PHOTONICS RESEARCH GROUP

III-V/silicon photonics for microwave photonics

The case of an electro-photonic frequency converter

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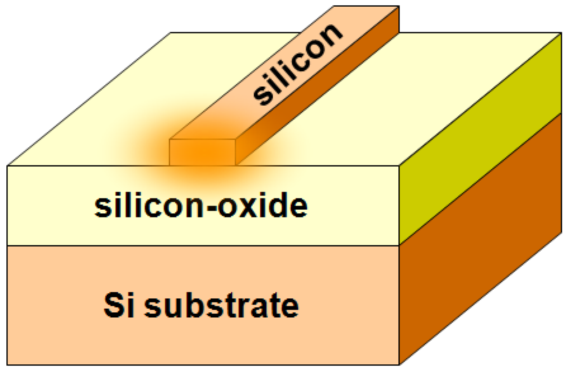
Outline

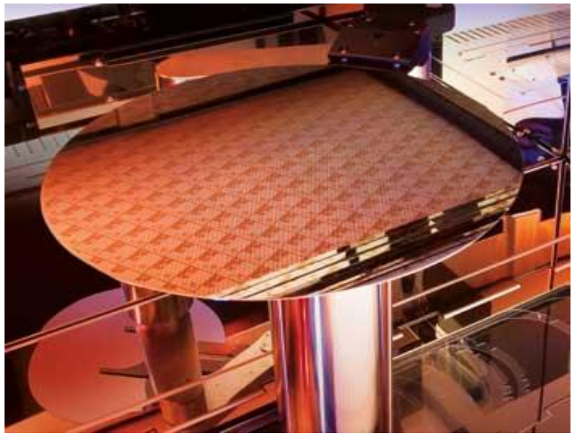
- Silicon photonics
- III-V/Silicon photonics
- Electro-photonic frequency converter as case for MWP applications

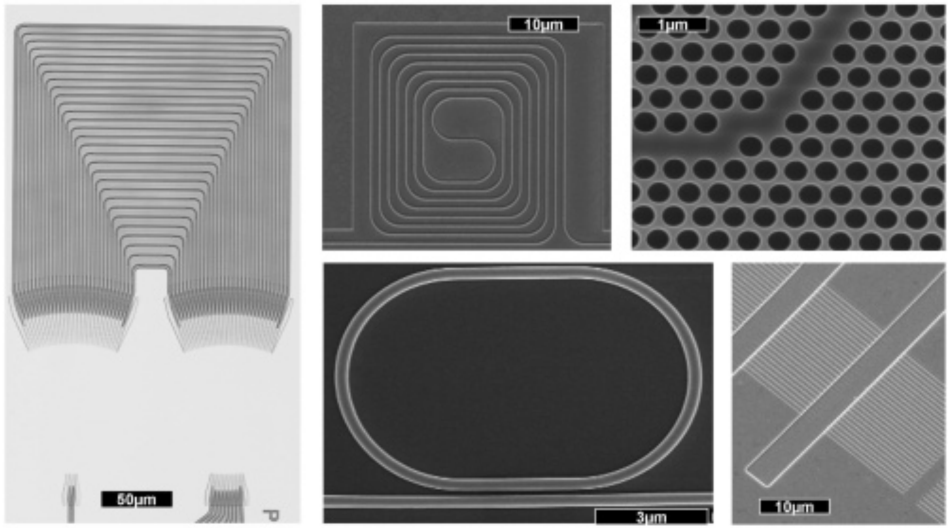
Silicon photonics

High index contrast waveguide structures

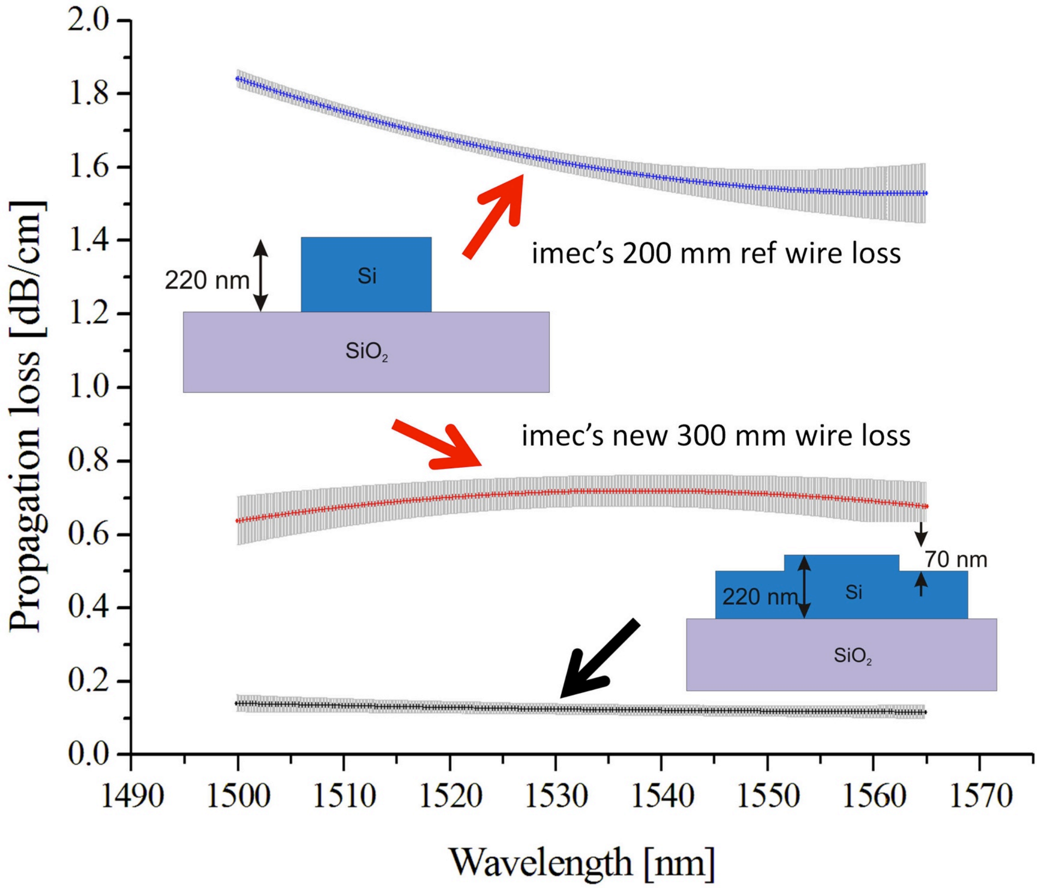
- Size reduction of photonic integrated circuits
- CMOS fabrication technology (200mm/300mm)
- High performance passive devices
- High performance Ge photodetectors
- High performance electro-optic devices

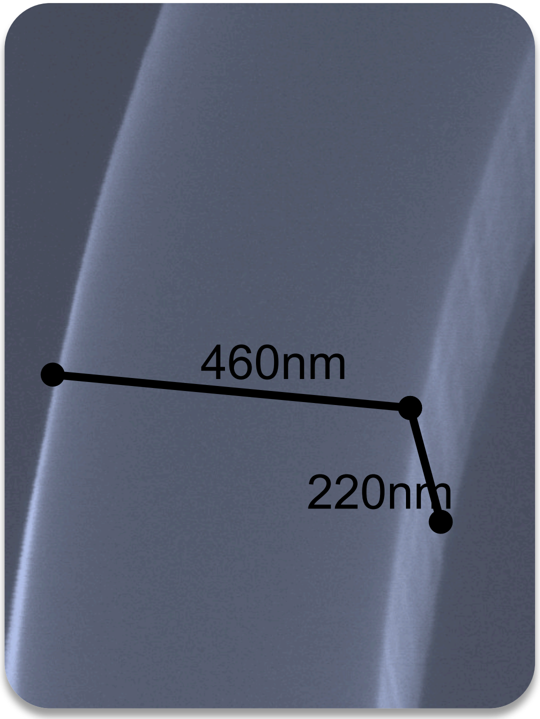


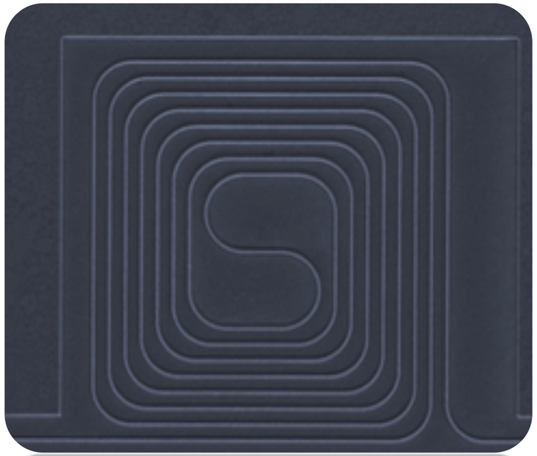




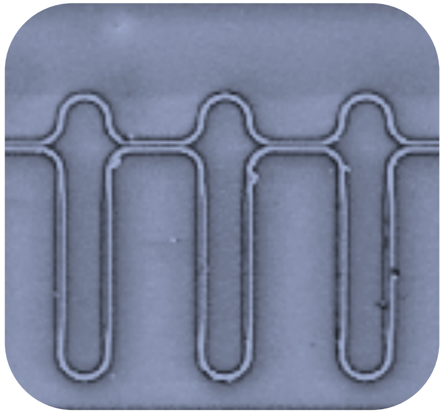
Silicon wire waveguides





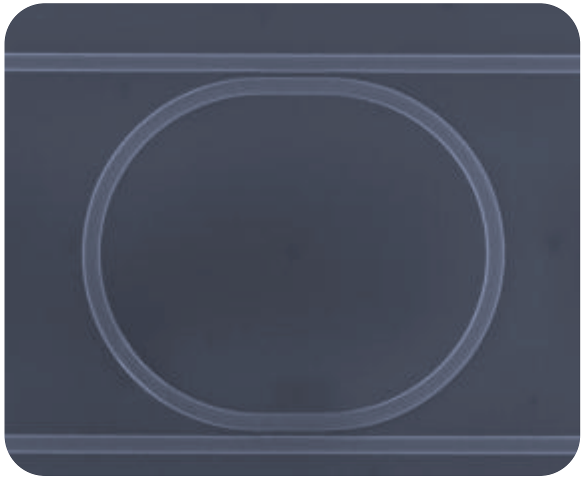


Spectral filters

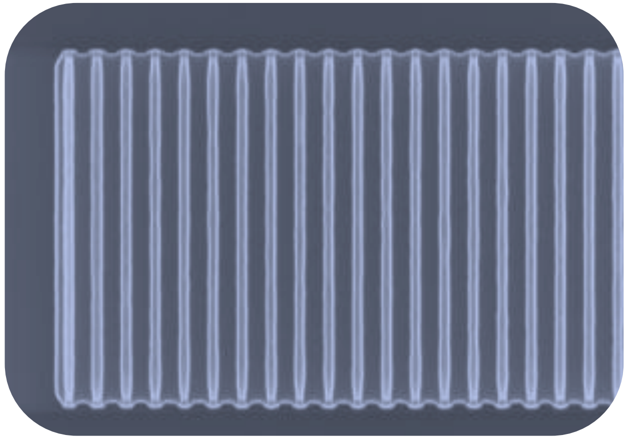


Mach-Zehnders

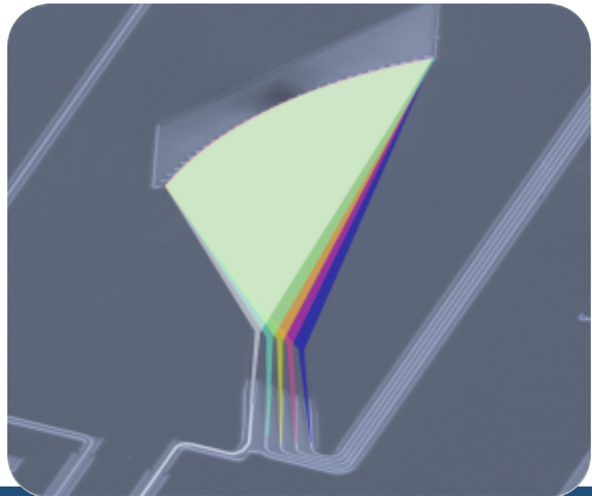
Ring resonators

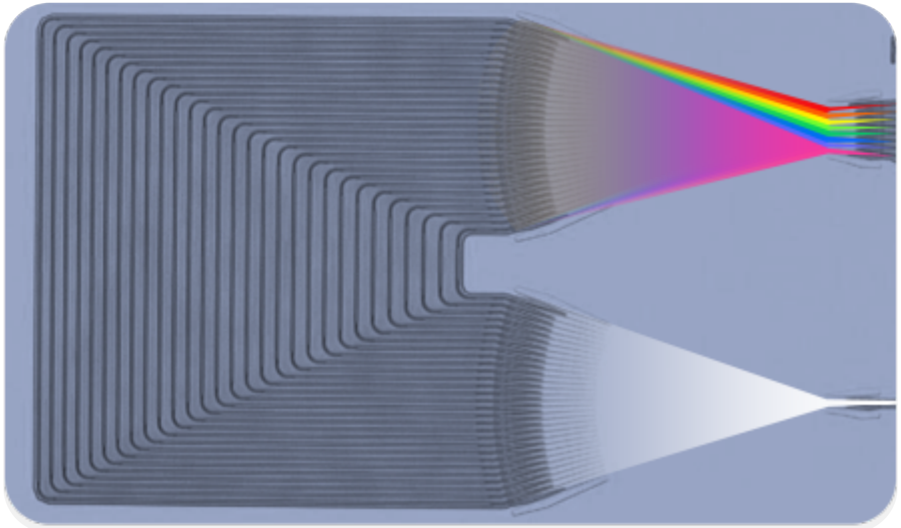


Bragg reflectors



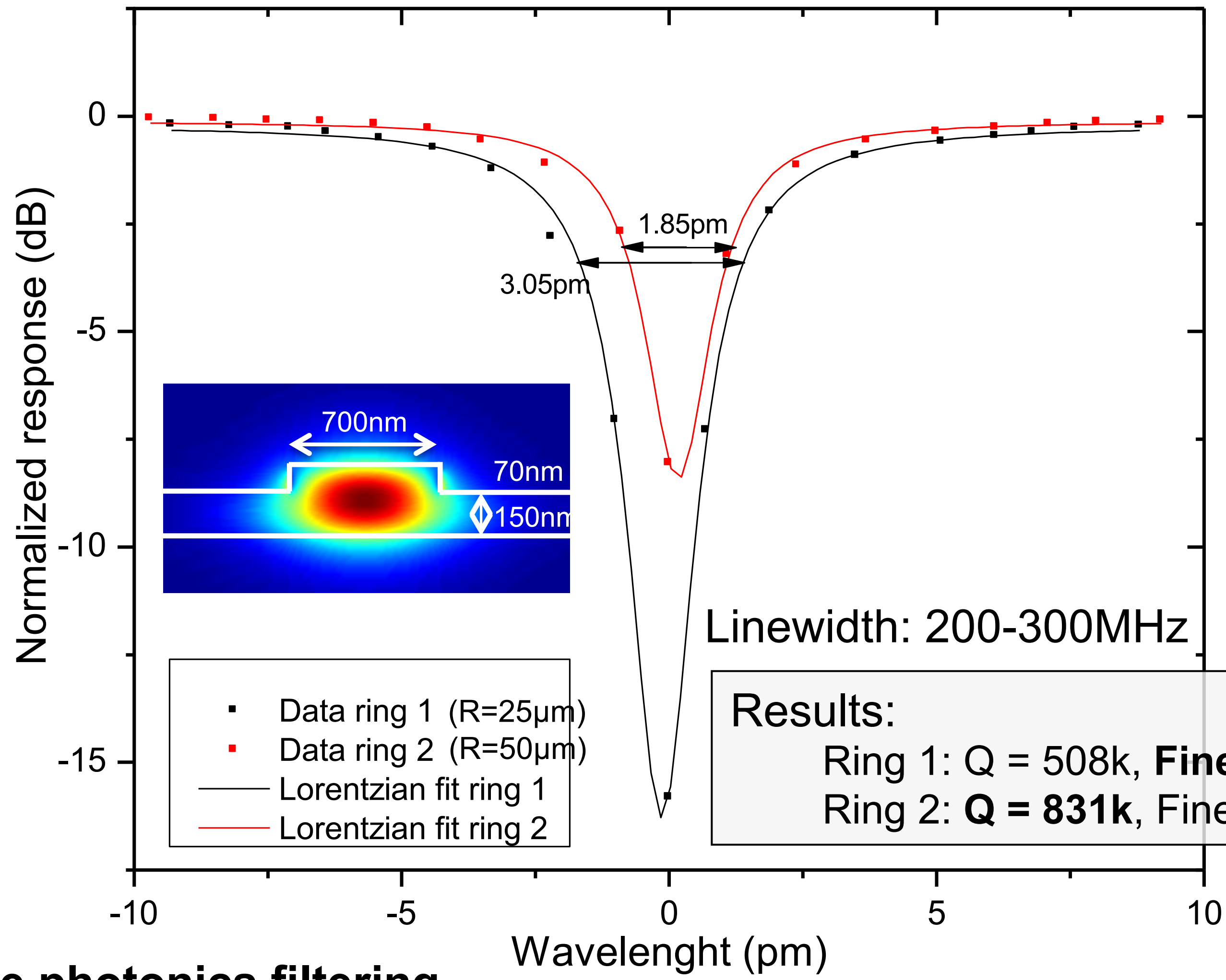
Echelle gratings





Arrayed waveguide gratings

Example: ring resonators with intrinsic Q of $8*10^5$



Results:

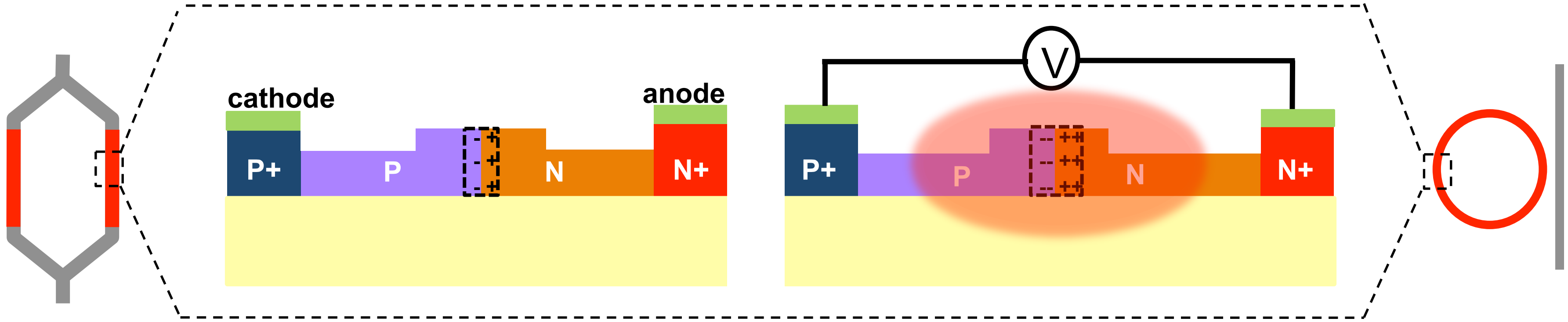
Ring 1: Q = 508k, **Finesse = 1340**

Ring 2: **Q = 831k**, Finesse = 1067

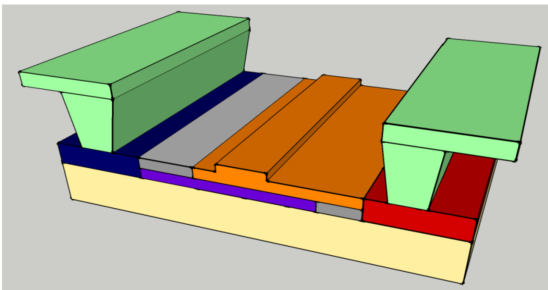
Microwave photonics filtering

High speed optical modulators

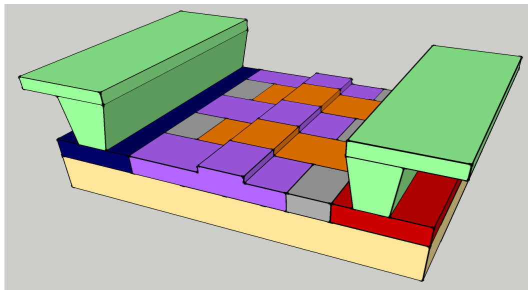
Based on carrier depletion in a lateral p-i-n diode => phase change



Doping patterns to enhance the modulation efficiency, linearity,…

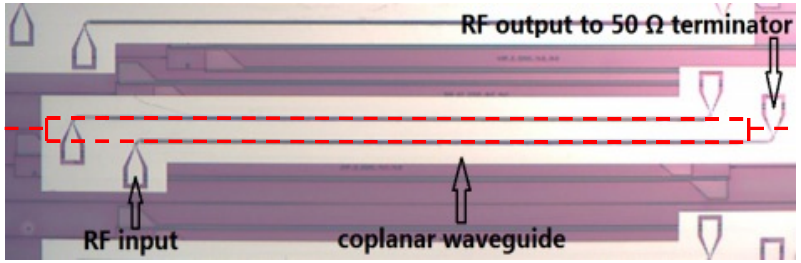


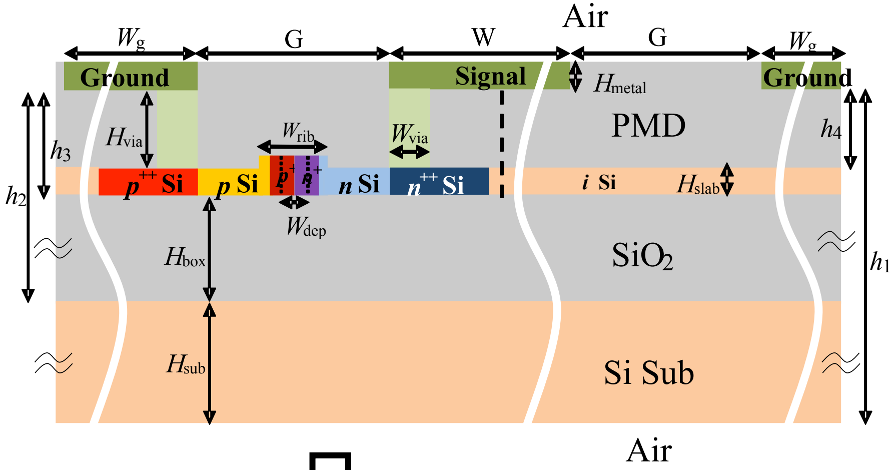
Vertical PN junction



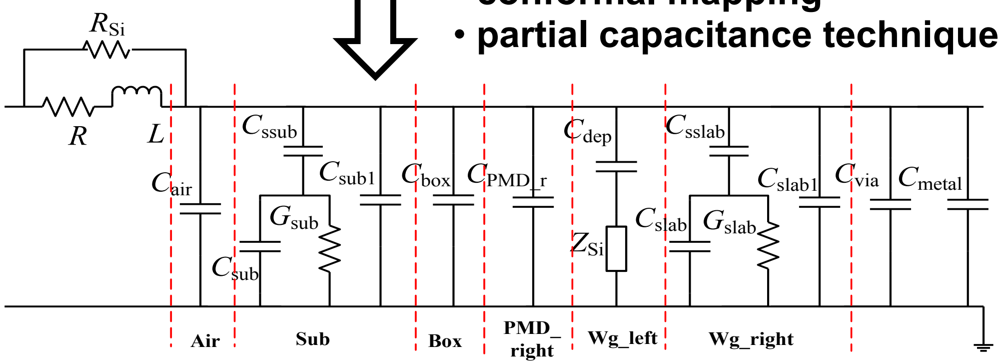
Interdigitated PN junction

High speed optical modulators



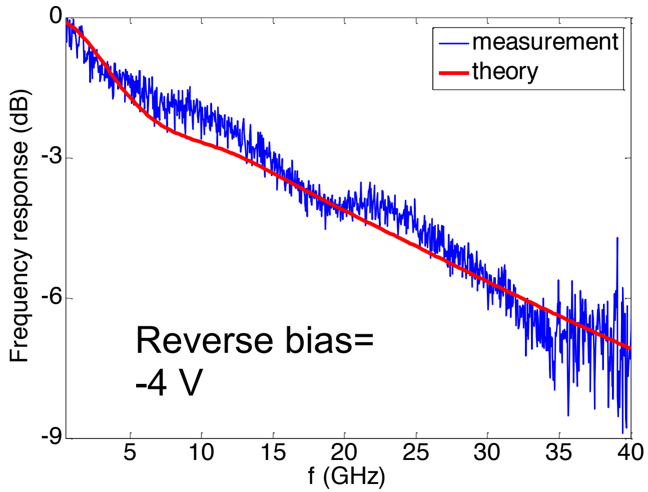


- **conformal mapping**
- **partial capacitance technique**



Bandwidth of the traveling wave design is determined by:

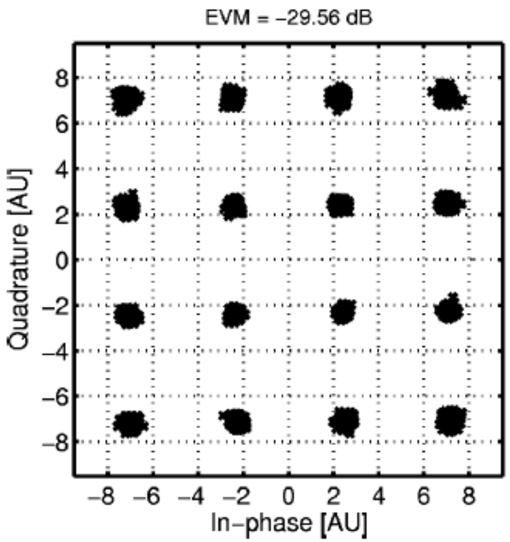
- **impedance match;**
- **RF attenuation;**
- **velocity match between RF and lightwave.**

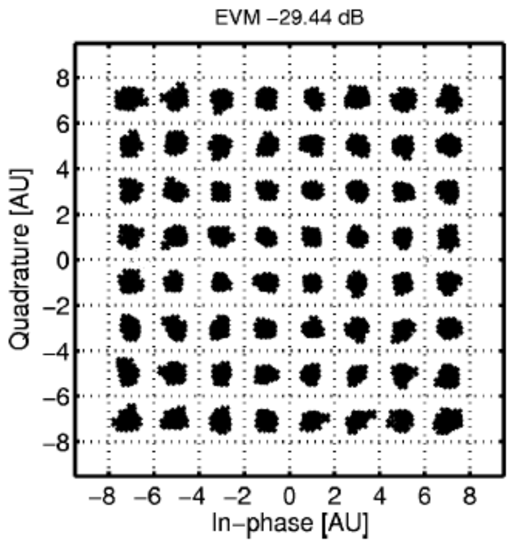


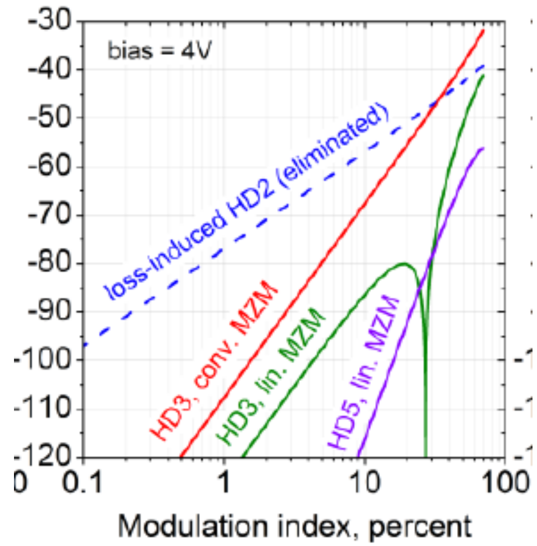
- f_{3dB} of $|S_{21}|$ is **15** GHz for **3** mm traveling wave electrode;
- f_{3dB} of $|S_{21}|$ is **5.5** GHz for **1.5** mm lumped electrode.

High speed optical modulators

- Currently most focus is on digital applications
- Literature on linear modulation in silicon is emerging [1] [2]





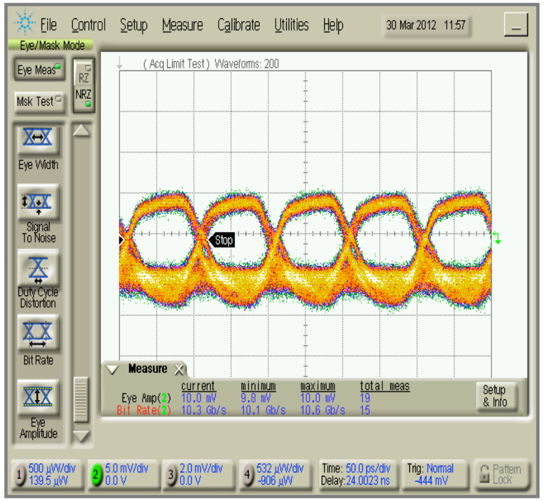


[1] A Silicon modulator enabling RF over fiber for 802.11 OFDM signals, JSTQE 16(1), p. 141 (2010)
[2] Broadband linearized silicon modulator, Opt. Expr. 19(5), p. 4485 (2011) (figure b)

Ge photodetectors

Process is currently being developed in imec

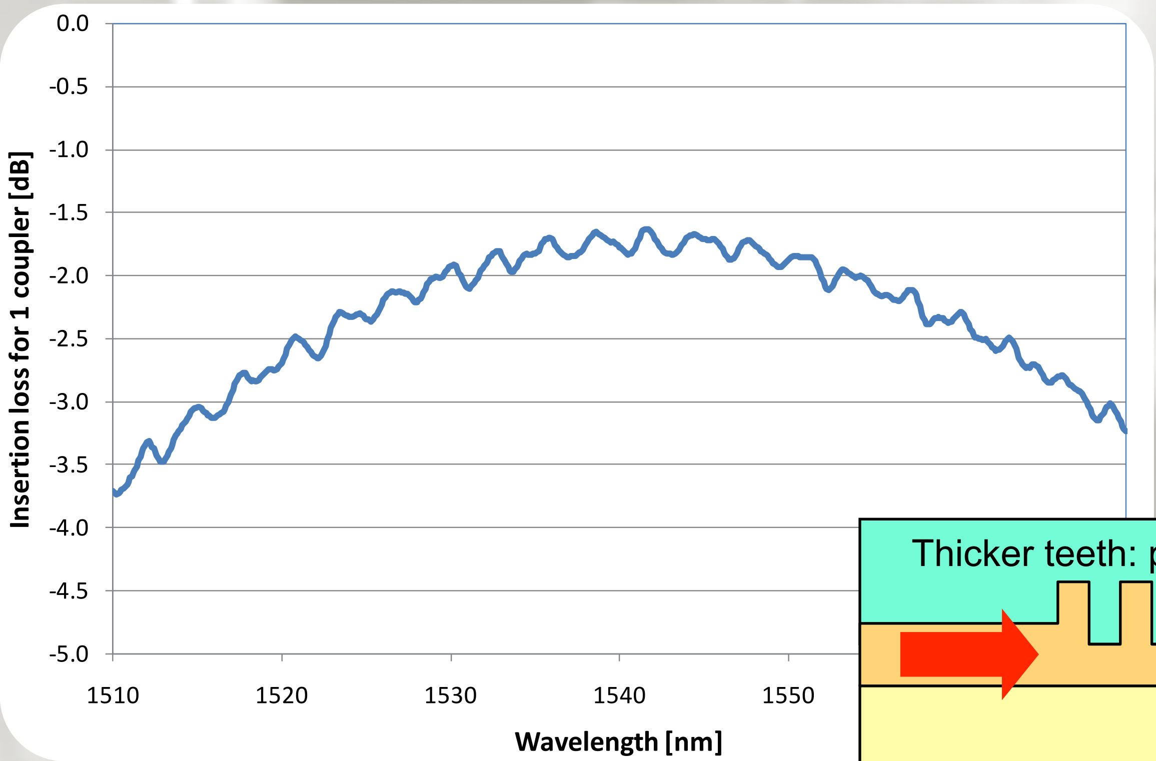
- First results: 10Gbit/s operation
- 100GHz bandwidth in a single PD and 10Gb/s operation in a balanced configuration has been shown (process: CEA-LETI)

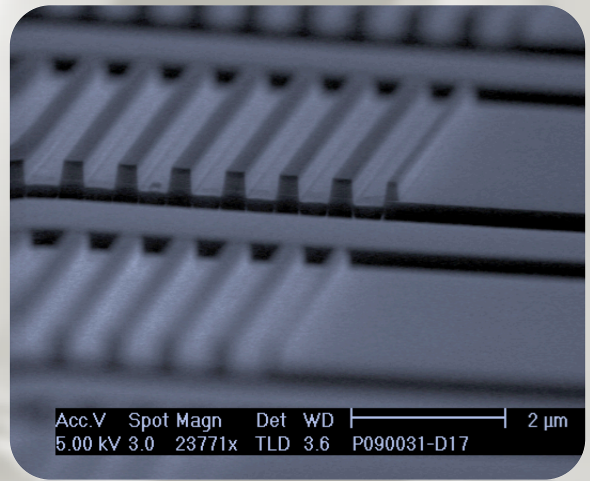


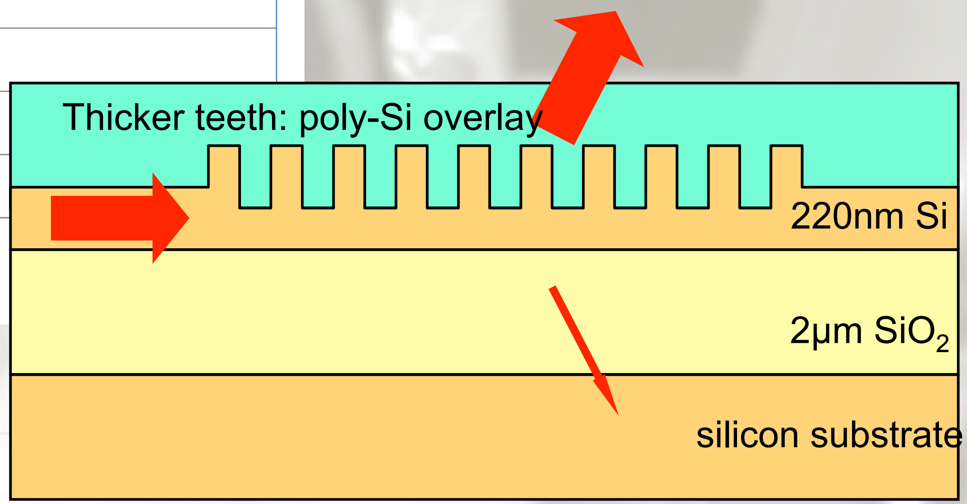
[1] Zero-bias 40Gbps Ge waveguide photodetector on Si Opt Expr 20(2), p.1096-1103

High-efficiency fiber-to-chip grating couplers

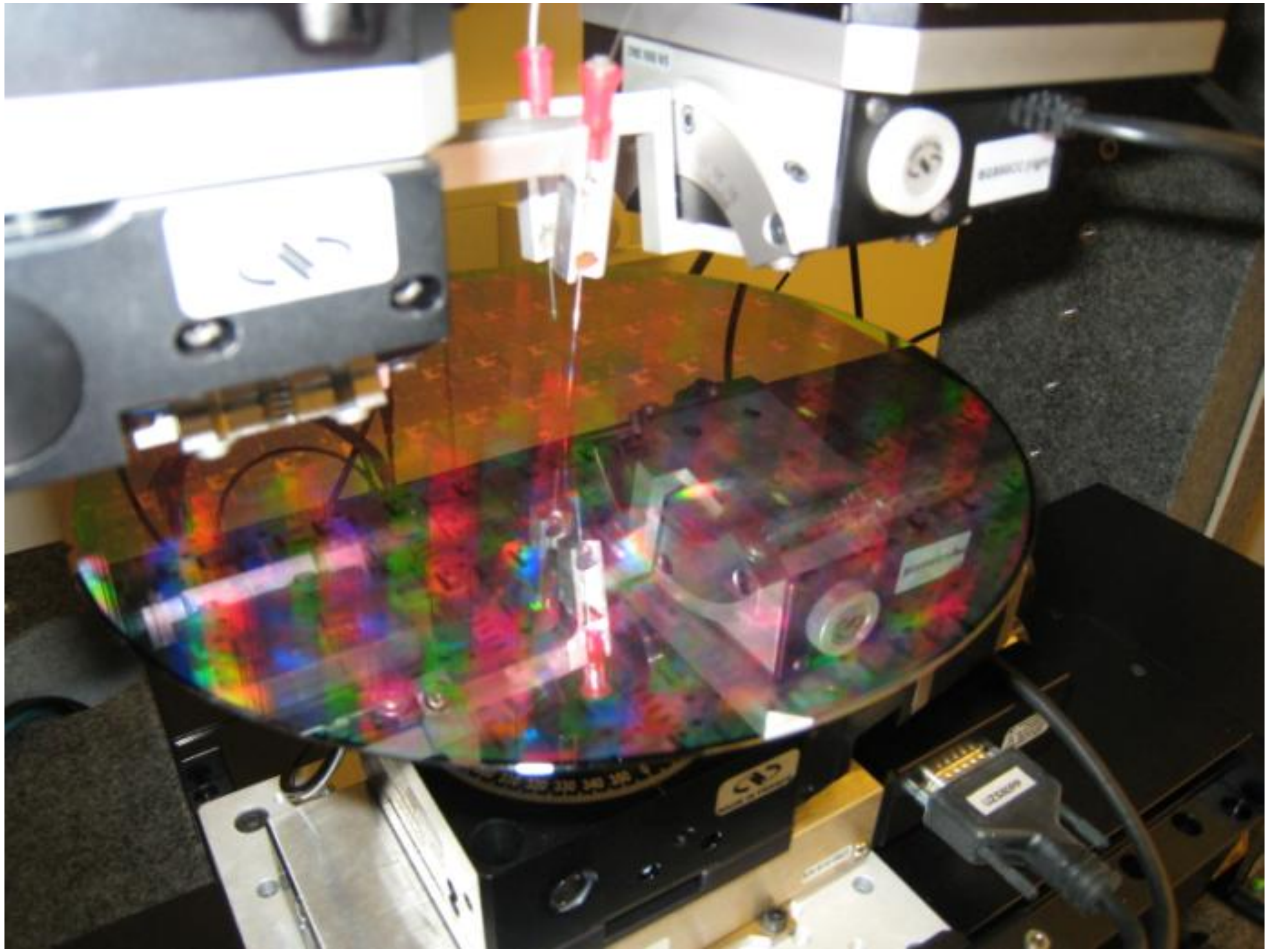
-1.6dB coupling efficiency







Automated wafer-scale measurement set-up



Grating couplers enable wafer-scale testing of the photonic integrated circuits

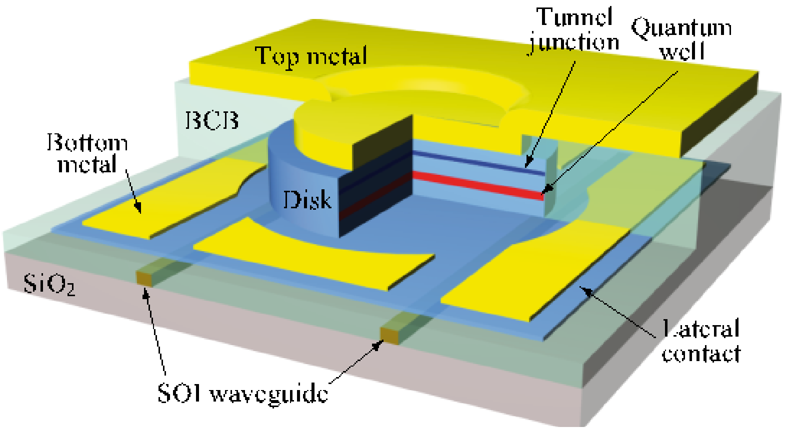
Outline

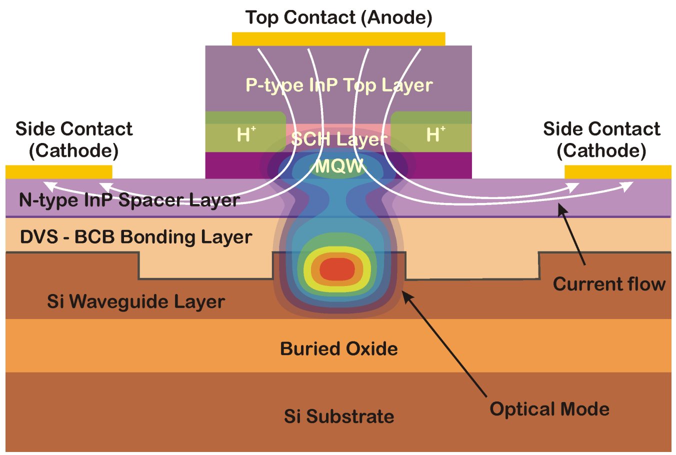
- Silicon photonics
- **III-V/Silicon photonics**
- Electro-photonic frequency converter as case for MWP applications

Silicon ++ photonics

Integration of light sources and optical amplifiers

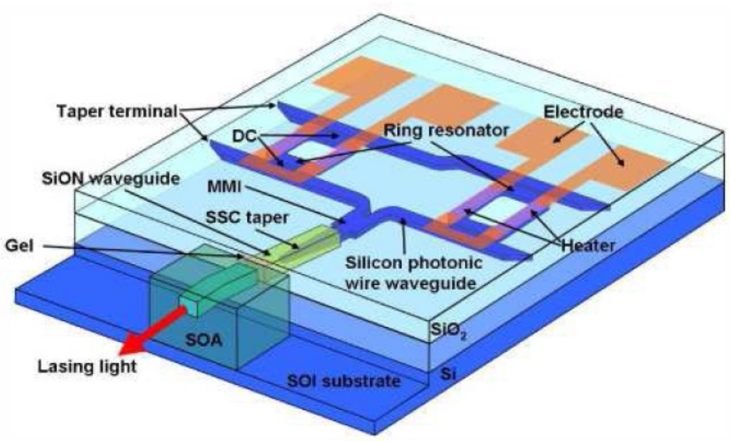
- Completes the set of building blocks
- Heterogeneous integration of III-V semiconductors
  - state-of-the art electrically injected light sources
  - Large design space and many technological choices





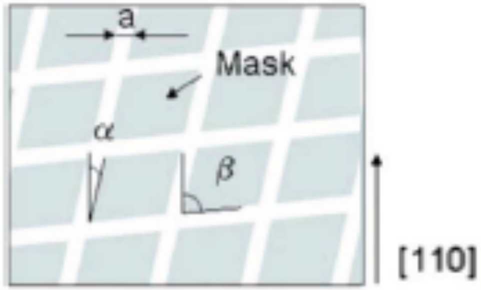
III-V integration on SOI

Hybrid / flip chip integration



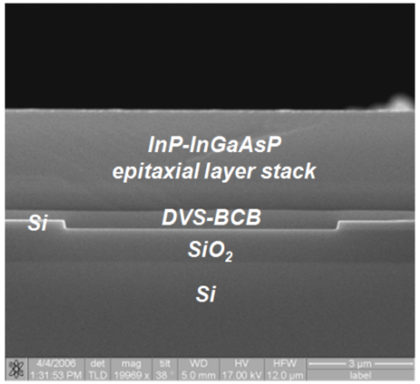
Song e.a. OE 17, 14063-14068 (2009)

III-V on Si heteroepitaxy



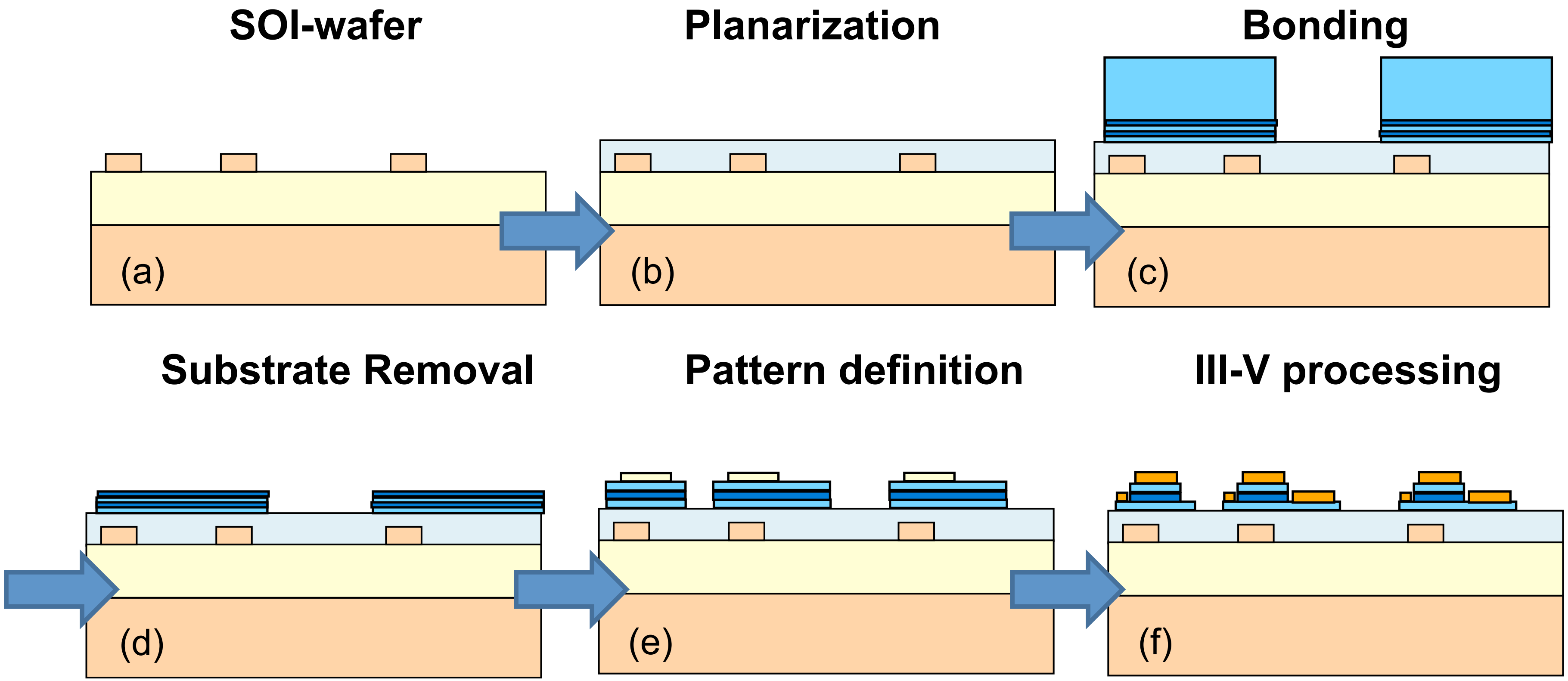
Junesand e.a., IPRM 2009 pp. 59

Wafer bonding



Roelkens e.a., LPR 2010

III-V integration on SOI

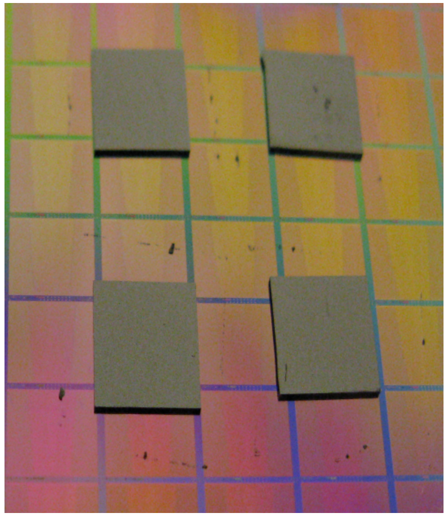


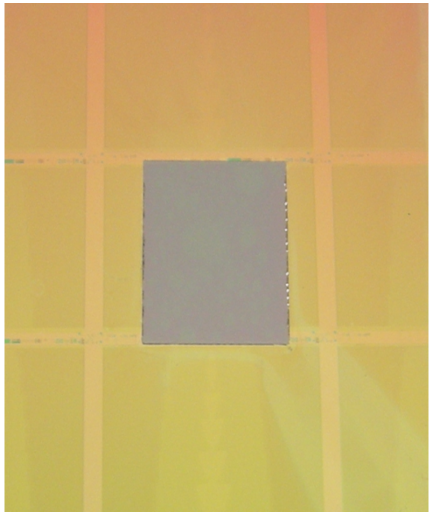
An adhesive bonding layer (DVS-BCB polymer) is used

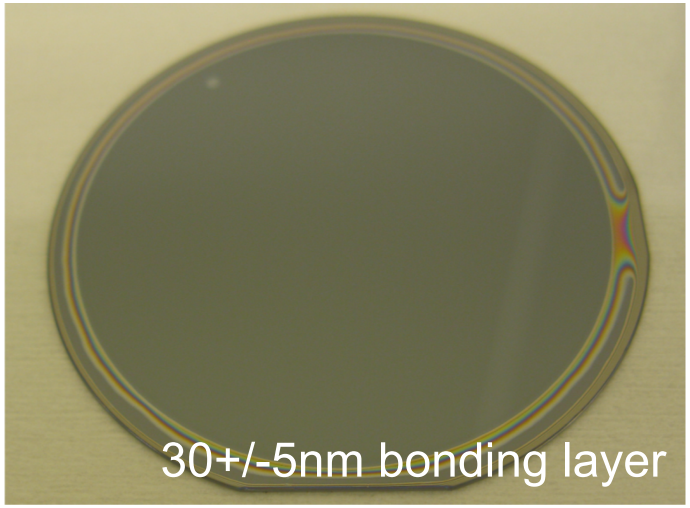
- Large range of bonding layer thicknesses (20nm to 2µm)
- Requirements on wafer quality are relaxed

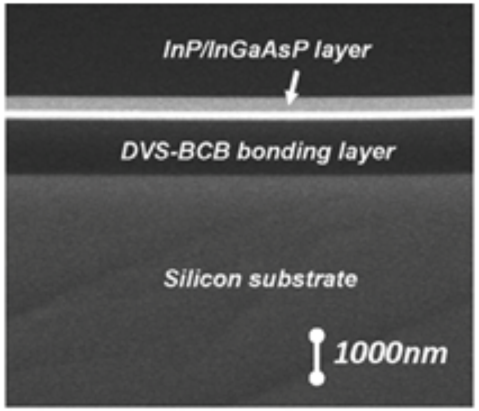
III-V integration on SOI

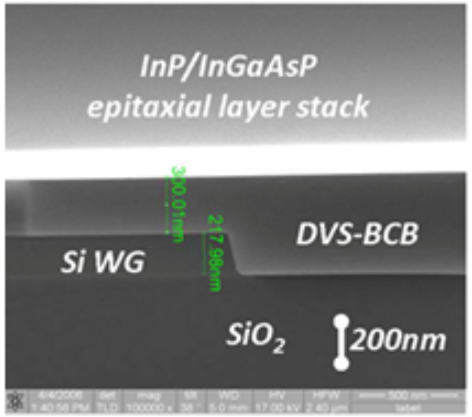
Both multiple die-to-wafer bonding and full wafer bonding (2inch)

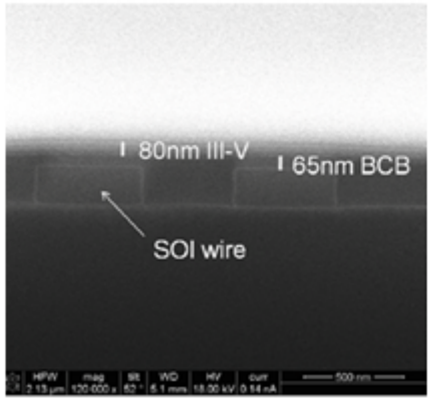






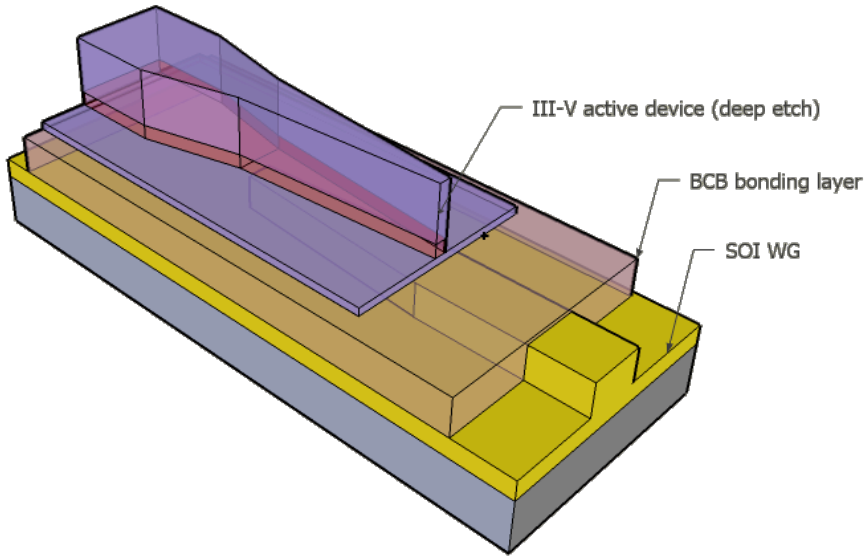


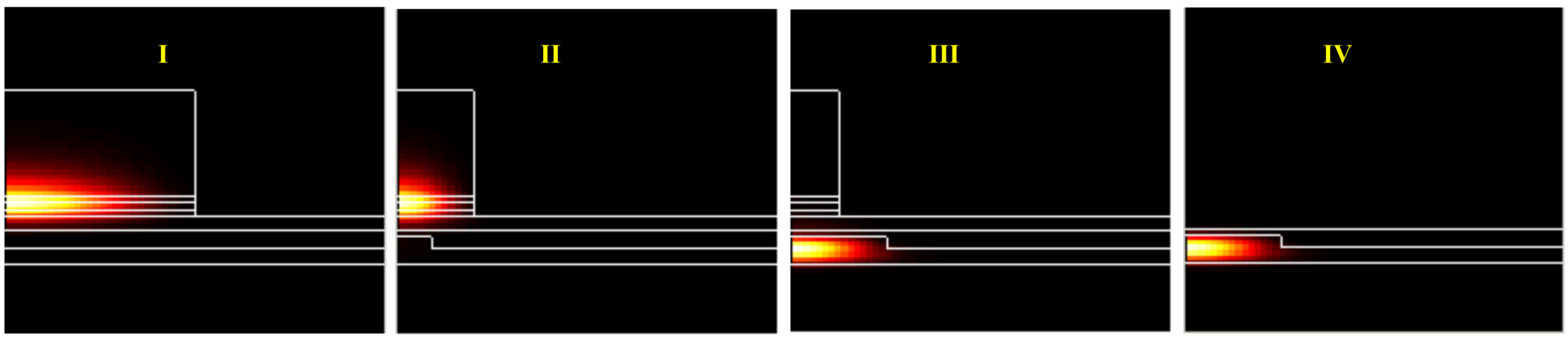




Example: III-V/Si extended cavity laser

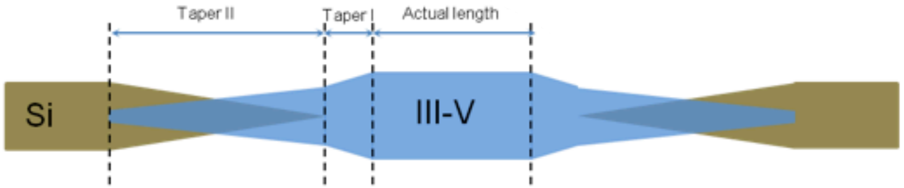
From full confinement in III-V to full confinement in SOI

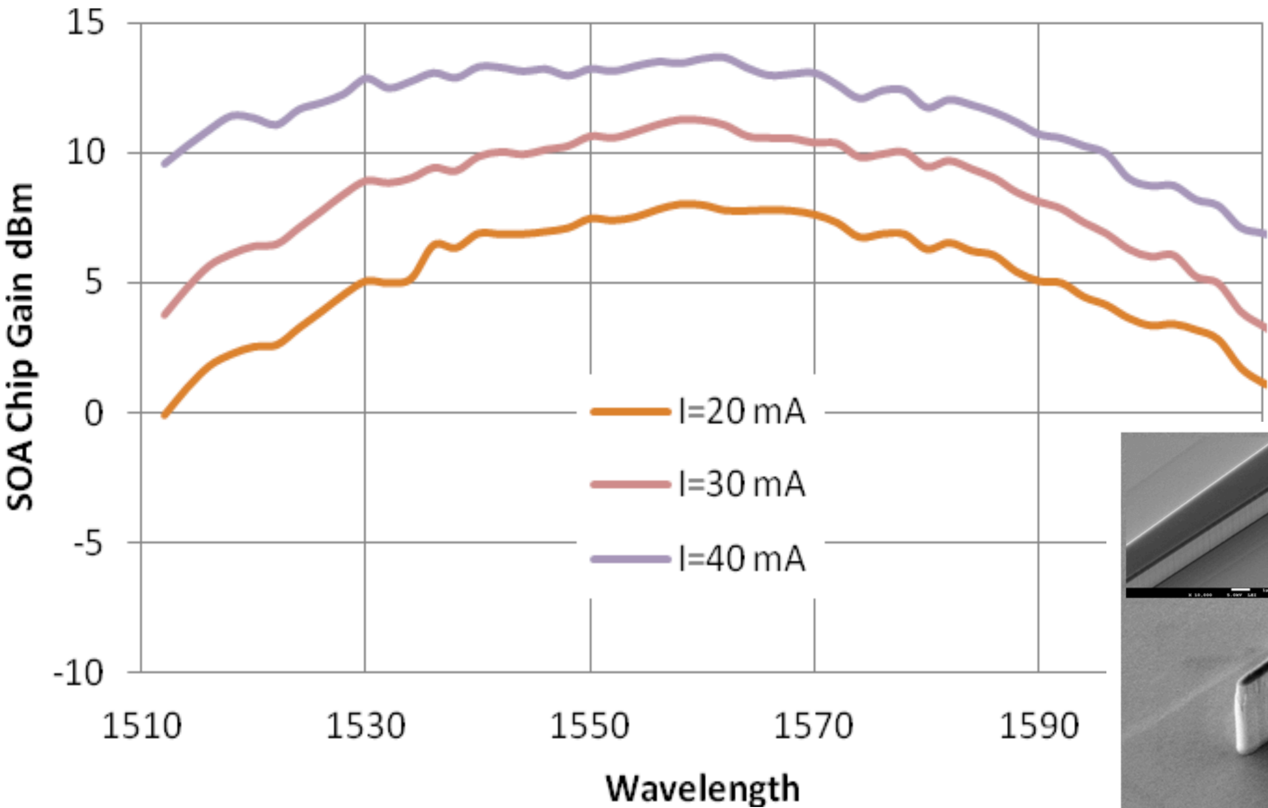


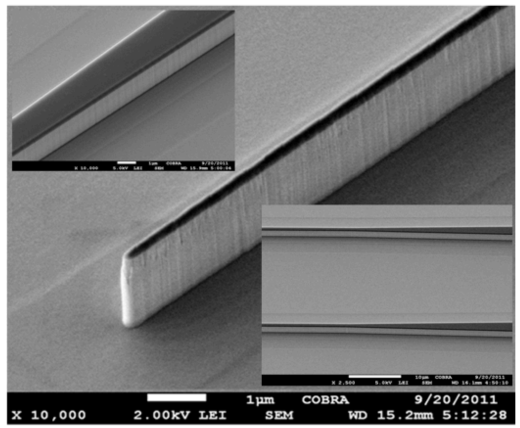


Fundamental mode in different cross-sections (BCB thickness=80nm)

Example: optical amplifier based on same technology







Example: integration of tunable laser with modulator

III-V/silicon tunable laser realized, co-integrated with silicon electro-optic modulator, based on ring resonator feedback

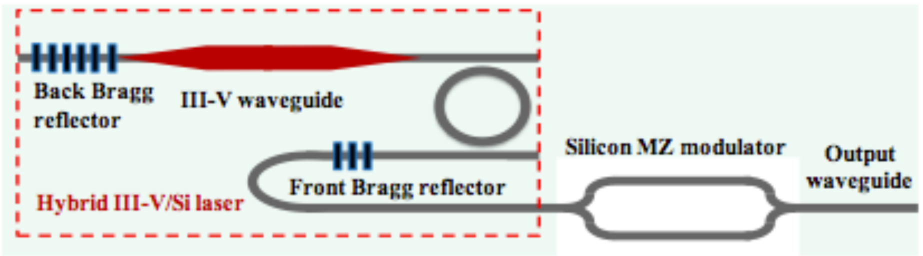
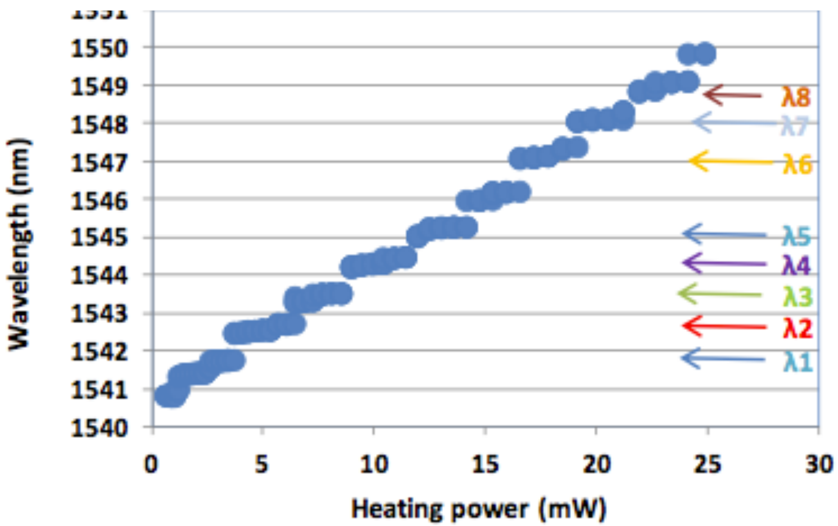
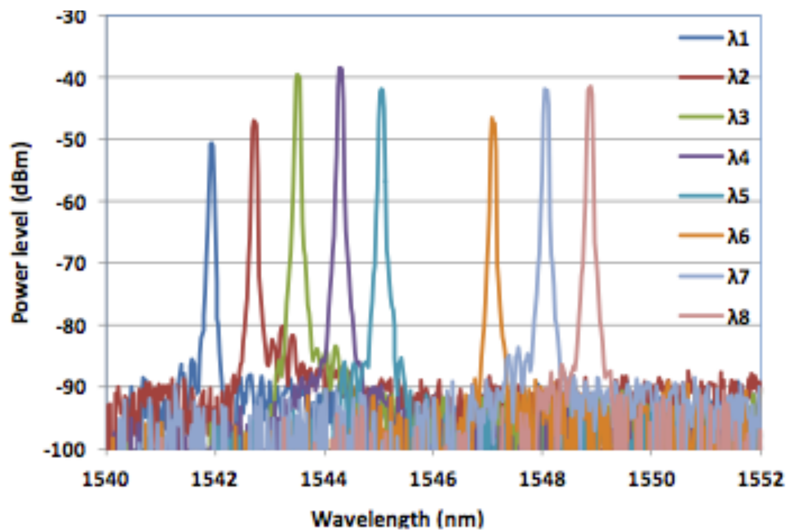
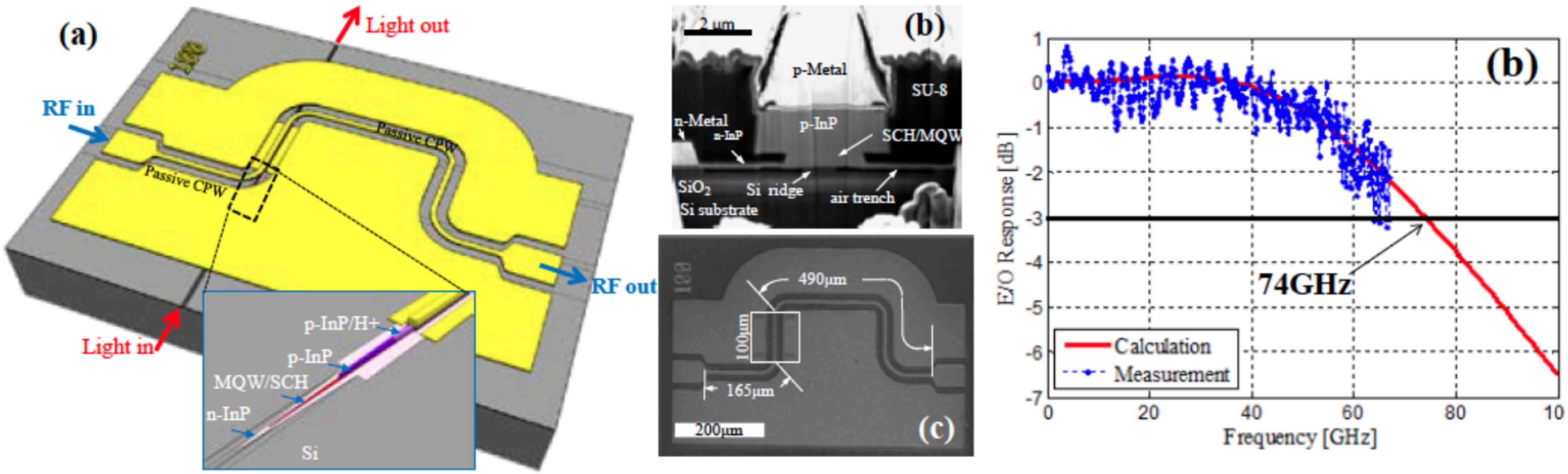


Fig. 1 Schematic view (left), and picture (right) of the ITLMZ chip





Demonstrations from other labs: hybrid EA modulators



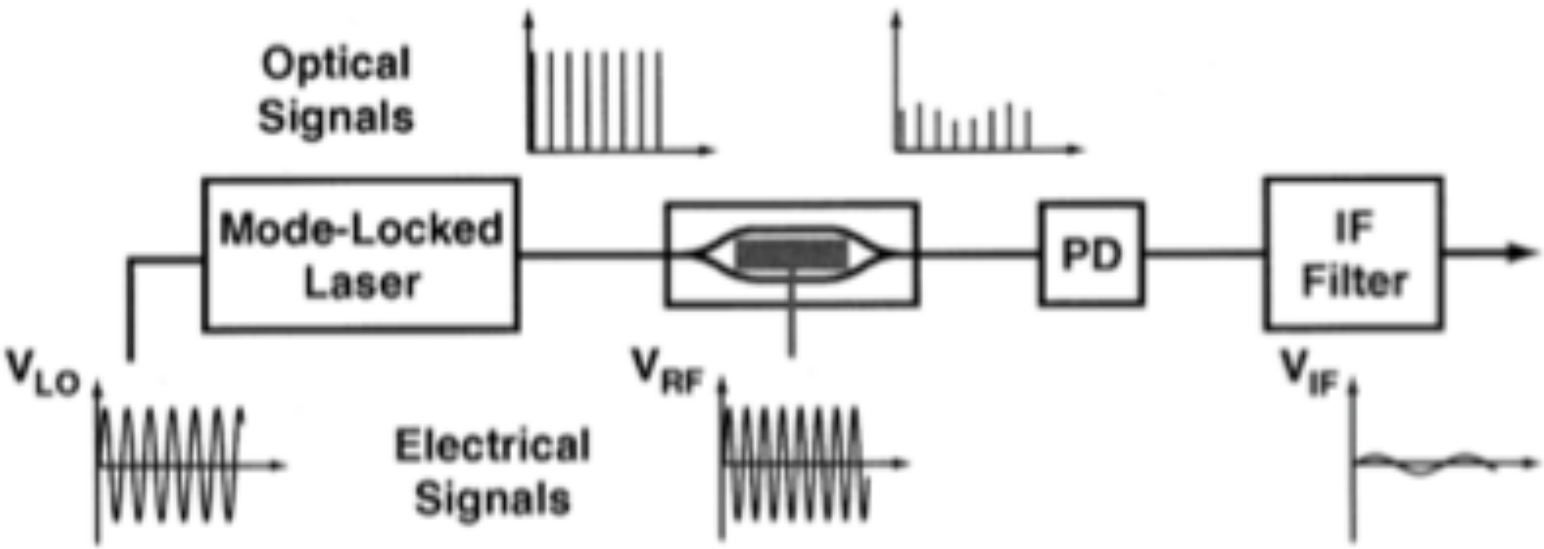
Y. Tang, J. Peters, J. Bowers, Over 67GHz bandwidth hybrid silicon electroabsorption modulator, Opt. Expr. 20(10), p. 11529 (2012)

Outline

- Silicon photonics
- III-V/Silicon photonics
- **Electro-photonic frequency converter as case for MWP applications**

Proposed implementation

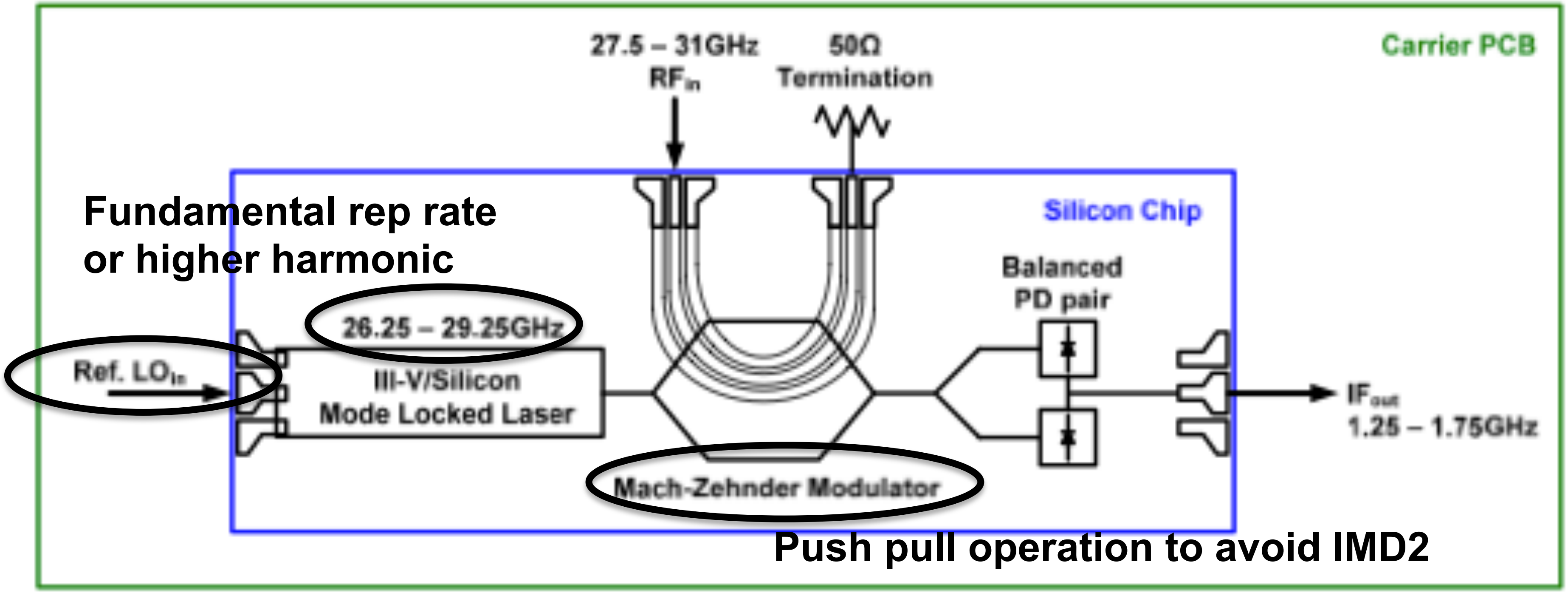
Concept of the electro-photonic frequency converter (EPFC)



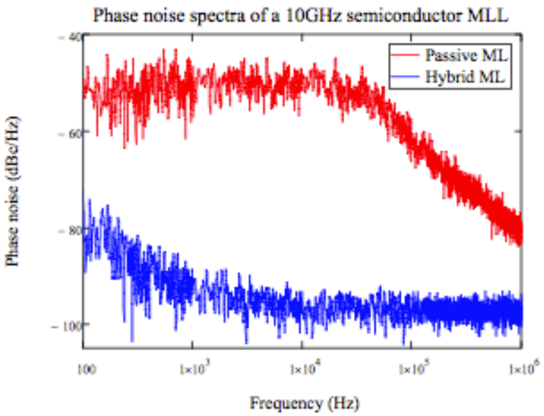
Implement functionality on III-V on silicon platform:

- III-V on silicon modelocked laser
- Silicon EO modulator or III-V EA modulator
- Silicon or III-V balanced detector pair

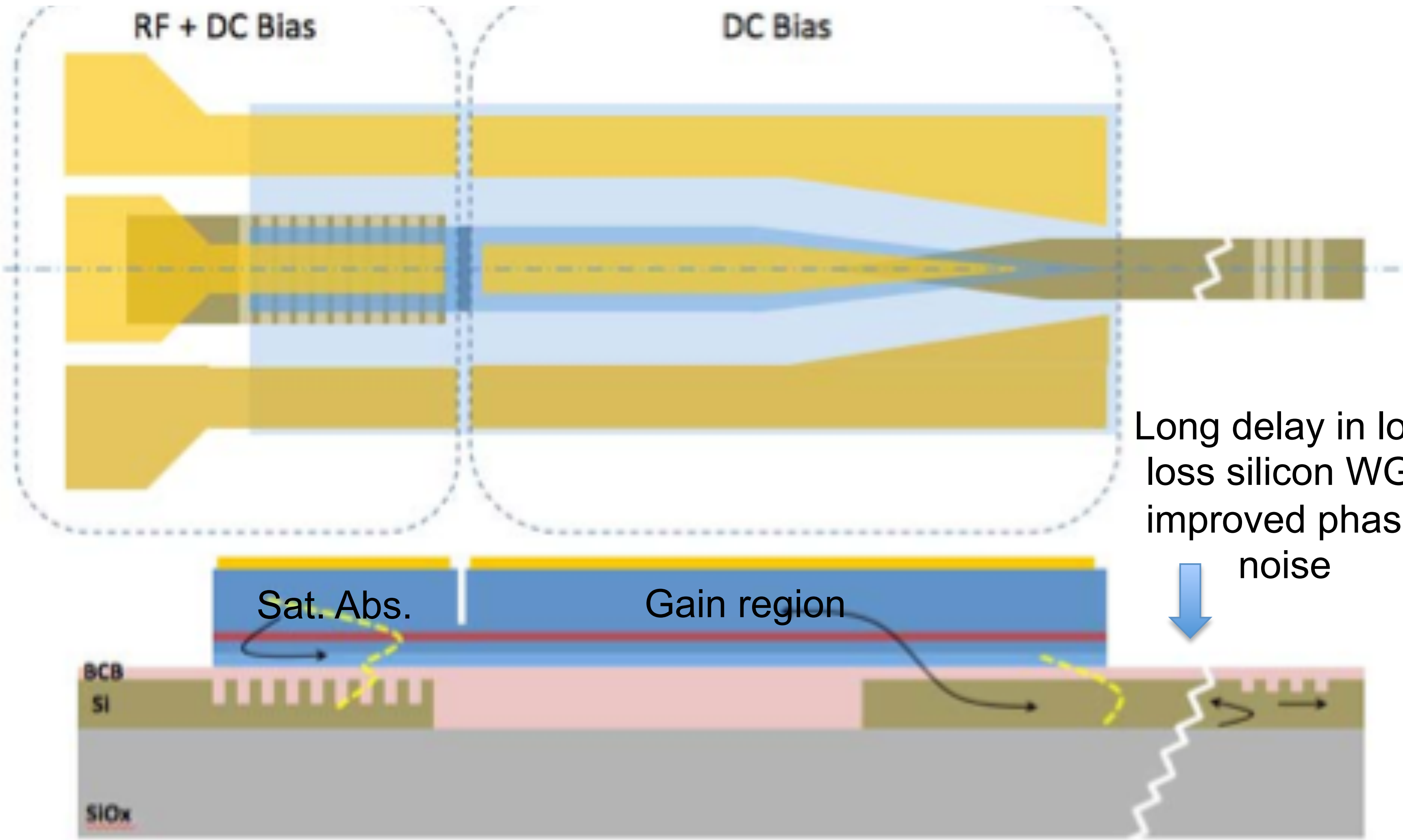
Proposed implementation



External reference
necessary to reach
phase-noise specs



Proposed implementation: Mode-locked laser



Long delay in low loss silicon WG: improved phase noise

Value of integration for frequency downconverter

Electro-photonic frequency conversion allows for:

- Broad bandwidth
- Flexibility
- Re-configurability

But also increased scalability at lower mass, volume and power consumption.