UNIVERSITEIT GENT imec
PHOTONICS RESEARCH GROUP
nb-photonics

Silicon photonics for application in life science

Roel Baets
Photonics Research Group, Ghent University – IMEC
Center for Nano- and Biophotonics, Ghent University

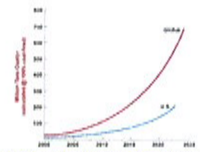
roel.baets@ugent.be

CMOSETR – May 2015 – Vancouver

What is silicon photonics?

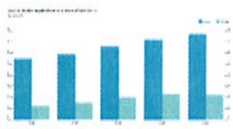
The implementation of high density photonic integrated circuits by means of CMOS process technology in a CMOS fab


Why silicon photonics matters



Evolution of energy usage by datacenters

Drastic reduction of energy consumption through optical fiber interconnect and silicon photonic chips



Evolution of cost of health care

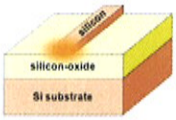
Affordable point of care solutions

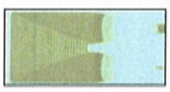
Outline

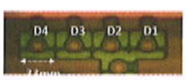
- An introduction to silicon photonics
- Biosensing and gas sensing
- Laser Doppler vibrometry and optical coherence tomography
- Spectroscopy-on-a-chip

Why silicon photonics

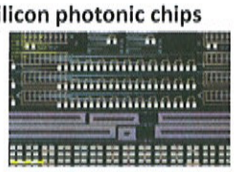
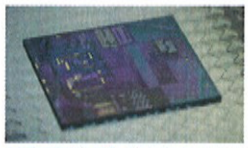
- High index contrast ⇒ very compact PICs
- CMOS technology ⇒ nm-precision, high yield, existing fabs, low cost in volume
- High performance passive devices
- High performance Ge photodetectors
- High performance modulators
- Wafer-level automated testing
- Hierarchical set of design tools
- Light source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

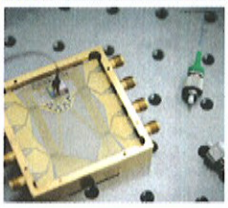




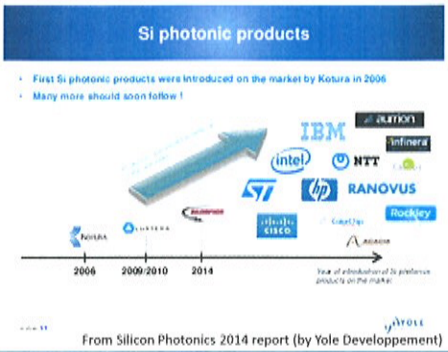


Silicon photonic chips




Industrial take-up



From Silicon Photonics 2014 report (by Yole Developpement)

Outline

An introduction to silicon photonics

➡ Biosensing and gas sensing

Laser Doppler vibrometry and optical coherence tomography

Spectroscopy-on-a-chip

Biosensors

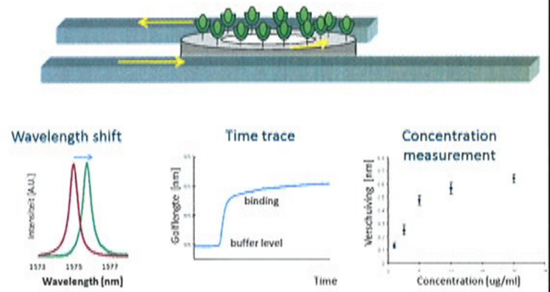
Detect presence and concentration of

- Proteins
- Viruses
- Bacteria
- DNA
- ...

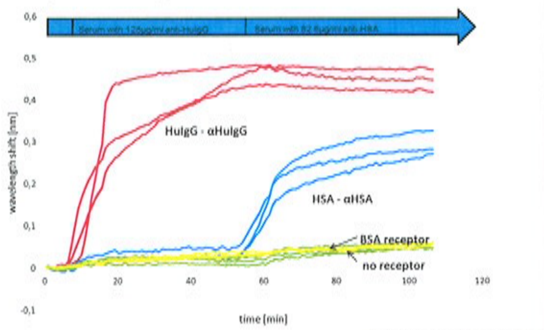
Two classes:

- Labeled: detection of label bound to biomolecule
- Label-free: direct detection of biomolecule

Label-free ring resonator biosensor

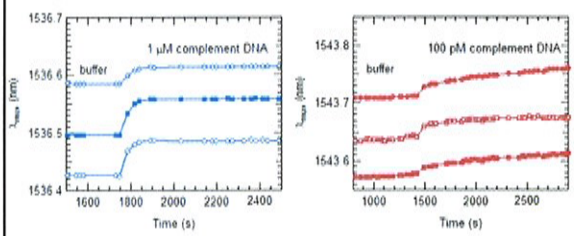


Multiplex sensing results



K. De Vos et al, Optics Express (2007)

DNA hybridisation

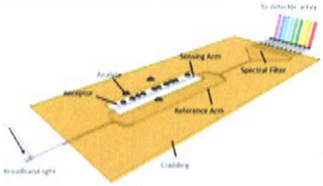


Concentrations down to 100 pM can be detected

Pocket project (FP7)

Pocket

- Detection of **Tuberculosis** biomarkers in urine
- SiN PIC-platform in visible: cheaper sources and detectors
- Cheap readout: broadband source + sensor + on-chip spectrometer

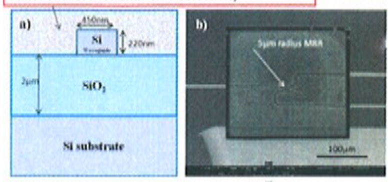


UNIVERSITEIT GENT, imec, CSIC, LIONEX, microfluidic ChipShop, trinean

Selective, reversible and fast ammonia gas detection

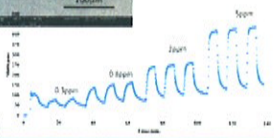
Application: breath analysis

Microporous silica layer, pores: 2nm; porosity: 45%
Functionalized for ammonia-selectivity



Sensitivity down to 100ppb demonstrated

No interference from H_2O and CO_2



N. Yebo et al, Optics Express, 20(11), pp. 11855 (2012)

Outline

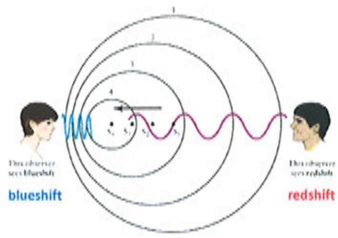
An introduction to silicon photonics

Biosensing and gas sensing

➡ Laser Doppler vibrometry and optical coherence tomography

Spectroscopy-on-a-chip

Doppler effect



$$\frac{\Delta f_{opt}}{f_{opt}} = \frac{2v_{target}}{c}$$

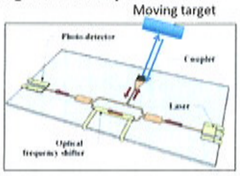
Example:
v_{target} =15 cm/s
c= 30 cm/ns
$\Delta f/f = 10^{-9}$
Δf = 100-1000 kHz

Laser Doppler Vibrometer: measuring the velocity of a surface

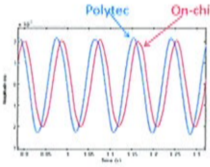
Polytec OFV-534 LDV sensor head.

miniaturization

Moving target



Doppler effect: $\frac{\Delta f_{opt}}{f_{opt}} = 2\frac{v_{target}}{c}$

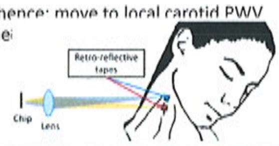


Y. Li et al, Optics Express (2013)

Piezo stack driver: fv =11.3 Hz; Vpp = 50 V [1]

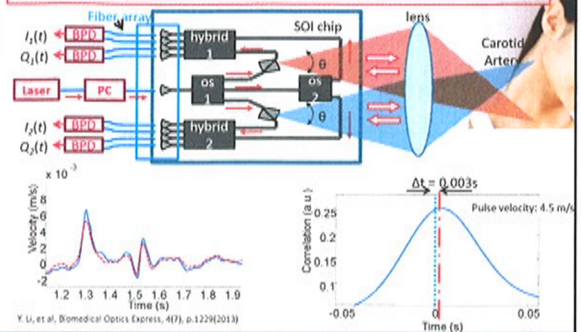
Pulse wave velocity measurement

- pulse wave velocity: measure for aortic stiffness, an important marker for atherosclerosis
- gold standard: carotid-femoral PWV
- not practical for general practitioner
- hence: move to local carotid PWV me



LDV-measurement of blood pulse velocity

Blood pulse velocity: increases when blood vessels become stiffer due to atherosclerosis



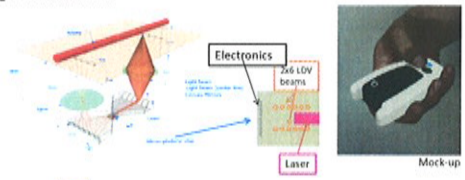
Y. Li, et al, Biomedical Optics Express, 4(7), p.1229(2013)

CARDIS project (Horizon 2020)

Goal: develop a prototype for a point-of-care LDV device

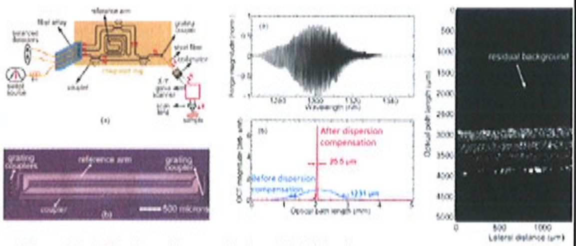
Timeframe: 2015-2018

Budget: 3.5 Meuro



imec UNIVERSITEIT GENT Medtronic SIOS Tyndall

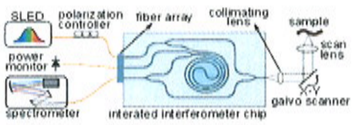
Silicon photonics circuit for swept source OCT



Silicon chip: 0.75 × 5 mm² (waveguide loss: 0.35 dB/cm)
Reference arm with 13 cm physical length (50.4 cm optical length)
Sensitivity: −62 dB with 115 μW power delivered to the sample
Axial resolution: 25 μm (limited by spectral bandwidth of fiber-chip grating couplers)

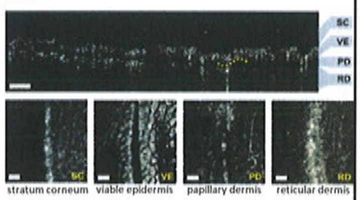
G. Yurtsever et al, Optics Letters 2014

Si_3N_4/SiO_2 circuit for Fourier domain OCT



LioniX

Si_3N_4/SiO_2 waveguides (TriPleX) on silicon chip: 10 × 33 mm²
Waveguide loss: 0.14 dB/cm
Reference arm with 19 cm physical length
Sensitivity: −65 dB with 100 μW power delivered to the sample



G. Yurtsever et al, Biomedical Optics Express (2014)

Outline

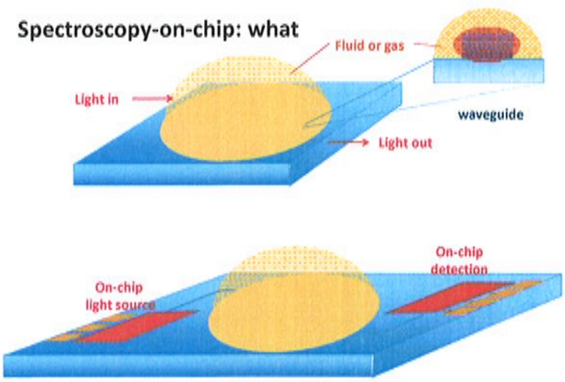
An introduction to silicon photonics

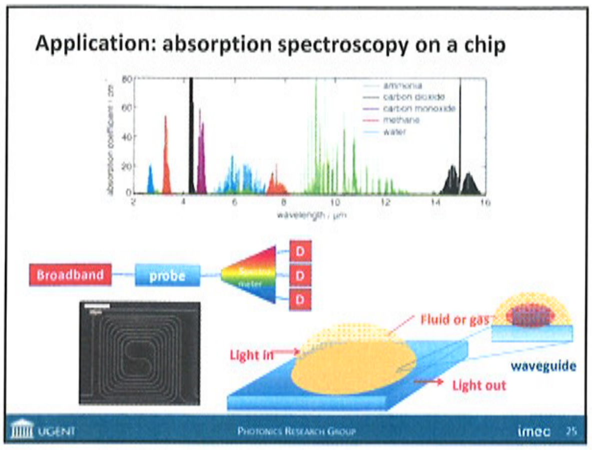
Biosensing and gas sensing

Laser Doppler vibrometry and optical coherence tomography

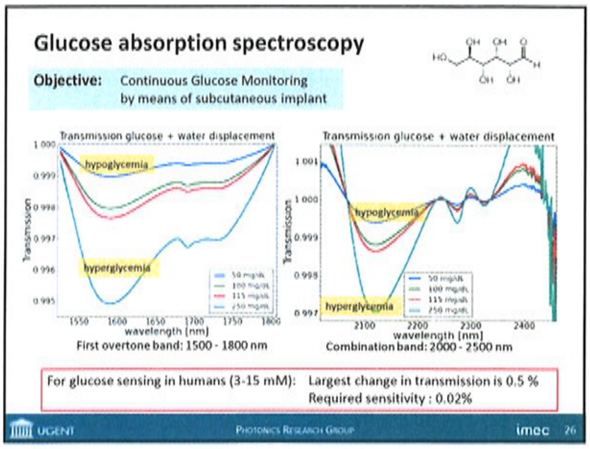
➔ Spectroscopy-on-a-chip

Spectroscopy-on-chip: what

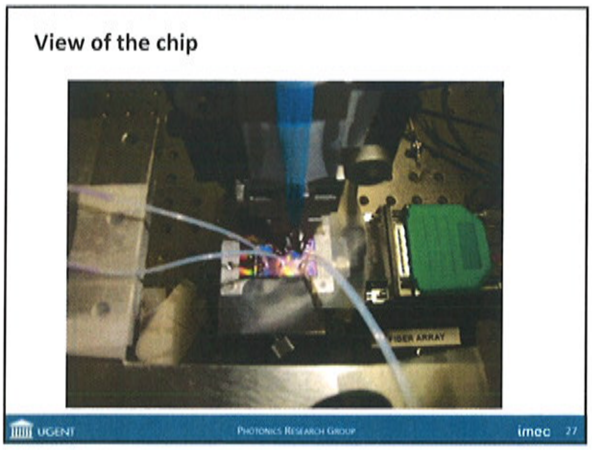




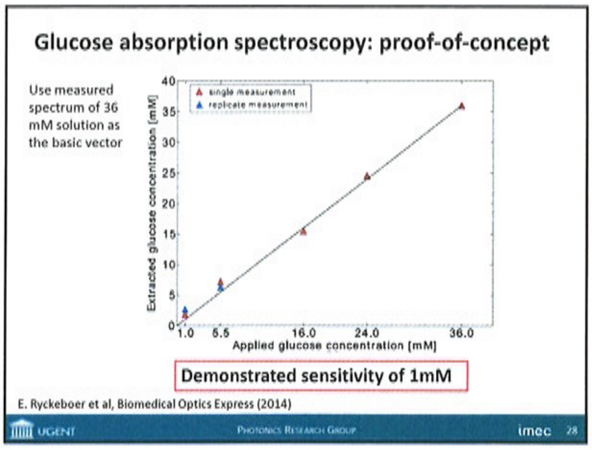
Application: absorption spectroscopy on a chip
ammonia
carbon dioxide
carbon monoxide
methane
water
wavelength / μm
Broadband
probe
D
D
D
Fluid or gas
Light in
waveguide
Light out
UGENT
Photonics Research Group
imec 25



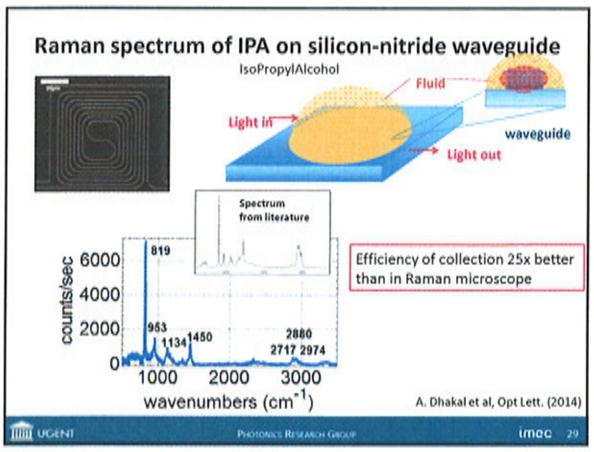
Glucose absorption spectroscopy
Objective: Continuous Glucose Monitoring by means of subcutaneous implant
Transmission glucose + water displacement
hypoglycemia
hyperglycemia
wavelength [nm]
First overtone band: 1500 - 1800 nm
Transmission glucose + water displacement
hypoglycemia
hyperglycemia
wavelength [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%
UGENT
Photonics Research Group
imec 26



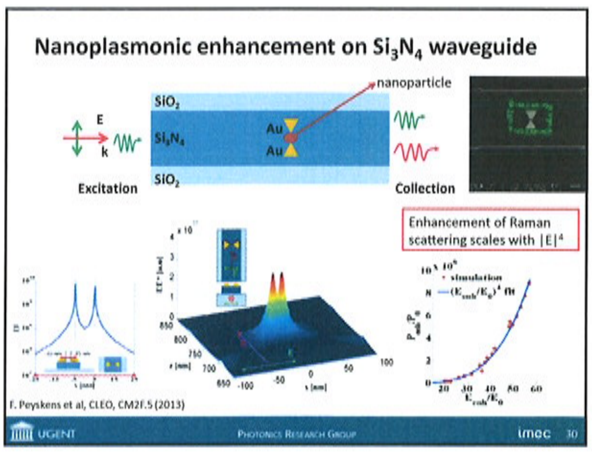
View of the chip
FIBER ARRAY
UGENT
Photonics Research Group
imec 27



Glucose absorption spectroscopy: proof-of-concept
Use measured spectrum of 36 mM solution as the basic vector
single measurement
replicate measurement
Extracted glucose concentration [mM]
Applied glucose concentration [mM]
Demonstrated sensitivity of 1mM
E. Ryckeboer et al, Biomedical Optics Express (2014)
UGENT
Photonics Research Group
imec 28



Raman spectrum of IPA on silicon-nitride waveguide
IsoPropylAlcohol
Fluid
Light in
waveguide
Light out
Spectrum from literature
counts/sec
wavenumbers (cm⁻¹)
Efficiency of collection 25x better than in Raman microscope
A. Dhakal et al, Opt Lett. (2014)
UGENT
Photonics Research Group
imec 29



Nanoplasmonic enhancement on Si3N4 waveguide
nanoparticle
SiO2
Si3N4
Au
Au
SiO2
Excitation
Collection
Enhancement of Raman scattering scales with |E|⁴
F. Peyskens et al, CLEO, CM2F.5 (2013)
UGENT
Photonics Research Group
imec 30

Session O4: Silicon Photonics — 13:30 Georgia A

Chairs:

13:30 Lawrence Chen, McGill University (lawrence.chen@mcgill.ca)
Silicon Photonics: Enabling Microwave Photonic Systems and Applications

13:50 Jianping Yao, University of Ottawa (jpyao@uottawa.ca)
Silicon Photonics for Microwave Signal Processing

14:10 Maurizio Burla, INRS-EMT (maurizio.burla@emt.inrs.ca; maurizio.burla@gmail.com)
with J. Azaña
Integrated Waveguide Bragg Gratings for Microwave Photonic Signal Processing: Current Trends and Future Prospects

14:30 Trevor James Hall, University of Ottawa (thall@site.uOttawa.ca)
Photonic Integrated Circuits for Electro-optic Microwave Frequency Multiplication and Frequency Translation: Spurious Harmonics Suppression by Design

14:50 COFFEE BREAK (GEORGIA FOYER)
****

15:10 Roel Baets, Ghent University (roel.baets@intec.ugent.be)
Silicon Photonics for Applications in Life Science

15:30 Xiaoguang (Leo) Liu, University of California, Davis (lxgliu@ucdavis.edu)
with H. Rashtian, B. Yu and J. Gu
High-Speed CMOS-based THz Interconnect with Micromachined Silicon Dielectric Waveguide

15:50 Mohamed Osman, McGill University (mohamed.osman2@mail.mcgill.ca)
with D. Plant
Silicon Photonics Enabled 400G/1T Short Reach Optical Interconnects

16:10 Sébastien Le Beux, École Centrale de Lyon (sebastien.le-beux@ec-lyon.fr)
Thermal Aware Design Method for VCSEL-based On-Chip Optical Interconnect

16:30 Bahram Jalali, University of California, Los Angeles (jalali@ucla.edu)
Optical Information Capacity of Silicon

16:50 Douglas M. Gill, IBM (dmgill@us.ibm.com)
CMOS Compatible Monolithic Traveling Wave Electro-Optic Modulators

Session S4: Radiation Effects and Detection — 13:30 Plaza B

Chairs: Nicola Guerrini, Science and Technology Facilities Council (nicola.guerrini@stfc.ac.uk)

13:30 Kate Shanks, Cornell University (ksg52@cornell.edu)
X-ray Area Detectors for High Dynamic Range Imaging

13:50 Klaus-Peter Ziock, Oak Ridge National Laboratory (ziockk@ornl.gov)
Data Fusion of Visual, LWIR, and Gamma-Ray Imaging for Nuclear Security

14:10 Antoine Touboul, University of Montpellier (antoine.touboul@ies.univ-montp2.fr)
Radiation Effects in Power Applications

14:30 Mokhtar Chmeissani, Institut de Física d'Altes Energies (mokhtar@ifae.es)
3D Semiconductor Sensor For Position Emission Tomography

14:50 COFFEE BREAK (GEORGIA FOYER)
****

15:10 Frédéric Wrobel, University of Montpellier (frederic.wrobel@ies.univ-montp2.fr)
Simulation Tools for Soft Error Rate Calculations in SRAM

15:30 Minoru Fujishima, Hiroshima University (fuji@hiroshima-u.ac.jp)
Evaluation and Modeling of Terahertz CMOS Devices

15:50 Salvador Pinillos Gimenez, Centro Universitário da FEI (sgimenez@fei.edu.br)
An Innovative Non-Standard Layout Style (Diamond) to Boost the Electrical Performance and the Radiation Tolerance of MOSFETs, Focusing on Space and Medical CMOS ICs Applications

16:10 Maurice Garcia-Sciveres, Lawrence Berkeley National Laboratory (mgarcia-sciveres@lbl.gov)
Data Compression Efficiency in Silicon Detector Readout

16:30 Amin Arbabian, Stanford University (arbabian.a@gmail.com)
RF and Microwave Imaging with Applications in Medicine

16:50 Jean-Luc Autran, Aix-Marseille University (jean-luc.autran@univ-amu.fr)
with P. Roche, G. Gasiot and D. Munteanu
Natural Radiation in Bulk CMOS and FD SOI

CMOS Emerging Technologies Research

Thank You to Our Sponsors

UBC

CMC Microsystems

acamp
ALBERTA CENTRE FOR ADVANCED MNT PRODUCTS

CRC Press
Taylor & Francis Group

Springer

CMOS Emerging Technologies Research

2015 Symposium Program

May 20 - 22, 2015

Hyatt Regency

Vancouver, Canada

UBC

CMC Microsystems

Updated May 13, 2015