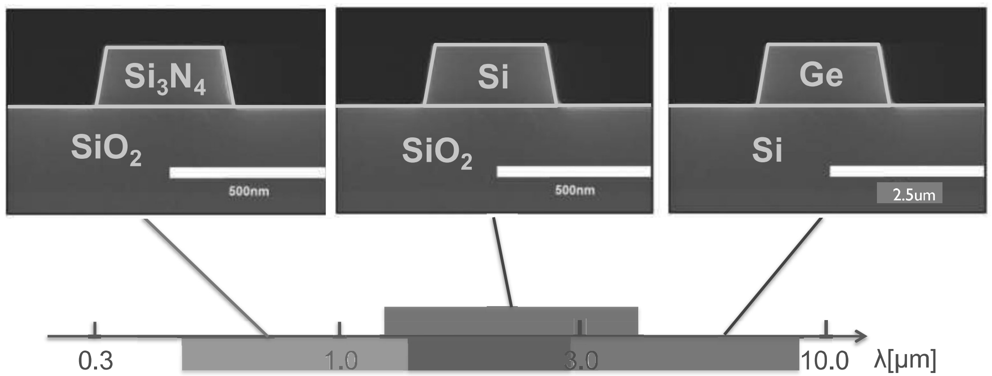
III-V/Si photonic integrated circuits for sensing applications

Gunther Roelkens, Photonics Research Group – Ghent University / imec

IPC 2021 – online meeting

III-V/Si photonic integrated circuit technology

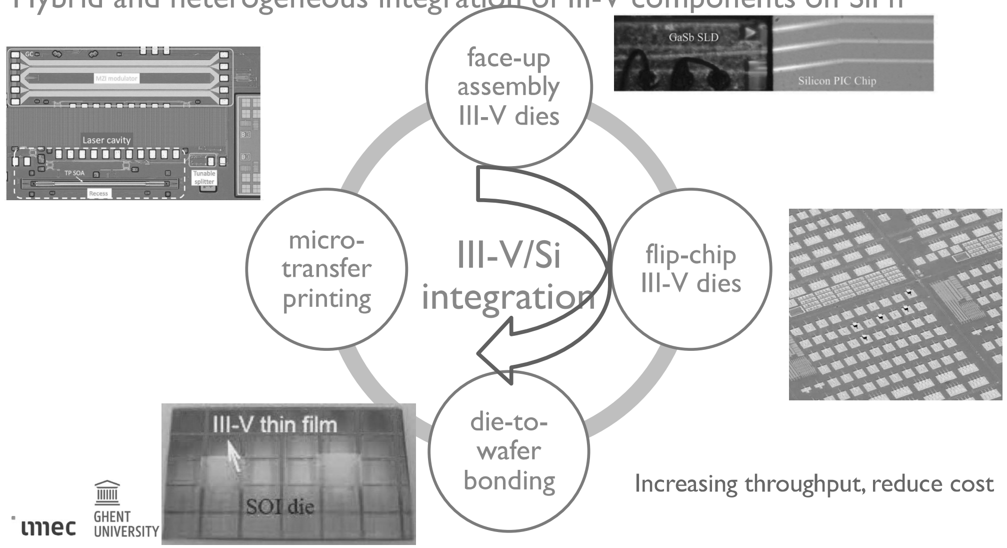
Silicon photonics for a wide wavelength range



Without leaving the CMOS fab

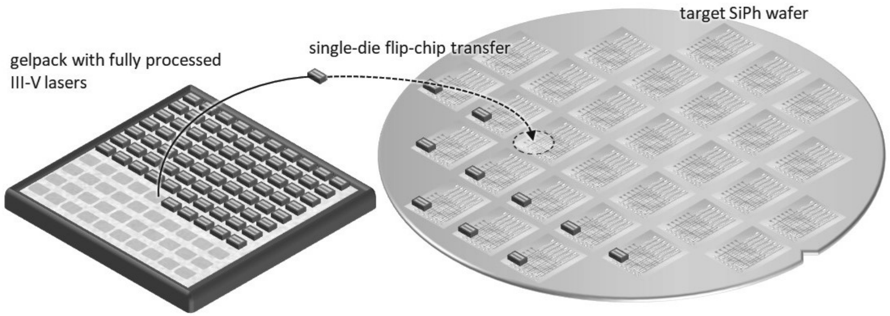
* Possibility to extend Si waveguide structures to longer wavelengths by removing the BOX, use Silicon-on-sapphire, use silicon-on-SiN,… but less mature

Hybrid and heterogeneous integration of III-V components on SiPh



Increasing throughput, reduce cost

Face-up assembly / Flip-chip integration



- Back-end integration
- Known good die
- Face up: Active alignment
- Flip-chip: Passive alignment (+/-0.5um 3sigma in plane)

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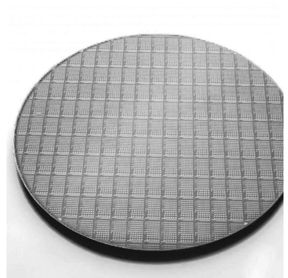
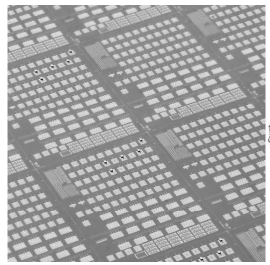
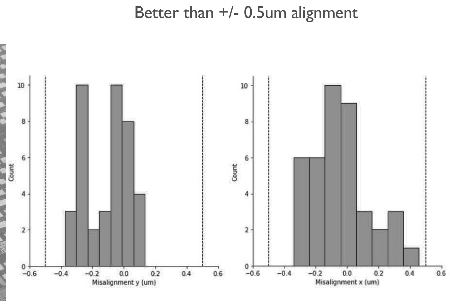
Flip-chip integration at imec (for InP diode lasers)







https://www.imec-int.com/en/press/imec-joins-forces-sivers-photonics-and-asm-amicra-accelerate-hybrid-integration-inp-lasers

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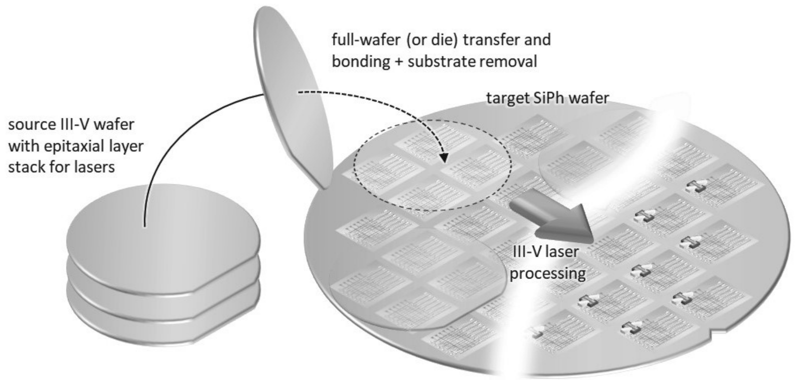
III-V/silicon (die-to-)wafer bonding



- High throughput integration
- Lithographic alignment of III-V device to silicon

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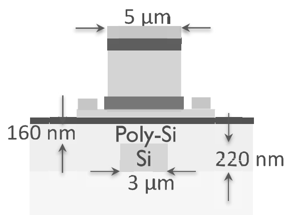
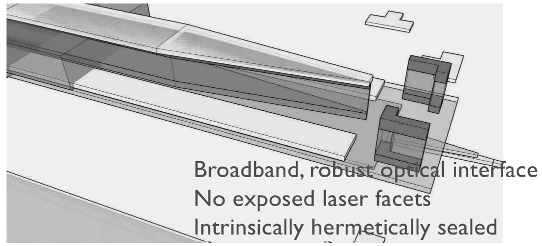
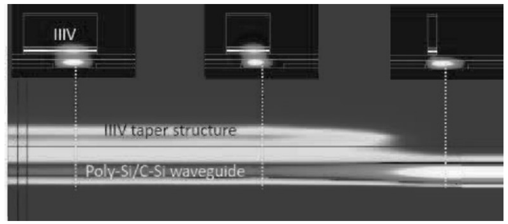
Alignment-tolerant III-V-Si coupling interface







- Broadband, robust optical interface
- No exposed laser facets
- Intrinsically hermetically sealed

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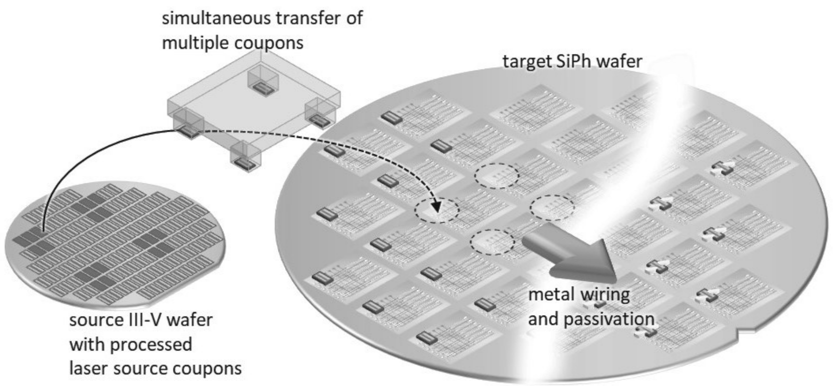
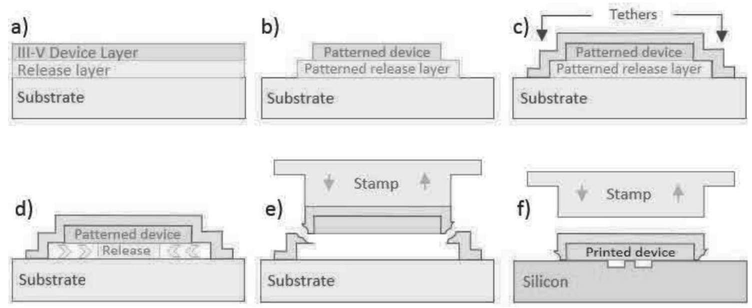
III-V/Si micro-transfer printing



Combines advantages of flip-chip (KGD) & die-to-wafer bonding (throughput)

III-V integration on SiPhotonics through micro-transfer printing

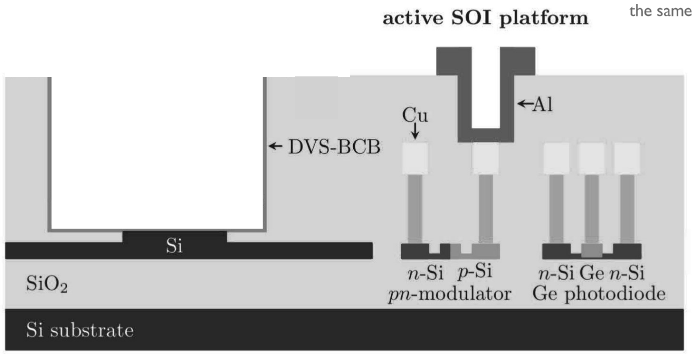
Device processing, release, pick-up & print



Transfer of released, micro-scale III-V devices to a Si target wafer

III-V integration on SiPhotonics through micro-transfer printing

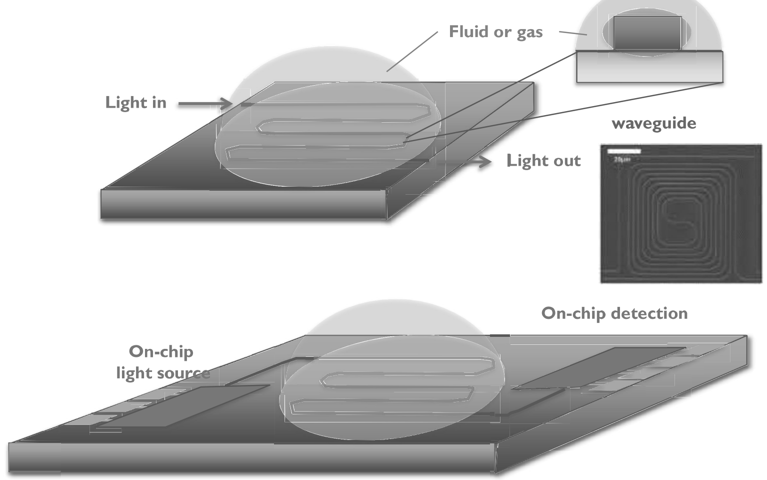
Final device cross-section is the same as for wafer bonding



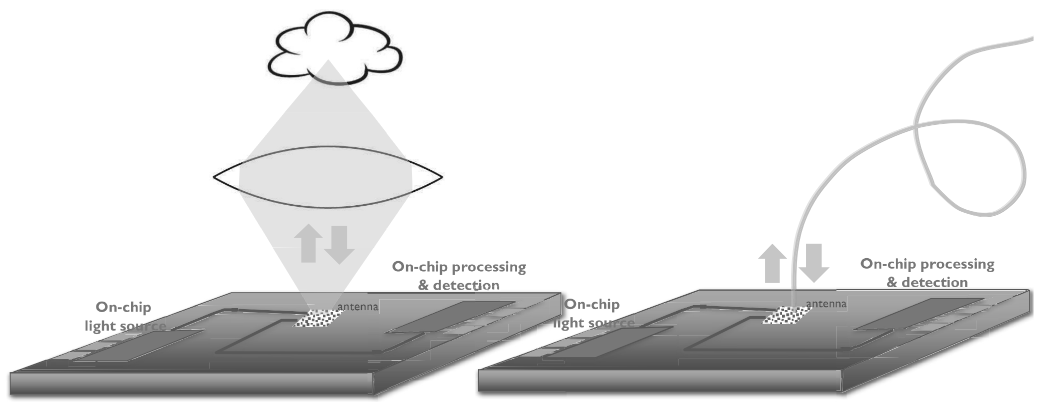
Local opening of back-end + integrate pre-fabricated thin-film optical amplifiers / lasers using an adhesive bonding agent + Cu-RDL

III-V/Si PICs for spectroscopic sensing

III-V/Si photonic integrated circuits for spectroscopy : near field



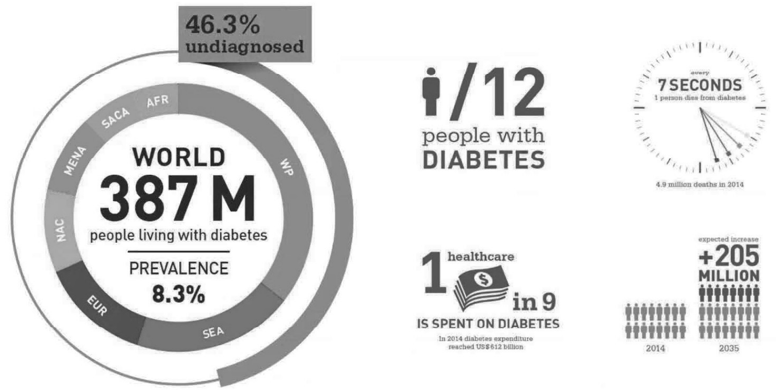
III-V/Si photonic integrated circuits for spectroscopy : far field



Blood constituent analysis (1.5-2.5um)

Use case: transdermal blood constituent analysis

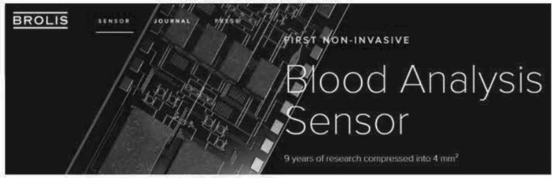
Diabetes is a major 21st century health challenge



http://www.idf.org/diabetesatlas/update-2014

Use case: transdermal blood constituent analysis

Transdermal measurement of glucose / lactate / ethanol

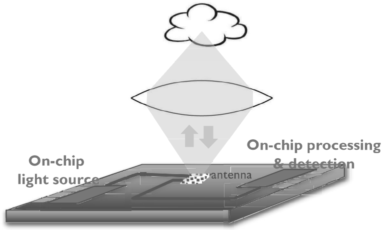


https://brolis-sensor.com

Results

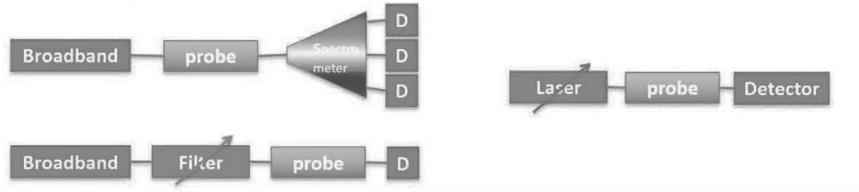
Transdermal sensor performance.

- Determination coefficient R^2 = 0.98 glucose / 0.92 lactate / 0.96 ethanol
- RMSEP = 0.7 mM glucose / 0.924 mM lactate / 0.2 permil ethanol
- MARD = 5.7% glucose / lactate, ethanol not relevant
- > 97% of data points within area A for glucose (clinically reliable)



Technology

(On-chip) absorption spectroscopy in the SWIR

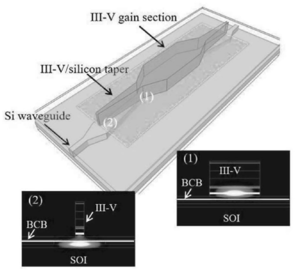


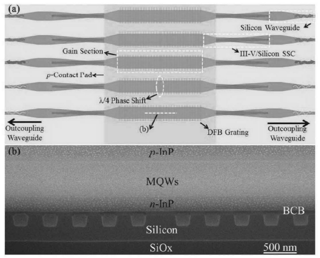
Ingredients:

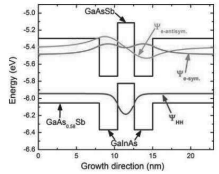
- III-V-on-silicon laser arrays / tunable lasers
- III-V-on-silicon photodetectors
- III-V-on-silicon broadband sources
- Integrated spectrometers & filters

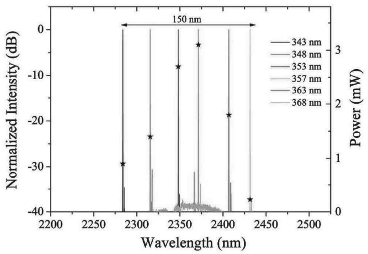
III-V-on-silicon laser arrays

InP type II diode lasers integrated on silicon using die-to-wafer bonding





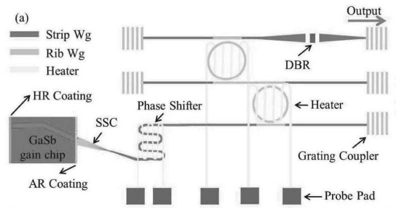


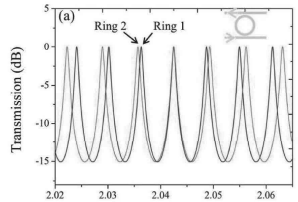


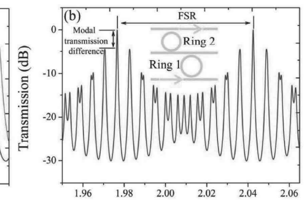
R. Wang et al., Optica 4(8), p.972-975 (2017)

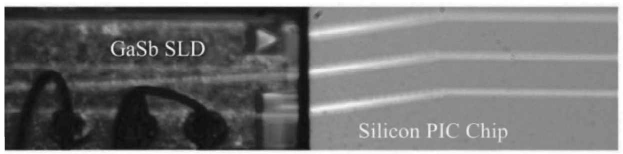
III-V-on-silicon widely tunable lasers

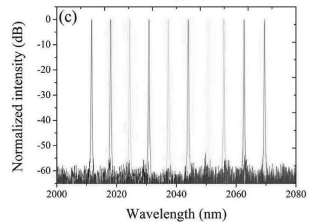
GaSb/Si extended cavity tunable lasers based on face-up assembly







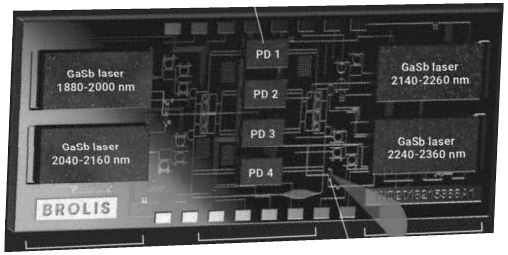




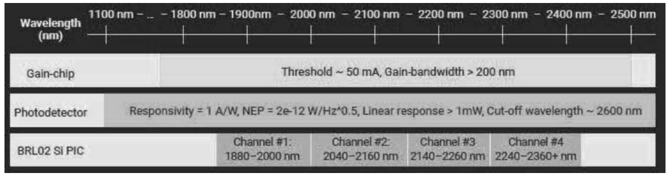
R. Wang et al., Opt. Express 24(25), p.28977 (2016)

III-V-on-silicon widely tunable lasers

GaSb/Si extended cavity tunable lasers



Courtesy of Brolis Sensor Technology



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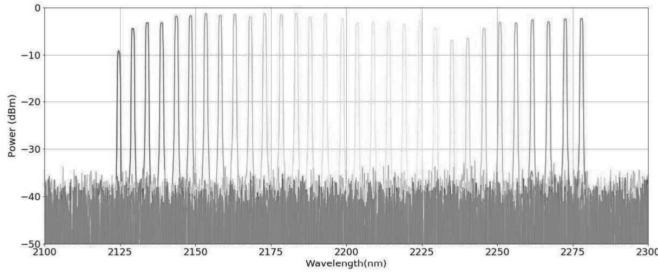
III-V-on-silicon tunable lasers

GaSb/Si extended cavity tunable lasers



Key performance @2200nm channel

- Tuning range 130nm
- Output power 0.1-0.3 mW CW @150mA current
- Output power 0.3-0.6 mW CW @300mA current
- SMSR > 30 dB
- Threshold 50mA
- Power consumption @150mA 0.3 W

Courtesy of Brolis Sensor Technology

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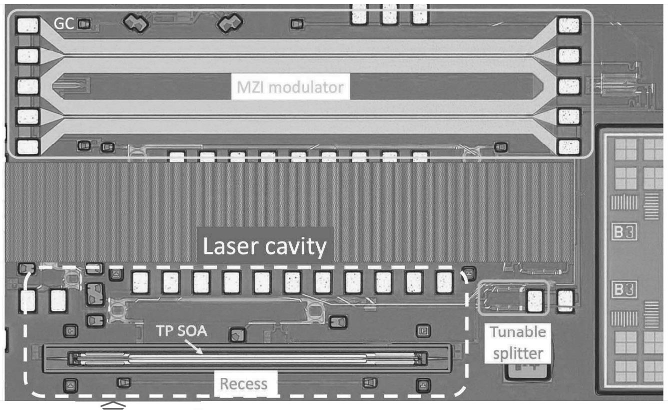
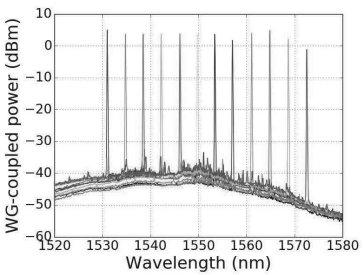
III-V-on-silicon tunable lasers

InP/Si extended cavity lasers on full SiPh platform through micro-transfer printing





J. Zhang et al., to be published

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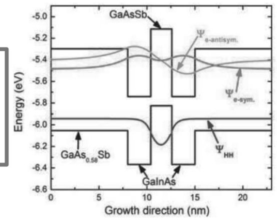
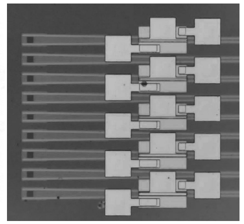
III-V-on-silicon photodetectors

InP type II photodetectors integrated through die to wafer bonding

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	$Ga_{0.32}In_{0.68}As$ $GaAs_{0.33}Sb_{0.67}$ $Ga_{0.32}In_{0.68}As$	2.6 nm*6 2.9 nm*6 2.6 nm*6
SCH		GaAsSb	130 nm
N-contact		N-InP	200 nm





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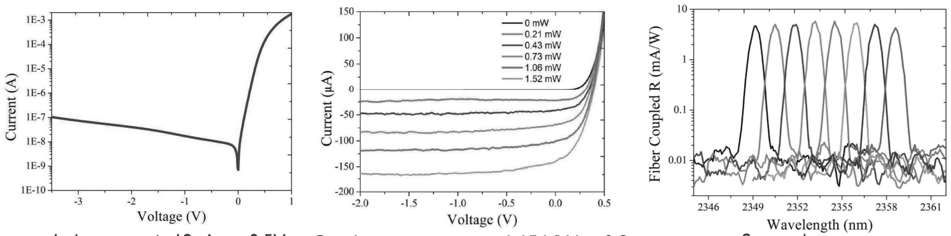
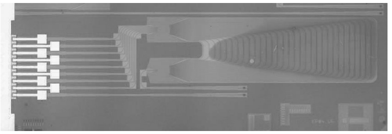
III-V-on-silicon photodetectors

InP type II photodetectors integrated through die-to-wafer bonding



dark current is 12nA at -0.5V. On-chip responsivity is 1.15A/W at 2.3um Spectral response



8 channel 2.3-2.4 um wavelength high resolution AWG spectrometer

R. Wang et al., Opt. Express 24(8), p.8480 (2016)

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Miniature CO2 sensor (4.3um)

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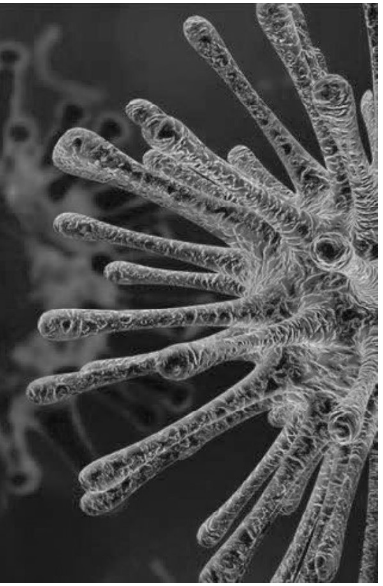
COVID19 pandemic

- Wear face masks
- Keep social distance
- Ventilation



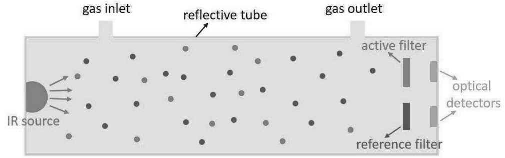
Datasheet Sensirion SCD30 Sensor Module

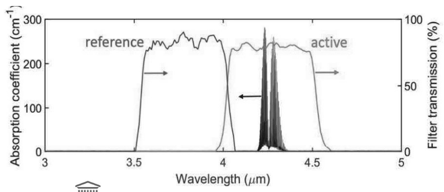
CO_2, humidity, and temperature sensor

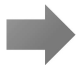
- NDIR CO_2 sensor technology
- Integrated temperature and humidity sensor
- Best performance-to-price ratio
- Dual-channel detection for superior stability
- Small form factor: 35 mm x 23 mm x 7 mm
- Measurement range: 400 ppm – 10.000 ppm
- Accuracy: ±(30 ppm + 3%)
- Current consumption: 19 mA @ 1 meas. per 2 s.
- Fully calibrated and linearized
- Digital interface UART or I²C

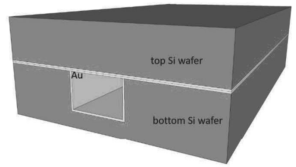
CO2 NDIR sensing on-chip

Typical NDIR CO_2 sensor









Hollow waveguide platform combined with MidIR LEDs and detectors

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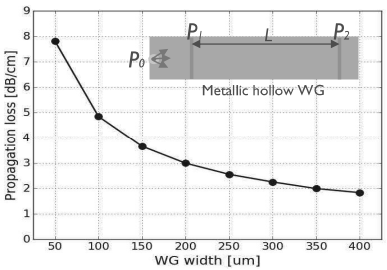
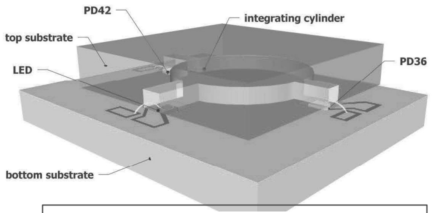
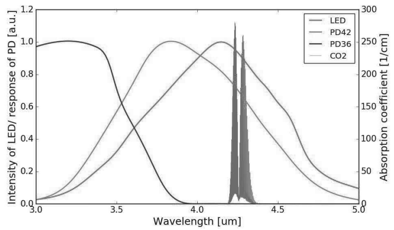
CO2 NDIR sensing on-chip



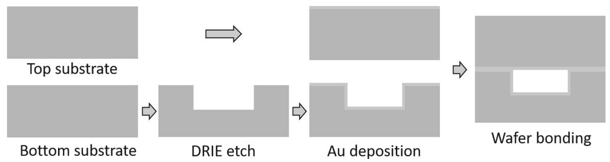


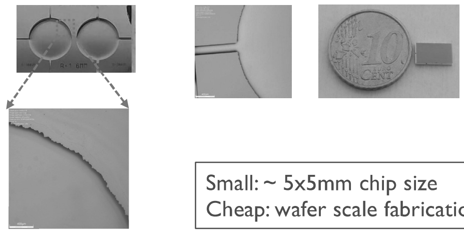
- Light source: InAsSbP p-i-n
- Detector: InAsSb p-i-n (PV)
- Light path: integrating cylinder

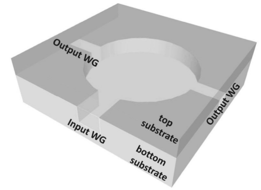


- Confinement factor in air = 100%
- Propagation loss 2dB/cm for 300um WG core

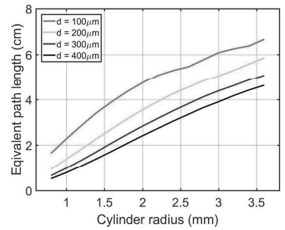
CO2 NDIR sensing on-chip







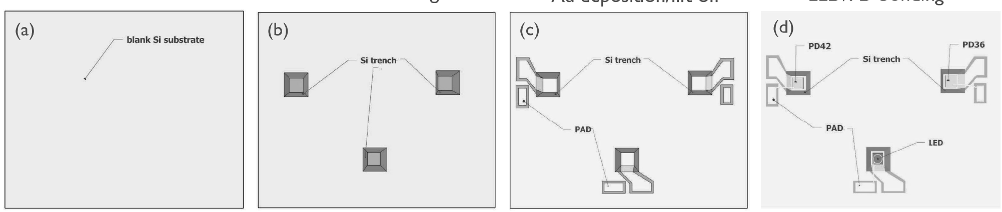
Equivalent path length



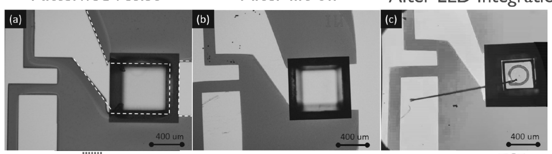
Small: ~ 5x5mm chip size
Cheap: wafer scale fabrication

CO2 NDIR sensing on-chip

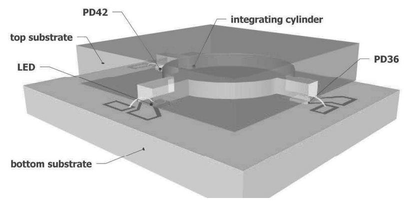
Blank Si substrate · KOH Si etching · Au deposition/lift-off · LED/PD bonding



Patterned resist · After lift-off · After LED integration

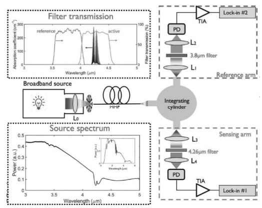


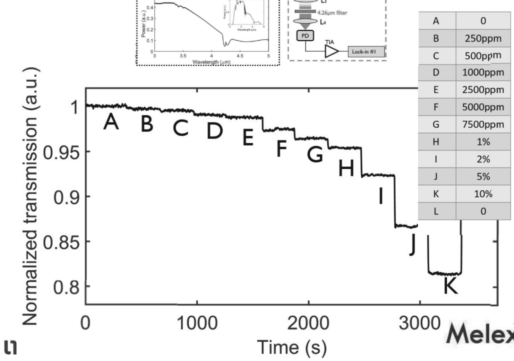
Au-Au direct bonding of both substrates

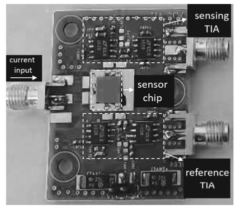


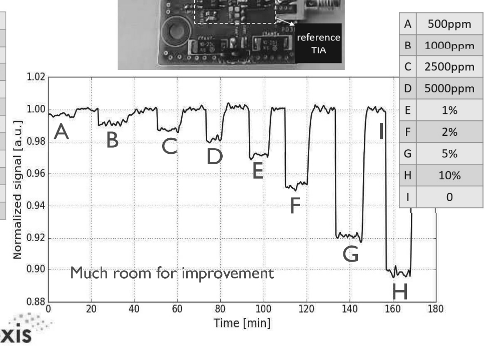
CO2 NDIR sensing on-chip

X. Jia et al., Sensors, 19(19), p.1 (2019)
X. Jia et al., Sensors, 21(16), p. 5347 (2021)









Thank you for your attention

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The Annual Conference of the IEEE Photonics Society

IPC

IPC was presented in a virtual format 18 – 21 October 2021. All technical sessions are currently available for on-demand viewing to registered attendees until 18 November 2021.