

Hybrid MBE-CBE Growth and Characterization of undoped $In_{0,53}Ga_{0,47}As$ on Fe-InP(001) for avalanche photodiodes (APDs)

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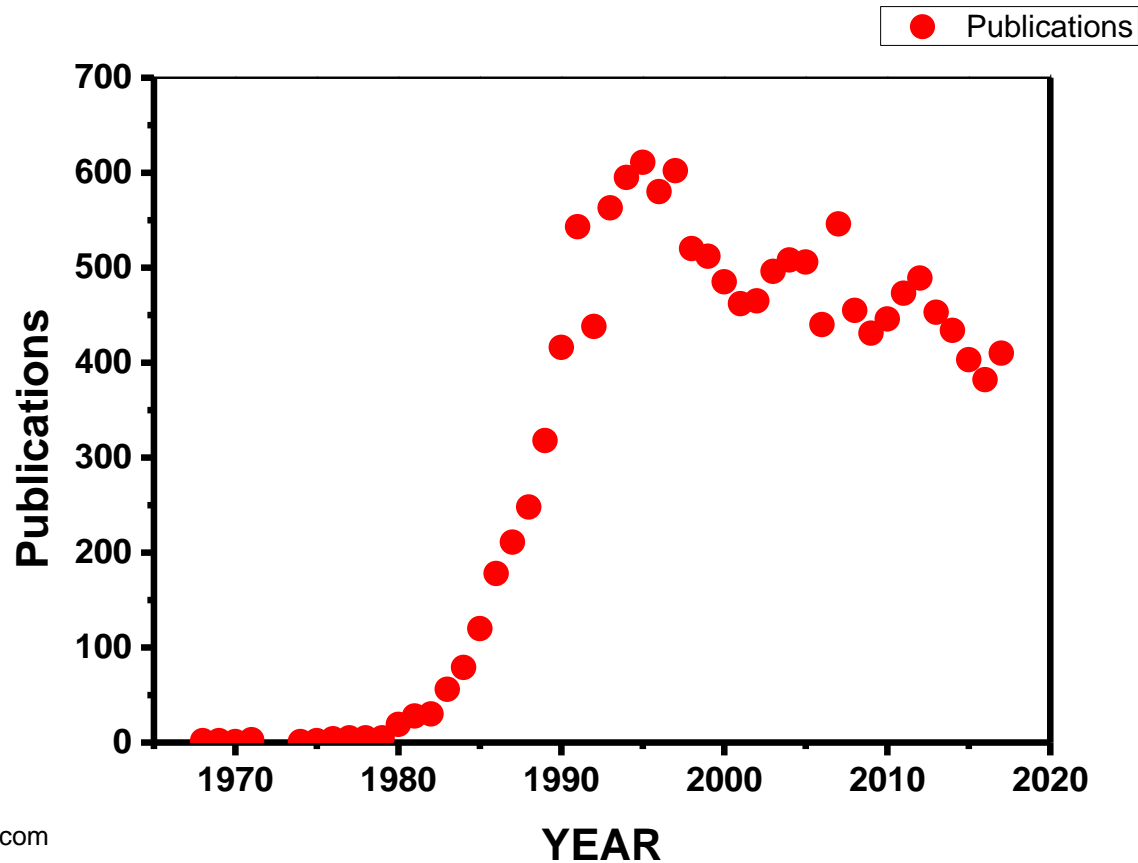
T.M. Diallo, M. El-gahouchi, M. Jellite, G. Gommé, H. Pelletier, A. Boucherif, S. Fafard, R. Arès



InGaAs/InP

**WHY IT IS STILL
IMPORTANT ?**

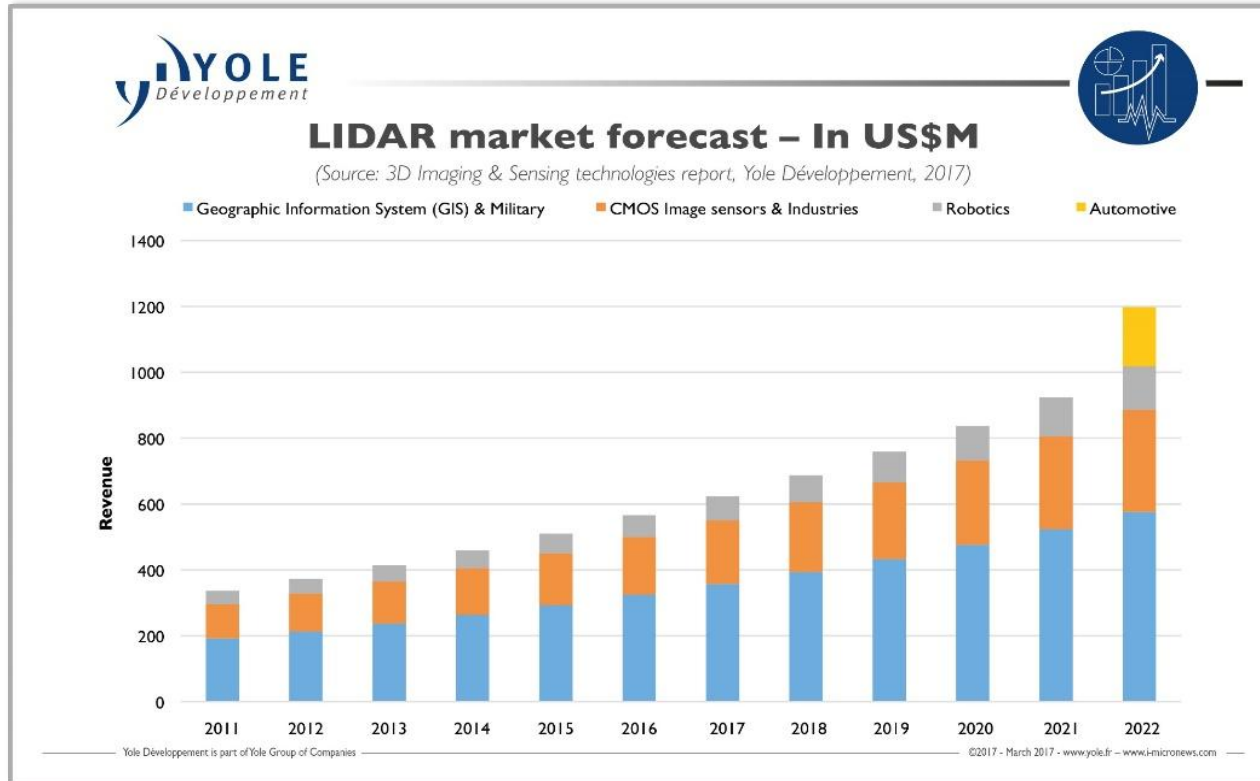
Introduction



<https://www.scopus.com>

Introduction

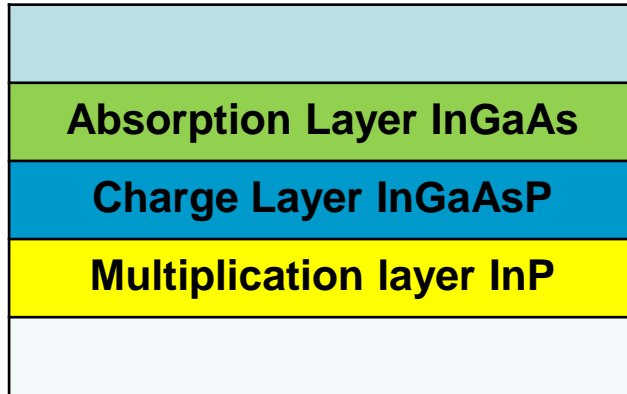
Application areas



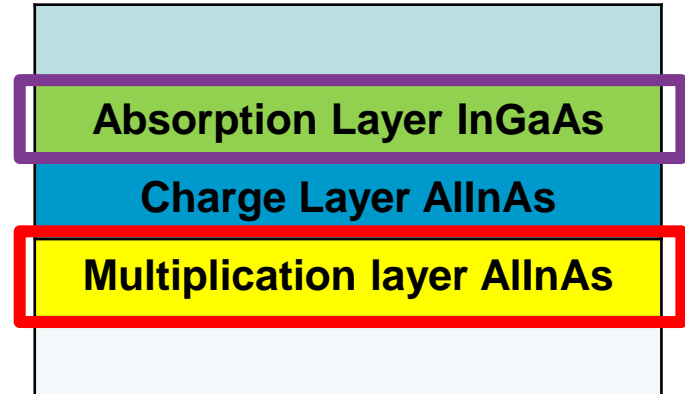
<https://www.engineering.com/lidar-complex-sensing-in-automotive-market-2027>

Introduction

Technology of APDs



SAGCM APDs



New SAGCM APDs

Goal:

- **High cristalline quality**
- **Low carrier background**
- **Uniformity**
- **High growth rate**

Is it possible to combine high throughput and high purity?



Hybrid Epitaxy

About Hybrid Epitaxy

Expectations

- Organometallic sources: TEGa



- High purity

- Solid source In
 - High growth rate



- Good uniformity

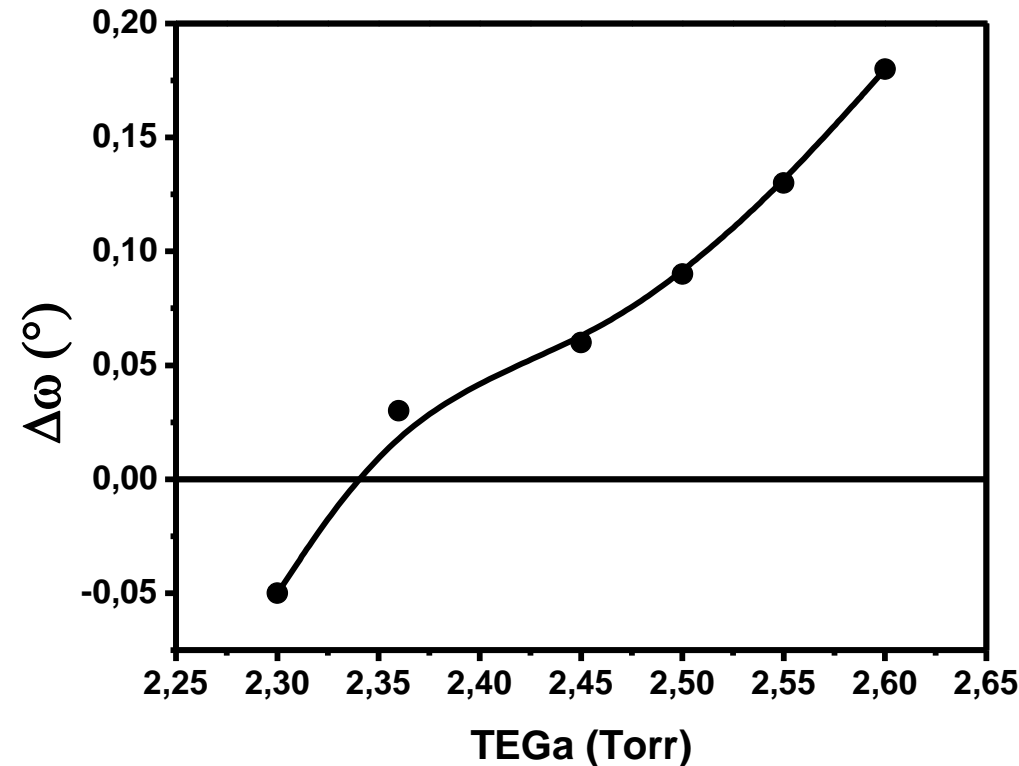
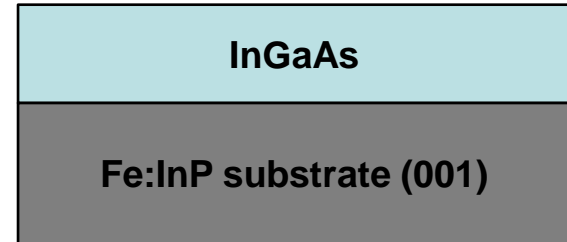
- High purity thermally cracked AsH_3

Experiments: Growth of InGaAs by Hybrid epitaxy- preliminary results

InGaAs Full Gas: Calibration LM

Growth conditions

TEGa (Torr)	TMIn (torr)	Cracked AsH ₃ (torr)	Growth T (°C)
Variable	2	10	500



Lattice Match

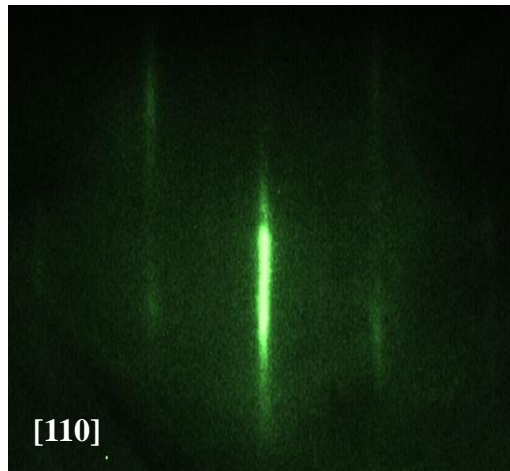
- **TMIn = 2 Torr**
- **TEGa = 2,35 Torr**

InGaAs Full Gas: Calibration LM

Growth conditions

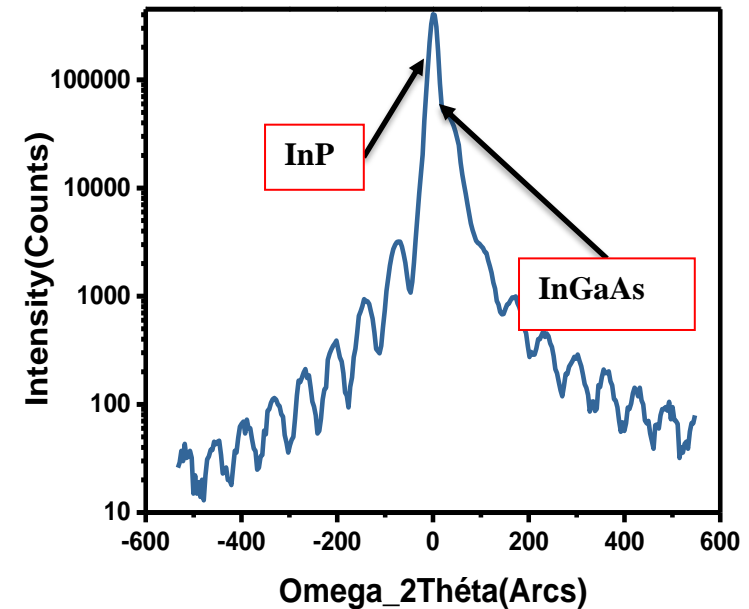
TEGa (Torr)	TMIIn (torr)	Cracked AsH ₃ (torr)	Growth T (°C)
2,35	2	10	500

Growth T (°C)=500°C



Streaky patterns

XRD



Mismatch

-85 ppm

Hall Effect

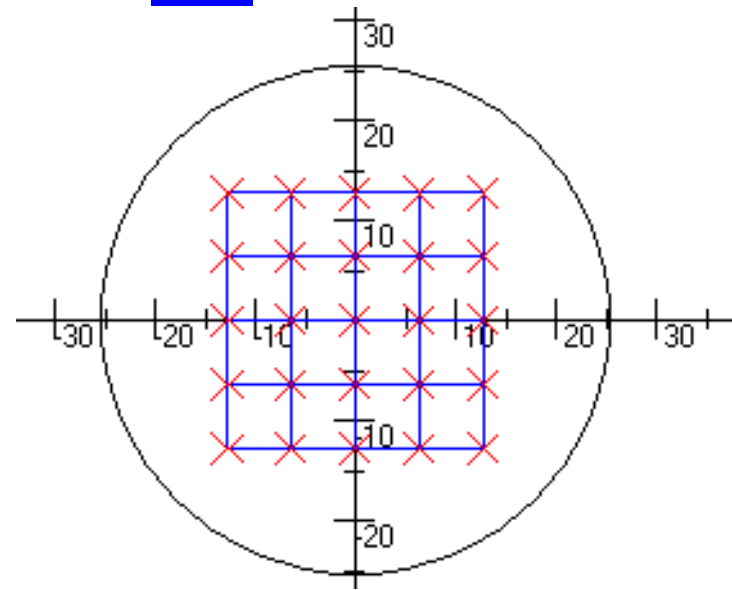
$n = 1E+16 \text{ cm}^{-3}$

InGaAs Full Gas: Uniformity Assessment

Growth conditions

TEGa (Torr)	TMIn (torr)	Cracked AsH ₃ (torr)	Growth T (°C)
0,7	0,72	10	500

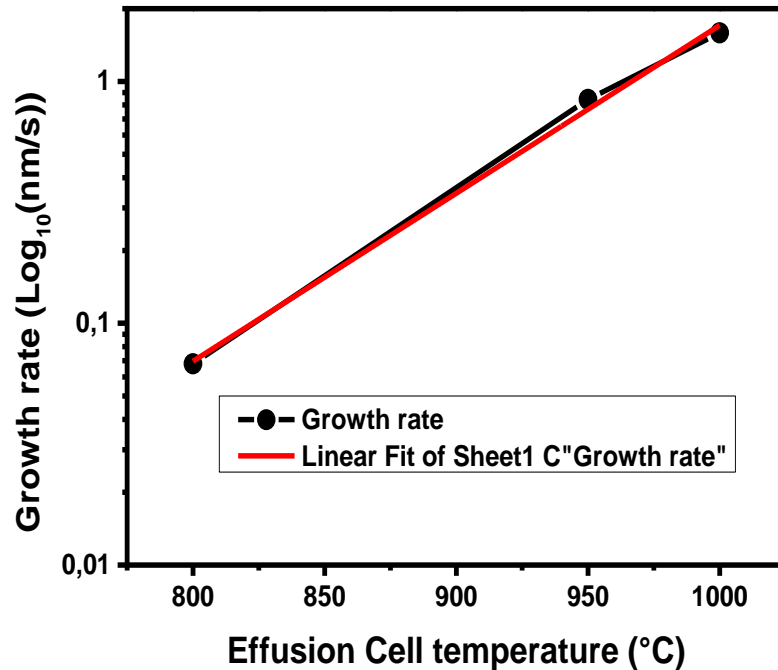
XRD



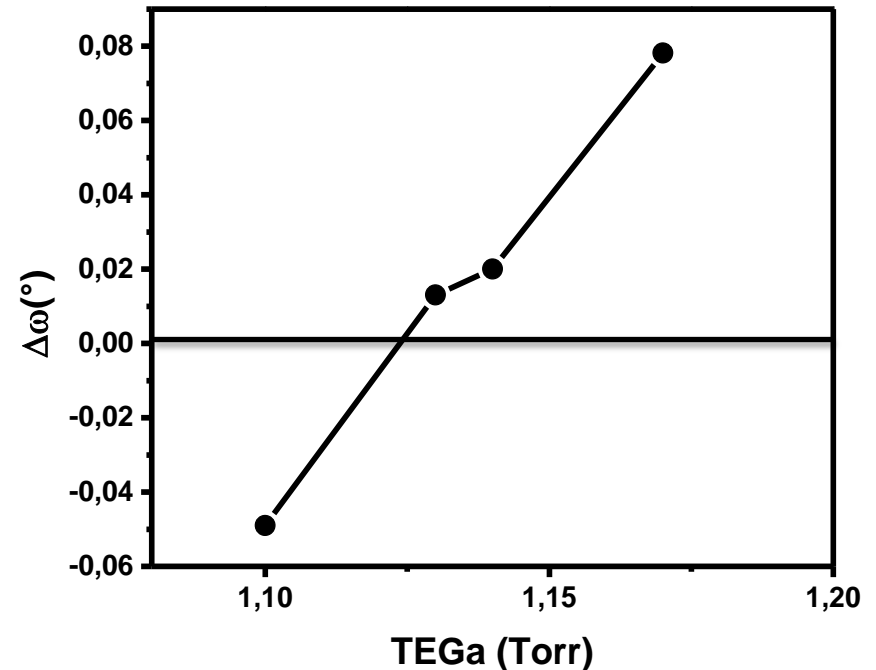
- Good crystallinity
- Smooth and flat surface
- Lattice matched on InP
- 2D growth
- Uniformity on 2" wafer
- Growth rate: 1.8 μ m/h

Mismatch: 980 \pm 216 ppm

InGaAs by Hybrid MBE-CBE



Effusion Cell temperature fixed at 866°C



Lattice Match

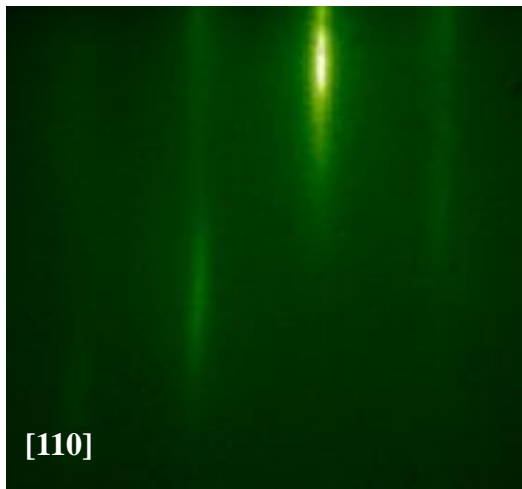
- Effusion Cell temperature: 866°C
 - TEGa [1.11; 1.115] Torr

InGaAs by Hybrid MBE-CBE: Hybrid InGaAs

Growth conditions

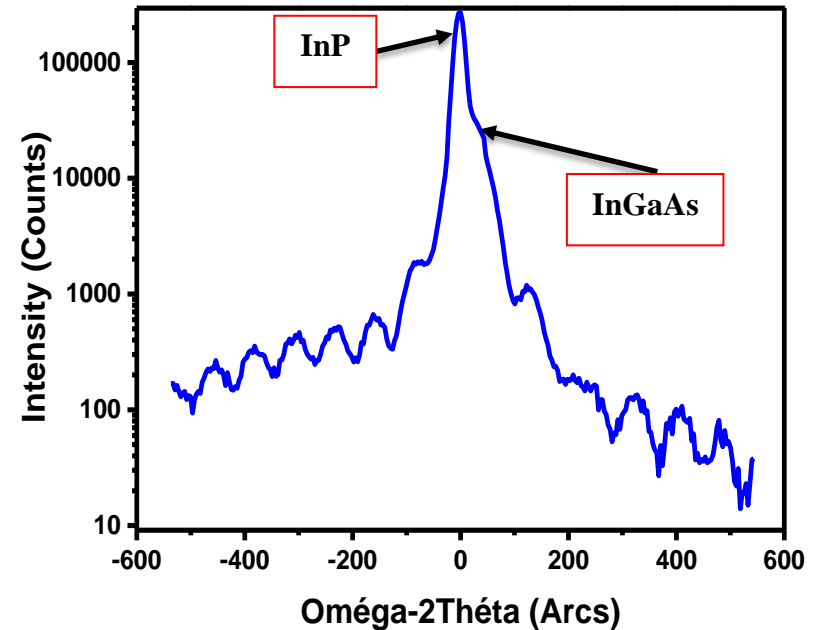
TEGa (Torr)	Kcell In(°C)	Cracked AsH ₃ (torr)	Growth T (°C)
1,12	866	10	500

Growth T (°C)=500°C



Streaky patterns

XRD



Mismatch

-96 ppm

Hall Effect

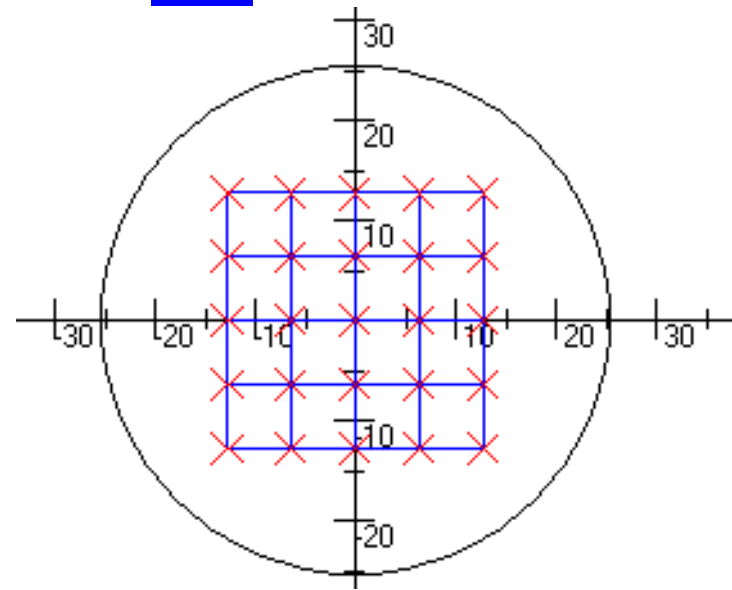
$n = 2E+14 \text{ cm}^{-3}$

Hybrid InGaAs: Uniformity Assessment

Growth conditions

TEGa (Torr)	Kcell In(°C)	Cracked AsH ₃ (torr)	Growth T (°C)
1,12	866	10	500

XRD

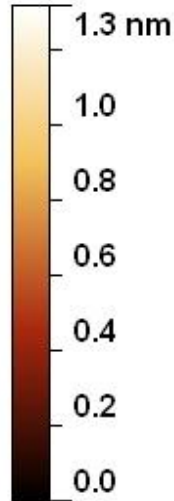
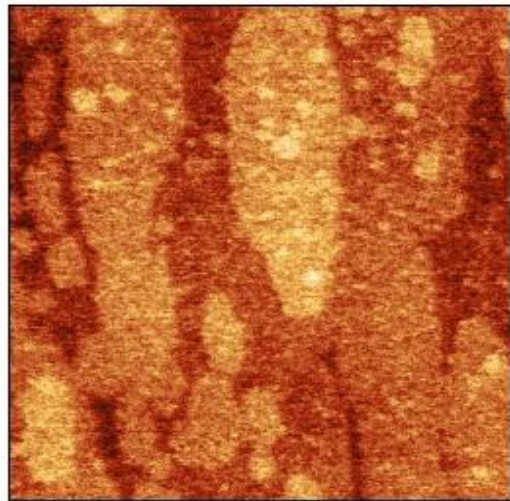


- Good crystallinity
- Smooth and flat surface
- Lattice matched on InP
- 2D growth
- Uniformity on 2" wafer
- Growth rate: 1.25 μ m/h
- Lower carrier background

Mismatch = 217 ± 263 ppm

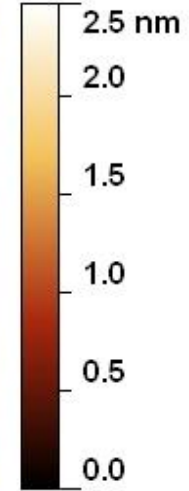
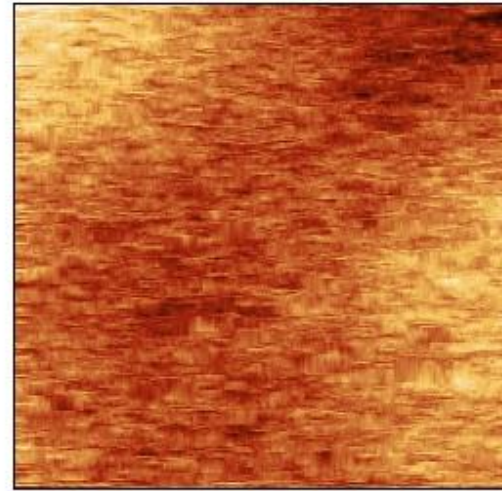
AFM Hybrid InGaAs et Full Gas InGaAs

1x1 μm^2



InGaAs Full Gas
RMS (sq)=0,2 nm

1x1 μm^2

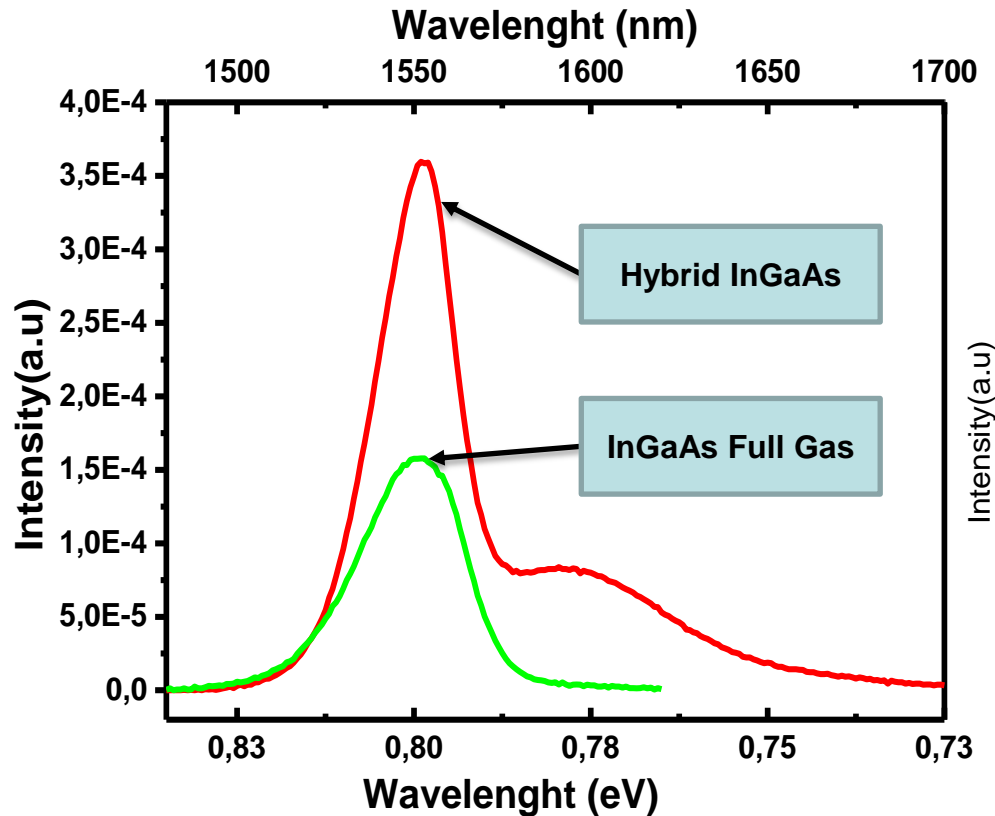


Hybride InGaAs
RMS (sq)=0,19 nm

Different growth dynamic

Photolumuminescence for both InGaAs

Very recent measurements
Photoluminescence at 32K



- Hybrid InGaAs
FWHM = 27 eV
- InGaAs Full Gas
FWHM = 34 eV

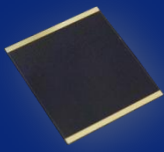
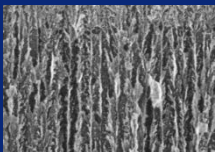
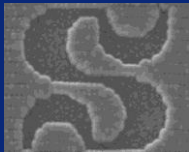
Higher purity than InGaAs Full Gas

InGaAs by Hybrid Epitaxy

- **Good crystallinity**
- **Uniformity on 2" wafer**
- **Higher purity than Full Gas**

Future works

- **Improve the purity**
- **Implementation in PIN detectors**



Thank you for your attention!

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