Optimization of InGaAs/GaAsSb based T2SL on InP in terms of dark current and spectral quantum efficiency

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8th of June 2023

Outline

- **Objective**

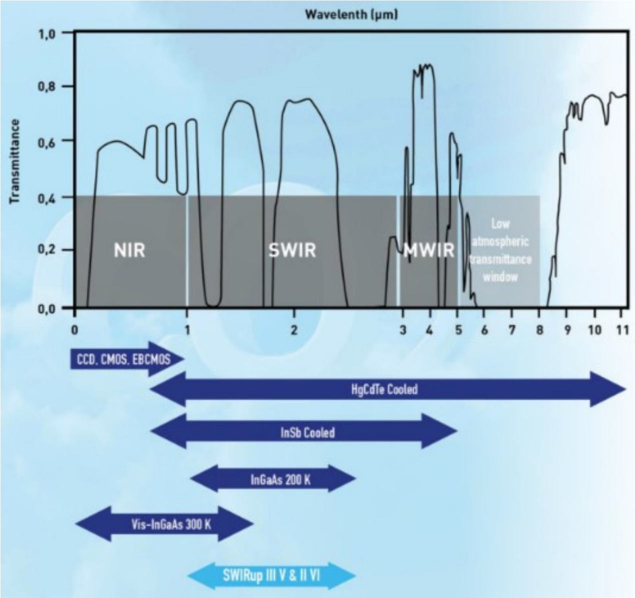
- **Transport in InGaAs/GaAsSb super lattice**
  - Localization issues in T2SL
  - Localization in ZA / InGaAs VB valence band offset

- **Playing with strain compensation**
  - Toward decent QE

- **Conclusion & perspectives**

Need for solution for all the SWIR band

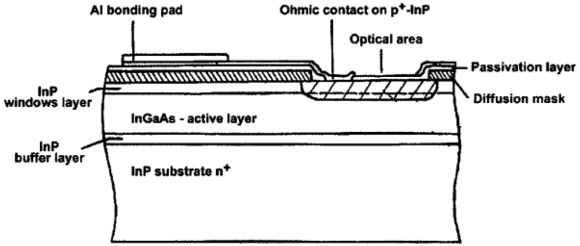
- **InGaAs lattice matched on InP material is the reference @ $\lambda_c \leq 1.7\mu m$**
  - InP high quality substrates available in 4’’ and 6’’
  - Minority carrier lifetime in the range of 2µs
  - Low dark current densities at T_{amb}
- **Active imaging**
  - Laser with high power at 1,55µm
  - Better atmospheric transmission
- **Space application**
  - $\lambda_{cut\ off} \geq 2{,}4\ \mu m$
  - Gas monitoring
    - $I_{dark} < 0{,}3\ nA/cm^2$ @175K
  - Earth imaging
    - $I_{dark} < 3\ \mu A/cm^2$ @270K

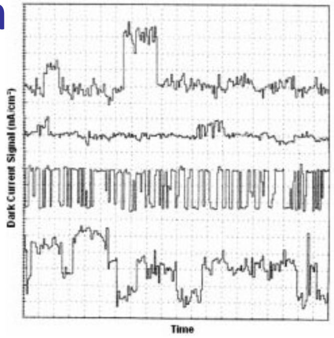


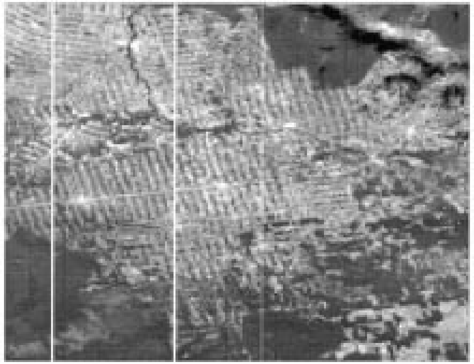
Several solutions

Strained InGaAs on buffer / InP

- RTS & dark current after irradiation

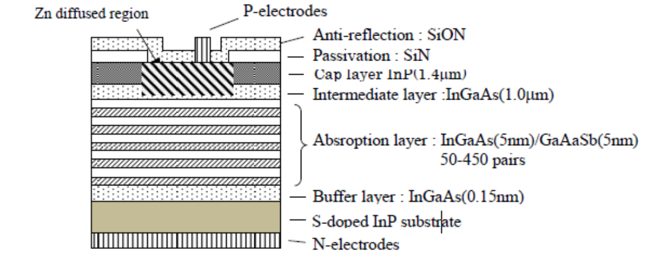






T2SL solutions on InP

- Inada et al. (2011)



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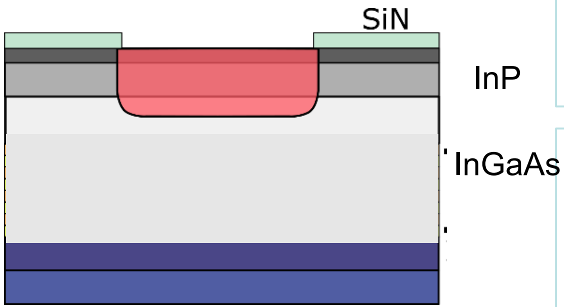
Fabrication issues vs standard InGaAs

MBE vs MOVPE growth

- Standard InGaAs on InP grown by MOVPE for InP cap
- Lack of pure SbH_3 precursors => MBE machine still more common

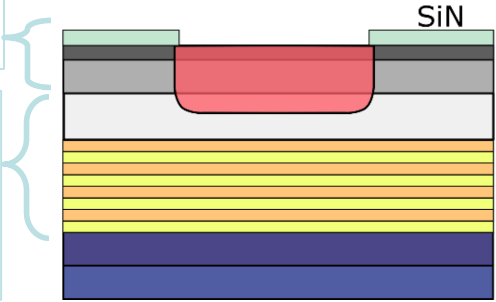


Cap layer

- ❑ Solution 1: P, As & Sb available in 1 MBE
- ❑ Solution 2: P source is not available
  - InP regrowth in MOVPE or GSMBE chamber
  - Zn diffusion optimization in InAlAs

Modification of active layer

- ❑ InGaAs in depleted region (>1µm)
- ❑ InGaAs/GaAsSb in neutral region



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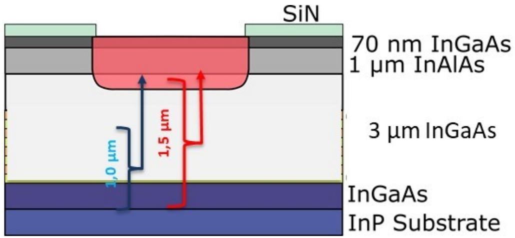
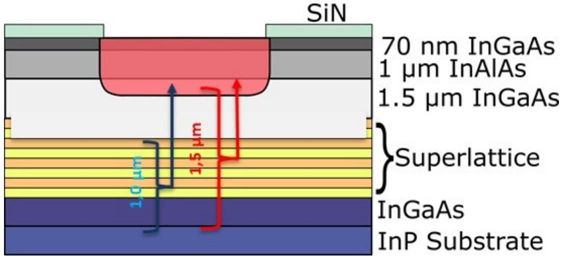
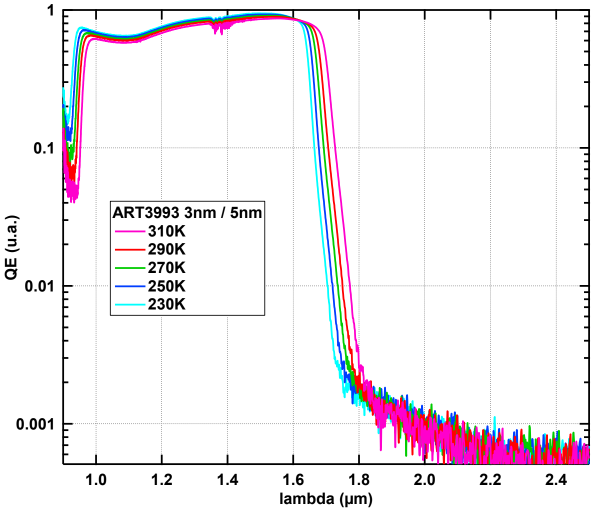
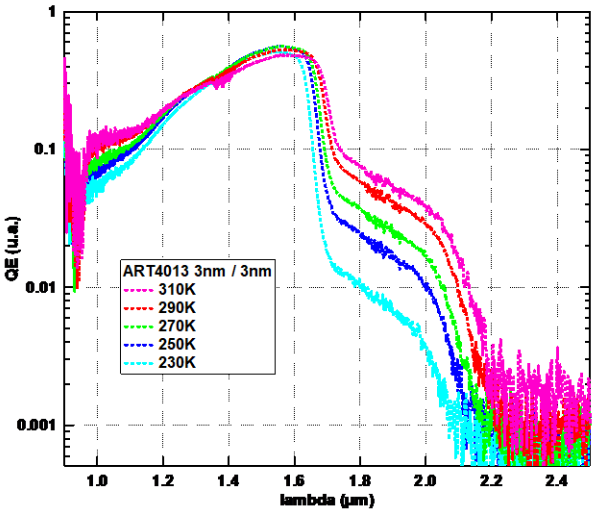
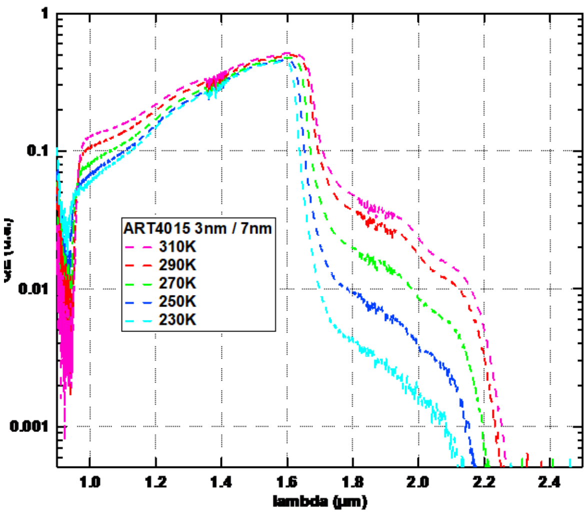
Effect of localization onto spectral responsivity











SWIRup
Infrared Space Image Sensors

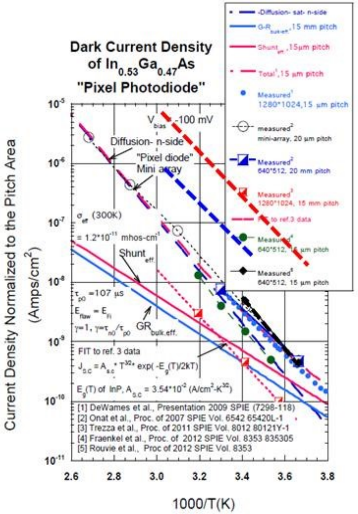
Conclusion for lattice matched T2SL

▶ Decent dark current

- 70nA/cm² @RT @1,65µm
- 200nA/cm² @RT @2,1µm

▶ Localization !!!!

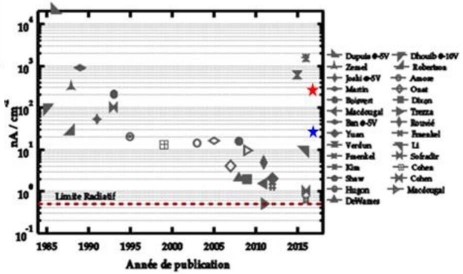
- QE < 10% with 1µm of SRL
- Localization at low temperature => MTF ??

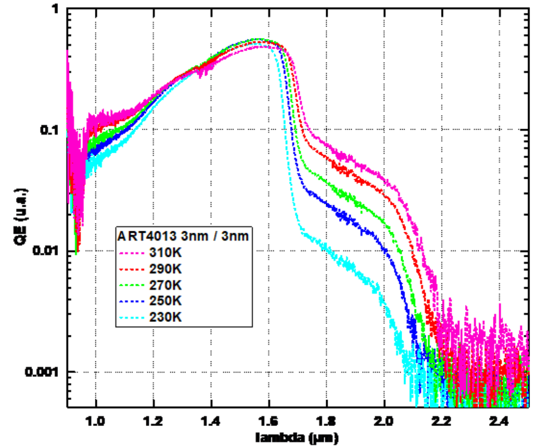


ART4013 (EJM/T2SL 2µm)

ART3993 (EJM/InGaAs)

Ref (MOVPE n-)





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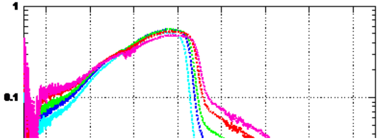
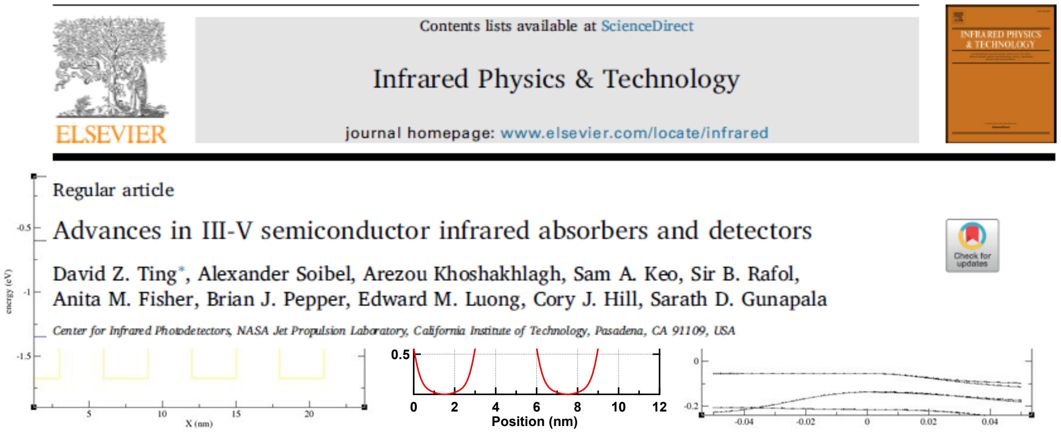
Explanation

ART4013





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Regular article

Advances in III-V semiconductor infrared absorbers and detectors

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- hh to VB InGaAs: 300meV
- $m_{eff} = 3{,}3\ m_0$
- E_{act} ~ 150 meV

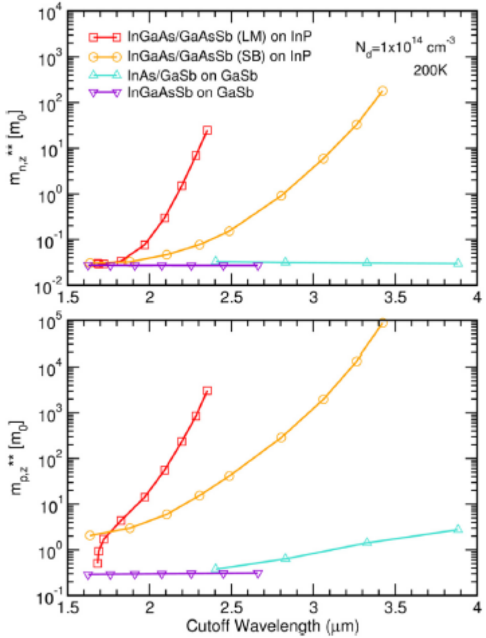

Fig. 2. (a) Calculated electron conductivity effective masses $m_{n,z}^{**}$ as functions of cutoff wavelength for bulk lattice-matched InGaAsSb alloy, and for InGaAs/GaAsSb and InAs/GaSb superlattices described in Fig. 1, and (b) the corresponding hole conductivity effective masses $m_{p,z}^{**}$.

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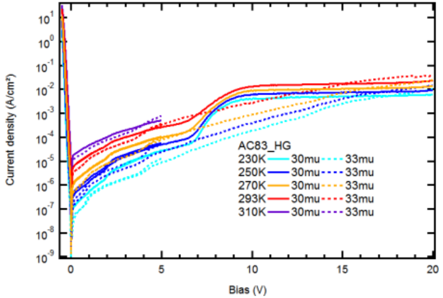
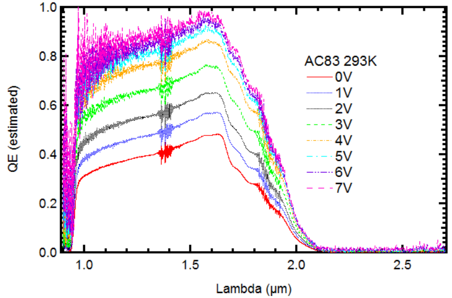
Localization between ZA & InGaAs interface

When bias > 4V

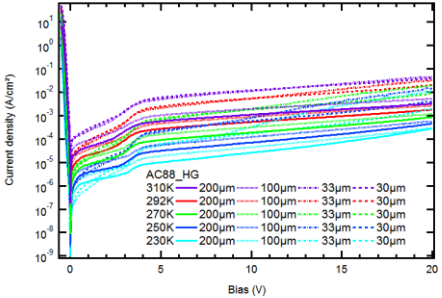
- QE peaked close to 100%
- Singularity in I(V)

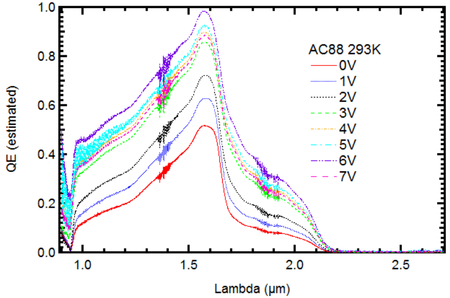
InGaAs 70nm
InAlAs 1µm 2.10^{16} cm^{-3}
InGaAs 1 µm 5.10^{15} cm^{-3}
T2SL 2 µm @ 5.10^{15}cm^{-3}
InGaAs 200nmnm





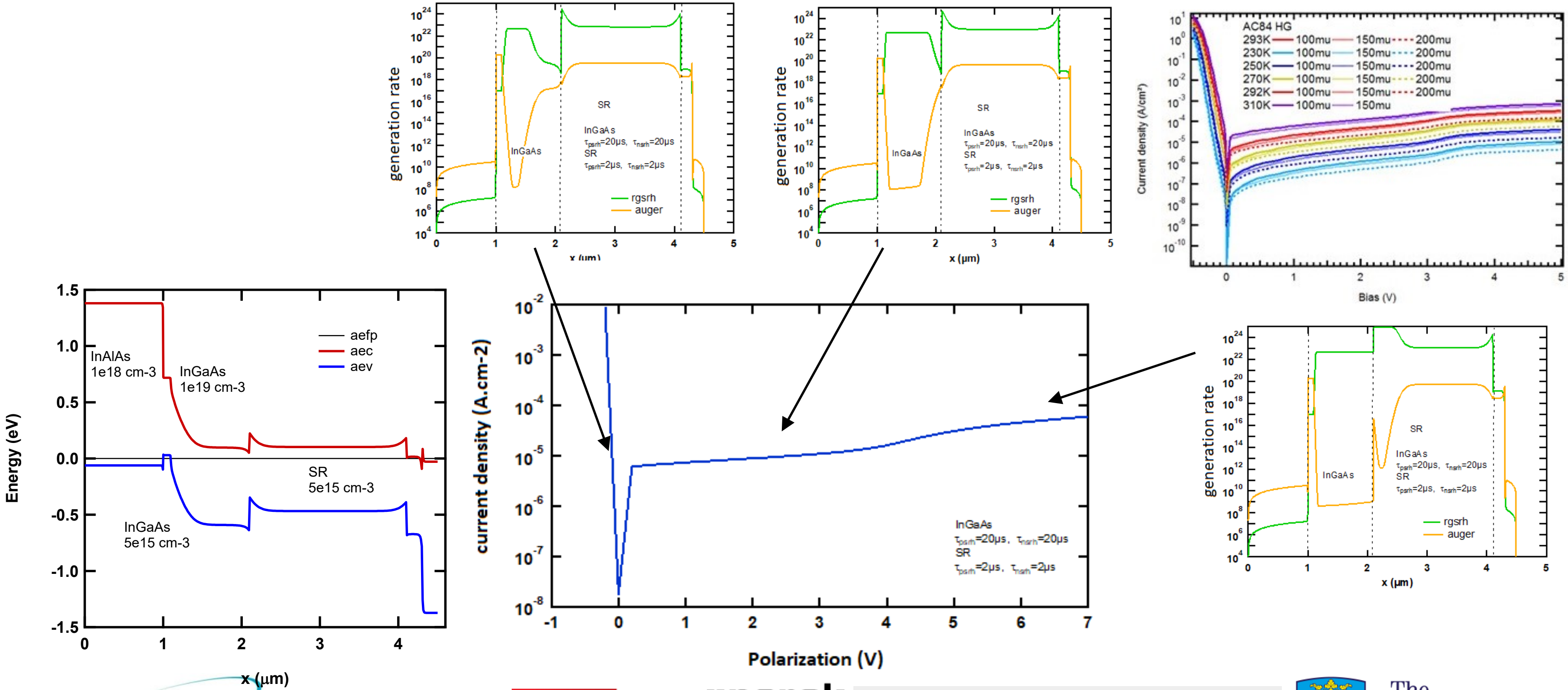
InGaAs 70nm
InAlAs 1µm 2.10^{16} cm^{-3}
InGaAs 1 µm 5.10^{15} cm^{-3}
T2SL (5nm/3nm) 2 µm @ 5.10^{15}cm^{-3}
InGaAs 200nmnm





Drift diffusion model

III-V lab presentation



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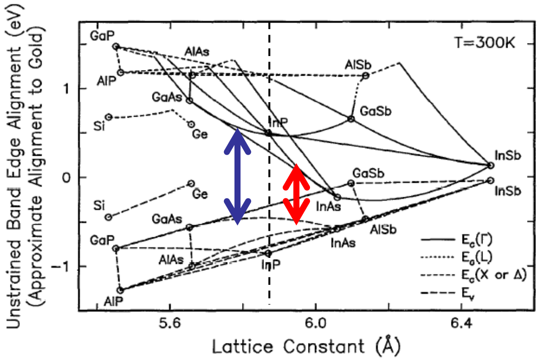
▶ Lattice matched InGaAs / GaAsSb

- m_{eff} from $3m_0$ (2,1µm) to $30m_0$ (2,5µm)
- $\Delta E_{HH-LH} > 4$ kT



▶ InGaAs in extension / GaAsSb in compression

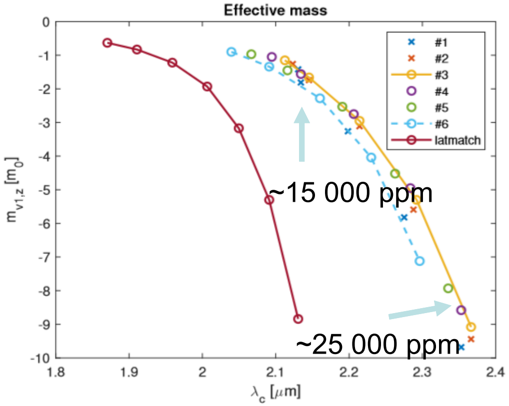
- Redshift but heavy holes ($>100m_0$)

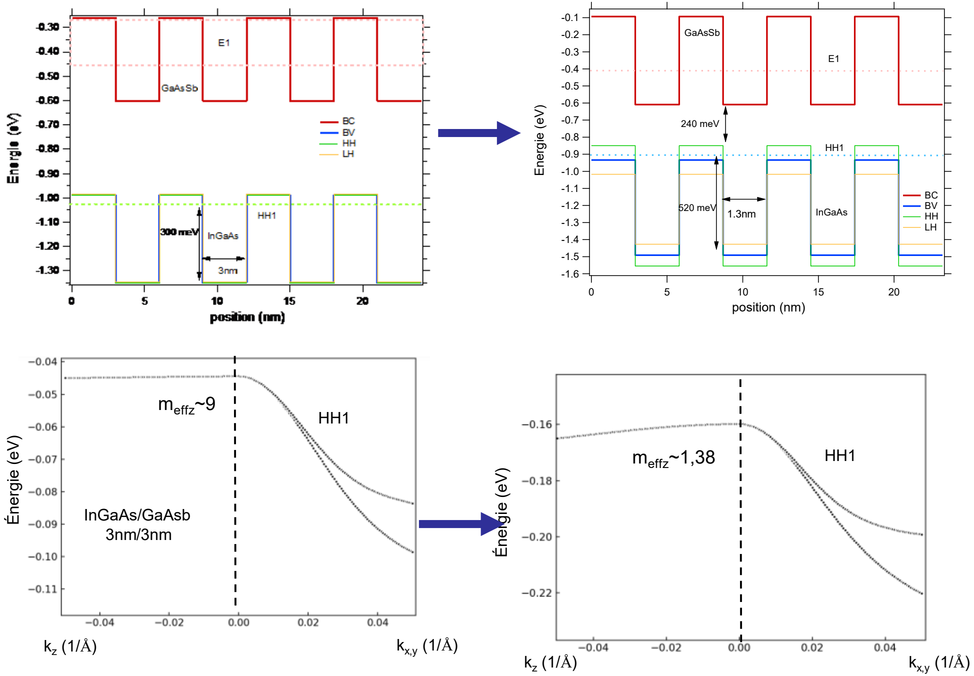
▶ InGaAs in compression / GaAsSb in extension

- LH / HH inversion or ΔE_{HH-LH} ~kT
- Blue shift

Strain compensated design

- **Strain compensation**
  - 5000 ppm achieved in InGaAs
  - Defect density increase with strain

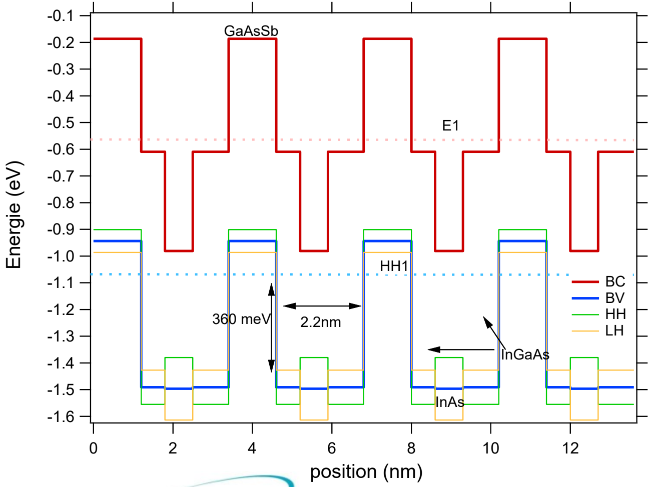




- **AC84**
  - 2,2nm / 2,2nm 5000ppm

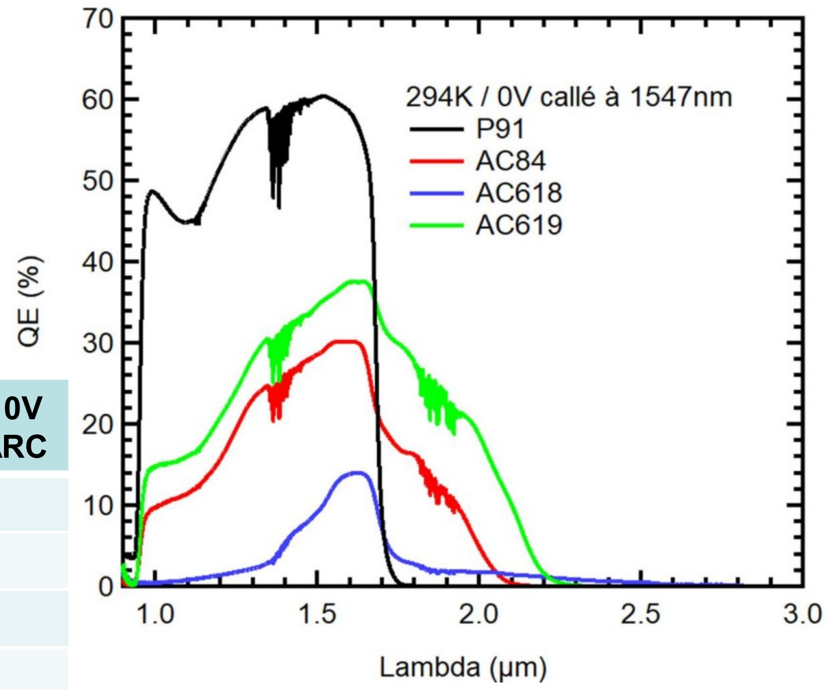
Design with a third layers

- **Introduction of InAs to decrease VBO**
- **AC83**
  - Strain compensation achieved up to 5000ppm
  - Layers compatibles to 2,1µm



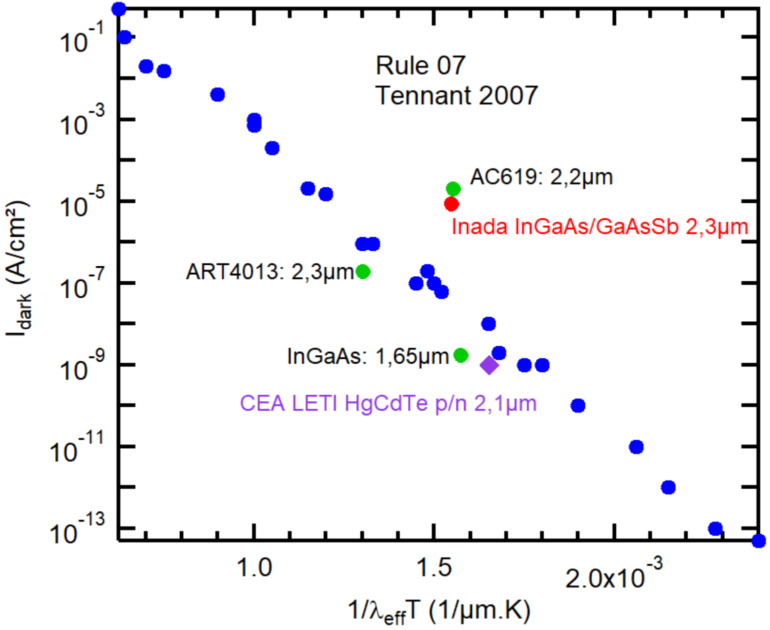
Spectrales responsivity @ 0V, 294K & 1546nm

- **AC619 delocalization effective**
  - 2,1µm achieved
  - Following AC83 / AC84
- **AC618 with still localization**
  - 2,9µm for 2,5µm @250K
  - Strong localization



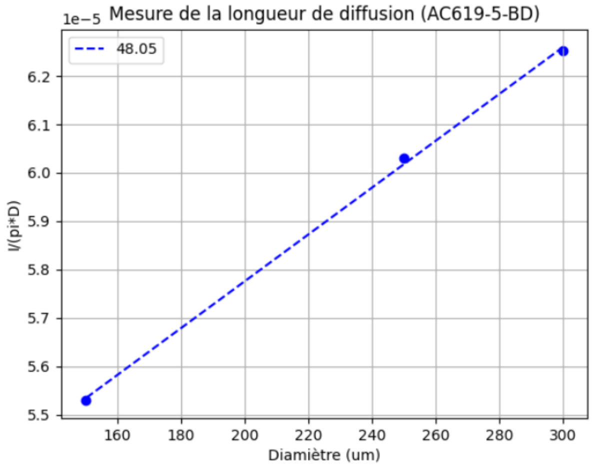
Sample	Rep @ 1547nm without ARC	Rep @ 1547nm with ARC	QE @1547nm / 0V / 300µm / RT / ARC
P91	418	**597**	60%
AC84	**210**	300	30%
AC618	**83**	119	12%
AC619	**249**	355	36%

- Position vs « rule 07 » reasonable
- Uncertainty with QE



Lateral collection in AC619

- **Lateral contribution in I_{dark}**
  - not proportional to surface
- **Contribution measured with photocurrent measurements**
  - L~40µm
- **Low MTF figure expected**



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Conclusion

- **Localization of hole is a strong issue in InGaAs / GaAsSb T2SL**
  - Improvement with :
    - Strain compensated InGaAs / GaAsSb
    - Introduction of InAs into InGaAs

- **Solution based on InGaAs / GaAsSb available for**
  - Cut off wavelength up to 2,1µm
  - Dark current density larger than rule 07

- **Issues**
  - Minority carrier lifetime bellow 300ns
  - Low FTM in 2D arrays with diffusion length larger than 40µm

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