# MetalGuide


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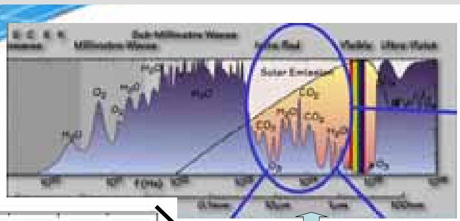
## Project Objectives

1) Developing the MOCVD [metalorganic chemical vapour deposition] growth of mid-infrared quantum cascade (QC) lasers

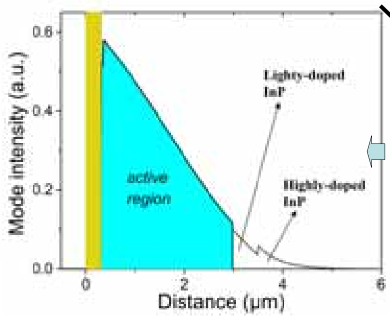
2) Developing metallic waveguides for mid-infrared semiconductor lasers (5µm<λ<16µm, InGaAs/AlInAs and InAs/AlSb material systems)

3) Adding novel functionalities to QC lasers (single-mode emission…) by the sole patterning of the metal contacts.

4) Low-loss DFB lasers based on the interplay between surface-plasmons and guided modes



The mid-IR range of the electro-magnetic spectrum covers the 5→ 15 um range. It is extremely important for sensing applications. Most molecules exhibit fingerprint absorptions in this range.

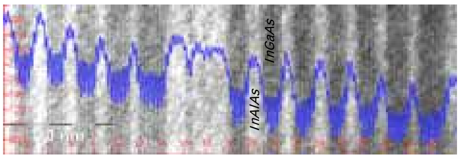



A typical surface-plasmon waveguide for mid-IR QC lasers. The optical mode is maximum at the device top interface and It decays exponentially-like into the substrate, through the active region.

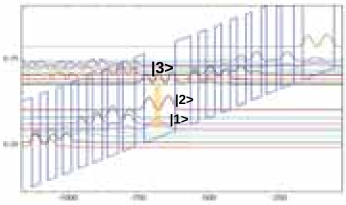
## Results T+6

### a) InGas/AlInAs – Why? It is the material of choice for high-performance mid-IR QC lasers

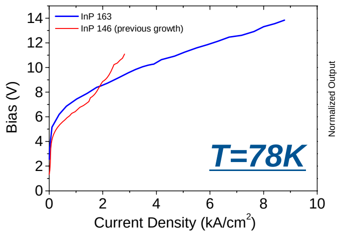
- **Optimization of the MOCVD growth of lattice matched InGaAs/AlInAs semiconductor heterostructures**
- Strategy: GROWTH → ELECTRO-OPTICAL CHARACTERIZATIONS → LAYER THICKNESS → TEM ANALYSIS
- Parameters mastered: Aluminum concentration, layer thicknesses, quantum well doping, contact layers doping
- **Realization of intersubband, 2-color mid-IR LEDs with optical/electrical characteristics corresponding to the design**



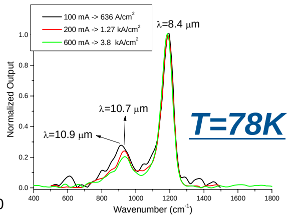

High resolution TEM of a calibration structure, showing that a thickness as low as 2 monolayers of InGaAs (at center of picture) can be controlled by MOCVD.




The quantum design used for MOCVD growth calibration purposes. The square moduli of the wavefunctions are shown, superimposed to the conduction band profile at the design field. The structure should nominally emit at two wavelengths: λ=8.5 µm (3→2 transition), and λ=10.5 µm (2→1 transition)



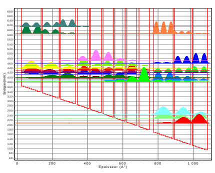

Current-voltage (I-V) characteristic of the LEDs. The red curve refers to the 1st growth run: the injection barrier is too thick, as confirmed by TEM analysis.
After re-calibration (blue curve, 2nd growth run) the device shows the correct electrical behavior in terms of injected current density and alignment bias.



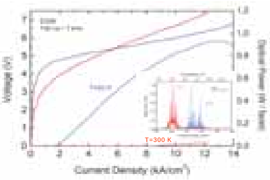

Electroluminescence spectra of the 2-color LED for different injected currents. The emission is peaked at λ=8.4 µm and at λ=10.7 µm, in excellent agreement with the design.

### b) InAs/AlSb: Why? The very low InAs effective mass ($m^*=0.023$) yields higher optical gains.

- **Growth and test of a *standard* InAs/AlSb QC laser at lambda=8.5 µm**
- The same wafer was re-processed in surface-plasmon QC lasers, by selectively removing the top claddings
- The comparison gives an initial feedback on the waveguide loss

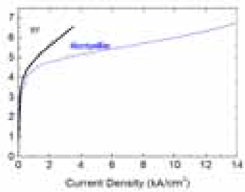


The quantum design used targets an emission wavelength of 8.5 µm.

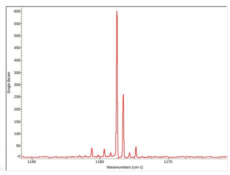



IV characteristic (main panel) and emission spectra (inset) of the laser devices with a waveguide based on dielectric claddings.

| | | | | |
|---|---|---|---|---|
| Substrat | InAs | - | N=1-2 x $10^{18}$ $cm^{-3}$ | |
| Cladding bas | InAs | 1.0 µm | N=2 x $10^{18}$ $cm^{-3}$ | |
| Spacer bas | InAs | 2.5 µm | N=5 x $10^{16}$ $cm^{-3}$ | |
| Zone active | 30 periodes | 2.25 µm | $n_s$=7 x $10^{11}$ $cm^{-2}$/period | n=3.38 |
| Spacer haut | InAs | 2.5 µm | N=5 x $10^{16}$ $cm^{-3}$ | |
| Cladding haut | InAs | 2 µm | N=2 x $10^{18}$ $cm^{-3}$ | |




The devices with metallic waveguide exhibits a higher contact resistance, due to the lack of a highly doped top contact layer.



The devices lase at the correct wave-length (λ=8.45 µm).

## Perspectives

- MOCVD-grown, mid-IR surface-plasmon QC lasers in the InGaAs/ AlInAs material system
- Single-mode emission *via* coupling between surface-plasmons and dielectric waveguides, and with purely metallic waveguides
- Development of a modulator based on surface-plasmon QC lasers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