Préparation des substrats III-V pour la reprise d'épitaxie

Atelier du GDR PULSE
Préparation des substrats pour l'épitaxie
22-24 mai 2018

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UNIVERSITÉ DE MONTPELLIER

Partie 2
Reprise sur III-Sb et applications

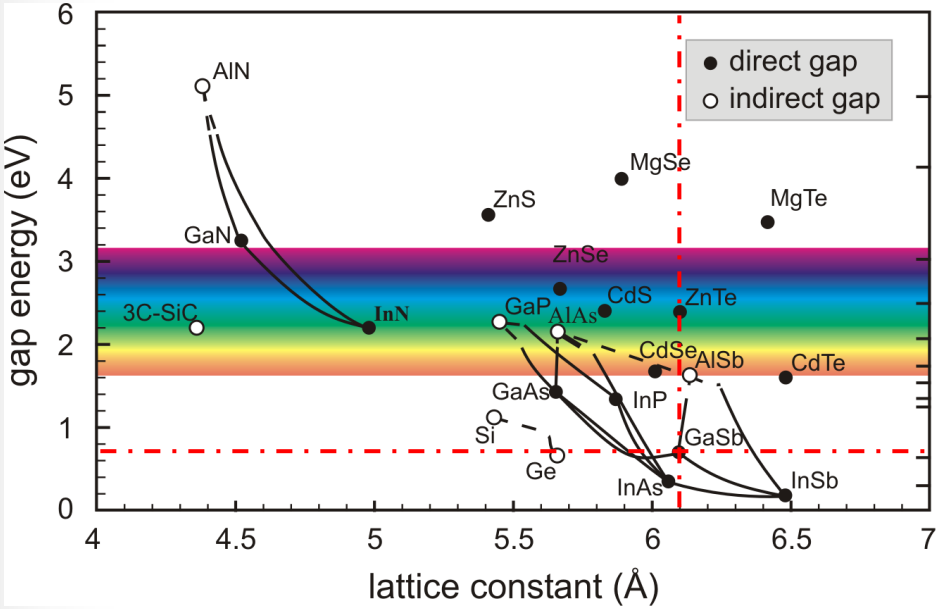
Laurent Cerutti

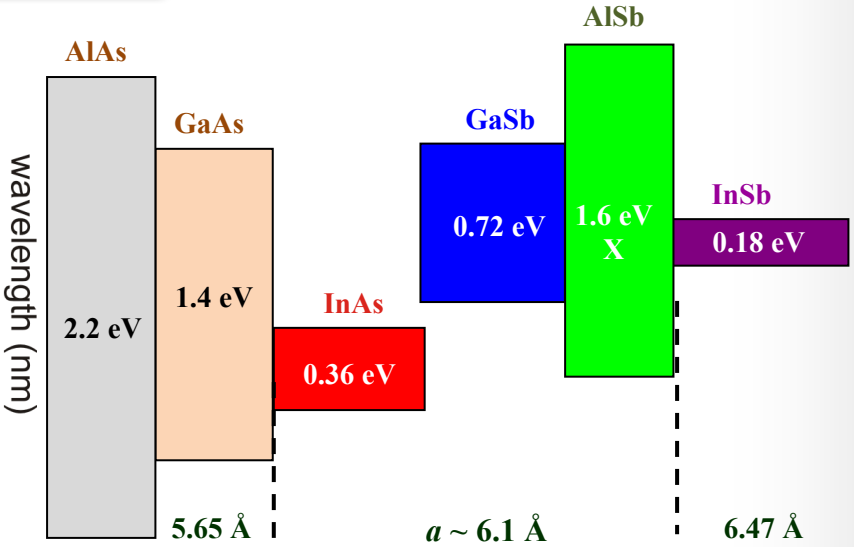
Q. Gaimard (Thèse 2014), V. N'Tsame-Guilengui (Thèse 2013), S. Roux (Thèse 2016)

Taliercio, A. Vicet, J.B. Rodriguez and E. Tournié

Université Montpellier – CNRS

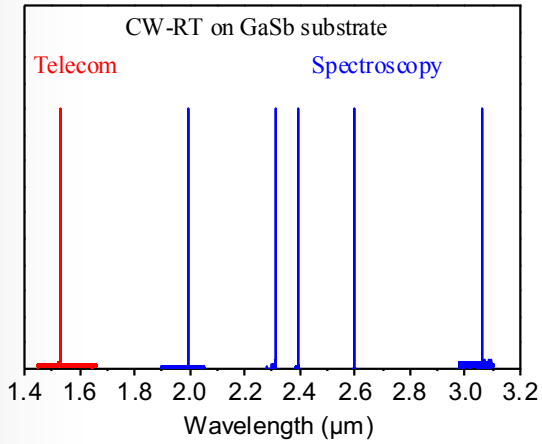
Properties of III-Sb



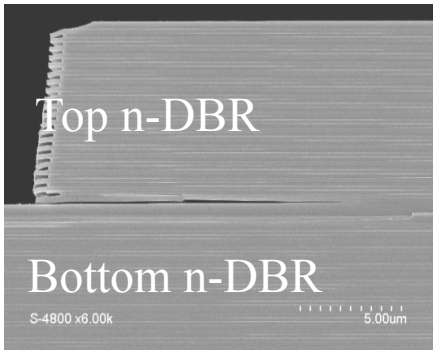


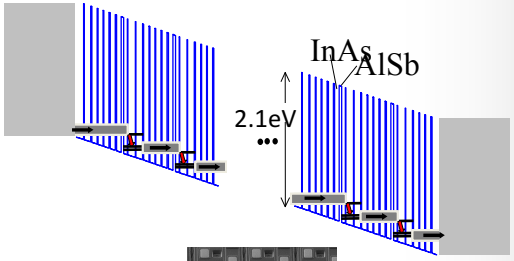
- a ~ 6.1 to 6.47 Å
- 0.2 to 1.6 eV band gaps
- Type I to type III band alignments

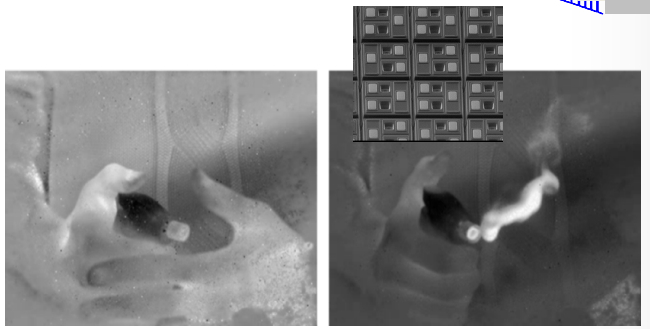
- Low effective masses
- High carrier mobilities



Devices and applications



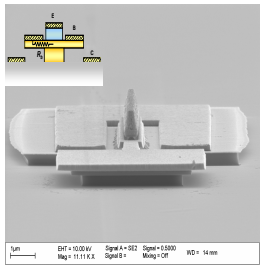




- Lasers
- V(E)CSEL
- QCLs, ICLs
- Photodetectors
- HEMT

Infrared optoelectronics
(1.5 µm < λ < 25 µm)

Spectroscopy, environment, medicine, security, free space communication,….



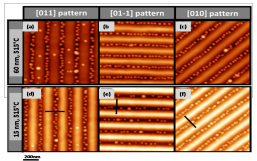
High performance for discrete function devices

Motivation for GaSb surface preparation

Integrated devices with various functions

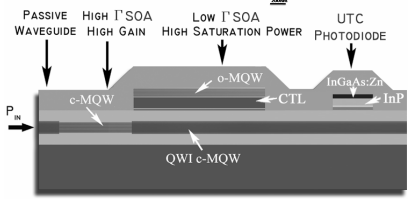
↗ Flexibility of integration = ↗ structuring & regrowth

- Localized and improved the emission (QDs, plasmons)



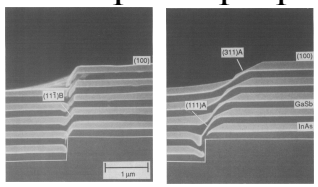
M.Helfrich *et al.* PSS Vol.209 (2012)

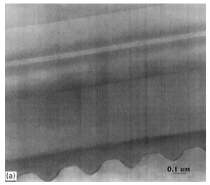
- Localized the optical guiding (waveguide)



J.W. Raring PhD-UCSB-2006

- Improved the electro and optical properties (DFB, RTD, …)

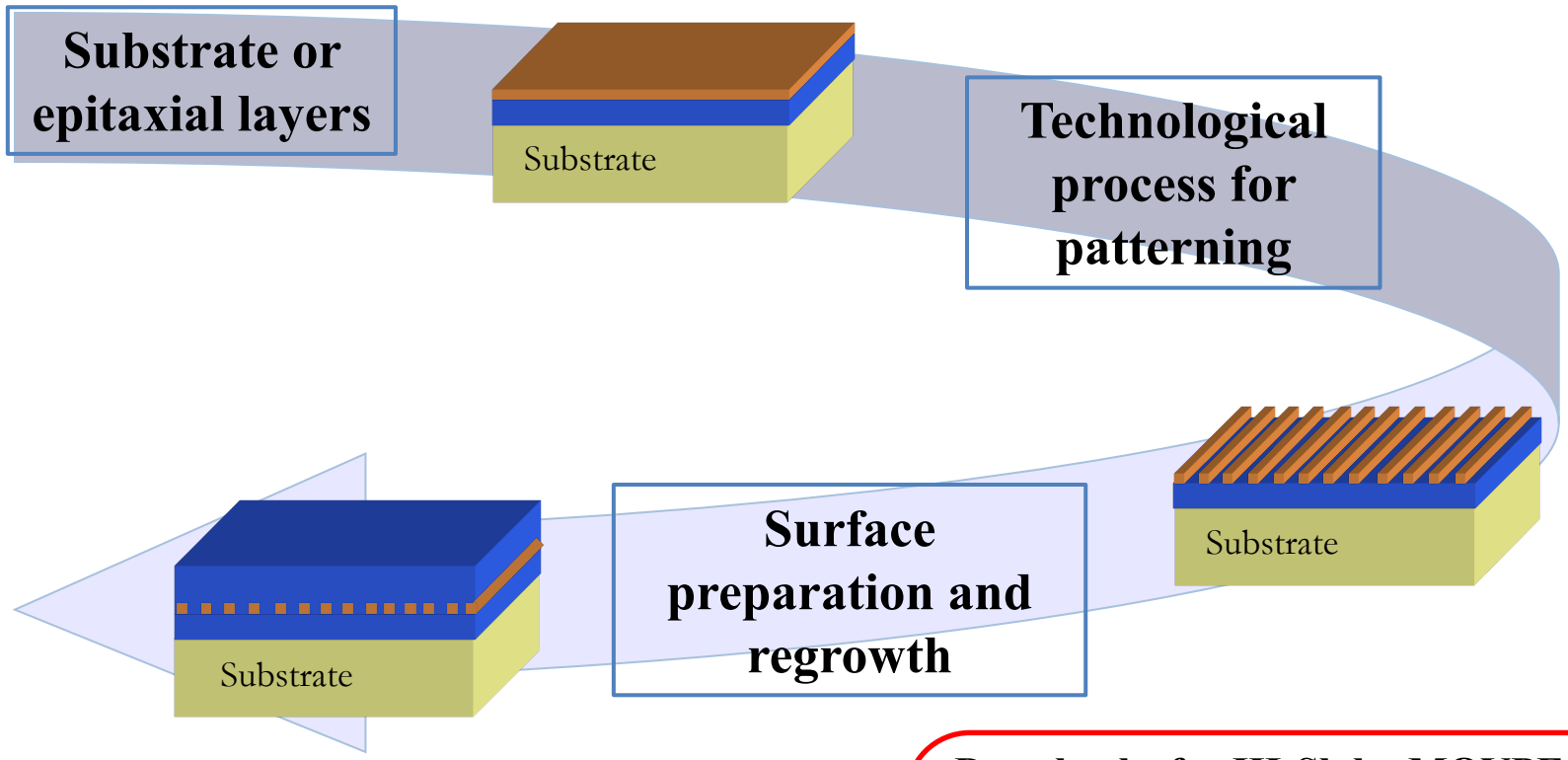




L.J. Mawst *et al.* JCG Vol.195 (1998)

- ….

Methodology of epitaxy on patterned substrate



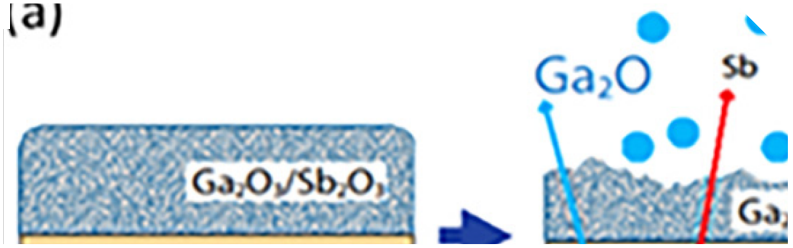
GaAs and InP ➔ MOVPE or CBE

Drawbacks for III-Sb by MOVPE

- Low growth temperature
- High Al content alloys
- Lack of high purity Sb precursor (high residual doping)

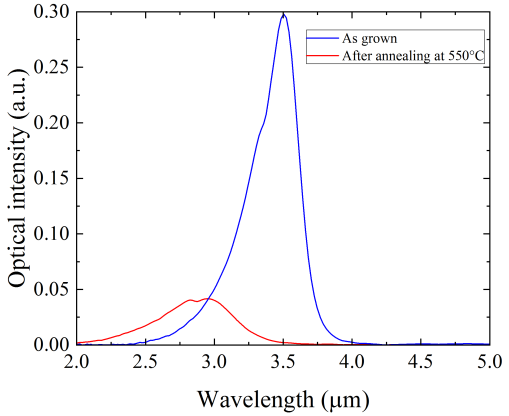
GaSb surface de-oxidation

Thermal oxide desorption ~ 550°C



Rough surface ➔ impact the structuring

High temperature ➔ Impact the layers already grown



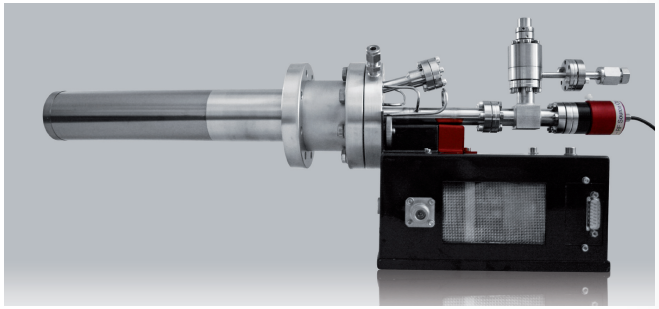
MBE with low temperature *in-situ* de-oxidation of the native oxide

GaSb surface de-oxidation

H assisted cleaning surface ➔ atomic H radicals (H^+)

$$Ga_2O_3 + 4H^+ \rightarrow 2H_2O \uparrow + Ga_2O\uparrow$$
$$Sb_2O_x + 2xH^+ \rightarrow xH_2O \uparrow + Sb_2\uparrow$$

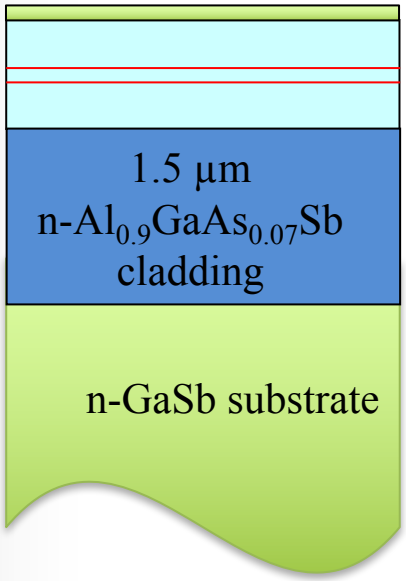
- Thermal sources
- Electron cyclotron resonance sources
- RF sources



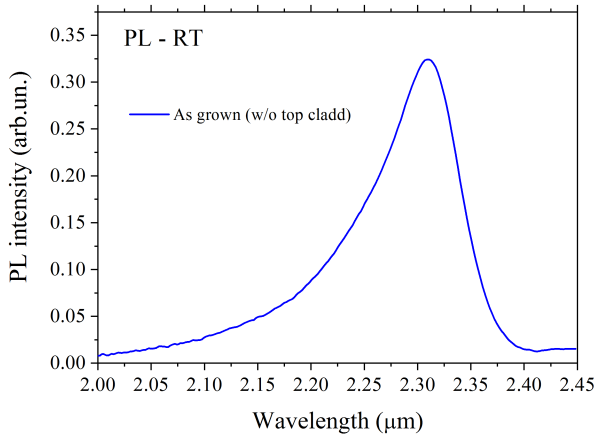
Dedicated structures:

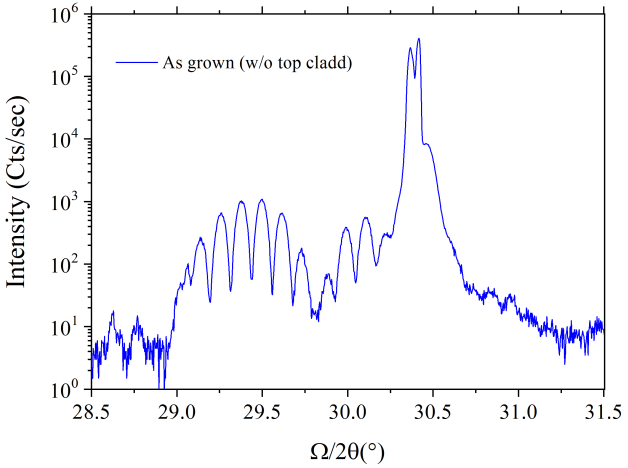
- Buried III-Sb DFB laser
- Buried all semiconductor plasmonic structure
- Frequency conversion

1st Growth

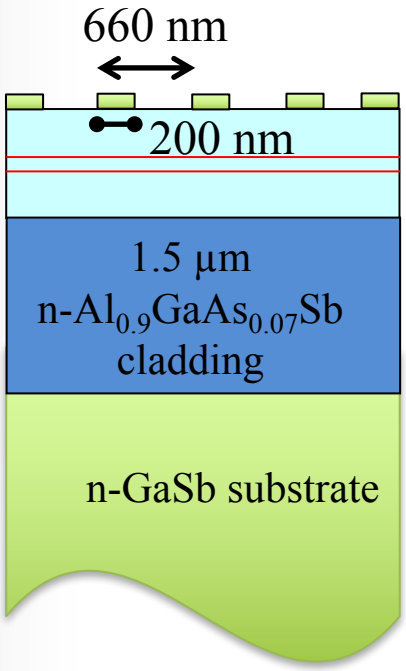


GaSb cap layer
10nm $Ga_{0.65}InAs_{0.1}Sb$ QWs
0.6 µm $Al_{0.25}GaAs_{0.03}Sb$ waveguide

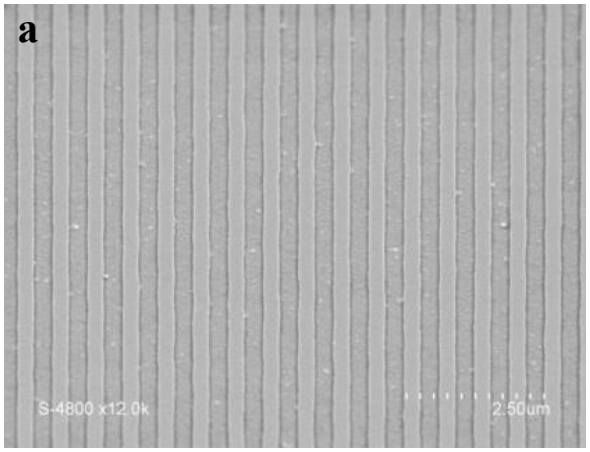


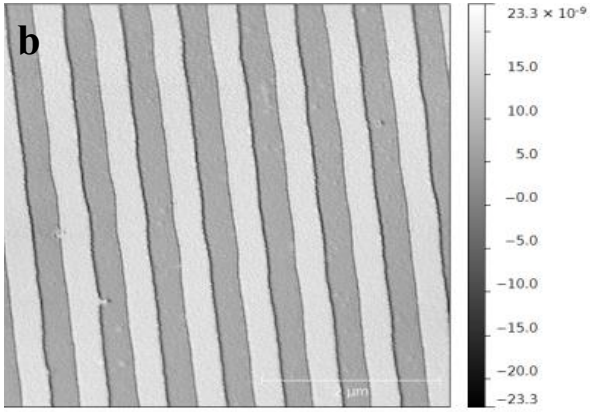


DFB processing



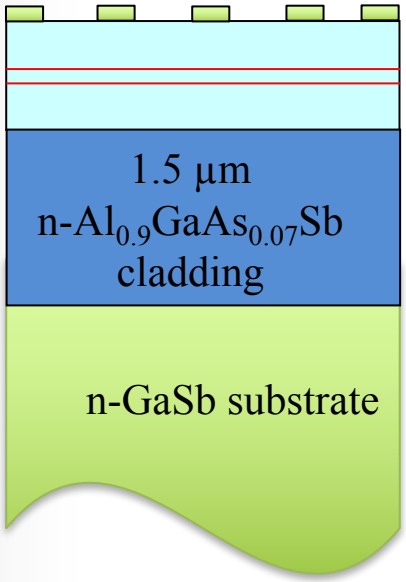
GaSb grating
10nm $Ga_{0.65}InAs_{0.1}Sb$ QWs
0.6 µm $Al_{0.25}GaAs_{0.03}Sb$ waveguide



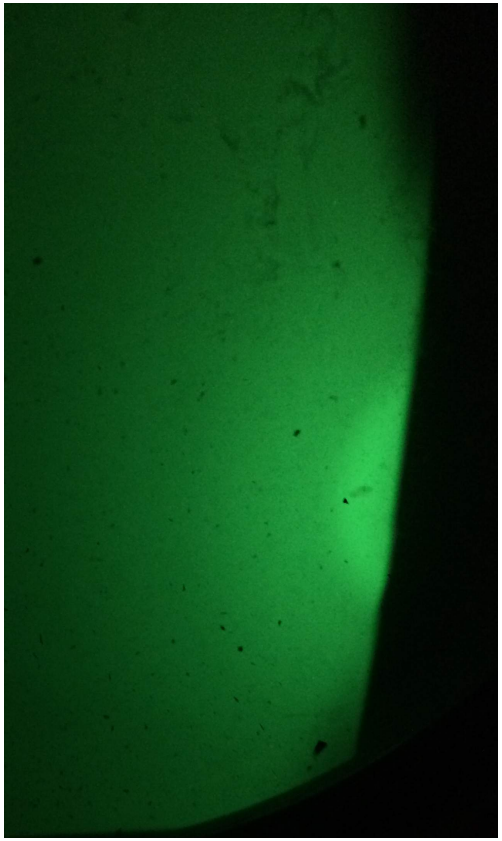


In situ surface preparation

Sb_2 + T_{sample} @ 450°C

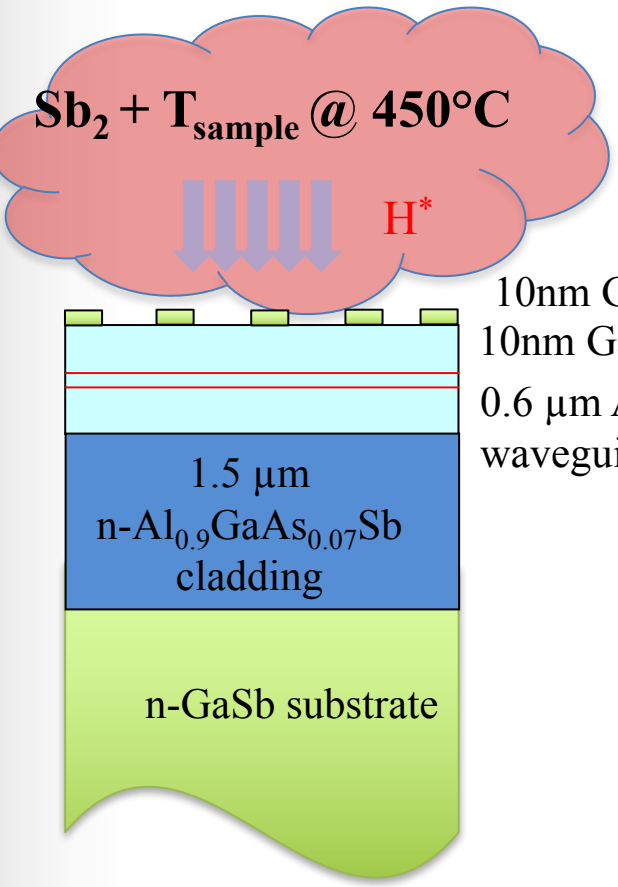


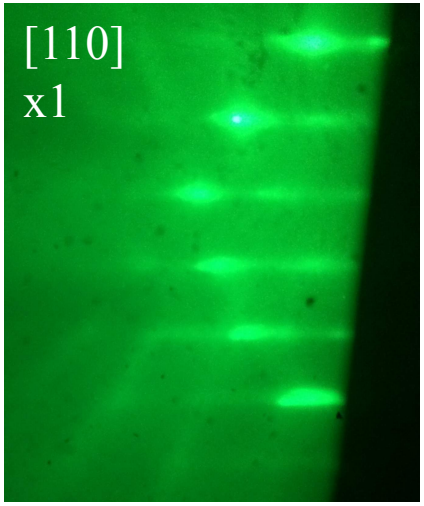
GaSb grating
10nm $Ga_{0.65}InAs_{0.1}Sb$ QWs
0.6 µm $Al_{0.25}GaAs_{0.03}Sb$
waveguide

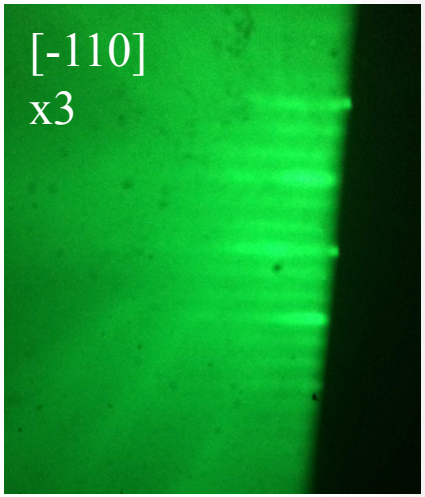


Amorphous surface ➔ oxide

In situ surface preparation



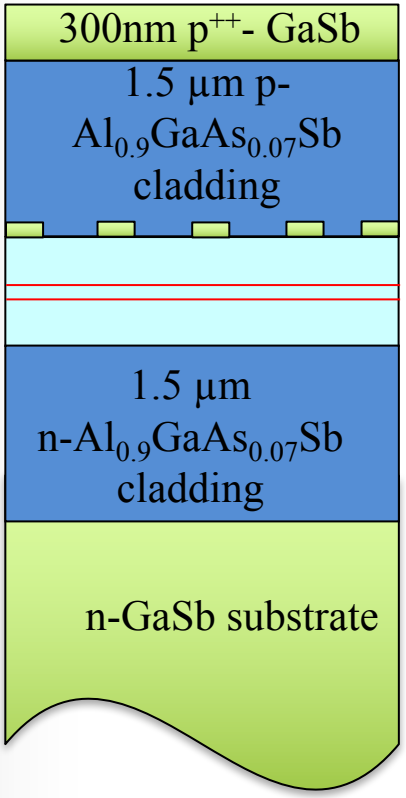


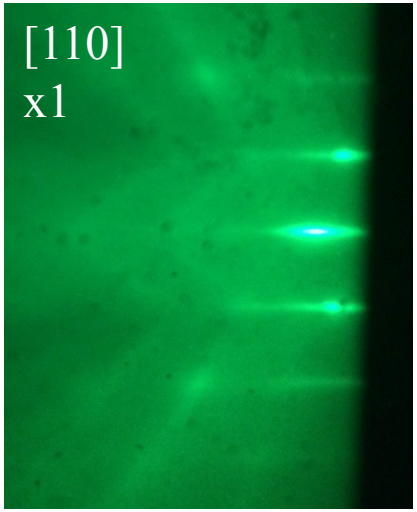


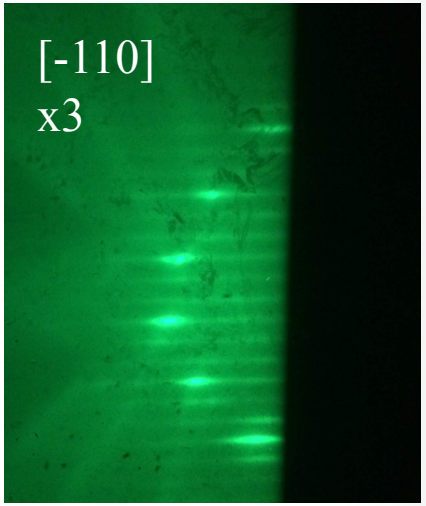
Streaky 1x3 reconstruction ➔ Cristalline surface

Regrowth on patterned surface

T_{Growth} @ 450°C

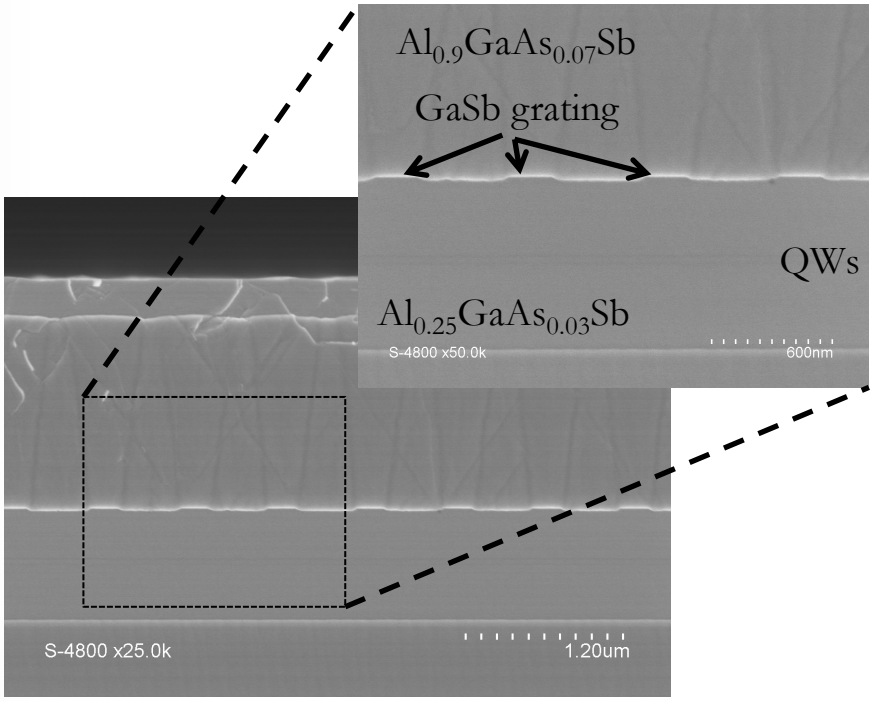


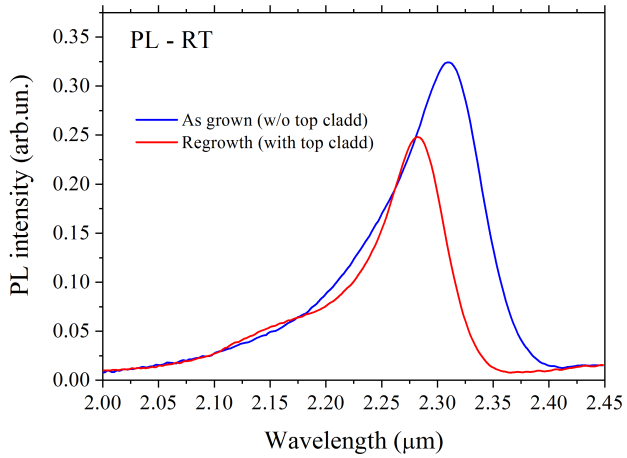


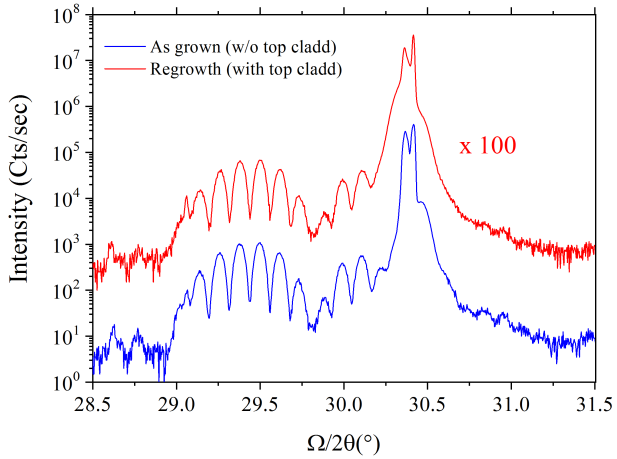


Streaky 1x3 reconstruction
➔ Cristalline growth

Structural and optical characterizations

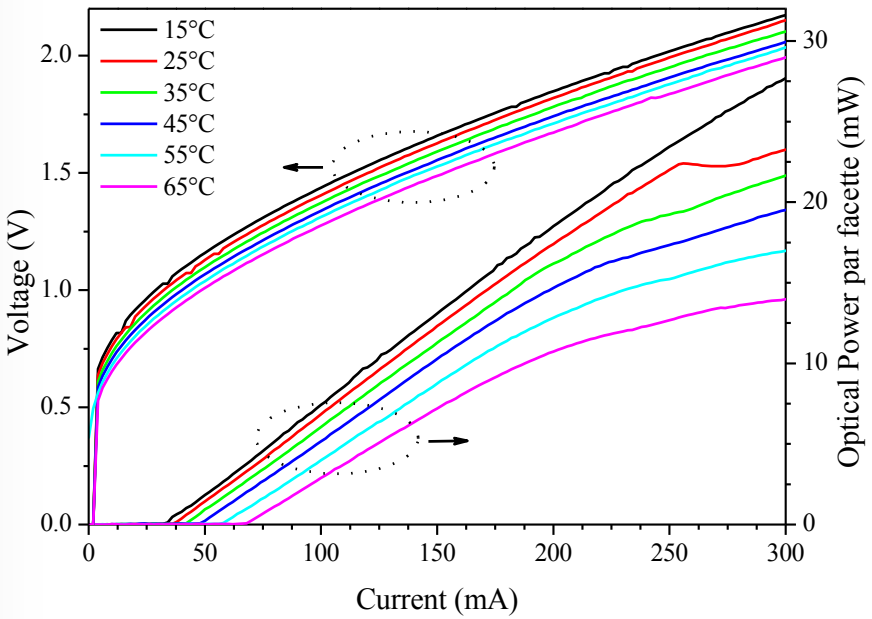


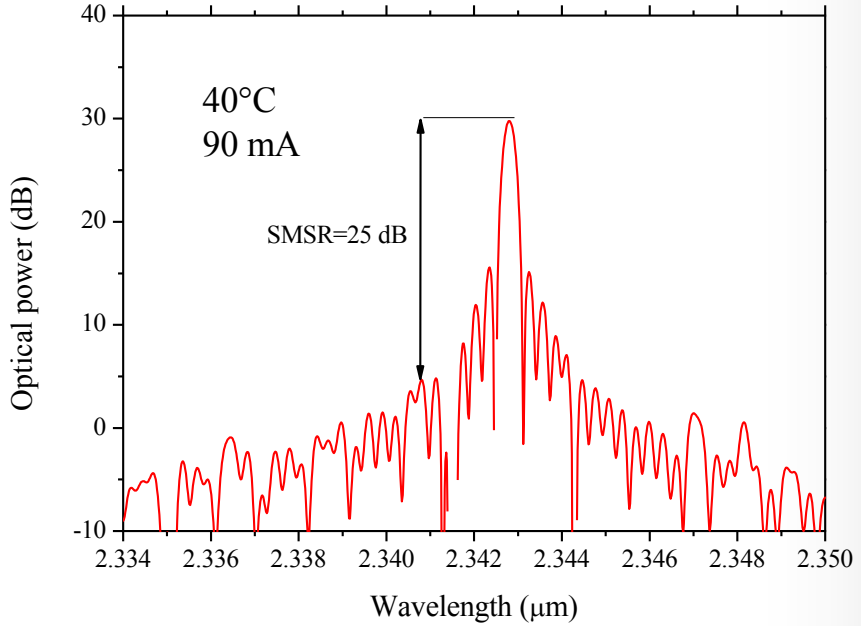




- Clear observation of the buried grating
- No degradation of the crystal and optical quality

Electro-optical characterizations





- CW operation @ T> 65°C
- P_{max} > 30mW @ 15°C
- Single mode, SMSR ~25 dB

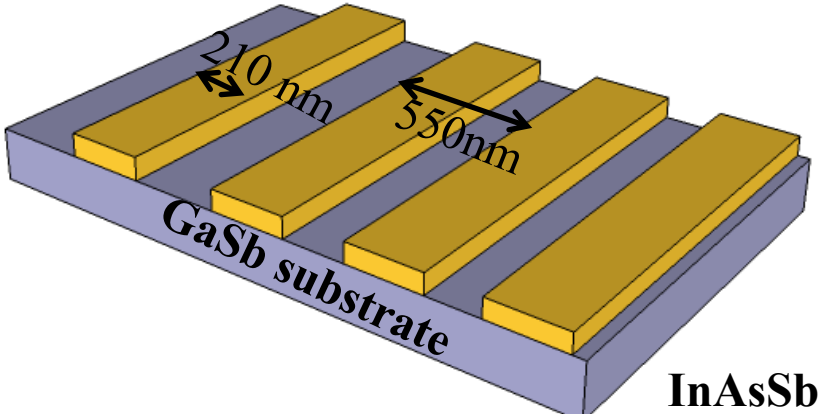
Q. Gaimard et al. APL **104** 2014

All semiconductor plasmonic structure

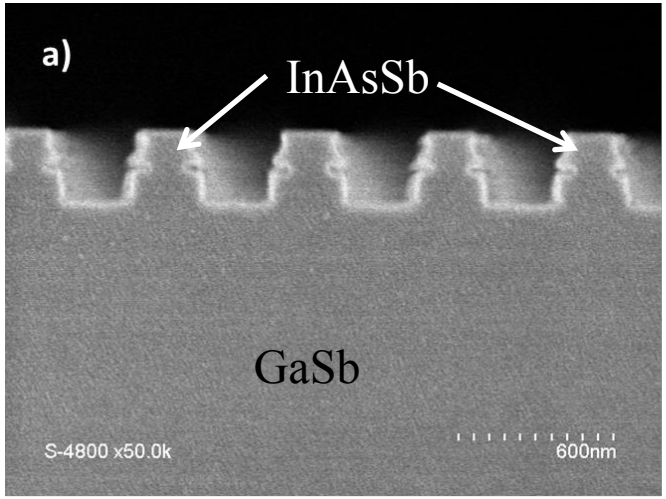
Properties of InAs(Sb):

- Low m^*, high μ
- High doping ~10^{20} cm^{-3}
- λ_p ~5.5 µm

InAs(Sb) good candidate for plasmonic applications



InAsSb array:
100 nm thick
n ~ 5.10^{19} e^-/cm^3

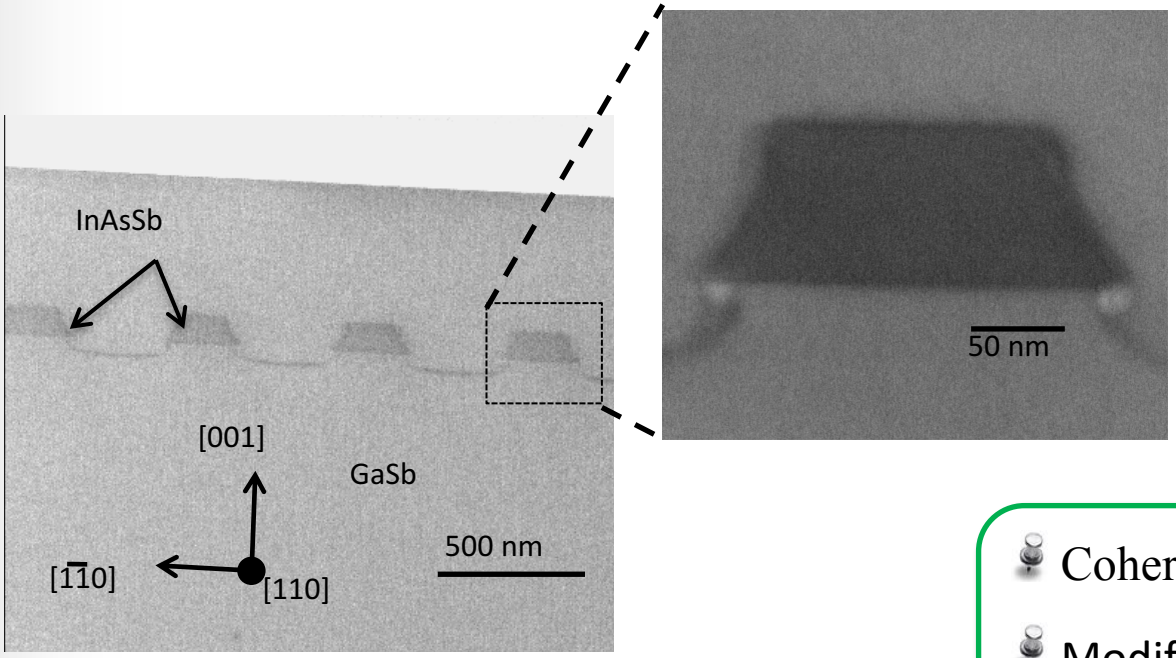


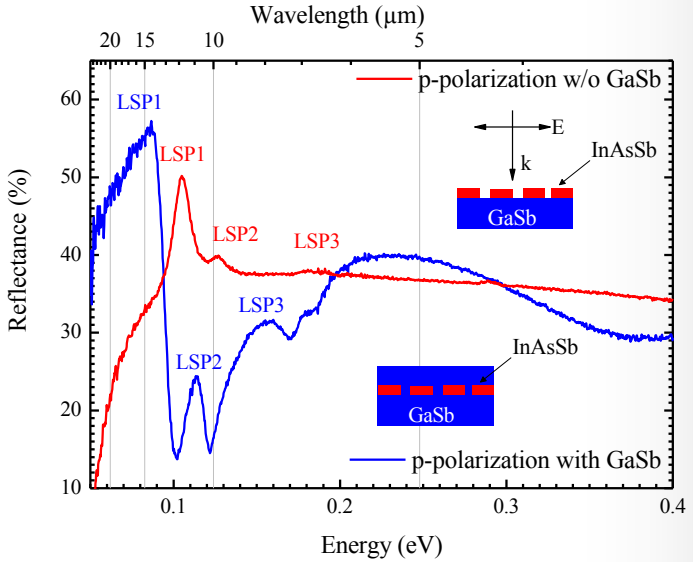
1st growth + processing

All semiconductor plasmonic structure

H assisted de-oxidation + regrowth:

- T_{deox} = 420°C + Sb_2 + H-plasma
- 500 nm of GaSb @ T_G = 420°C





- Coherent growth at the interface
- Modification of the surrounded dielectric material

T. Taliercio et al. Opt. Xpress **23** (23) 2015

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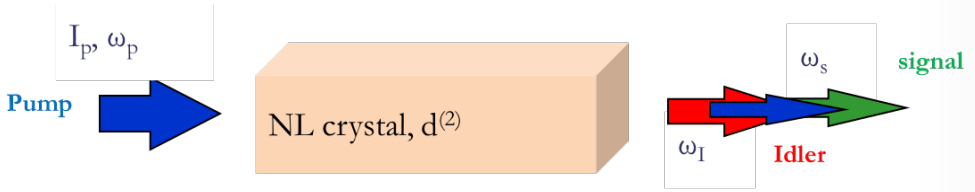
Non linear optics: Why use a semiconductor ?

Optical Parametric Oscillator (OPO)



Zinc-Blende semiconductor:

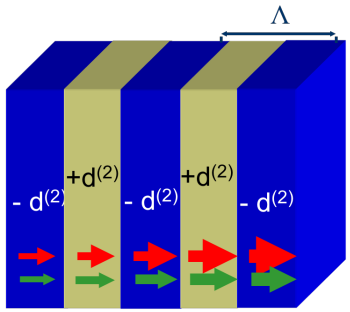
- High $d^{(2)}$
- Low optical losses

$d^{(2)}$ increases :

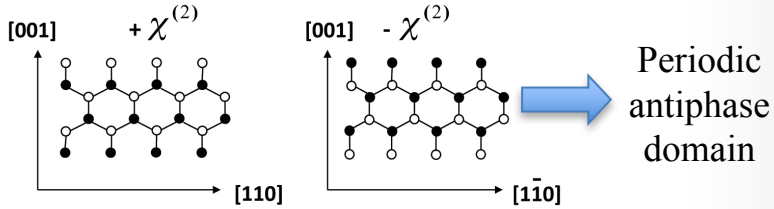
- $\Delta Z \searrow \Rightarrow$ III-V > II-VI
- $Eg \searrow \Rightarrow$ InSb > InAs > GaSb > GaAs

Transparency window in the MIR : GaSb > InAs & InSb

BUT zinc-blende semiconductor are optically isotropic



Quasi Phase Matching (QPM)



Rotation of 90° = switch group III and V

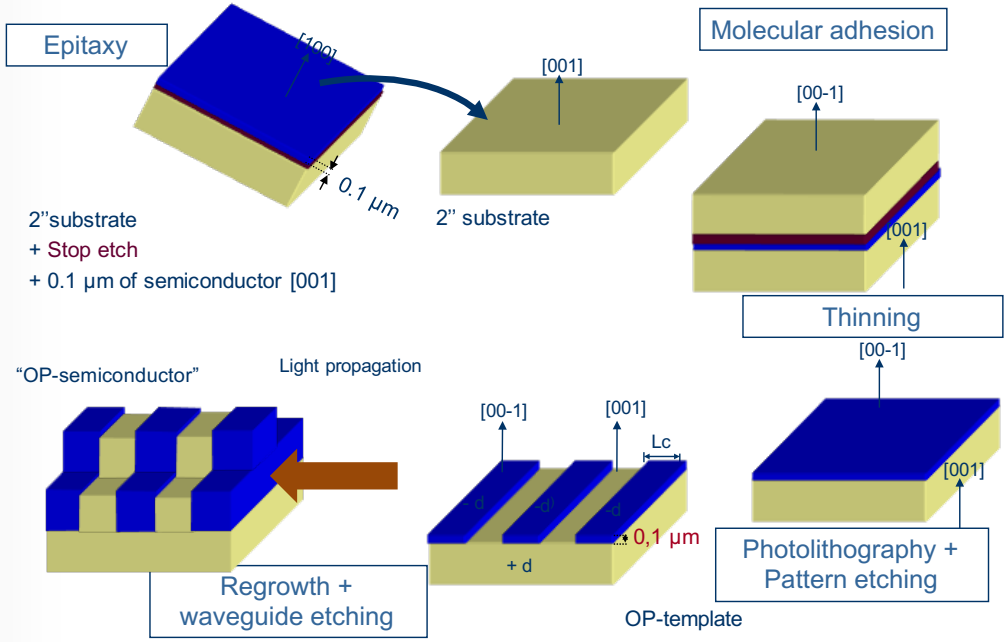
Periodic antiphase domain

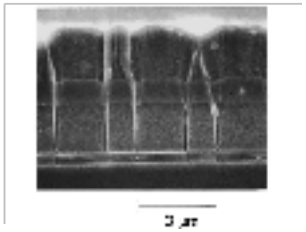
Bonding and etching

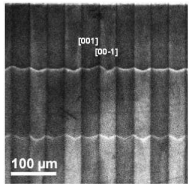
S.J.B. Yoo *et al.* APL Vol.66 (1995)

M.B. Oron *et al.* Proc; of SPIE Vol.6875 (2008)

A. Grisard *et al.* Opt. Mat. Xpress Vol.8 (2012)

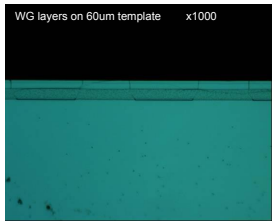






III-V lab

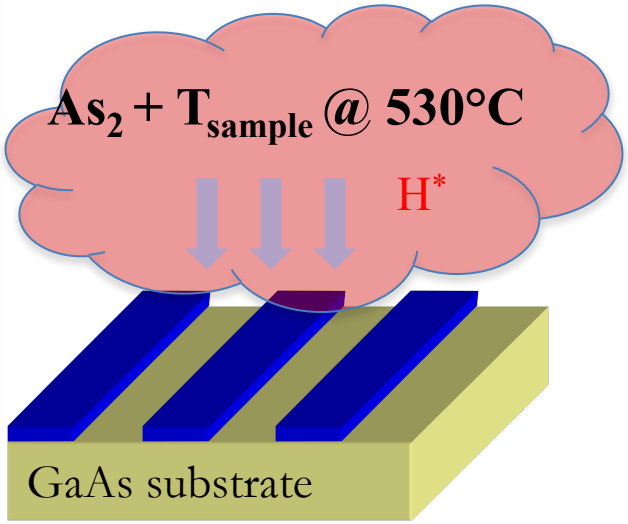
THALES
RESEARCH & TECHNOLOGY

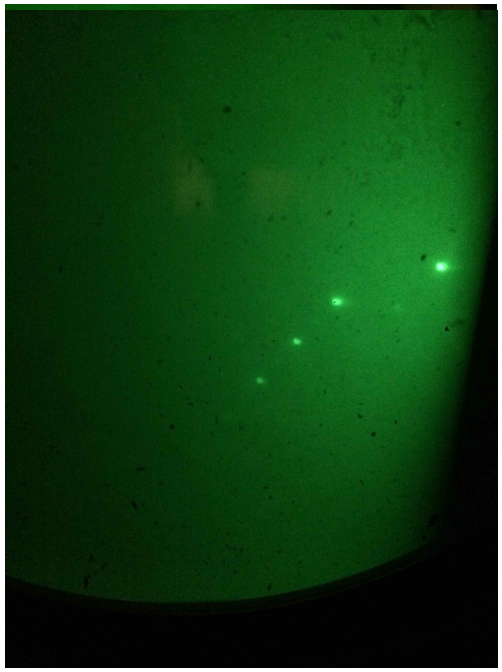


Well established fabrication of OP GaAs template

GaSb epitaxy on OP GaAs ➜ **Metamorphic** growth with epitaxy on **patterned surface**

Growth of GaSb on OP GaAs substrate



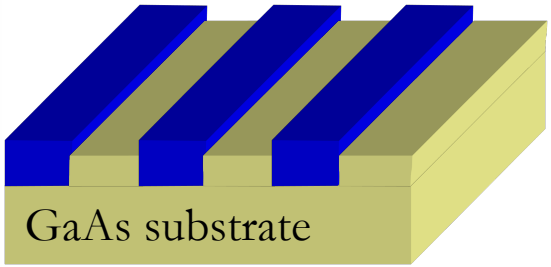


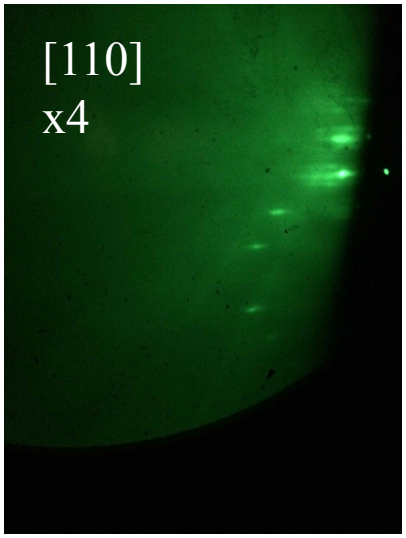
GaAs : [001]

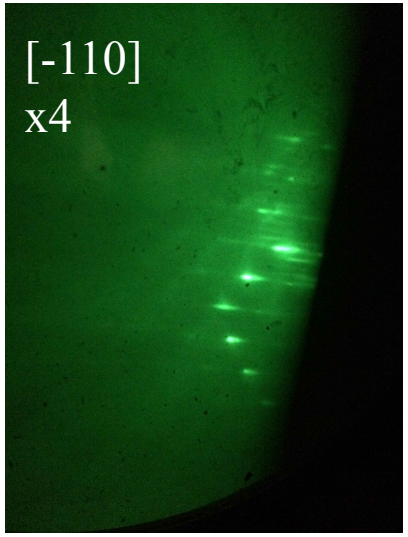
GaAs : [00-1]

Low temperature plasma de-oxidation
➔ No degradation of the adhesion
➔ Surface cleaning

GaAs buffer - T_{Growth} @ 530°C





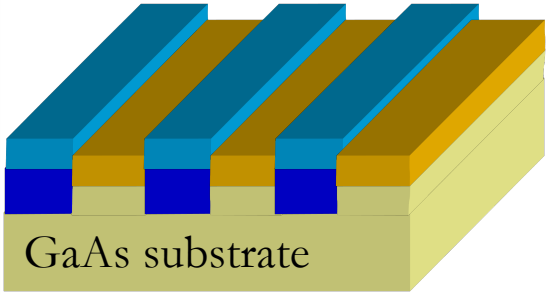


GaAs : [001]

GaAs : [00-1]

Streaky 4x4 reconstruction
➔ Antiphase domain

GaSb layer - T_{Growth} @ 480°C

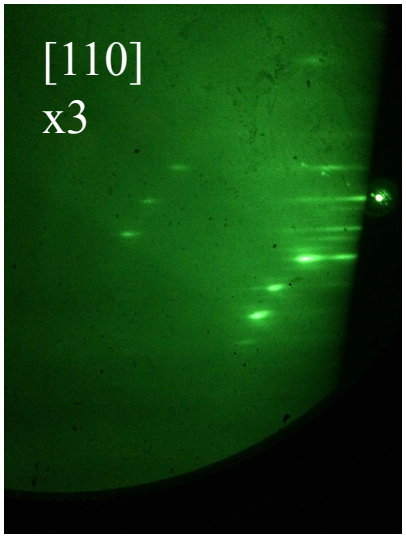


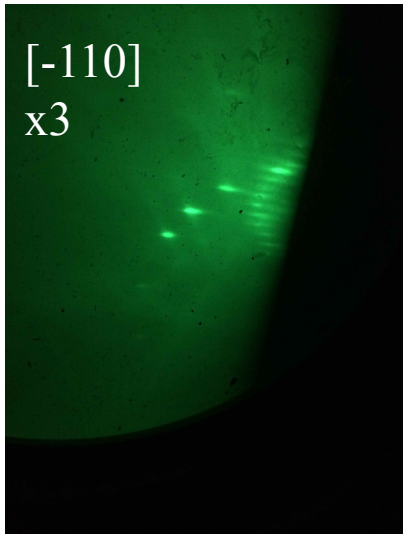
GaAs : [001]

GaAs : [00-1]

GaSb : [001]

GaSb : [00-1]

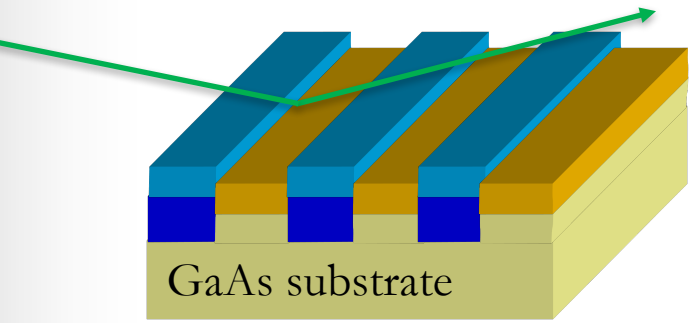




Streaky 3x3 reconstruction

➔ Conservation of the APD in the GaSb

Growth of GaSb on OP GaAs substrate



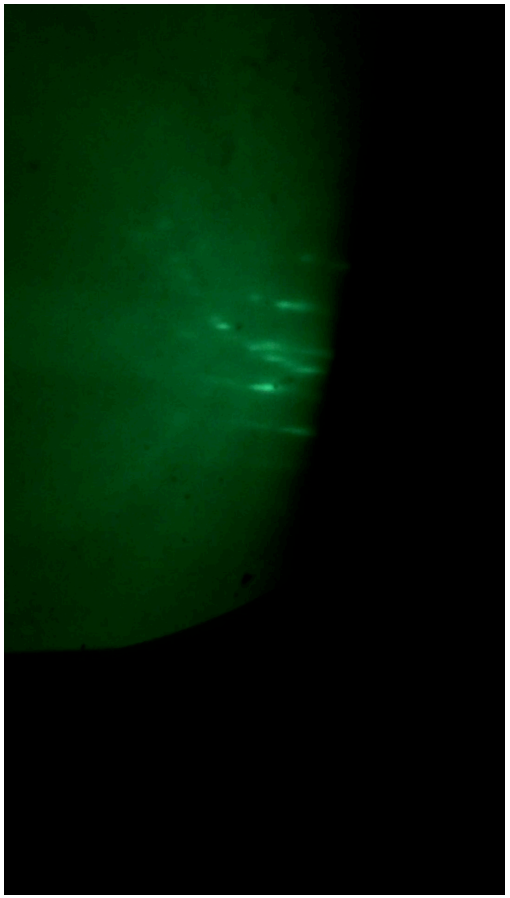
GaAs : [001]

GaAs : [00-1]

GaSb : [001]

GaSb : [00-1]

[110]

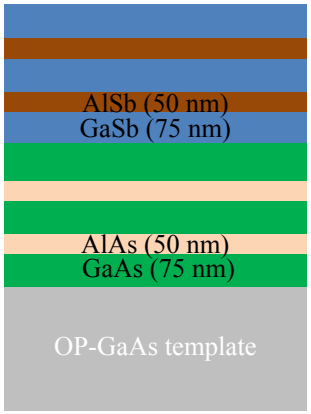


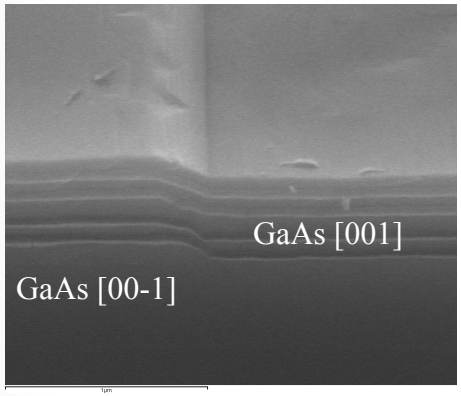
Streaky 1 & 5 reconstruction at low tempertaure on the same orientation

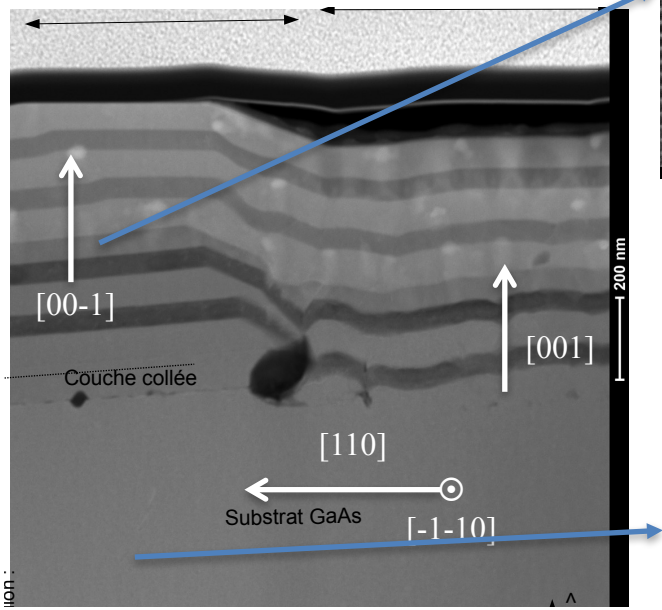
➔ Conservation of the polarity

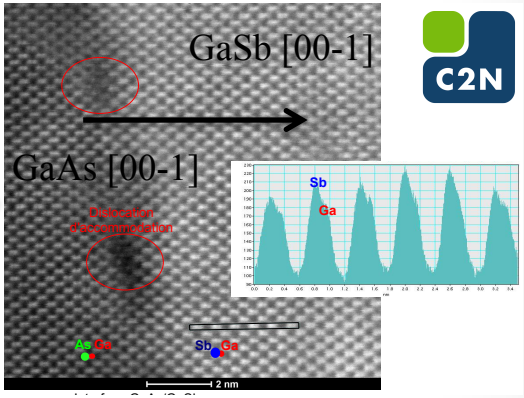
Growth of GaSb on OP GaAs substrate

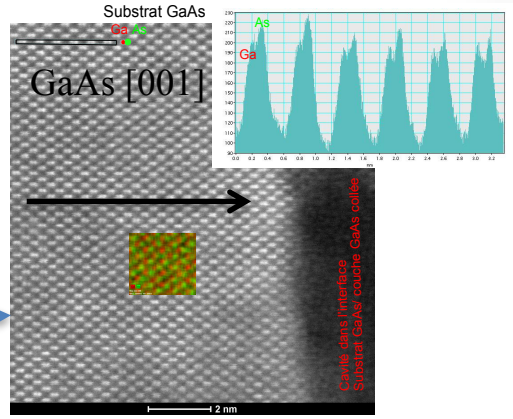
Marker layers ➜ effect of the growth







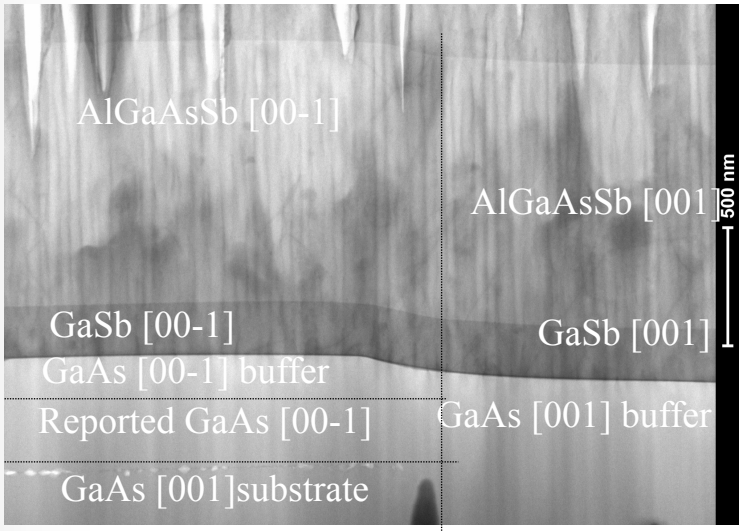


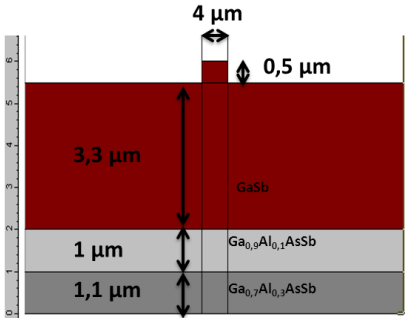


- Keep the corrugation with {113}B facet
- Keep the polarity

Non linear optics : GaSb waveguide on OP-GaAs substrate

Waveguide for OPO

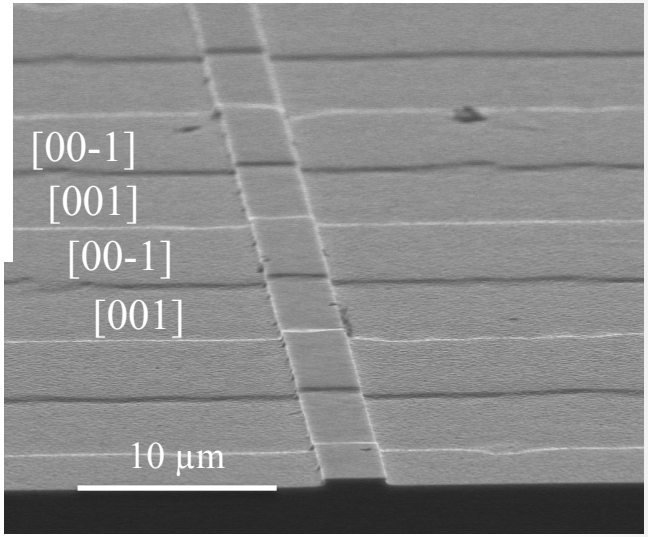




III-V lab

C2N

THALES
RESEARCH & TECHNOLOGY



Optical losses at 2 µm : 1 - 5 dB/cm

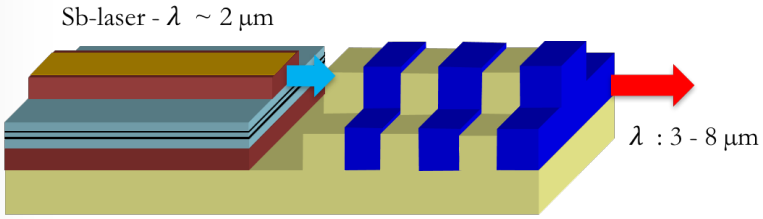
- Keep the polarity
- No defects at the antiphase boundary

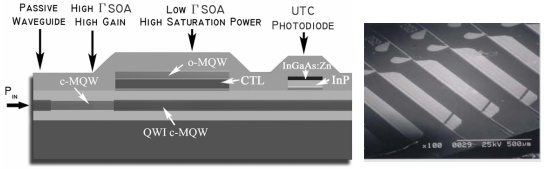
n.i.d. GaSb ➔ p ~3.10^{16} cm^{-3}
Too high for parametric oscillation

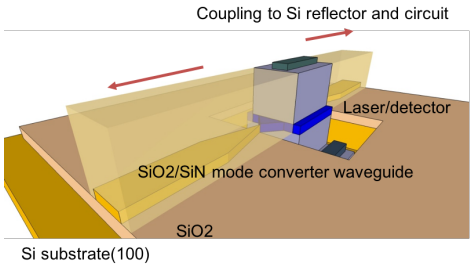
S.Roux et al. Opt. Mat . Xpress **7** (8) 2017

- Development of Sb-based optoelectronic devices with integrated function
  - Buried DFB
  - Buried all semiconductor plamsonic structures
  - OPO (?)

- Co planar intergration ? / III-Sb Photonic integrated circuit







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