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# Investigation of a Quantum Dot Vertical External-Cavity Surface-Emitting Laser: Towards THz Frequency Generation

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## Introduction

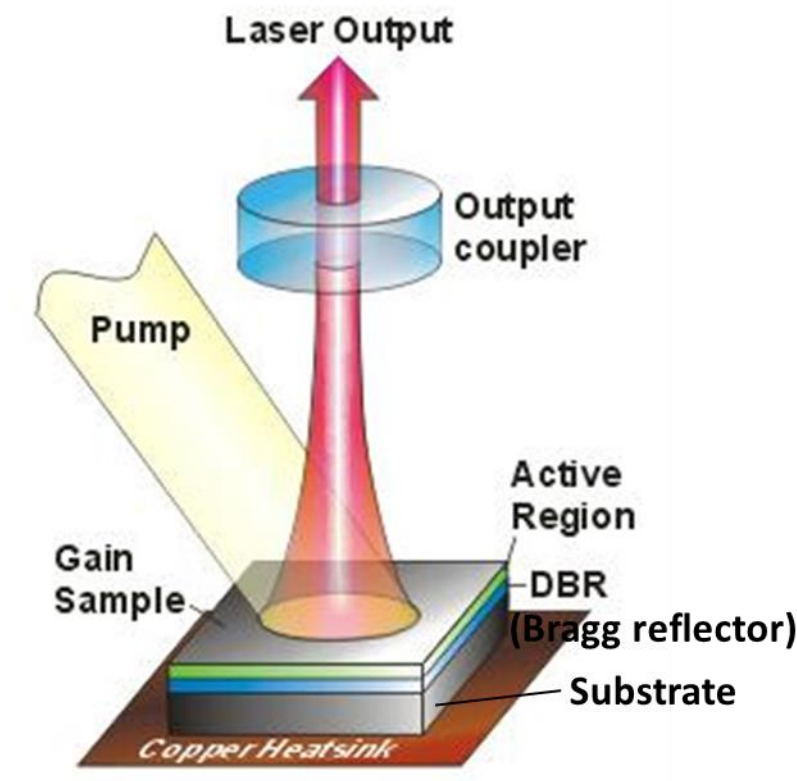
The Terahertz (THz) frequency domain is attractive due to many applications in imaging, sensing and communication.

Problem: Few efficient room temperature THz sources are available

Solution: **Coherent dual wavelength QD based VECSEL for the THz generation by wavelength beating**

### Why VECSEL ?

- Low intensity and phase noise
- High output power (W)
- Possible Electrical injection
- Cavity engineering
- Low wavelength linewidth (kHz)



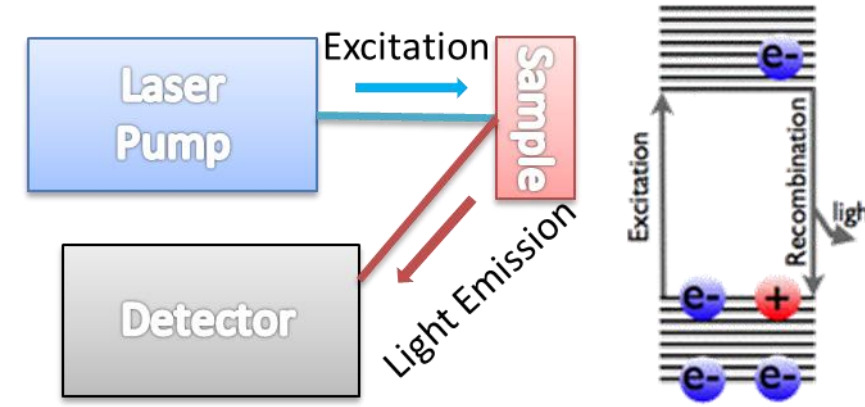
Schematic of an optically pumped VECSEL

VECSEL: ideal for stable coherent dual wavelength laser but requires weak mode coupling → QDs

Telecom wavelength (centered at 1550 nm)

Checked by

Photoluminescence

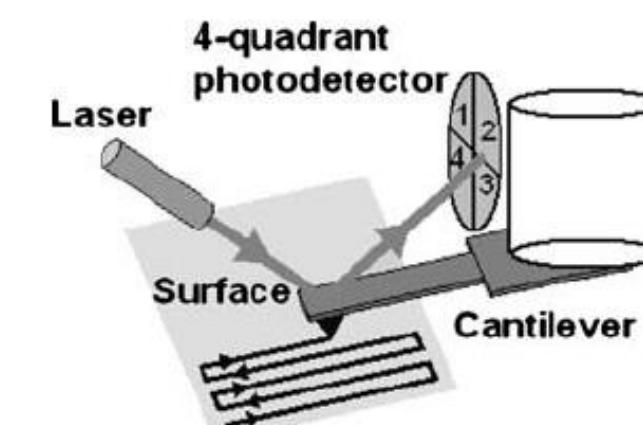


### Requirements for the QDs

Weak Coupling between QDs (low density)

Checked by

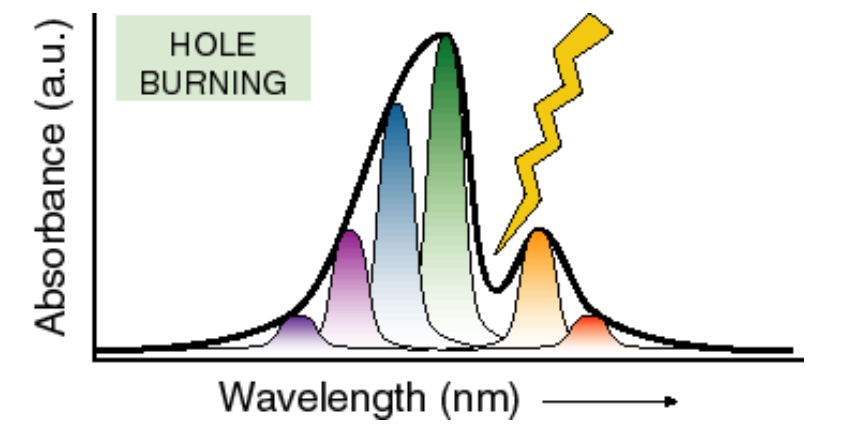
Atomic Force Microscopy



Coupling estimation (measurement of the Homogeneous linewidth)

Followed by

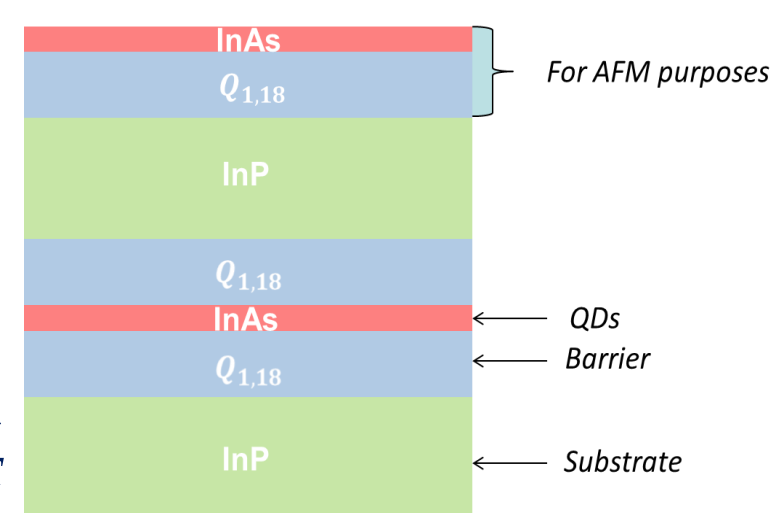
Spectral Hole Burning



## Photoluminescence & Atomic Force Microscopy Preliminary results

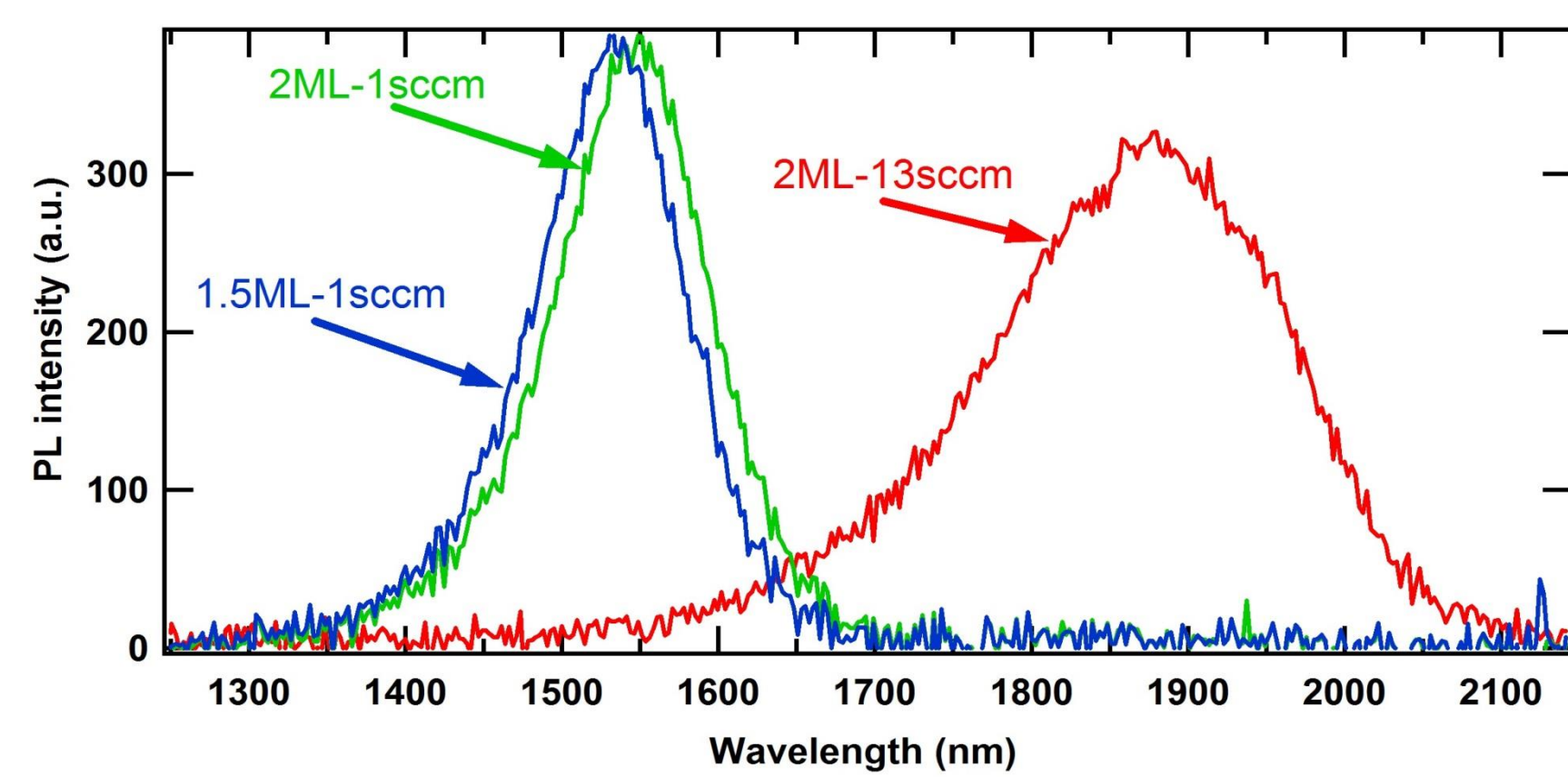
### Molecular Beam Epitaxy (MBE) Growth parameters:

- The Arsenic Flow (Standard Cubic Centimeter per Minute)
- The quantity of deposited InAs (1 MonoLayer = 0.3 nm)



Schematic cross view of the gain medium grown by MBE

### Photoluminescence of the InAs/InP Quantum Dots

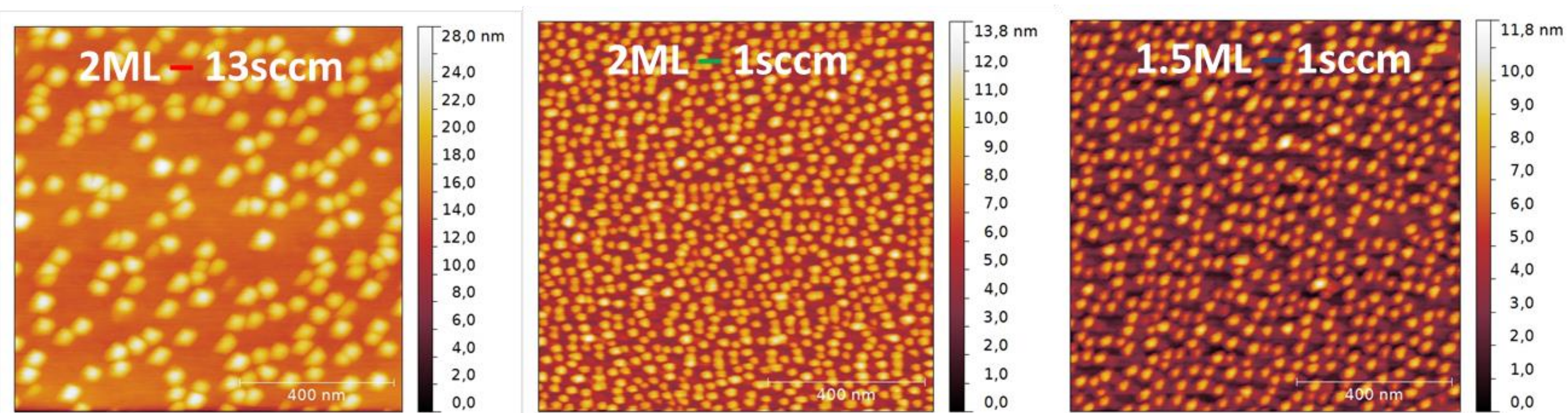


Increase of the quantity of deposited InAs & Arsenic flow → higher emission wavelength (lower energy) & bigger QDs

→ Stronger evolution with As Flow

Photoluminescence spectra of InAs QDs for different growth parameters

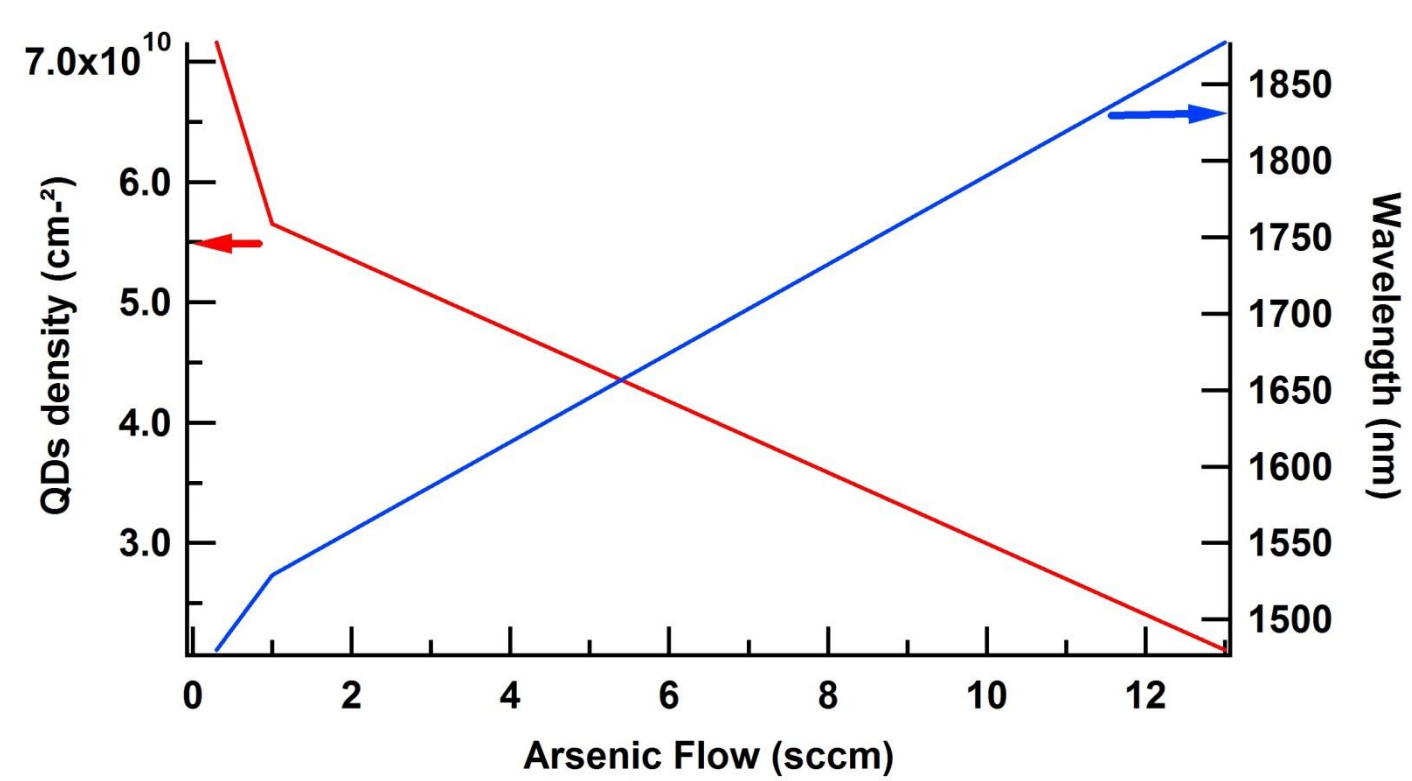
### Atomic Force Microscopy



AFM images (1x1 μm<sup>2</sup>) of the InAs/InP Quantum Dots which have different growth parameters

- When the quantity of deposited InAs increases, the density increases and saturates
- When the Arsenic Flow increases, the QDs get bigger and the density greatly decreases

### Overview: Results so far



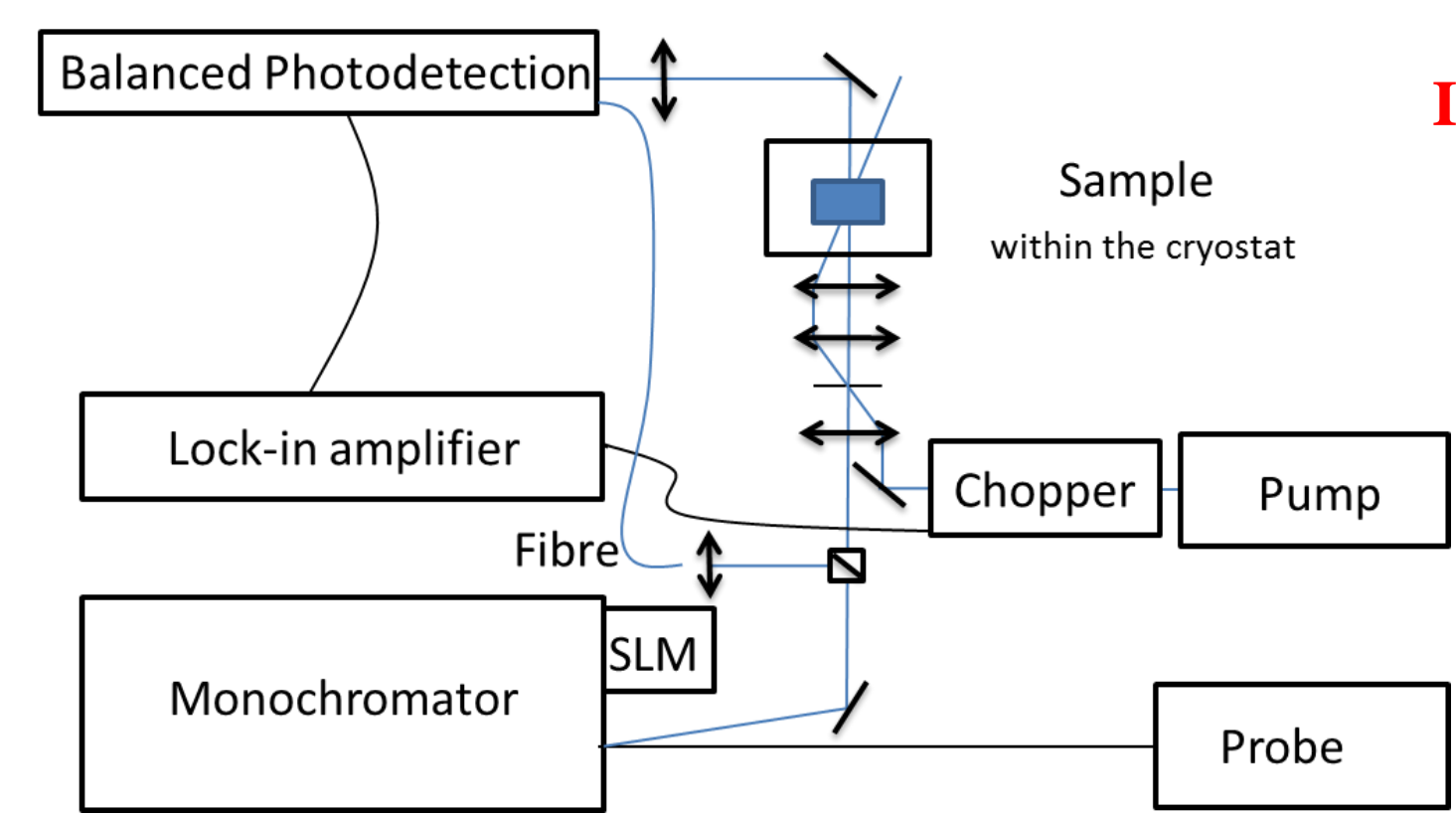
For 1.5 ML: QDs density and wavelength as a function of As Flow

As Flow (sccm)	InAs deposited (ML)	Central Wavelength (nm)	Density (cm <sup>-2</sup> )
0.3	1.5	1480	7.16E+10
0.3	2	1514	9.20E+10
0.3	2.5	1470	5.02E+10
1	1.5	1530	5.56E+10
1	2	1547	9.85E+10
1	2.5	1578	1.32E+10
13	1.5	1877	2.11E+10
13	2	1880	2.31E+10
13	2.5	1945	2.90E+10

Recap chart for the samples

## Saturation Spectroscopy : Spectral Hole Burning (SHB)

### Overall experiment



Overall Spectral Hole Burning schematic ; SLM = Spatial light modulator : selects the wavelength of the probe

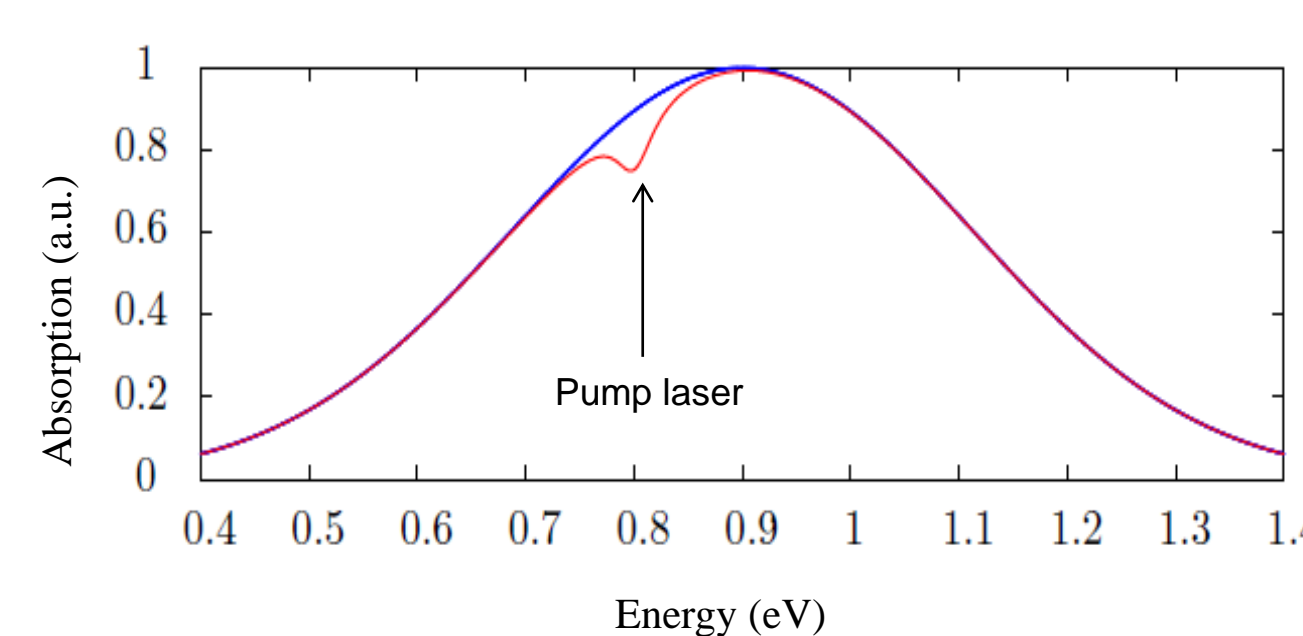
In order to obtain the homogeneous linewidth  $\gamma$

$$\gamma = \frac{1}{T_2} = \frac{\Gamma_{hb}}{2}$$

The pump laser saturates the QDs; it creates a hole in the spectrum

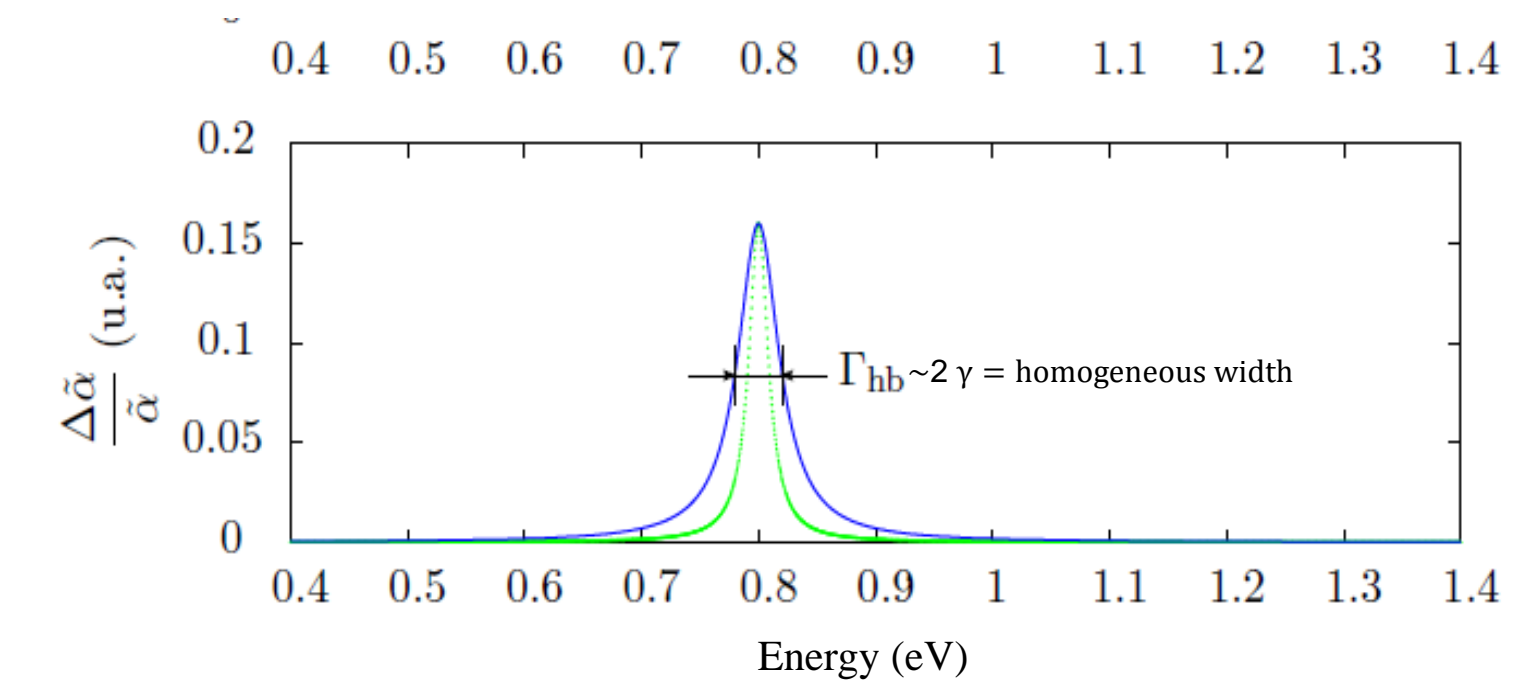
The probe laser detects the hole by probing the spectrum

### Inhomogeneous Broadening with SHB



Saturated absorption with SHB (red curve) and unsaturated absorption (blue curve)

### SHB Expected Results



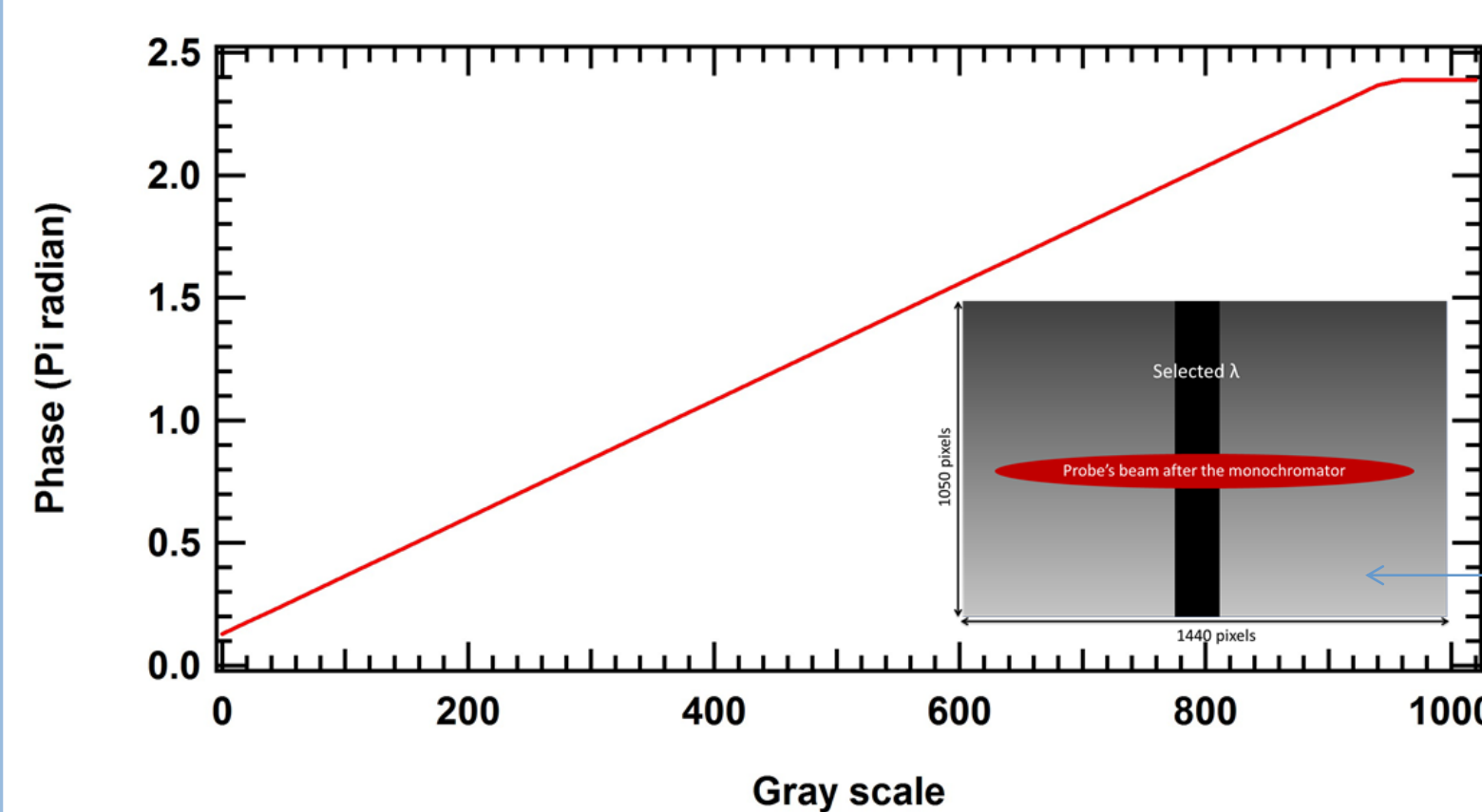
Differential absorption spectrum (blue curve) and unsaturated homogeneous absorption (green curve)

SHB leads to the differential absorption spectrum given by:

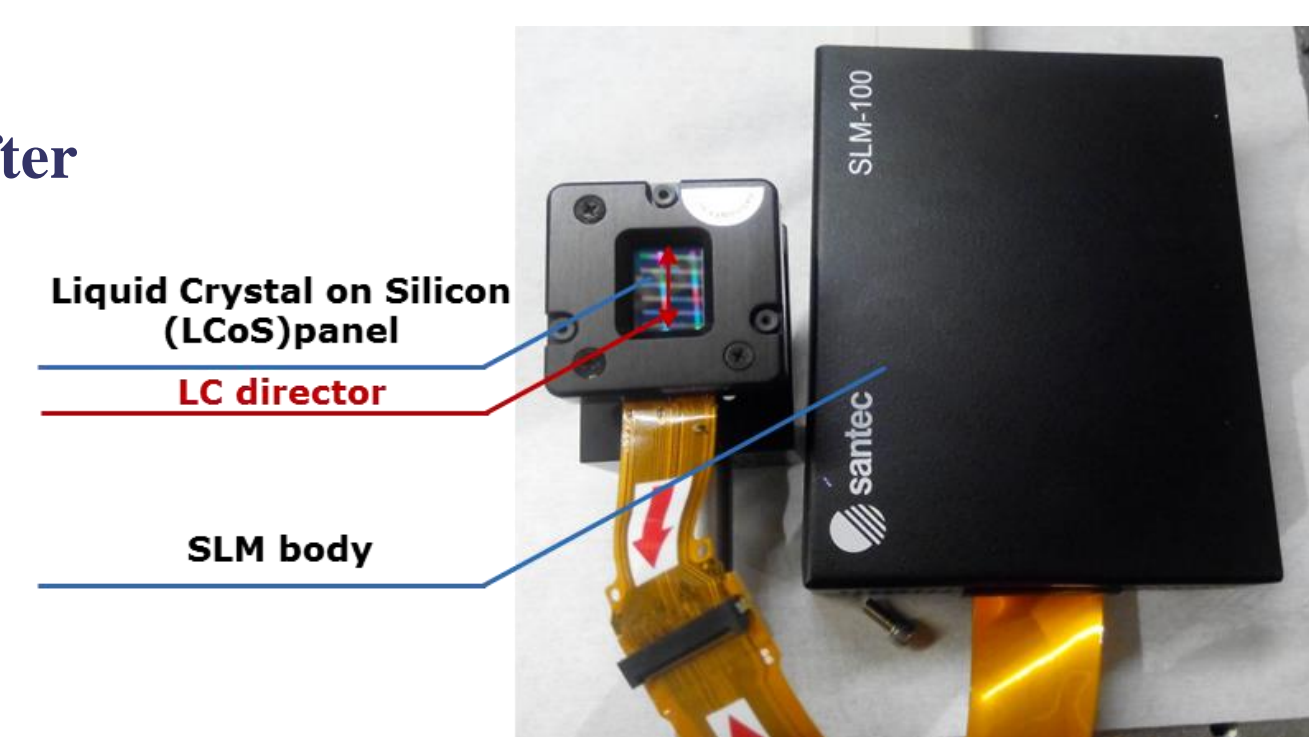
$$\frac{\Delta\tilde{\alpha}}{\tilde{\alpha}}(\omega) = \frac{\tilde{\alpha}^{(0)}(\omega) - \tilde{\alpha}(\omega)}{\tilde{\alpha}^{(0)}(\omega)} = \frac{S}{2} \cdot \frac{(\Gamma_{hb}/2)^2}{(\omega - \omega_p)^2 + (\Gamma_{hb}/2)^2}$$

## Spatial Light Modulator

The LCoS panel selects the wavelength of the probe after the monochromator



Calibration curve: Applied Gray level and its resulting phase at 1550 nm & SLM panel during SHB



Picture of the Spatial Light Modulator

Gray gradient: vertical phase is a linear function = tilted mirror

Black band: phase is constant and unchanged in order to send the required wavelength on the sample

## Conclusion

### Conclusions:

- QDs density (and coupling) mainly controlled by the As flow: changed from  $10 \times 10^{10}$  down to  $10^{10} \text{ cm}^{-2}$ , with a strong effect on the wavelength emission: from 1500 nm to 1945 nm
- Possible growth of InAs/InP QDs with high emission wavelength (1945 nm)
- Use of a calibrated at 1550nm Spatial Light Modulator for selecting the probe's wavelength during SHB experiment

### Perspectives:

- Realisation of SHB in order to get the homogeneous linewidth broadening as a function of QDs density, temperature, input power
- VECSEL optical characterization
- Further development: towards electrical injection