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

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Introduction

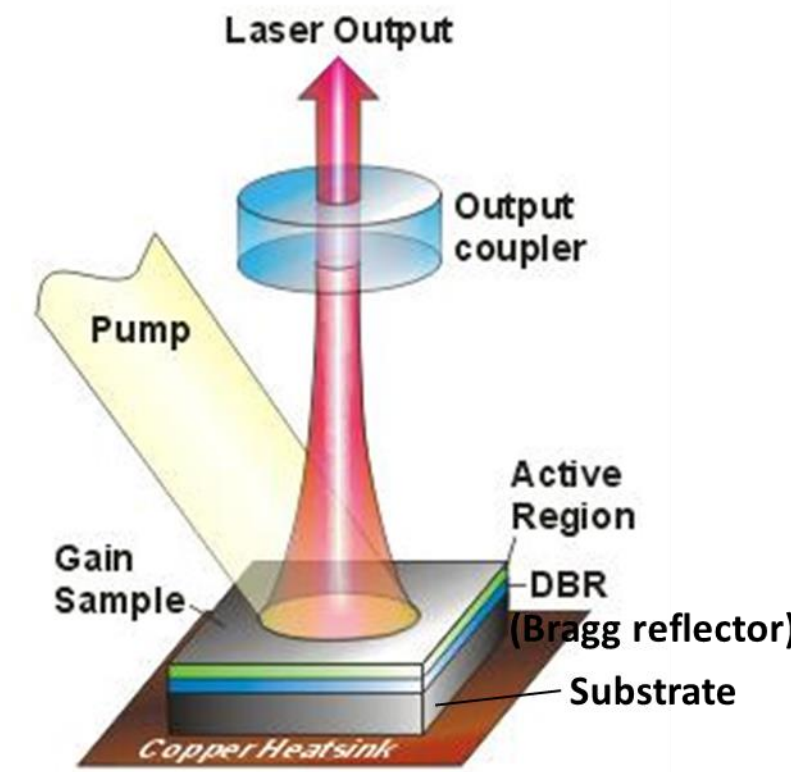
The Terahertz (THz) frequency domain is attractive due to many applications in imaging, sensing and communication.

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

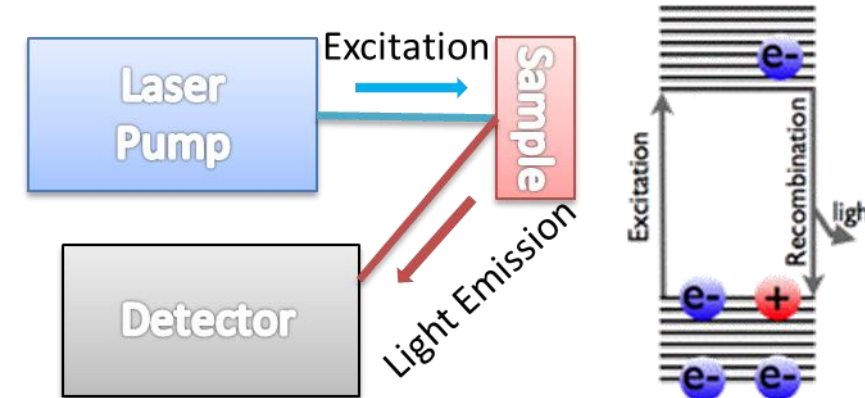
VECSEL: ideal for stable coherent dual wavelength laser but requires weak mode coupling → QDs

Requirements for the QDs

Telecom wavelength (centered at 1550 nm)

Checked by

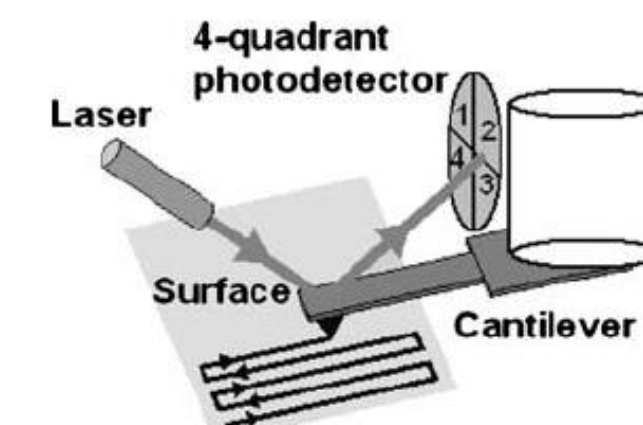
Photoluminescence



Weak Coupling between QDs (low density)

Checked by

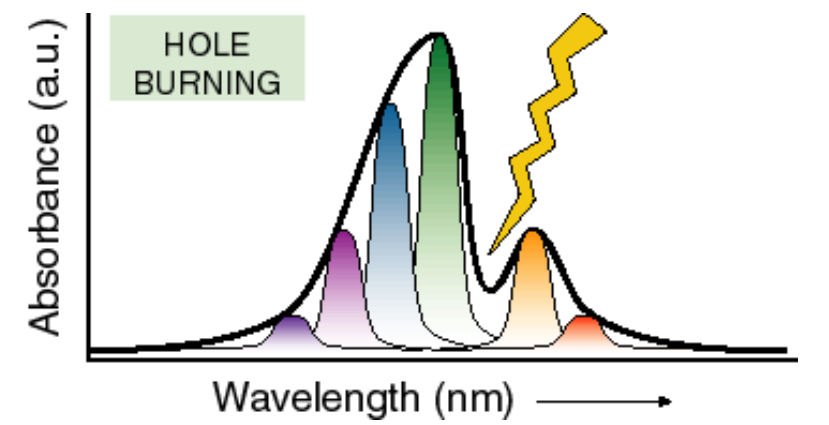
Atomic Force Microscopy



Coupling estimation (measurement of the Homogeneous linewidth)

Followed by

Spectral Hole Burning

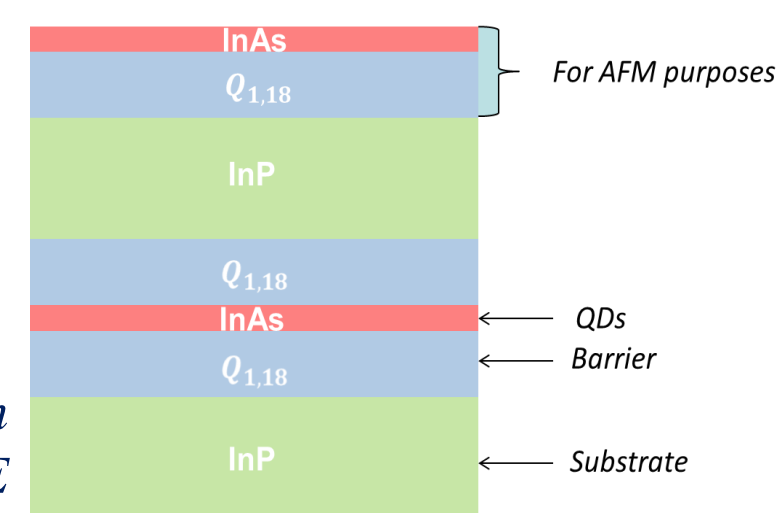


Photoluminescence & Atomic Force Microscopy Preliminary results

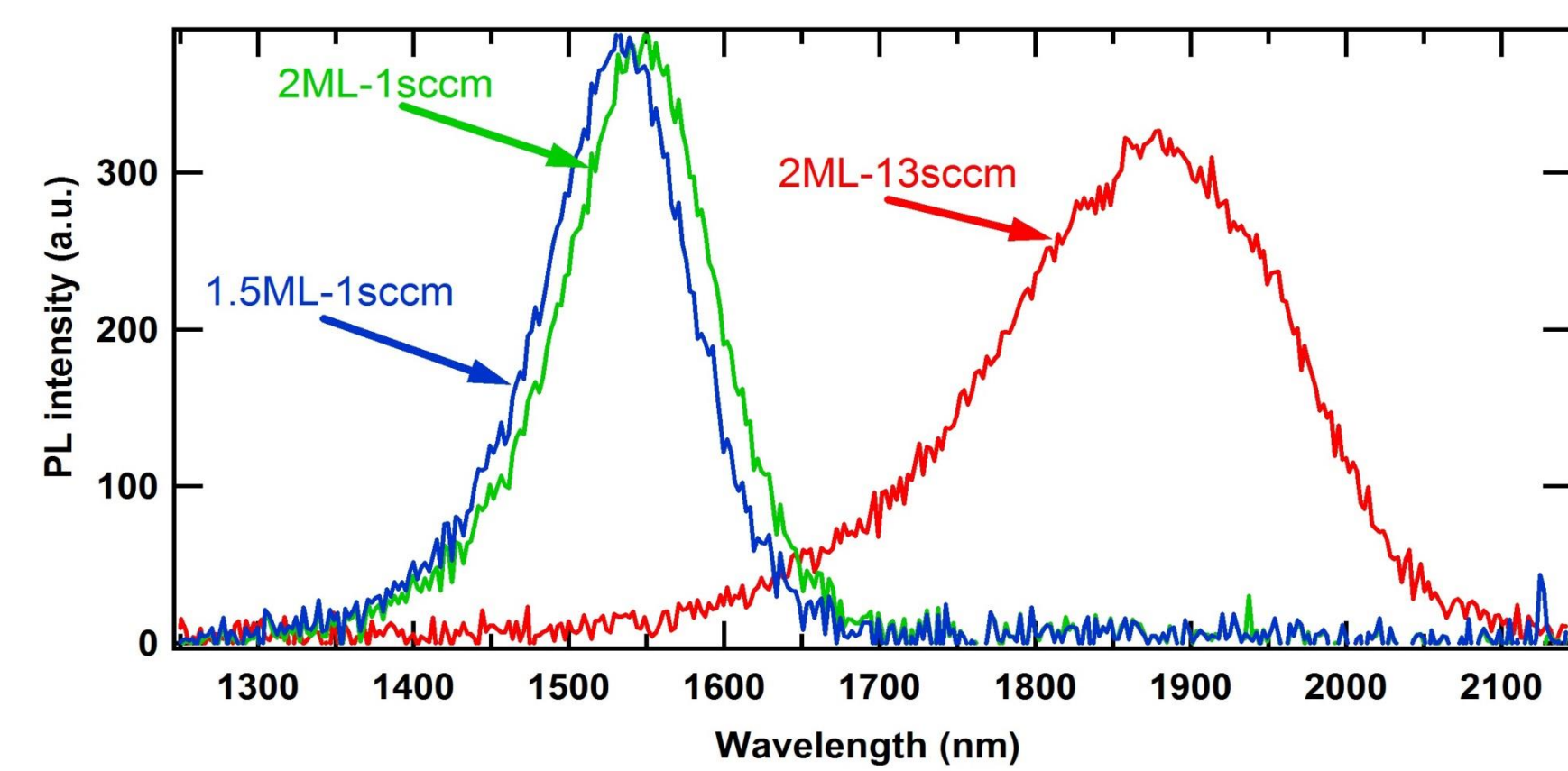
Molecular Beam Epitaxy (MBE) Growth parameters:

- 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



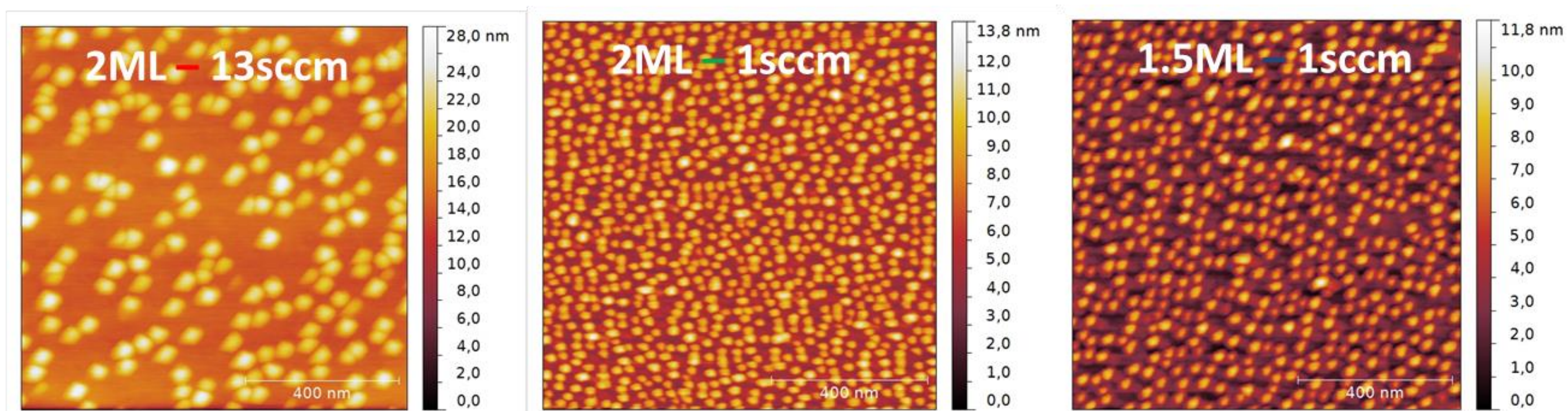
Photoluminescence of the InAs/InP Quantum Dots



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

→ Stronger evolution with As Flow

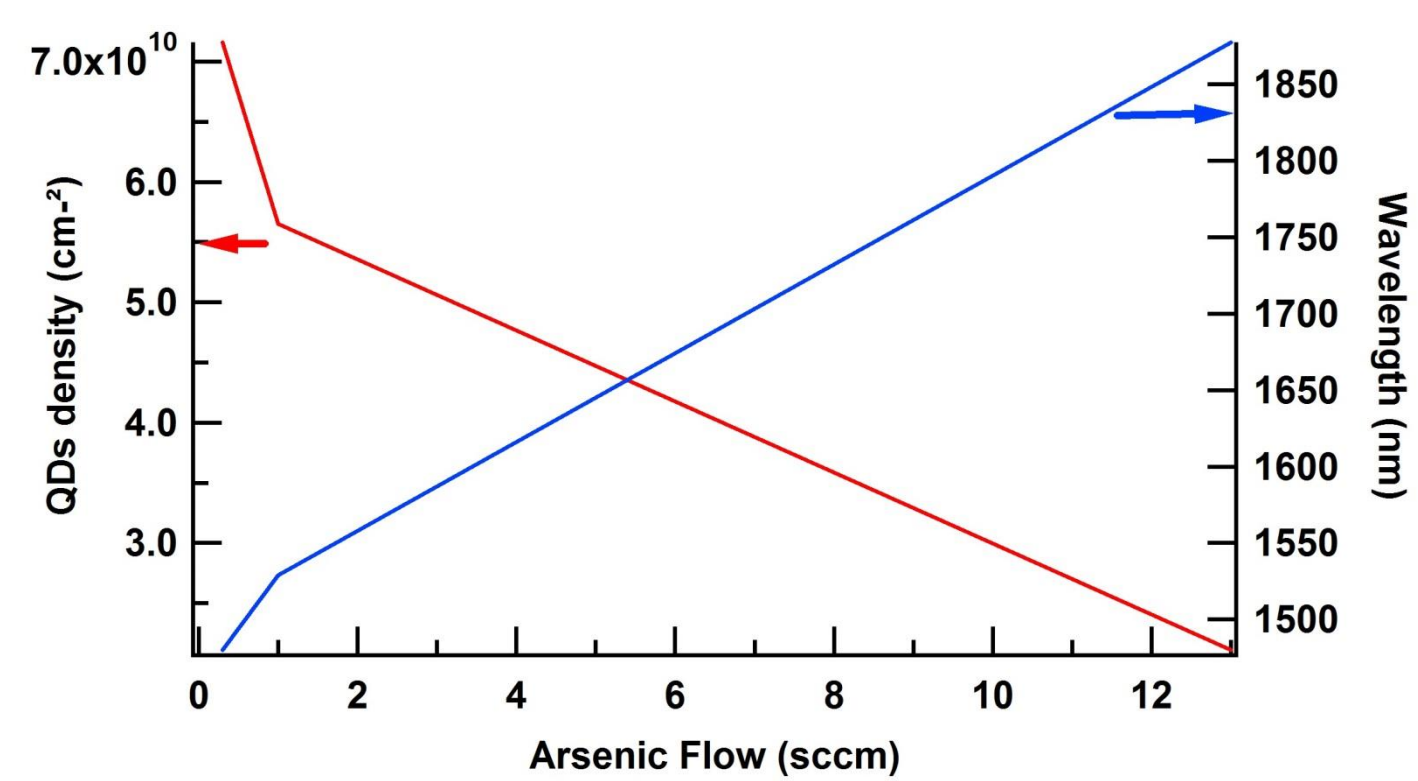
Atomic Force Microscopy



AFM images (1x1 μm²) 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



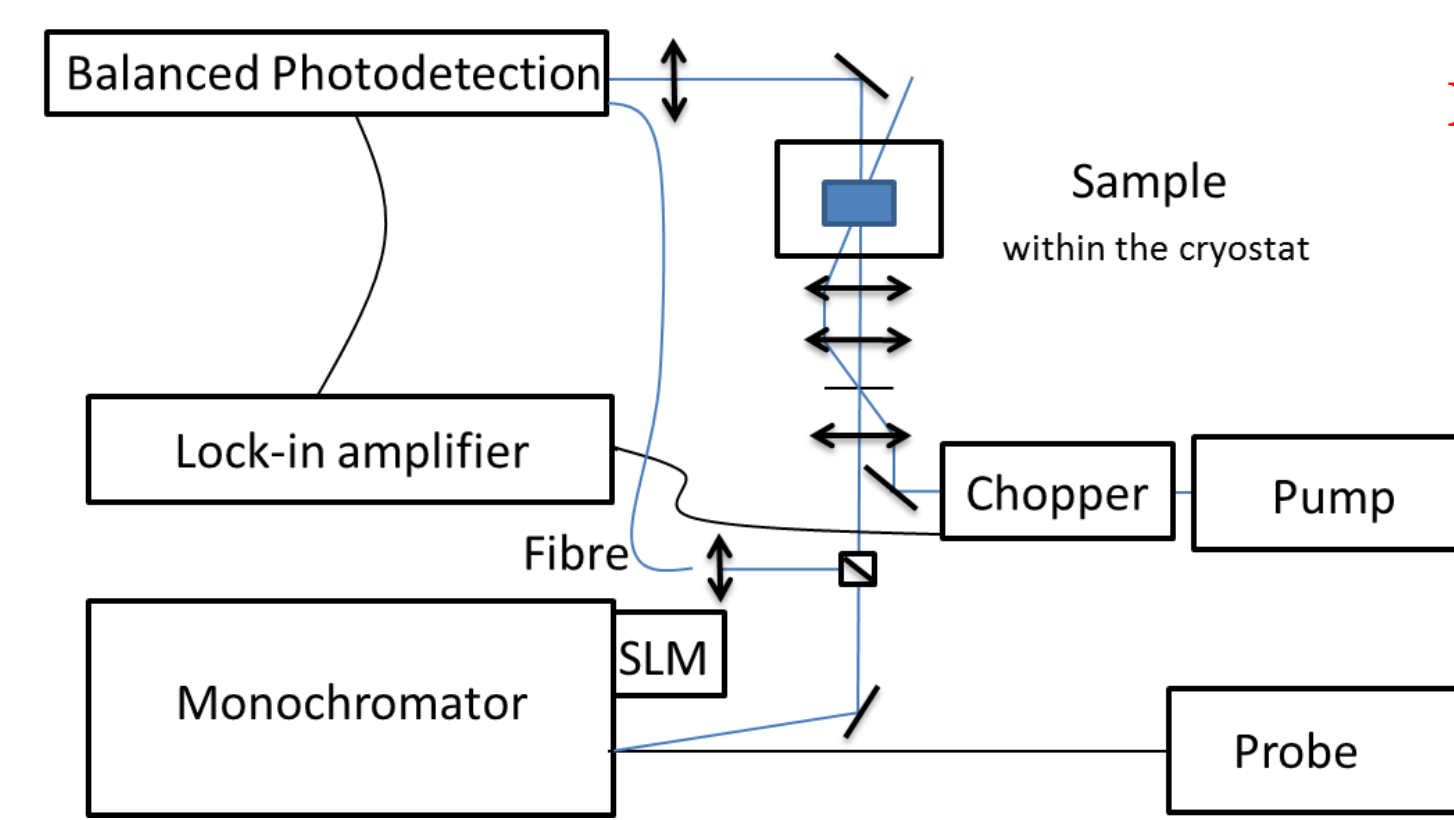
For 1.5 ML: QDs density and wavelength as a function of As Flow

As Flow (sccm)	InAs deposited (ML)	Central Wavelength (nm)	Density (cm ⁻²)
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

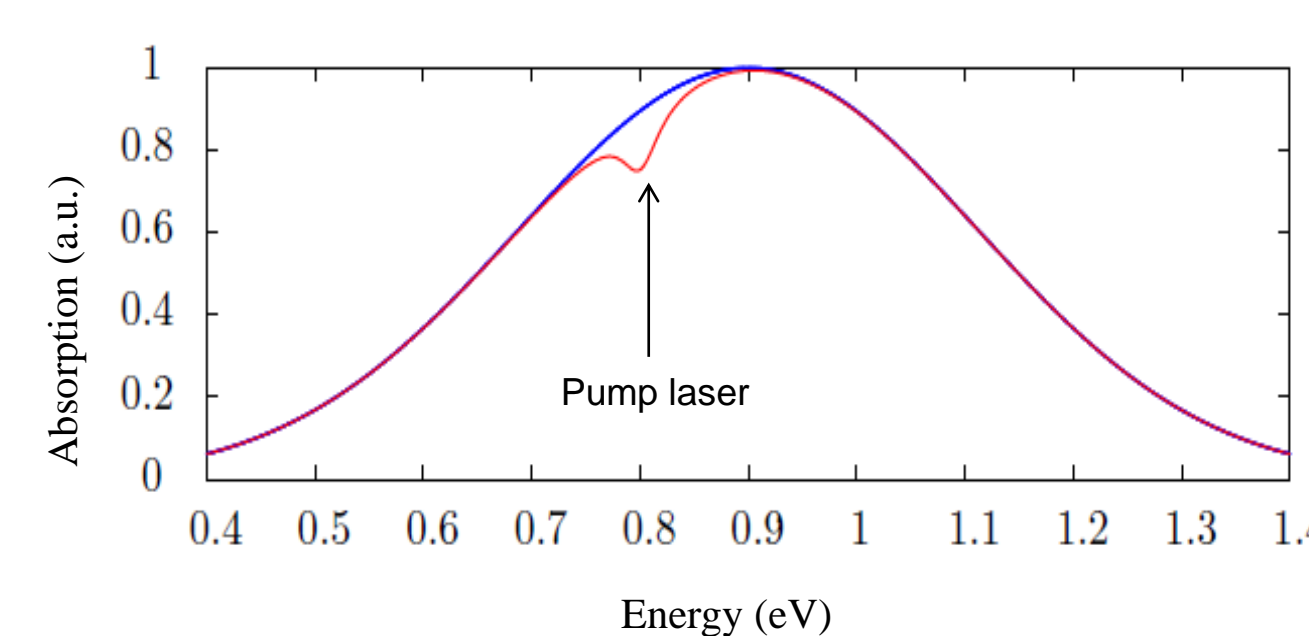
In order to obtain the homogeneous linewidth γ

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

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

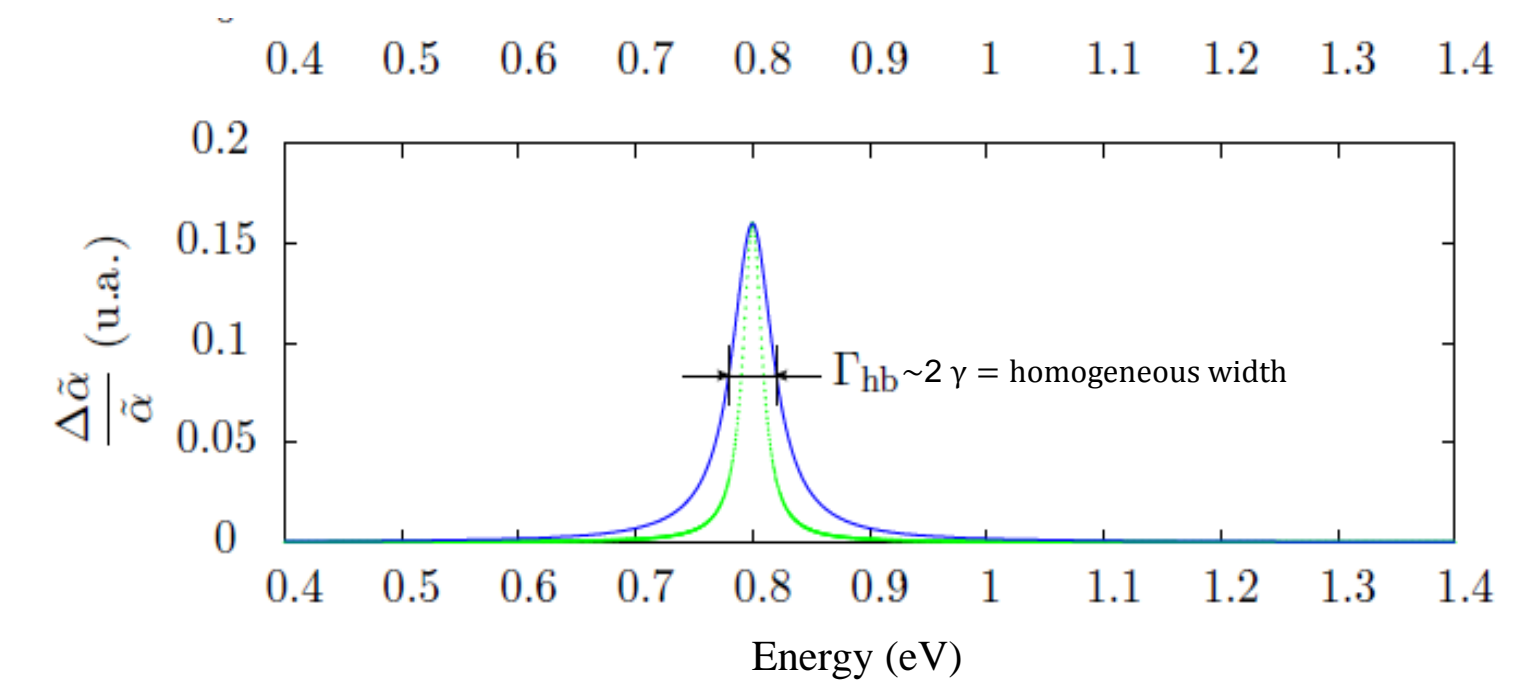
The probe laser detects the hole by probing the spectrum

Inhomogeneous Broadening with SHB



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

SHB Expected Results



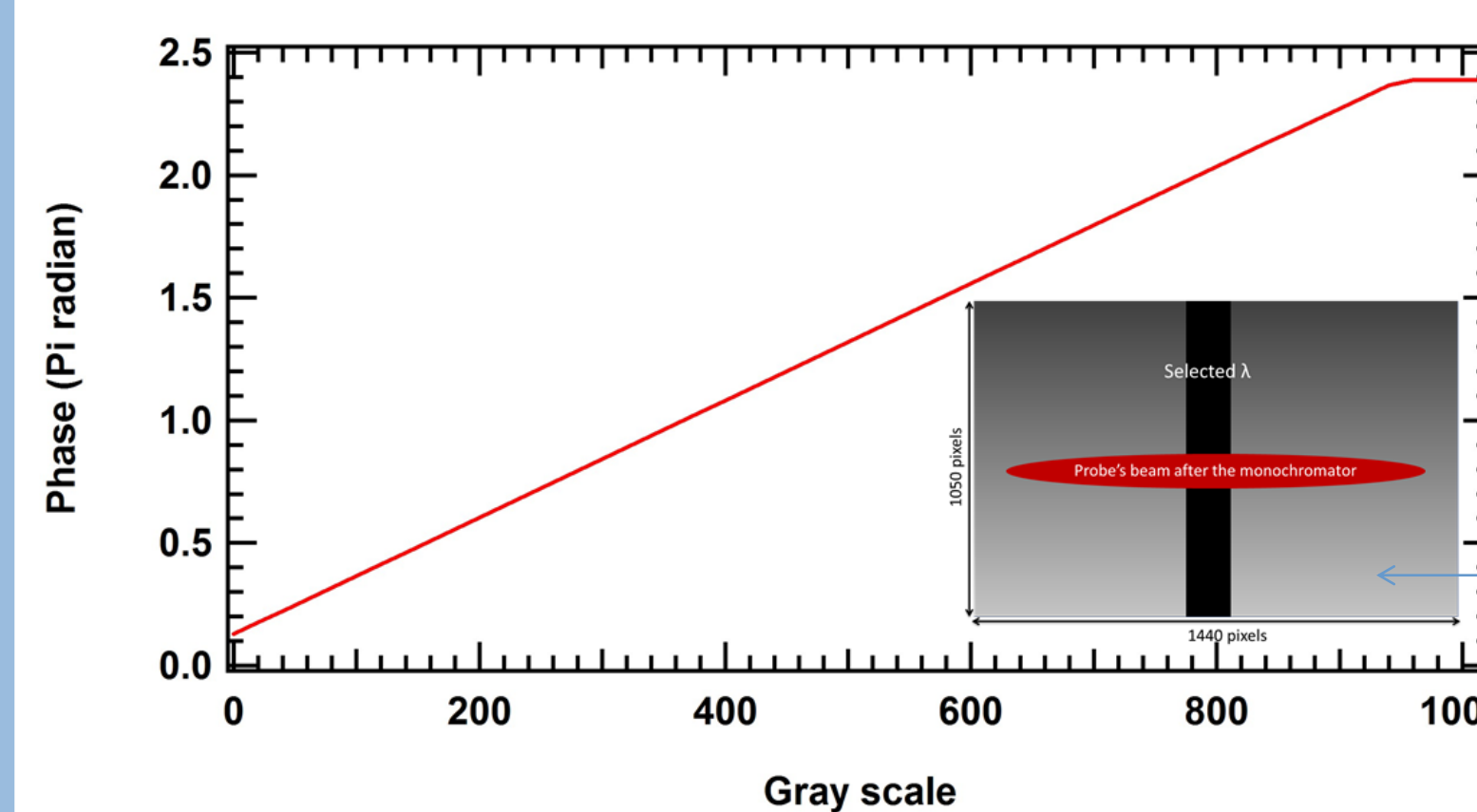
Differential absorption spectrum (blue curve) and unsaturated homogeneous absorption (green curve)

SHB leads to the differential absorption spectrum given by:

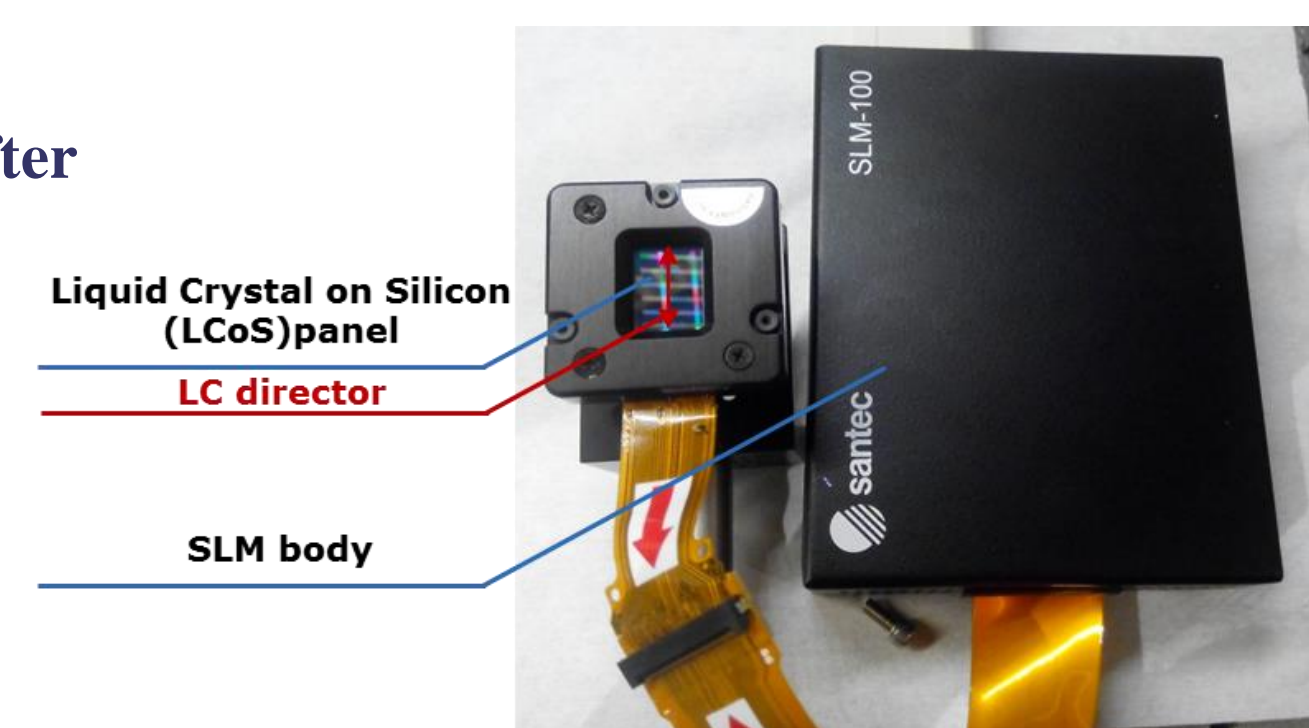
$$\frac{\Delta \tilde{\alpha}(\omega)}{\tilde{\alpha}(\omega)} = \frac{\tilde{\alpha}^{(0)}(\omega) - \tilde{\alpha}(\omega)}{\tilde{\alpha}^{(0)}(\omega)} = \frac{S}{2} \cdot \frac{(\Gamma_{hb}/2)^2}{(\omega - \omega_p)^2 + (\Gamma_{hb}/2)^2}$$

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 10×10^{10} down to 10^{10} 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