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InP-based quantum-dot/-dash lasers emitting in the O-band

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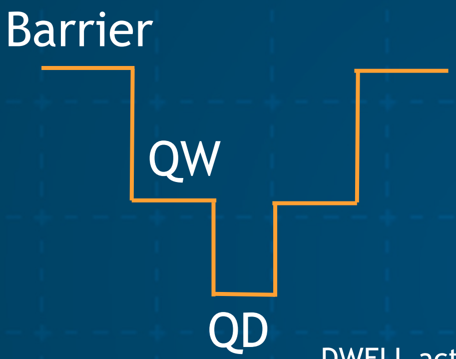
Highlights

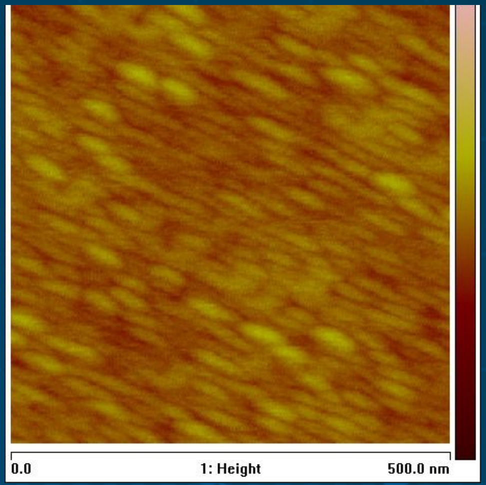
Idea: Explore the possibility of moving 1.3µm QD lasers to the InP platform

- **Motivation**
  - Why QDs?
  - Why InP vs. GaAs?
- **State-of-the-art**
  - 1.3µm QD lasers on GaAs
  - 1.55µm and beyond QD lasers on InP
- **Approach**
  - Tune 1.55µm DWELL

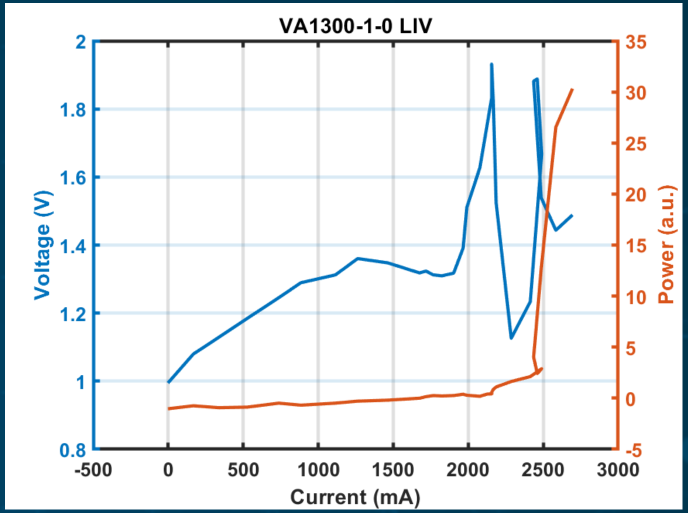


DWELL active region

- **Results**



0.5µm X 0.5µm AFM scan

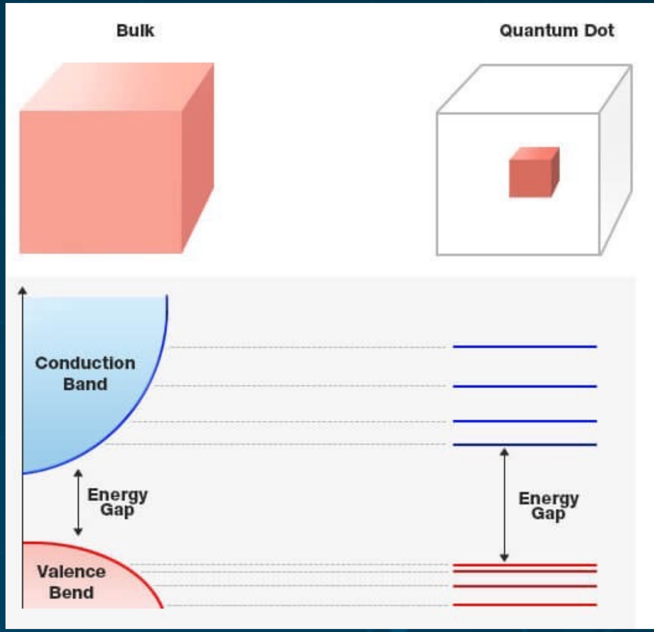


LIV from InP-based 1.3µm QD laser

  - Emission wavelength tuning
  - Preliminary laser results

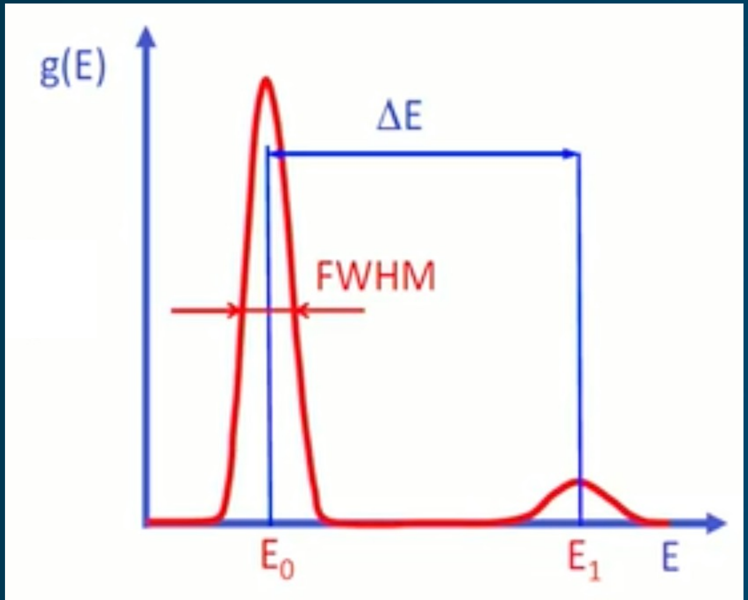
Motivation: QD-based active regions

- **Material properties:**
  - Quantization in all 3 spatial directions
  - Discrete energy states



Energy levels: bulk vs QD

- **Device properties:**
  - Low threshold current
  - High material gain
  - Reduced linewidth enhancement factor
  - High temperature stability
  - Emission wavelength range
  - Increased tolerance to defects

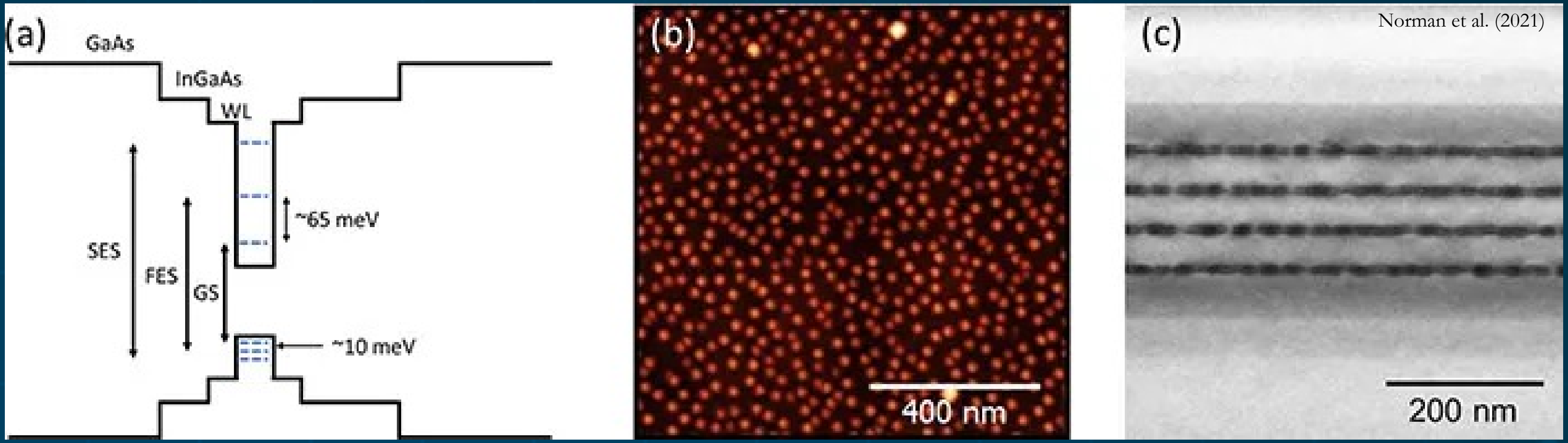


Low linewidth enhancement

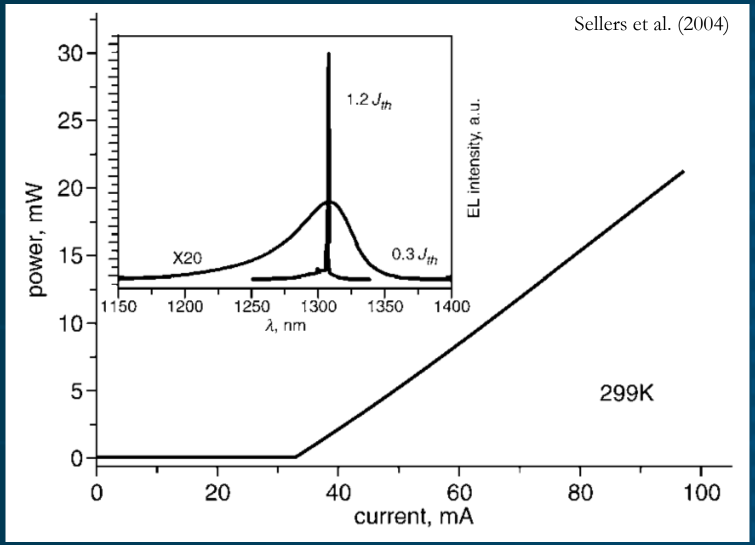
Joshi et. al (2022); Medium (2019)

State-of-the-art (O-band)

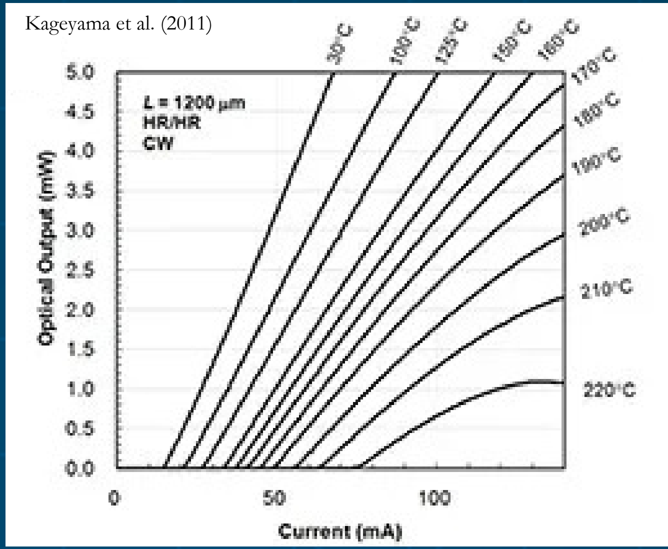
- **1.3μm GaAs-based lasers**
  - DWELL configuration
  - Extremely low threshold
  - High-temperature operation
  - Grown on Si substrates



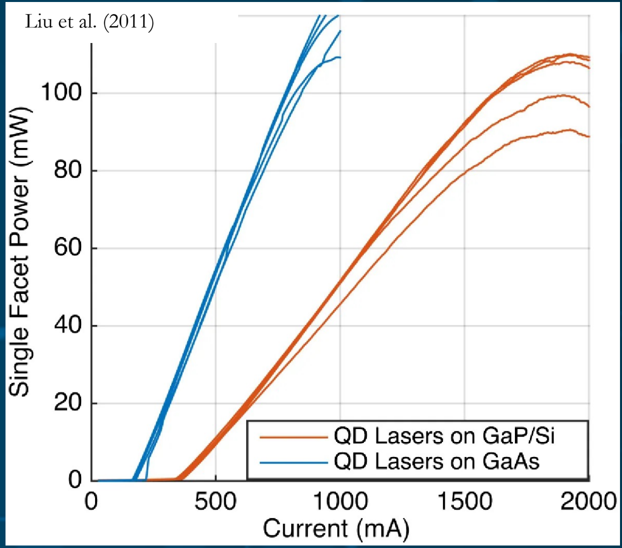
Norman et al. (2021)



Sellers et al. (2004)



Kageyama et al. (2011)

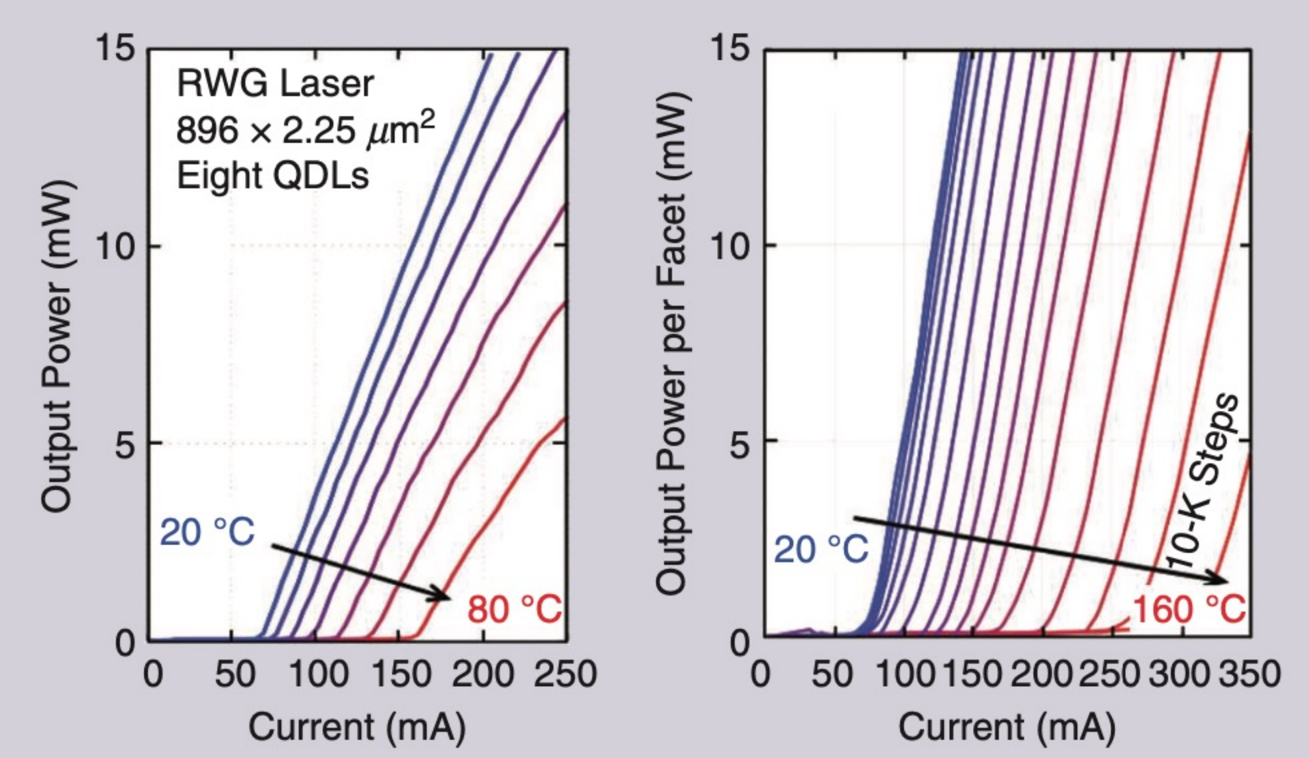


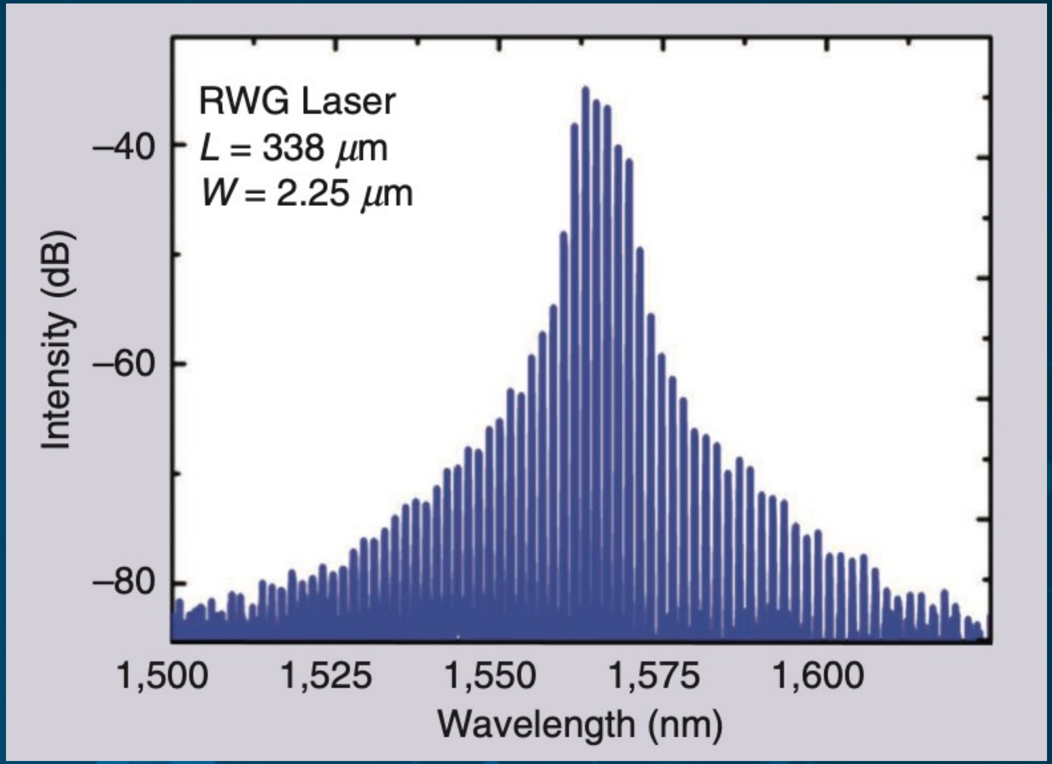
Liu et al. (2011)

Device results from various works

State-of-the-art (C-band)

- 1.55µm InP-based lasers



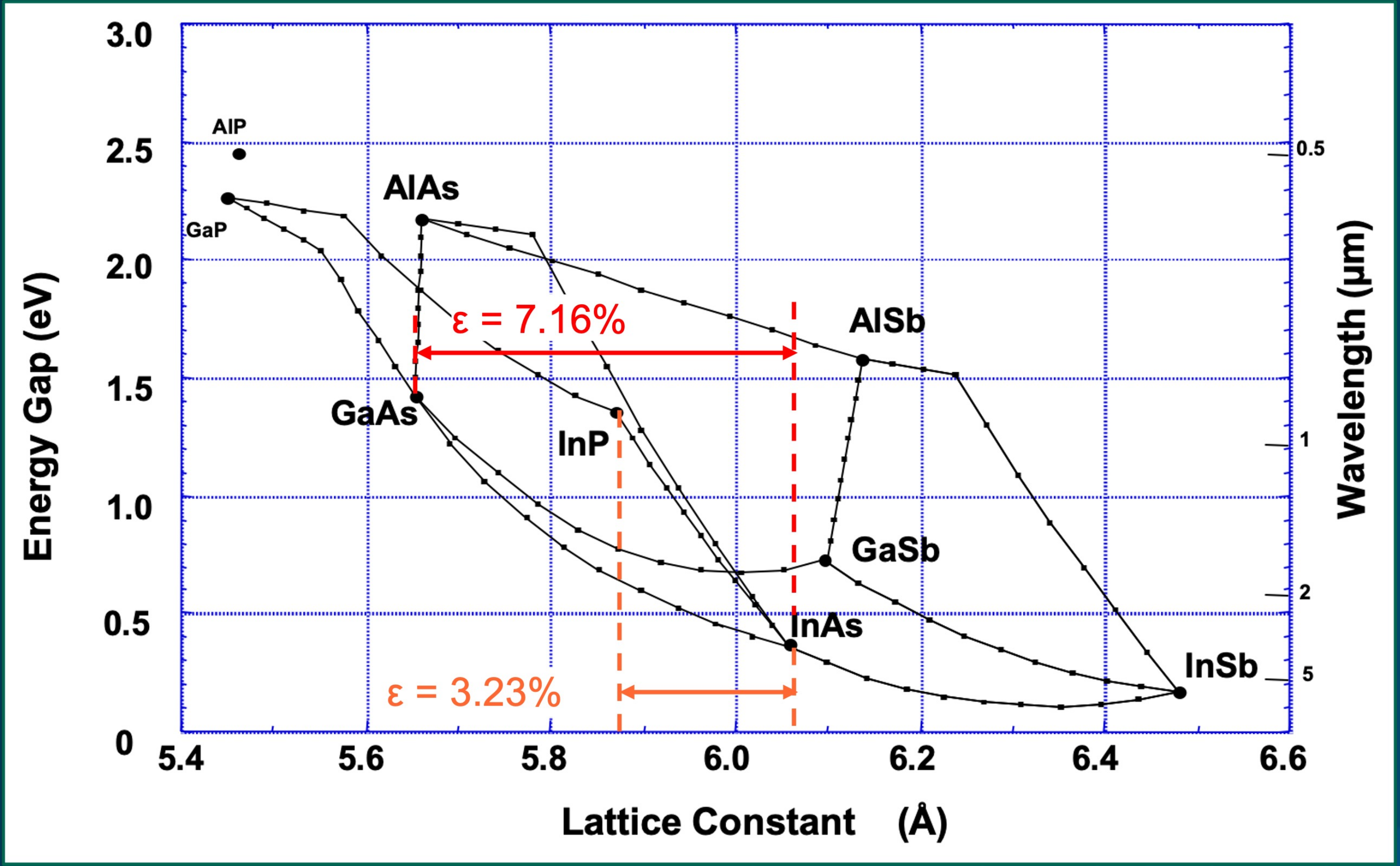


Device results from Bauer et al. (2021)

- High temperature stability
- Linewidth reduction
- High speed operation possible
- Broadband amplification demonstrated

Why InP-based at 1.3μm?

- 1.3μm lasers well-established on GaAs substrates



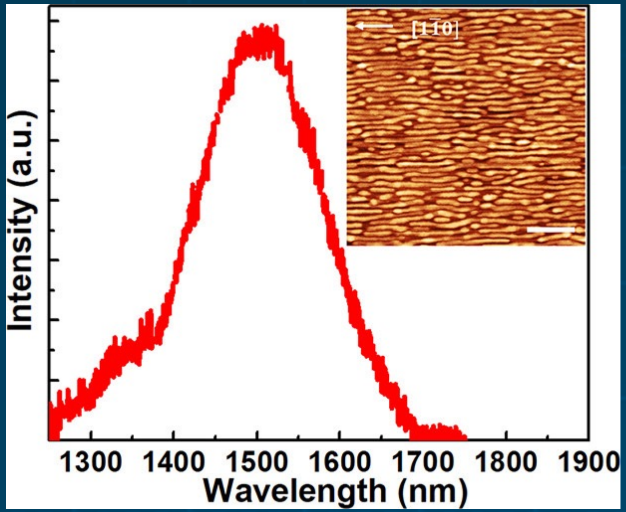
- **Material advantages:**
  - Lower lattice mismatch → lower strain
  - Material choices for strain compensation
  - Wider gain range

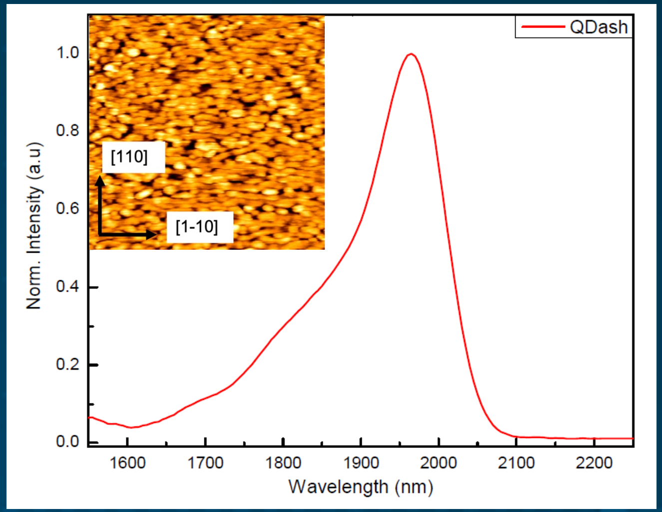
- **Device characteristics:**
  - Higher modal gain vs. GaAs-based lasers
  - Allows for short cavity devices (<1mm)

Approach

Main goal : Moving emission wavelength of InAs/InP QDs to 1.3µm

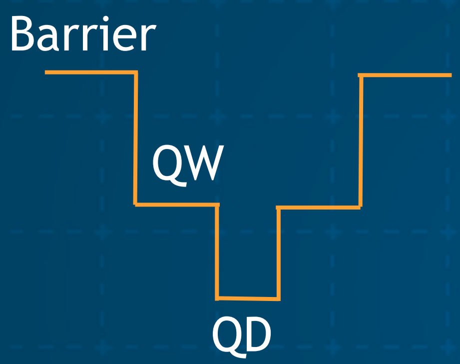
- **Starting point**





InAs/InP Qdashes at 1.55µm and 2µm (PL and AFM)

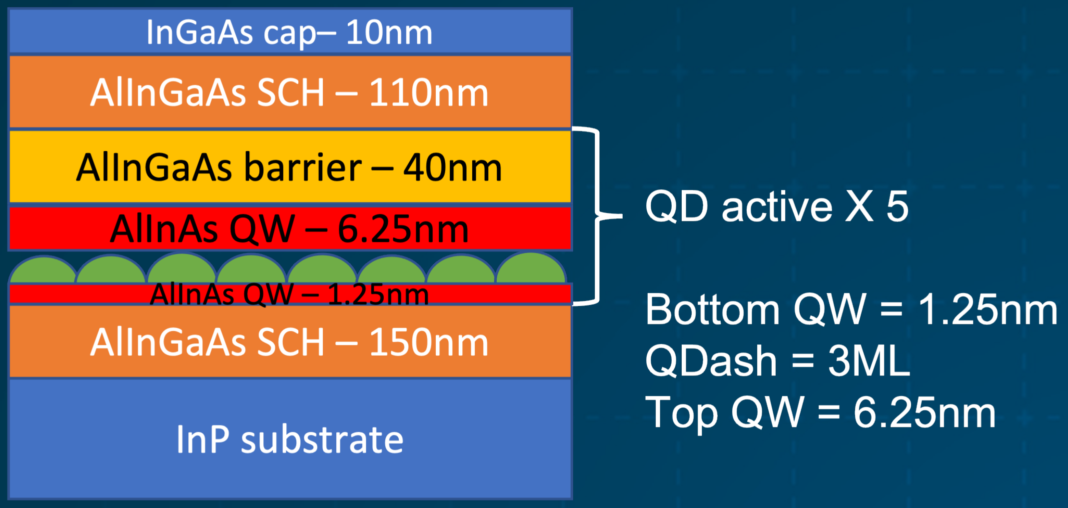
- **Approach**



  - **QD** : composition – InAs ; thickness – for 3D growth
  - **Barrier:** Higher bandgap InAlGaAs , lattice-matched to InP
  - **QW:** In(Al)GaAs – **can be tuned for emission wavelength**

Wan et al. (2018)

Experiment: PL tuning



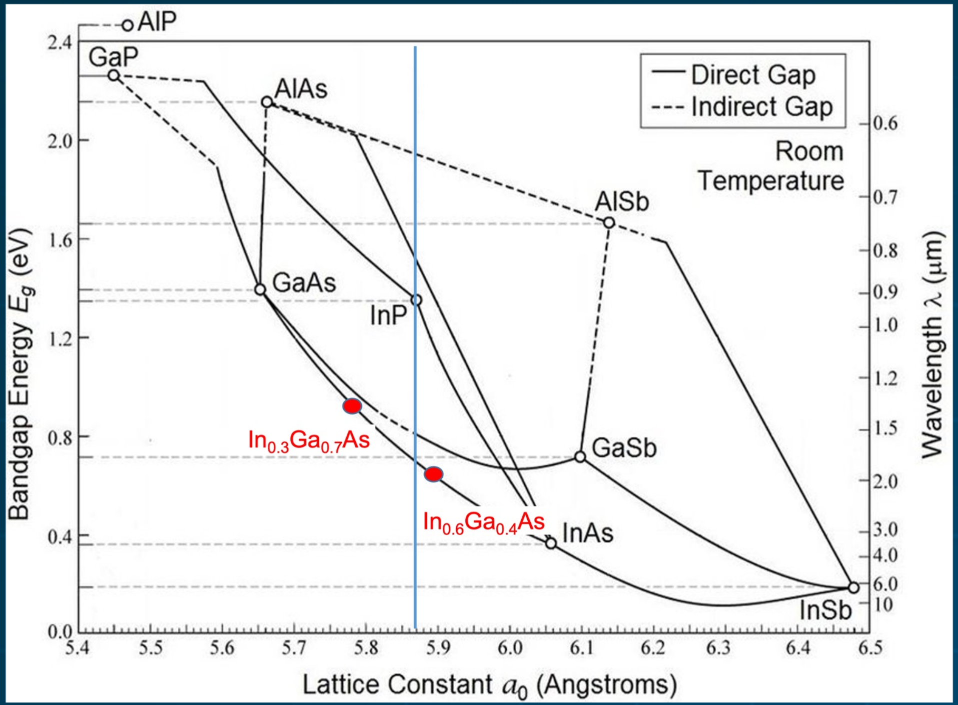
SCH: 60/40 (AlInAs/InGaAs)
Barrier: 50/50 (AlInAs/InGaAs)

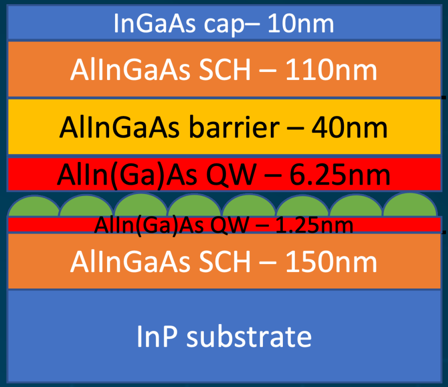
PL structure

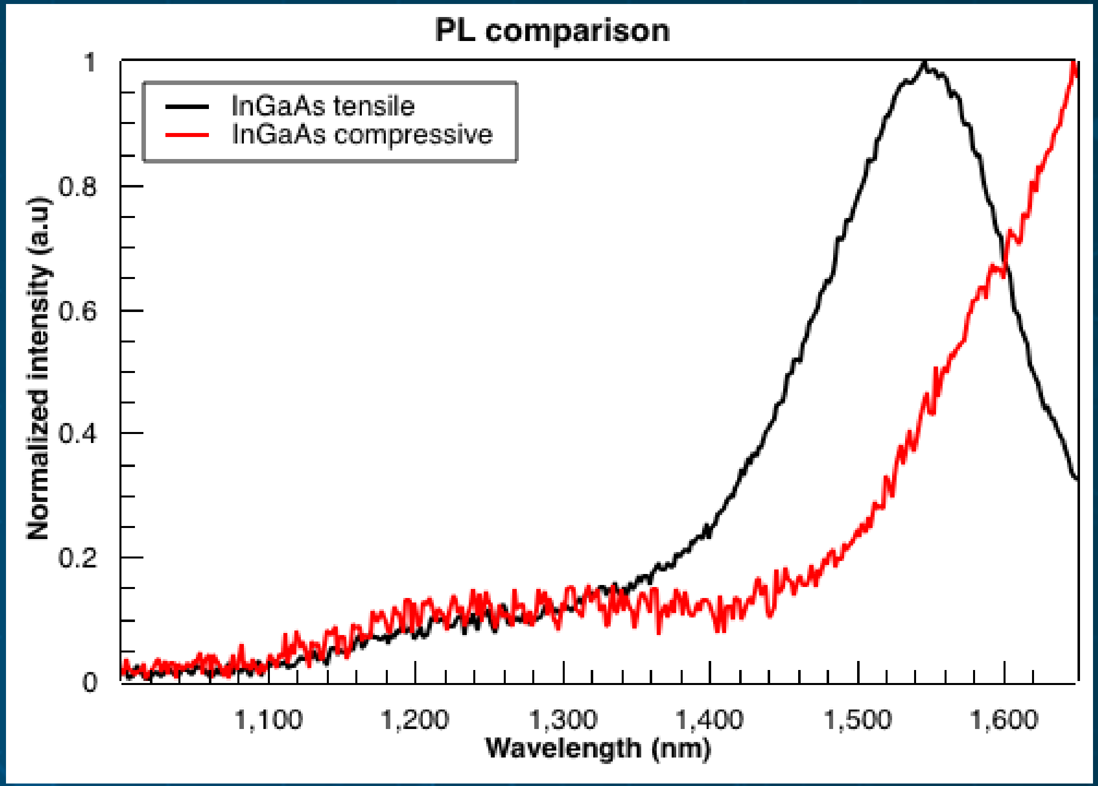
- **PL structure growth:**
  - **InP oxide desorption**: 540℃ for 5 min
  - **AlInGaAs SCH and barrier** compositions from 1.55μm lasers – grown as digital alloys of lattice-matched compositions
  - **Growth temperature** : ~490 ℃
  - **QD/Dash**: InAs thickness based on RHEED pattern
  - **QW** (asymmetric) composition tuned

- **PL measurement:**
  - Pump: 635nm (5mW average)
  - InGaAs FW detector
  - Room-temperature
  - Standard lock-in technique

PL: Initial results

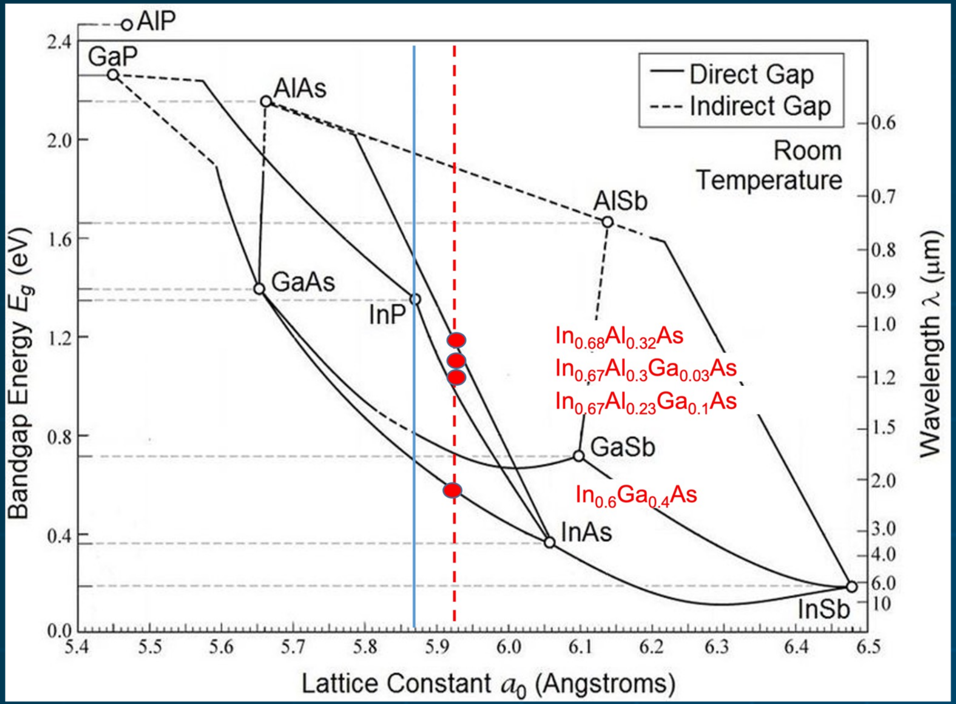


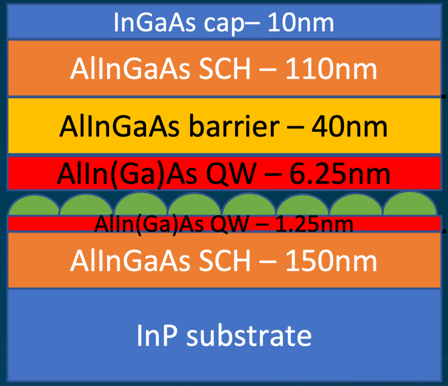


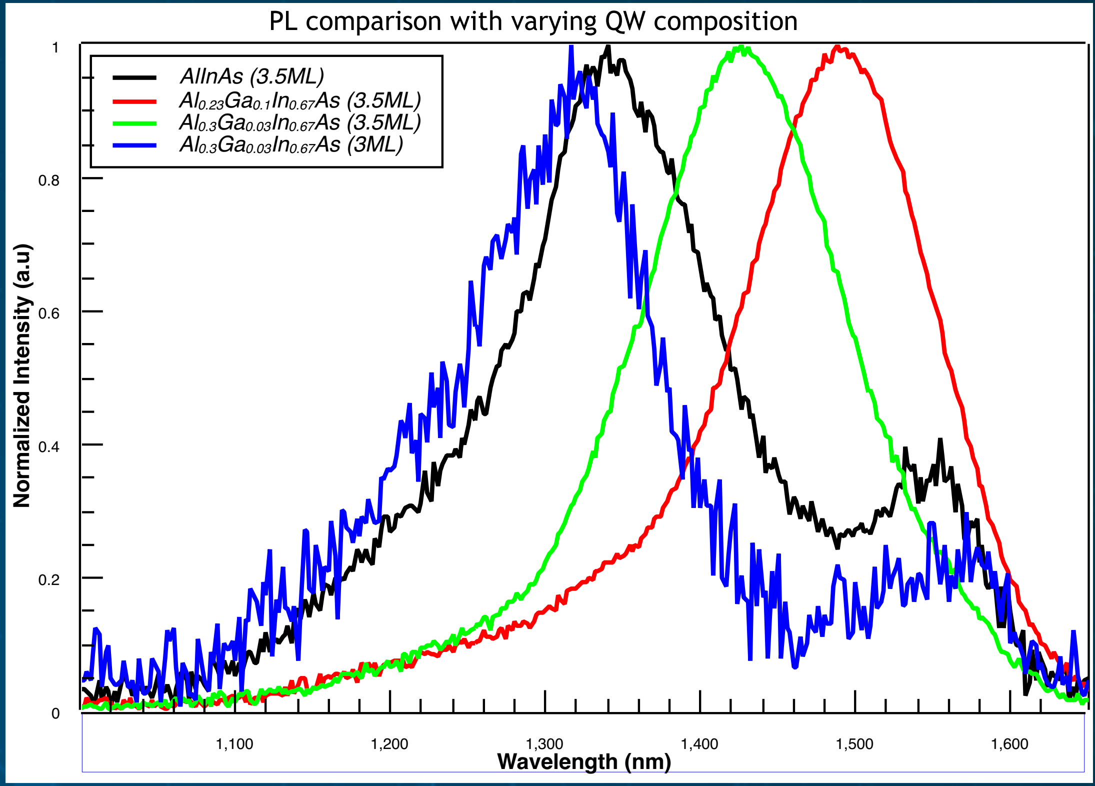


- $In_{0.6}Ga_{0.4}As$ QW (compressive) : Peak @ 1.75µm
- $In_{0.3}Ga_{0.7}As$ QW (tensile): Peak @ 1.55µm
- Can we keep QW compressive and bring down emission λ?

PL: Initial results

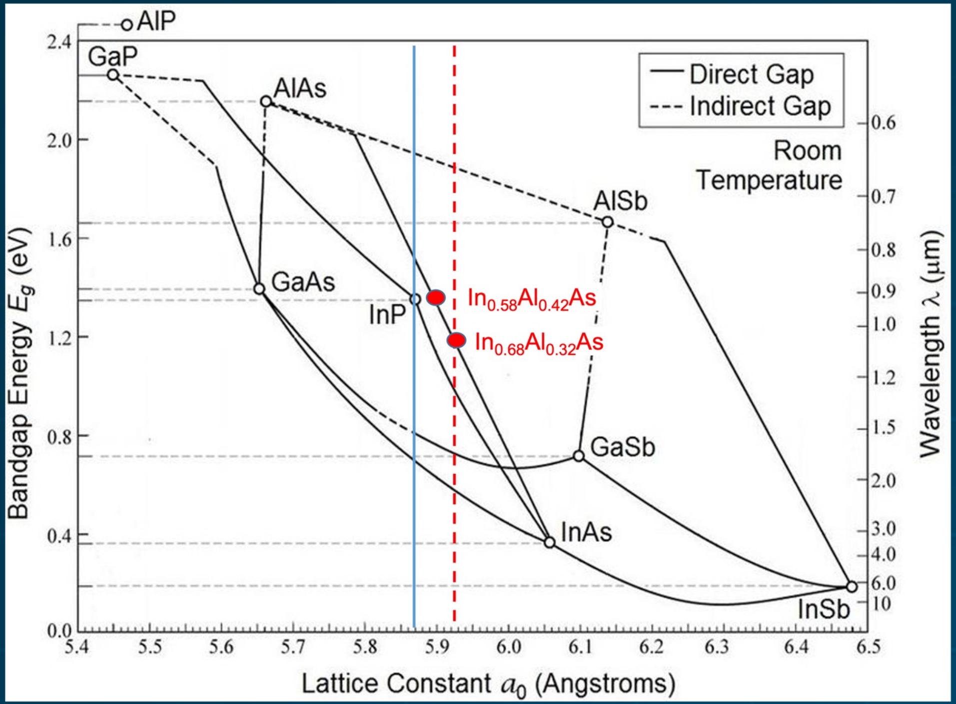


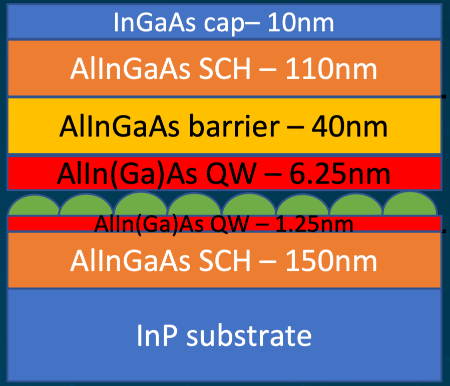


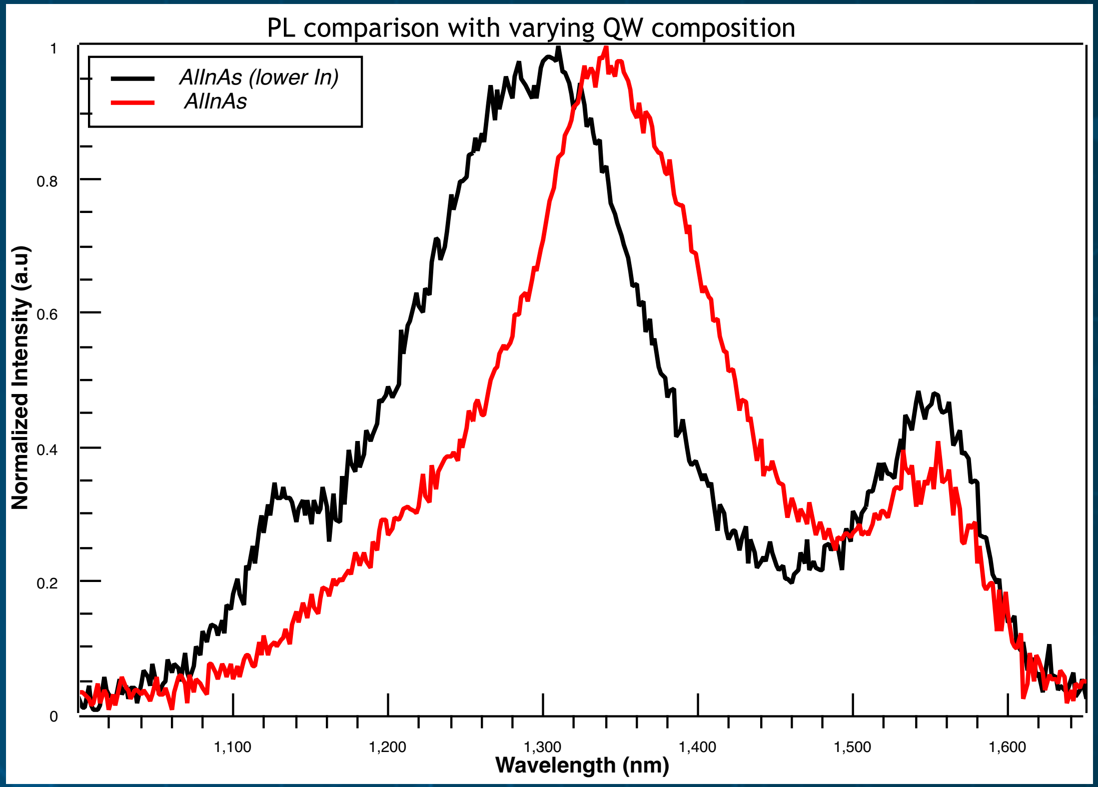


- Emission λ blueshifts with increasing bandgap for QW
- Emission efficiency drops & additional peak observed
- Peak needs to move lower – for detuning

PL: Initial results

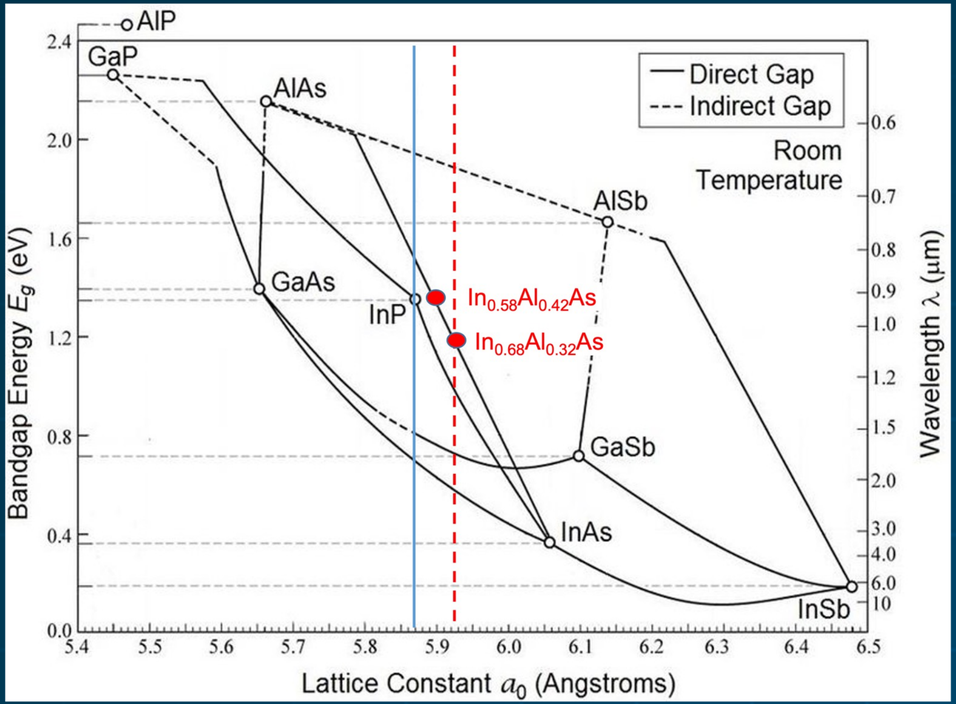


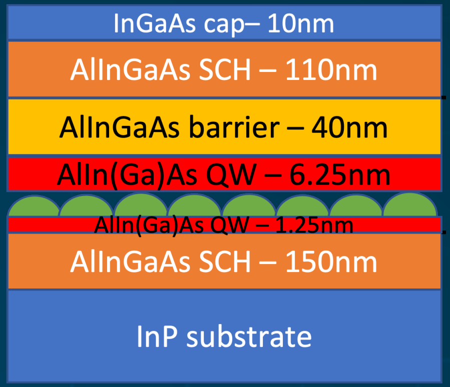


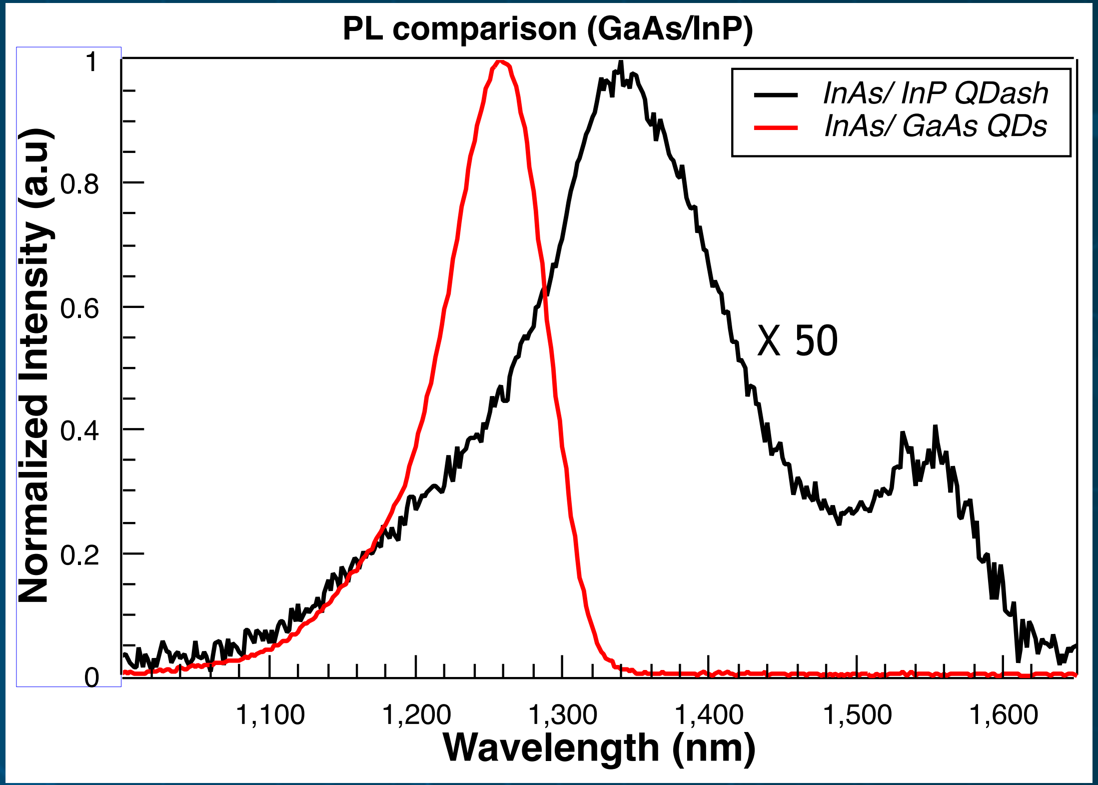


- Emission λ at ~1285nm
- Intensity still LOW and additional peaks exist

PL: Initial results

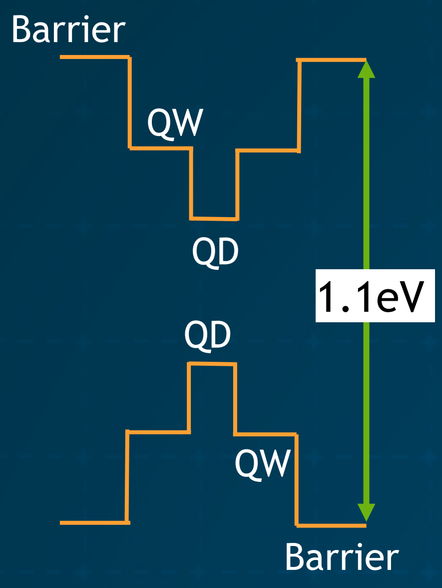




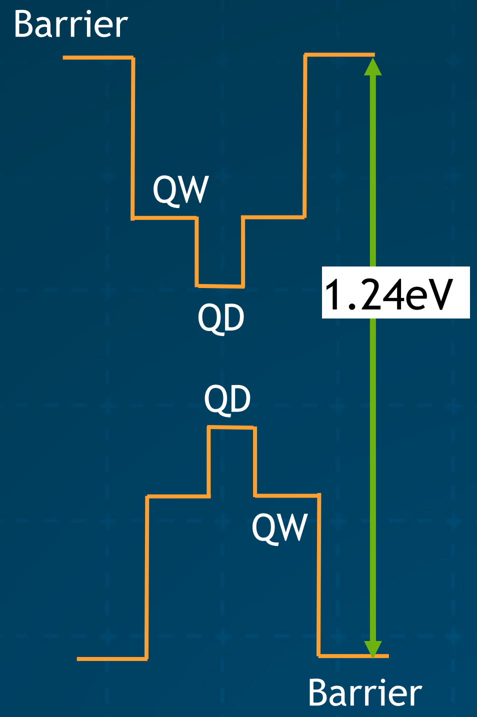


- Emission λ at ~1285nm
- Intensity still LOW and additional peaks exist
- NOT comparable to InAs/GaAs QDs at 1.3μm

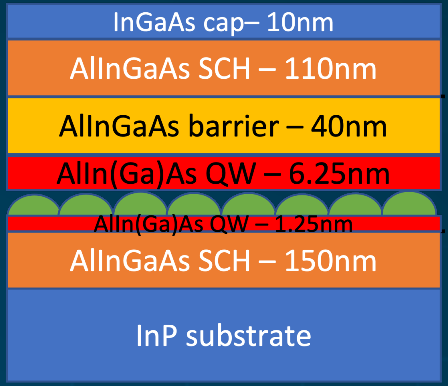
PL: Optimization results

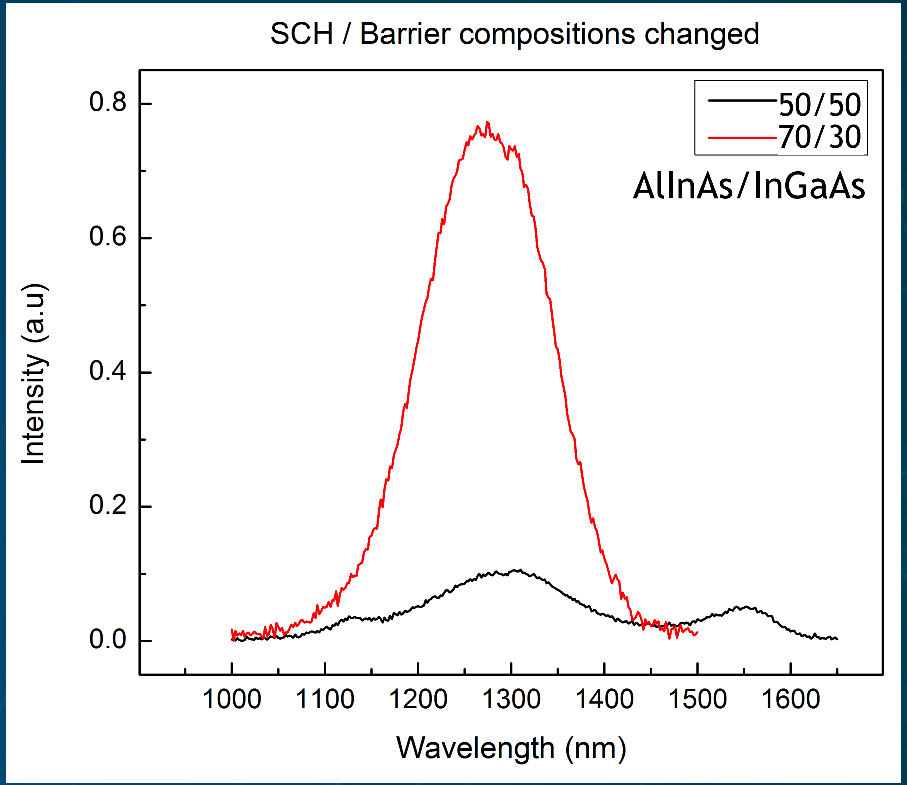


1.55µm design



Improved design

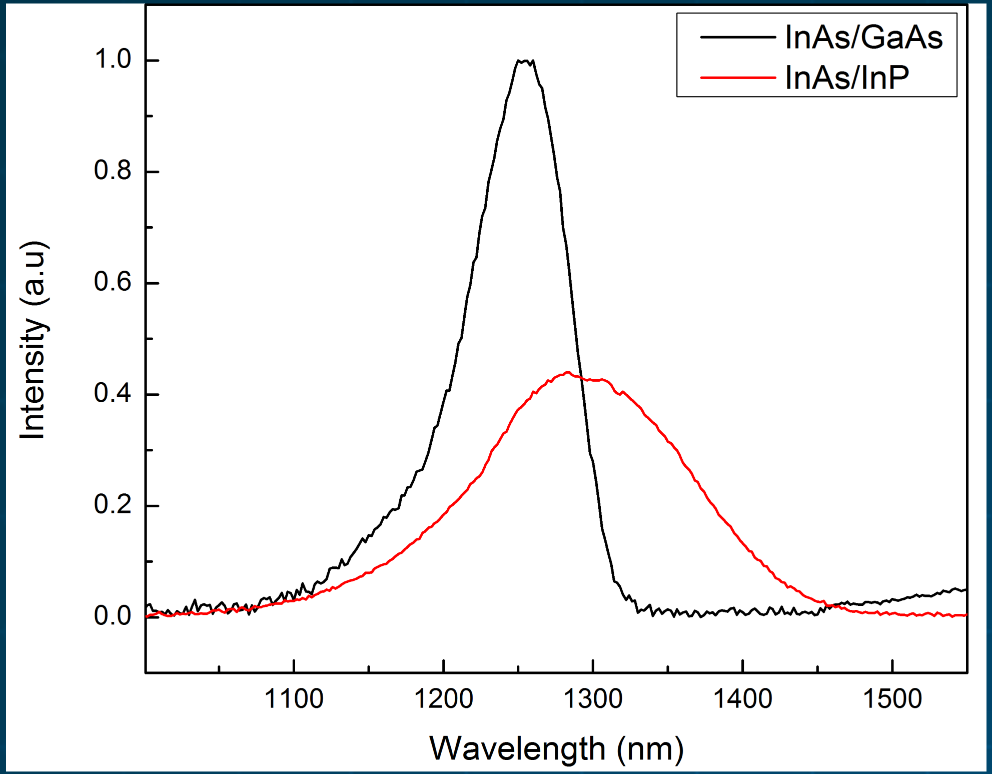


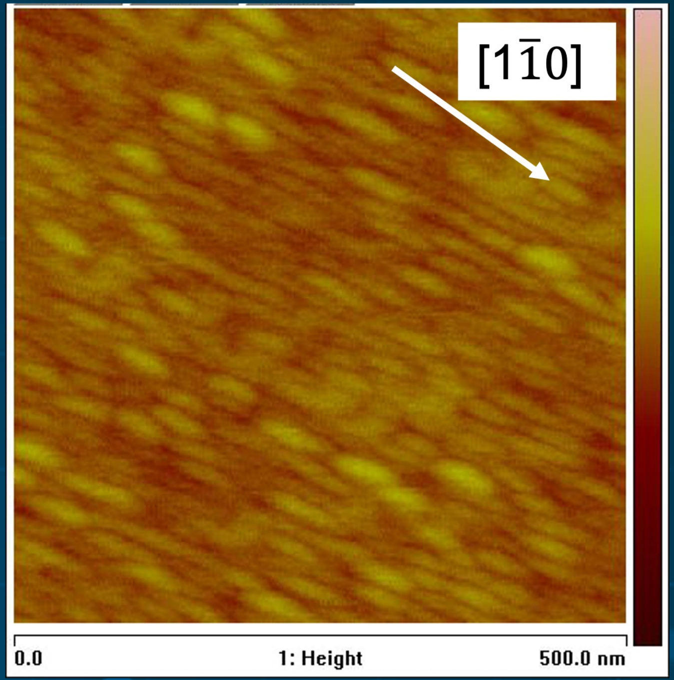


- Initial design borrowed from 1.55µm structure
  – low carrier confinement for 1.3µm
- Barrier height increased

Kopf et al. (1992)

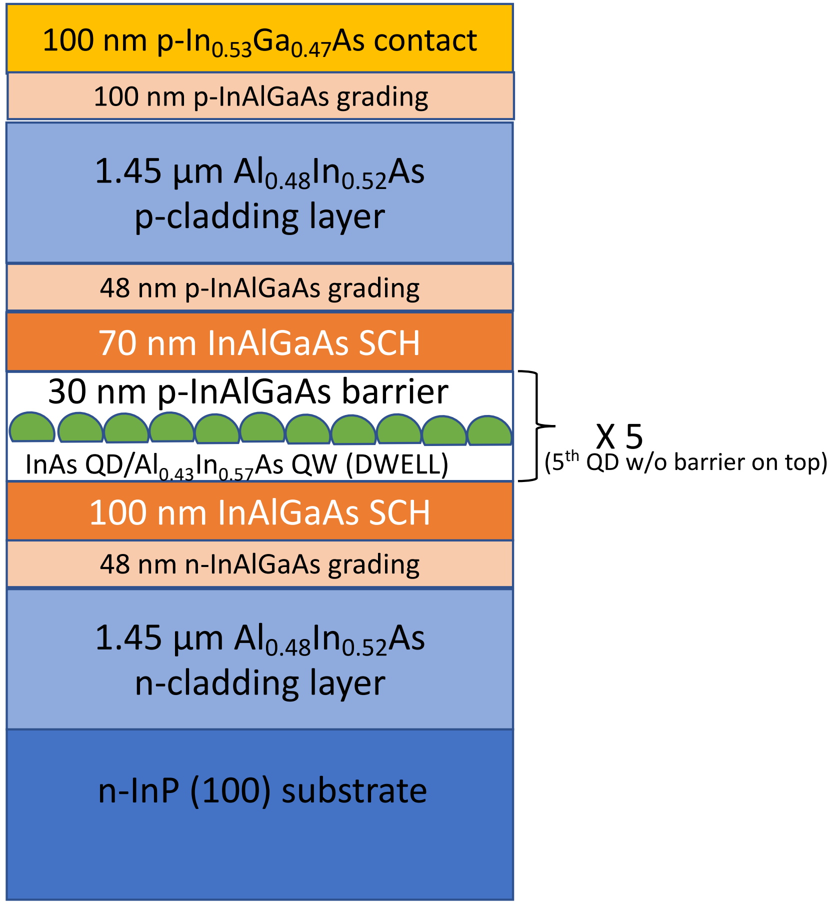
PL & AFM: Optimization results





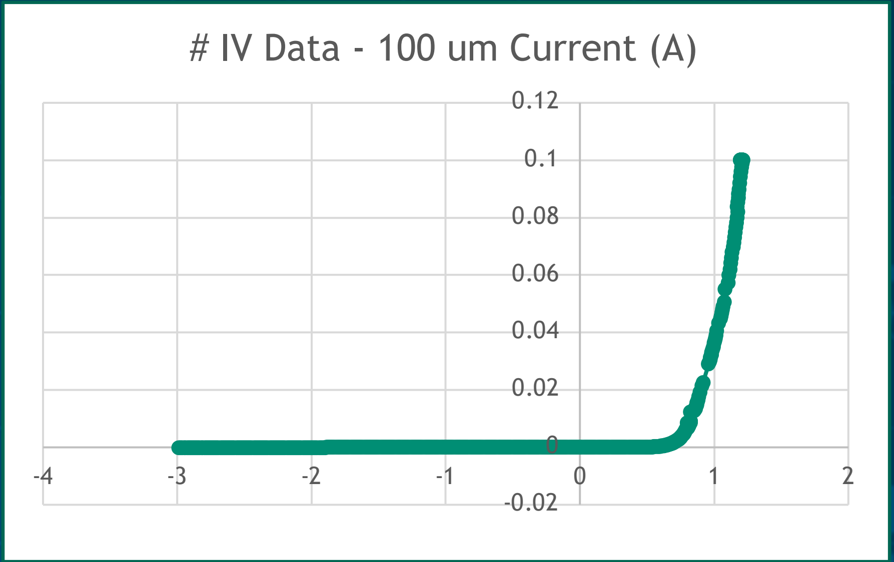
- **Comparison between GaAs & InP-based QDs (5x):**
  - Intensity – 1:0.45
  - Linewidth – 48 meV vs. 97 meV
- **Structural parameters:**
  - Areal density : ~$10^{10}/cm^2$
  - Dimensions : 15-20nm wide ; 50-125nm long

Preliminary laser design and results



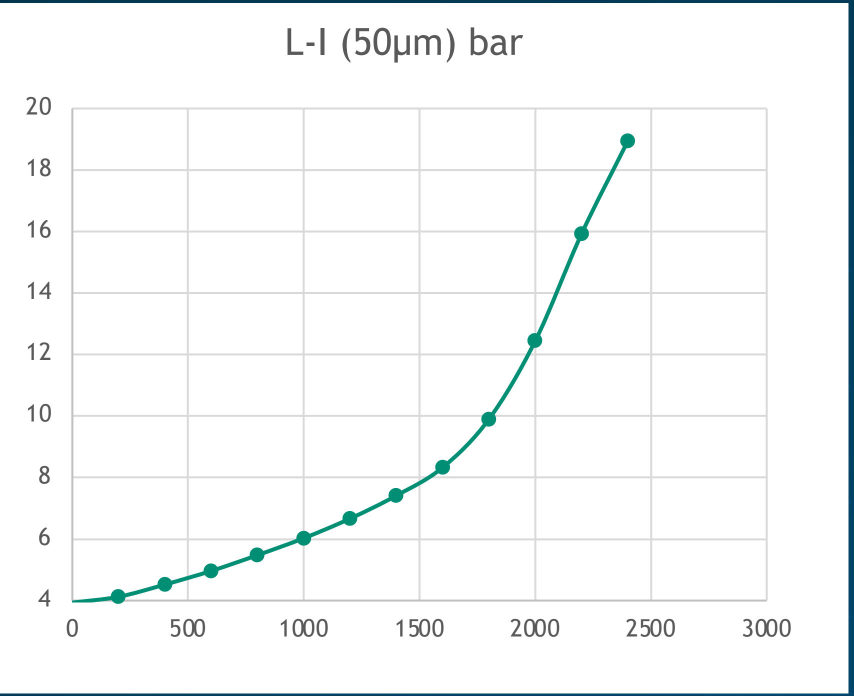
SCH :AlInAs/InGaAs -80/20
Barrier: AlInAs/InGaAs – 70/30

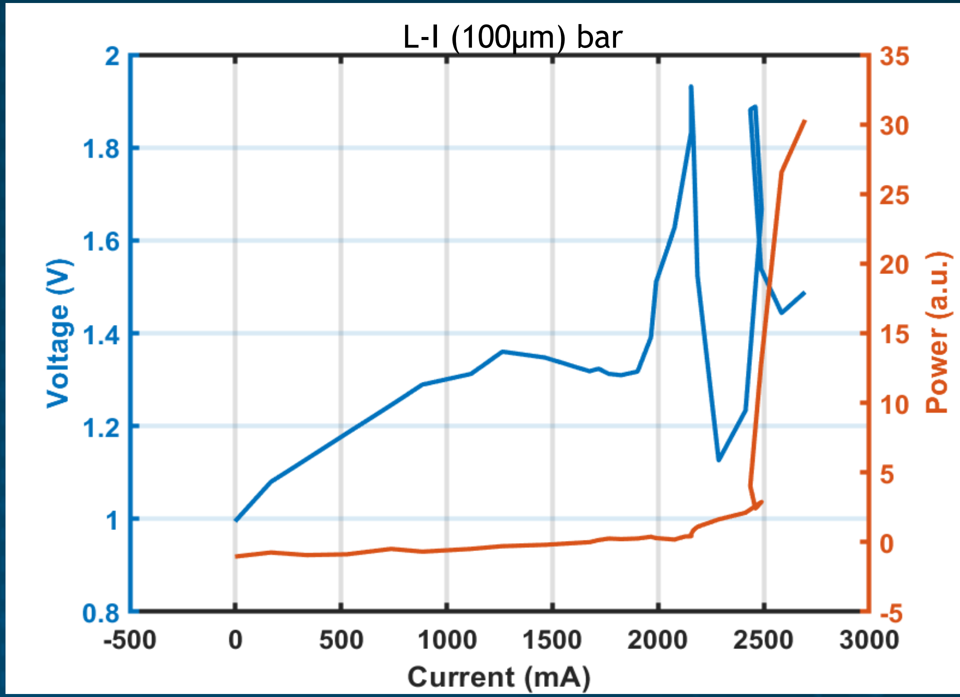
- **Device dimensions:**
  - 50µm X 1mm & 100µm X 1mm
  - Both broad-area and ridge-waveguide lasers fabricated



  - I-V profile & turn-on voltage as expected

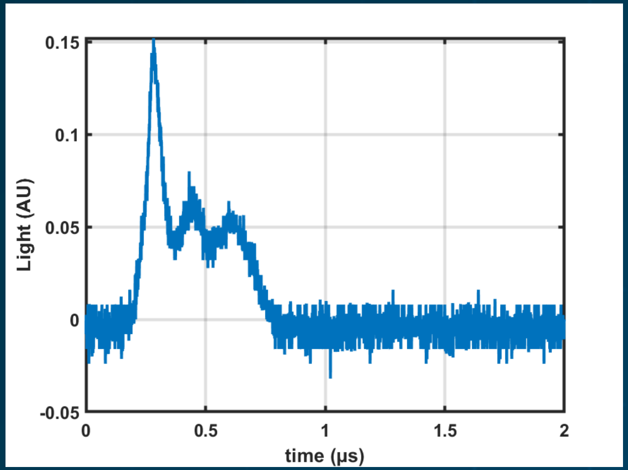
Preliminary laser results



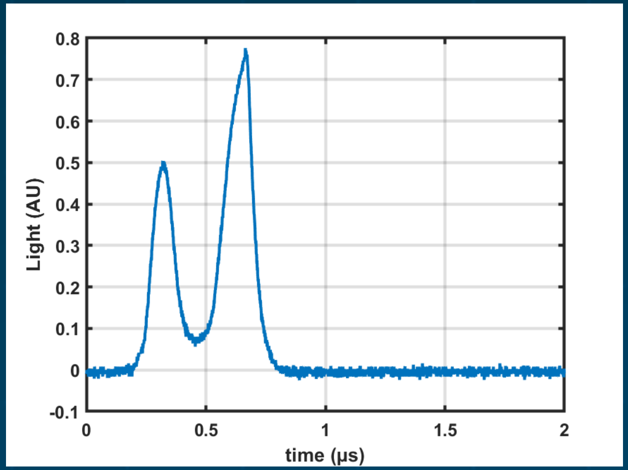


- L-I shows soft turn-on characteristic in both devices (Pulsed - 0.5 microseconds pw and 1ms rep rate)
- Threshold values are extremely HIGH – makes lasing behavior unstable

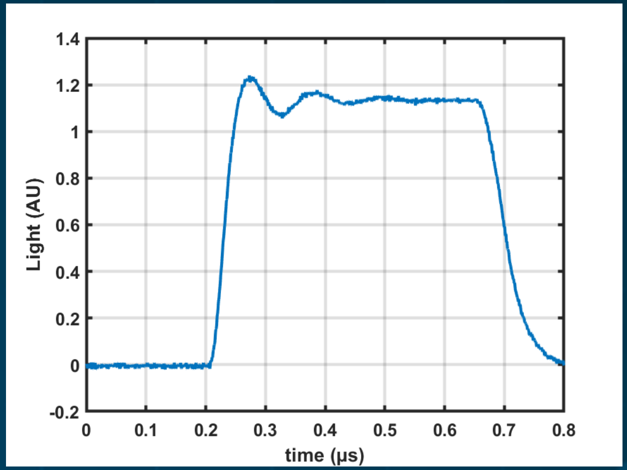
Preliminary laser results (issues)



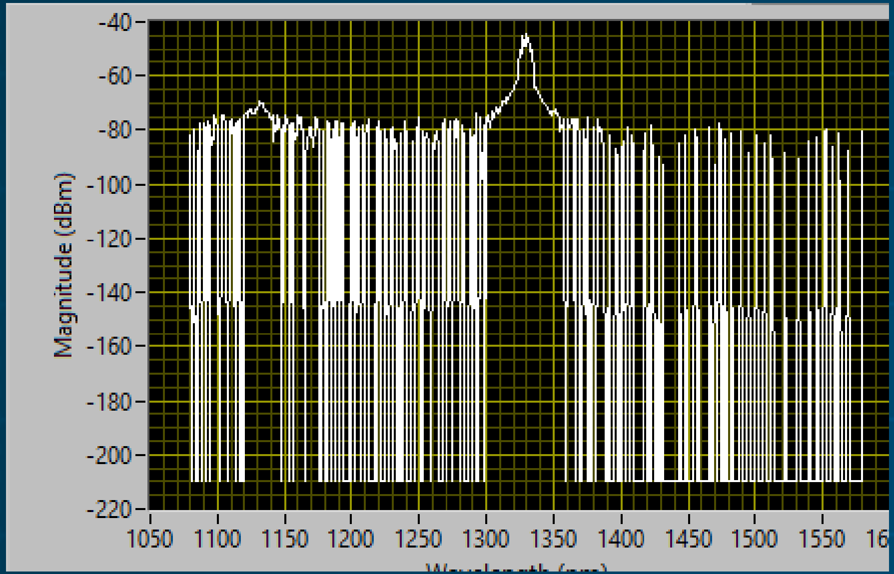
2.6 A



2.9 A



Reference (QW laser)

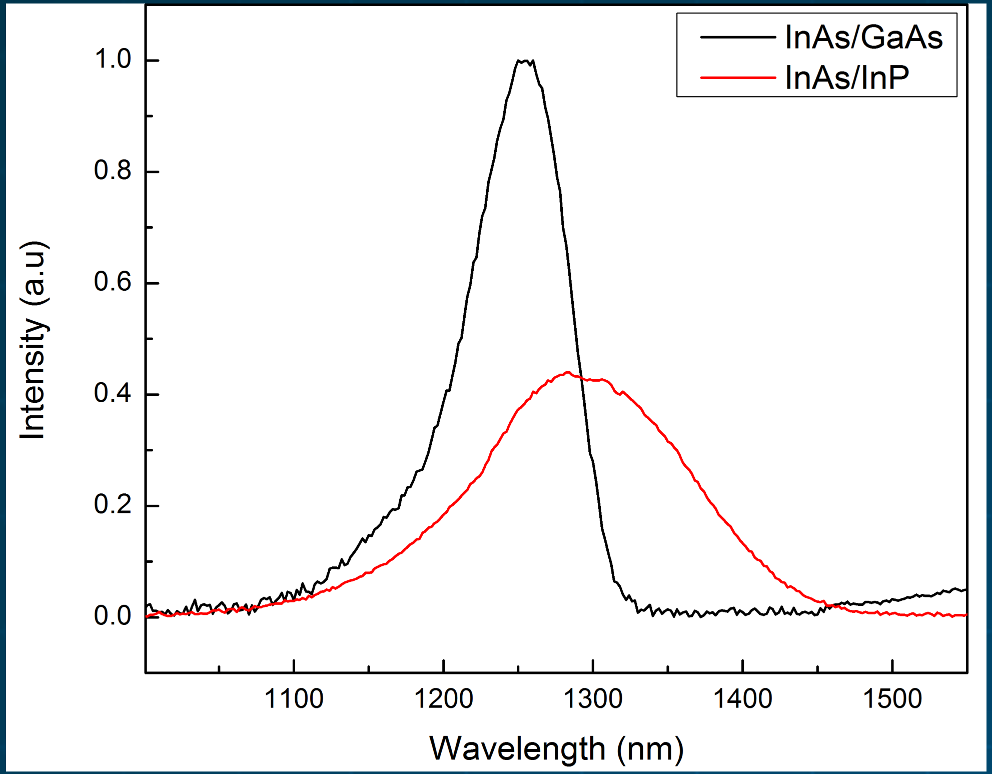


- Light traces above threshold show peculiar features
  – compared to 1030nm QW laser
- Cause: heat in active region or presence of absorptive layer

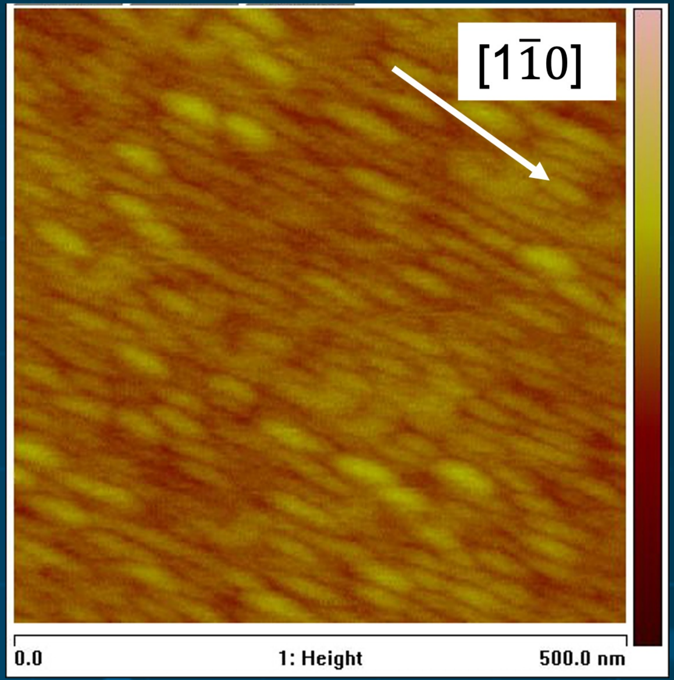
Conclusions

- InP-based QDs (InAs) tuned to emit at 1.3μm
  - QW composition optimized in a DWELL configuration
- Band structure and growth conditions partially optimized
- Preliminary devices fabricated:
  - I-V characteristics as expected
  - L-I profile shows a soft turn-on with high threshold
  - Light traces reveal odd behavior – may be related to heating of devices

Questions?



InAs/GaAs
InAs/InP
1.0
0.8
0.6
0.4
0.2
0.0
Intensity (a.u)
1100
1200
1300
1400
1500
Wavelength (nm)



[1$\bar{1}$0]
0.0
1: Height
500.0 nm