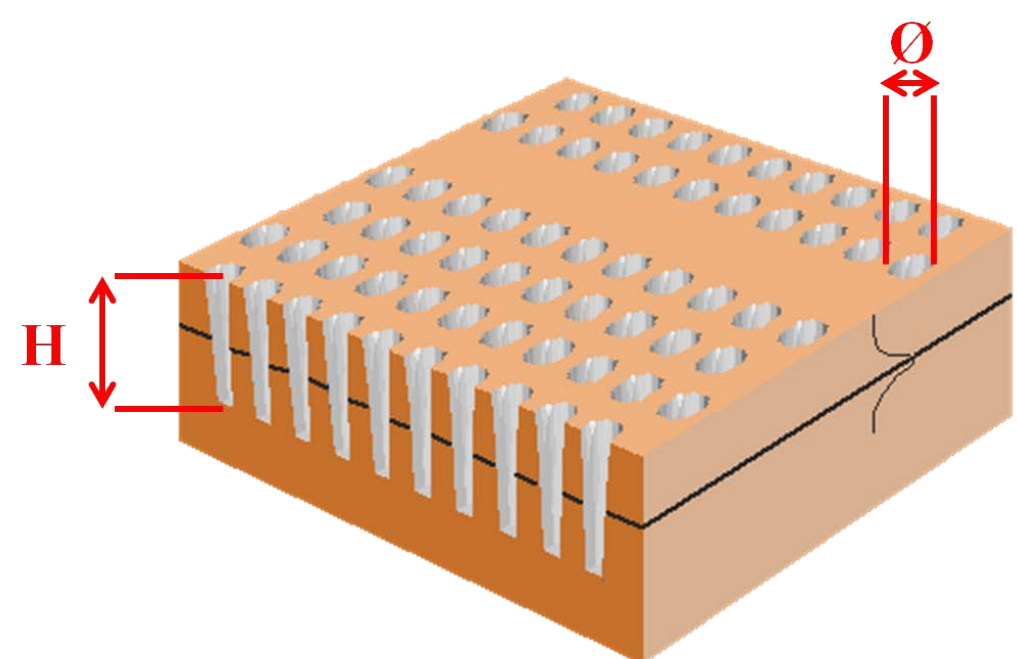
## Issue

## Towards the realization of laser diodes all PhC electrically pumped in GaSb system

- Heterostructure AlGaAsSb / InGaAsSb for an emission around 2.3  $\mu\text{m}$

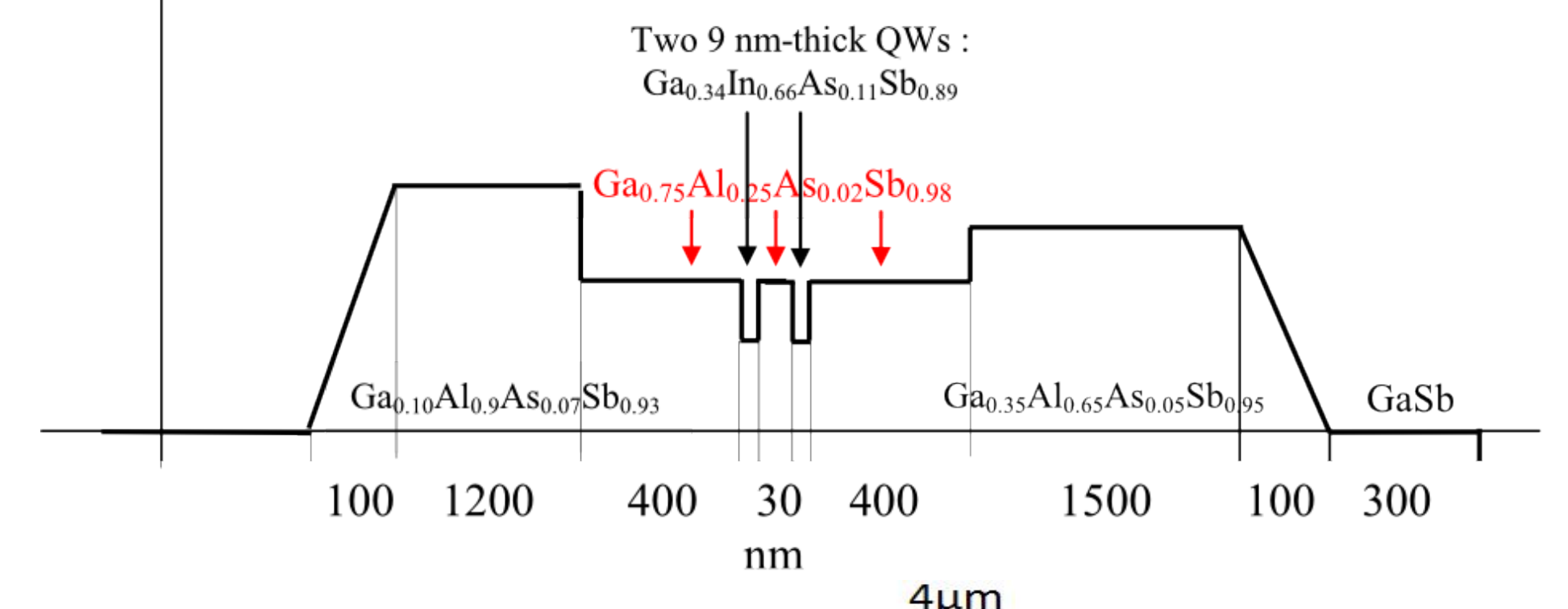


- Etching of submicron patterns with high aspect ratio in the heterostructure :
  - Characteristic dimensions :  $\varnothing \sim 375 \text{ nm}$ ,  $H \sim 3.5 \mu\text{m}$
  - Aspect ratio : 1:9

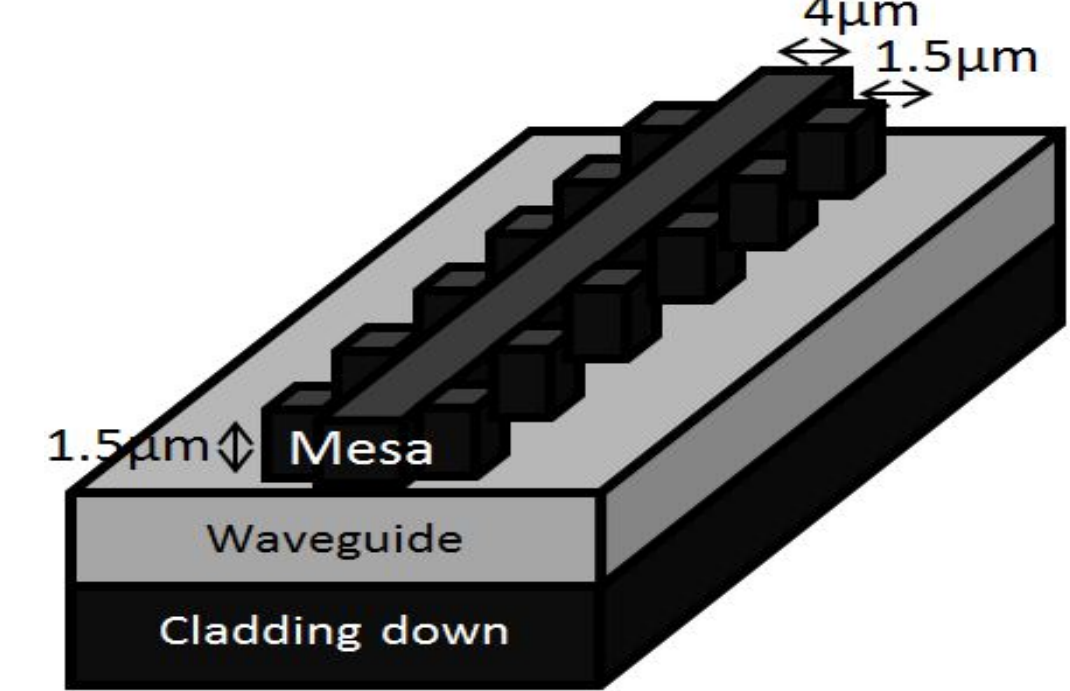


## Towards the realization of side wall corrugated index coupled distributed feedback GaSb based laser diode

- Heterostructure AlGaAsSb / InGaAsSb for an emission around 2.3  $\mu\text{m}$



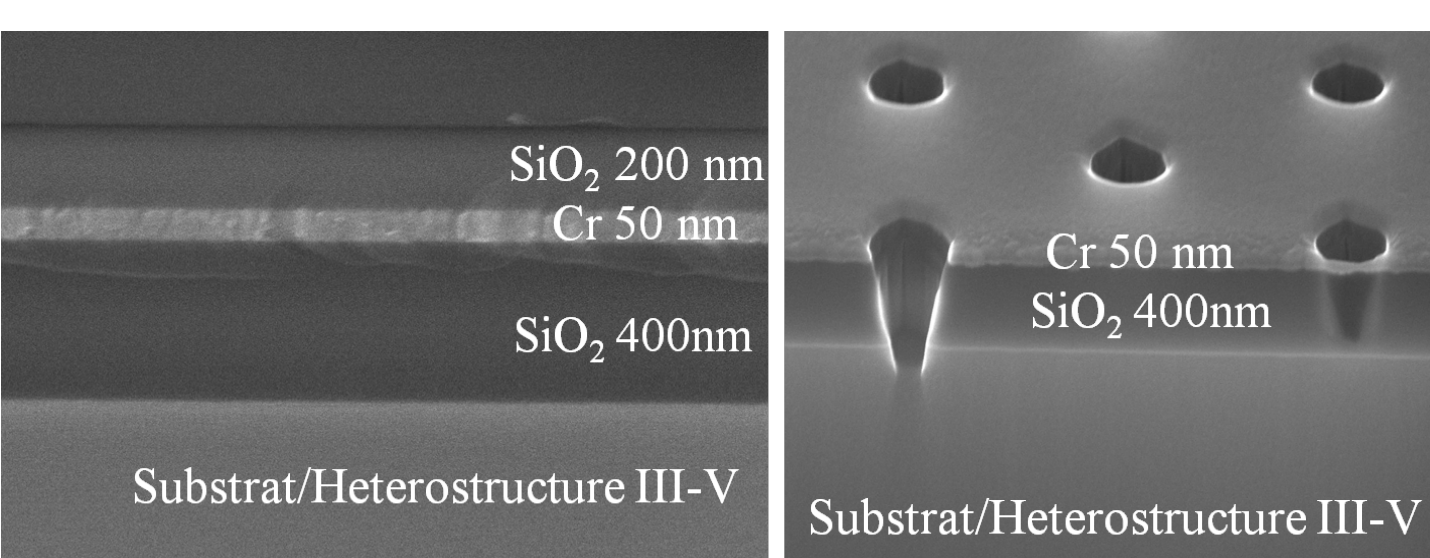
- 2<sup>nd</sup> order DFB laser
  - Feedback from corrugated waveguide
- Shallower etching
- Smooth sidewalls
- Smooth etched bottom



## Previous work

## Realization of laser diodes all PhC electrically pumped in GaSb system

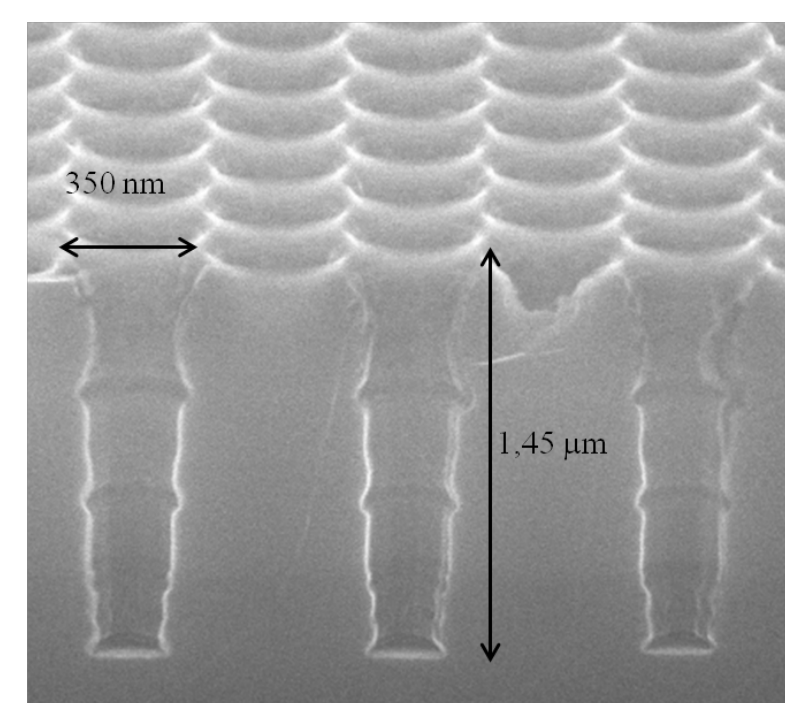
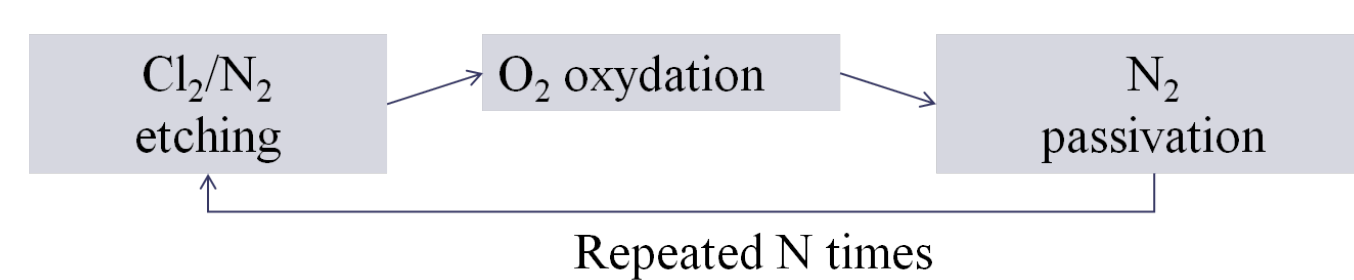
Masking strategy adopted



Tri-layer mask used to open the submicron patterns in III-V substrate

Photonic Crystals FIB cut after complete transfer in the mask

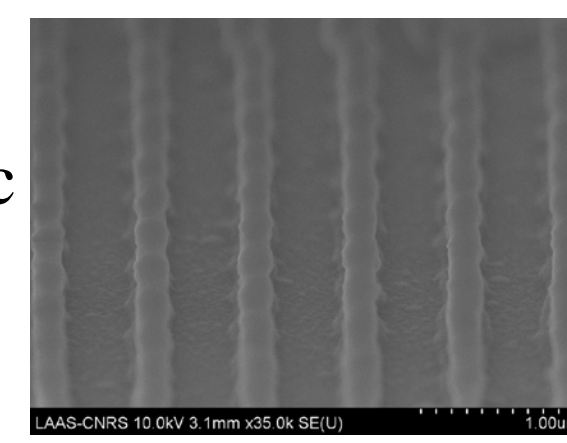
« Masking strategy for all ICP-RIE etching of high aspect ratio Photonic Crystals in GaSb » A. Larrue, and al., JINTE (2008)  
 "Inductively coupled plasma etching of high aspect ratio two-dimensional photonic crystals in Al-rich AlGaAs and AlGaAsSb" A. Larrue, and al., JVSTB Vol. 29(2), pp. 021006 (2011)

Development of a multi-step etching process combining  $\text{Cl}_2/\text{N}_2$ ,  $\text{O}_2$  and  $\text{N}_2$  ICP plasma etching

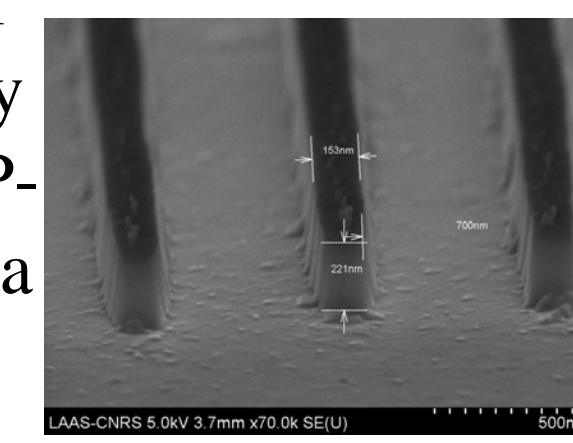
Photonic crystals etched in heterostructure AlGaAsInSb/AlGaAsSb

## Realization of side wall corrugated index coupled distributed feedback GaSb based laser diode

- ❖ Realization of the grating by holographic lithography in resist



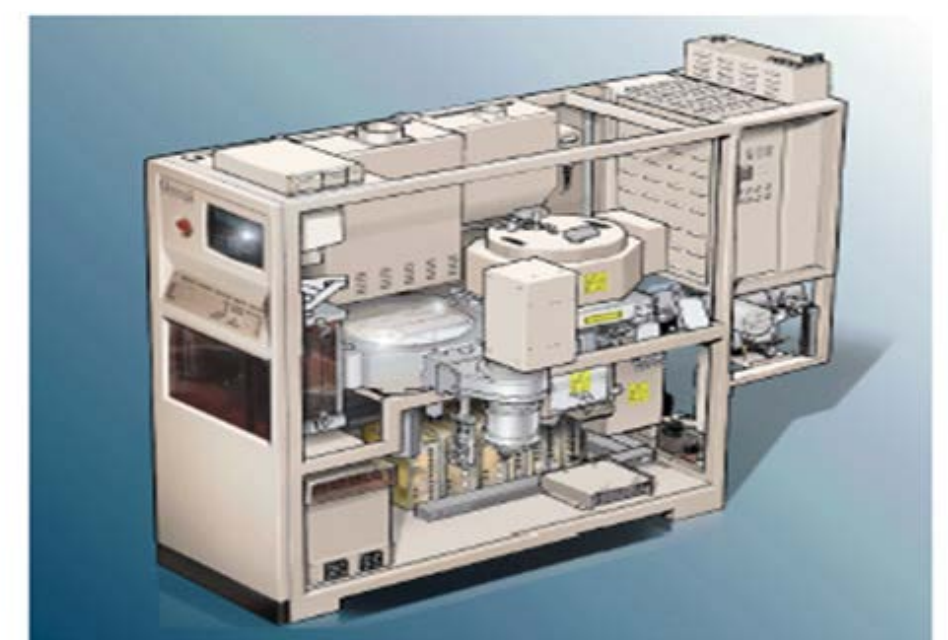
- ❖ Transfer of the grating by  $\text{CHF}_3/\text{O}_2$  ICP-RIE through a 150  $\mu\text{m}$   $\text{SiO}_2$  mask



- ❖ Definition of the mesa by optical lithography

- ❖ Dry etched with  $\text{Cl}_2/\text{N}_2/\text{Ar}$  ICP-RIE of the pattern through the top cladding. The etching is stopped on the top of the waveguide

System tool : SPTS ICP Omega201



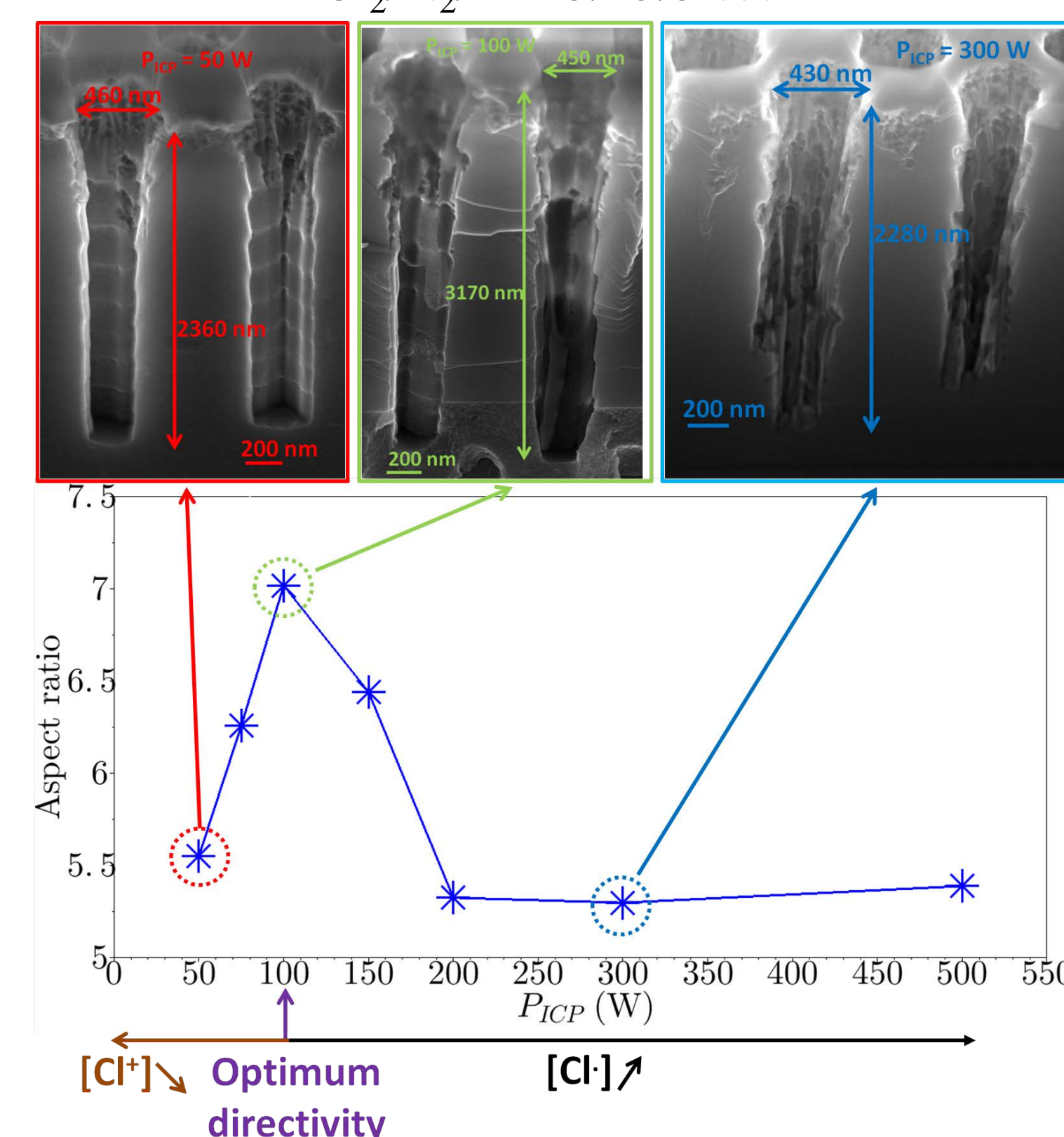
Operating range :

- ❖ Gas :  $\text{CHF}_3$ ,  $\text{CF}_4$ ,  $\text{O}_2$ ,  $\text{Cl}_2$ ,  $\text{N}_2$ , Ar
- ❖ RF plasma powers (13.56 MHz) :  $P_{\text{ICP}}$  = from 0 to 600 W
- ❖ RF bias power of the wafer :  $P_{\text{bias}}$  = from 0 to 100 W
- ❖ Electrostatic chuck
- ❖ Helium cooling :  $-20^\circ\text{C} < T_{\text{wafer}} < 60^\circ\text{C}$
- ❖ Pressure : from 2 to 50 mTorr

## Optimization of the process of chlorinated ICP-RIE etching III-V materials

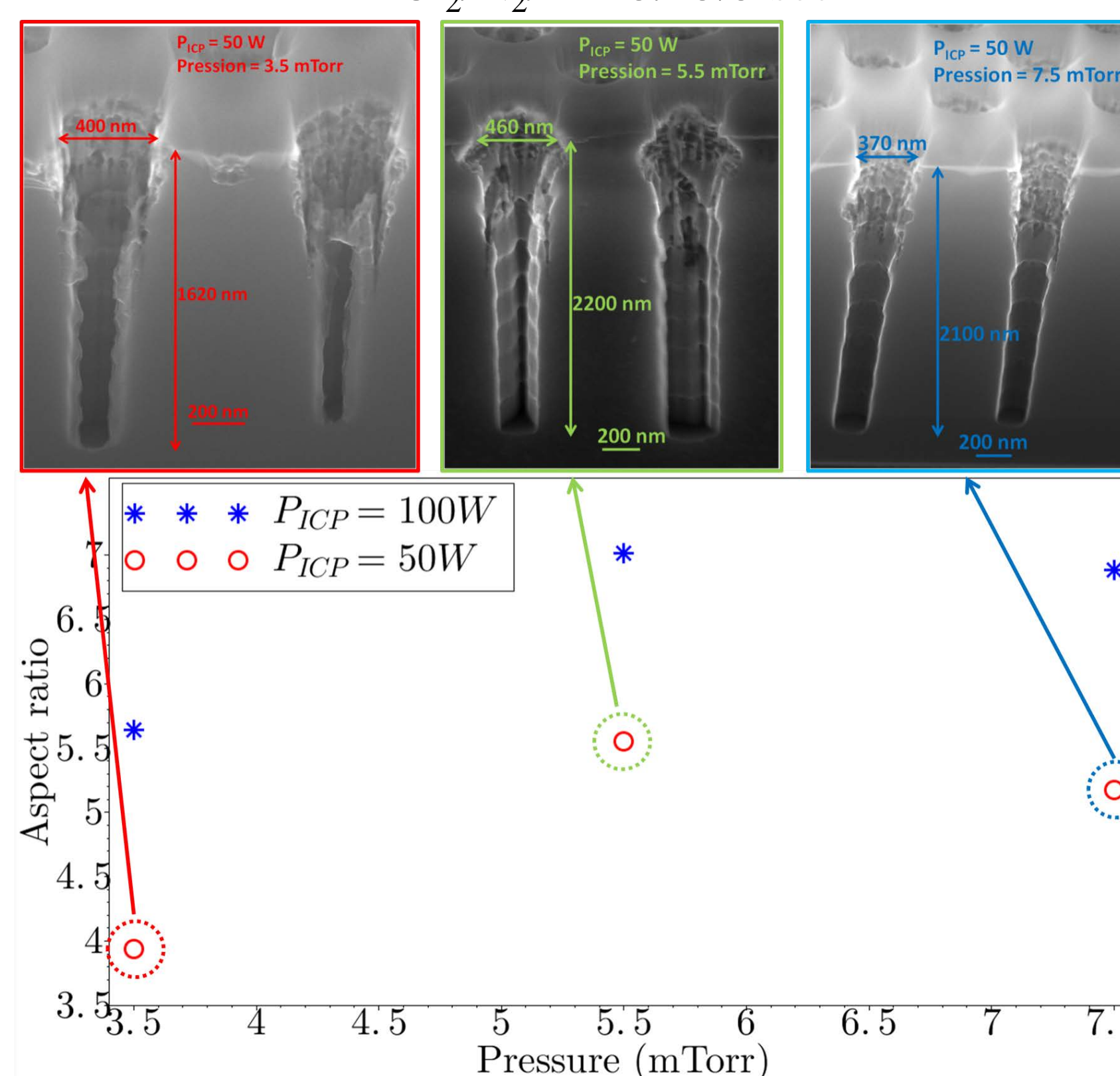
## Influence of ICP power :

$P_{\text{bias}} = 60 \text{ W}$  – Pression = 5.5 mTorr –  $\text{Cl}_2/\text{N}_2/\text{Ar}$  45/15/5 sccm

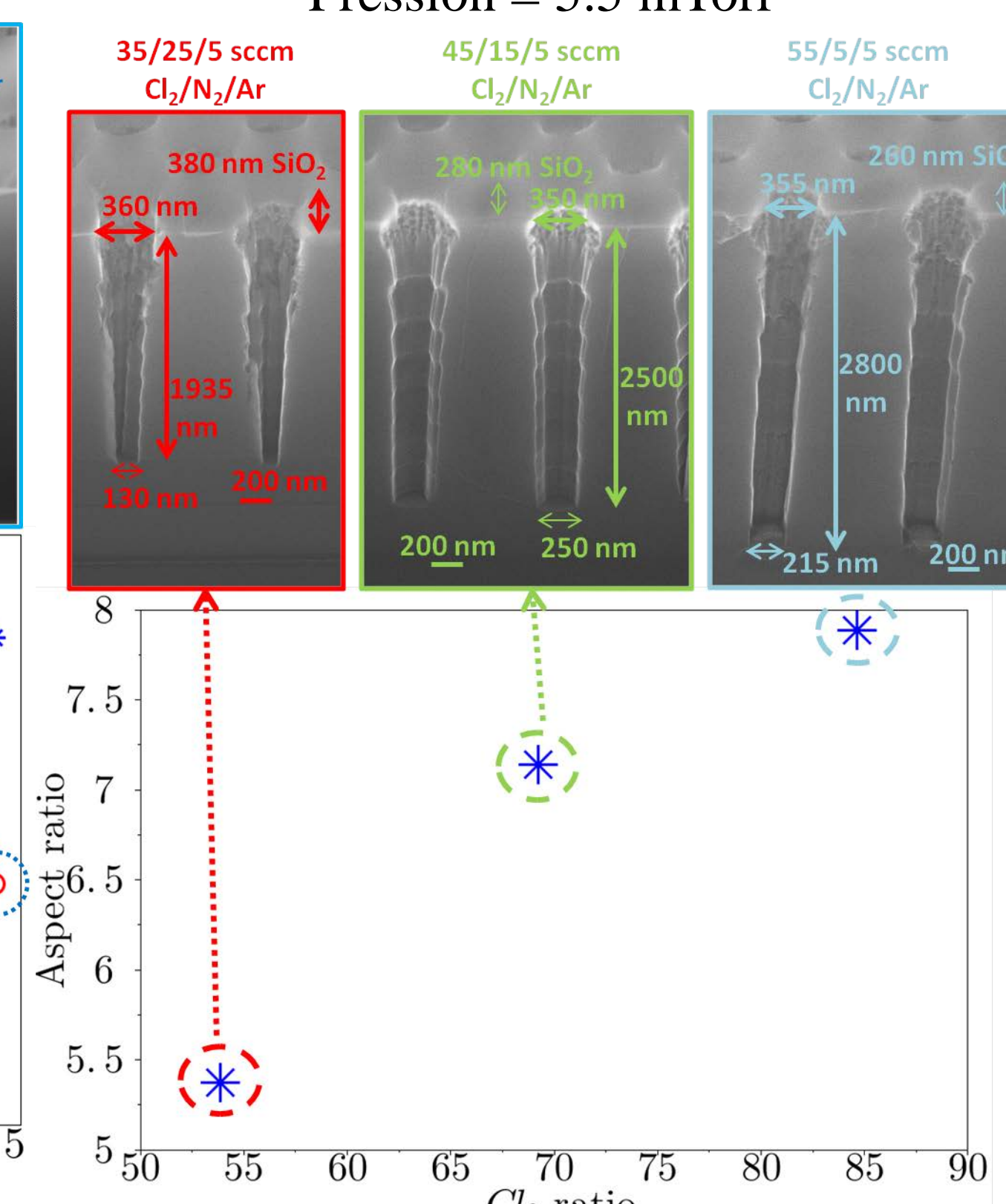


## Influence of pressure :

$P_{\text{ICP}} = 75 \text{ W}$  –  $P_{\text{bias}} = 60 \text{ W}$  –  $\text{Cl}_2/\text{N}_2/\text{Ar}$  45/15/5 sccm

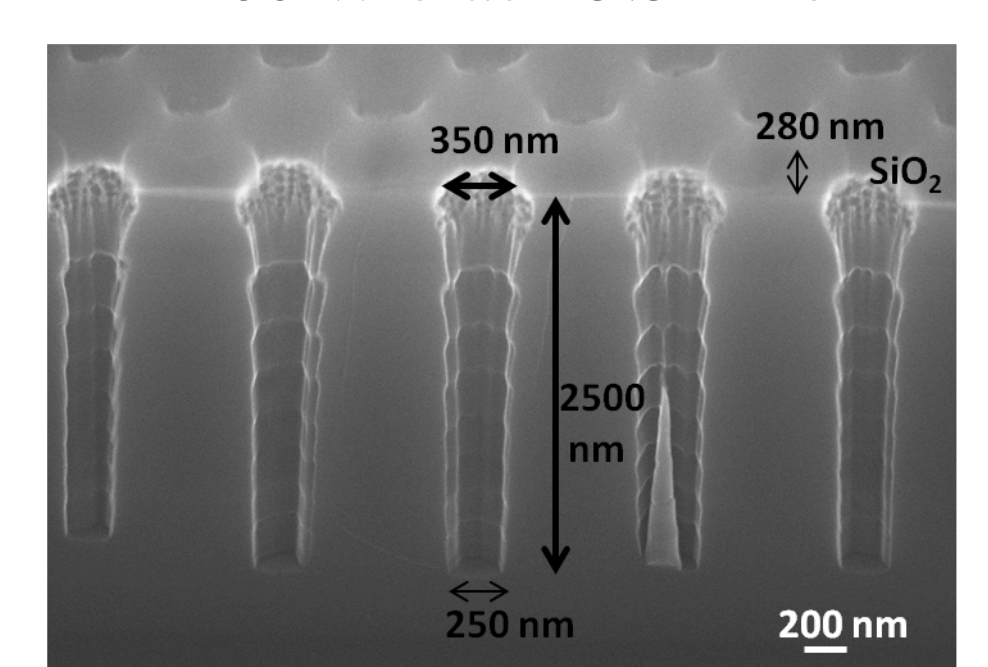
Influence of  $\text{Cl}_2$  ratio :

$P_{\text{ICP}} = 75 \text{ W}$  –  $P_{\text{bias}} = 60 \text{ W}$  – Pression = 5.5 mTorr

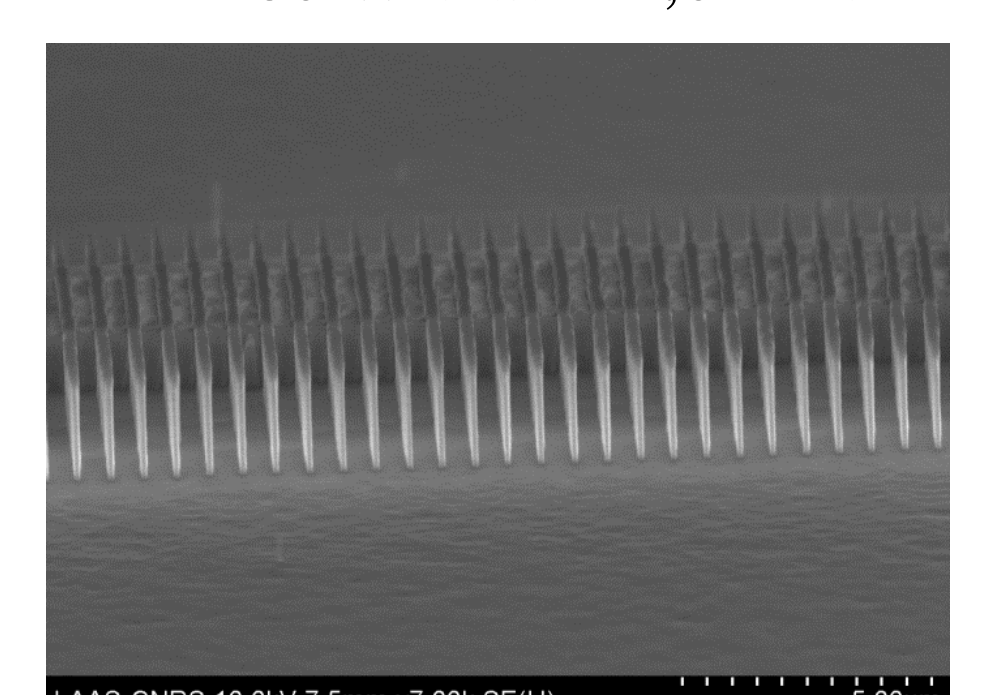


## Deep etching process optimized :

$\text{Cl}_2/\text{N}_2/\text{Ar}$  45/15/5 sccm – 75 W ICP 60 W bias - 5.5 mTorr



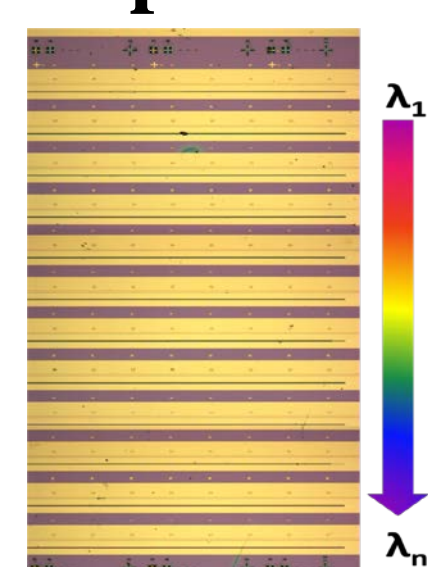
$\text{Cl}_2/\text{N}_2/\text{Ar}$  45/15/5 sccm – 500 W ICP 60 W bias – 7.0 mTorr



## Conclusion

Deep dry etching of shallow features in high Al content AlGaAsSb can be achieved using  $\text{Cl}_2/\text{N}_2/\text{Ar}$  chemistries. Good performances are achieved provided that the etching regime (ICP or RIE) is chosen in accordance with the designed geometry and aspect ratio, and devices with good opto-electrical performances were fabricated.

- ✓ Establishment of a high aspect ratio deep etching process of PhC in GaInAsSb/AlGaAsSb system
- ✓ Successful insertion of this technological step in a complete process



- ✓ Establishment of deep etching process of grating in GaInAsSb/AlGaAsSb system
- ✓ Successful insertion of this technological step in a complete process