PHOTONICS RESEARCH GROUP

TUTORIAL

SILICON-PHOTONICS-BASED SPECTROSCOPIC SENSING FOR ENVIRONMENTAL MONITORING AND HEALTH CARE

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Ghent University and imec

Optical Fiber Conference (OFC) 2021
Online presentation
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ABSTRACT

Spectroscopic sensing is a powerful modality for numerous applications in medicine, biotechnology and structural health monitoring. Often the implementation is bulky or costly, which is a barrier for high volume markets. Integrated photonics - in particular silicon and silicon nitride photonics - is changing this and will boost spectroscopic sensing to such markets, for example in personalized medicine. This tutorial will discuss underlying principles, technologies and application cases.

Acknowledgements:
Photonics Research Group, Ghent University – imec
imec: SOI and SiN PIC manufacturing platforms
ePIXfab, European Silicon Photonics Alliance
Funding by European Commission (H2020 and ERC), FWO, Methusalem-program

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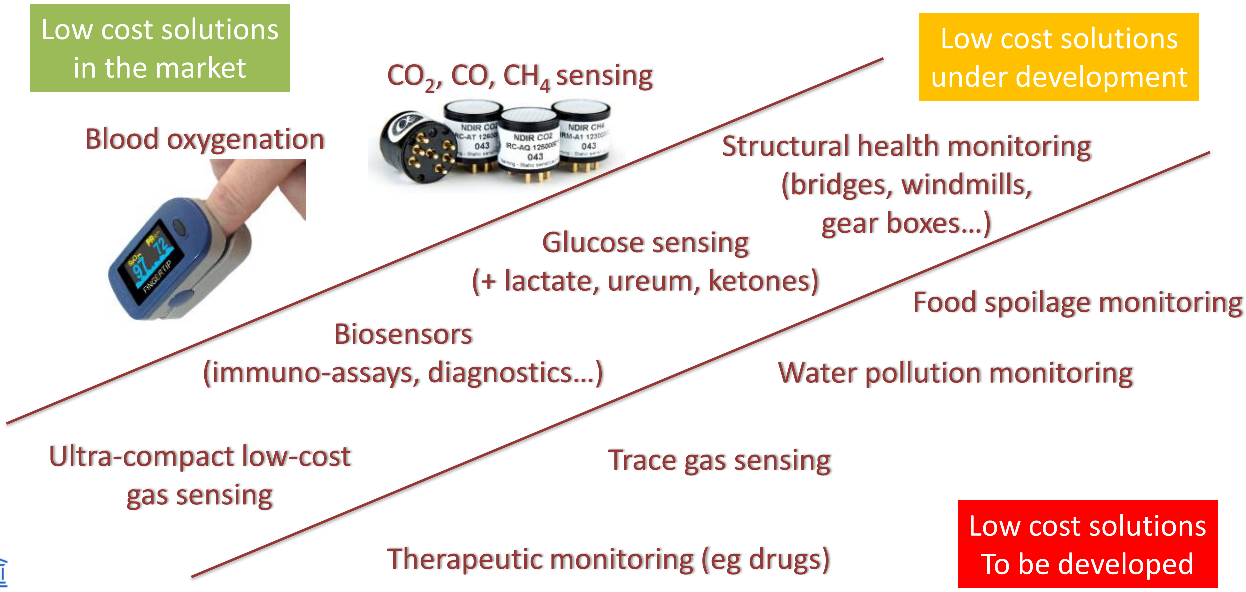
SPECTROSCOPIC SENSING: VAST APPLICATION SPACE



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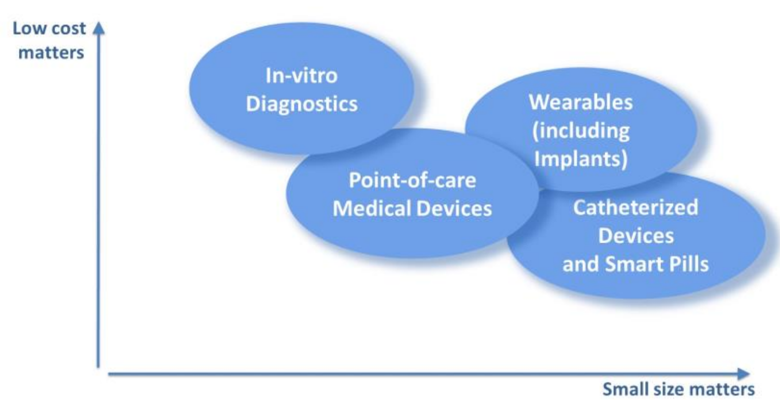
WHY MOVE TO MORE INTEGRATED SOLUTIONS USING SILICON PHOTONICS?

Low cost in volume

Mature technology and supply chain

Extreme miniaturization

Medical applications



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OUTLINE

- Brief introduction to silicon and silicon nitride PICs
- Spectroscopic sensing modalities
- On-chip spectrometers
- On-chip tunable lasers
- On-chip Raman spectroscopy
- Application cases

WHAT IS SILICON PHOTONICS?

The implementation of high density photonic integrated circuits by means of CMOS process technology in a CMOS fab

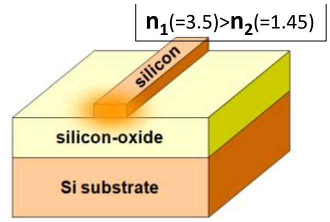


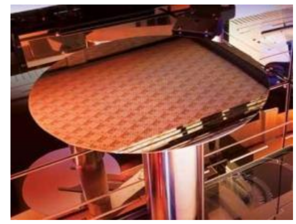
Pictures, courtesy of imec

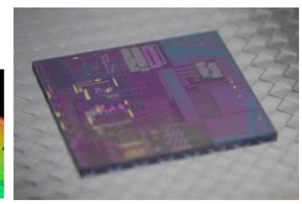
Enabling complex optical functionality on a compact chip at low cost

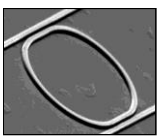
Why silicon photonics

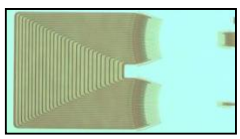
- High index contrast ⇒ **very compact PICs**
- CMOS technology ⇒ **nm-precision, high yield, existing fabs, low cost in volume**
- High performance passive devices
- High bitrate Ge photodetectors
- High bitrate modulators
- Wafer-level automated testing
- Hierarchical set of design tools
- Light source integration (hybrid/monolithic?)
- Integration with electronics (hybrid/monolithic?)











Chip cost in a CMOS fab (order of magnitude)

	Simple/small chip	Complex/large chip
Very low volume (**MPW**) (~ 100-1000 chips per year)	100€	1000€
Low volume (<10K chips per year)	10€	100€
Moderate volume (10K – 1M chips per year)	3€	30€
High volume (>1M chips per year)	1€	10€

In high volume, the chip is "for free"

Even in moderate volume the cost per chip is low

Even in low volume the chip has a high value for money

Transceivers for Data centers and for Telecom

Under development:
Data rate: 800 Gb/s
Symbol rate: 100 Gbaud

Typical data rate: 100-400 Gb/s
Typical symbol rate: 25-50 GBaud

- PSM4 (4 parallel fibers)
- WDM (4 wavelengths)
- PAM4
- Coherent (2 polarisations + QPSK)
- Coherent (16-QAM)

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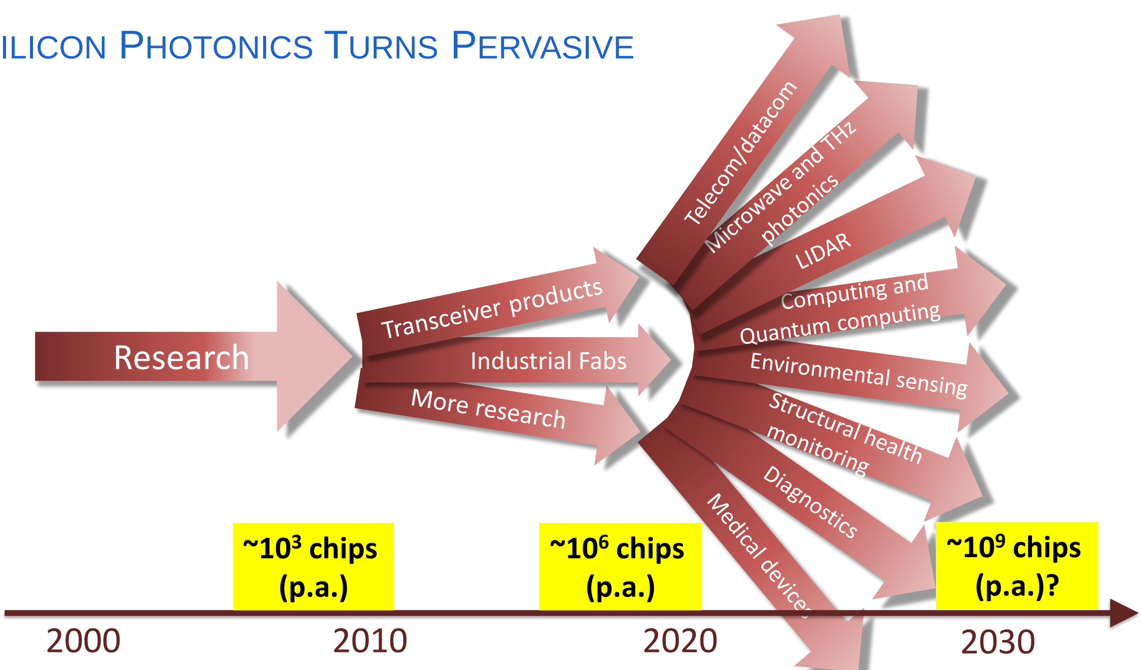
Silicon Photonics Turns Pervasive



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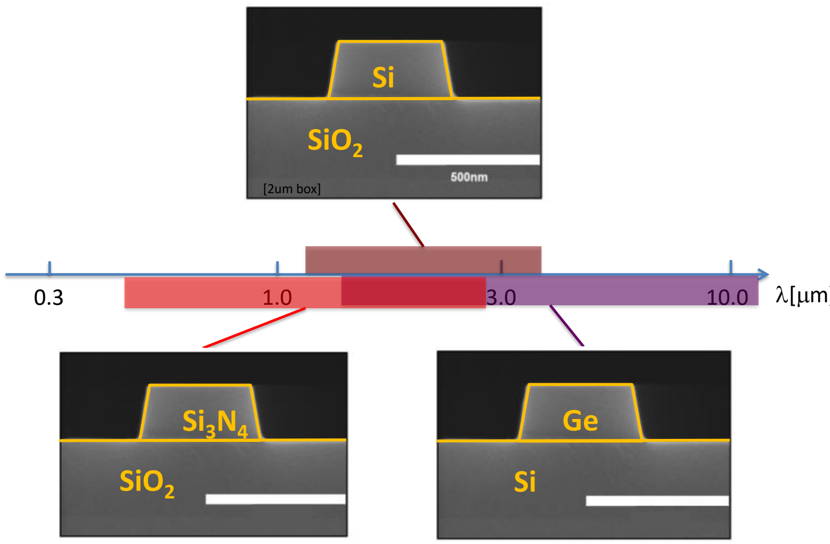
Silicon photonics: extending the wavelength range

Without leaving the CMOS fab



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Complementarity of SOI and SiN and Ge-on-Si (GOS)

	SOI	SiN	GOS
Compactness (high index contrast)			
High speed modulation			
Thermo-optic modulation			
High speed detection			
Optical loss (linear) (< 1.1 μm)			
Optical loss (linear) (1.1 – 4 μm)			(only above 2 μm)
Optical loss (linear) (> 4 μm)			
Optical loss (nonlinear)	(1-2 μm range)		
Sensitivity to fab error			
Temperature sensitivity			

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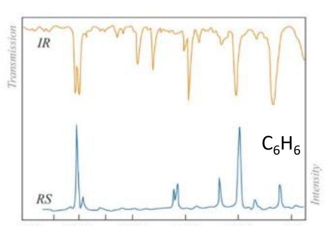
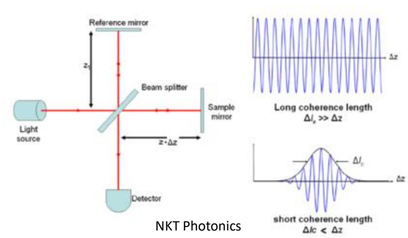
SENSING MODALITIES

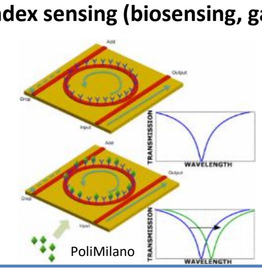
Vibrational spectroscopy (absorption, Raman)



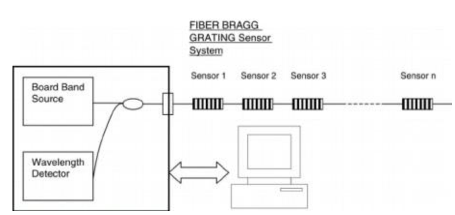
3D imaging (Lidar, OCT, LDV)



Refractive index sensing (biosensing, gas sensing)



Fiber sensor readout (FBG, Brillouin, Raman)



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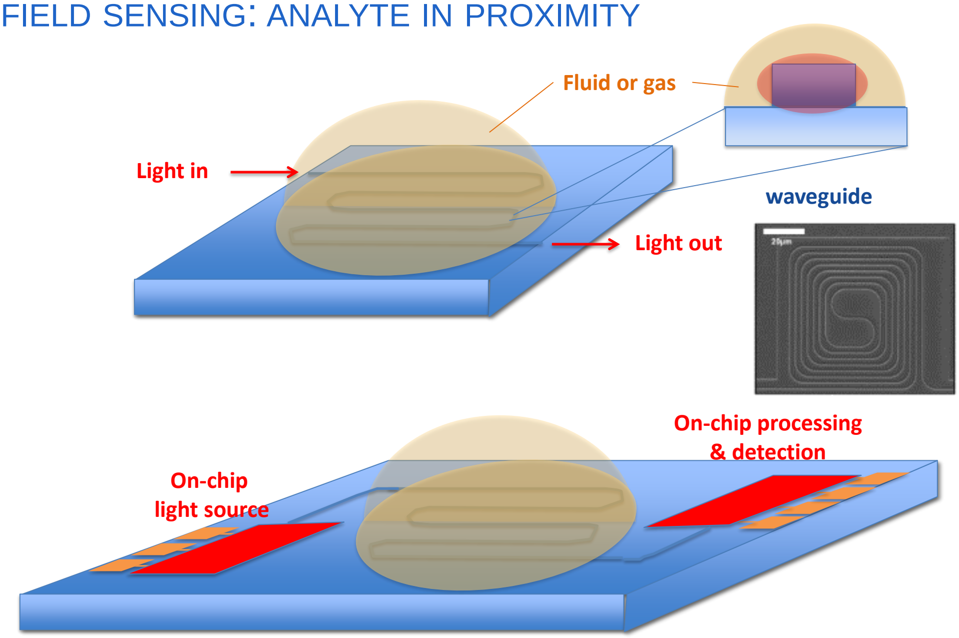
Near field sensing: analyte in proximity



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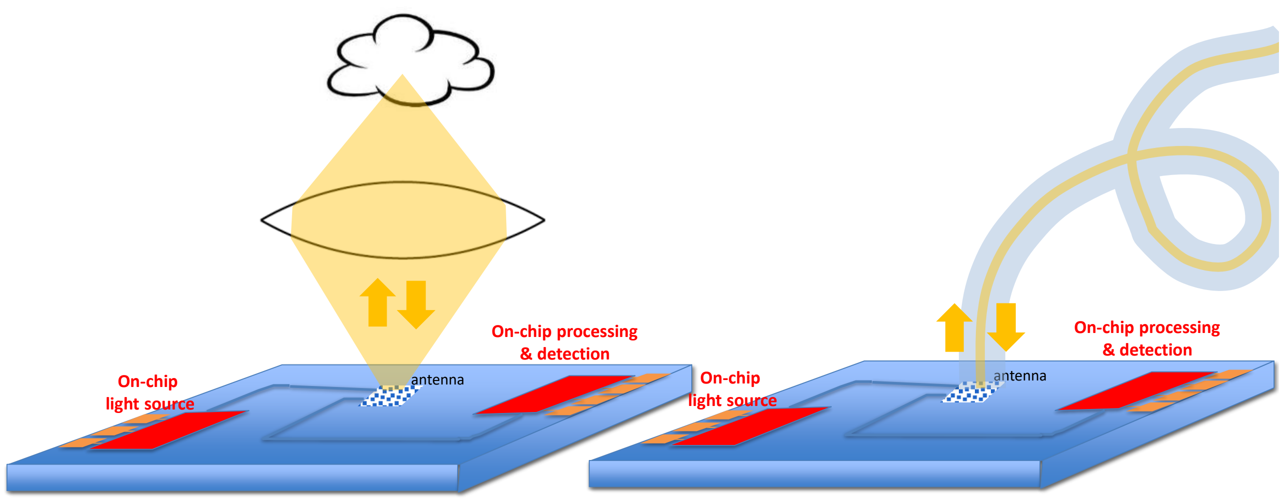
Far-field sensing: sensed area is remote



Remote sensing through free space imaging

Remote sensing through fiber interconnect

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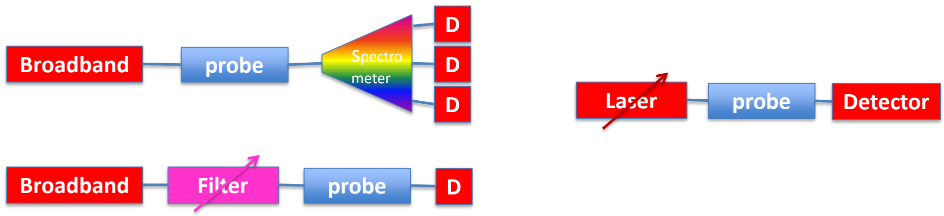
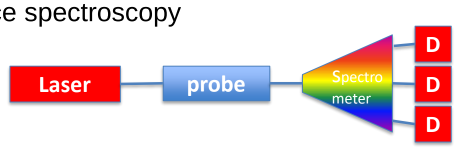
SPECTROSCOPY-ON-CHIP: APPROACHES

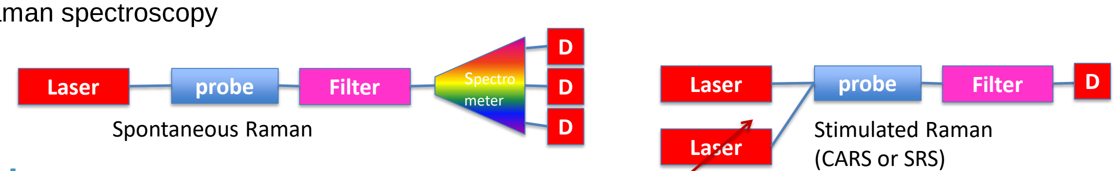
Absorption spectroscopy



Fluorescence spectroscopy



Raman spectroscopy



SPECTROSCOPY-ON-CHIP: APPROACHES

Absorption spectroscopy (eg Tunable Diode Laser Absorption Spectroscopy = TDLAS)

$T(\lambda) = e^{-(\alpha(\lambda)+\alpha_s)L}$

$dT/d\alpha$ max when $(\alpha(\lambda) + \alpha_S)L=1$

Optimal (total) loss: 4.3 dB

When $\alpha_{tot}L<<1$: signal ~ 1- $\alpha_{tot}L$

"Indirect" absorption spectroscopy

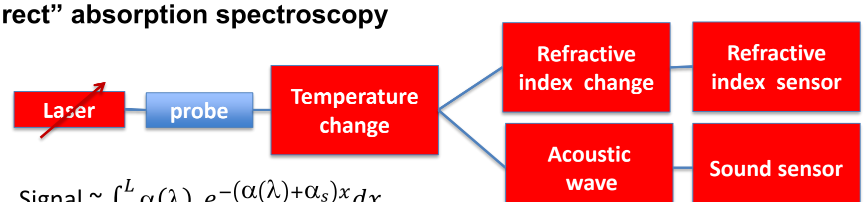


Photo-thermal spectroscopy

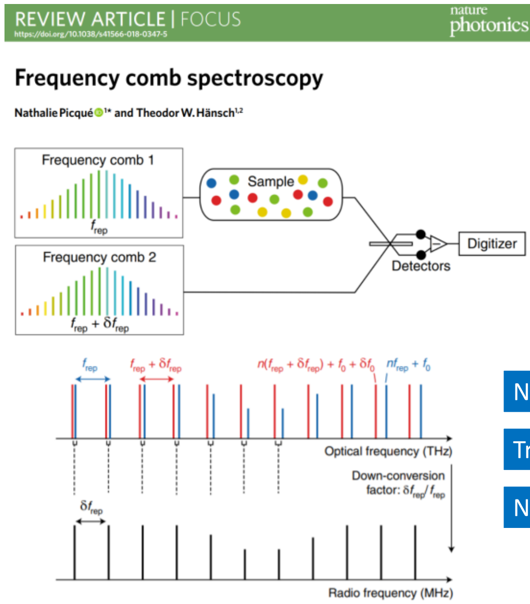
Photo-acoustic spectroscopy

Signal ~ $\int_0^L \alpha(\lambda)\ e^{-(\alpha(\lambda)+\alpha_s)x} dx$

No optical detector

When $\alpha_{tot}L<<1$: signal ~ $\alpha(\lambda)L$

DUAL COMB ABSORPTION SPECTROSCOPY



No need for laser tuning

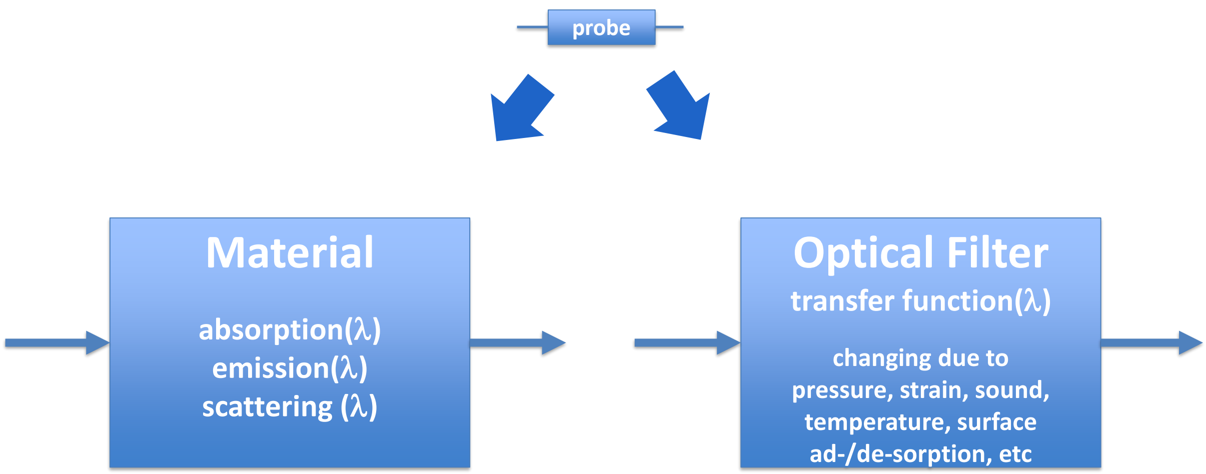
Translation of optical spectrum to RF spectrum

Need for high speed detectors

WHAT IF ABSORPTION IS WEAK?

- increase path length
  - spirals on chip
  - on-chip integrating sphere
  - resonant optical device
- (non-optical) resonant signal enhancement of modulated signals
- densification of analyte
  - adsorption to waveguide surface
  - adsorption in a mesoporous coating covering waveguide

Probe



Identify a material
and measure its density

Identify a physical/chemical mechanism
and measure its amplitude

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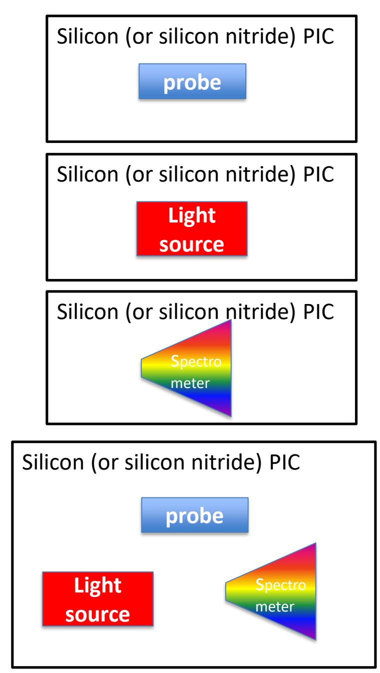
Key components needed

probe	Probe on-chip
Spectrometer	Integrated spectrometer
Broadband	Integrated broadband source
Laser	Integrated laser
Laser	Integrated tunable laser
Comb Laser	Integrated comb source



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Outline

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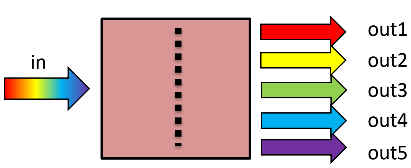
Spectrometers

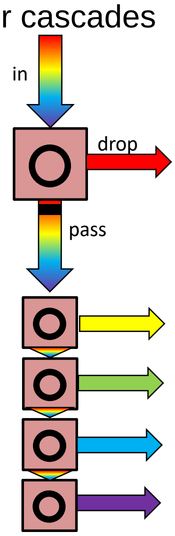
And Combinations!

Dispersive devices



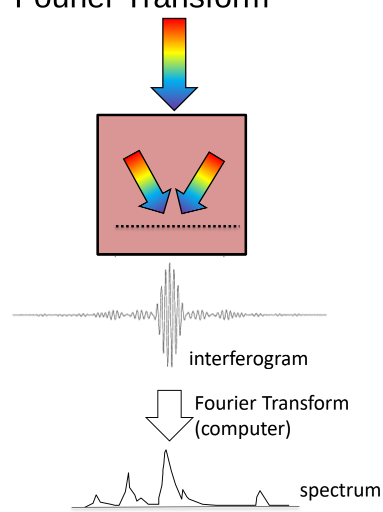
Mechanism used: grating diffraction (multi-beam interference)

Filter cascades



Mechanism used: resonance or interference or Bragg reflection

Fourier Transform



Mechanism used: two-beam interference

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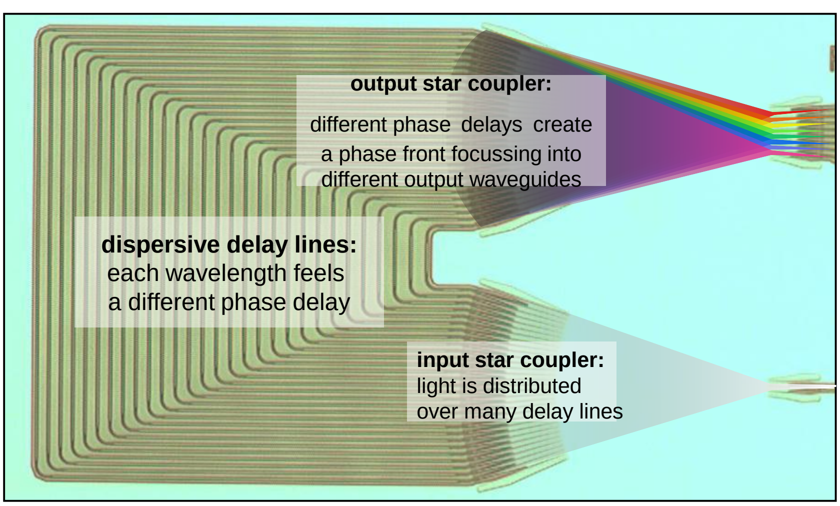
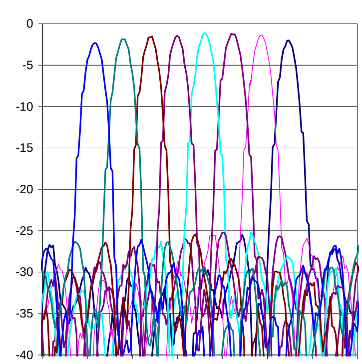
Figures of Merit

- Spectral resolution (channel spacing)
- Overall bandwidth (Free Spectral Range)
- Crosstalk and dynamic range
- Absolute wavelength accuracy
- Polarisation sensitivity
- Chip area needed
- Sensitivity to fabrication error
- Sensitivity to temperature
- Complexity of design

→ Many solutions depending on application context

Arrayed Waveguide Grating (AWG) spectrometer (200 x 350 µm^2)





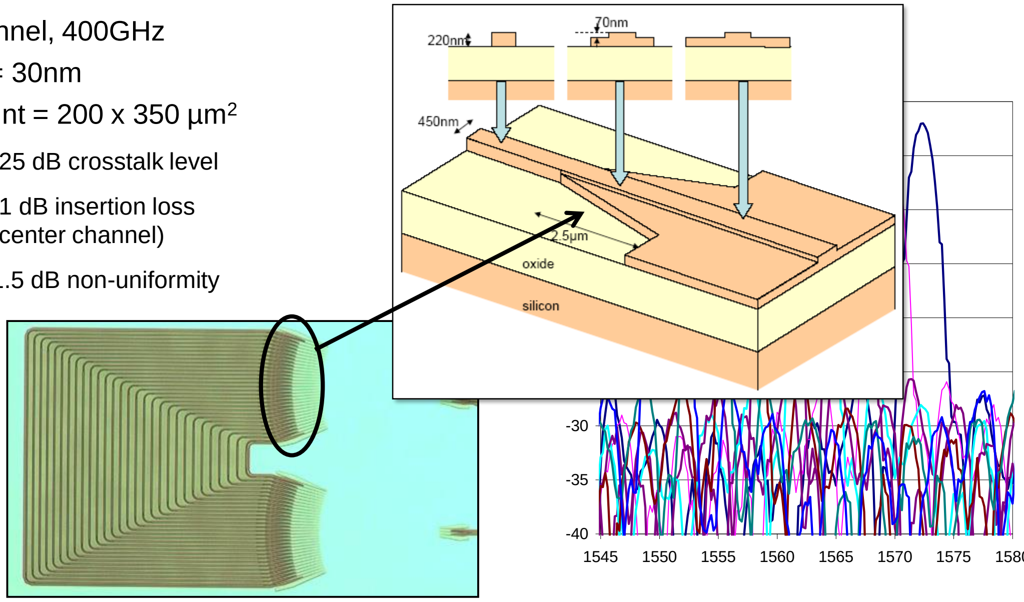
Arrayed Waveguide Grating

8-channel, 400GHz

FSR = 30nm

footprint = 200 x 350 µm^2

- -25 dB crosstalk level
- -1 dB insertion loss (center channel)
- 1.5 dB non-uniformity



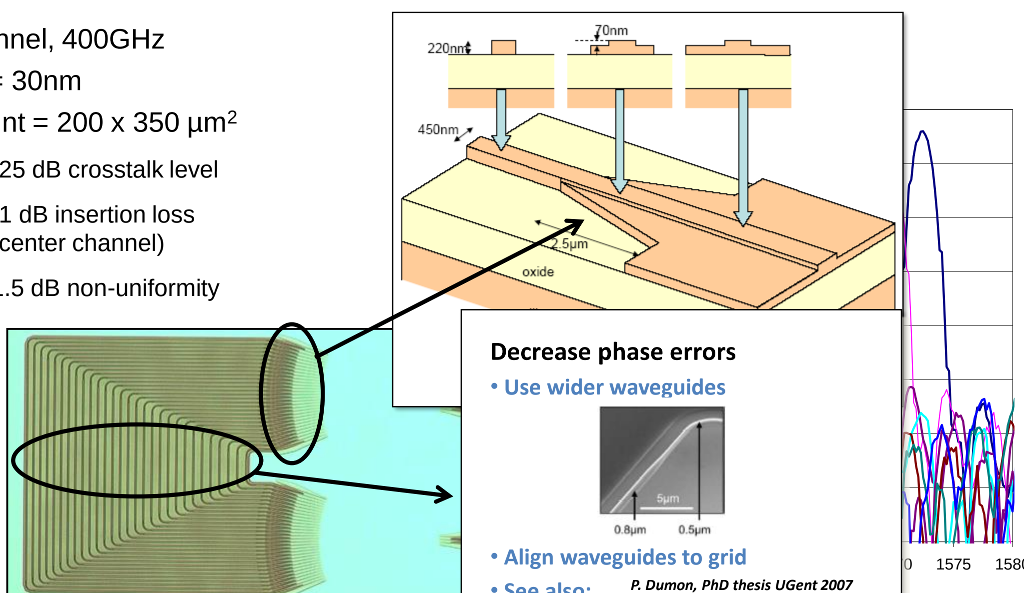
Arrayed Waveguide Grating design

8-channel, 400GHz

FSR = 30nm

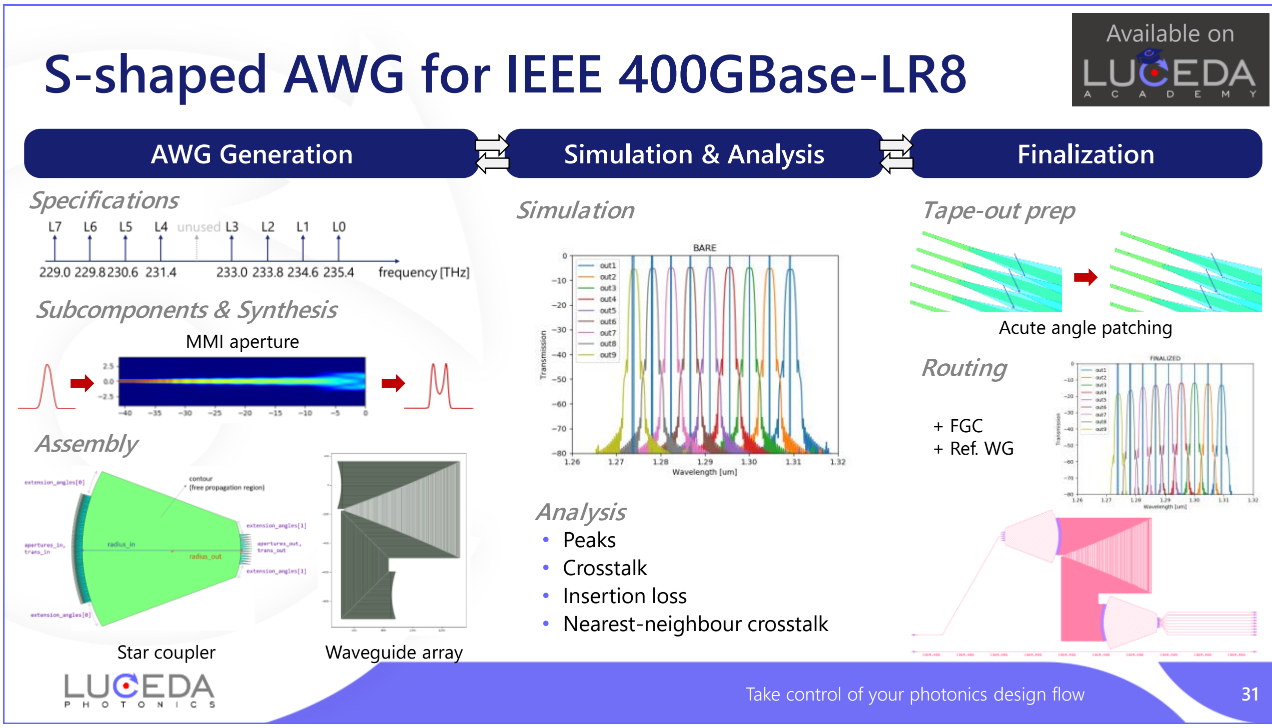
footprint = 200 x 350 µm^2

- -25 dB crosstalk level
- -1 dB insertion loss (center channel)
- 1.5 dB non-uniformity

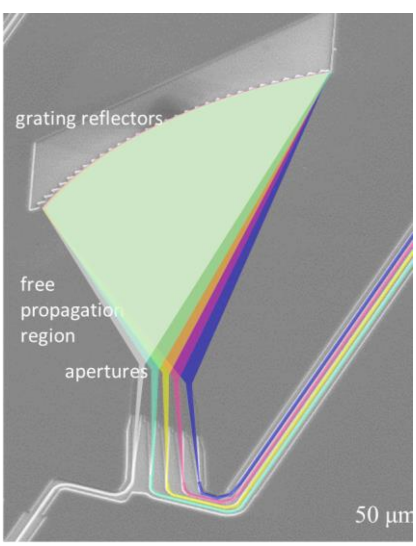


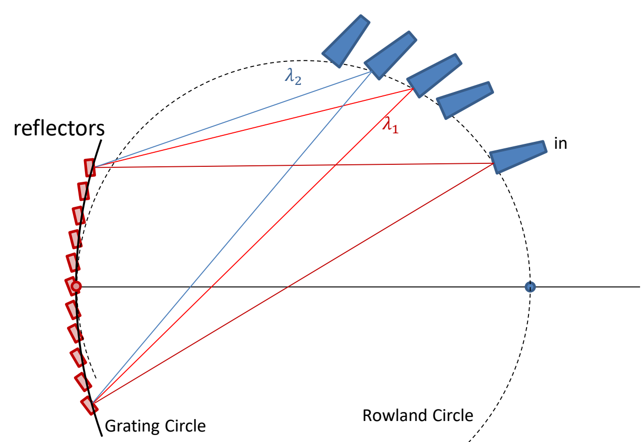
Decrease phase errors

- Use wider waveguides
- Align waveguides to grid
- See also: *P. Dumon, PhD thesis UGent 2007*
  S. Selvaraja, PhD thesis UGent 2014
  (http://photonics.intec.ugent.be)



Echelle Diffraction Gratings (EDG) aka Planar Concave Grating (PCG)





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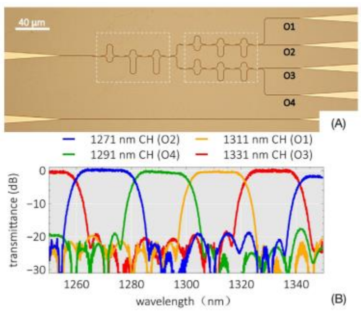
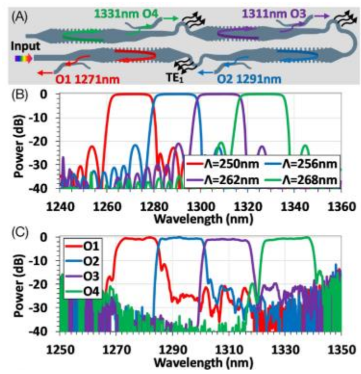
FILTER CASCADES

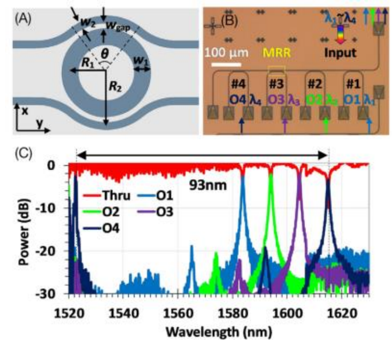
Mach-Zehnder Interferometers (MZI)



Distributed Bragg Reflectors (DBR)



Micro Ring Resonators (MRR)



D. Liu et al, Microw. Opt. Techn. Lett. 2020
[*https://doi.org/10.1002/mop.32509*](https://doi.org/10.1002/mop.32509)

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REVIEWS OF SILICON MICRO RING RESONATORS

Laser Photonics Rev. **6**, No. 1, 47–73 (2012) / **DOI** 10.1002/lpor.201100017

Silicon microring resonators

Wim Bogaerts*, Peter De Heyn, Thomas Van Vaerenbergh, Katrien De Vos, Shankar Kumar Selvaraja, Tom Claes, Pieter Dumon, Peter Bienstman, Dries Van Thourhout, and Roel Baets

IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 24, NO. 6, NOVEMBER/DECEMBER 2018 5900324

Integrated Silicon Photonic Microresonators: Emerging Technologies

Zhanshi Yao, Kaiyi Wu, Bo Xue Tan, Jiawei Wang, Yu Li, Yu Zhang, and Andrew W. Poon, *Member, IEEE*

IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 26, NO. 2, MARCH/APRIL 2020 8200810

Statistical Behavioral Models of Silicon Ring Resonators at a Commercial CMOS Foundry

Peng Sun, Jared Hulme, Thomas Van Vaerenbergh, Jinsoo Rhim, Charles Baudot, Frederic Boeuf, Nathalie Vulliet, Ashkan Seyedi, Marco Fiorentino, and Raymond G. Beausoleil

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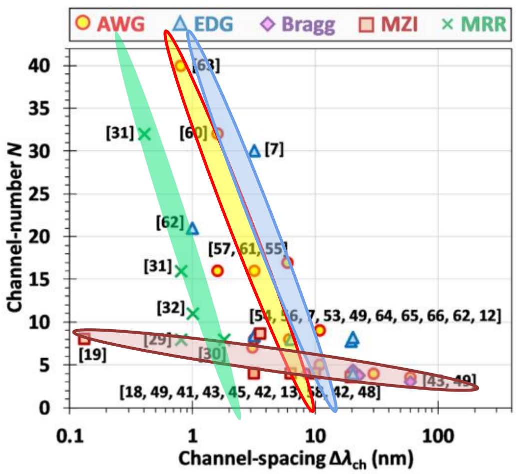
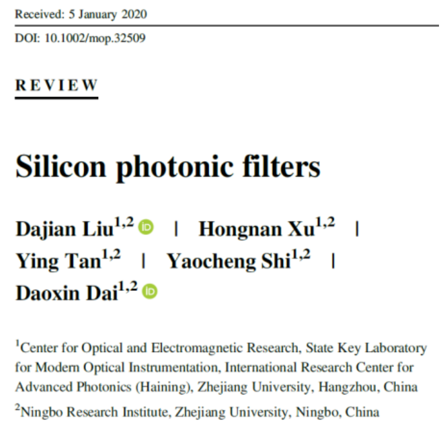
Comparisons: Channel # and Spacing in SOI-based Spectrometers




Received: 5 January 2020
DOI: 10.1002/mop.32509

REVIEW

Silicon photonic filters

Dajian Liu[1,2] | Hongnan Xu[1,2] | Ying Tan[1,2] | Yaocheng Shi[1,2] | Daoxin Dai[1,2]

[1]Center for Optical and Electromagnetic Research, State Key Laboratory for Modern Optical Instrumentation, International Research Center for Advanced Photonics (Haining), Zhejiang University, Hangzhou, China
[2]Ningbo Research Institute, Zhejiang University, Ningbo, China

D. Liu et al, Microw. Opt. Techn. Lett. 2020 *https://doi.org/10.1002/mop.32509*

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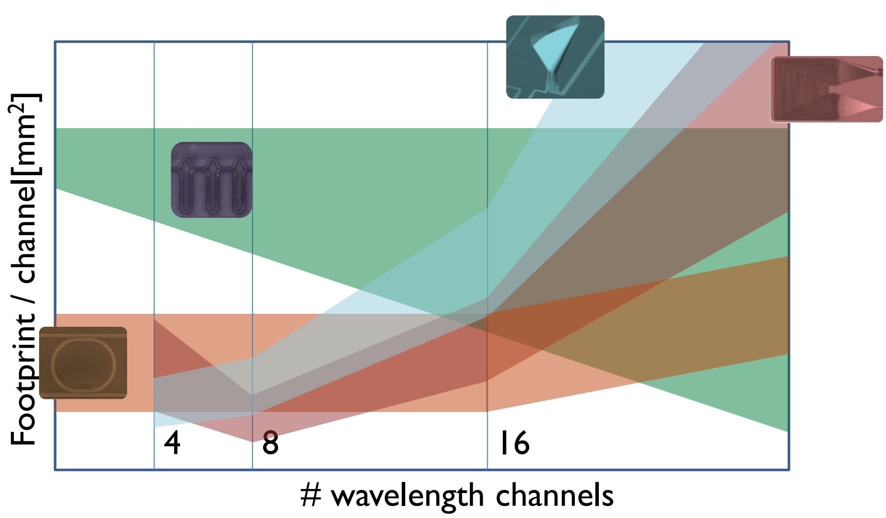
Comparisons: Footprint of SOI-based Spectrometers



W. Bogaerts et al, Proc. SPIE 9365 (2015) doi:10.1117/12.2082785

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COMPARISONS: AWGS AND EDG (PCG) ACROSS PLATFORMS

Table 1. Performance Comparison between AWGs and PCGs Across Different Platforms

Device/Technology	Central Wavelength (μm)	Footprint (μm^2)	No. of Channels/Channel Spacing (nm)	FSR (nm)	Insertion Loss (dB)	Crosstalk (dB)
AWG/SOI [38]	1.55	530 × 435	16/3.2	57.6	<3.0	>25.0
AWG/Si_3N_4 [41]	0.89	450 × 750	12/2.0	30	<1.5	20.0
AWG/Ge-on-Si [42]	5.3	1000 × 1000	5/19.0	148	2.5	20
S-AWG/SOI [36]	1.55	305 × 260	4/30	144	<2	19
PCG/SOI [36]	1.55	700 × 385	8/6.5	100	<1.5	<20
PCG/SOI [44]	3.8	1800 × 1700	8/10	105	<2	<20
PCG/Ge-on-Si [45]	5.0	1500 × 1200	6/25	170	<5	22

A. Subramanian et al, Photonics Research (2015) *doi:10.1364/PRJ.3.000B47*

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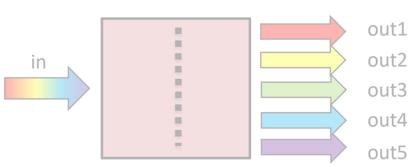
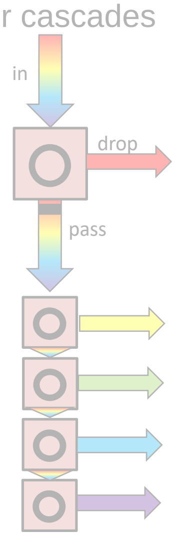
SPECTROMETERS

Dispersive devices



Mechanism used: grating diffraction (multi-beam interference)

Filter cascades



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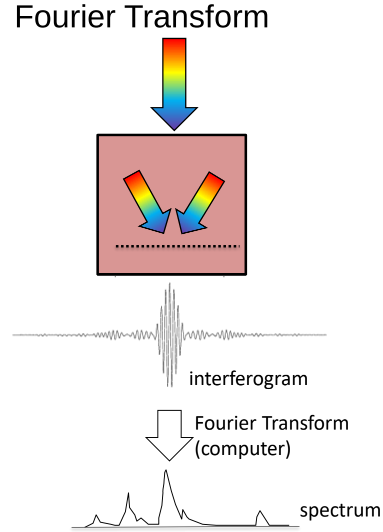

Mechanism used: two-beam interference

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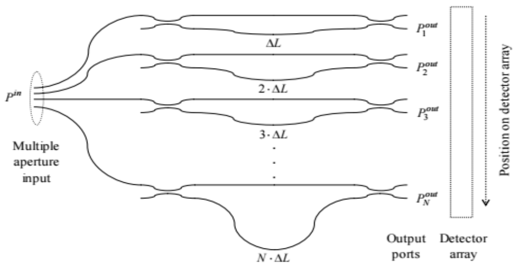
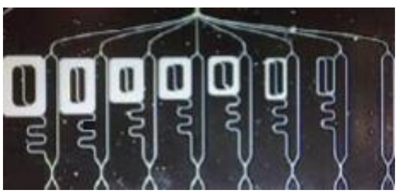
SPATIAL HETERODYNE SPECTROMETERS (SHS)

Set of parallel MZIs with increasing pathlength difference





Bandwidth: 0.184 nm
Resolution: 0.023 nm

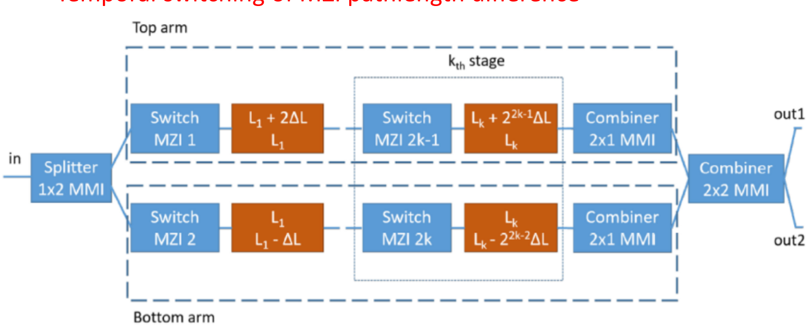
SHS:

- Interferogram is created by **an array of waveguide MZI** with increasing OPD, recorded by a detector array.
- Bandwidth limited by FSR of MZI
- Number of MZI channels: $N = \frac{2\Delta\lambda}{\delta\lambda}$
- Recent work:
  - SHS on CMOS compatible SiN platform(TriPleX^{TM})
  - Resolution of 0.023nm, bandwidth 0.184nm at 1550nm requires area of 4mm × 8mm.

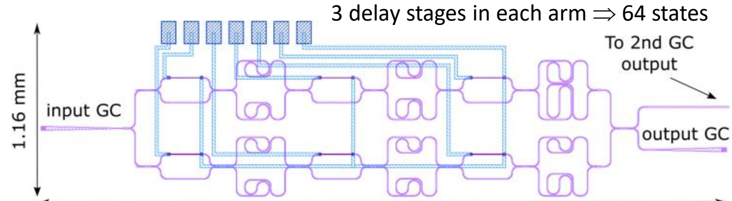
M. Florjanczyk et al., Optics express (2007)
Y. Li et al., IEEE Phot. Tech. Lett. (2016) 10.1109/LPT.2016.2615319

DIGITAL FOURIER TRANSFORM SPECTROMETER

Temporal switching of MZI pathlength difference



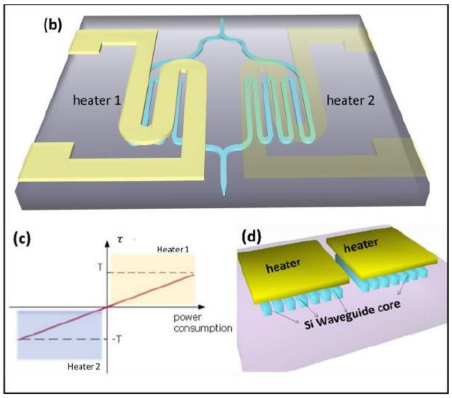
Bandwidth: 130 nm (around 2300 nm)
Resolution: 1.5 nm

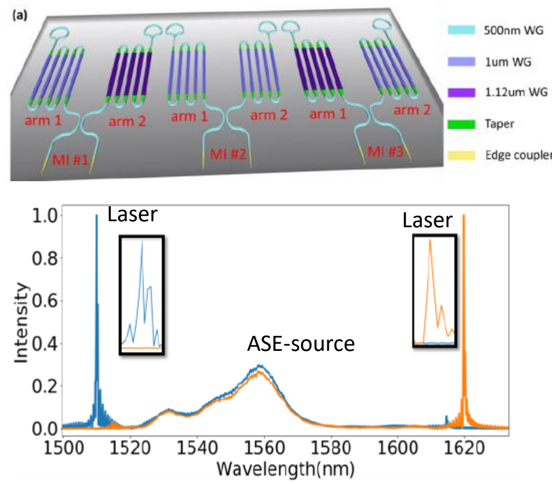


F. Pavanello et al, IEEE Phot. Journ. (2019) 10.1109/JPHOT.2019.2914013

Temporal Fourier-Transform Spectrometer

Temporal tuning of MZI pathlength difference





Bandwidth: > 130 nm
Resolution: 0.16 nm

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A. Li et al, Lasers and Phot. Rev. (2021) doi.org/10.1002/lpor.202000358

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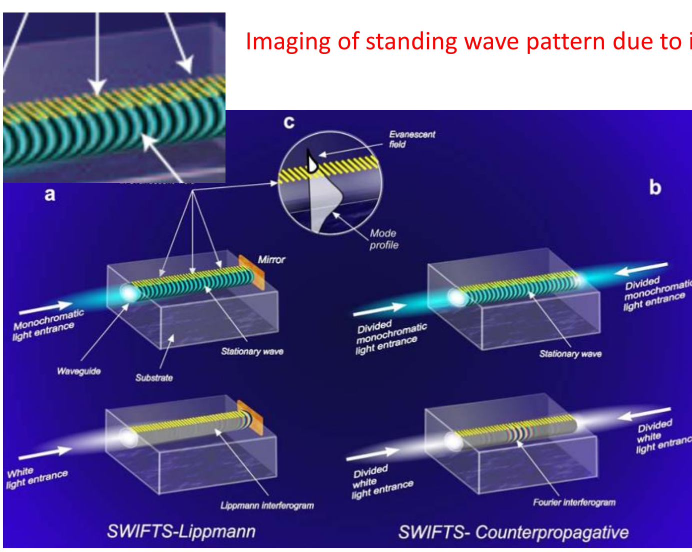
Stationary Wave Integrated FTS (SWIFTs)



Imaging of standing wave pattern due to interference of counterpropagating waves

SWIFTs:

- Interferogram created as **an optical standing wave**, is scattered by Nano-dots loaded on waveguide and recorded by a detector array.
- Increasing waveguide length (L) gives higher resolution: $\delta\lambda = \frac{\lambda^2}{n_{eff}L}$[1]
- Operational bandwidth is limited by **subsampling**:
  - Period of the interferogram = $\frac{\lambda}{2n_{eff}}$ << pixel pitch of commercially available detector array

Bandwidth: ~ 100 nm
Resolution: 4 nm

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E. Le Coarer, et al. Nature Photonics (2007) doi:10.1038/nphoton.2007.138

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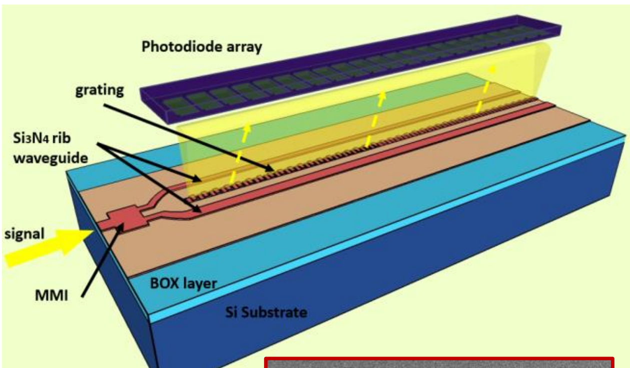
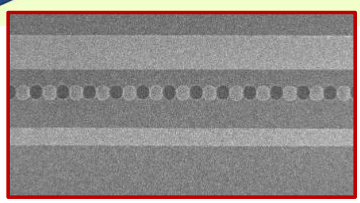
CO-PROPAGATIVE STATIONARY FOURIER TRANSFORM SPECTROMETER

Imaging of standing wave pattern due to interference of co-propagating waves





- Interferogram is created by the interference between the **evanescent fields of two waveguide modes propagating at different phase velocity** (due to waveguides with different width)
- Interferogram is diffracted by a grating towards a detector array .
- Subsampling is avoided → broadband operation:
  - Interferogram period = $\frac{\lambda}{\Delta n_{eff}}$
  - Increased by a factor $\frac{2n_{eff}}{\Delta n_{eff}}$ comparing with SWIFTS
- Still allows for moderately high resolution $\frac{\lambda^2}{\Delta n_{eff} L}$

X. Nie et al, Optics Express (2017) doi:10.1364/OE.25.00A409 43

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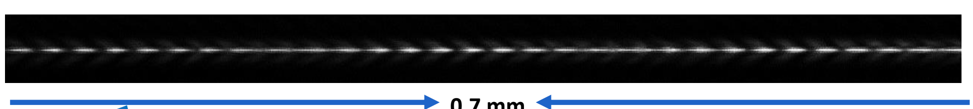
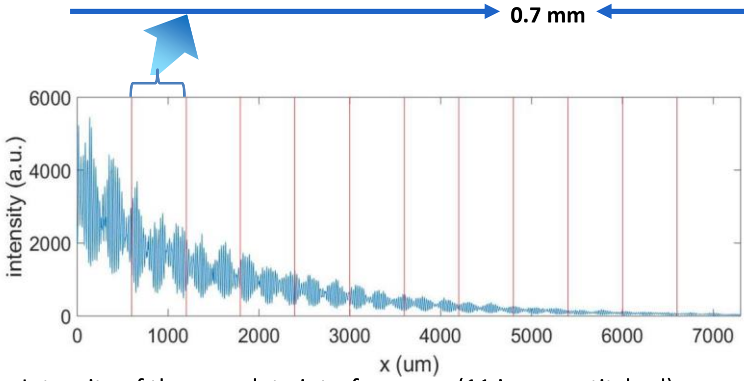
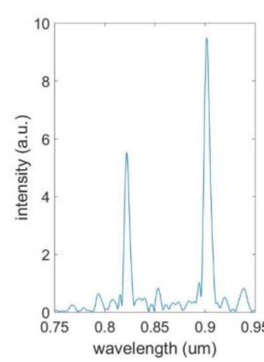
CO-PROPAGATIVE STATIONARY FOURIER TRANSFORM SPECTROMETER

Dual-wavelength injection:





Intensity of the complete interferogram (11 images stitched)



Fourier transform mapped to wavelength axis

Bandwidth: ~ 100 nm
Resolution: 6 nm

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X. Nie et al, Optics Express (2017) doi:10.1364/OE.25.00A409 44

Outline

- Brief introduction to silicon and silicon nitride PICs
- Spectroscopic sensing modalities
- On-chip spectrometers
- ➡ On-chip tunable lasers
- On-chip Raman spectroscopy
- Application cases

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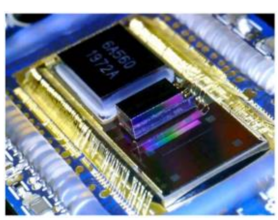
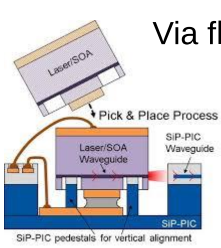
Hybrid integration of III-V light sources in silicon PIC

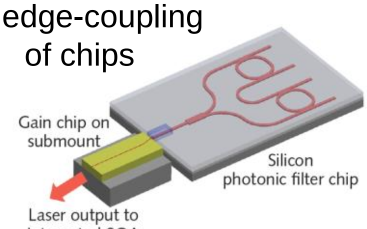
Via a micro-optic bench



Via flip-chip



Via edge-coupling of chips



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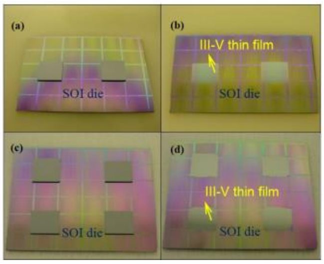
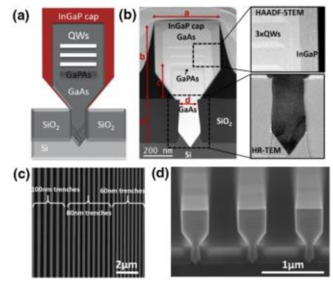
Wafer-level Heterogeneous integration of III-V light sources on silicon PIC

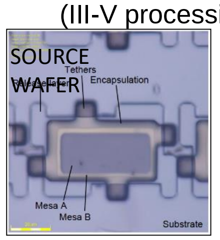
die-to-wafer bonding
(III-V processing after bonding)

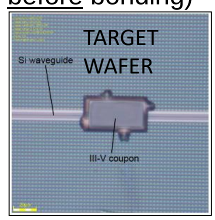


III-V epitaxy on silicon



micro transfer printing
(III-V processing before bonding)





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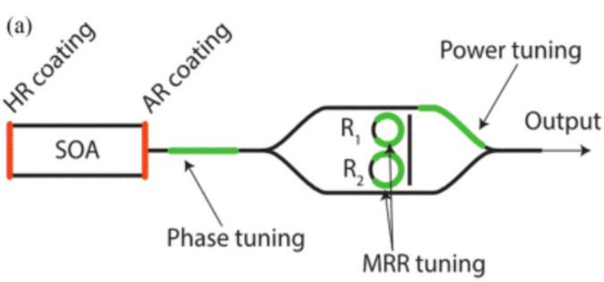
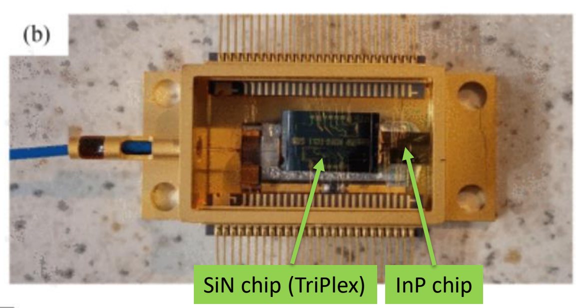
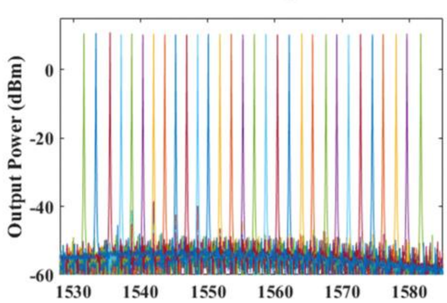
Hybrid integration of InP RSOA and SiN PIC for widely tunable C-band laser







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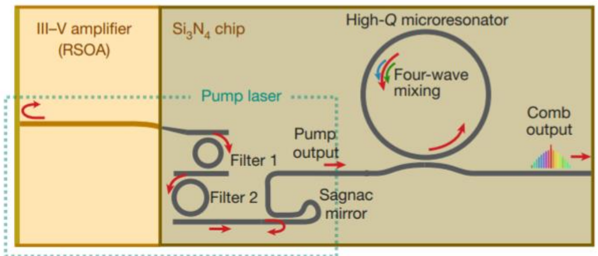
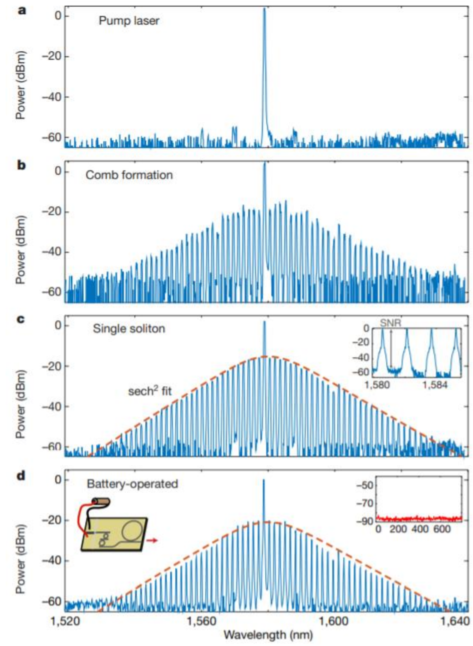
Y. Lin et al, IEEE Phot. Journ. (2018)
10.1109/JPHOT.2018.2842026

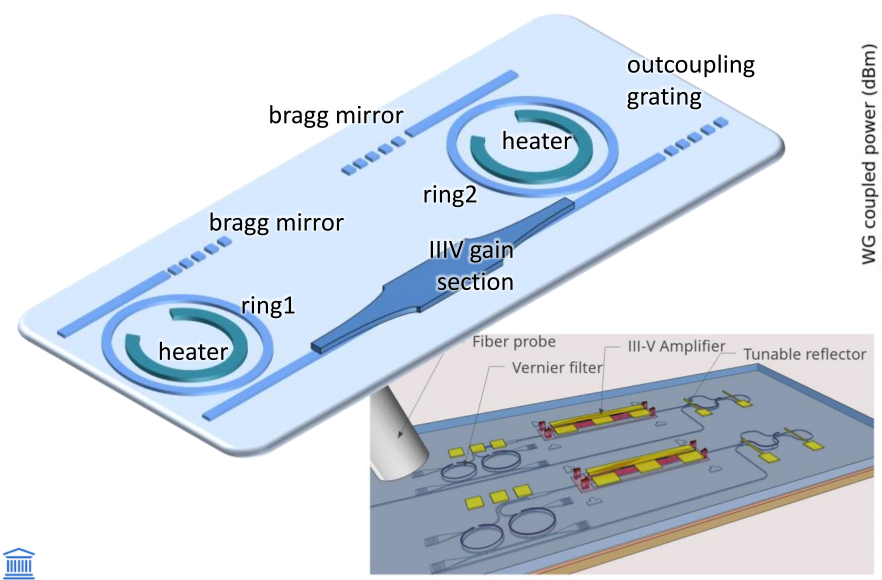
Hybrid integration of InP RSOA and SiN PIC for C-band Kerr comb source

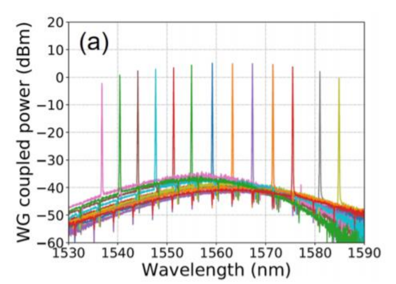




B. Stern et al., Nature (2018)
https://doi.org/10.1038/s41586-018-0598-9

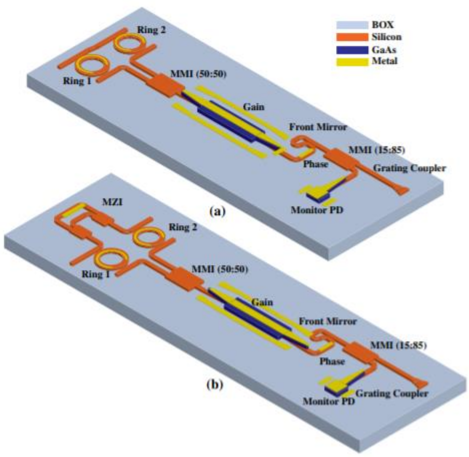
Micro-Transfer-Printed widely tunable C-band laser on Silicon

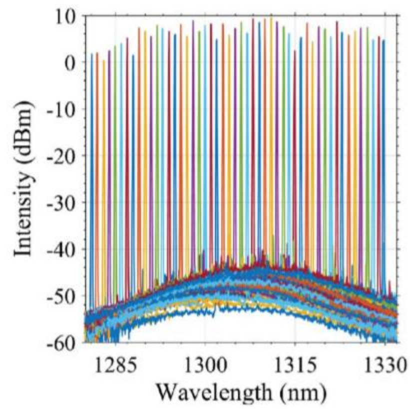




Jing Zhang et al, APL Photonics (2019) [doi:10.1063/1.5120004](https://doi.org/10.1063/1.5120004)

EPI-BONDED WIDELY TUNABLE O-BAND LASER ON SILICON





A. Malik et al, Photonics Research (2020) https://doi.org/10.1364/PRJ.394726

OUTLINE

Brief introduction to silicon and silicon nitride PICs

Spectroscopic sensing modalities

On-chip spectrometers

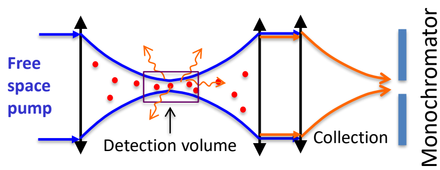
On-chip tunable lasers

➡ On-chip Raman spectroscopy

Application cases

WAVEGUIDE-ENHANCED RAMAN SPECTROSCOPY

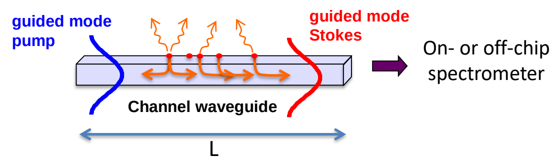
Free space excitation and collection in a confocal microscope



$$\frac{P_{coll}}{P_{pump}} = 2\frac{\lambda_0}{n}\rho\sigma_{scat}$$

density — scattering cross-section

Waveguide-based excitation and collection

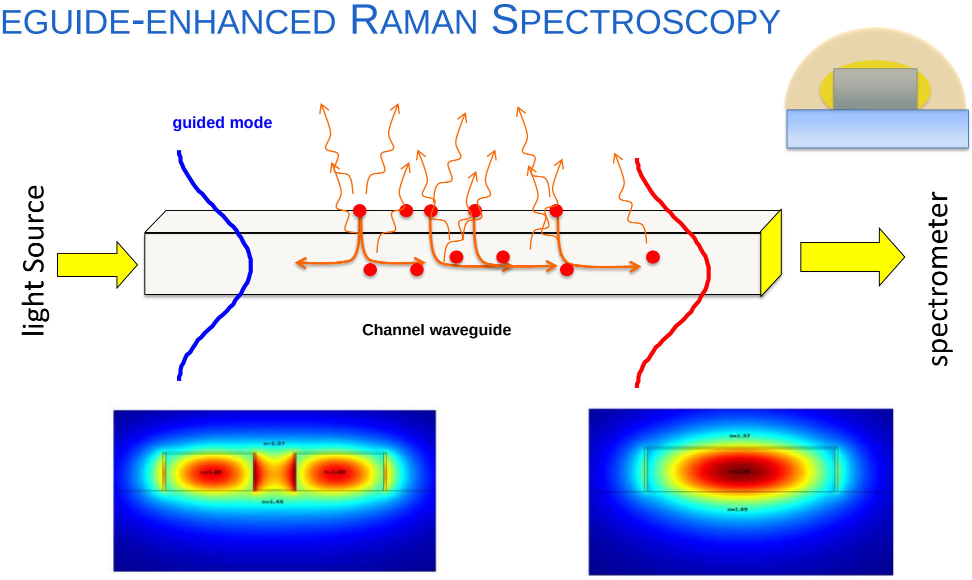


$$\frac{P_{coll}}{P_{pump}} = L\eta_0\rho\sigma_{scat}$$

$$\eta_0 \equiv \frac{1}{n(\vec{r})k_v}\left(\frac{\pi n_g \lambda_0}{\varepsilon_0}\right)^2 \left(\frac{\iint_{Clad} |\vec{e}_m(\vec{r})|^2 \, d\vec{r}}{\iint_\infty \varepsilon(\vec{r})|\vec{e}_m(\vec{r})|^2 \, d\vec{r}}\right)^2$$

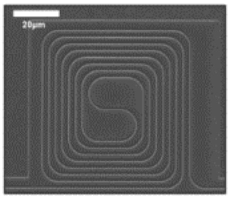
High index contrast matters

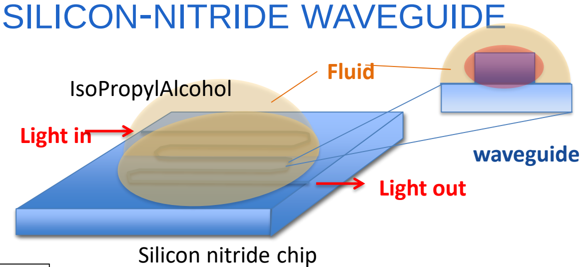
WAVEGUIDE-ENHANCED RAMAN SPECTROSCOPY

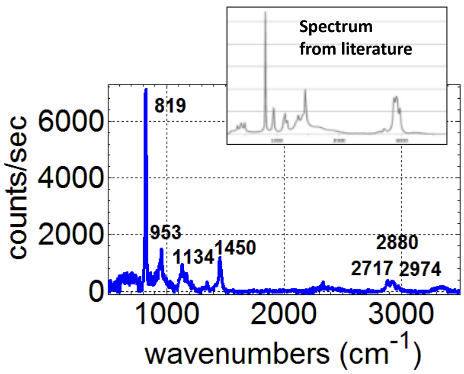


A. Dhakal et al., ACS. Photonics. **3**, 2141-2149 (2016)
Z. Wang et al., Opt. Letters. **41**, 4146-4149 (2016)
C. Evans et al., ACS Photonics 3, 1662-1669 (2016)

Raman spectrum of IPA on silicon-nitride waveguide





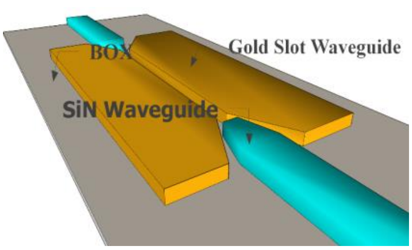


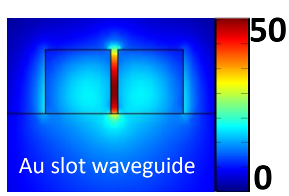
Efficiency of collection 10-100x better than in Raman microscope

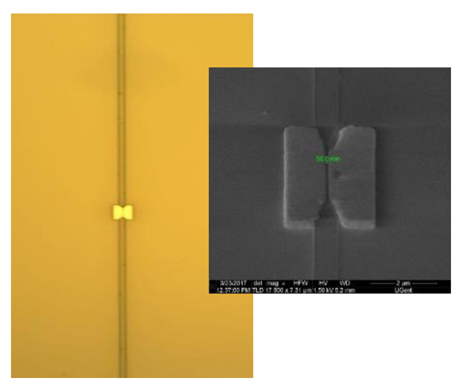
A. Dhakal et al, Opt. Lett. (2014) doi:10.1364/ol.39.004025

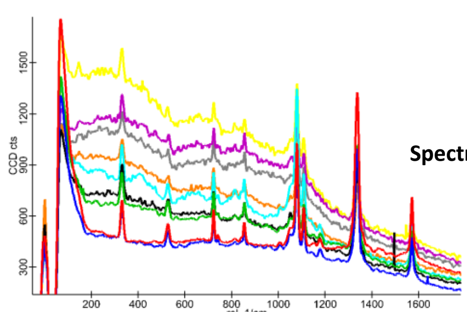
A. Dhakal et al, Optics Express (2015) doi:10.1364/OE.23.027391 55

Using metal slot waveguides to enhance the Raman scattering









Spectrum of NTP (4-NitroThioPhenol) bound to gold

A. Raza et al, ECIO 2017

A. Raza et al, CLEO2018 doi:10.1364/CLEO_SI.2018.SW3L.6

A. Raza et al, APL Photonics 2018 doi:10.1063/1.5048266

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OUTLINE

Brief introduction to silicon and silicon nitride PICs

Spectroscopic sensing modalities

On-chip spectrometers

On-chip tunable lasers

On-chip Raman spectroscopy

Application cases

OUTLINE

Brief introduction to silicon and silicon nitride PICs

Spectroscopic sensing modalities

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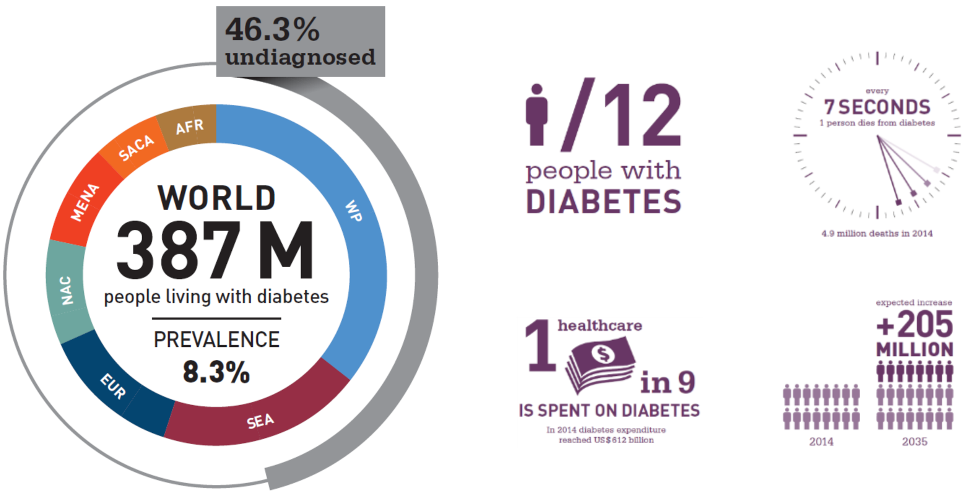
On-chip tunable lasers

On-chip Raman spectroscopy

Application cases

- Glucose monitoring
- Biosensing
- Gas sensing
- Fiber Bragg Grating readout
- Water pollutant monitoring

Diabetes is a major 21st century health challenge



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

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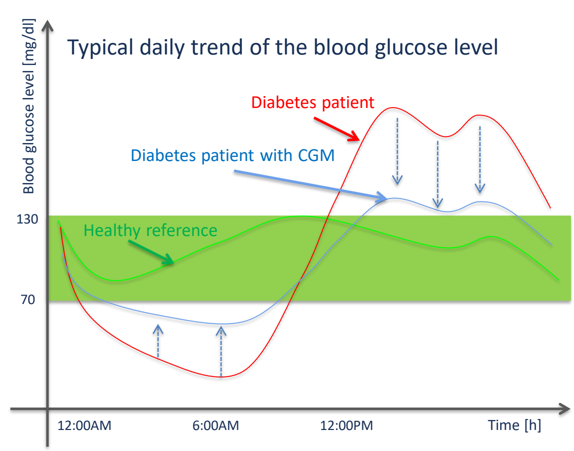
Continuous Glucose Monitoring (CGM) has proven to improve glycemic control of diabetes patients

CGM systems show positive health impact *

- lower average blood glucose levels
- decrease of hypoglycemic frequency



* Liebl A, Henrichs HR, Heinemann L, et al. Continuous glucose monitoring: evidence and consensus statement for clinical use. J Diabetes Sci Technol . 2013;7:500-519

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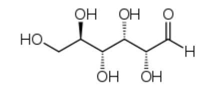
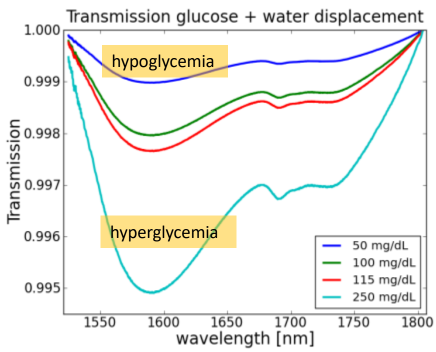
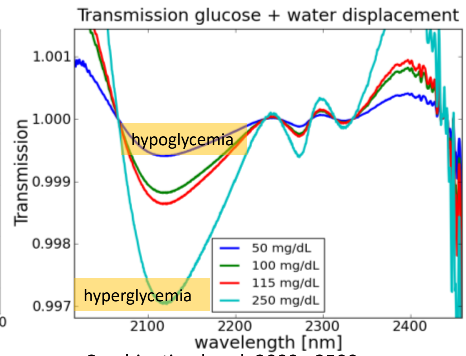
GLUCOSE ABSORPTION SPECTROSCOPY





First overtone band: 1500 - 1800 nm



Combination band: 2000 - 2500 nm

For glucose sensing in humans (3-15 mM):	Largest change in transmission is 0.5 % Required sensitivity : 0.02%

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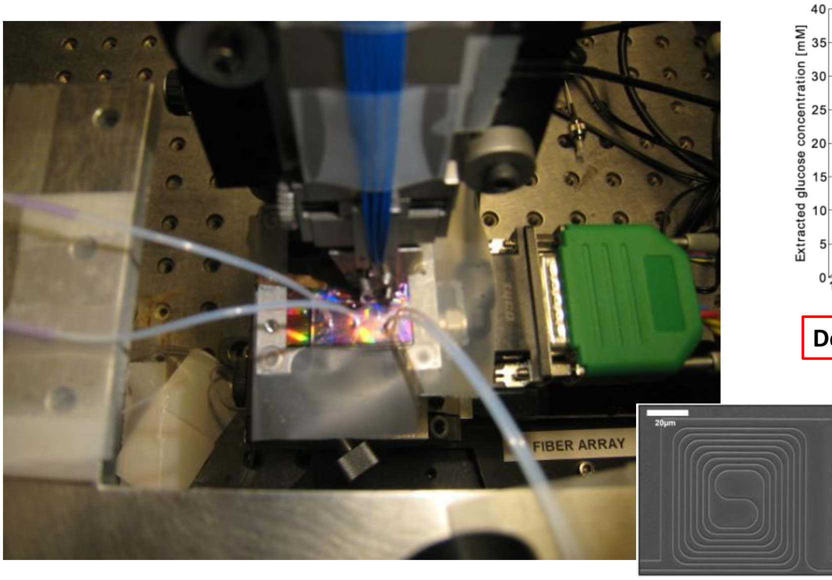
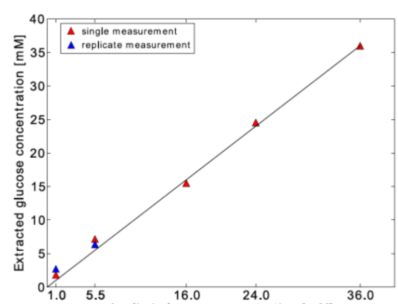
PROOF-OF-CONCEPT DEMO OF GLUCOSE SENSING IN THE LAB





Demonstrated sensitivity of 1mM

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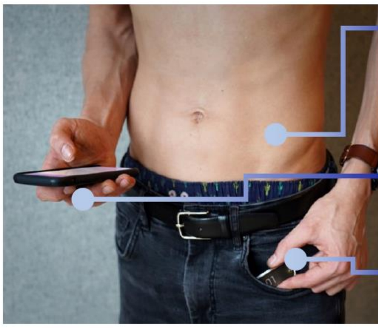
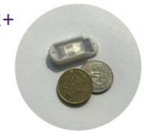
E. Ryckeboer et al, Biomedical Optics Express (2014) doi:10.1364/boe.5.001636

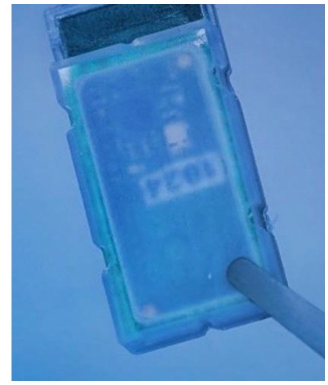
Continuous Glucose Monitoring with Subcutaneous Implant



- Invisible, coin-sized 2+ years implant (rechargeable)



- Mobile app/cloud/connection to 3rd party iCGM devices
- Waterproof Bluetooth display unit



Implant

Microspectrometer chip

https://indigomed.com/

indigo

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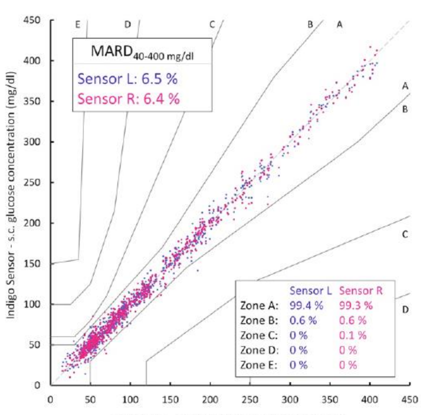
Continuous Glucose Monitoring with Subcutaneous Implant



Results on pig model (D. Stocker, EASD 2020)

https://indigomed.com/

indigo

Indigo Diabetes Initiates First Clinical Study of its Continuous Glucose Monitoring Sensor

BY INDIGO | MAR 18, 2021 | 2021, NEWS

March 18, 2021 – Ghent, Belgium

> ***Ground-breaking subcutaneous sensor aims to continuously monitor multiple metabolites including ketones in people living with diabetes***

BELGIUM – Ghent, March 18, 2021 – Indigo Diabetes N.V. ('Indigo' or the 'Company'), a pioneering developer of medical solutions using nanophotonics, announces that its continuous multi-metabolite ('CMM') sensor has been successfully implanted subcutaneously in the first three participants of its first clinical study, designed to evaluate the device. Indigo's CMM sensor is in development for the continuous measurement of glucose, ketone and lactate levels in people living with diabetes.

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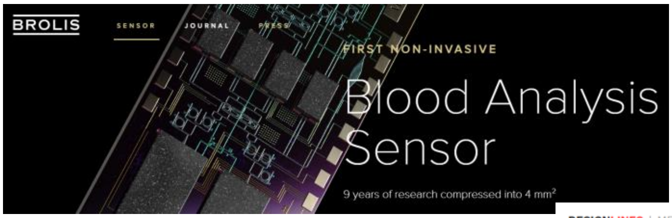
NON-INVASIVE GLUCOSE MONITORING BASED ON SILICON PHOTONICS



http://brolis.tech


DESIGNLINES | MEDICAL DESIGNLINE

Rockley Photonics to Deliver Glucose Monitoring for Apple Smartwatches

By Nitin Dahad 05.04.2021 0

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Ad closed by Google

Rockley Photonics, which recently announced a $1.2 billion listing on the New York Stock Exchange via a special purpose acquisition company (SPAC), is thought to be developing advanced health monitoring features for smartwatches including for Apple.

Apple began purchasing products from Rockley in 2017; it is now Rockley's largest customer with $70 million of NRE commitment to date.

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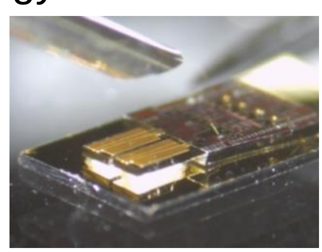
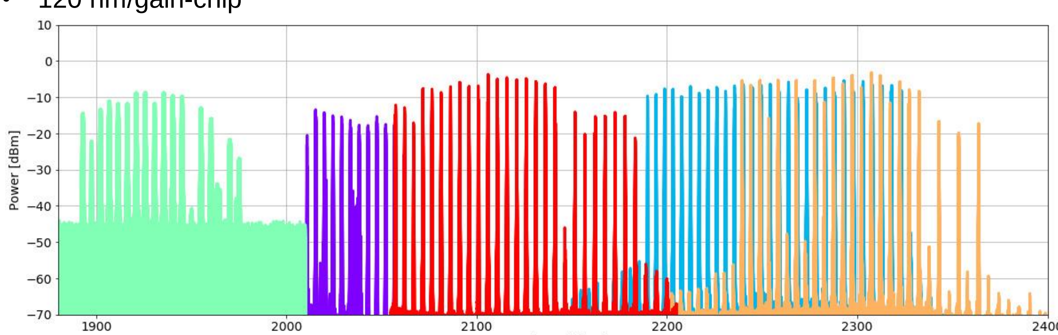
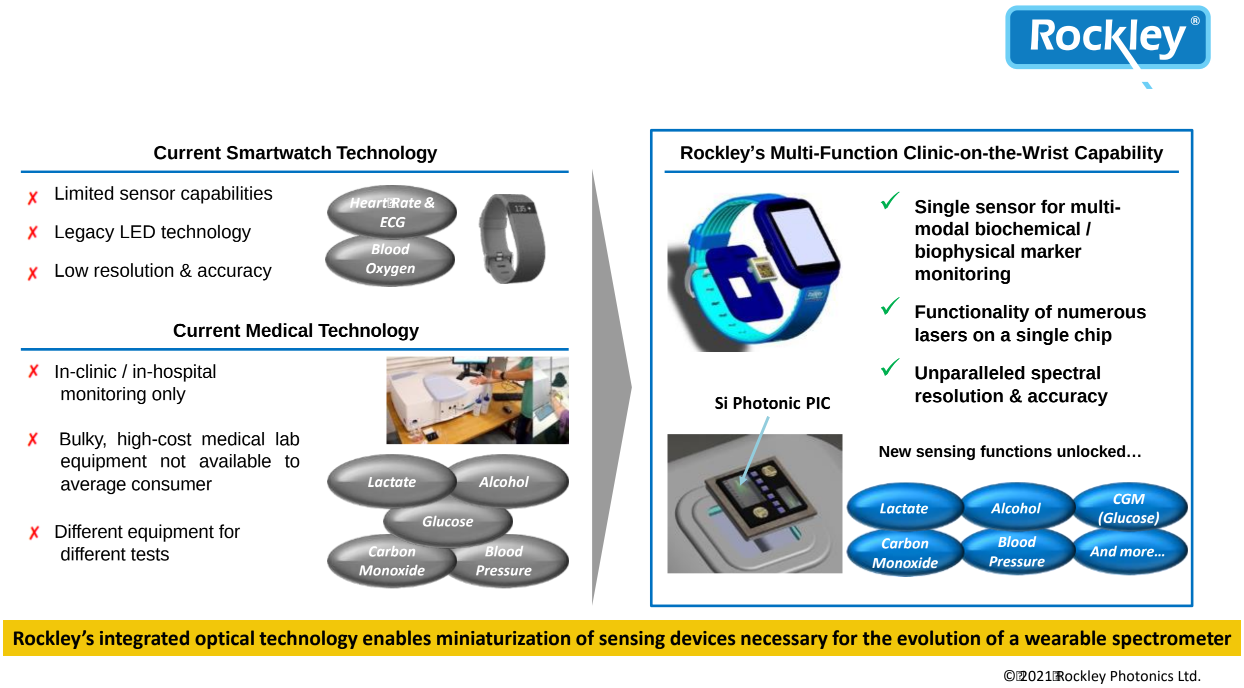
Brolis: GaSb tunable laser technology with silicon PIC

- GaSb gain chips hybridly integrated with silicon PIC
- 1880 – 2430 nm
- 0.1- 1 mW output power
- Tuning speed up to 2 kHz
- 120 nm/gain-chip





BROLIS



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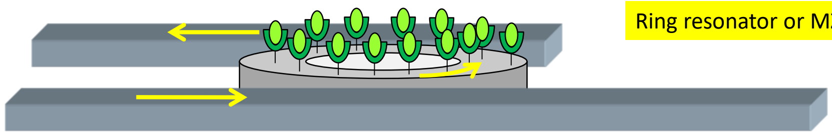
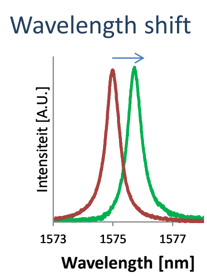
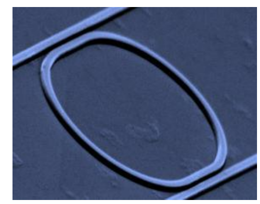
LABEL-FREE BIOSENSOR
THROUGH REFRACTIVE INDEX SENSING OF ANTIGEN-ANTIBODY BINDING







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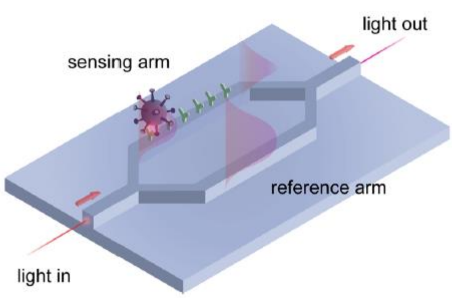
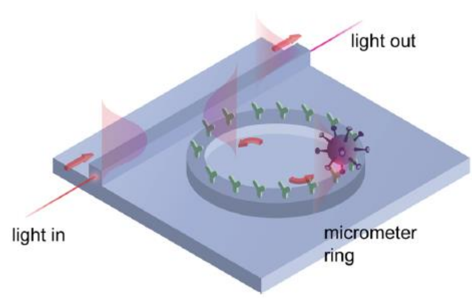
KEY PHOTONIC BIOSENSOR DEVICES



Mach-Zehnder Interferometer (MZI)



Micro-ring resonator (MRR)

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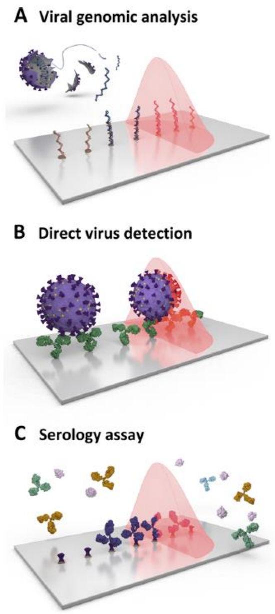
M. Soler et al, ACS Sens. (2020) doi.org/10.1021/acssensors.0c01180

BIOSENSING STRATEGIES FOR VIRAL INFECTION DIAGNOSIS



A. Genomic detection

Chip is functionalized with short stretches of nucleic acids, with complementary sequence to the viral target

B. Antigen-directed virus detection

Chip is functionalized with antibodies that bind to spike proteins at the surface of the virus

C. Serological test (blood)

Chip is functionalized with antigens that bind to antibodies that result from the body's immune response to the virus

M. Soler et al, ACS Sens. (2020) doi.org/10.1021/acssensors.0c01180

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Genalyte

https://www.genalyte.com/

COVID-19 Multi-Antigen Serology Panel

Semi-Quantitative detection of antibodies to SARS-CoV-2

Who We Are

Genalyte is a CAP accredited, CLIA certified lab specializing in large scale serology testing. Our Maverick™ SARS-CoV-2 Multi-Antigen Serology Panel uses a multiplex format to test patient samples for antibodies to five SARS-CoV-2 proteins. The result is unparalleled accuracy across a variety of patient populations.

Our Platform

The Maverick™ Diagnostic System (MDS) uses silicon chip based photonic ring resonance technology to perform multiple simultaneous rapid tests on a small volume of whole blood. The system is cloud-connected for assay protocol retrieval and clinical oversight. Results are available in 20 minutes. FDA Cleared in 2019.

General Population: 7-14 days

MAVERICK	PCR Result Pos	PCR Result Neg	
Pos	46	0	46
Neg	7	303	310
	53	303	

Post Seroconversion: >14 days

MAVERICK	PCR Result Pos	PCR Result Neg	
Pos	86	0	86
Neg	2	303	305
	88	303	

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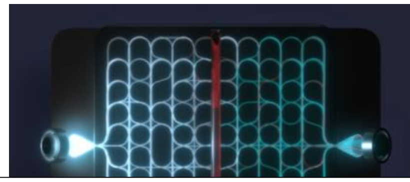
Biosensors for Home and PoC use

- Consumer price
- Rapid self-test for STDs, Covid-19, flu



Antelope DX to join forces with In The Pocket and Extra Horizon for the development of its easy-to-use, high-quality home testing device.

The first test on the market will be the Covid 19 & Flu self-test.

Ghent 15.04.2021. Antelope Dx, a Belgian based company that aims to bring high-quality health testing for the individual, announces the collaboration with In The Pocket and Extra Horizon for the development of an app and cloud-based services for its self-tests.

https://www.antelope-dx.com/

ANTELOPE DX

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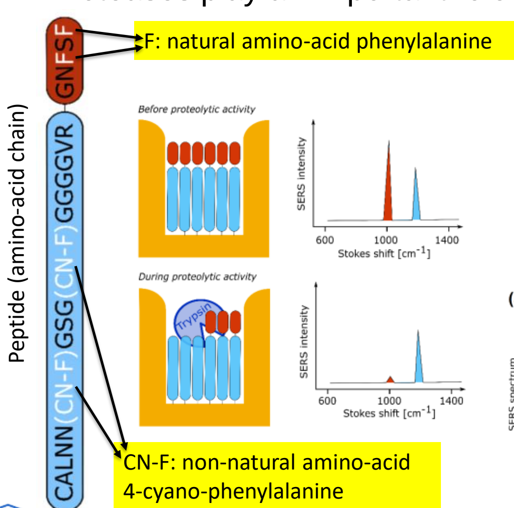
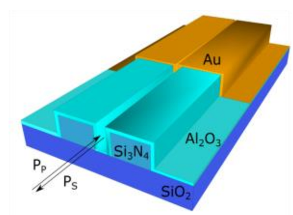
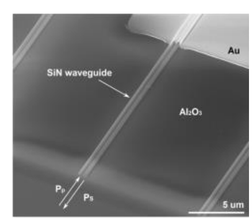
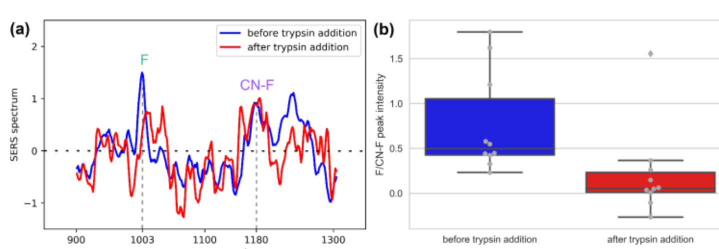
On-chip Raman spectroscopy for monitoring of enzymatic activity

Proteases play an important role in signaling pathways in relation to various diseases









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N. Turk et al, Biomed. Opt. Expr. (2020) doi:10.1364/BOE.398038 74

Outline

Brief introduction to silicon and silicon nitride PICs

Spectroscopic sensing modalities

On-chip spectrometers

On-chip tunable lasers

On-chip Raman spectroscopy

Application cases

- Glucose monitoring
- Biosensing
- Gas sensing
- Fiber Bragg Grating readout
- Water pollutant monitoring

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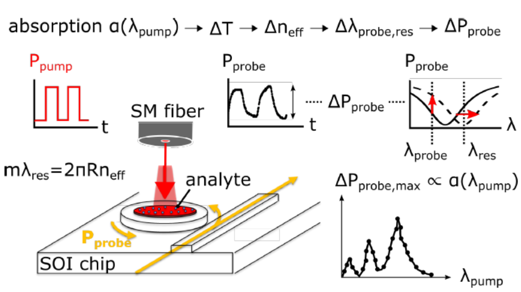
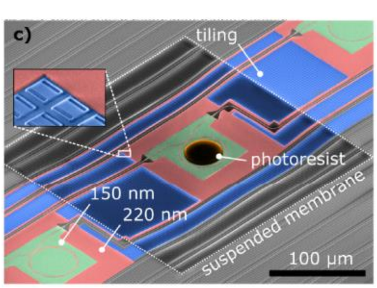
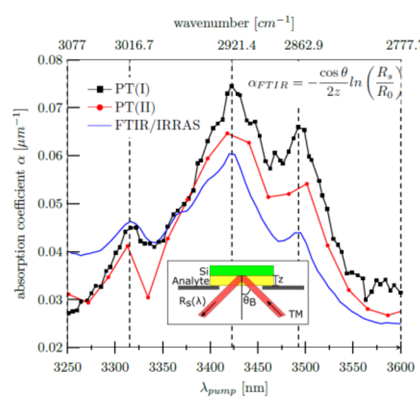
Mid-IR photothermal absorption spectroscopy with SOI ring







Proof-of-concept demonstration using photoresist as analyte

Vasiliev et al, ACS-Sensors (2017) 10.1021/acssensors.6b00428

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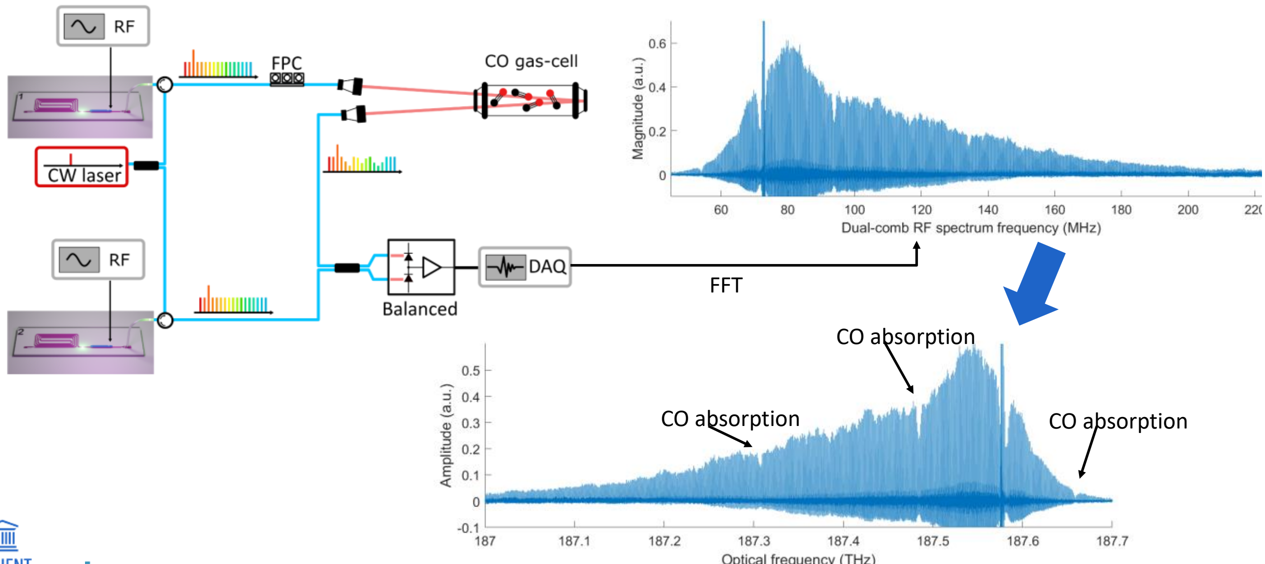
Dual-comb spectroscopy of CO with two InP-on-SOI comb lasers



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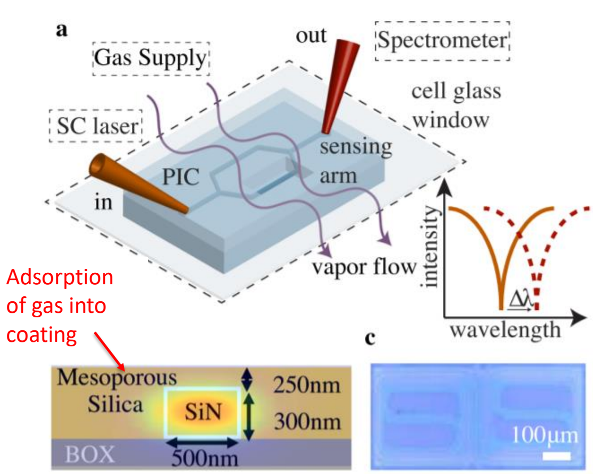
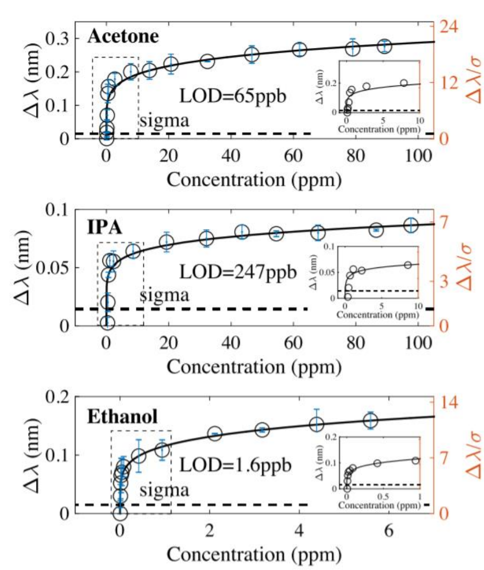
K. Van Gasse et al, CLEO (2021)

Ultrasensitive gas sensing with refractive index sensors

Medical application: breath analysis





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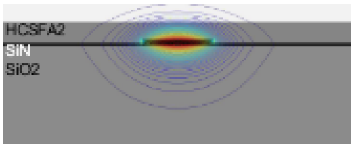
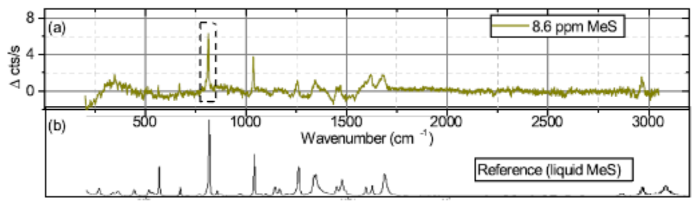
G. Antonacci et al, APL Photonics 2020 [doi:10.1063/5.0013577]

TRACE GAS SENSING WITH ON-CHIP RAMAN SPECTROSCOPY



Hypersorbent polymer (HCSFA2) coating on SiN waveguides. Partition coefficient ~ 10^8



Raman spectrum of gaseous MeS
(methyl salicylate, a hydrogen-bond basic organic ester)

Detection limit ~100 ppb
Densification ~ 10^8

S. Holmstrom et al. Optica (2016) https://doi.org/10.1364/OPTICA.3.000891

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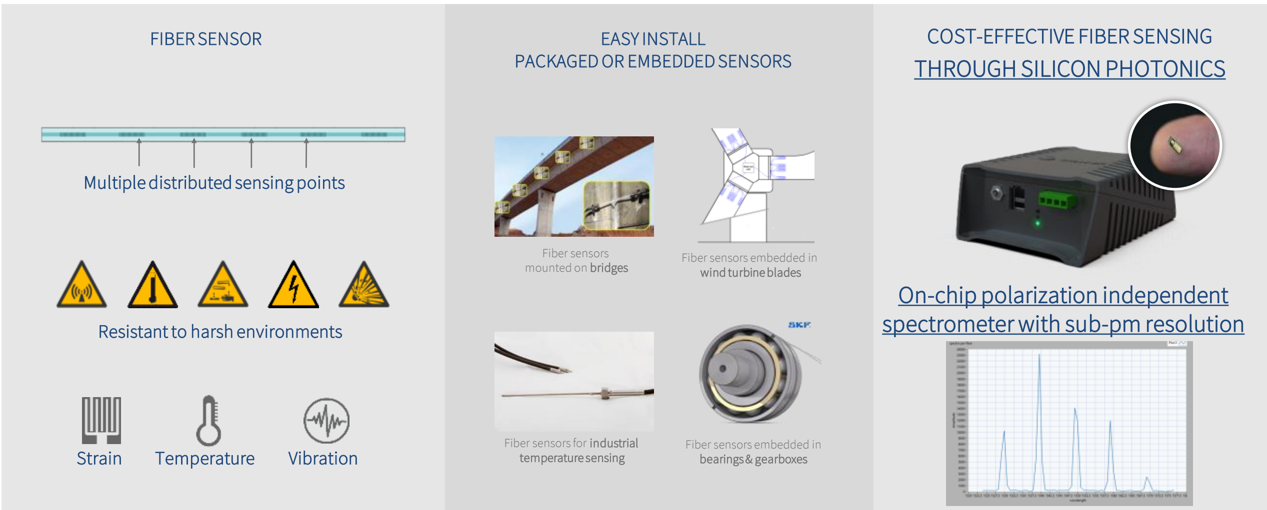
SENTEA FBG INTERROGATOR



SENTEA

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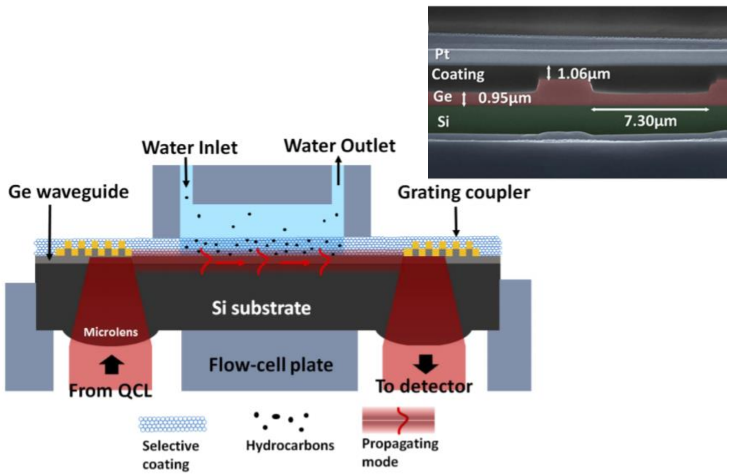
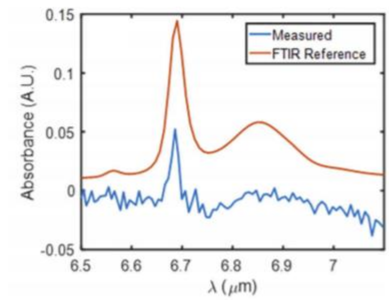
MID-IR ABSORPTION SPECTROSCOPY OF TOLUENE IN WATER



Ge-on-Si (GOS) waveguide with mesoporous coating, probed with external tunable QCL (6.5-7.5 µm)



Absorption spectrum

Limit of detection ~ 7 ppm
Density enrichment ~ 760-860x

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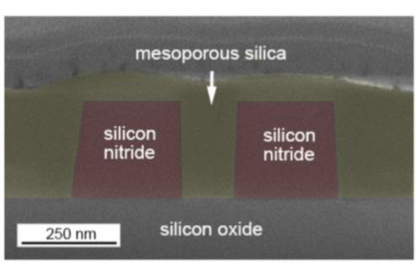
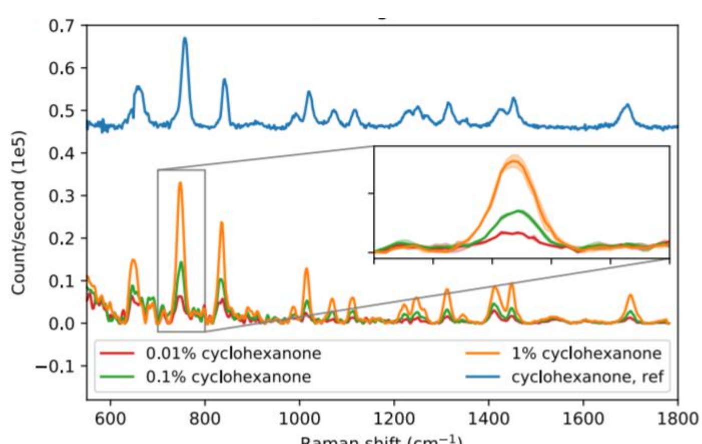
N. Teigell Benetez et al, Optics Express (2020) 10.1364/OE.399646

ON-CHIP RAMAN SPECTROSCOPY OF CYCLOHEXANONE IN WATER



Silicon nitride slot waveguide covered with mesoporous silica



Detection of Cyclohexanone in water
(pump wavelength: 785 nm)

Detection down to 100 ppm demonstrated
Density enrichment by mesoporous coating ~ 600x

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Z. Liu et al, Optics Letters (2021) doi:10.1364/OL.416464

SUMMARY

Silicon PICs (SOI, SiN, GOS)

- compact
- low cost

Enabling many spectroscopic sensing modalities

- absorption spectroscopy
- Raman spectroscopy
- readout of spectral filters (RI-sensing, FBG…)

Emerging industrial take-up

- personal health care
- monitoring of critical functions (infrastructure, water quality, safety, industrial sensing…)