

# SILICON PHOTONICS

CLEO Europe 2021 / Short Course / Dries Van Thourhout

Slides available from: <https://users.ugent.be/~dvthourh/cleo2021/>



## 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

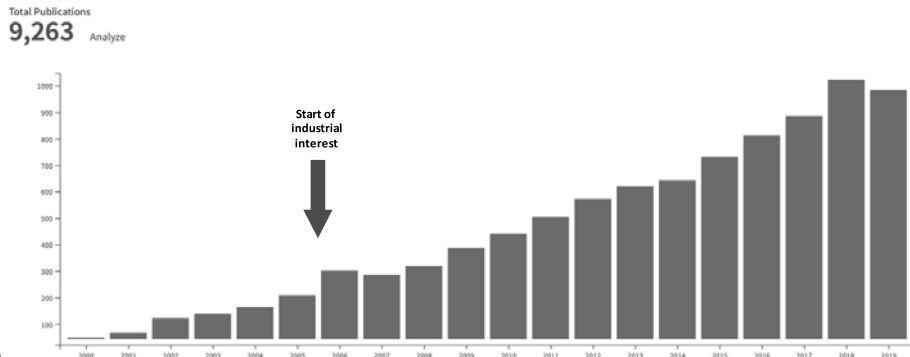


## PAST 20 YEARS: STUNNING RESEARCH PROGRESS

Citation report for 9,263 results from Web of Science Core Collection between 2000 and 2019 Go

You searched for: TOPIC: (silicon and photonic) ...More

This report reflects citations to source items indexed within Web of Science Core Collection. Perform a Cited Reference Search to include citations to items not indexed within Web of Science Core Collection.



40Gb/s, 50Gb/s and 100 Gb/s Ethernet (future: 400Gb/s)

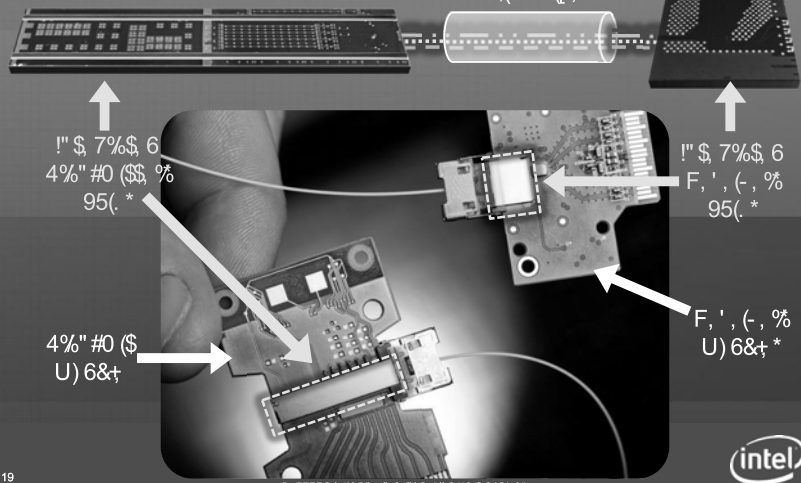
### INDUSTRIAL DEVELOPMENT

#### COM AND DATACOM

- ...s on parallel fibers)
- ... x 25 Gb/s on single fiber)
- ... (SK)
- ...s (e.g. 12 x 2.5 Gb/s)

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### Comparison of IBM CMOS Nanophotonics with existing Si Photonics

#### Si CMOS Photonics

Others (Announced)

- ✓ 130nm design rules for CMOS
- ✓ 130nm design rules for Micro-Photonics
- ✓ CMOS FEOL integrated (Ge-last after activation)
- ✓ Large Litho variations - active tuning is required
- ✓ 6mm<sup>2</sup> per transceiver channel



#### Si CMOS Nano-Photonics

IBM (Announcing now)

- ✓ 130nm design rules for CMOS
- ✓ 65nm design rules for Nano-Photonics
- ✓ CMOS FEOL integrated (Ge-first prior to activation)
- ✓ Small Litho variations - active tuning not required
- ✓ 0.5mm<sup>2</sup> per transceiver channel

#### IBM CMOS Nanophotonics technology:

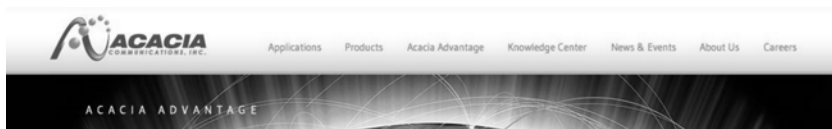
- 10x higher integration density
- The only amenable for Terabit/s-class single-chip CMOS transceivers
- 50channels x 20Gbps = 1Tbps transceiver occupies only 5x5mm<sup>2</sup> of a CMOS die (can be smaller than 2x2mm<sup>2</sup> without pad frame and capacitors)

<http://www.research.ibm.com/photronics>

© 2010 IBM Corporation



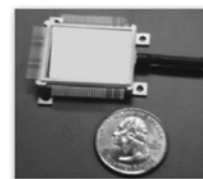
Luxtera Proprietary



- Unique Expertise
- Digital Signal Processing
- Silicon Photonics Integration**
- High Speed Transceiver Design

## Silicon Photonics Integration

Acacia's recently announced its own Silicon Photonics monolithic Integrated Circuit is being used in the Coherent CFP platform. Acacia's highly integrated full duplex Silicon Photonics single-chip PIC is low cost, low power, ultra-compact and can be manufactured in high volume. Coupled with Acacia's internally developed low-power coherent ASIC, the company can deliver a 100G Coherent CFP product at half the cost and one-third the power and size of long haul 100G solutions.



Acacia's PIC has numerous benefits compared to legacy optical components. It leverages mature CMOS processes resulting in high yield and low costs. With these processes, the wafers are large and yield is high resulting in further reduction in cost of each of these IC's. Unlike legacy optical material, these integrated circuits are testable on wafer before they are packaged; this keeps the yields high. Also due to the materials being used, the PIC does not need any temperature control or hermetic packaging, keeping overall requirements simple and costs low.

#### LEARN MORE

##### White Papers

- Challenges and Key Technologies for Coherent Metro 100G Transceivers
- A Robust Real-Time 100G Transceiver with Soft-Decision Forward Error Correction

##### LATEST NEWS

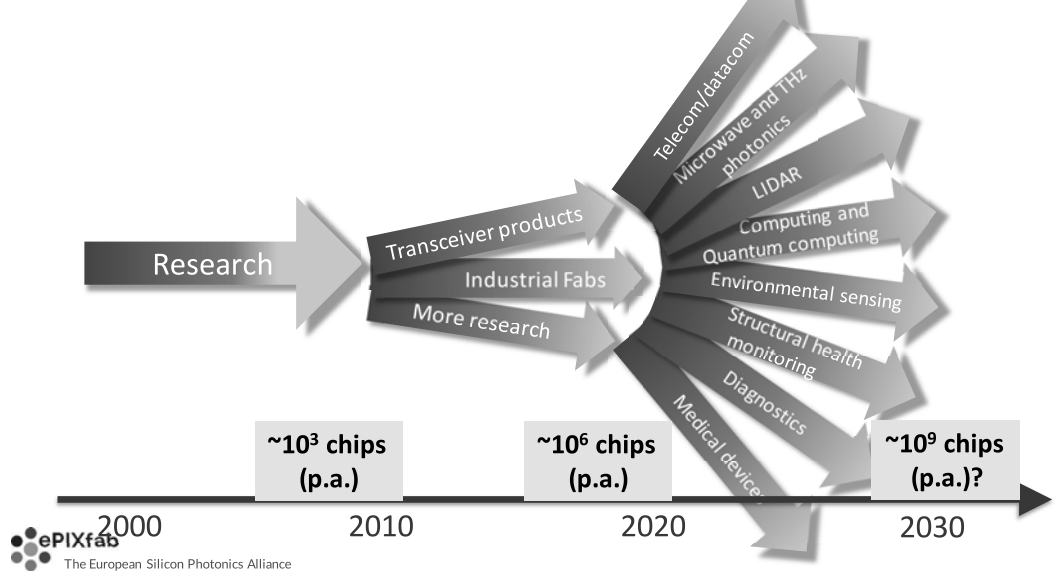
Acacia Communications Increases Volume for the AC-100 CFP Due to Exceptional Global Demand

Acacia Communications Announces the Industry's First Coherent Flex-rate 400G Sx7 Transceiver Module

Acacia Communications Announces Successful Interoperability of 100G Coherent Pluggable CFP Transceiver Solutions for Metro Deployments



# OTHER APPLICATIONS RAPIDLY EMERGING



# EXAMPLE: DETECTION OF HART DISEASES

On-chip laser doppler vibrometer to measure skin displacement above arteries

**LDV 1**, **LDV 2**, **Cardi**, **HORIZON 2020**

**Components:** Phase modulator, 1x6 splitter, Laser input, Transmit-receive antenna pair, Optical hybrids and PDs

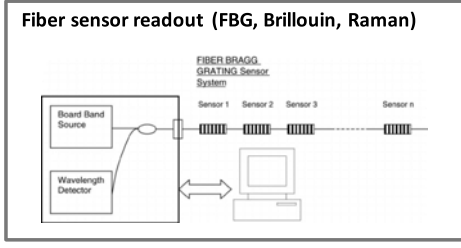
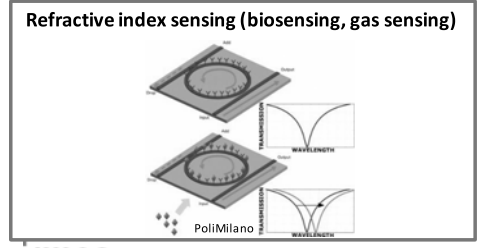
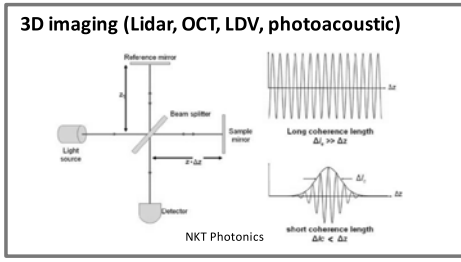
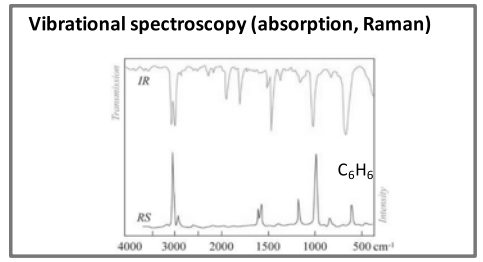
**Microscope image:** 2.5 mm width, 5 mm height, Laser input, Measurement beams

**Photonic integrated circuit (PIC)**

**Prof. R. Baets, Y. Li**

**Logos:** GENT UNIVERSITY, imec

# OPTICAL SENSING



# CONTINUOUS GLUCOSE MONITORING WITH SUBCUTANEOUS IMPLANT

- Invisible, coin-sized 2+ years implant (rechargeable)
- Mobile app/cloud/connection to 3<sup>rd</sup> party iCGM devices
- Waterproof Bluetooth display unit

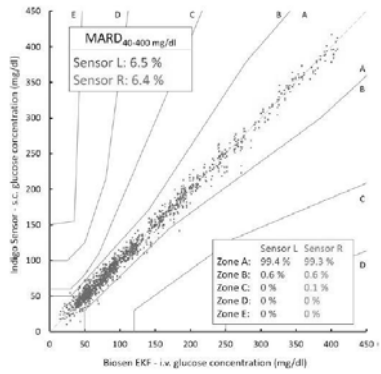
**Implant**

**Microspectrometer chip**

<https://indigomed.com/>

**indigo**

# CONTINUOUS GLUCOSE MONITORING WITH SUBCUTANEOUS IMPLANT



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

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

BY INDIGO | MAR 18, 2021 | 2021, NEWS

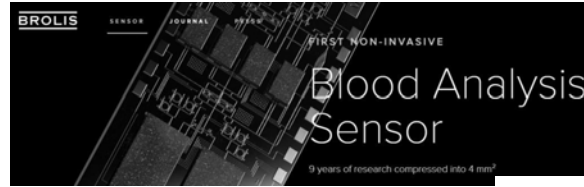
March 18, 2021 - Ghent, Belgium

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.

<https://indigomed.com/>  
indigo

# 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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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.



**Current Smartwatch Technology**

- x Limited sensor capabilities
- x Legacy LED technology
- x Low resolution & accuracy

Heart Rate & ECG  
Blood Oxygen

**Current Medical Technology**

- x In-clinic / in-hospital monitoring only
- x Bulky, high-cost medical lab equipment not available to average consumer
- x Different equipment for different tests

Lactate Alcohol  
Glucose  
Carbon Monoxide Blood Pressure

**Rockley's Multi-Function Clinic-on-the-Wrist Capability**

Si Photonic PIC

- Single sensor for multi-modal biochemical / biophysical marker monitoring
- Functionality of numerous lasers on a single chip
- Unparalleled spectral resolution & accuracy

New sensing functions unlocked...

Lactate Alcohol CGM (Glucose)  
Carbon Monoxide Blood Pressure And more...

## BROLIS: GaSb TUNABLE LASER TECHNOLOGY WITH SILICON PIC

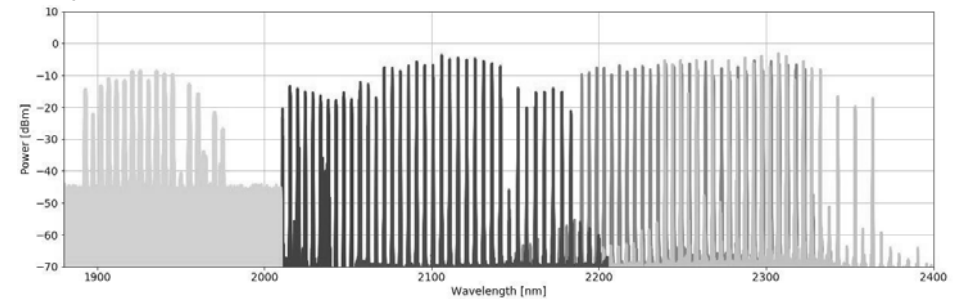
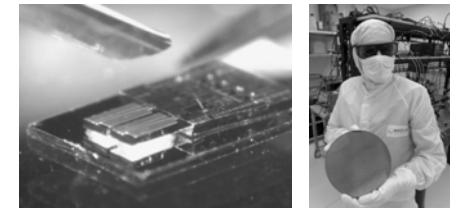
GaSb gain chips hybridly integrated with silicon PIC

1880 - 2430 nm

0.1- 1 mW output power

Tuning speed up to 2 kHz

120 nm/gain-chip

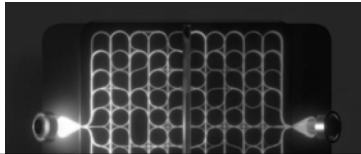





Rockley's integrated optical technology enables miniaturization of sensing devices necessary for the evolution of a wearable spectrometer



## 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.**

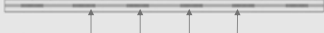







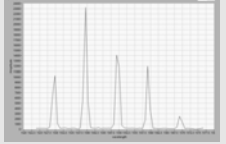
Ghent 15.04.2021. Antelope Dx, a Belgian based company that aims to bring high-quality health testing for the individual, announces the collaboration with In The Pocket and Extra Horizon for the development of an app and cloud-based services for its self-tests.

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



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## SENTEA FBG INTERROGATOR

<p><b>FIBER SENSOR</b></p>  <p>Multiple distributed sensing points</p>  <p>Resistant to harsh environments</p>  <p>Strain    Temperature    Vibration</p>	<p><b>EASY INSTALL PACKAGED OR EMBEDDED SENSORS</b></p>  <p>Fiber sensors mounted on bridges</p>  <p>Fiber sensors embedded in wind turbine blades</p>  <p>Fiber sensors for industrial temperature sensing</p>  <p>Fiber sensors embedded in bearings &amp; gearboxes</p>	<p><b>COST-EFFECTIVE FIBER SENSING THROUGH SILICON PHOTONICS</b></p>  <p><u>On-chip polarization independent spectrometer with sub-pm resolution</u></p> 
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## WHY INTEGRATED PHOTONICS ?

### Telecom applications

- WDM introduces need for highly integrated optical circuits

### Datacom applications

- Increasing need for bandwidth between racks/servers/boards/modules/...
- Single channel solutions no longer fulfill requirements
- Need for densely integrated electronics + optics

### New applications

- Imagine millimeter size spectrometer with source included
- Embed in tissue (glucose sensing, structural health monitoring ...)
- RF-photonics
- Quantum systems on a chip
- ...



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## PHOTONICS ↔ ELECTRONICS

### Many building blocks

- Laser, Modulator, Detector Filter

### Many technologies and materials

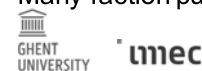
- Laser : III-V semiconductors
- Modulator : LiNbO3
- Filter : Glass, Polymers

### High processing requirements

- Analog devices
- Low Yield

### No economies of scale advantage

### Many faction pushing own solution



### Single building block

- Transistor

### Single material

- Silicon

### Relaxed processing requirements

- Digital devices
- High yield

### Massive economies of scale

### Common ITRS roadmap

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## “SILICON PHOTONICS” SOLVES THIS BOTTLENECK ?

### Single material platform

- Silicon transparent at telecom wavelengths
- Very high contrast : compact circuits
- Detectors (germanium), Modulators (pn-junction)

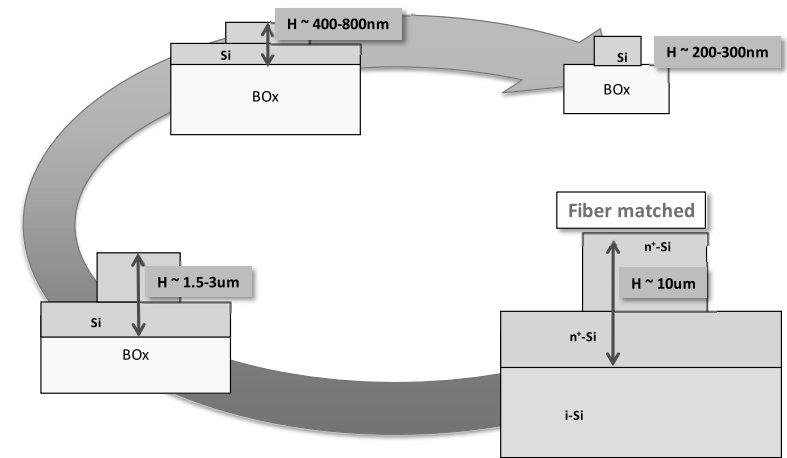
### Reuse installed equipment base

- Use best equipment available
- But no capital expense ...

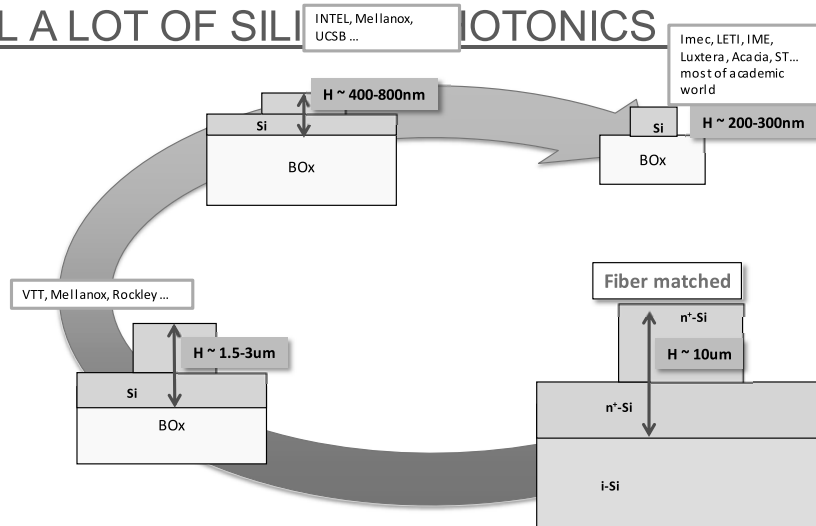
### Some standardization ongoing

- 200nm and 300nm layer thickness seem popular
- Platform building ongoing

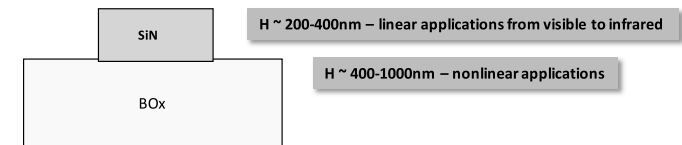
## STILL A LOT OF SILICON PHOTONICS ...



## STILL A LOT OF SILICON PHOTONICS



## AND EVEN MORE: SILICON NITRIDE...



# DIFFERENT APPLICATIONS = DIFFERENT REQUIREMENTS

Different specifications:

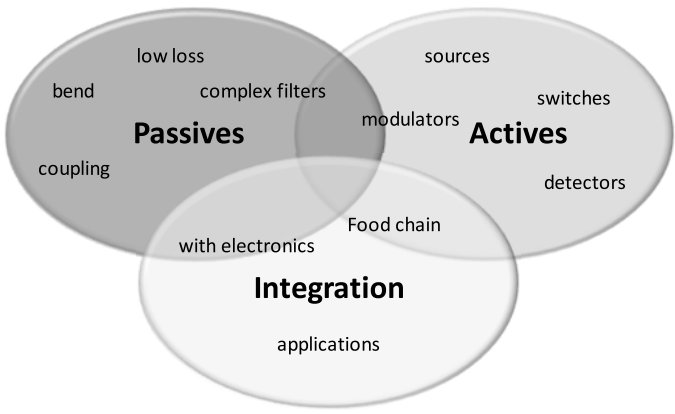
- Cost
- Power consumption
- Signal quality (e.g. chirp, linearity, polarization independence)
- Loss

Different applications

- Long range telecom, Metro, Fiber-To-The-Home (FTTX)
- Optical interconnect (Between Racks – Boards – Chips)
- Sensing in consumer applications (cost is key!)
- Quantum computing (performance is key !)
- ...



# Outline



# ACKNOWLEDGEMENTS

Funding through national and EU research projects



Thanks for providing slides and supporting material:

- Peter Dedobbelaere (Luxtera), Chris Doerr (Acacia), Yuri Vlasov (IBM), Thomas Schrans (Rockley), Lars Zimmermann (IHP), Wim Bogaerts (PRG), Philippe Absil (imec), Roel Baets (PRG), Abdul Rahim (PRG) ...

Bogaerts e.a., JSTQE 16, 33-44 (2010)

Available from our website - [www.photonics.intec.ugent.be](http://www.photonics.intec.ugent.be)

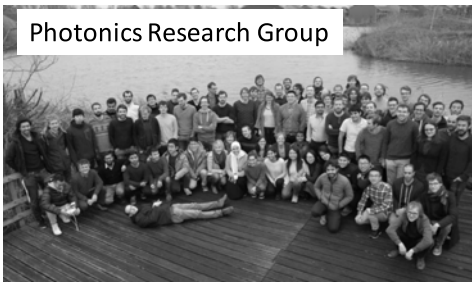
Gnan e.a., Electronic Lett. 44, p115 (2008)

Available from general literature



Our YouTube Channel:

# ACKNOWLEDGEMENTS



**UGent (PRG):** Profs. Baets, Roelkens, Kuyken, Bogaerts, Bienstman, Le Thomas, Clemmen, Morthier  
**UGent (other):** Profs. Beeckman, Hens, Geiregat  
**IMEC:** Joris Van Campenhout, Marianna Pantouvaki, Cedric Huyghebaert, Bernardette Kunert and their respective teams



## FURTHER REFERENCE

- PhD's dissertations available on website Photonics Research Group
  - See: <http://photonics.intec.ugent.be/contact/people.asp>
- Examples:
  - [Dirk Taillaert, Roosterkoppelaars voor koppeling tussen optische vezels en nanofotonische golfgeleiders, Grating Couplers as Interface between Optical Fibres and Nanophotonic Waveguides, 11/2004](#)
  - [Wim Bogaerts, Nanofotonische Golfgeleiders en Fotonische Kristallen in Silicium-op-Isolator, Nanophotonic Waveguides and Photonic Crystals in Silicon-on-Insulator, 4/2004](#)
  - [Pieter Dumon, Ultra-compacte geïntegreerde optische filters in silicium-op-isolator op basis van waferschaaltechnologie, Ultra-Compact Integrated Optical Filters in Silicon-on-insulator by Means of Wafer-Scale Technology, 3/2007](#)
  - [Shankar Kumar Selvaraja, Fabricagetechnologieën op waferschaal voor fotonische geïntegreerde circuits in silicium, Wafer-Scale Fabrication Technology for Silicon Photonic Integrated Circuits, 2/2011](#)
  - [Joost Brouckaert, Integratie van fotodetectoren op siliciumgebaseerde fotonische circuits voor spectroscopische toepassingen, Integration of Photodetectors on Silicon Photonic Integrated Circuits \(PICs\) for Spectroscopic Applications, 10/2010](#)
  - [Shibnath Pathak, Silicon Nano-Photonics Based Arrayed Waveguide Gratings, 3/2014](#)



Our YouTube Channel: YouTube

## FURTHER REFERENCE

- Book: “Silicon Photonics Design”
  - By [Lukas Chrostowski](#), *University of British Columbia, Vancouver*, [Michael Hochberg](#), *Coriant Advanced Technology Group*
  - <https://www.cambridge.org/core/books/silicon-photonics-design/BF3CF13E8542BCE67FD2BBC7104ECEAB>
- Special issue IEEE Proceedings on “Silicon Photonics”, December 2018
  - Edited by C. Doerr & R. Baets
  - <https://proceedingsoftheieee.ieee.org/view-recent-issues/december-2018/>
- ePIXfab: <https://epixfab.eu/resources/links-and-downloads/>

Our YouTube Channel: YouTube



## PHOTONICS RESEARCH GROUP

Prof. dr. ir. Dries Van Thourhout

E [dries.vanhourhout@ugent.be](mailto:dries.vanhourhout@ugent.be)

T +32 9 264 3438

@PhotonicsUGent  
 @DThourhout  
 Dries Van Thourhout

[www.photonics.intec.ugent.be](http://www.photonics.intec.ugent.be)