In-situ reflectance and curvature measurements during AlGaInAs MQWs growth on InP/SiO2/Si substrates

Jean Decobert[1], Claire Besancon[1,3], Jean-Pierre Le Goec[1], Nicolas Vaissiere[1], Cécilia Dupré[2], Viviane Muffato[2], Frank Fournel[2], Christophe Jany[2], Franck Bassani[3], Sylvain David[3], Thierry Baron[3]

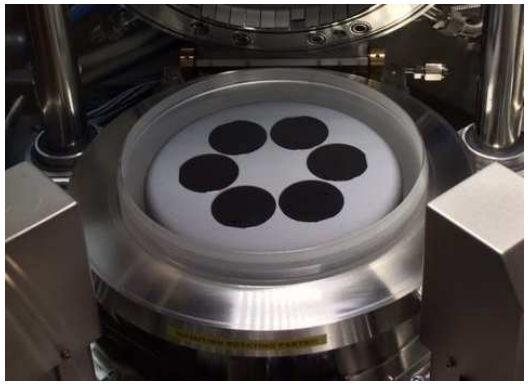
[1] *III-V Lab, a joint lab of 'Nokia Bell Labs', 'Thales Research and Technology' and 'CEA-LETI', France*
[2] *CEA-LETI, France*
[3] *Univ. Grenoble-Alpes, CNRS, CEA-LETI, LTM France*

Outline

- **New CCS MOVPE system at III-V Lab**
  - Epitaxy tool
  - In-situ characterization tools
- **Silicon Photonics applications**
  - III-V integration on silicon
  - Regrowth onto InP bonded seeds
  - Fabrication process for InPoSi seed
- **Regrowth of AlGaInAs-based MQW onto InPoSi seed**
  - In-situ characterizations (reflectance, curvature)
  - Ex-situ characterizations (AFM, TEM, XRD, PL)
- **Conclusion**

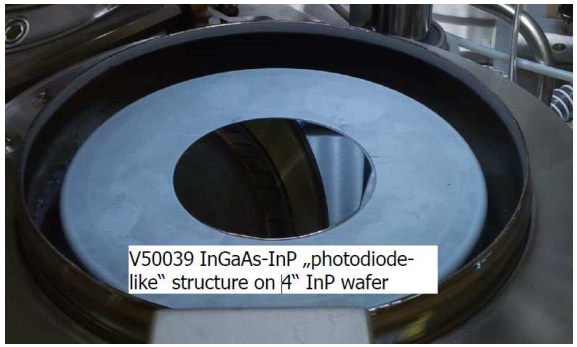
Recent acquisition of a 6x2" CCS reactor

- **MOVPE system for R&D and small scale production**
  - Close Coupled Showerhead (CCS) under H2 or N2
  - Configuration : 6x2”, 3x3”, 1x4” (and 1x6”) **on InP or GaAs**



6x2”

3x3”



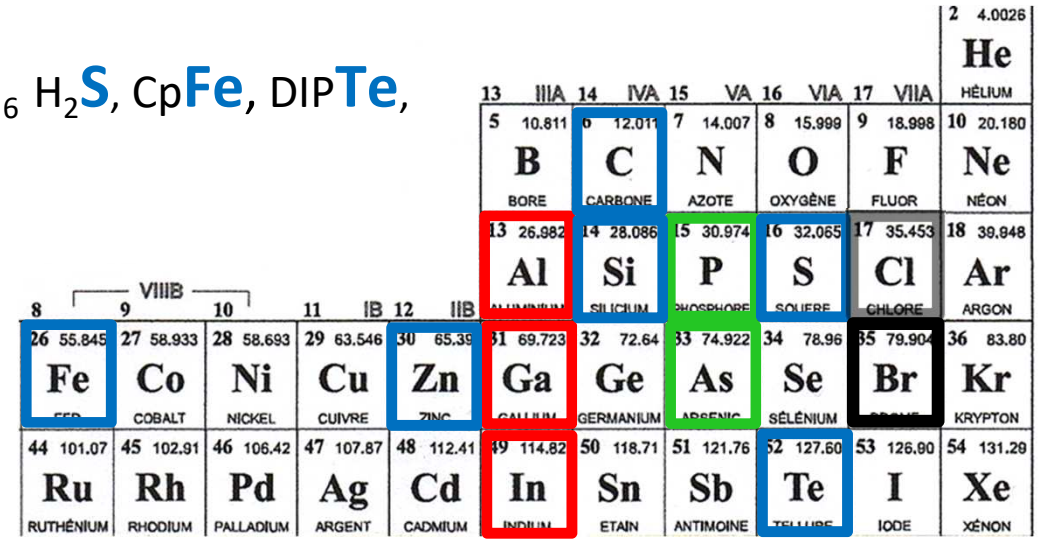
1x4”

III-V lab

Recent acquisition of a 6x2" CCS reactor

▶ MOVPE system for R&D and small scale production

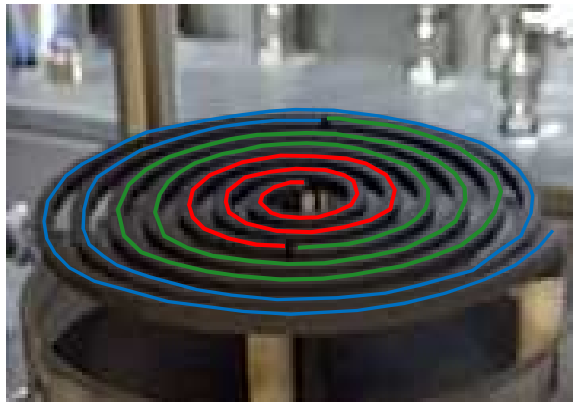
- Close Coupled Showerhead (CCS) under H2 or N2
- Configuration : 6x2”, 3x3”, 1x4” (and 1x6”) **on InP or GaAs**
- Elements available :
  - III elements : TM**In**, TM**Ga**, TM**Al**,
  - V elements : **As**H_3, **P**H_3,
  - Dopants : DE**Zn**, **C**Br_4, **Si**$_2H_6$ H_2**S**, Cp**Fe**, DIP**Te**,



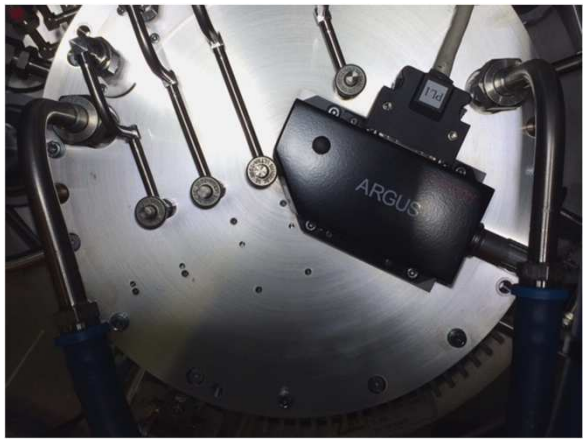
NOKIA leti CEA tech THALES

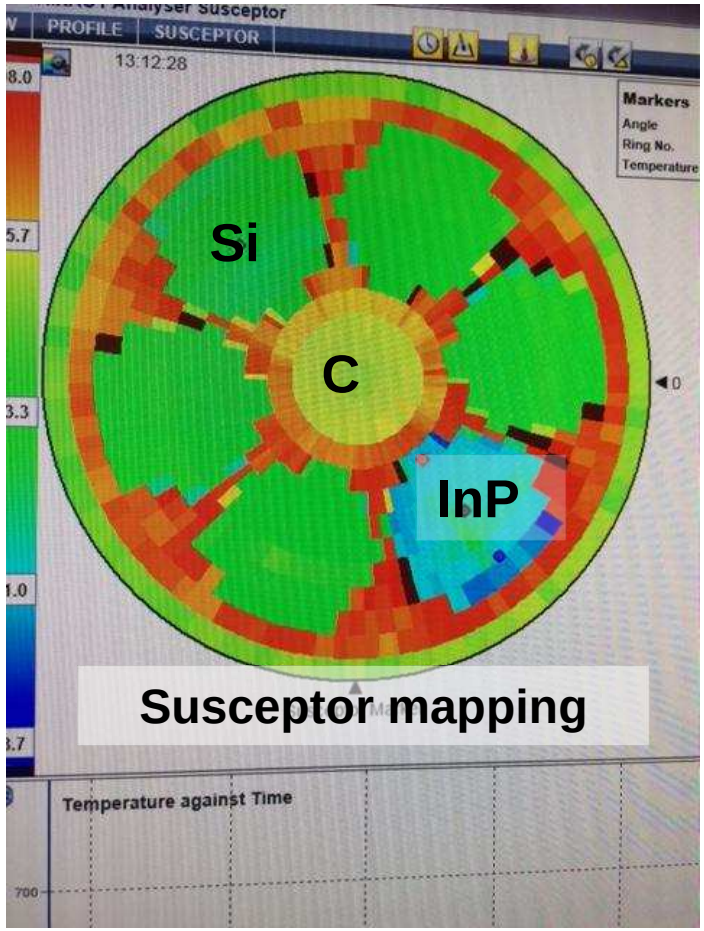
In-situ characterizations

Susceptor topside thermal mapping: monitor and control (ARGUS)



Heating system





Susceptor mapping

In-situ characterizations with Epicurve TT from Laytec

- *Susceptor surface temperature : monitor and control (ARGUS)*
- ***Wafer true surface temperature measurement (Pyrometer 950 nm)***
- ***Reflectometry (at 950, 650 and 405 nm)***
- ***Curvature : related to total strain***

LAYTEC Knowledge is key

NOKIA leti CEA tech THALES

Outline

- **New CCS MOVPE system at III-V Lab**
  - Epitaxy tool
  - In-situ characterization tools
- **Silicon Photonics applications**
  - III-V integration on silicon
  - Regrowth onto InP bonded seeds
  - Fabrication process for InPoSi seed
- **Regrowth of AlGaInAs-based MQW onto InPoSi seed**
  - In-situ characterizations (reflectance, curvature)
  - Ex-situ characterizations (AFM, TEM, XRD, PL)
- **Conclusion**

Motivation

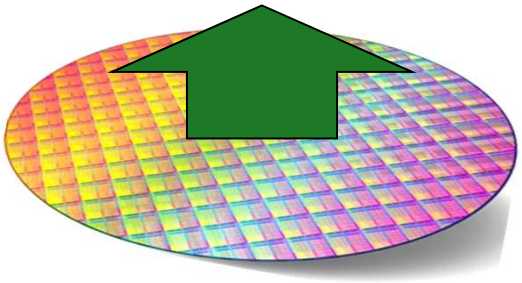
- **Silicon photonics: III-V integration on Silicon**

+ Emitting properties	+ Production volume
+ Active functions	+ Passive functions
+ Process Maturity	+ Electronic properties
- Costs	+ Costs
	- Emitting properties

- **2 approach families :**

Hetero-epitaxy

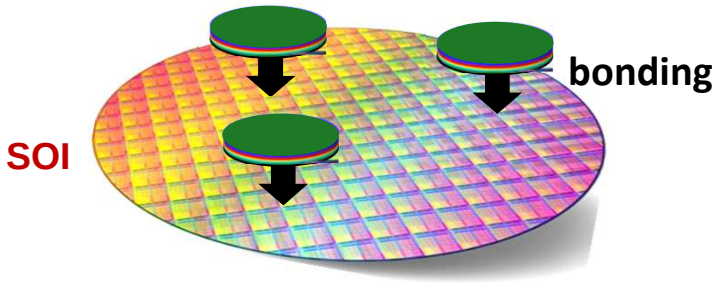
III-V direct-growth



Crystal quality issues

Wafer-bonding

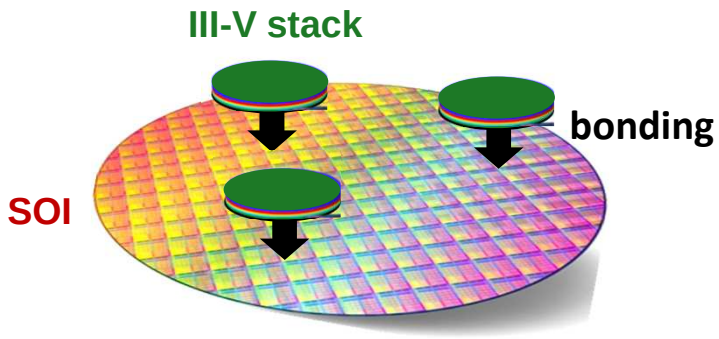
III-V reverse stack

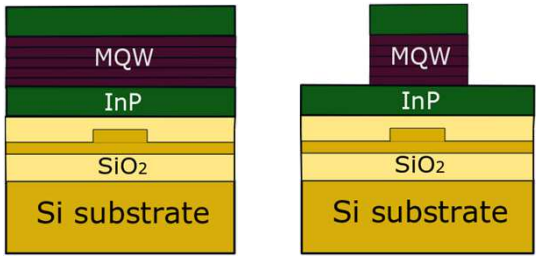


Bonding process and regrowth issues

Motivation

Wafer-bonding : conventional approach

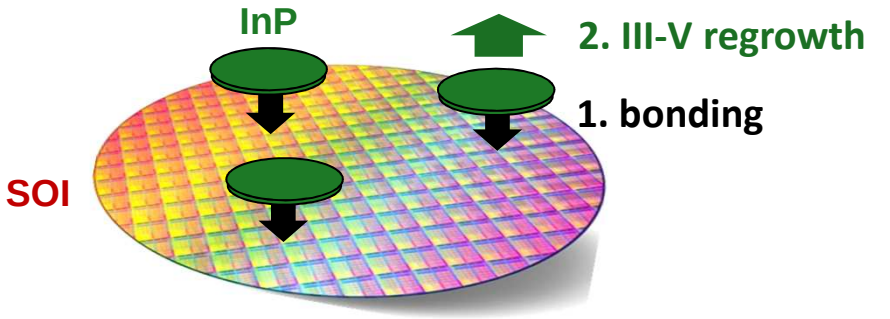


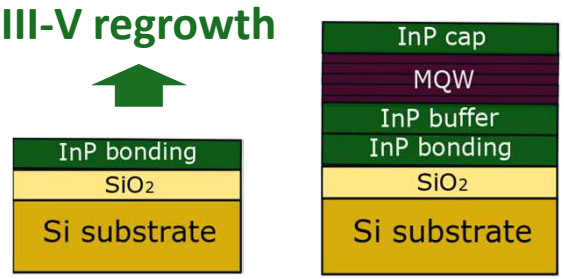


No further regrowth

Wafer-bonding: regrowth <u>after</u> bonding

Goal: extend all the III-V mature know-how into the silicon photonics platform





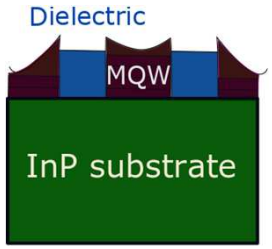
MQW: MultiQuantum Wells

Examples of *III-V Lab* know-how

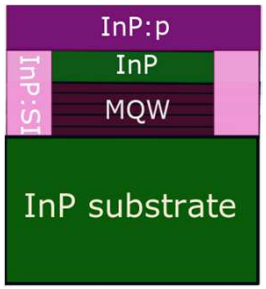
Multi-step growth processes on InP wafers :

Examples of typical mature regrowth steps available at III-V Lab :

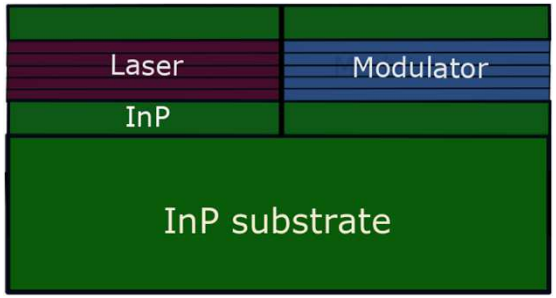
InP classical platform



SAG[1]
Selective Area Growth



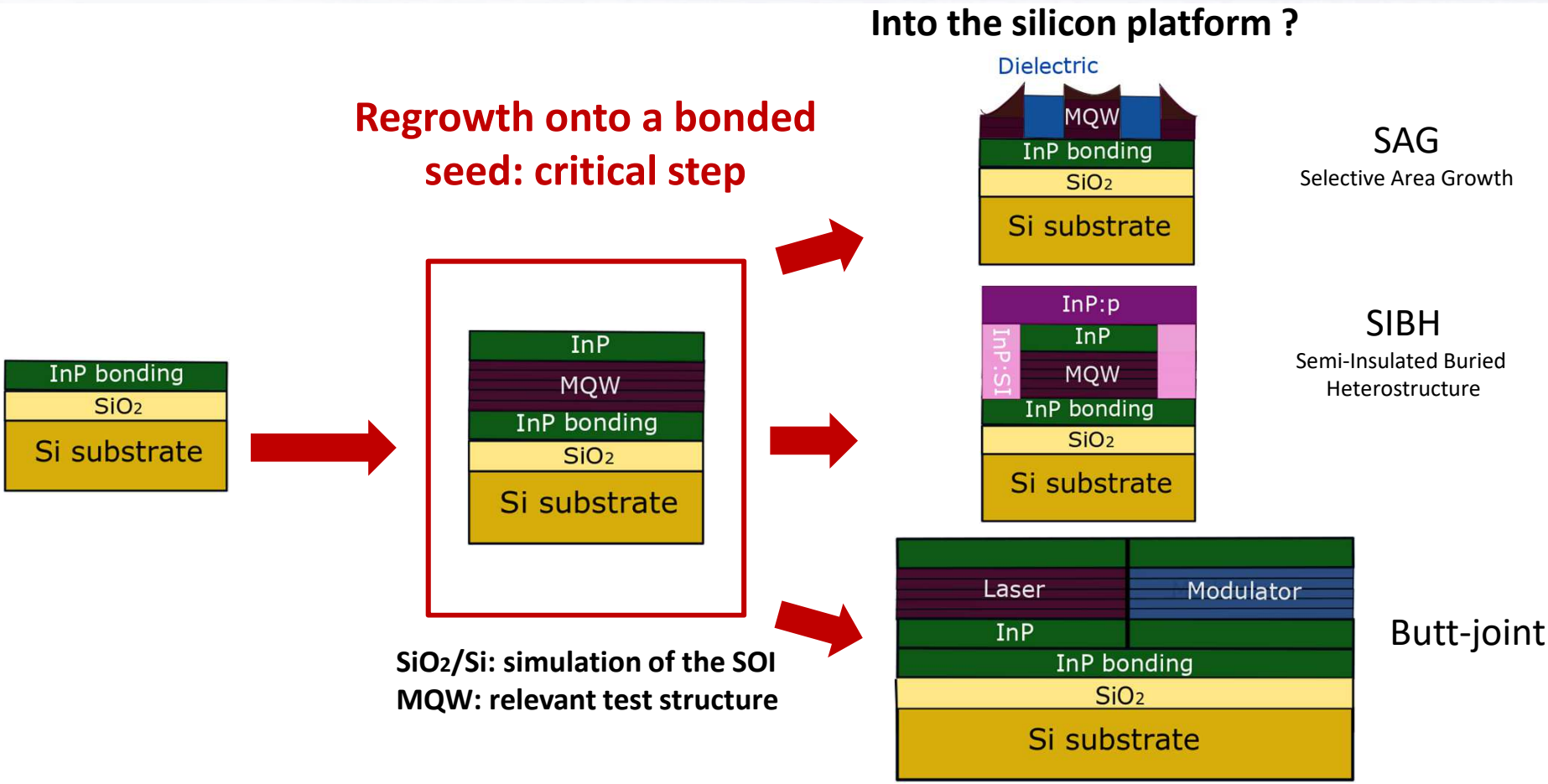
SIBH[2]
Semi-Insulated Buried Heterostructure



Butt-joint

[1] N. Dupuis *et al., IEEE Photonics Technol. Lett., 2008.*
[2] C. Jany *et al., ECOC 2007*

Goal: transfer into the silicon platform

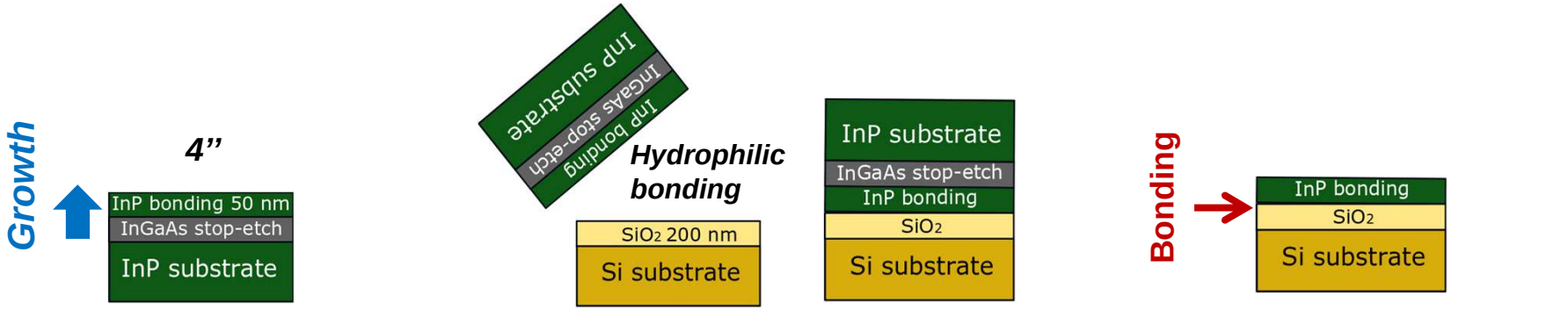


Fabrication process
InP/SiO2/Si = InPoSi

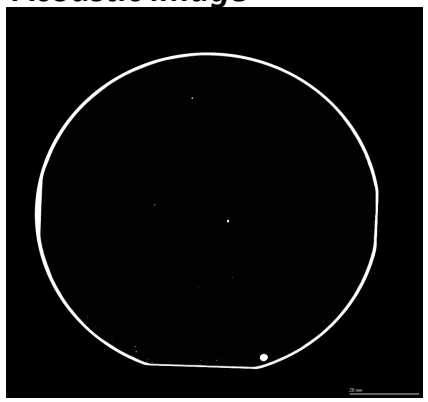
1) MOVPE growth on an InP substrate

2) Direct-bonding with a thermally-oxidized Si substrate

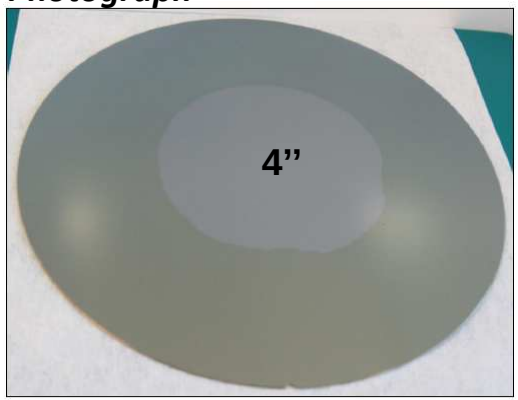
3) Etching of the InP substrate and the InGaAs sacrificial layer



Acoustic image



Photograph

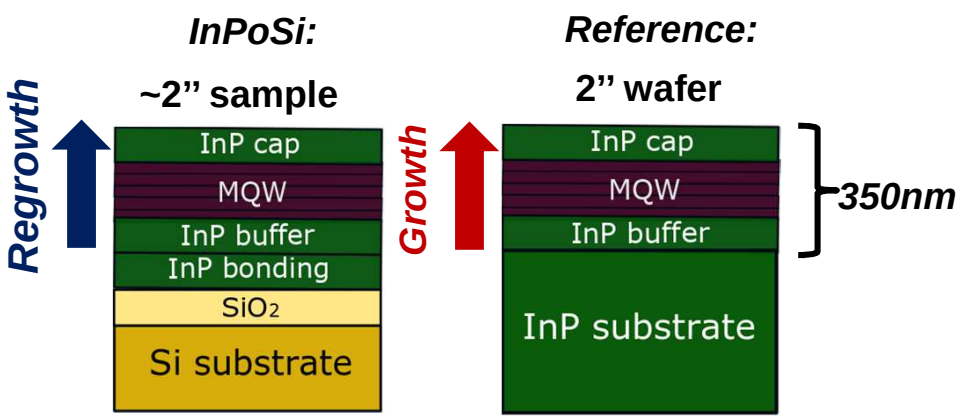


Cleaved into small samples for regrowth tests

Outline

- **New CCS MOVPE system at III-V Lab**
  - Epitaxy tool
  - In-situ characterization tools
- **Silicon Photonics applications**
  - III-V integration on silicon
  - Regrowth onto InP bonded seeds
  - Fabrication process for InPoSi seed
- **Regrowth of AlGaInAs-based MQW onto InPoSi seed**
  - In-situ characterizations (reflectance, curvature)
  - Ex-situ characterizations (AFM, TEM, XRD, PL)
- **Conclusion**

4) Regrowth of InP based AlGaInAs MQW



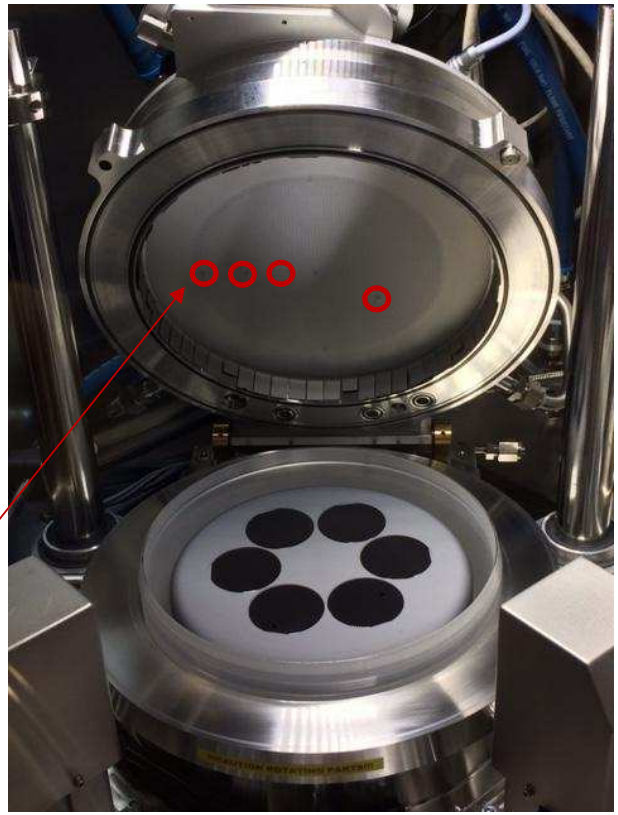
In-situ characterizations:

Reflectance
Curvature

Ex-situ characterizations:

Atomic force Microscope
STEM / TEM
X-ray diffraction
Photoluminescence

Holes for in-situ measurements

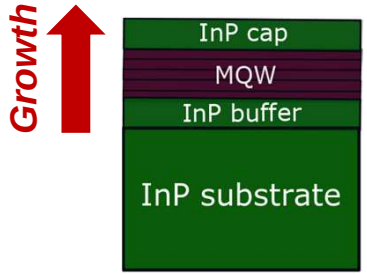


Aixtron CCS reactor
6x2", 3x3" and 1x4" capacity

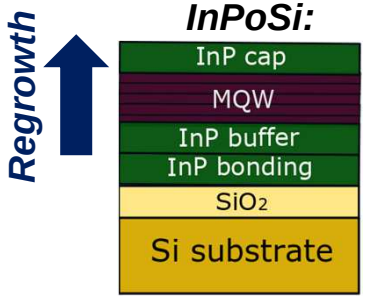
Reflectance measurements

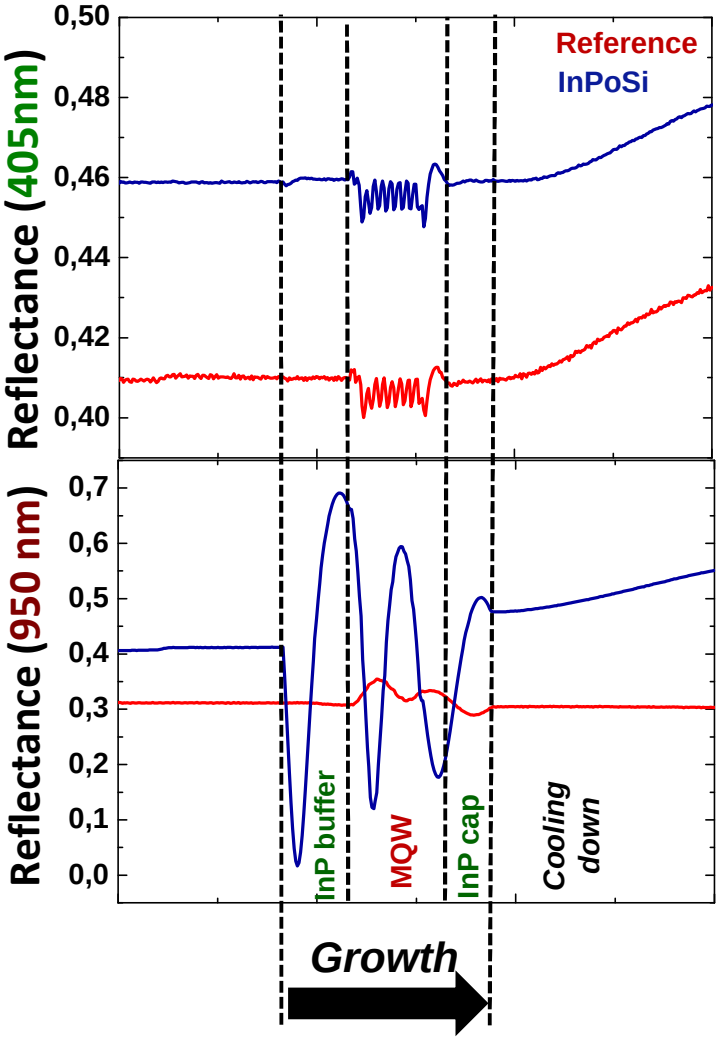
Reflectance signals:
-> 405nm: surface quality
-> 950nm: growth rate (GR)

Reference:



InPoSi:



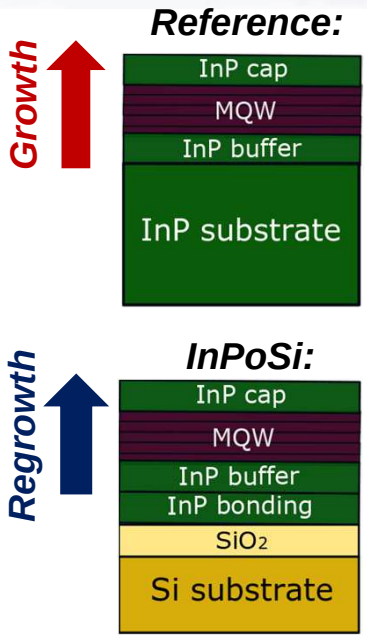


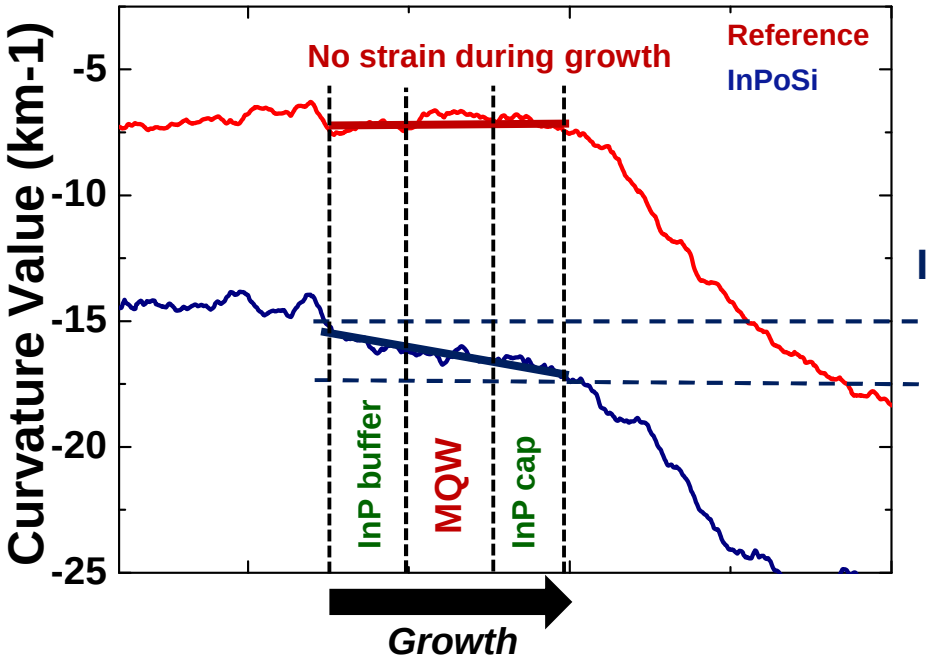
No degradation of the signal: high-quality material

Large index contrast in InPoSi: high amplitude oscillation

$GR_{InP\_InPoSi} = GR_{InP\_Reference} = 2.1\mu m/h$

Curvature measurement





Tensile

Compressive

In-situ measurement:

$$\Delta\frac{1}{R} = 2.4\ km^{-1}$$

T_{growth} = 650°C

α_{InP} = 4,56ppm/K

α_{Si} = 2,62ppm/K

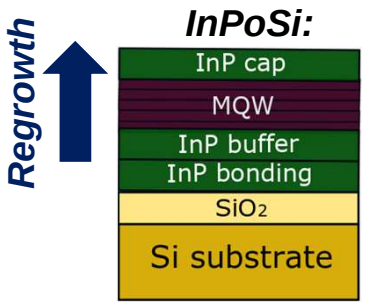
CTE strain = $(T_{growth} - T_{bonding}) \times (\alpha_{InP} - \alpha_{Si})$

Theorical CTE strain = 670ppm $\Leftrightarrow$ $\Delta\frac{1}{R} = 2.7\ km^{-1}$

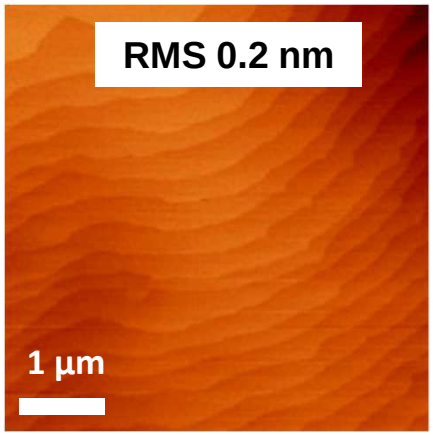
Stoney law

Ex-situ characterization

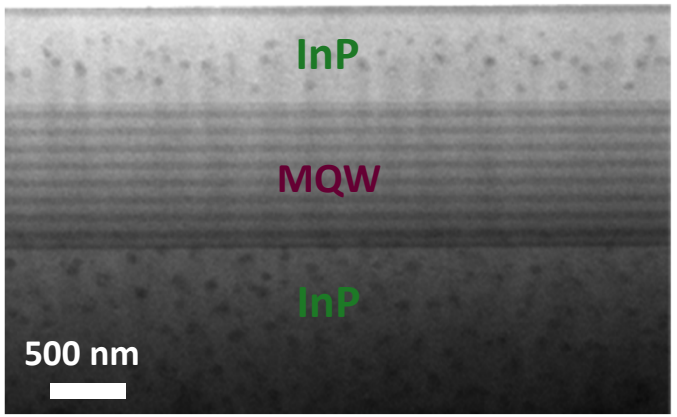
AFM – STEM/TEM



AFM

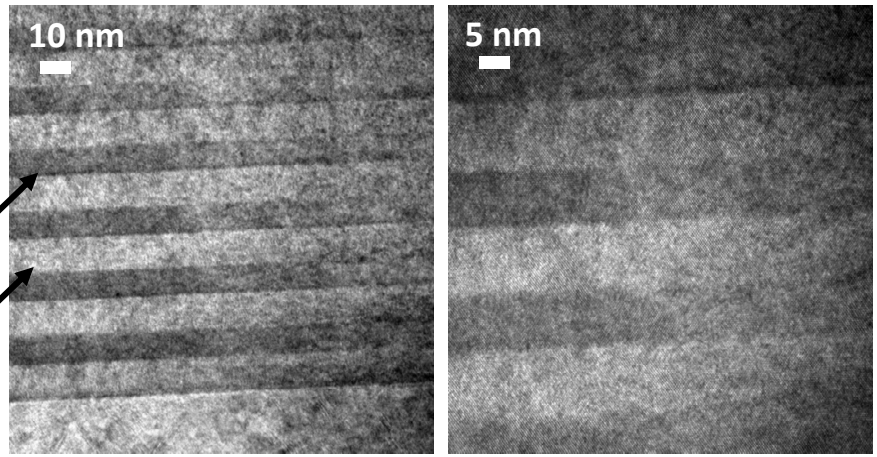


STEM



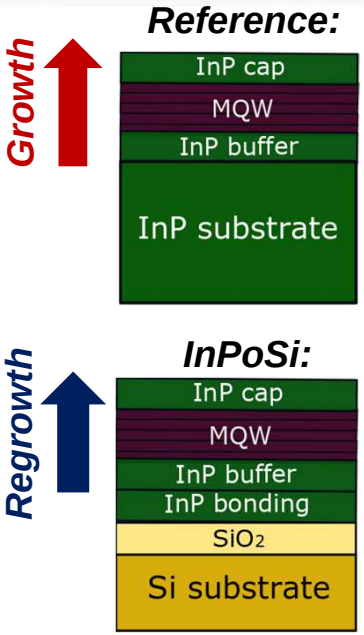
AFM: $RMS_{InPoSi} = RMS_{Reference}$
TEM:No trace of dislocations, High-crystal quality

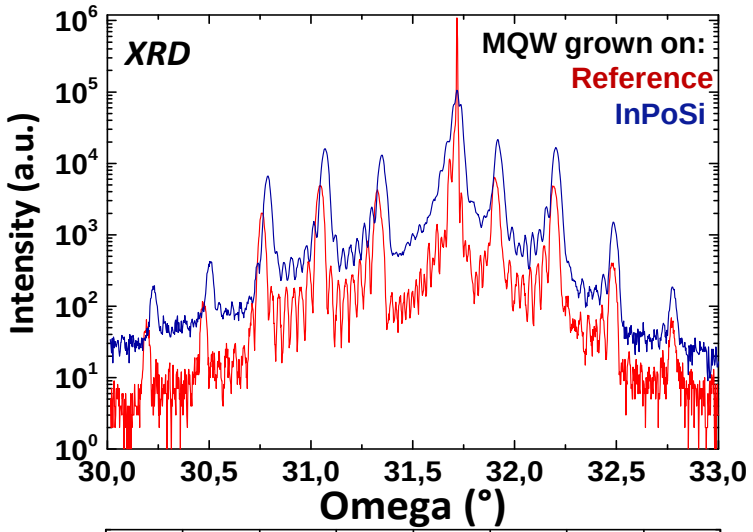
TEM



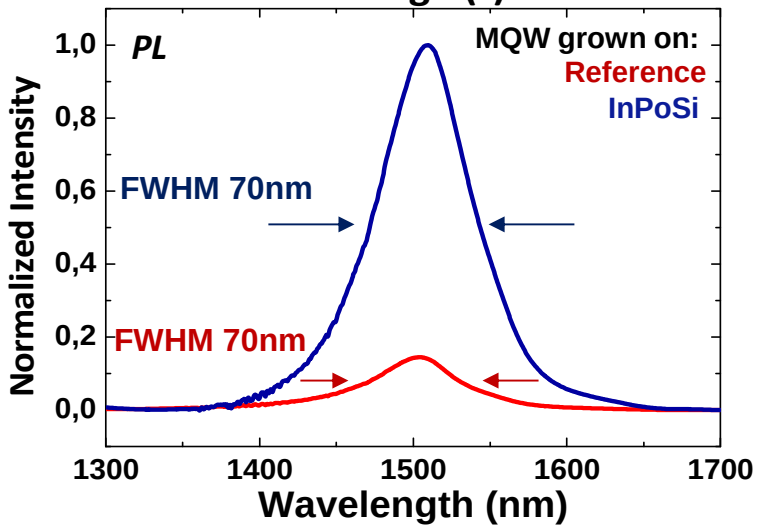
Well-defined interfaces

X-Ray Diffraction - Photoluminescence





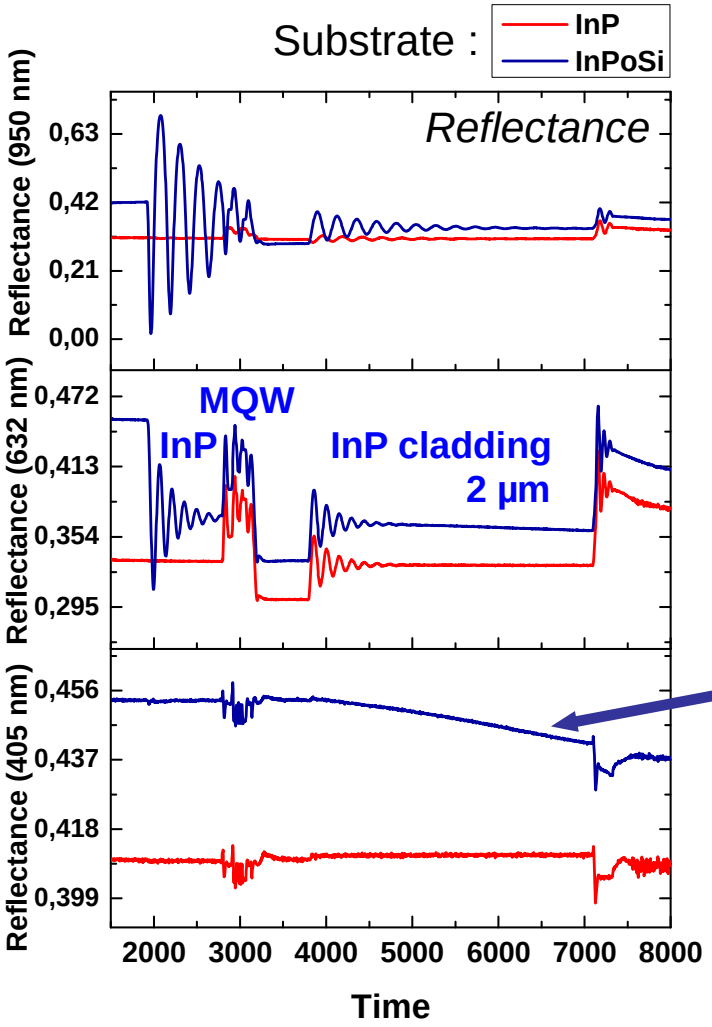
Sharp and intense satellite peaks: high crystal quality

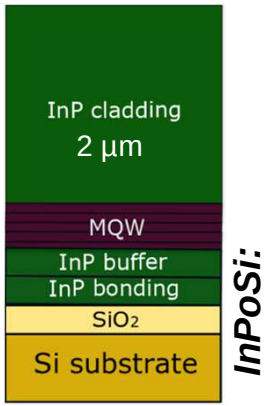


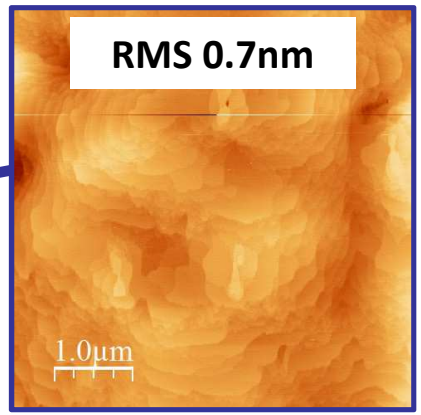
InPoSi PL peak 7 times more intense than that of the reference.
-> High index contrast in InP/SiO_2/Si
-> increasing the excitation and collection of the photons

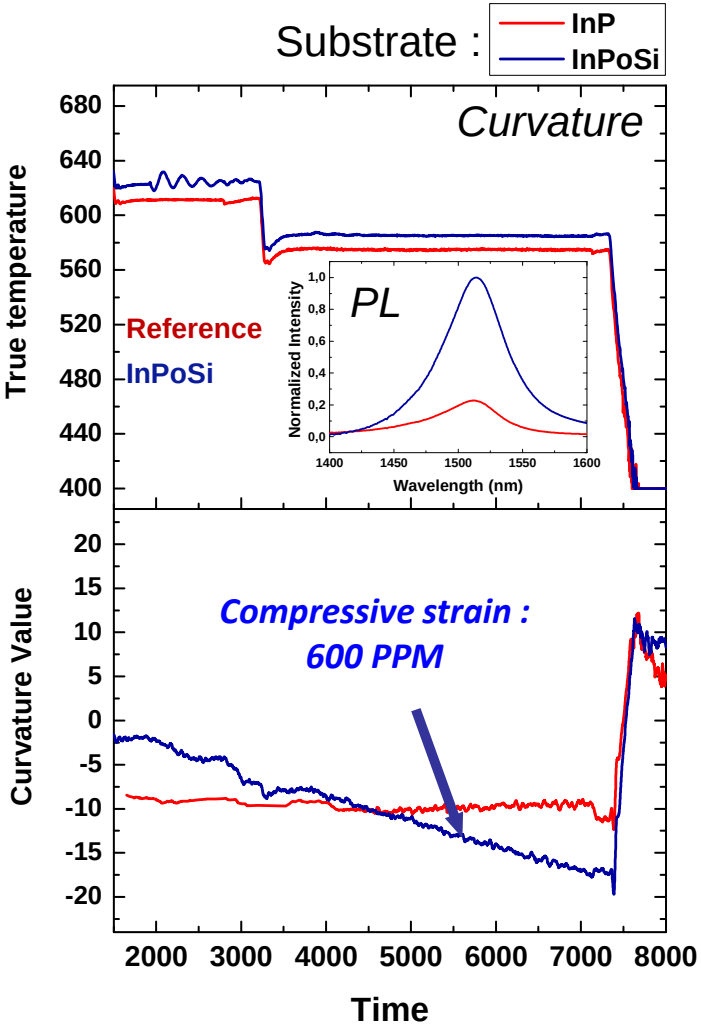
$FWHM_{InPoSi} = FWHM_{Reference}$

2.5 µm thick heterostructure on InP and InPoSi substrates









NOKIA leti CEA tech THALES

Outline

- **New CCS MOVPE system at III-V Lab**
  - Epiaxy tool
  - In-situ characterization tools
- **Silicon Photonics applications**
  - III-V integration on silicon
  - Regrowth onto InP bonded seeds
  - Fabrication process for InPoSi seed
- **Regrowth of AlGaInAs-based MQW onto InPoSi seed**
  - In-situ characterizations (reflectance, curvature)
  - Ex-situ characterizations (AFM, TEM, XRD, PL)
- **Conclusion**

Conclusion

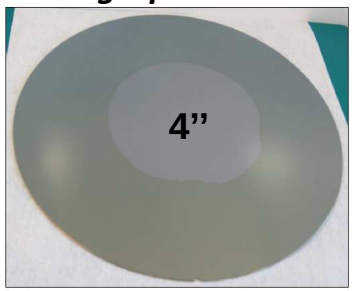
-The fabrication process for a 4” InPoSi (InP-SiO_2/Si) template has been presented

-The regrowth of high-quality AlGaInAs-based MQW has been demonstrated on an InPoSi template compared a reference on an InP substrate

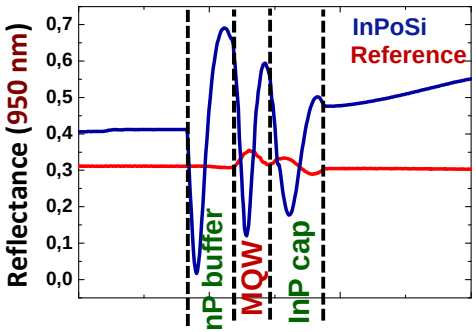
-> *In-situ measurements* have been carried out on a bonded template showing high-quality material (reflectance) and a good correlation with the theorical thermal strain induced in an InPoSi template (curvature)

-> *Ex-situ measurements* also account for the high-quality of the regrown material

Photograph



In-situ measurements



TEM