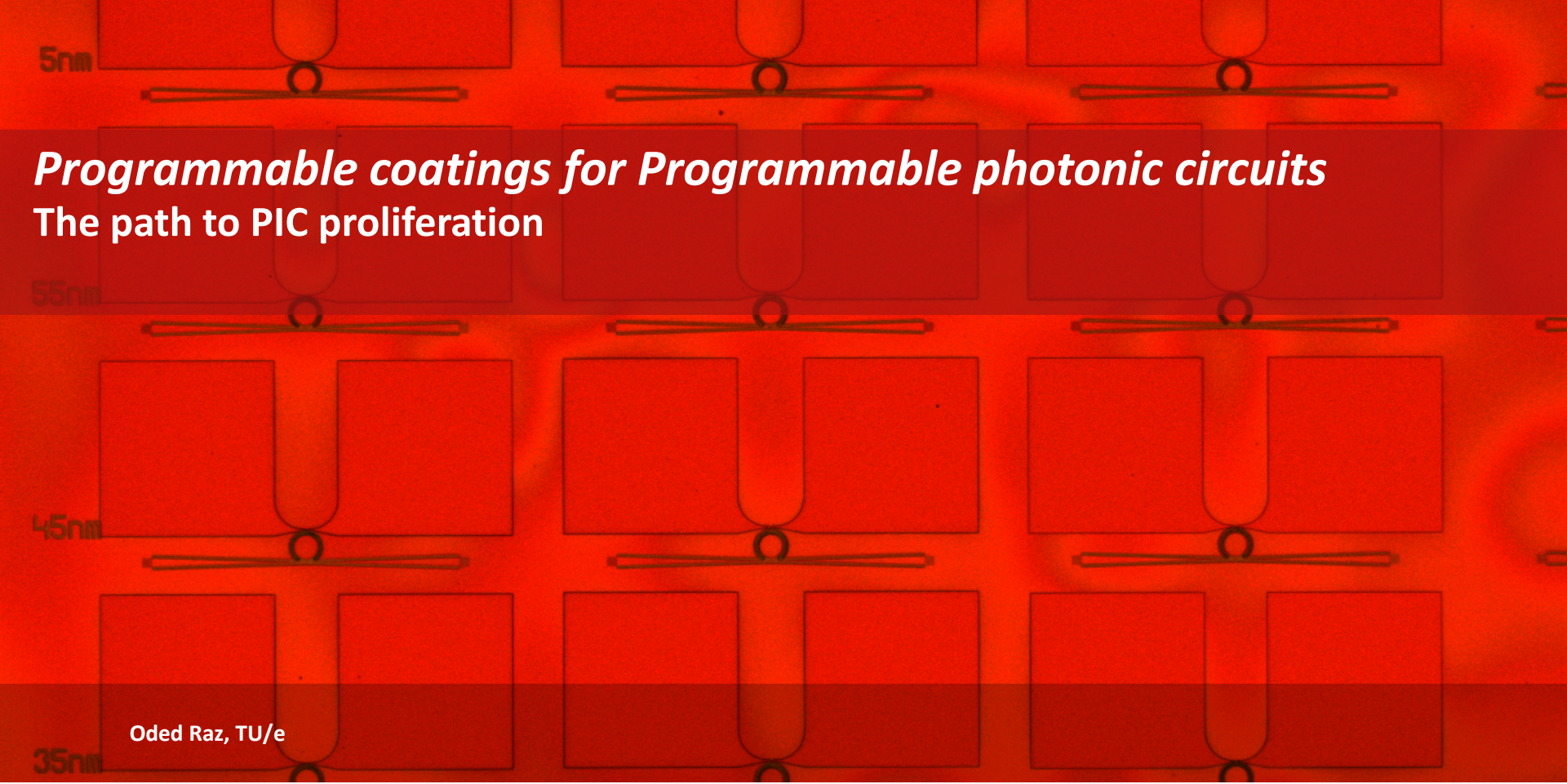


Programmable coatings for Programmable photonic circuits

The path to PIC proliferation

Oded Raz, TU/e

Electrical Engineering, Electro Optic Communication (ECO) group

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

“Prediction is very difficult, especially if it's about the future”

Niels Bohr

What to take home from this talk

- Integrated photonics is still in its infancy (in terms of volumes, yield, complexity, etc)
- Now is the time to introduce clever programmable coatings to enable post-processing functional manipulation/programming
- Polymers offer a wide range of possibilities for creating adaptive coatings which can make un-organic semi-conductor devices programmable
- New ideas are welcome ☺

“Study the past if you would define the future.”

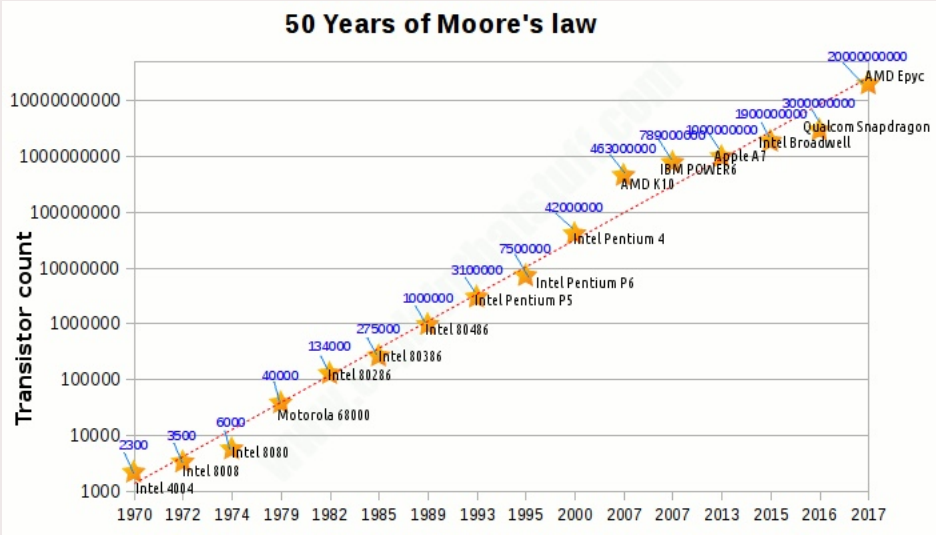
Confucius

- History may set us on the wrong path
  - VLSI, the corner stone of micro electronics
  - Photonic integration as an exercise in increased integration density
  - The challenges of fabrication
  - Simple analogy, complicated story…
- History is all we have to get us going
  - The shift from fixed to programmable – isn’t it wonderful?
  - Why does it make sense to bring programmability to photonics?
- We are not alone! attempts at programmable photonics
- Programmable photonics in TU/e – The future!

History may set us on the wrong path

VLSI, the corner stone of micro electronics

- More(Moore) is more!
- With more transistors we can definitely do more: memory, logic, mixed signal…
- Building blocks are simple and render themselves to miniaturization (thanks to immense investment in R&D)
- Function is the result of interconnection of many basic components
- Only limit is power dissipation (leakage current)
- Reliability of single transistor (1e-7 FIT – or one in 10^16 seconds or once every 300 million years)

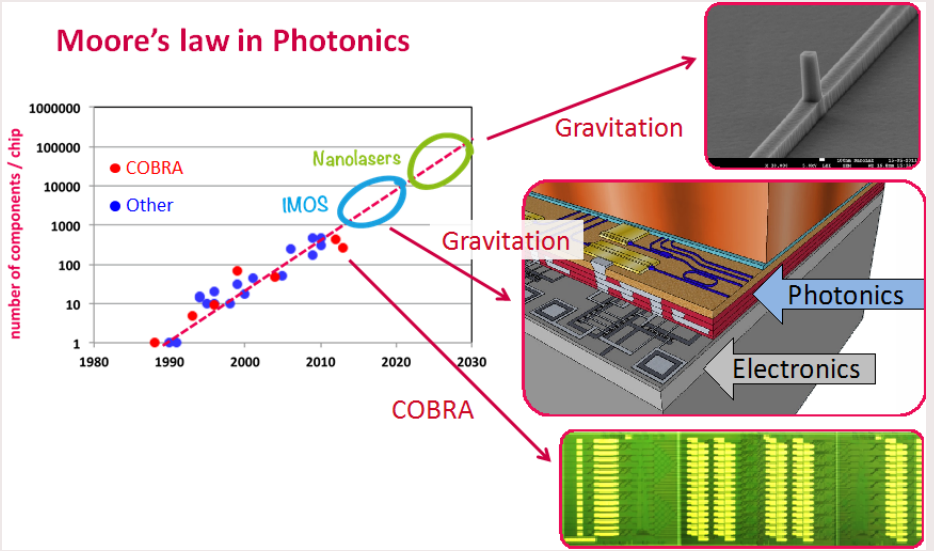


https://www.explainthatstuff.com/integratedcircuits.html

History may set us on the wrong path

Photonic integration as an exercise in increased integration density

- If the function of the entire PIC is dependent on all parts working and the single device yield is 99%, what is the PIC yield if we put 100 of them on the PIC?
  - 99%
  - 80%
  - 36% (5% for 300 devices)
- And BTW, do we really need >1000 devices on a PIC? Or 10000?
  - What is the function?
  - Can it be controlled?
  - Can it be powered up?



PHI group, EE department TU/e

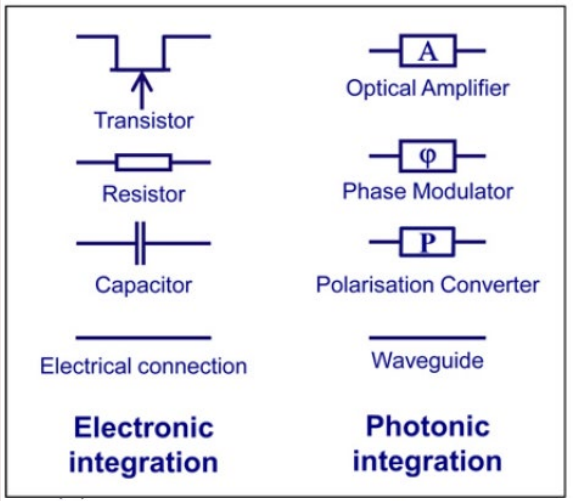
How to reach the mass market for photonics?

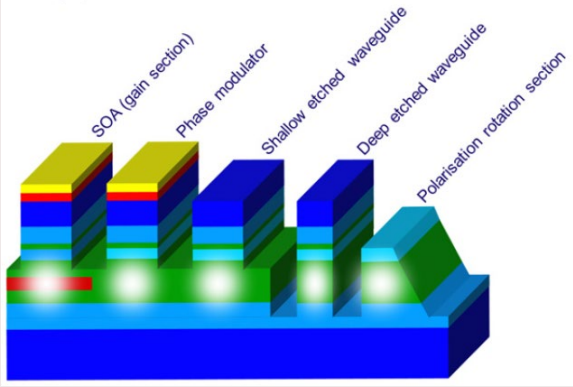
Huub Ambrosius former manager of the TU/e cleanroom on the challenges of fabrication

History may set us on the wrong path

Simple analogy, complicated story…

- Every PIC uses a fixed set of components
- Just like electronics, simple!
- But what are these components doing?
- Can any of those single components be compared in versatility to a CMOS transistor?
- What is the size of a single building block?



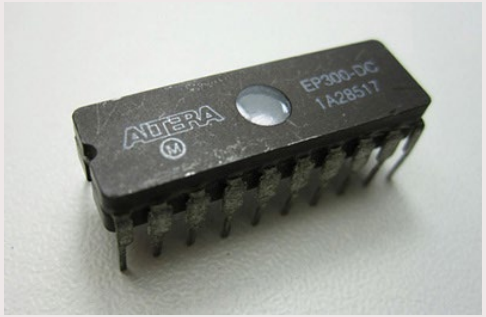


M. Smit et al, Semicond. Sci. Technol. 29 (2014) 083001

History is all we have to get us going…

The shift from fixed to programmable – isn't it wonderful?

- Programmable controllable logic ICs introduced in the mid 80s
- Enabled fast prototyping and flexible deployment and reconfiguration of electronic logic circuits (via "SW" update)
- Currently penetrated many consumer applications and emerging as promising solutions for deep learning computers



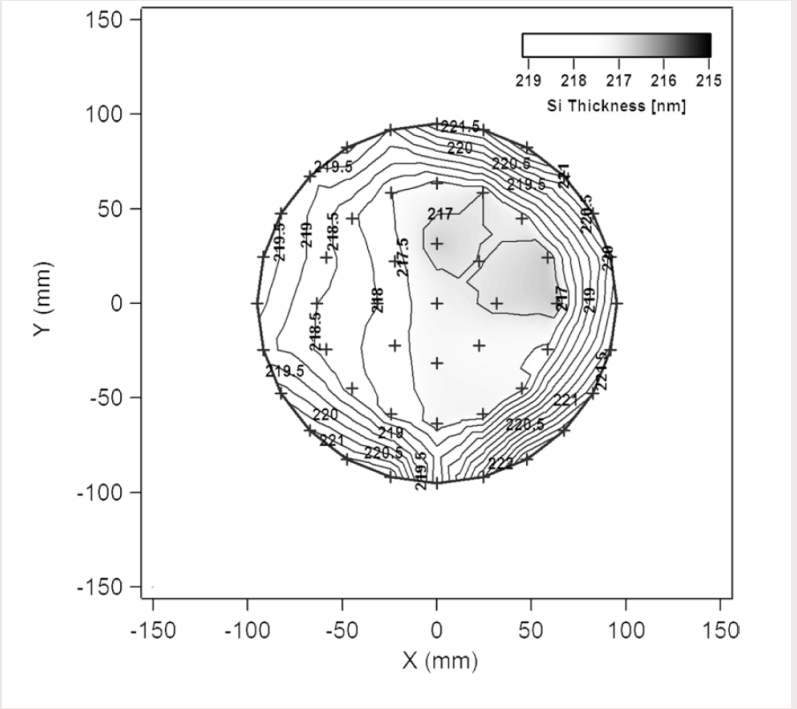
Altera EP300, circa 1985 (~100,00 transistors)

Xilinx VU19P. 2019 (35 Billion transistors!!!)

History is all we have to get us going…

Why does it make sense to bring programmability to photonics?

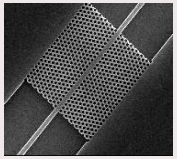
- Wafers are not uniform
- Small problem for electronics, big headache for photonics
- Same device design on two different positions on the same wafer will yield two different circuit behaviors!

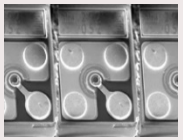


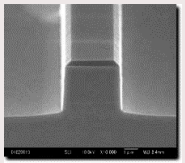
S.K. Selvaraja et al, IEEE JSTQE 16 (2010)

History is all we have to get us going…

Why does it make sense to bring programmability to photonics?





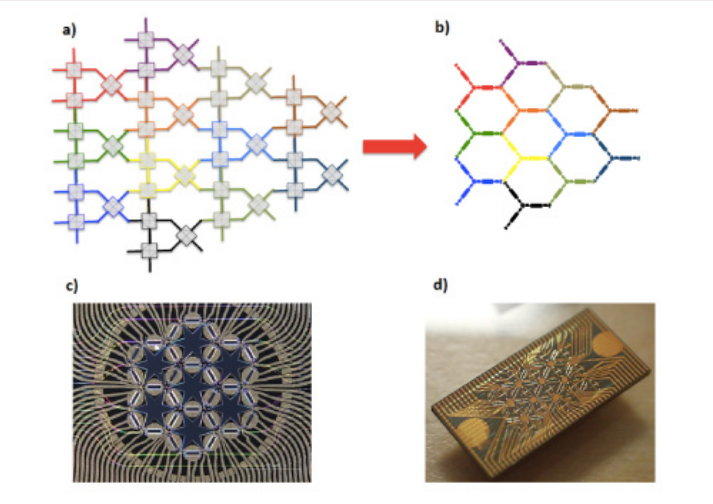


- Many platforms each with its unique advantages and applications
- Meeting design specification requires sub nano-meter resolution in lithography
- To compensate for deviations from design, devices include many active tuning elements
- Concepts for programmable photonics are emerging

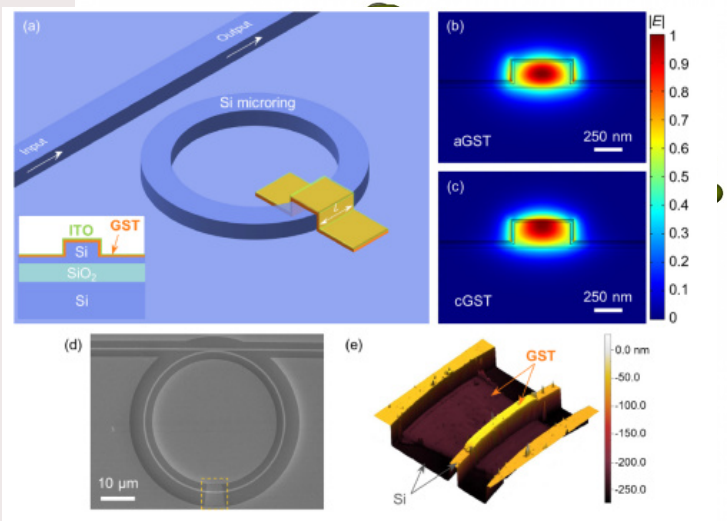
Generic programmable PICs (similar to electronic programmable ICs) will bring great benefits but how can they be made?

We are not alone…

Attempts at programmable photonics across the globe



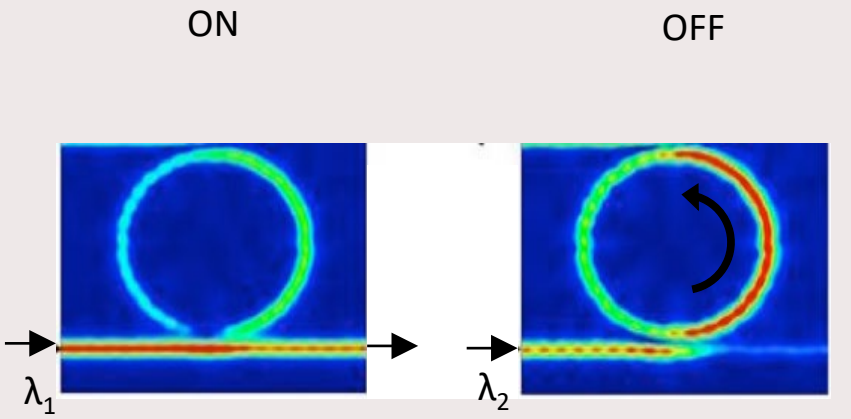
Field-programmable photonic arrays
D. Pérez, et al, Optics Express, 2018

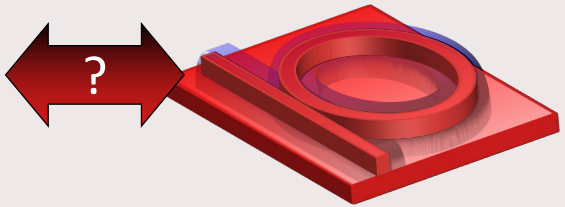


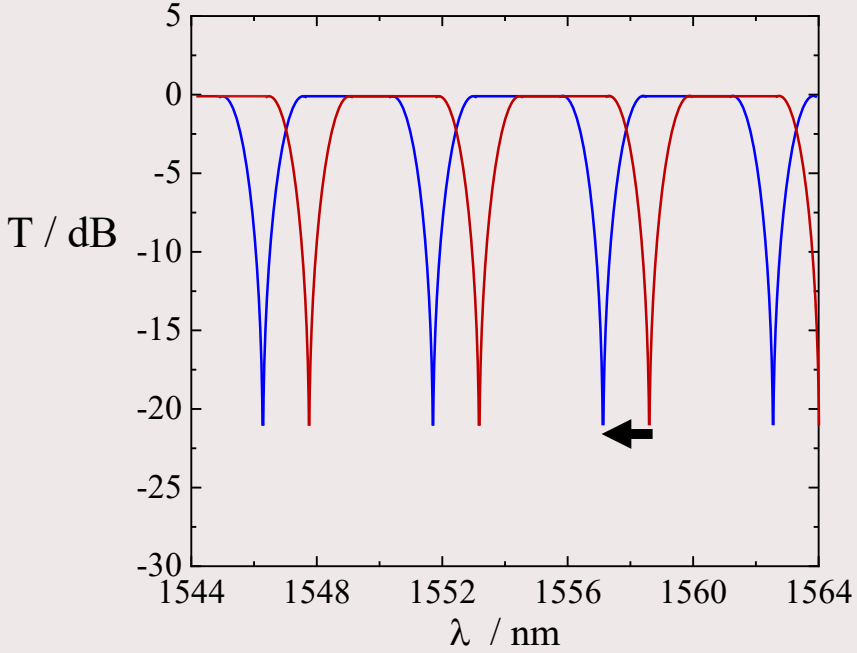
GST-on-silicon hybrid nanophotonic integrated circuits: a non-volatile quasi-continuously reprogrammable platform
J. Zheng, et al, Optics Material Express, 2018

Programmable photonics in the TU/e

Achieving programming via the cladding

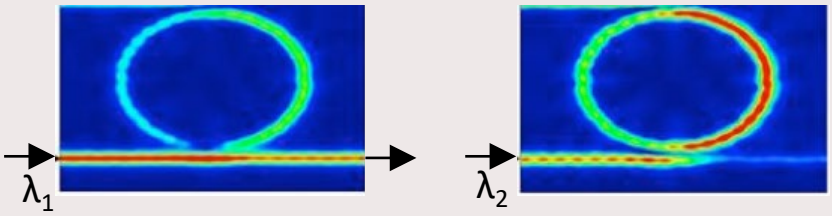




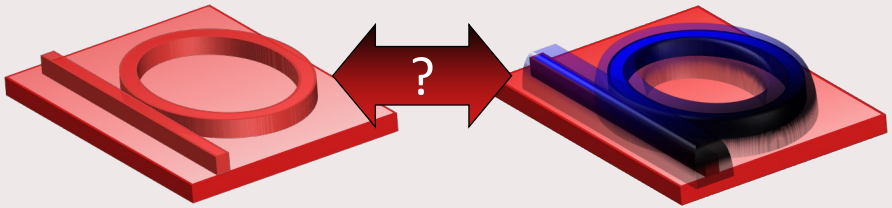


Programmable photonics in the TU/e

Achieving programming via the cladding – what we need?



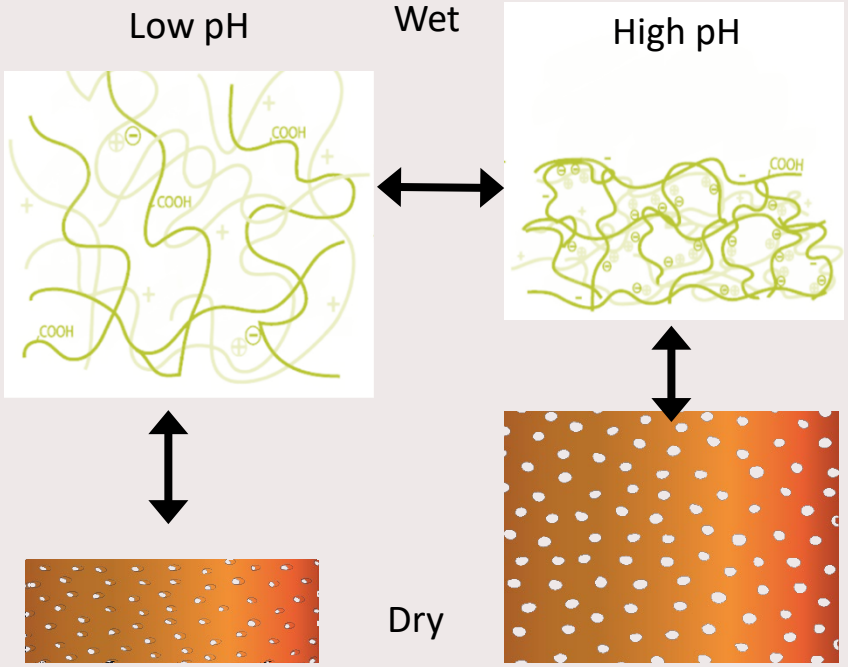
- Continuous power consumption
- Additional tuning circuits
- High optical loss



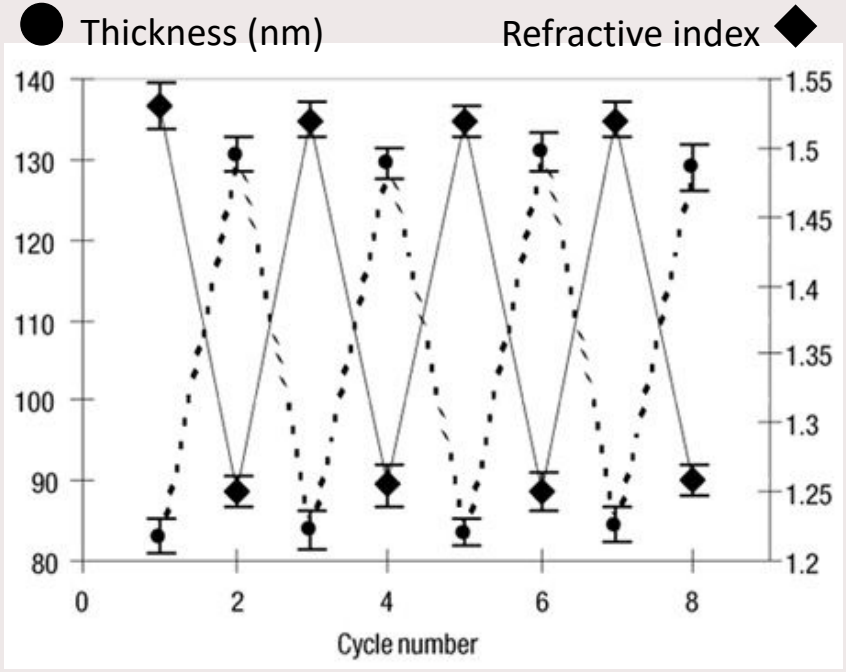
+ Non-volatile/no power input
+ No tuning circuits
+ Low loss
+ Easy to apply

Programmable photonics in the TU/e

Reversibly swellable PEM with adjustable porosity



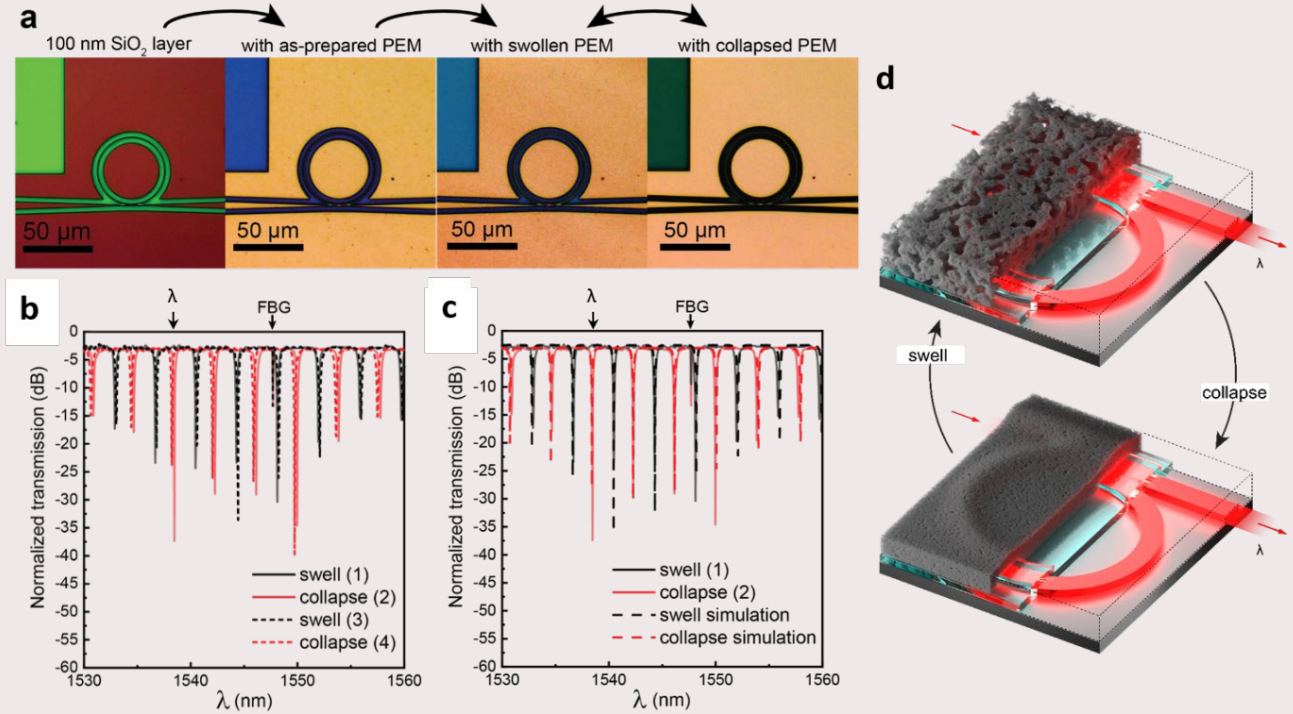
Adapted from Chia, K. *et al. Langmuir*, **25** (2009)



Hiller, J. *et al. Nat. Mater.*, **1** (2002)

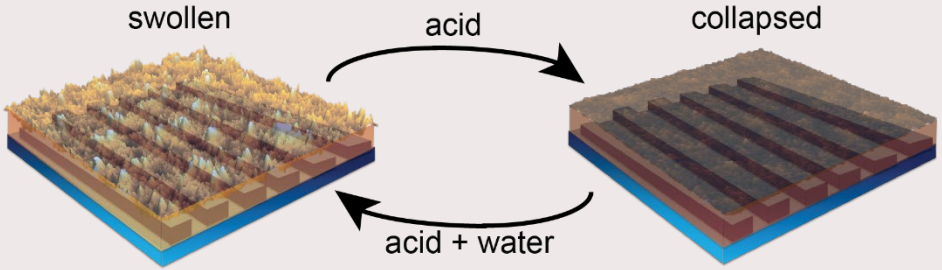
Programmable photonics in the TU/e

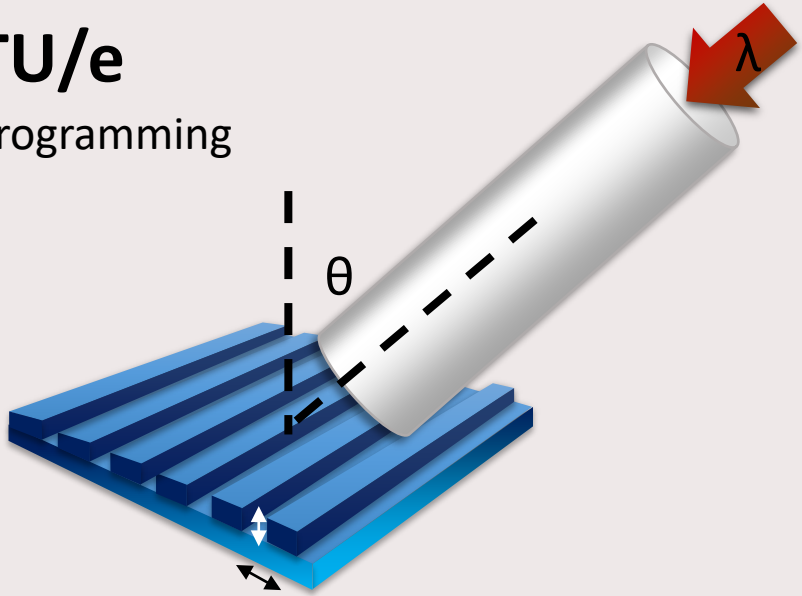
Programmable all pass ring filter using PEM cladding manipulation

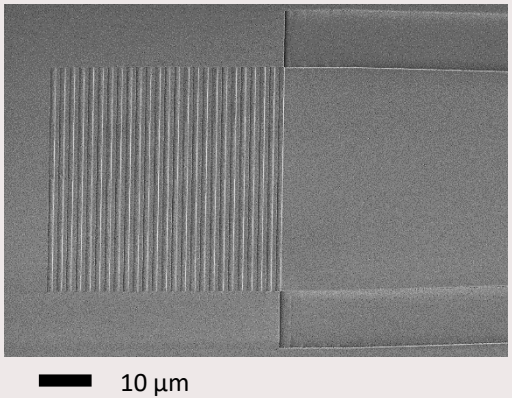


Programmable photonics in the TU/e

Adjustment of grating coupler response using PEM programming



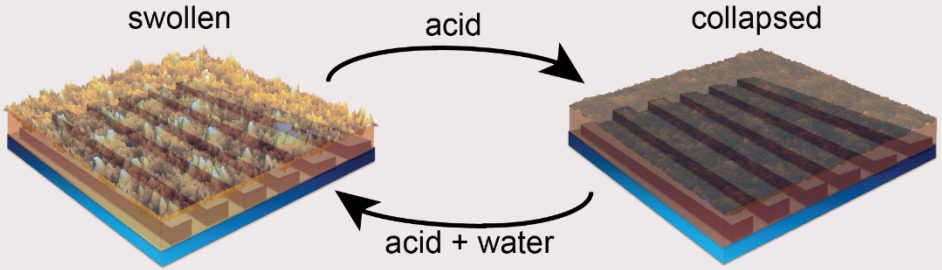


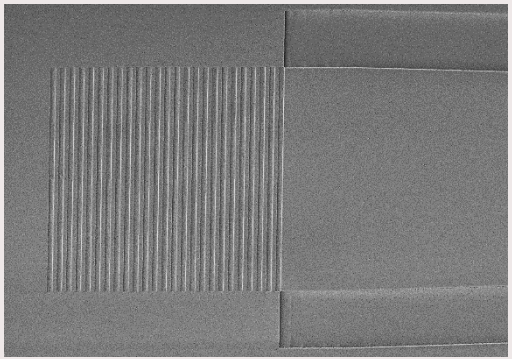


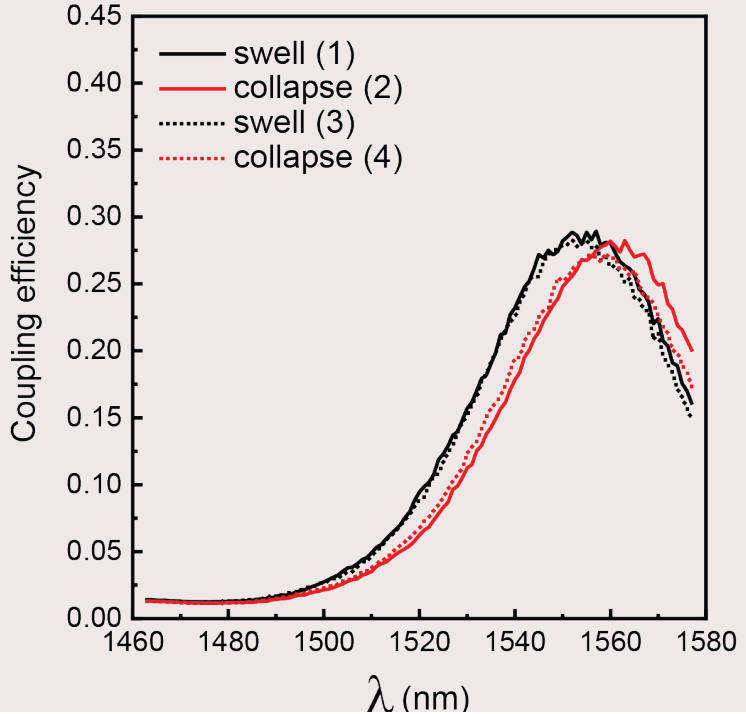
Correction of
- Insertion angle
- Critical device dimensions

Programmable photonics in the TU/e

Adjustment of grating coupler response using PEM programming







Programmable photonics in the TU/e

Dr. Mahir Asif Mohammed

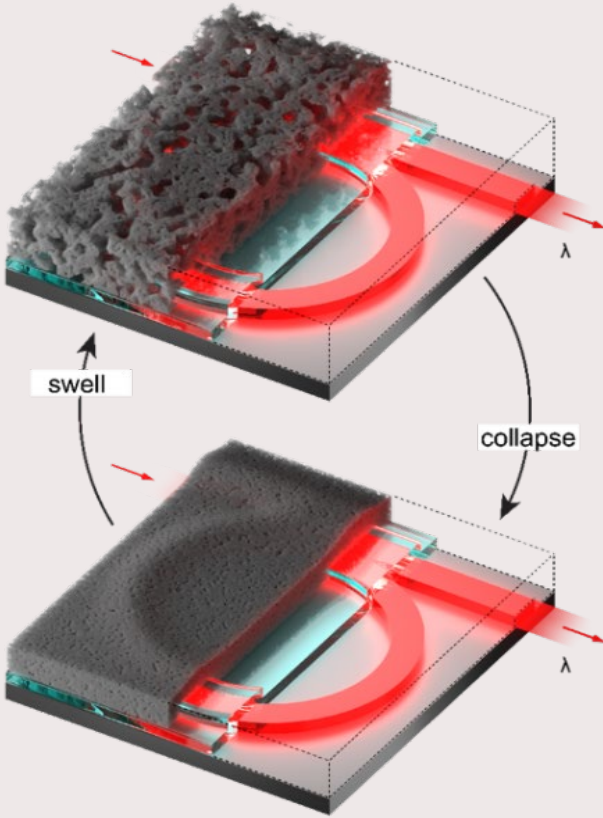
Christian Sproncken

Dr. Patty Stabile

Prof. Ilja Voets

“Those who have knowledge, don't predict. Those who predict, don't have knowledge”, Lao Tzu

- Photonics is a leading candidate technology for solving major societal problems
- If we want to speed up the uptake of photonics radical paradigm shifts in the design, manufacturing and application of photonic integrated circuits are needed
- Polymer chemistry is virgin ground in the search for programmable coatings and can be a game changer in the field of photonics!




Thank you