be POM invited

PHOTONICS RESEARCH GROUP

PHOTONIC NEUROMORPHIC COMPUTING USING SILICON CHIPS

Peter Bienstman, Joni Dambre, Aleksio Lugnan, Stijn Sackesyn, Chonghuai Ma, Emmanuel Gooteeraa, Muhammed Gerafa, Sarah Masaad

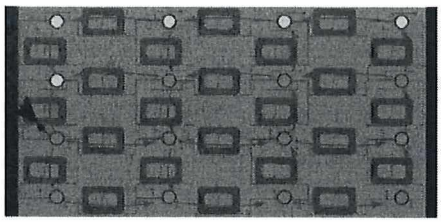
GHENT UNIVERSITY imec

1

THE BLACK BOX

2

WHAT CAN THIS CHIP DO?



3

SEVERAL THINGS!

- Do arbitrary boolean calculations with memory on a bitstream
- Recognise arbitrary 5-bit headers at 12.5 Gbps
- Perform speech recognition of isolated digits
- Does not consume any active power
- Easily upscalable to higher speeds

4

HOW DOES IT DO IT?

Using "Reservoir Computing", a brain-inspired technique to solve pattern recognition problems in a fast and power-efficient way

5

WHAT IS RESERVOIR COMPUTING?

6

WHAT IS RESERVOIR COMPUTING?

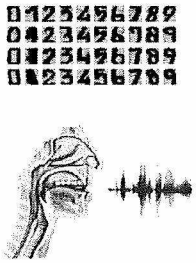
From field of machine learning (2002)

Addressing issues with recurrent neural networks

Originally mainly in software

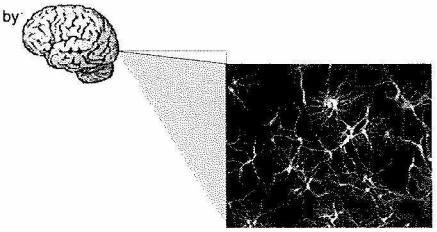
Quite successful:

- Digit recognition
- Speech recognition
- Robot control
- ...



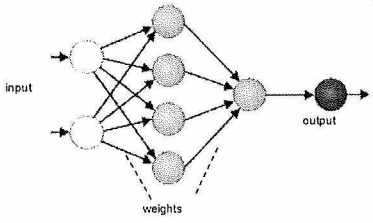
SHORT HISTORY OF NEURAL NETWORKS

Inspired by

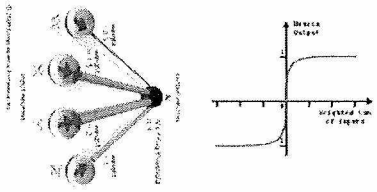


SIMPLIFIED MODEL

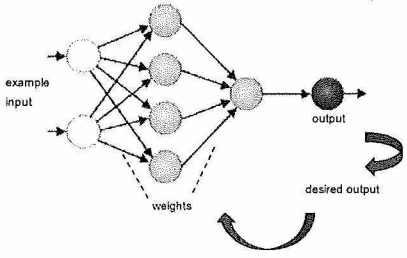
Feed-forward network, i.e. no feedback



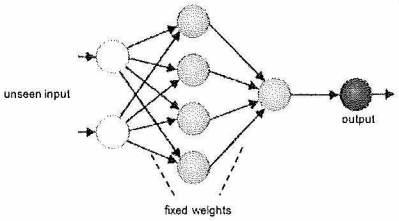
NEURONS



TRAINING

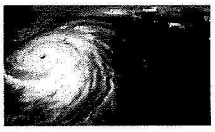


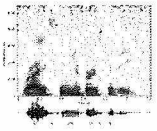
TESTING / USING



NO MEMORY!

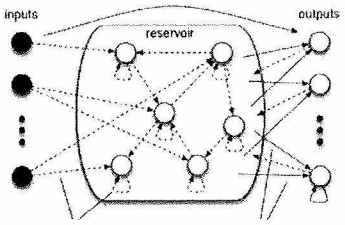
Many real-world problems are temporal, calling for some memory in our system (e.g. through feedback)





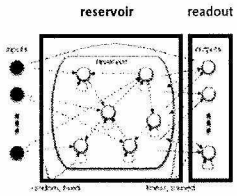
ADDING FEEDBACK

Very hard to train!

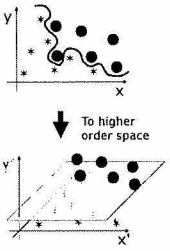


SOLUTION: RESERVOIR COMPUTING

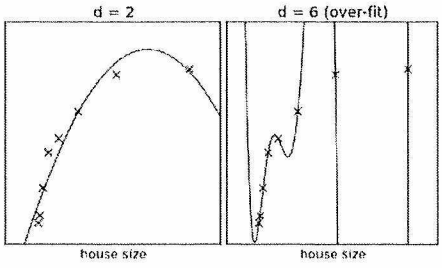
Don't train the neural network, only train the linear readout



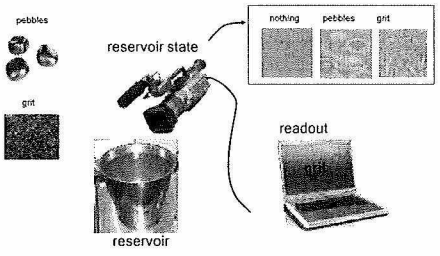
WHY DOES IT WORK?



OVERFITTING

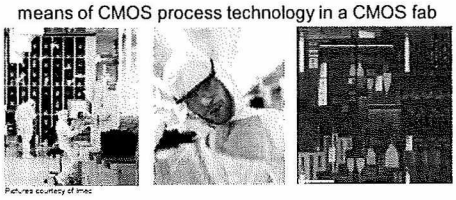


A HARDWARE IMPLEMENTATION…



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

PASSIVE SILICON RESERVOIR

- Silicon photonics: mature technology
- Giant multipath interferometer
- Nodes are simple splitters/combiners
- Non-linearity in readout suffices
- No active power consumption inside chip
- No longer limited by timescale of non-linearity

Vandoorne et al, Nature Comms, 5, 3541, 2014

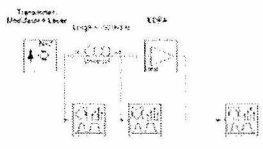
ADVANTAGES

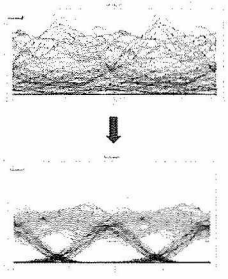
- Scalability:
  - — we spent a lot of effort to slow down the signal!
  - — easily scalable to higher speeds by shortening the delays
- No active power consumption on chip
- Same generic chip can be used for:
  - — digital tasks
  - — analog tasks

  So, generalizes to different applications

NON-LINEAR DISPERSION COMPENSATION AT 32 GBPS

SENDING SIGNALS THROUGH AN OPTICAL LINK SUFFERS FROM DISTORTION

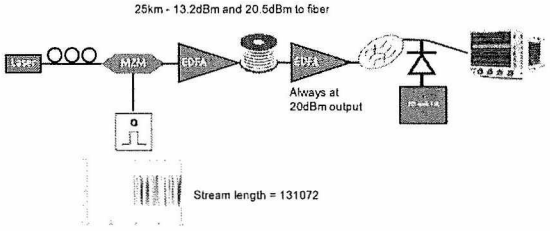




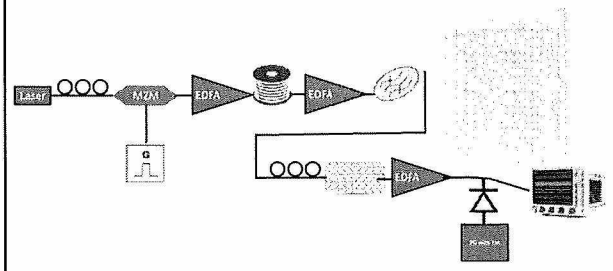
Fixing these problems requires expensive digital processing.

Can we do it in the optical domain at high speeds?

REFERENCE MEASUREMENT WITHOUT RESERVOIR



MEASUREMENT WITH RESERVOIR CHIP



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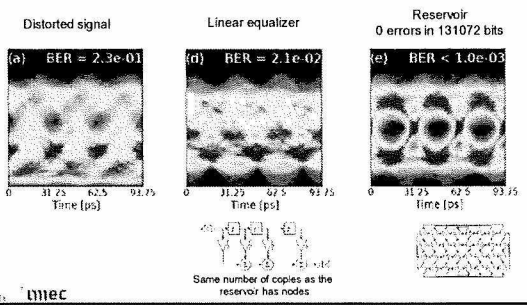
EXPERIMENTS: RC IS BETTER AT EQUALISING THIS NL DISTORTED SIGNAL



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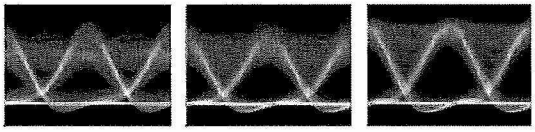
SIMULATIONS: "BAD" NON-LINEAR DETECTOR EVEN BETTER



Distorted stream

Compensated stream using RC
BER: 3 orders of magnitude better

compensated stream with extra non-linearity from TIA
BER: 7 orders of magnitude better

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RC EQUALISATION OF KK RECEIVERS

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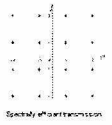
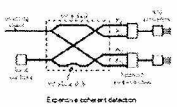
MOTIVATION

Coherent transmission is the optimal choice for medium-long range communications



Coherent detection costs are too high for short links



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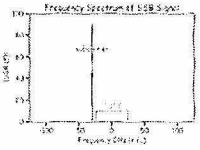
KRAMERS-KRONIG RX

Kramers-Kronig (KK) Receiver is an alternative scheme for coherent receivers which uses direct detection (i.e., amplitude of the signal) to extract the phase information. Certain conditions must be respected for accurate reconstruction:

1. Single sideband signal: the spectrum of the signal must be located to one side of a subcarrier



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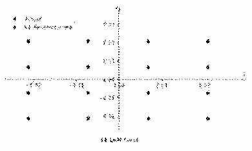
KRAMERS-KRONIG RX

2. Large CSPR: the carrier-to-signal power ratio (CSPR) must be high



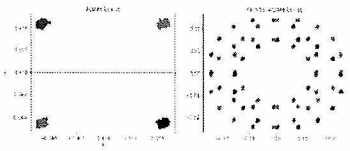
Subcarrier can be added...

- At the detector (popular, but need for extra local oscillator)
- At the source (leads to extra NL effects in fibre)

KRAMERS-KRONIG RX

For a KK receiver to correctly demodulate a signal $a(t)$ it should have the following form $a(t) = A + a_s(t)\exp(i\pi Bt)$; where A is the high-power subcarrier, $a_s(t)$ is the message signal, and $\exp(i\pi Bt)$ frequency shifts the signal

For a 4 QAM signal, the message signal $a_s(t)$ (left) and the KK compatible signal $a(t)$ (right) are shown below



SIGNAL RECONSTRUCTION

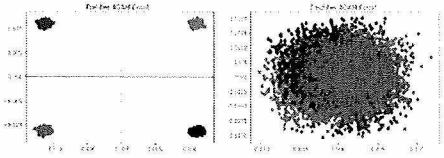
(A) Intensity (direct detection): $|A + a_s(t)\exp(i\pi Bt)|^2$

(B) KK DSP: $a(t) = A + a_s(t)\exp(i\pi Bt)$

(C) Carrier removal and frequency shift: $a_s(t)$

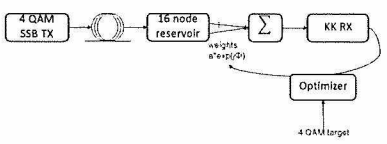
Complexity Analysis of the Kramers-Kronig Receiver Christoph Füllner et al

HIGH-POWER CARRIER LEADS TO NL FIBRE EFFECTS



COMPENSATING NONLINEAR FIBER EFFECTS USING RC

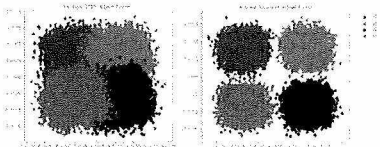
- We backpropagate through entire NL KK receiver during training
- Can use the 4 QAM signal as target signal (as opposed to target signal before the receiver).



RC OUTPERFORMS LINEAR EQUALISATION

Distorted signal after 40 km fiber equalized using 16-tap optical tapped delay line (left) and 16-node reservoir (right).

Testing on 26,700 symbols, training on 6,000 symbols.



Linear equalization: BER 4e-2 | Reservoir equalization: BER 9e-5

OTHER TELECOM TASKS

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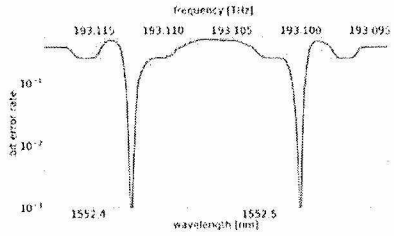
SOLVE A TASK SIMULTANEOUSLY ON 2 WDM CHANNELS



XOR task

Same readout for both channels!

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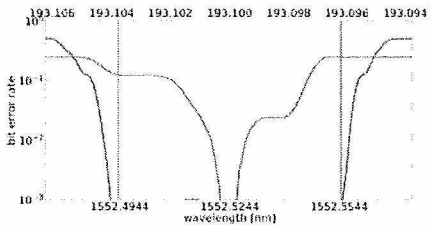
IMPROVE ROBUSTNESS AGAINST WAVELENGTH DRIFT



Multiwavelength training gives 8 GHz vs 3 GHz window

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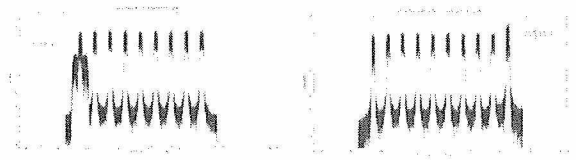
JAMMING DETECTION

Successful identification in real time of in-band and out-of-band jamming



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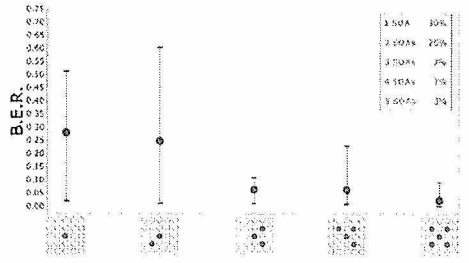
MODULATION FORMAT IDENTIFICATION: BPSK VS QPSK



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BIOLOGICAL CELL SORTING

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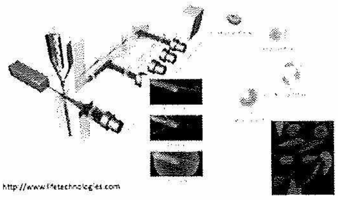
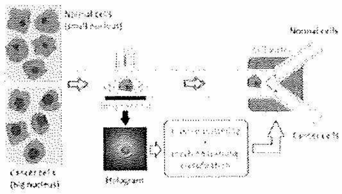
Flow cytometry



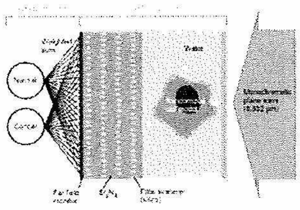
http://www.lifetechnologies.com

Digital holography



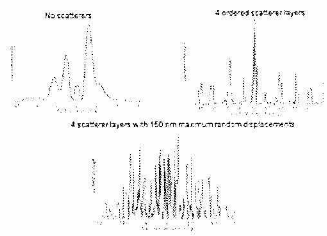
Goal: 1000 microfluidic channels in parallel ⟹ ~ 1000 classifications each ms

A spatial analog of reservoir computing

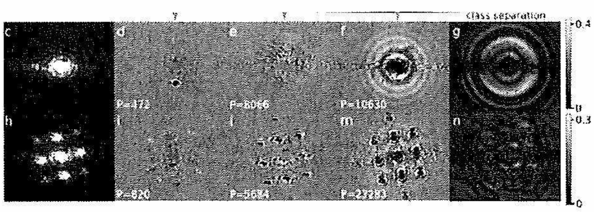


Phase-to-intensity transfer function is sinusoidal ⟹ Power-independent nonlinearity available for computation

Scatterers increase hologram complexity



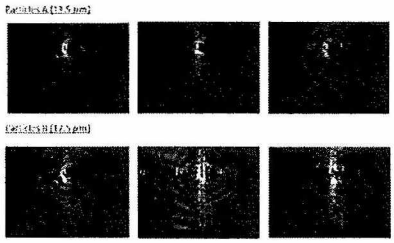
Experiments on beads with different sizes



Much faster than other works in literature

Classification task	Classifier	Image resolution	Imaging method	Image FoV	Classification performance	Accelerator	Execution time / particle	Mass flow control
Beads with diameters of 7, 10 and 15 µm	CNN	21 × 21	Microscope	[illegible]	[illegible]	GPU	[illegible]	Unreported
3 white blood cell (WBC) types	Random forest	31 × 31	Lens-free	Unreported	[illegible]	GPU	0.2 ms	Unreported
4 WBC types and [illegible]	Deep CNN	Cropped	Time-stretch microscope	25 µm	[illegible]	GPU	[illegible]	[illegible]
Beads with diameters of 15.2 and 15 µm (our work)	Linear (log. regression)	[illegible]	Lens-free	[illegible]	[illegible]	None	[illegible]	Yes

NEXT STEPS: EXPERIMENTS WITH AN EVENT CAMERA



No need for background subtraction!

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CONCLUSIONS

Reservoir computing
is interesting new paradigm
for all-optical information processing

NEoteRIC

Nebula

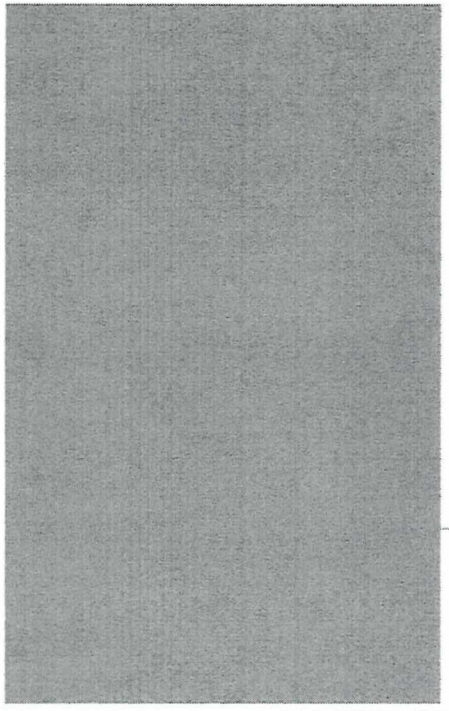
imec

To Ilse Van Royen (UGent-imec)

Te doen

Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

BePOM 2021 RC.pptx
8 MB



The bePOM21 programme includes 5 technical sessions, an industrial session, online poster sessions, paper discussions and networking sessions on Gather Town.

Day #1 - Topic #1
Quantum, non-linear and laser optics
Tutorial: Prof. Nathalie Vermeulen (VUB)
Invited: Dr. Stéphane Clemmen (ULB)

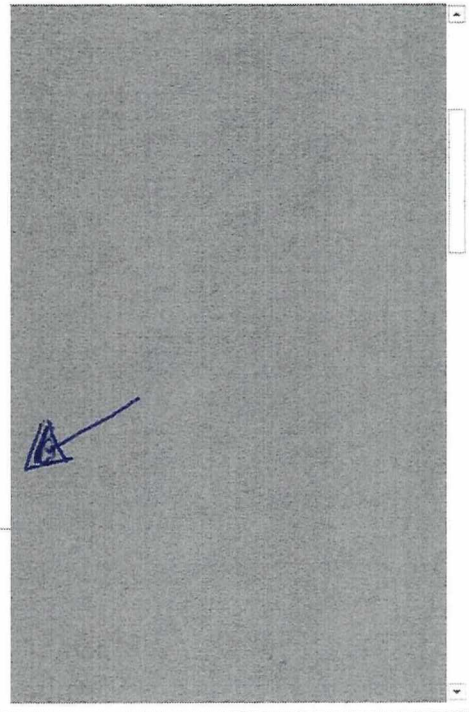
Day #1 - Industry representation
Tutorial: by Prof Hugo Thienpont (VUB)
Industrial participants among which Antwerp Space, CommScope, Lasea & Schréder

Day #1 - Topic #2
Sensing, imaging and spectroscopy
Tutorial: Prof. Michel Voué (UMons)
Invited: Prof. Francesca Cecchet (UNamur)

Day #2 - Topic #3
Optical fibers and intergrated optics
Tutorial: Prof. Peter Bientsman (UGent)
Invited: Dr Agnieszka Gierej (VUB)

Day #2 - Topic #4
Optical design
Tutorial: Prof. Fabian Duerr (VUB)

Day #2 - Topic #5
Nanophotonics, plasmonics and metamaterials
Tutorial: Prof. Sofie Cambré (UAntwerpen)
Invited: Dr. Liliana D'Alba Altamirano



All folders are up to date. Connected to: Microsoft Exchange 100%

3°C ENG 13:12 26/01/2022

Welcome to the Belgian Photonics Online Meetup

The goal of bePOM is to strengthen the Belgian photonics network, associating research groups from all the universities in Belgium working on fundamental and applied topics in photonics. It will give the opportunity to early career and established researchers to (re-)discover and learn about the ongoing research topics in the Belgian cities next-door, without moving from their home universities.

bePOM is an entirely free virtual conference and is affiliated with the POM conference

Second bePOM edition - 23 & 24 September 2021

Our event is over! Thank you very much to all the participants!

After the success of bePOM2020, several new members of the Belgian photonics community joinded the scientific and organizing committee and pulled together this second edition.

The novelties are:

- 2 days of conference
- contributed talks by topic selected upon the abstracts
- the use of Gather Town for the networking and poster sessions
- 2 poster prizes sponsored by MDPI Biosensors & NanoFar
- 3 paper discussions
- an industry representation session

Scientific and organizing Committee

- (new member) Dr Tatevik Chalyan | Vrije Universiteit Brussel
- Dr Michaël Lobet | University of Namur - Harvard University
- Dr Sébastien Mouchet | University of Namur - University of Exeter
- Dr Gilles Rosolen | University of Mons
- (new member) Dr Ir Lien Smeesters | Vrije Universiteit Brussel
- (new member) Ma Migle Stabryte | Universiteit Gent
- (new member) Dr Denis Tihon | UCLouvain - University of Cambridge
- (new member) Dr Koen Vanmol | Vrije Universiteit Brussel
- Dr Isabelle Derycke | University of Namur
- Mrs Karin Demoitelle | University of Namur

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B-PHOT Student Chapter
@BPHOTChapter

We kick off our 🚀 James Webb Space Telescope Launch event 🔭!
Join us 😎
🔗 Registration link: shorturl.at/eyMN
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Sensing, imaging and spectroscopy session

14:30 | Tutorial: Prof. Michel Voué (UMons)

What can we learn from imaging ellipsometry analysis of plasmonic nanocomposite materials?

15:10 | Invited: Prof. Francesca Cecchet (UNamur)

Vibrational nonlinear optical spectroscopy as innovative, label-free and highly sensitive bio-recognition solution

15:40 | Contributed talks

Margot Vandermotten (VUB) - *In-vitro DILI monitoring using Raman spectroscopy*

Aina Fitó Parera (UAntwerpen) - *Spectroscopic techniques to characterise encapsulated dye molecules inside single wall carbon nanotubes*

16:10 | Paper discussion - Indy Magnus (VUB)

L. Smeesters, I. Magnus, et al, "Potato quality assessment by monitoring the acrylamide precursors using reflection spectroscopy and machine learning", Journal of Food Engineering 311, 110699, 2021.

16:40 | Beer break & networking

Day #2 : Friday 24 September 2021

Optical fibers and integrated optics session

08:45 | Tutorial: Prof. Peter Bienstman (UGent - IMEC)

Photonic neuromorphic computing using silicon chips

09:25 | Invited: Dr. Agnieszka Gierej (VUB)

Fabrication of microstructured polymer optical fibers

09:55 | Contributed talks

Enes Lievens (UGent) - *Characterization of electro-optically active thin films for photonic circuits*

Médéric Loyez (UMons) - *Cancer cells detection using optical fiber sensors*

10:25 | Paper discussion - Awanish Pandey (UGent – IMEC)

A. Pandey et al., "Nonreciprocal Light Propagation in a Cascaded All-Silicon Microring Modulator", ACS Photonics 8(7), 1997-2006, 2021

10:55 | e-coffee break "Coffee & Chocolate"

Optical design session

11:20 | Tutorial: Prof. Fabian Duerr (VUB)

"First time right" freeform optics design

12:00 | Invited: Dr. Lionel Clermont (ULiège)