1071

Semiconductors

M | Silicon compatible materials and integrated devices for photonics and optical sensing

This symposium will focus on innovative materials and devices integrated on Si platform with the main objective to bring together people involved on this topic but working in different application fields from telecommunication to sensing.

Scope:

The extensive and ever advancing miniaturization in microelectronics imposes higher and higher barriers. To master these challenges, more and more materials with highly specific properties have already been and still have to be integrated on the Si technology platform. However, this high rate of innovation does not only drive the development of microelectronics, but also creates new emerging application fields. This especially applies to integrated Si-based photonics which has an enormous bandwidth of potential applications ranging from telecommunication to optical sensing. Several classes of Si compatible materials have been explored for light emitters, amplifiers and detectors, also their coupling with plasmonic materials permits to manipulate light at the nanoscale on the Si platform. The same integrated photonic devices are recently also devoted to the emerging field of on-chip biological and chemical sensing by allowing ultra-high sensing performance and efficient CMOS-compatible readout schemes.

This symposium intends to highlight the newest developments and breakthroughs in terms of materials and their integration for photonic purposes, integrated device design and architecture, as well as advanced and innovative applications. Many topics are highly interdisciplinary and settled at the interface between optics, electronics, material science, chemistry and biology. Thus, this symposium will provide a discussion forum which brings scientists and engineers from these areas together and stimulates an exchange between academia and industry.

Hot topics to be covered by the symposium:

The symposium will include, but will not exclusively limited, to the following hot topics.

Materials science with related integration techniques:

- Si nanostructures like clusters and nanowires
- rare earth based materials
- compound semiconductor and Ge integration for light emission and detection
- C-based materials
- plasmonic materials and metamaterials

The sessions will include also the following devices and application areas:

- light emitters and detectors
- modulators, optical switches
- resonators, photonic crystals, plasmonic sensors
- integrated waveguide sensing
- building blocks for telecommunication

List of invited speakers *(confirmed)*:

- Ryan Bailey (University of Illinois, Urbana, USA)
- Silke Christiansen (Helmholtz-Center for Materials and Energy Berlin -HZB- , Germany) *"Three-dimensional silicon based nano-architectures for energy conversion and sensing"*
- Philippe Fauchet (Vanderbilt University, USA) *"Photonic crystals for sensors"*
- Ewold Verhagen (FOM Institute, The Netherlands) *"Nano-optomechanical sensing with subwavelength light fields"*
- Romain Quidant (ICFO - The Institute of Photonic Sciences, Spain) *"Nanoplasmonics for biosensing"*
- Gunther Roelkens (University of Ghent, Belgium) *"III-V on silicon photonic integrated circuits for optical communication and sensing"*
- Ioannis Raptis (Institute of Nanosciences & Nanotechnologies (INN) NCSR 'Demokritos', Greece)
- Markus Schmidt (IPHT Jena, Germany) *"Hybrid fibers: a new base for plasmonic nanoprobes and optofluidic nanoparticle sensing"*
- Pol Van Dorpe (IMEC, Belgium)
- Ralf B. Wehrspohn (Fraunhofer Institute, Germany) *"Stable field-enhanced emission and surface ionization from silicon nano-tip arrays"*

List of scientific committee:

- Katerina Dohnalova - University of Amsterdam, The Netherlands
- Blas Garrido - Universitat de Barcelona, Spain
- Peter Masher - McMaster University, Canada
- Daniel Navarro Urrios - CNR-NEST, Italy
- Alexei Nazarov - NAS Ukraine, Kiev

nb-photonics
Center for Nano- and Biophotonics
Ghent University

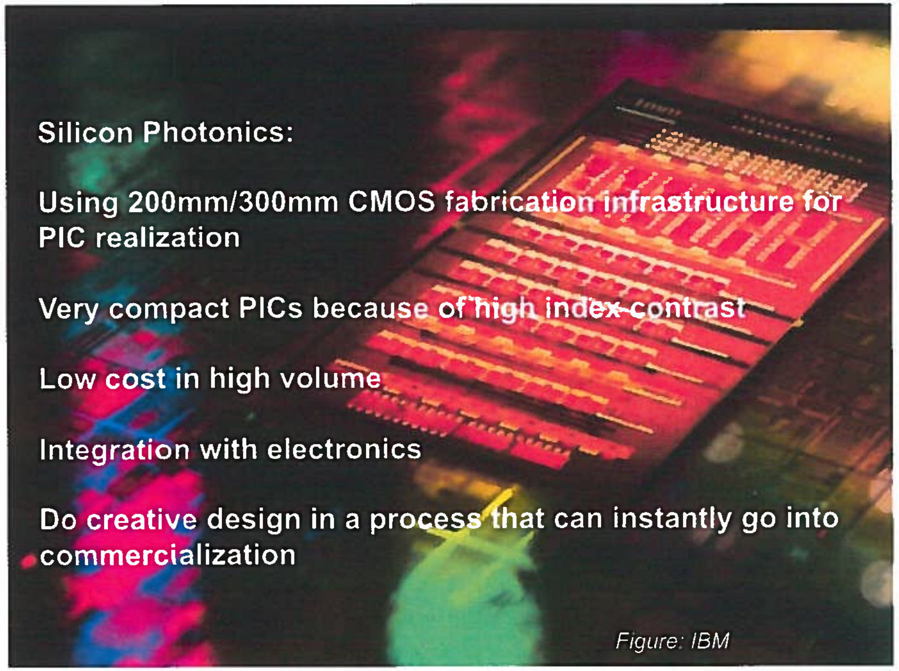
UNIVERSITEIT GENT imec
PHOTONICS RESEARCH GROUP

Heterogeneous III-V-on-Silicon Photonic Integrated Circuits for Communication and Sensing Applications

Gunther Roelkens

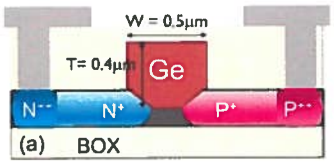
Photonics Research Group, Ghent University / imec - Belgium

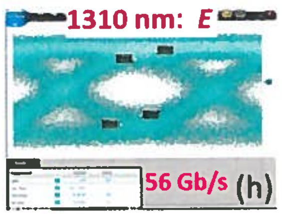
European Material Research Society Spring meeting 2016

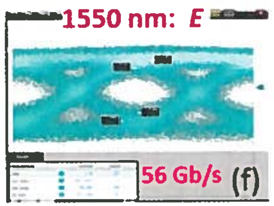


III-V-on-silicon photonics for optical interconnect applications

Germanium photodetectors







56Gbit/s operation both in C-band and O-band (-1 V bias)

Responsivity: 0.7 A/W (C-band) and 0.9 A/W (O-band)

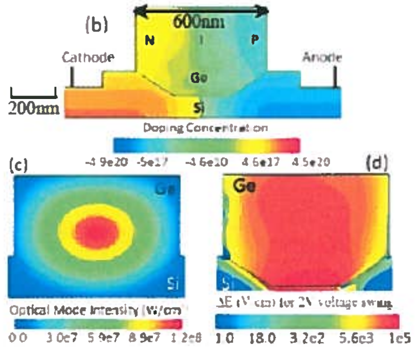
[Chen, OFC 2016]

Ge electroabsorption modulators

50GHz EO bandwidth
5dB insertion loss
12fJ/bit dynamic PC

- Use Franz-Keldysh effect in Germanium
- Shift operation to 1550nm by adding 1% Si

56 Gbit/s @ 1550 nm wavelength

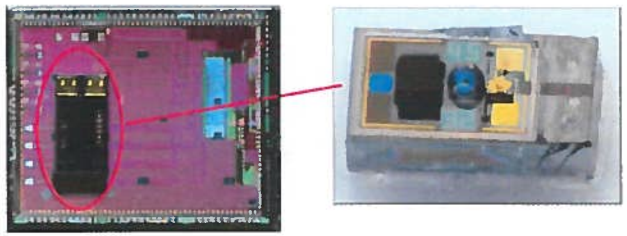


[Gupta, OFC 2015, 2016]

Lasers for optical interconnect applications

100 Gbps off-board transceivers: 4 x 28Gbps parallel

- one single laser per transceiver
- no hermetic sealing of full transceiver: laser needs hermetic sealing
- Pick-and-place assembly



Silicon Photonic die **MEMS Laser Source**

Source: Luxtera

Lasers for optical interconnect applications

What if we go to 400GbE or 1.6TbE transceivers ?

1 fiber x 56G x 8 lasers

4 fibers x 56G x 2 lasers

4 fibers x 56GB PAM-4 x 1 laser

1 fiber x 56G x 32 lasers

4 fibers x 56G x 8 lasers

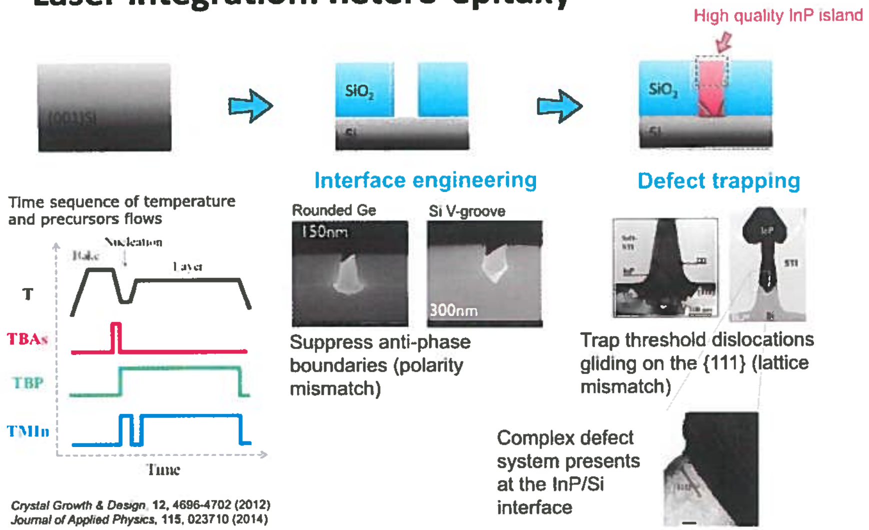
4 fibers x 56GB PAM-4 x 4 lasers

need a scalable approach for laser integration on Si Photonic ICs

- More lasers on a single chip
- High throughput manufacturing
- Lower cost per laser on the chip

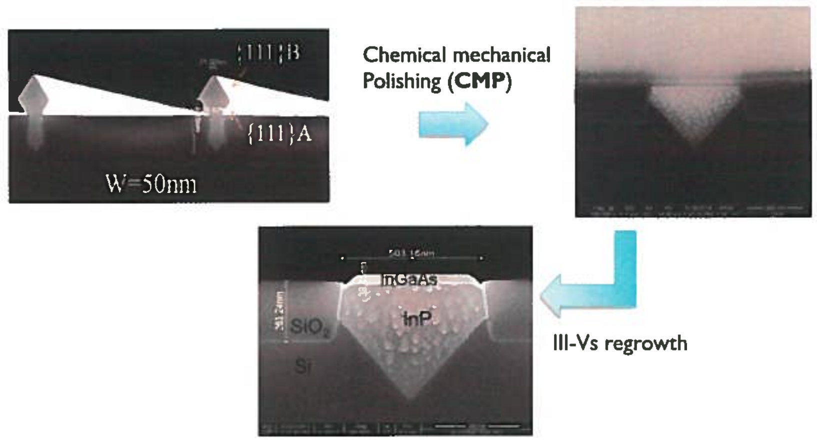
III-V on silicon integration is an enabling technology

Laser integration: hetero-epitaxy



Crystal Growth & Design, 12, 4696-4702 (2012)
Journal of Applied Physics, 115, 023710 (2014)

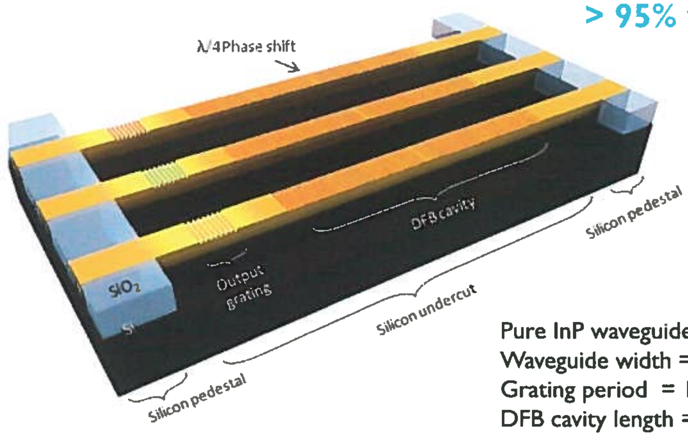
Laser integration: hetero-epitaxy



Laser integration: hetero-epitaxy

Schematic plot of the monolithic InP lasers on silicon

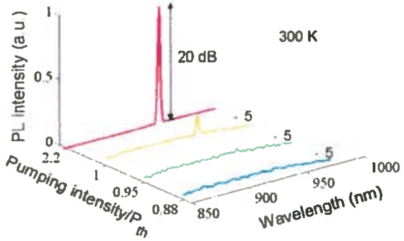
> 95% yield

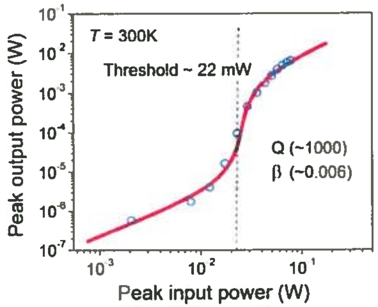


Pure InP waveguide
Waveguide width = 500 nm
Grating period = 163 nm
DFB cavity length = 45 μm

Laser integration: hetero-epitaxy

Pumping condition:
532 nm wavelength
9 ns pulse duration

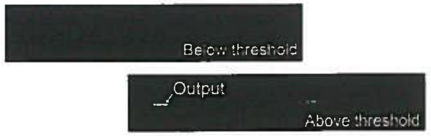




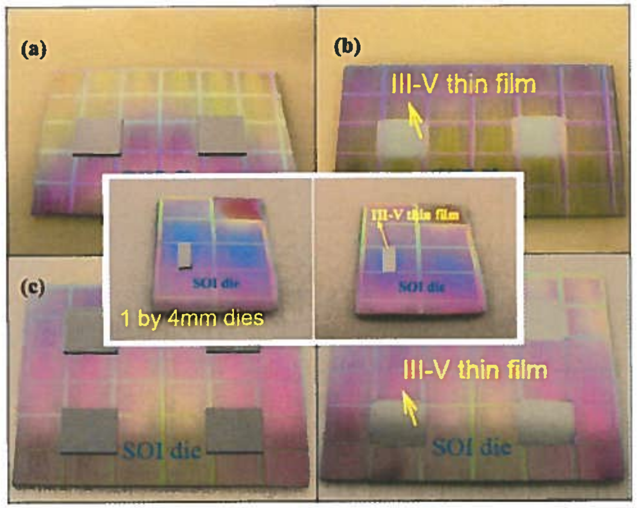
Room for improvement:

Use narrow waveguide
– better material

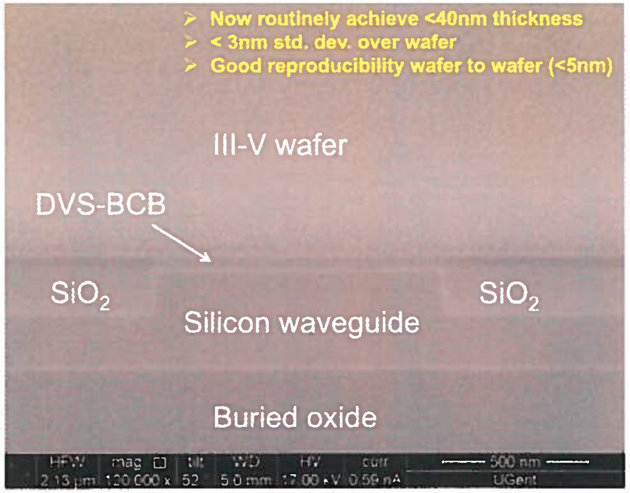
Heterostructure
– reduced carrier loss



III-V integration on SOI



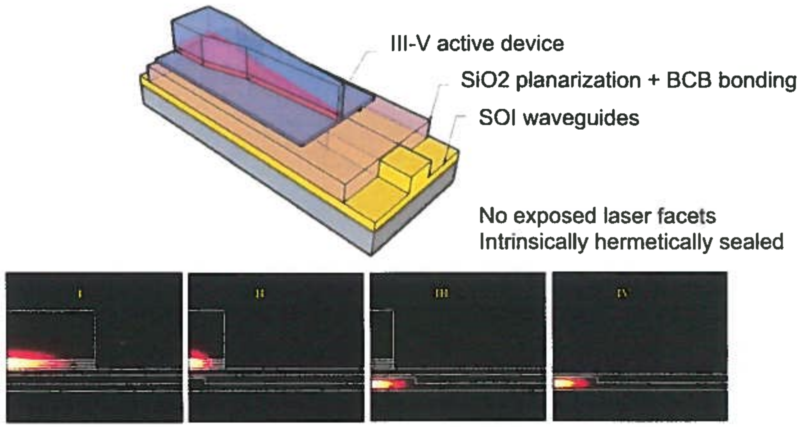
III-V integration on SOI



[Keyvaninia, Optical Materials Express 2013]

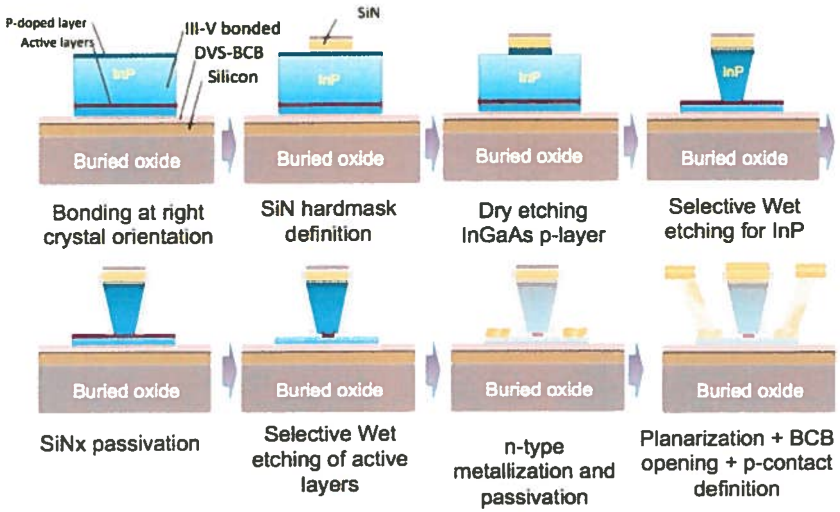
Lasers for optical interconnect applications

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

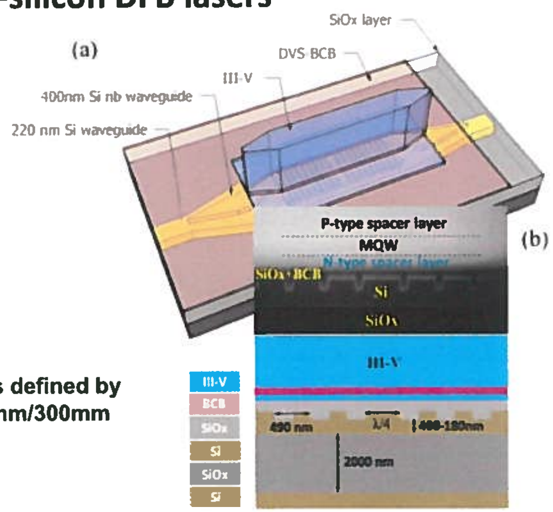


Fundamental mode in different cross-sections (BCB thickness=80nm)

Process flow



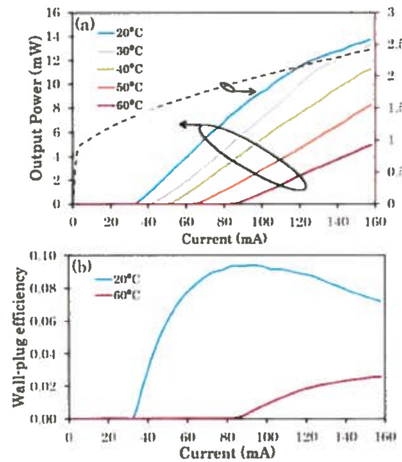
III-V-on-silicon DFB lasers

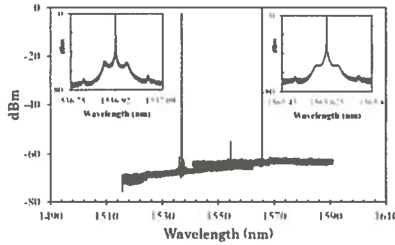


DFB gratings defined by DUV on 200mm/300mm

[Keyvaninia, Optics Letters 2013]

III-V-on-silicon DFB lasers– static characteristics

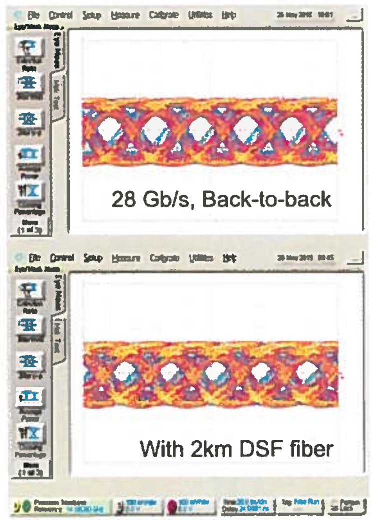


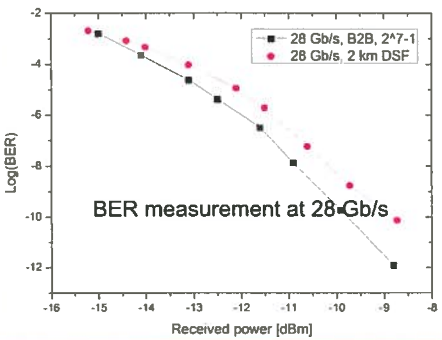


Gratings:
- 480nm/490nm period, 25% duty cycle
- Fabricated using deep UV litho
- First order gratings available as well

DFB lasers – direct modulation

[Abassi, Optics Express 2015]
[Abassi, OFC 2016]

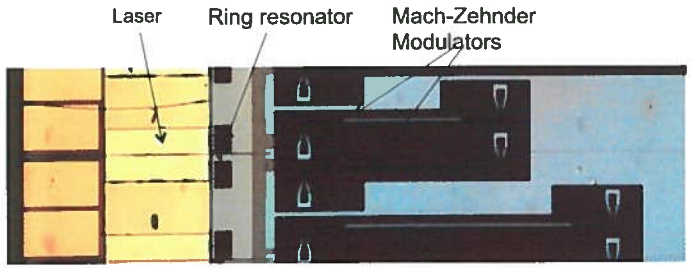




III-V-on-silicon extended cavity tunable laser

[Duan, ECOC 2012]
[Keyvaninia, Opt. Express 2013]

III-V/silicon tunable laser realized
- 8nm tuning range, based on thermo-optic tuning of silicon ring resonator
- >40dB SMSR
- threshold of 35mA
- 4mW optical output power, 1.7MHz linewidth
- co-integrated with silicon modulator



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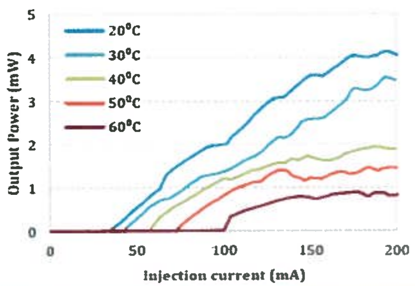
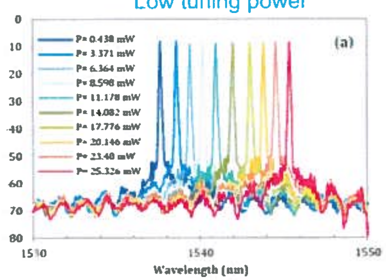
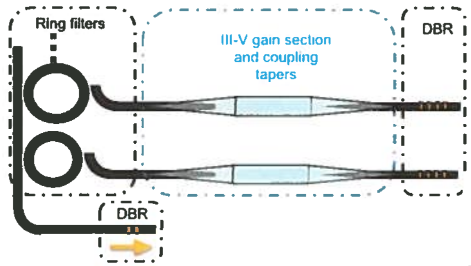


Low tuning power

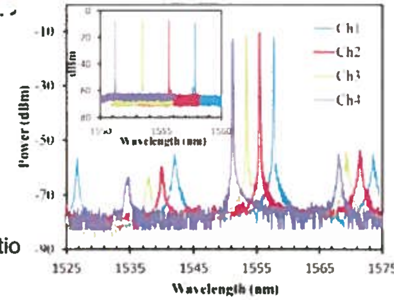


[Keyvanina, Optics Express 2013]

III-V-on-silicon multi-wavelength laser sources



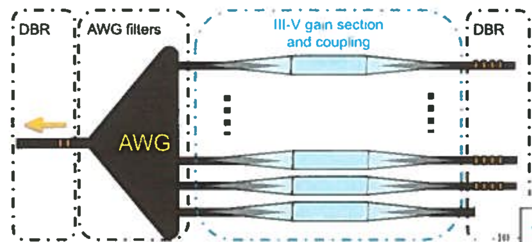
- More than 40dB side mode suppression ratio
- 2mW output power from all channels
- CW operation up to 60°C



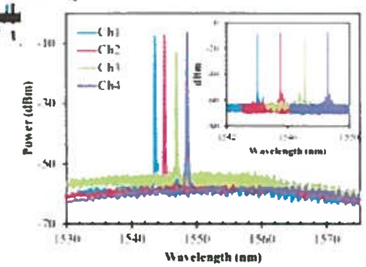
Keyvaninia et al., ACP PDP 2012

[Keyvanina, Optics Express 2013]

III-V-on-silicon multi-wavelength laser sources

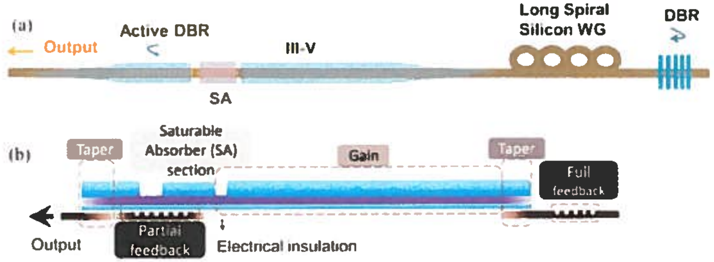


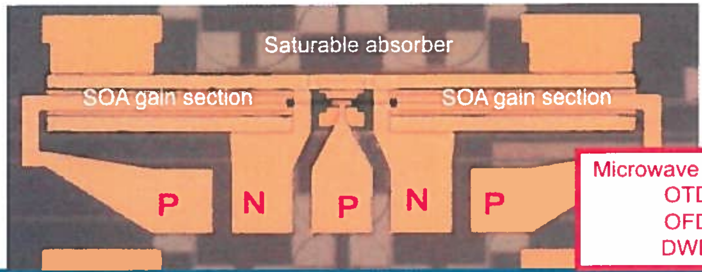
- More than 40dB side mode suppression ratio
- Up to 5mW output power
- 1.2 MHz linewidth



Keyvaninia et al., ACP PDP 2012

Anti-colliding pulse type modelocked lasers

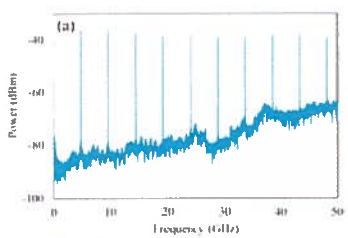




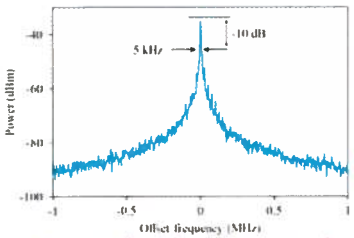
Microwave photonics
OTDM
OFDM
DWDM

[Keyvaninia, Optics Letters 2015]

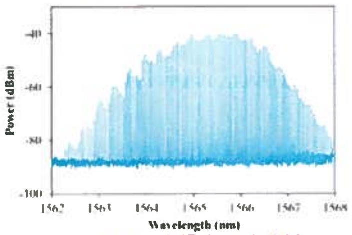
Modelocked laser performance - ACPMLL



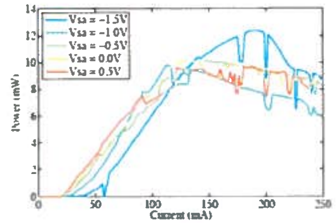
Narrow pulses (ps) – broad RF spectrum



Narrow linewidth under passive ML



3.5nm 10dB bandwidth

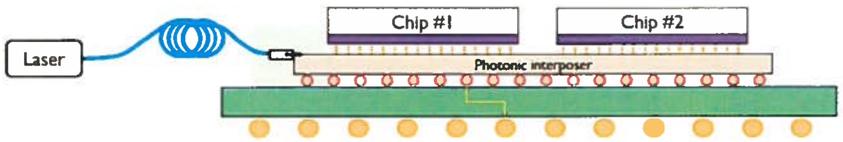


High optical output power

Photonic interposers

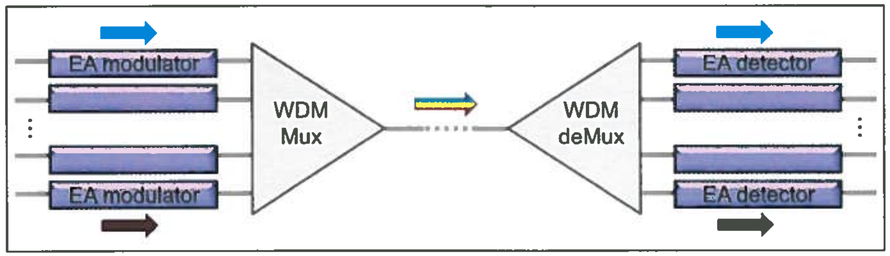
Previous device demonstrations geared towards off-board or off-chip communications

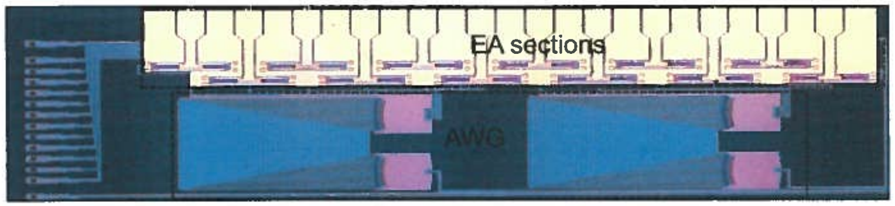
In the future there will also be a need for photonic interposers



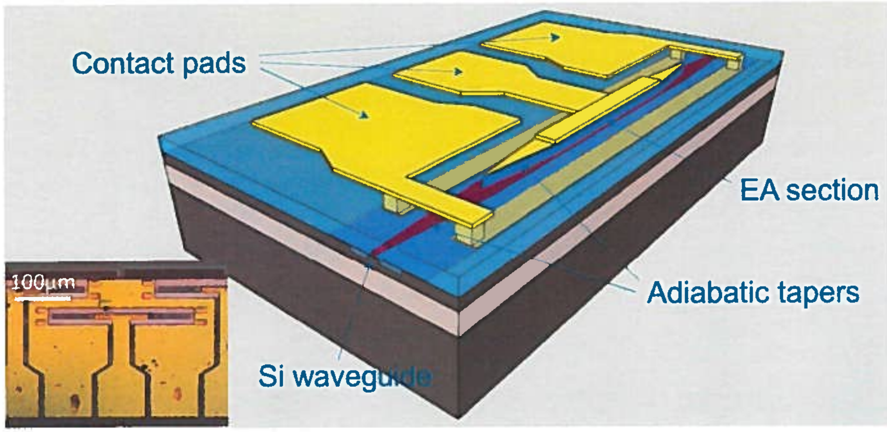
Package I/O Requirements					
CMOS tech node	20-28nm	14nm	10nm	7nm	5nm
I/O Bandwidth	2.5Tbps	5Tbps	10Tbps	25Tbps	50Tbps
I/O Energy	10pJ/bit	5pJ/bit	1-2pJ/bit	0.1-1pJ/bit	50-500fJ/bit
Channel Rate	up to 35Gb/s	up to 50Gb/s	up to 70Gb/s	up to 100Gb/s	up to 140Gb/s
Cost Target	$$$$/Tbps	$$$/Tbps	$$$/Tbps	$$/Tbps	$/Tbps
Optical I/O Distance & Appl.	5m to 2km Network	1m to 2km Backplane	5cm to 2km Board	5mm to 2km Interposer	1mm to 2km Chip

III-V-on-silicon EAM based photonic interposer





III-V-on-silicon EAM based photonic interposer

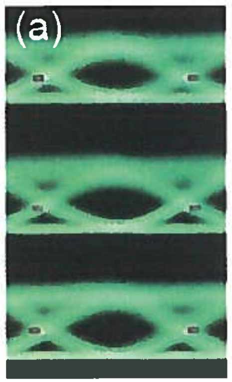


III-V-on-silicon EAM based photonic interposer

Channel 1
λ = 1557.58nm
V_{bias} = -2.0V
ER = 6.4dB
SNR = 4.7

Channel 3
λ = 1560.68nm
V_{bias} = -1.6V
ER = 7.7dB
SNR = 6.1

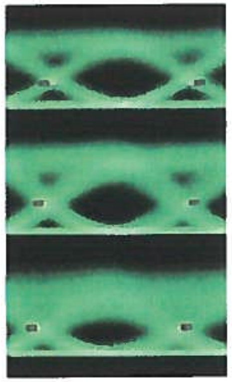
Channel 5
λ = 1563.84nm
V_{bias} = -1.7V
ER = 6.6dB
SNR = 5.1



Channel 2
λ = 1559.18nm
V_{bias} = -1.4V
ER = 8.1dB
SNR = 5.3

Channel 4
λ = 1562.28nm
V_{bias} = -1.7V
ER = 10.8dB
SNR = 5.7

Channel 6
λ = 1565.41nm
V_{bias} = -1.78V
ER = 12.7dB
SNR = 3.9



6 x 30Gb/s

III-V-on-silicon EAM based photonic interposer

Channel 1
λ = 1557.6nm
V_{bias} = -2.8V

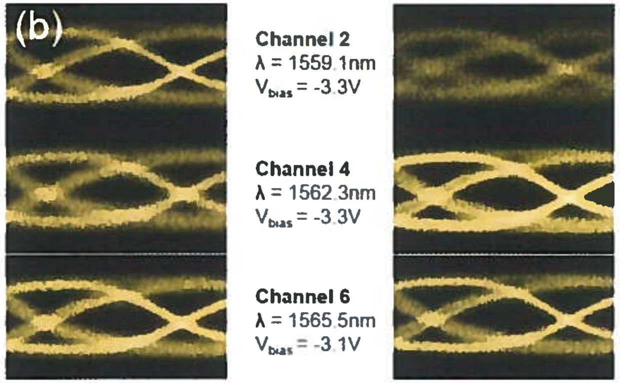
Channel 2
λ = 1559.1nm
V_{bias} = -3.3V

Channel 3
λ = 1560.7nm
V_{bias} = -3V

Channel 4
λ = 1562.3nm
V_{bias} = -3.3V

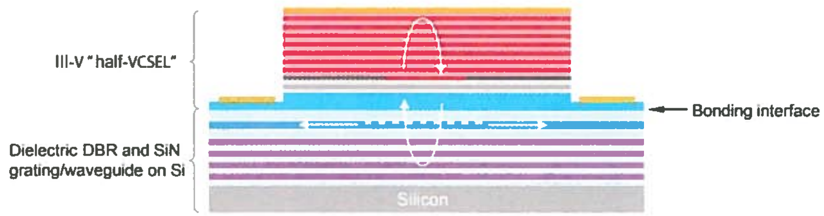
Channel 5
λ = 1563.9nm
V_{bias} = -3.1V

Channel 6
λ = 1565.5nm
V_{bias} = -3.1V



6 x 30Gb/s

850nm GaAs VCSEL photonic interposers



Integrate 850nm VCSELs through wafer bonding on a SiN-on-insulator waveguide platform

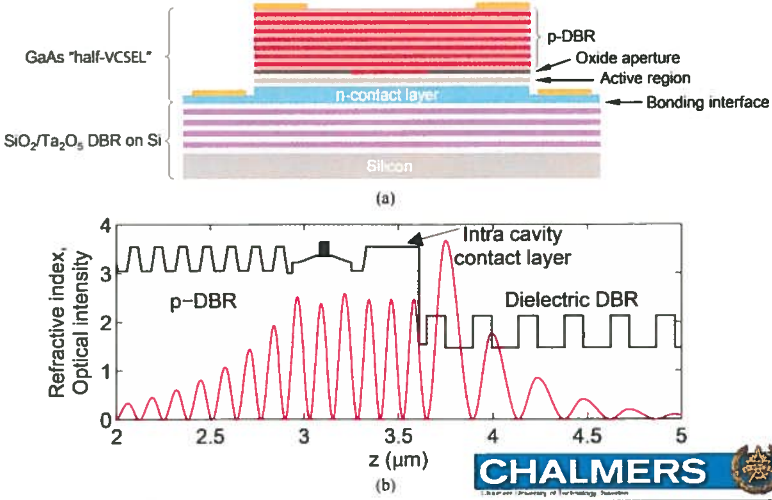
Implement dielectric DBR on silicon substrate

Implement intra-cavity outcoupling grating

Direct modulation

CHALMERS

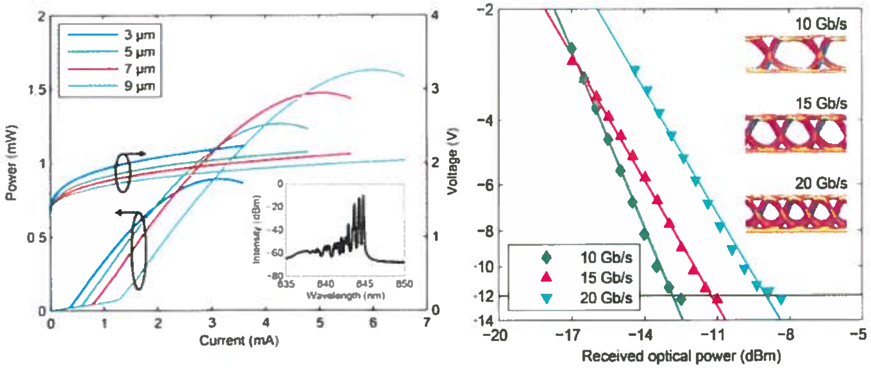
850nm GaAs VCSEL photonic interposers



CHALMERS

850nm GaAs VCSEL photonic interposers

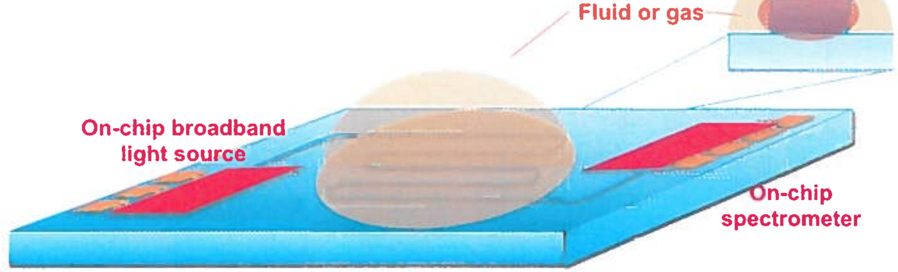
CHALMERS



[Haglund, Optics Express 2015]
[Haglund, Photonics Technology Letters 2015]

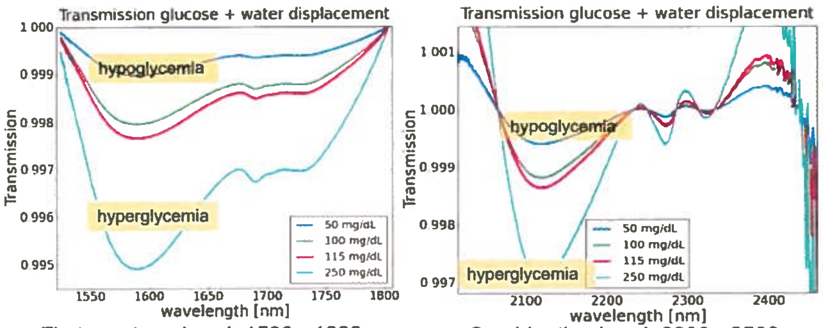
III-V-on-silicon photonics for optical sensing applications

III-V-on-silicon for spectroscopy-on-chip



Spectroscopy-on-chip: use the characteristic absorption features of molecules to detect their presence and concentration

Measurement of glucose concentration (diabetes)



First overtone band: 1500 - 1800 nm

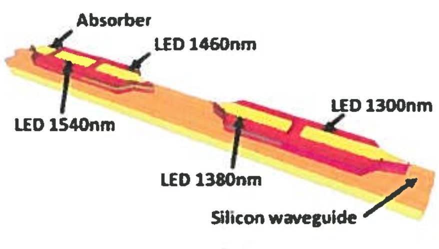
Combination band: 2000 - 2500 nm

Need for broadband light sources and integrated spectrometers
Wavelenght range of interest: 1.2 – 2.5um

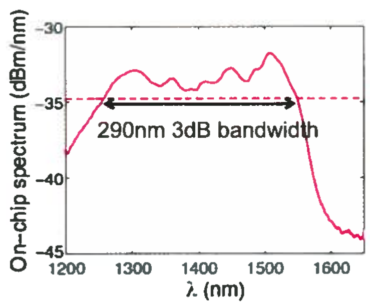
Broadband waveguide coupled LEDs

Problem with bulk/quantum well III-V stacks: limited bandwidth

- Solution 1: multiple die-to-wafer bonding + quantum well intermixing to extend the wavelength range



UCSB



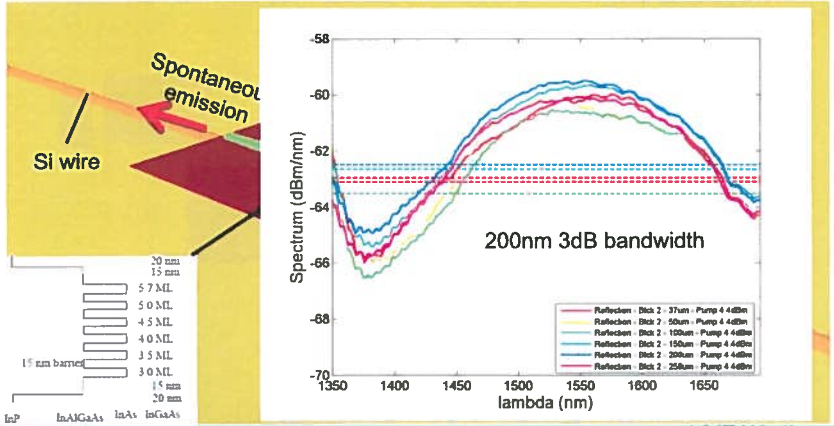
[De Groote, Optics Letters 2014]

[De Groote, M.VI.2, EMRS 2016] [De Groote, GFP 2015]

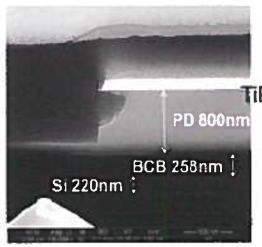
Broadband waveguide coupled LEDs

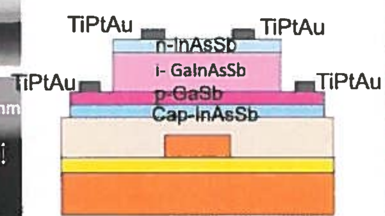
Problem with bulk/quantum well III-V stacks: limited bandwidth

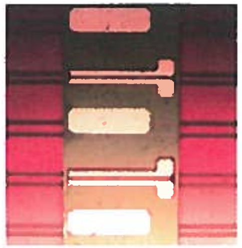
- Solution 2: use chirped quantum dot waveguide material



GaSb-based short-wave infrared photodetectors





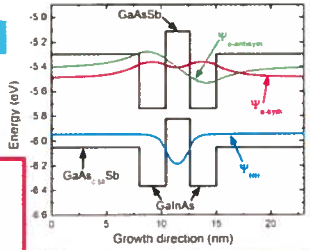


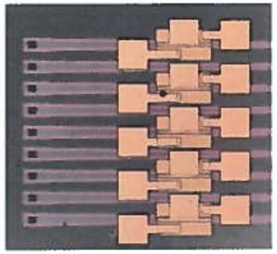
- Dark current: 1µA at room temperature
- Responsivity 0.4 A/W at room temperature (2µm-2.5µm)
- Detector footprint: 50µmx20µm

[N. Hattasan, Photonics Technology Letters 2012]

InP-based type II short-wave infrared photodetectors

Layer		Material	Thickness
P-contact		InGaAs	100 nm
P-cladding		P-InP	1.5 µm
SCH		P-AlGaAsSb	250 nm
MQW	Barrier	$GaAs_{0.55}Sb_{0.42}$	9nm*7
	Well	$Ga_{0.32}In_{0.68}As$	2.6 nm*6
		$GaAs_{0.33}Sb_{0.67}$	2.9 nm*6
		$Ga_{0.32}In_{0.68}As$	2.6 nm*6
SCH		GaAsSb	130 nm
N-contact		N-InP	200 nm



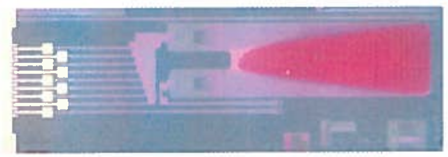


12nA dark current at -0.5V
2.4um cut-off wavelength
On-chip responsivity > 1A/W

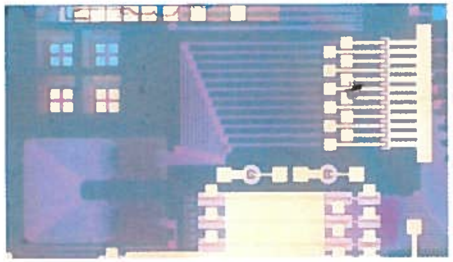
[R. Wang, Optics Express 2015]

Top view of the fabricated devices

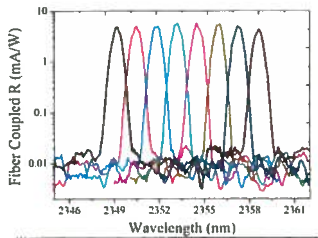
InP-based type II short-wave infrared photodetectors

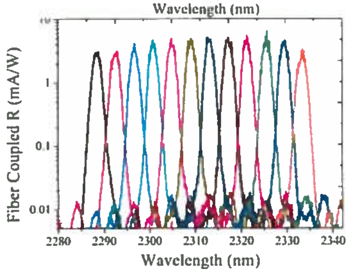


8 channel 2.3-2.4 um wavelength high resolution AWG spectrometer



12 channel 2.3-2.4 um wavelength low resolution AWG spectrometer





Conclusions

III-V on silicon integration is maturing

- improving performance
- improving yield and process control

First applications in silicon photonic transceivers

- WDM laser arrays on silicon
- Mode-locked lasers on silicon
- EAMs on silicon
- GaAs VCSELs on silicon

Other applications in the field of optical spectroscopic sensing