



Hybrid III-V/Si DFB laser integration on a 200 mm fully CMOS-compatible silicon photonics platform

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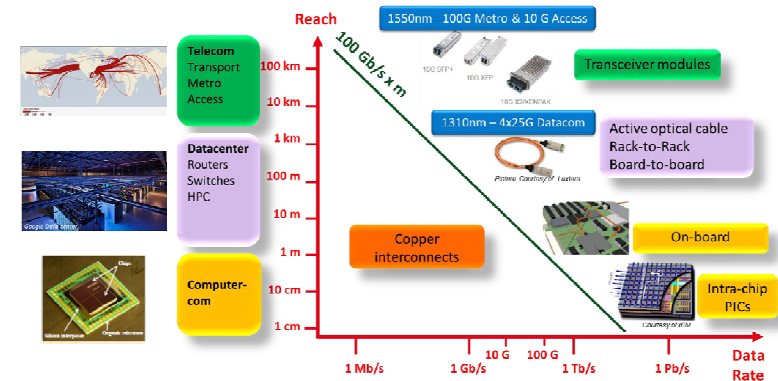
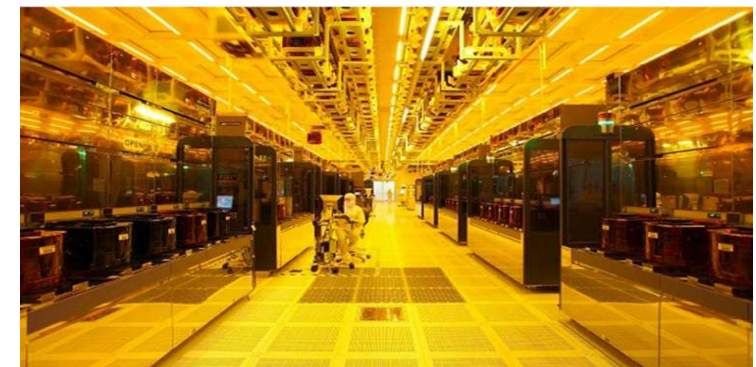
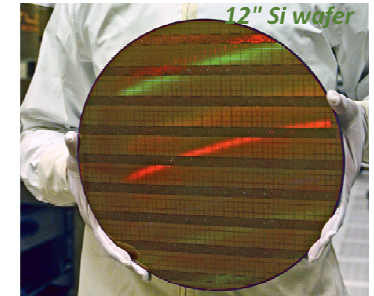
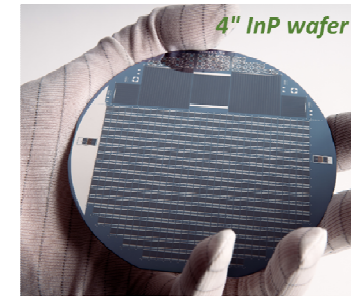


Outline of Presentation

- Introduction & Objectives
- Hybrid III-V/Si DFB laser – Process description & Fabrication
- Hybrid III-V/Si DFB laser – Optical characterization
- Result discussion
- Conclusion & Perspectives

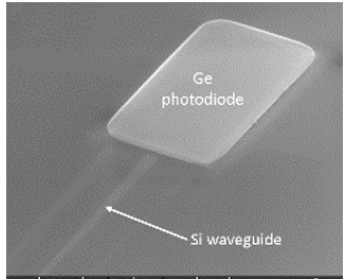
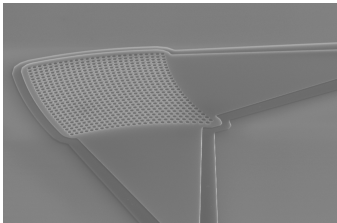
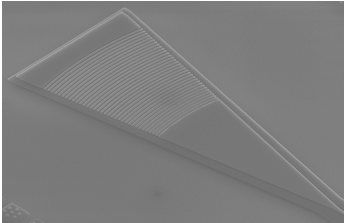
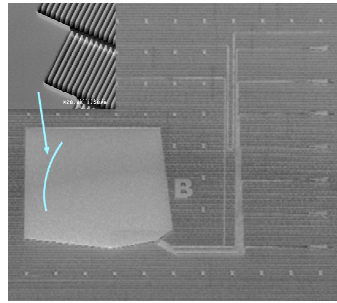
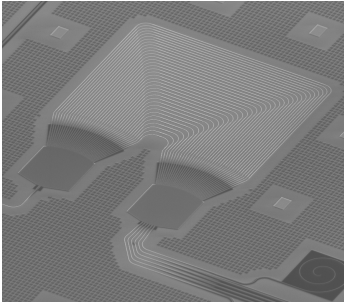
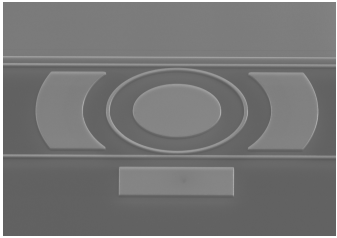
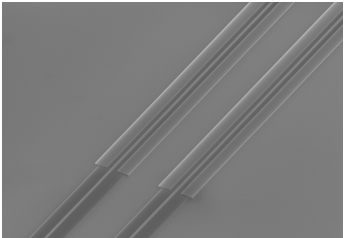
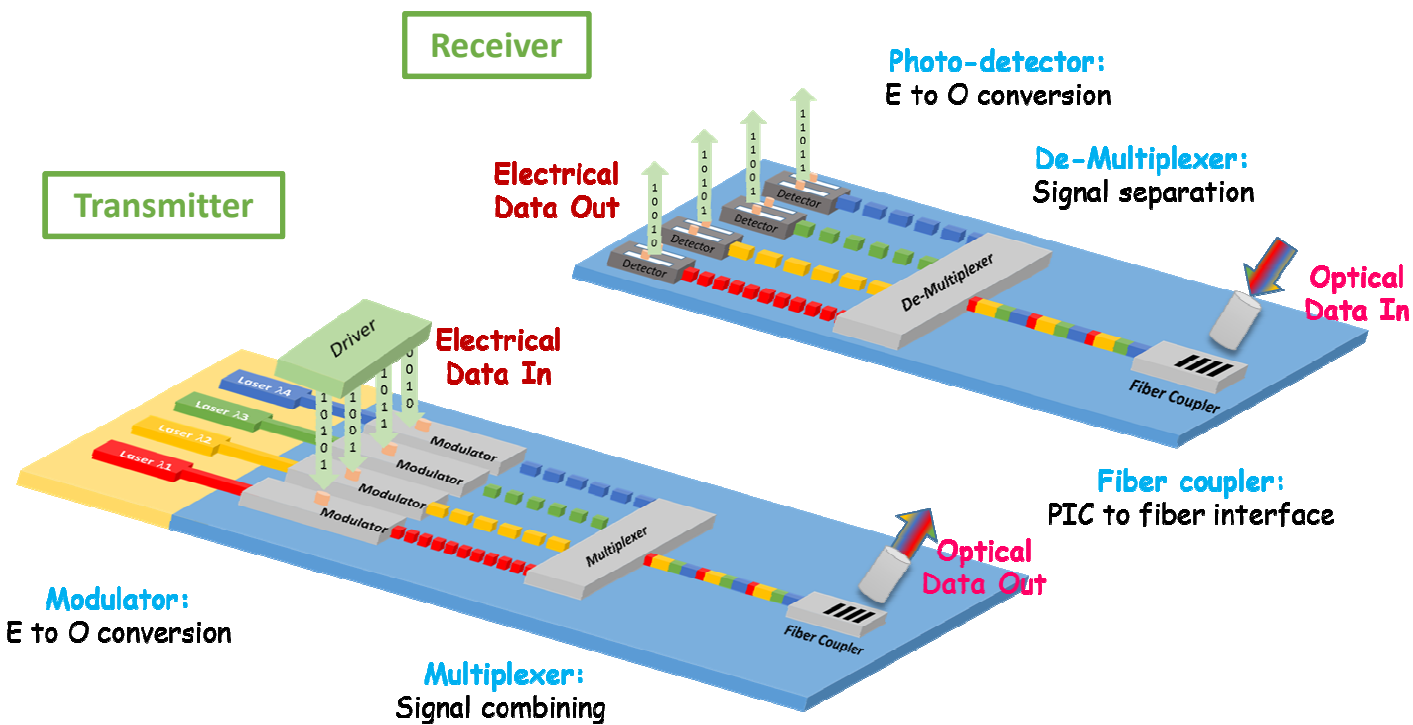
What is silicon photonic ?

- Silicon photonic aims at integrating in the silicon microelectronic CMOS technology circuits and modules initially based on other technologies (InP, InGaAs, LNbO₃, SiO₂, ...)
- Making photonic integrated circuits on Silicon using CMOS process technology in a CMOS fab.
- Merging photonics and CMOS.
- Expected benefits:
 - Higher integration level
 - Low cost, high volume facilities
 - Access to mature packaging and EDA tools
 - WDM and scaling to >1 Tb/s
 - Solving electrical interconnect limits in Data centers, Supercomputers and ICs with higher capacity, lower cost optical interconnects



Silicon Photonic Building Blocks

Silicon Photonic Links



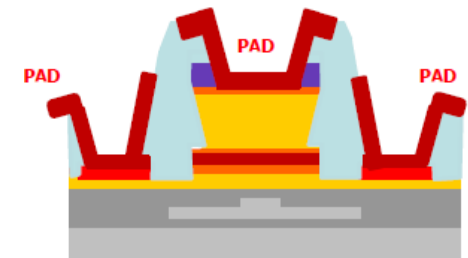
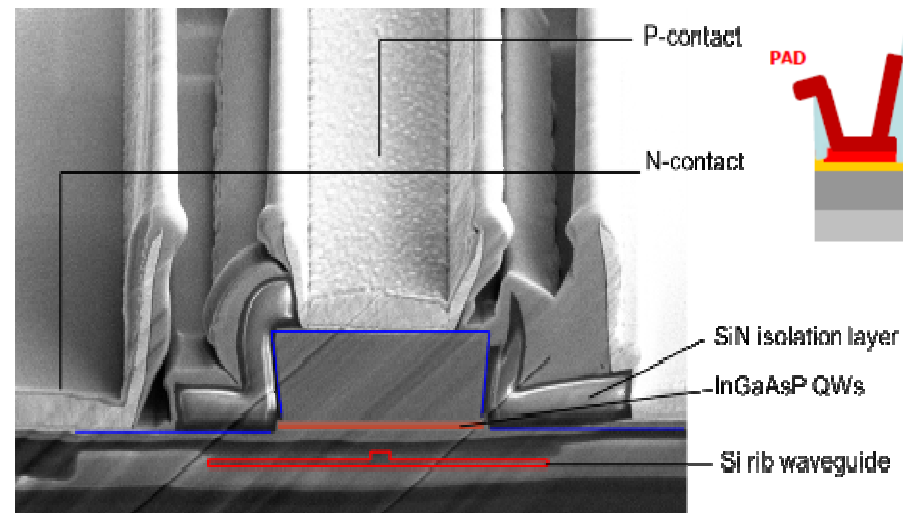
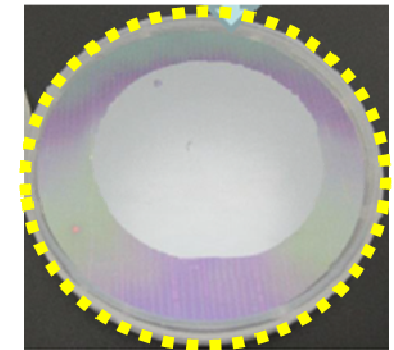
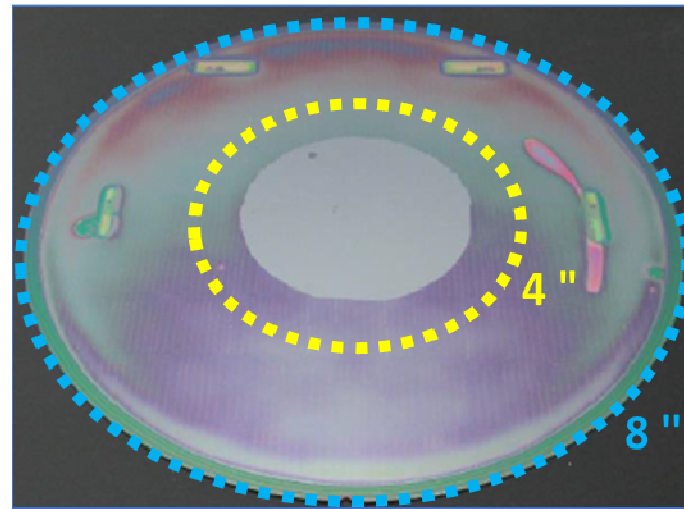
Hybrid III-V/Si laser – Current process

- CMOS compatible process for silicon part
- III-V substrate bonding on silicon
- Si wafer downsizing to 100mm
- Laser process steps using III-V fabrication line:
 - Noble metals
 - Lift-off
 - RIE etch

⇒ Not CMOS compatible process

⇒ Not planarized BEOL

⇒ Cost advantage of silicon photonics based the use of CMOS platforms and large wafer format is no more valid



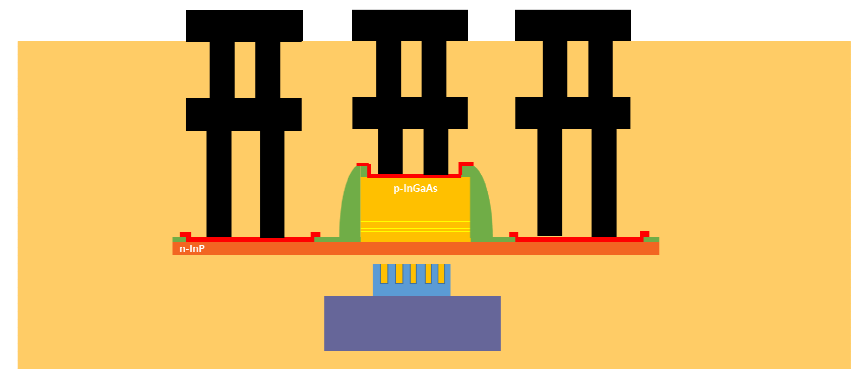
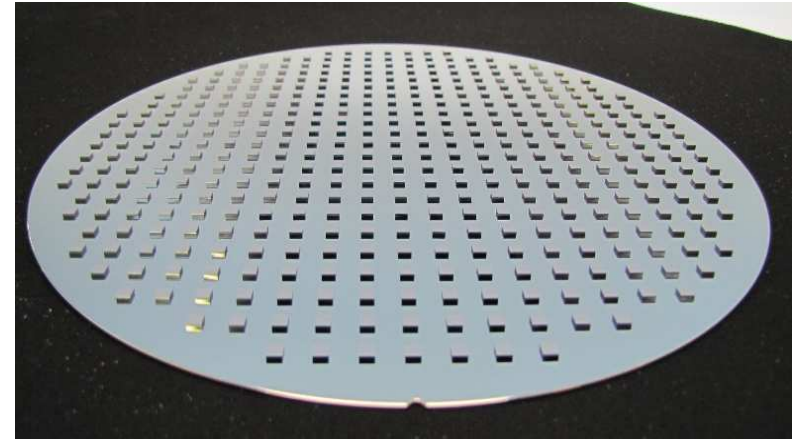
Hybrid III-V/Si laser – Targeted process

Final objectives:

- CMOS compatible process for silicon part
- III-V die bonding on silicon
- 200 or 300mm Si wafers
- Compatible with mature silicon photonic platform
- Laser process steps cmos compatible process:
 - No noble metals
 - Conventional patterning steps
- Planarized multi-metal level BEOL

In this work:

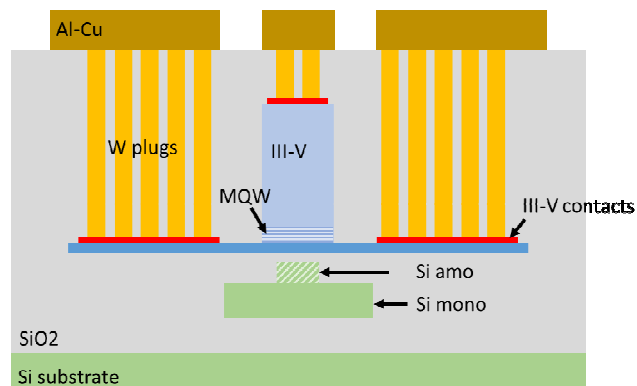
- Modular integration of hybrid laser on 200mm mature Si platform
- III-V substrate bonding
- III-V patterning on 200mm CMOS fab
- CMOS compatible contacts on III-V



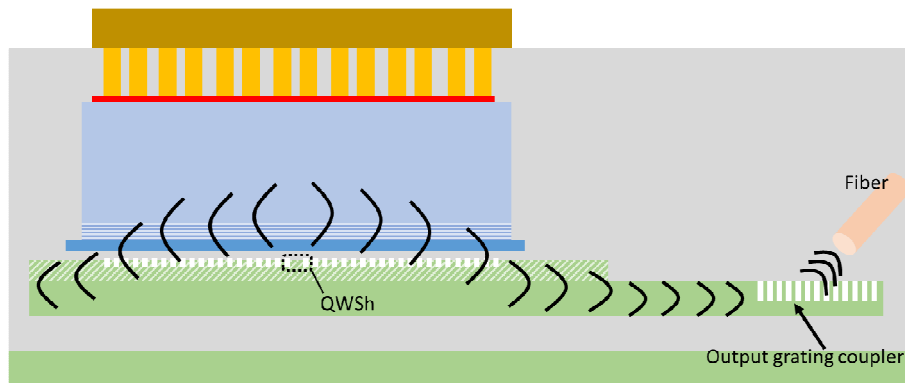
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Hybrid III-V/Si DFB laser structure & integration scheme



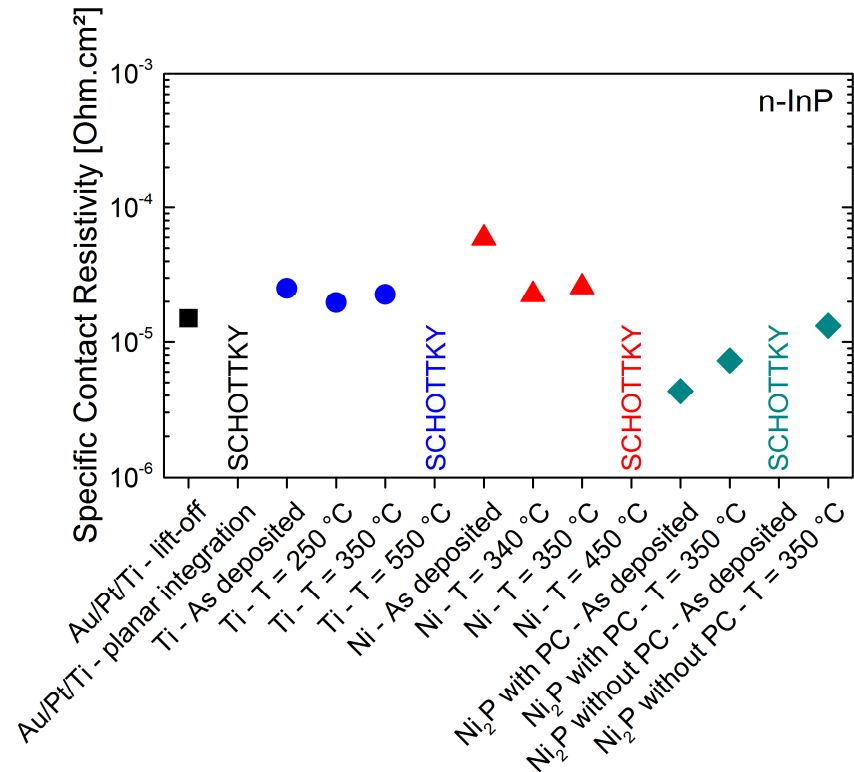
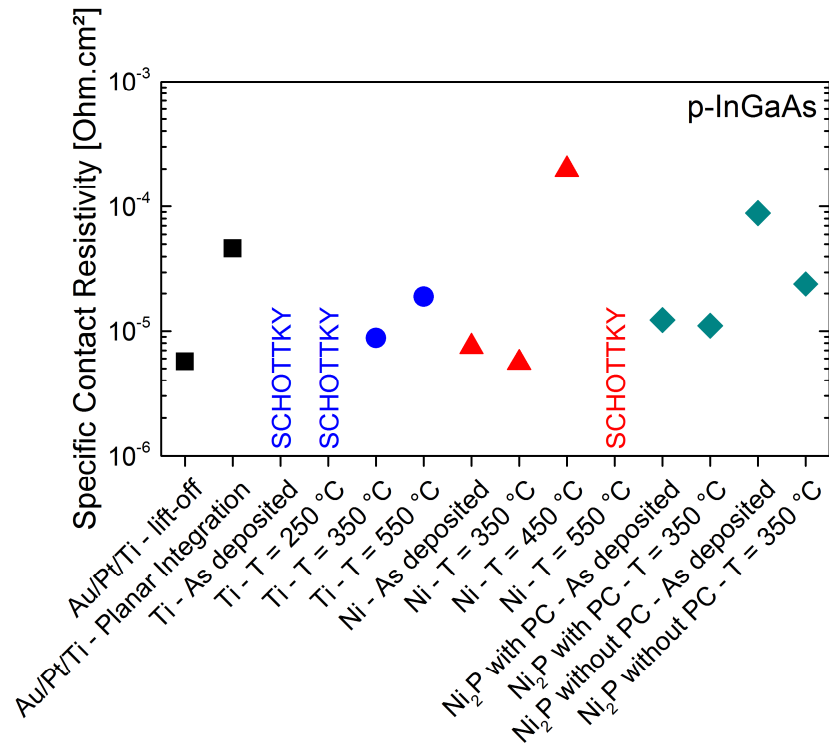
Transversal views of the laser



Longitudinal view of the laser

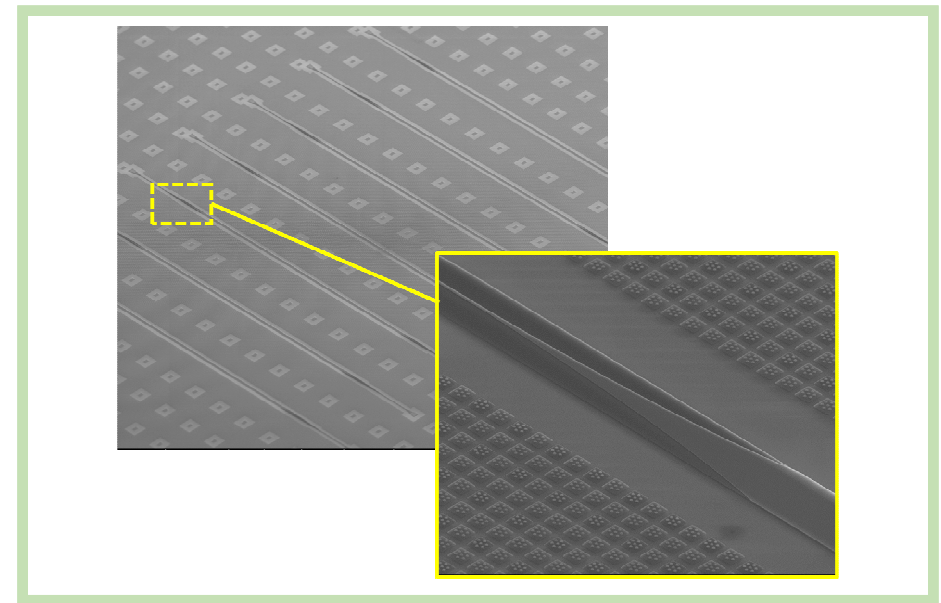
- Silicon waveguide patterning
- Localized silicon thickening
- Bragg grating patterning
- III-V wafer/die bonding
- III-V patterning
- III-V contact metallization
- Tungsten Plug
- Planar BEOL

Preliminary studies: CMOS compatible contacts on III-V



- Best choice: Ni₂P wo annealing for n-InP and Ni with 350°C annealing for P-InGaAs
- Integration constraint & process cost => use the same contact for n-InP and P-InGaAs

Hybrid III/V on Si DFB laser fabrication description

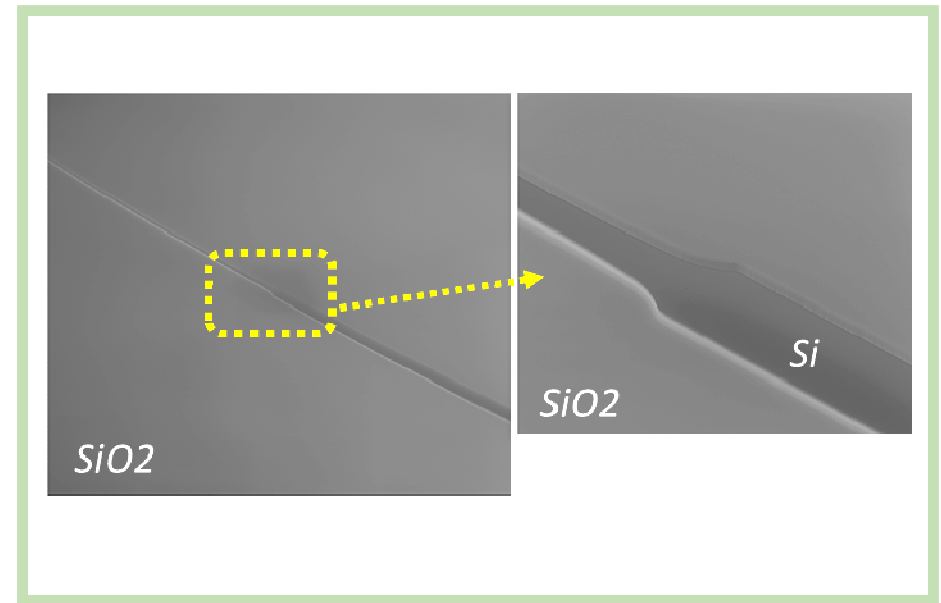


- Silicon photonic platform – Encapsulated passive device

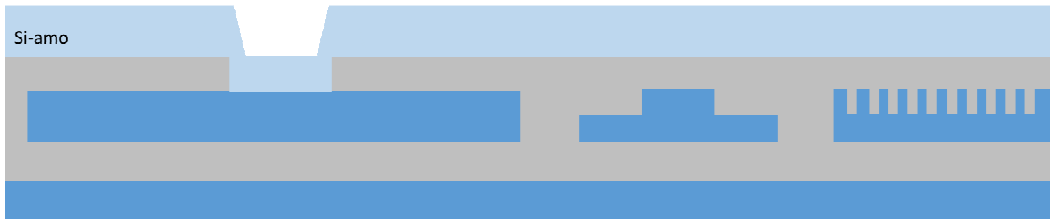
Hybrid III/V on Si DFB laser fabrication description



- Cavity patterning

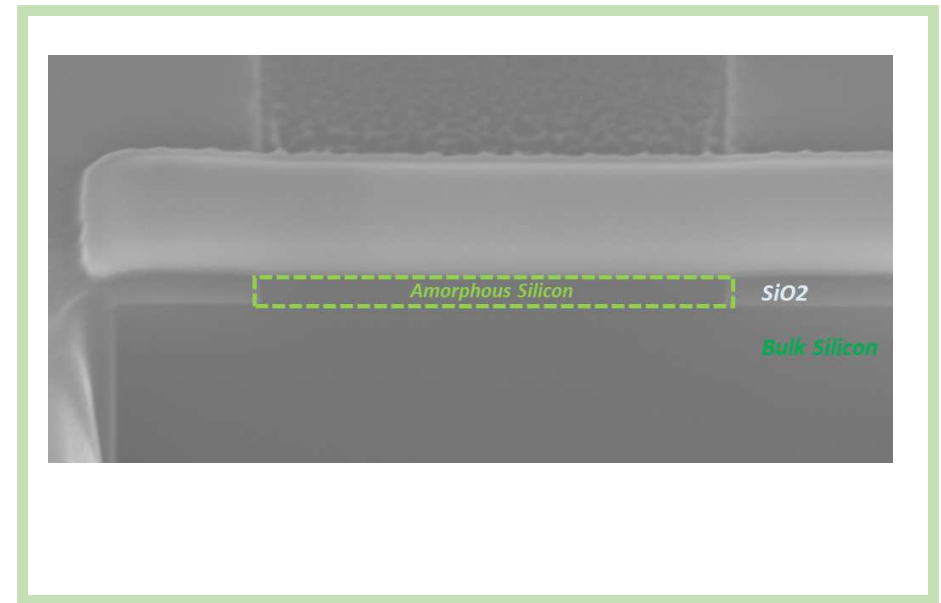


Hybrid III/V on Si DFB laser fabrication description



- Amorphous silicon deposition

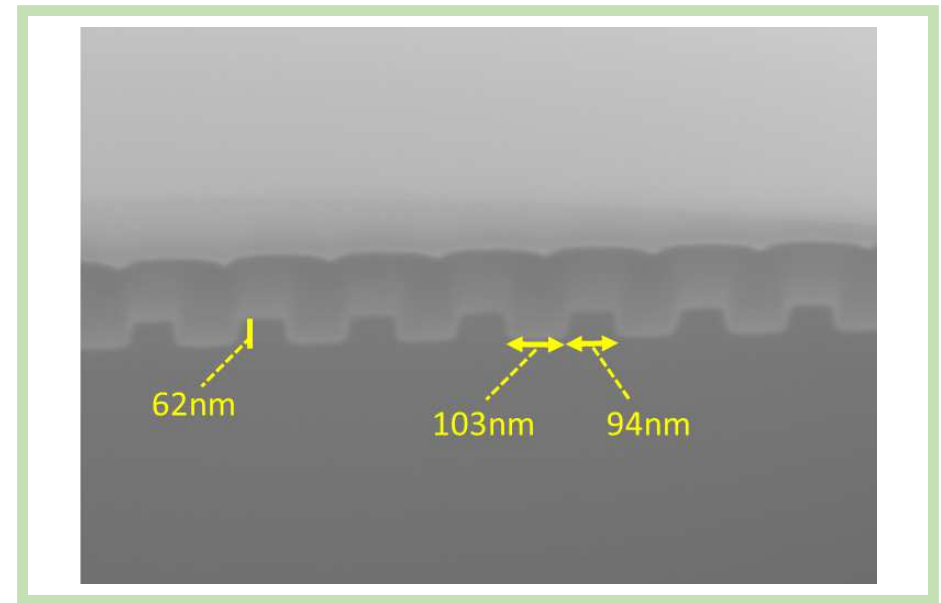
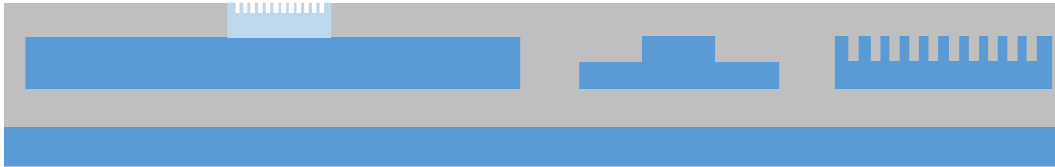
Hybrid III/V on Si DFB laser fabrication description



- Silicon Chemical Mechanical Polishing (EPD on SiO₂)

➡ Localized silicon thickening – no changes in the photonic core process

Hybrid III/V on Si DFB laser fabrication description



- Bragg reflector patterning – silicon partial etch

Hybrid III/V on Si DFB laser fabrication description

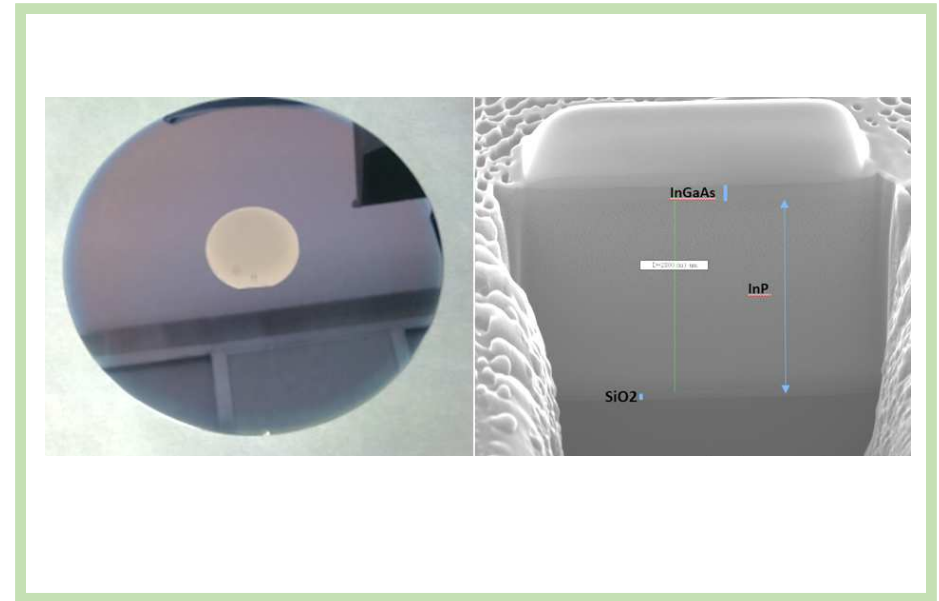


- Oxide encapsulation and planarization
- Surface preparation for bonding

Hybrid III/V on Si DFB laser fabrication description



- III-V wafer bonding
- Substrate removal



Hybrid III/V on Si DFB laser fabrication description



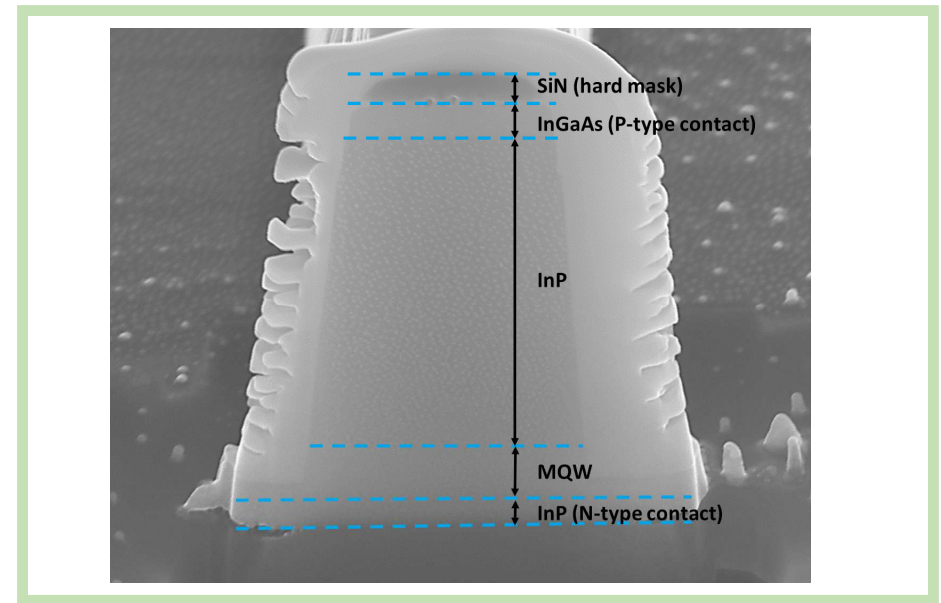
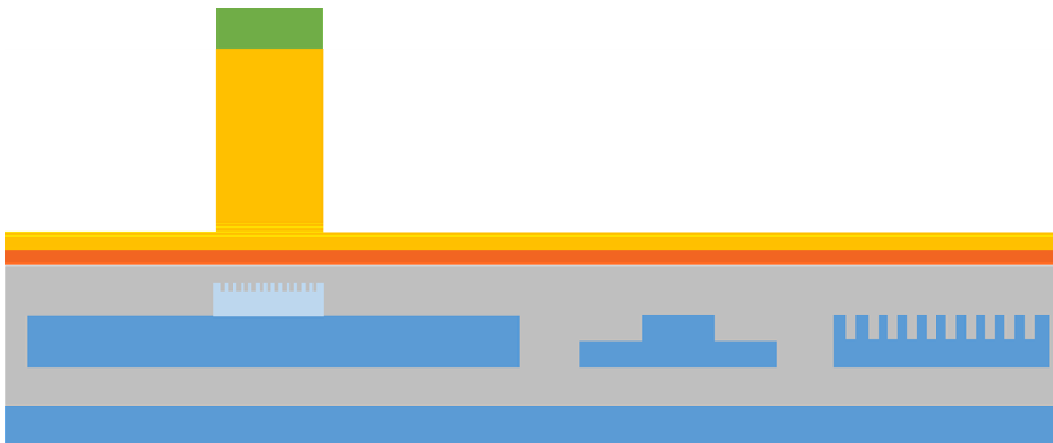
- Laser GAIN: PECVD SiN Hard mask deposition

Hybrid III/V on Si DFB laser fabrication description



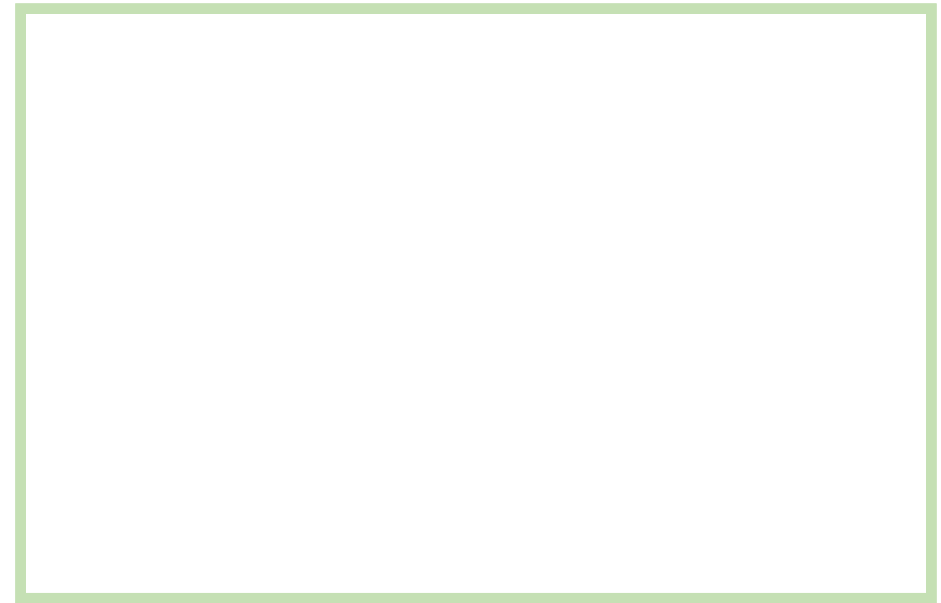
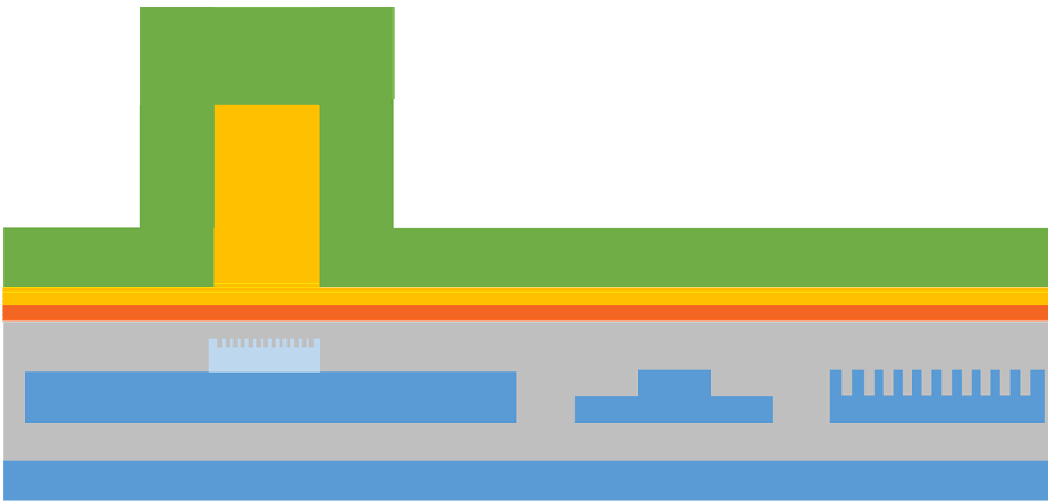
- Laser GAIN: Hard mask patterning

Hybrid III/V on Si DFB laser fabrication description



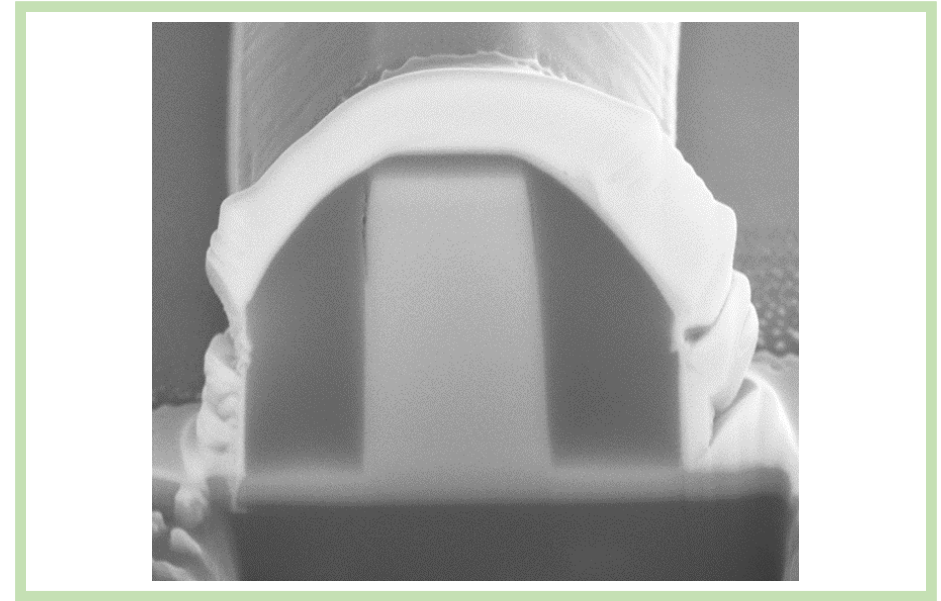
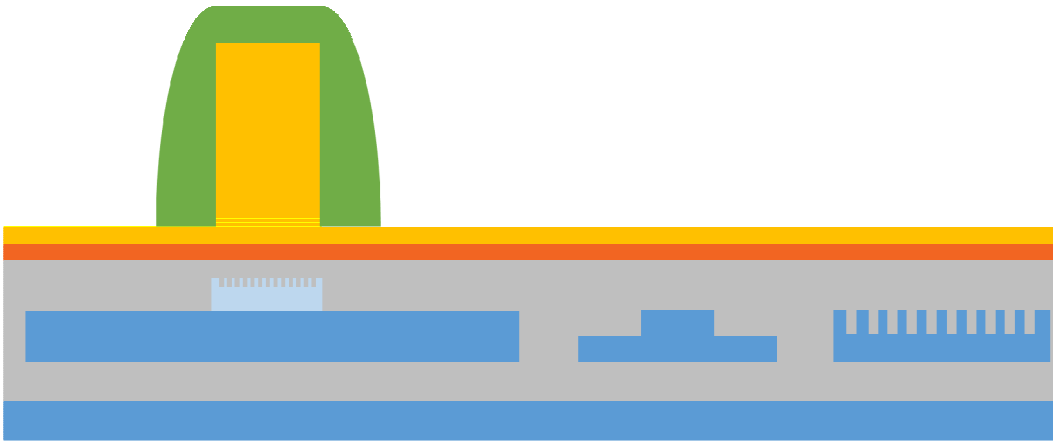
- Laser GAIN: InGaAs/InP dry etch with EPD on MQW

Hybrid III/V on Si DFB laser fabrication description



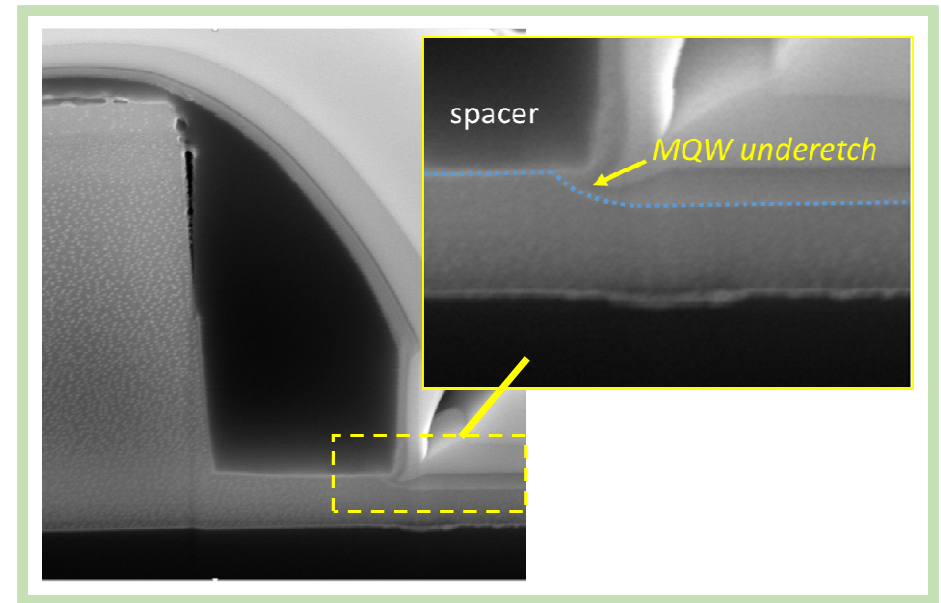
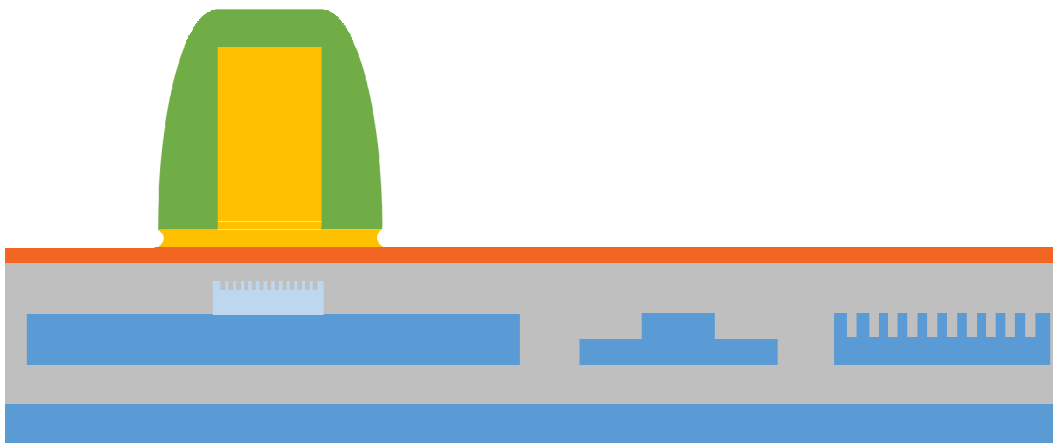
- Laser GAIN: PECVD SiN deposition

Hybrid III/V on Si DFB laser fabrication description



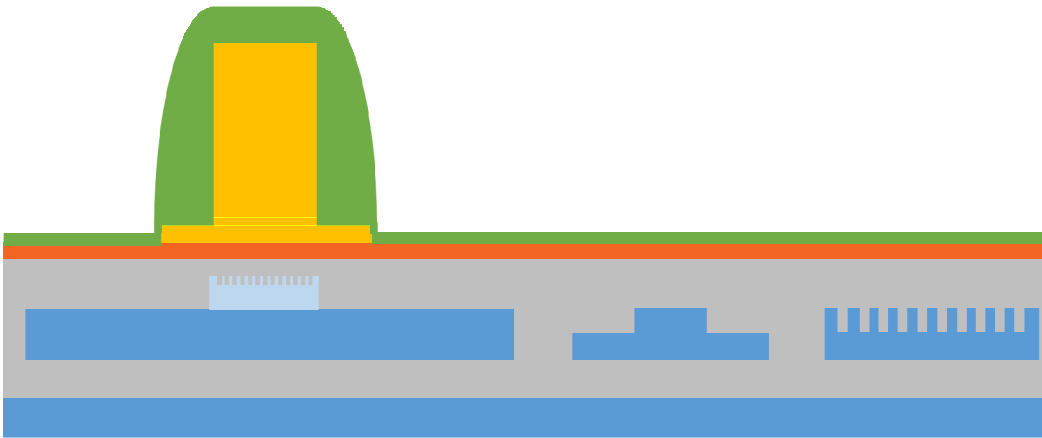
- Laser GAIN: SiN spacer patterning

Hybrid III/V on Si DFB laser fabrication description



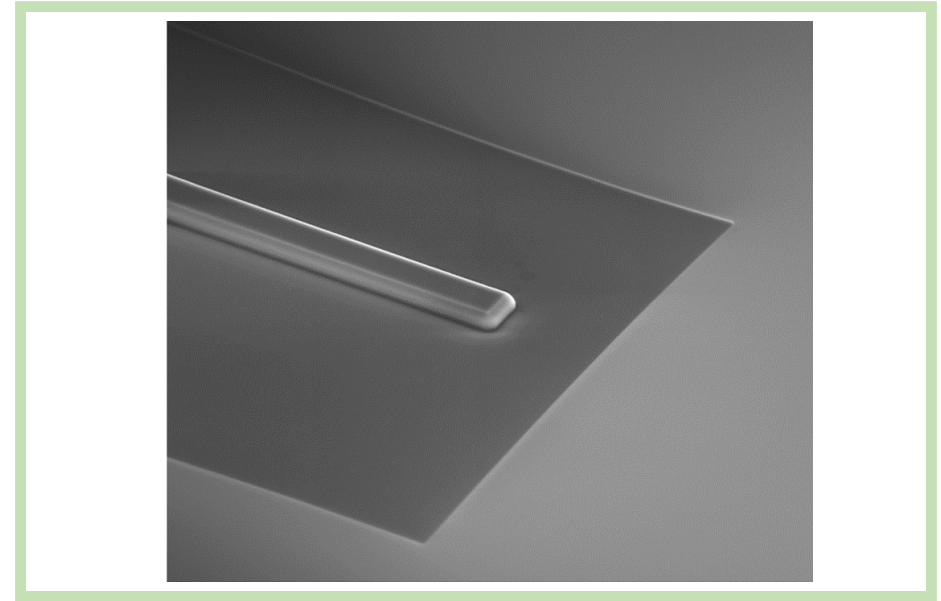
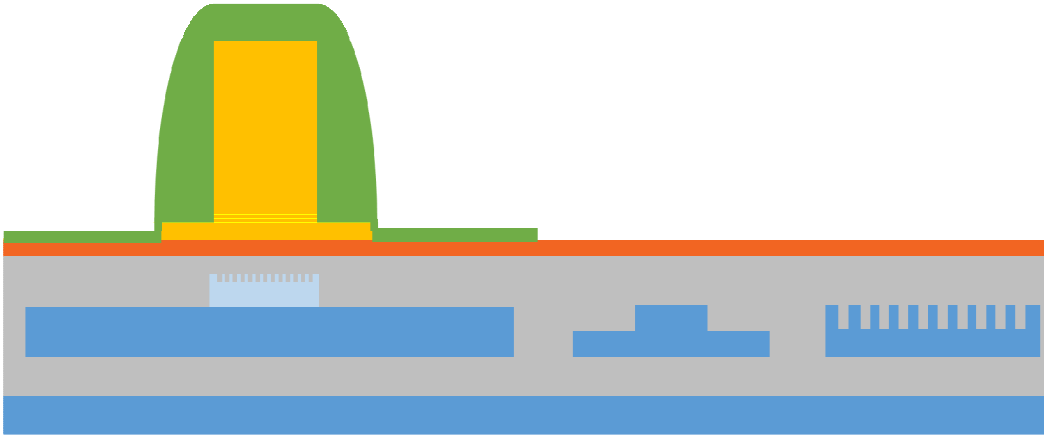
- Laser GAIN: Remaining MQW wet etch (diluted $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2$), highly selective vs. InP

Hybrid III/V on Si DFB laser fabrication description



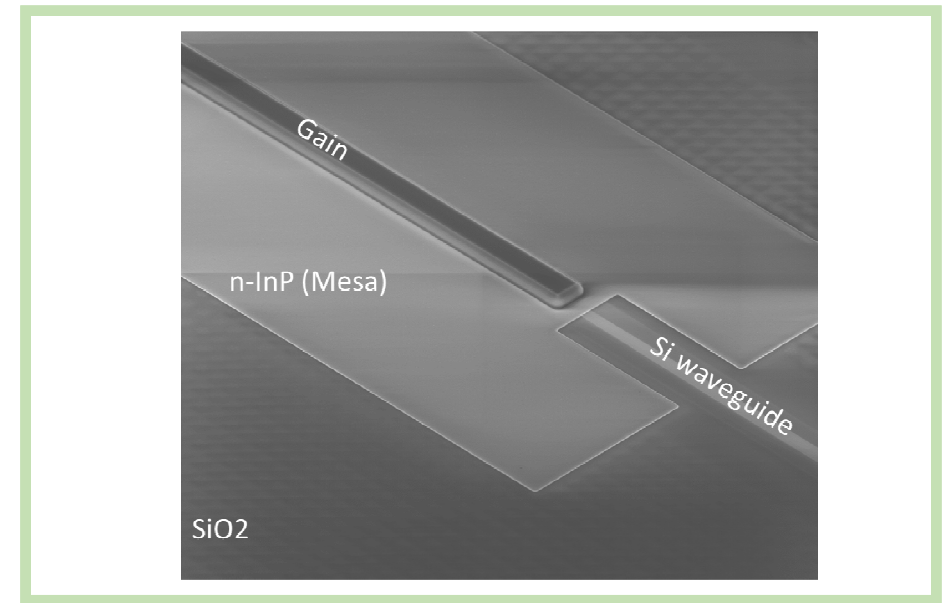
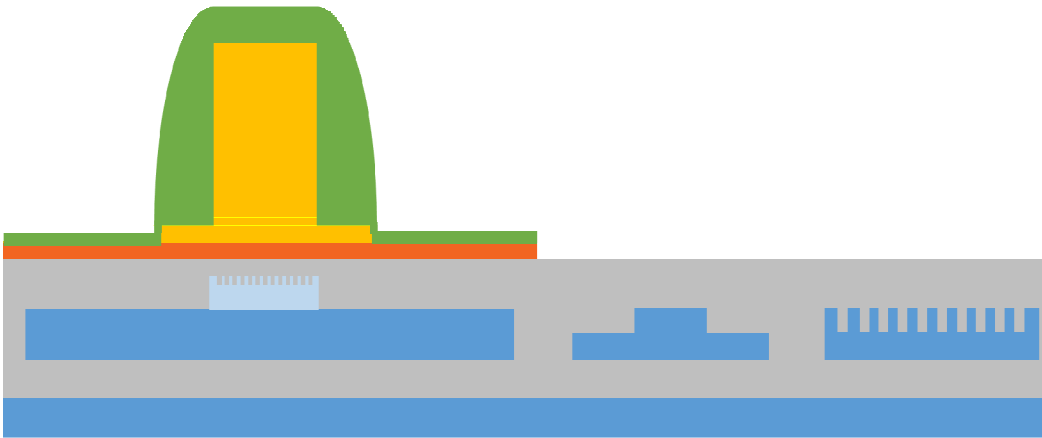
- Laser MESA: PECVD SiN Hard mask deposition

Hybrid III/V on Si DFB laser fabrication description



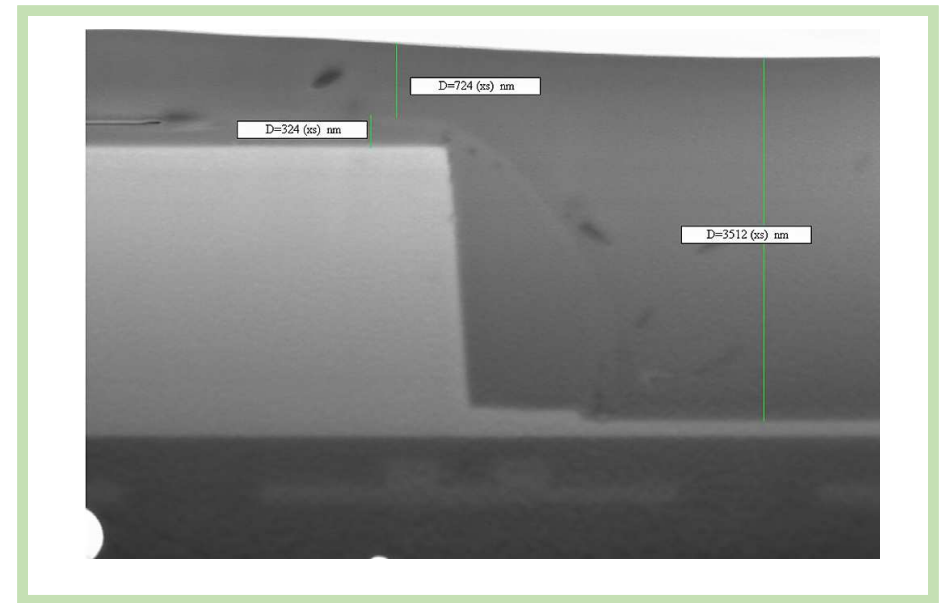
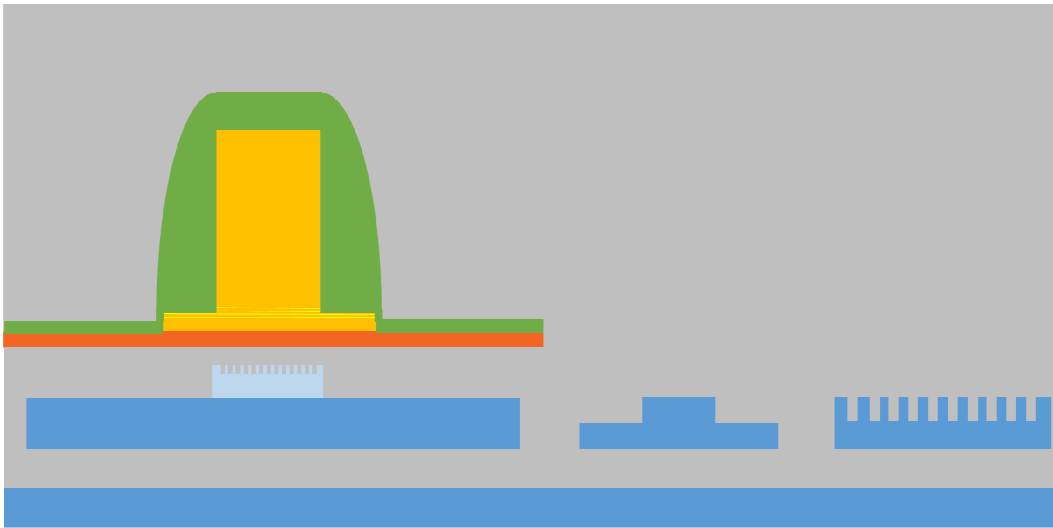
- Laser MESA: Hard mask patterning

Hybrid III/V on Si DFB laser fabrication description

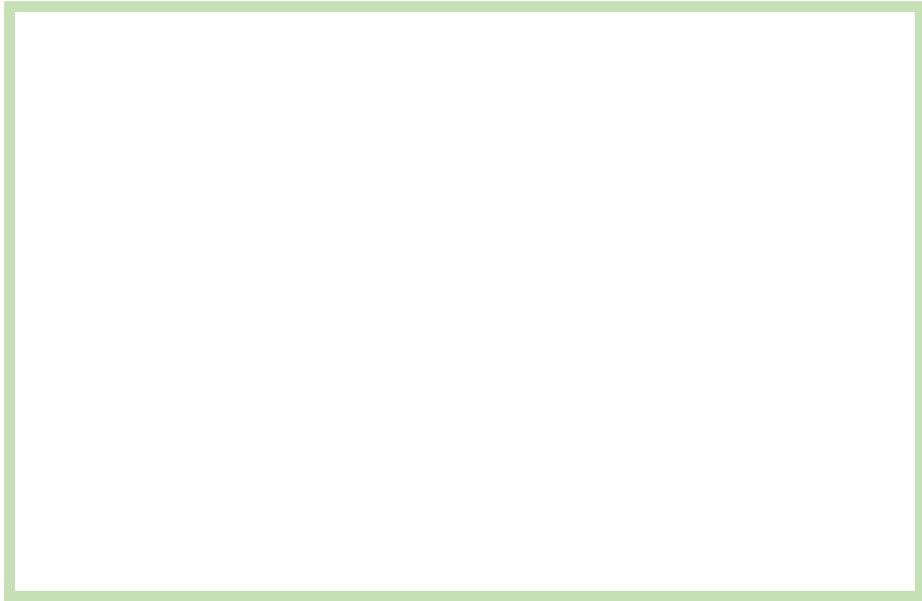


- Laser MESA: InP dry etch

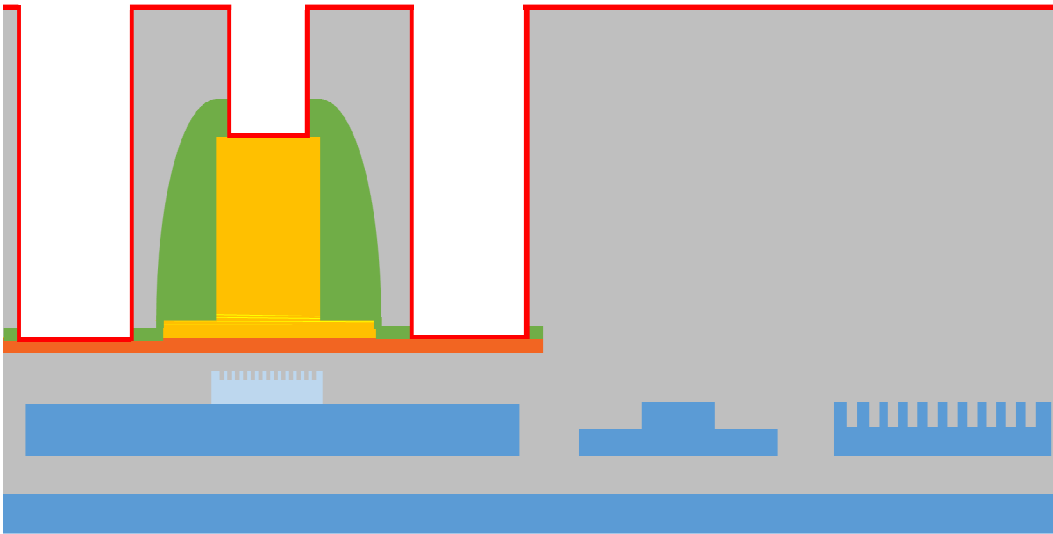
Hybrid III/V on Si DFB laser fabrication description



- Oxide encapsulation & planarization

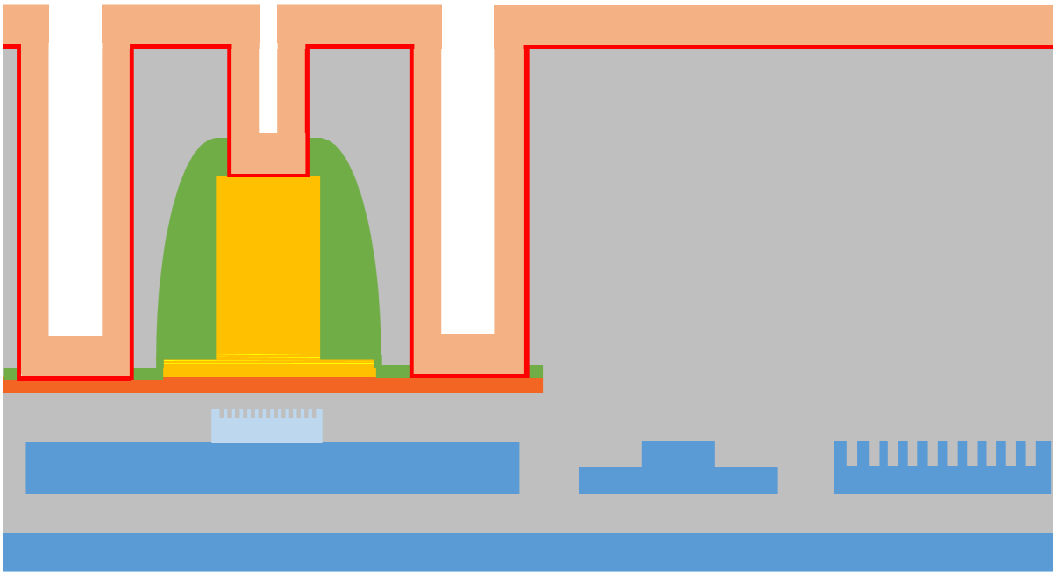


Hybrid III/V on Si DFB laser fabrication description



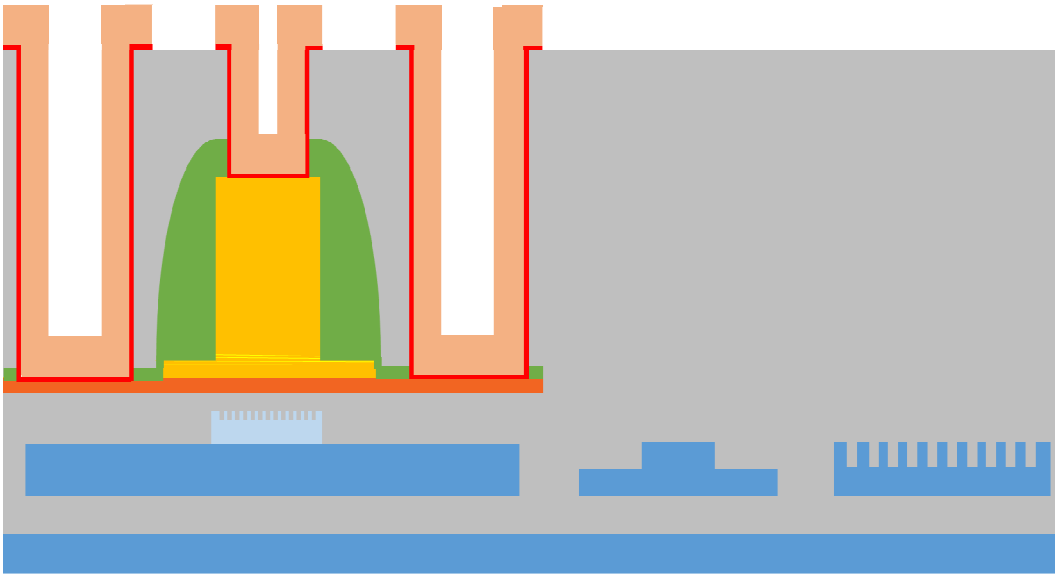
- Ni or Ni₂P deposition & annealing

Hybrid III/V on Si DFB laser fabrication description



- AlCu Deposition

Hybrid III/V on Si DFB laser fabrication description

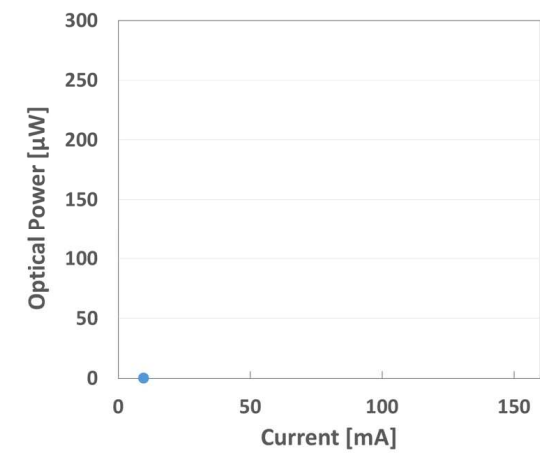
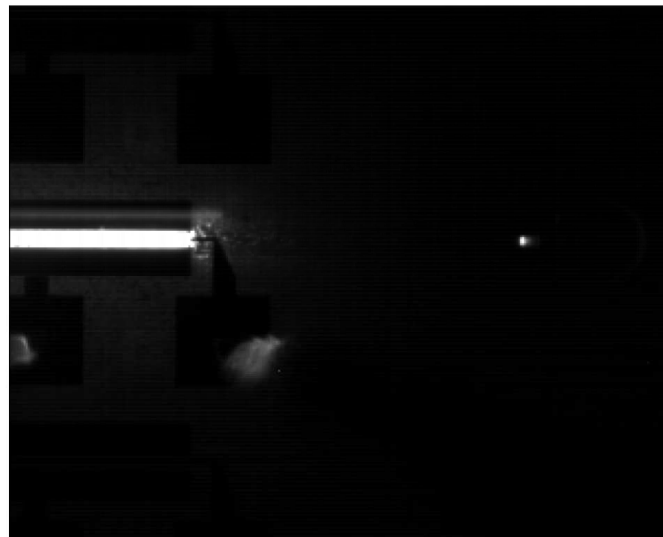
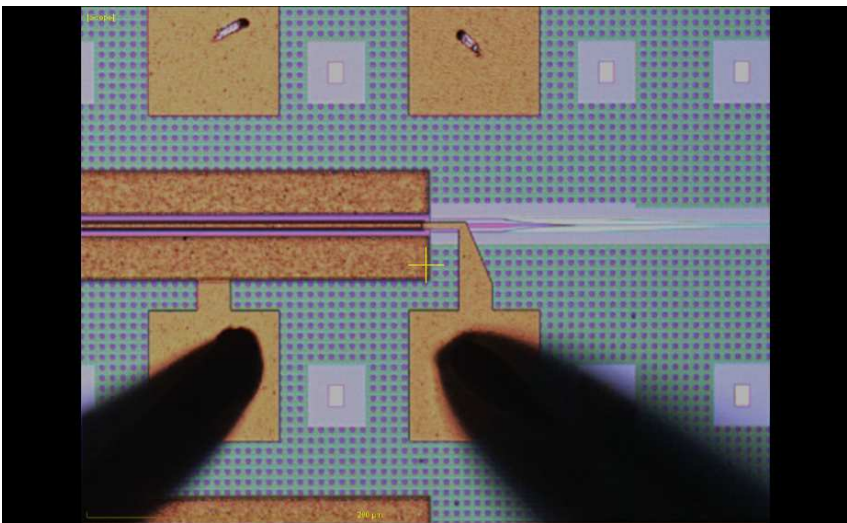
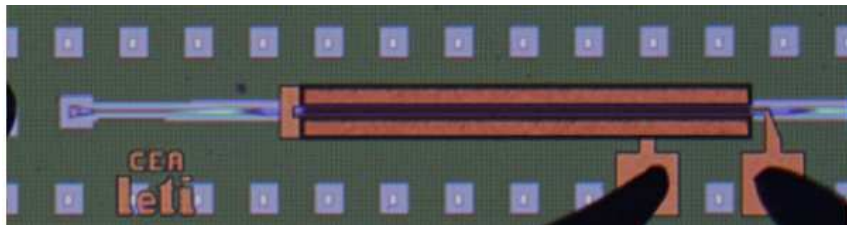


- AlCu patterning

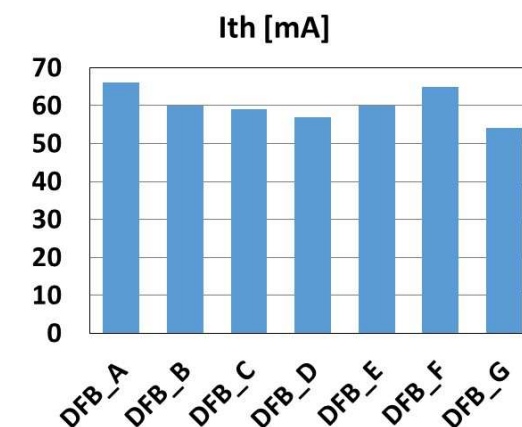
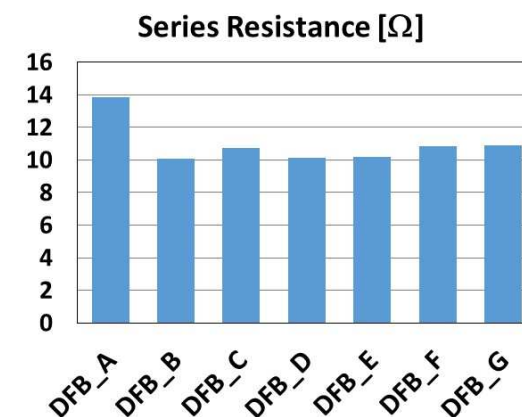
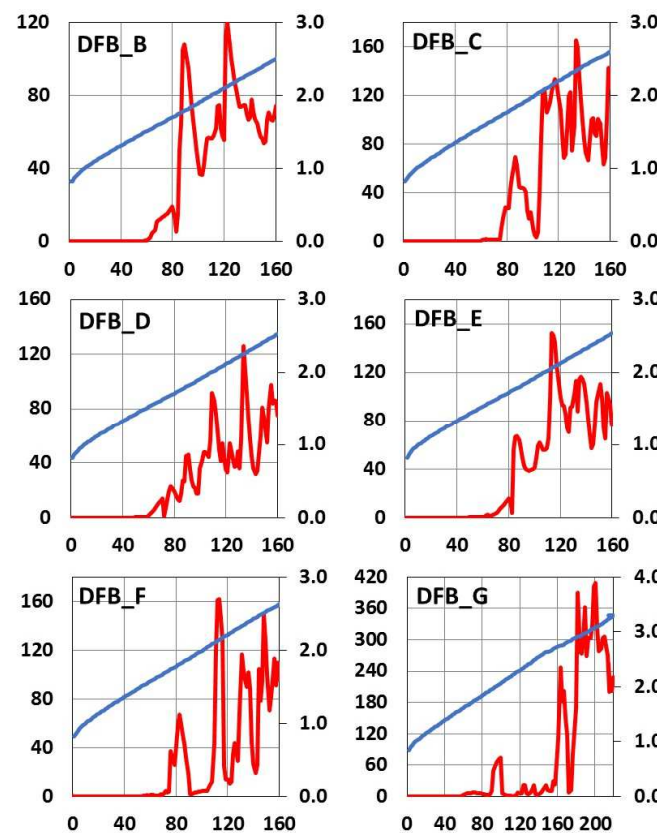
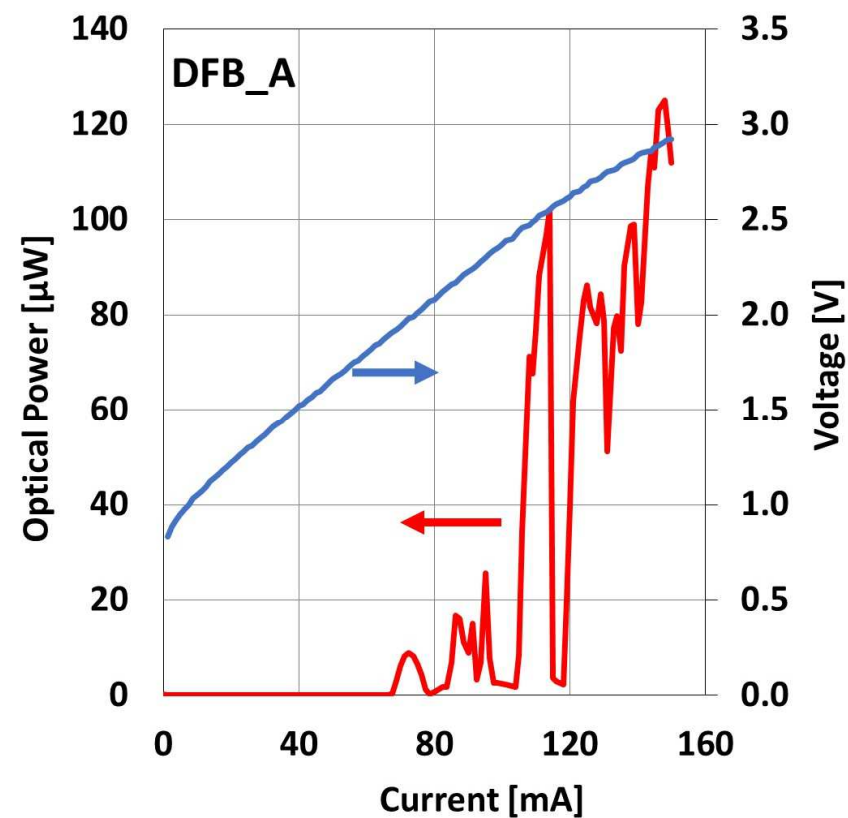
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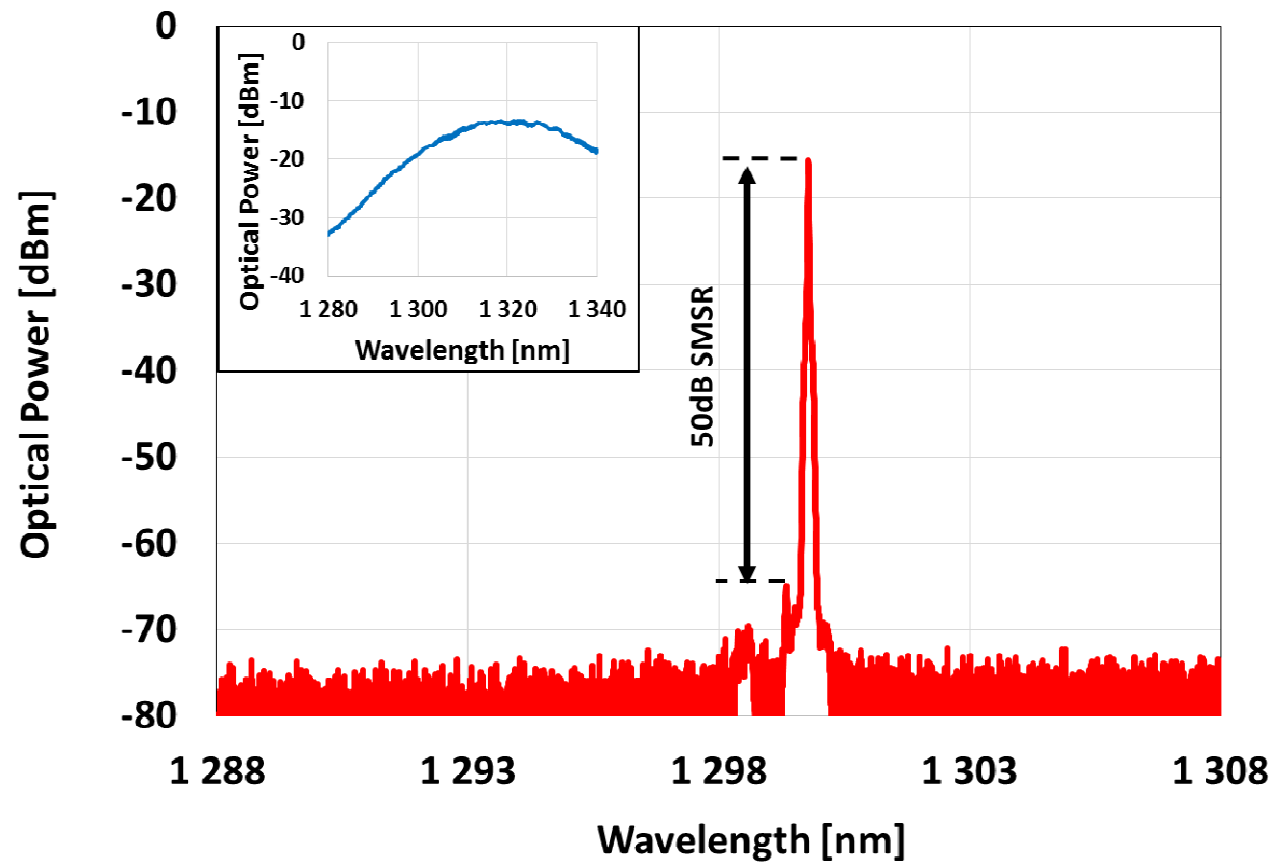
Optical Characterization



Optical Characterization: LIV characteristics

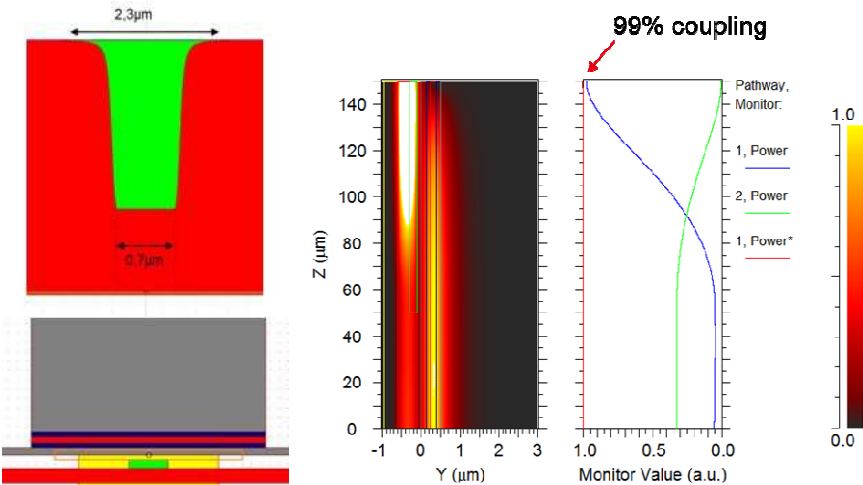


Optical Characterization: Spectrum



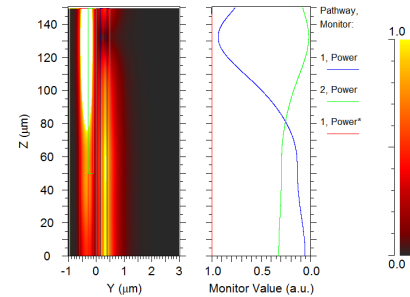
Result discussion: Impact of a-Si on laser operation

Standard model (Si mono only)

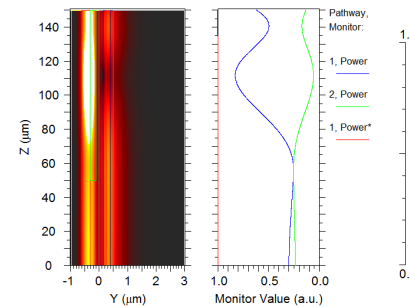


- With the same design, the thickness of amorphous silicon must be reduced to take into account the index difference of Si-amor (3.523 @ 1310nm) and Si-mono (3.506 @ 1310nm)

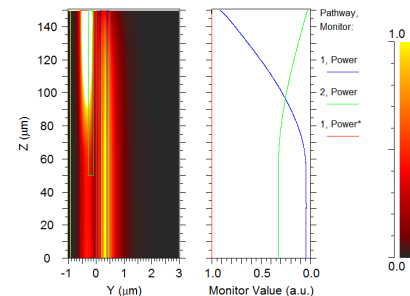
Same model Si-Amo / Si mono



- Si Amo 200nm
77% coupling => Cavity instability



- Si Amo 220nm
Adiabatic coupling failure
Mode less confined on the QW => less power



- Si Amo 180nm
Adiabatic coupling almost achieved
Good mode confinement

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Conclusion & Perspectives

- The monolithic integration of a fully **CMOS compatible** hybrid DFB laser on a 200mm silicon photonics platform has been demonstrated.
- Amorphous silicon is used to **locally thicken the silicon with a damascene process** to build the laser with no impact on the photonic core process.
- The conventional Au-based contacts used in III-V laser are replaced by **Ni-based alloyed contact** with no penalties on the series resistance.
- Single wavelength behavior demonstrated with **SMSR reaching 50dB**.
- Lasing threshold around 60 mA with an output power in the waveguide $> 3\text{mW}$ at 160mA

Conclusion & Perspectives

- New iteration with design optimized for Si stack including part of amorphous silicon.
- W-plugs and multi-level planar BEOL
- Integration on the full platform (with active devices)
- Process with III-V die bonding instead of wafer bonding

