Past and future of InP-based photonic integration

Meint Smit

Acknowledgements:
The COBRA team
NWO, EU-IST program, STW, IOP

COBRA

Technische Universiteit Eindhoven
University of Technology

Where innovation starts

COBRA

Communication Technologies:
Basic Research and Applications

COBRA staff

~25 scientific staff & technicians
~25 postdocs
~50 PhD

Core
- Materials (HGF)
- Components (OED)
- Systems (ECO)

Other
- Radio Communications (CWSe)
- Electromagnetics (EM)
- Micro Electronics (MsM)
- Signal Processing (SPS)
- Functional Materials

800 m^2 cleanroom

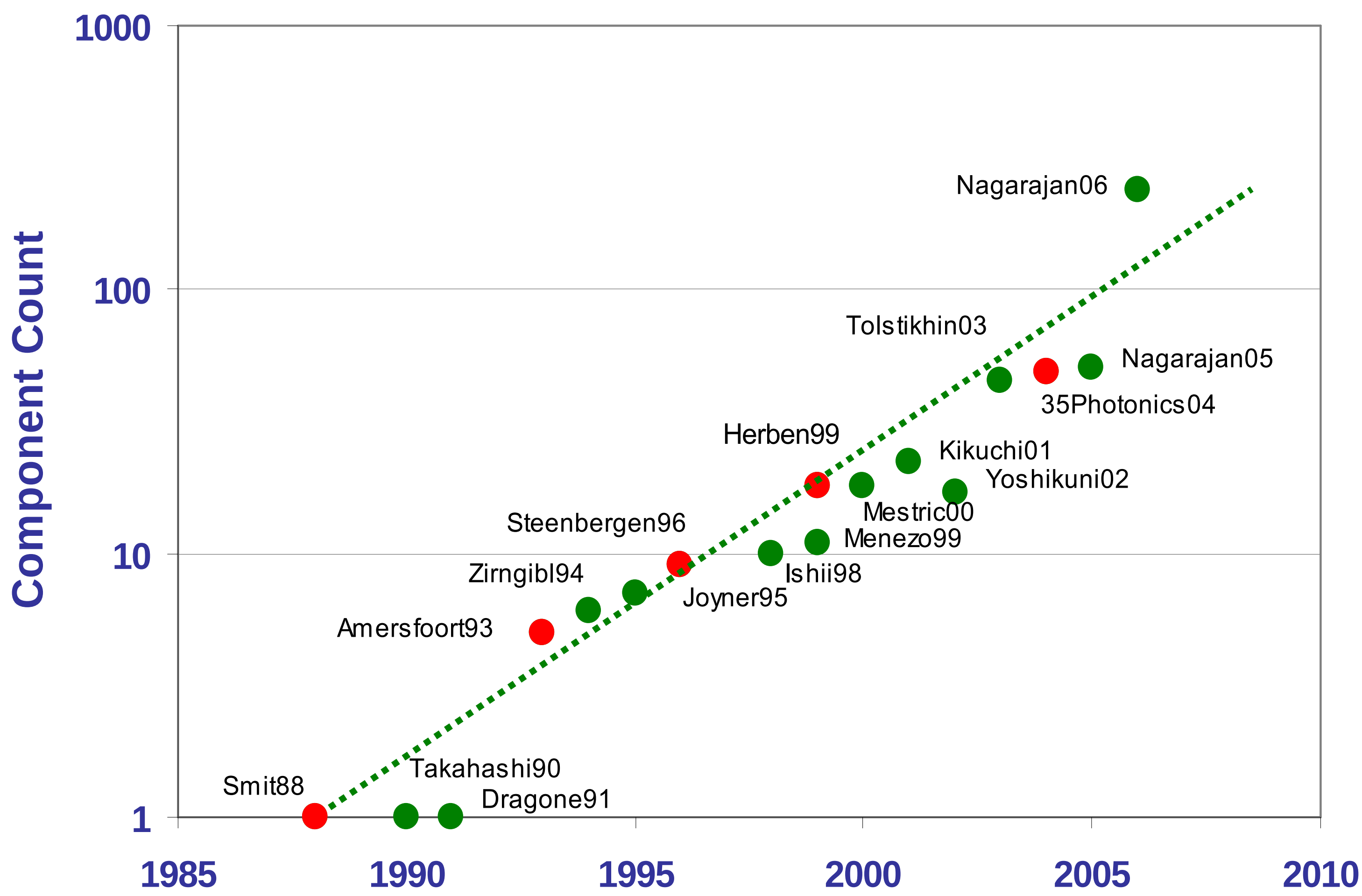
COBRA

Technische Universiteit Eindhoven University of Technology

Outline

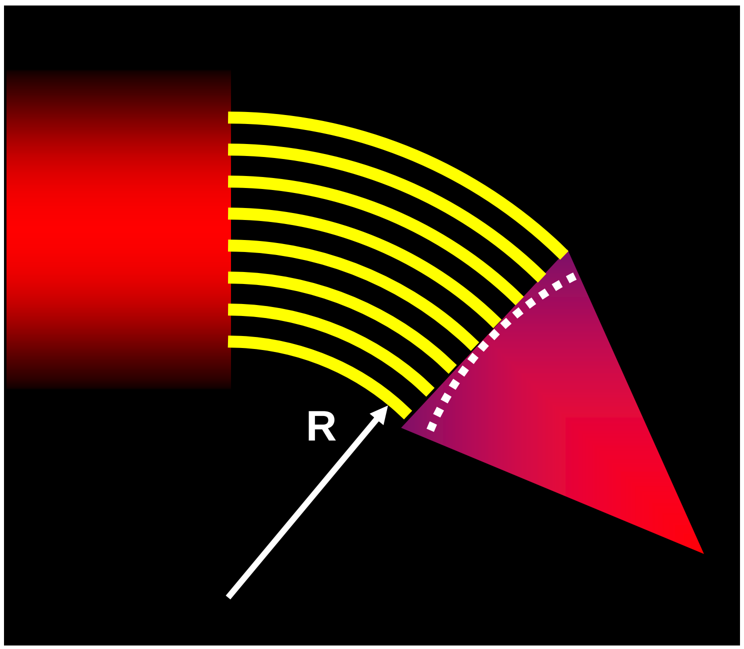
- The Past / Moore's law in Photonics
- The Future / 1 Generic Integration Technology
- The Future / 2 Nanophotonic Integration Technology

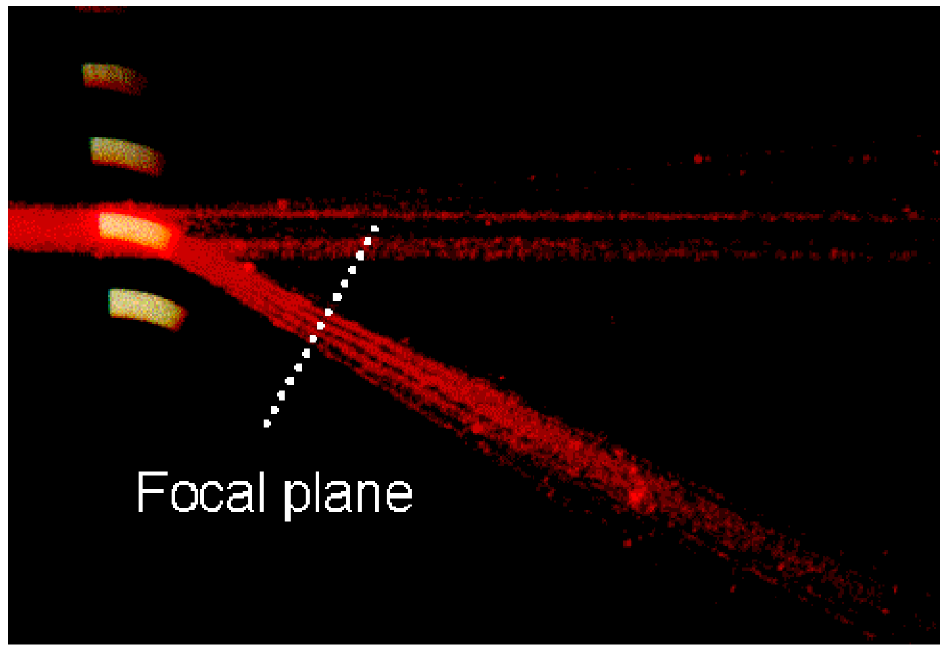
Moore's law for WDM PICs



AWG demultiplexer

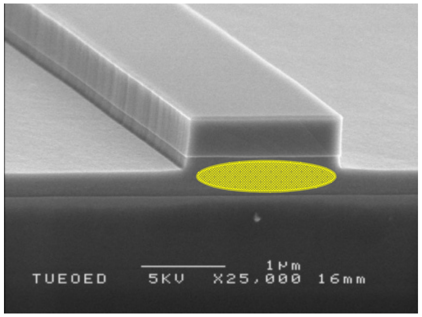
Meint Smit, Electronics Letters 1988

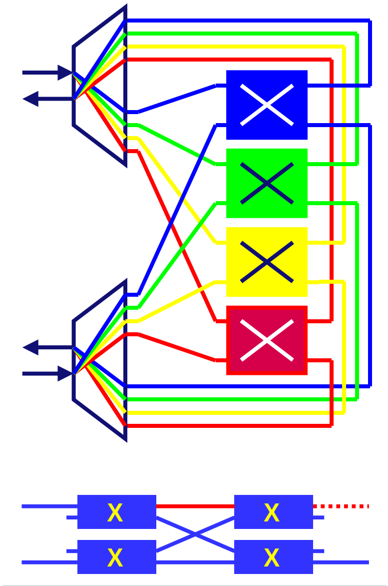


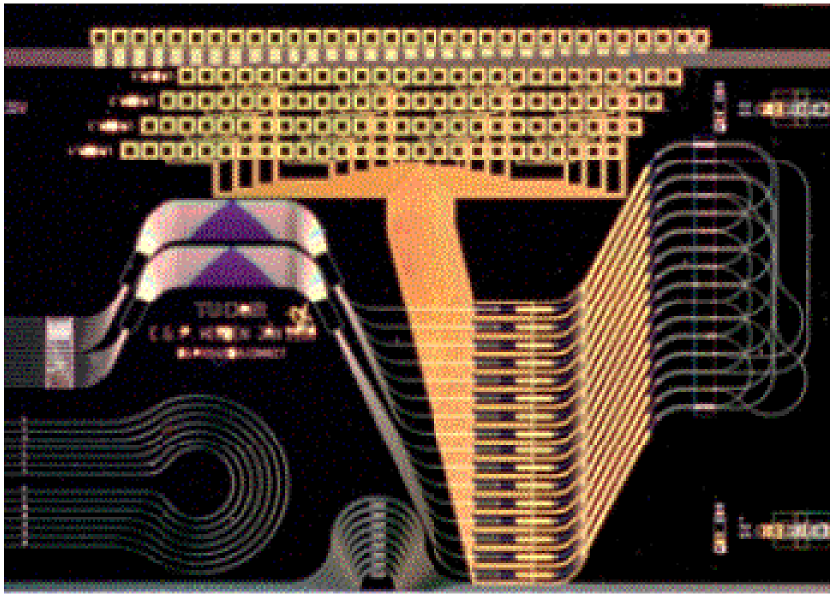


Example of Photonic IC: 4λ OXC

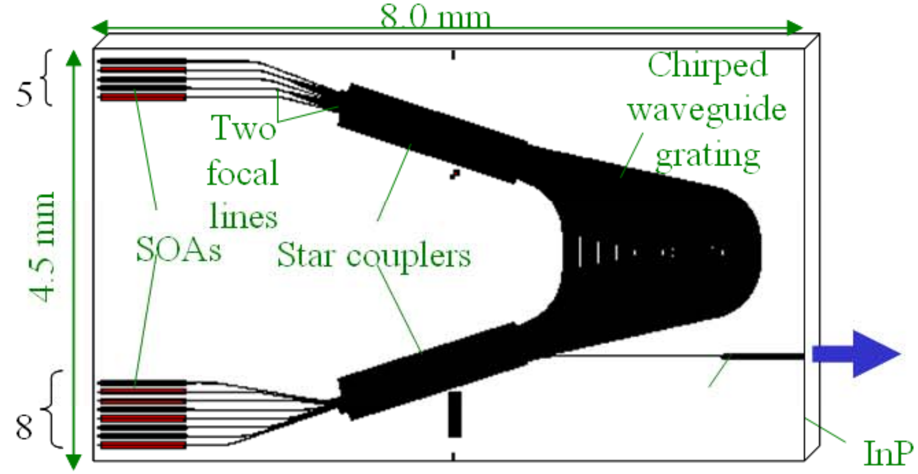
Herben, PTL, 1999

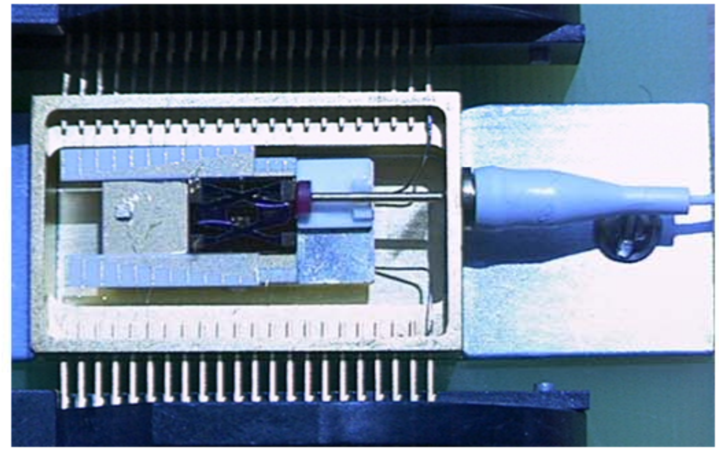


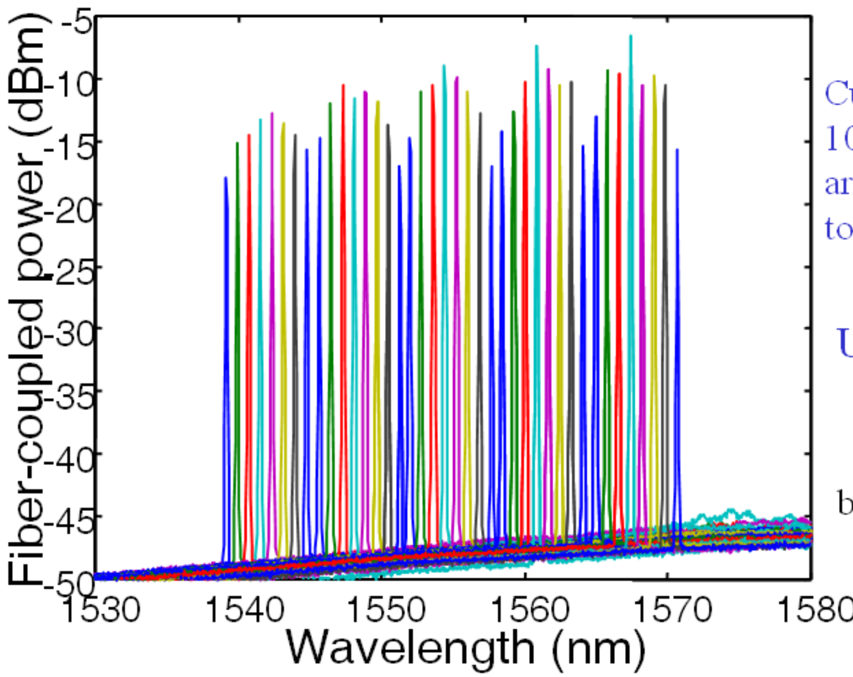




40-wavelength digitally tunable laser







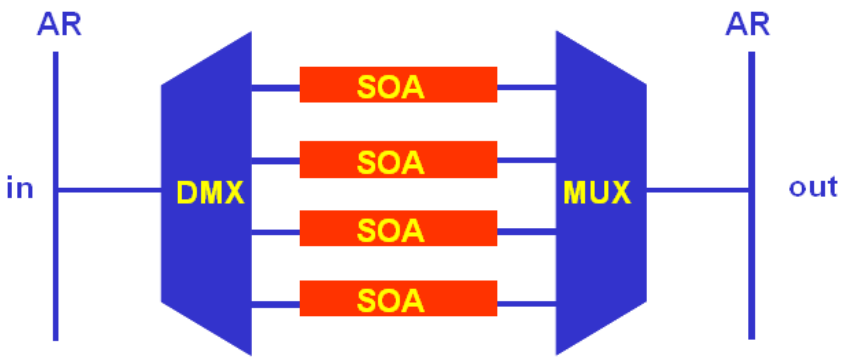
Currents:
100 mA to each
array SOA, 75 mA
to output SOA

Unpackaged chip

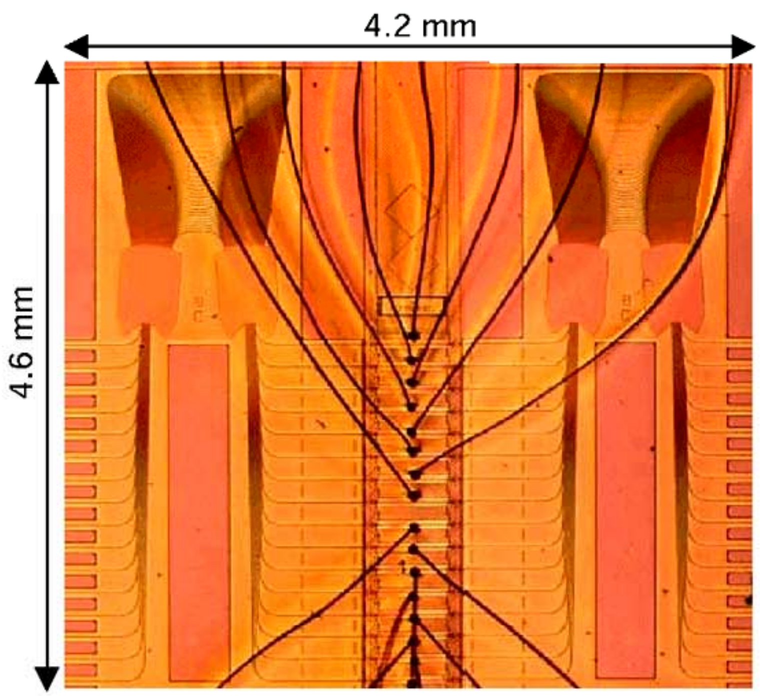
Measurement
bandwidth = 0.1 nm

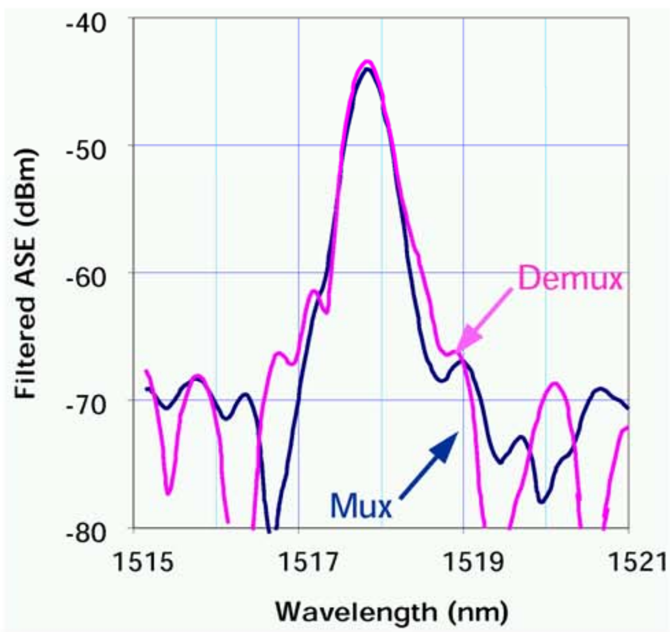
Lucent Technologies
Bell Labs Innovations

16-channel PHASAR wavelength selector



- 100-GHz channel spacing
- Crosstalk < -35 dB
- Zero-loss operation @ 50 mA for all channels

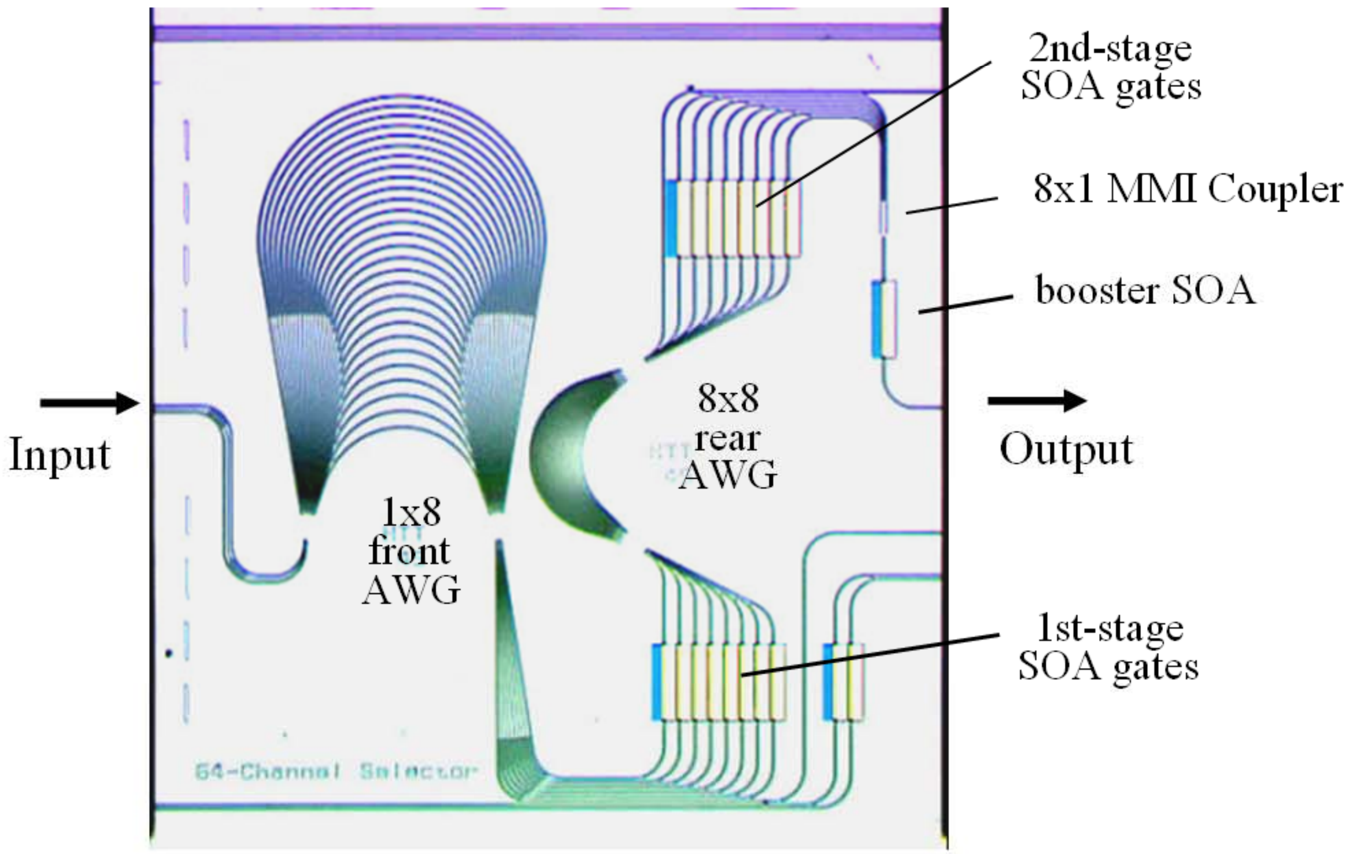




R. Mestric et al, OFC'2000, March 2000, Baltimore

1-out-of-64 WDM channel selector

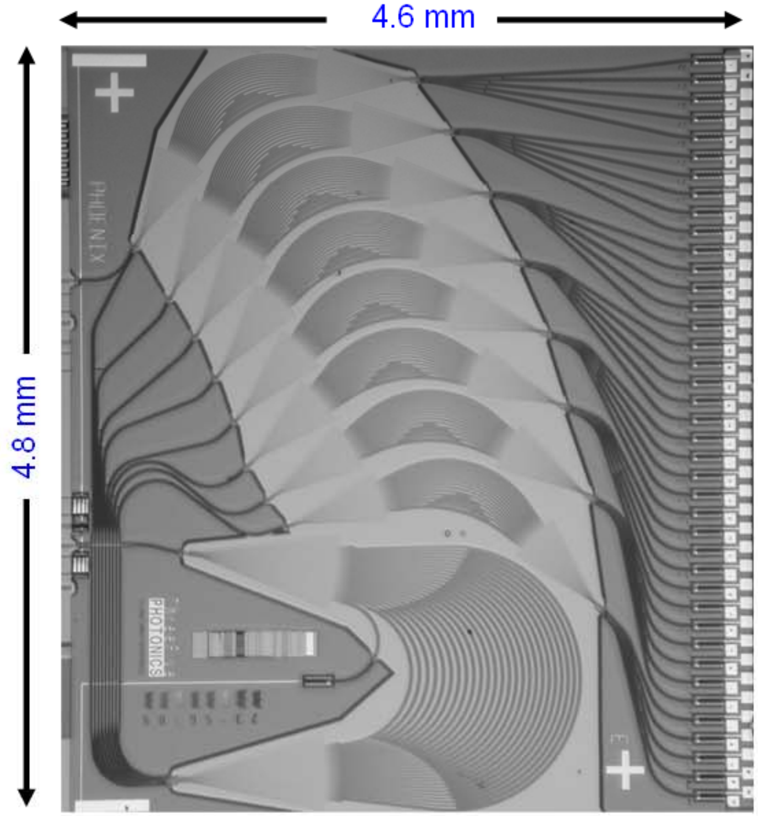
(N.Kikuchi, EL, 2002)

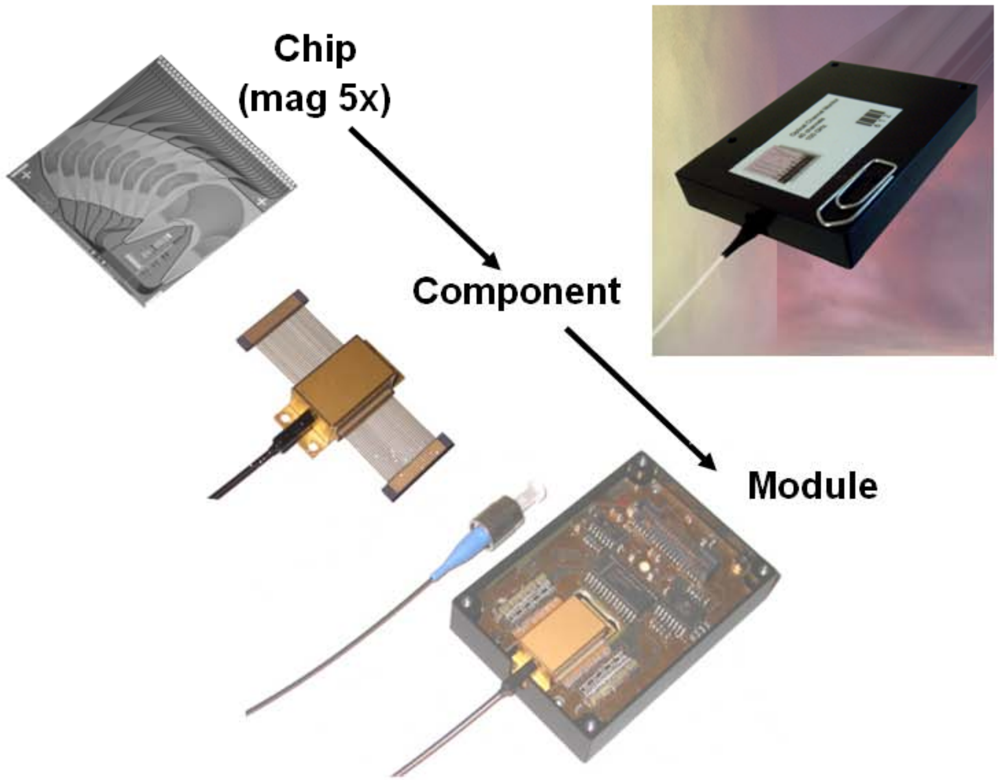


(chip size : 7.0 x 7.0 mm^2)

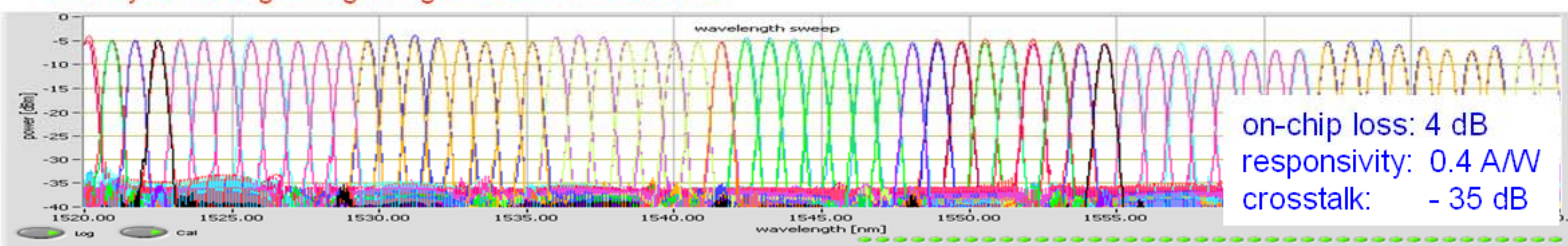
Today's technology for WDM integration:

World's smallest integrated AWGs: 40 channels integrated

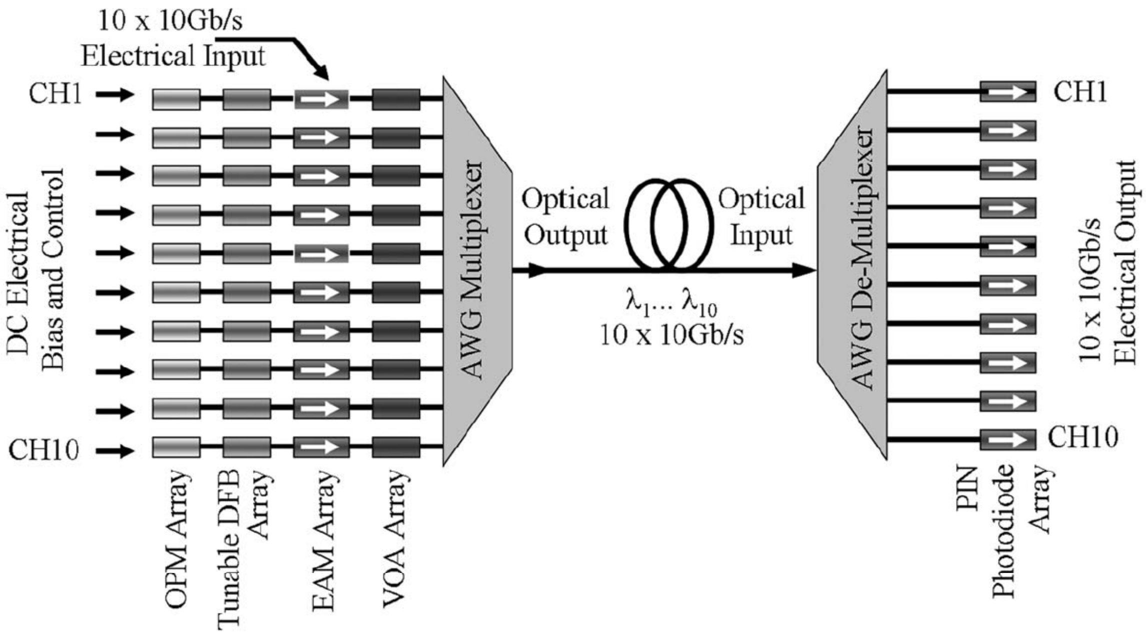


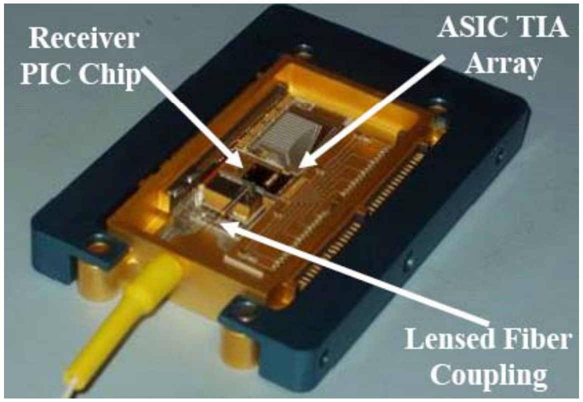


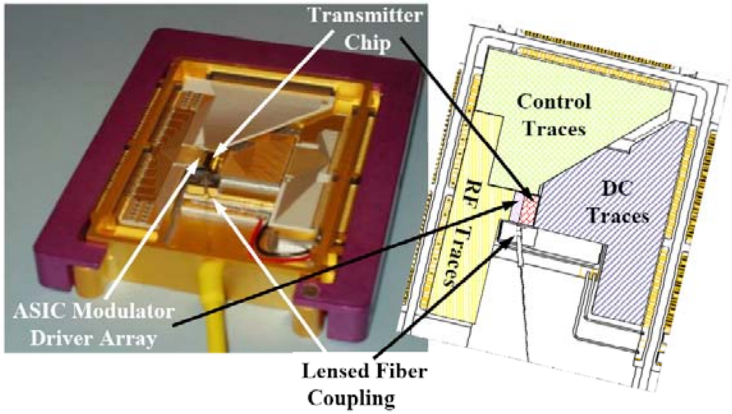
9 arrayed waveguide gratings+ 40 Photodetectors



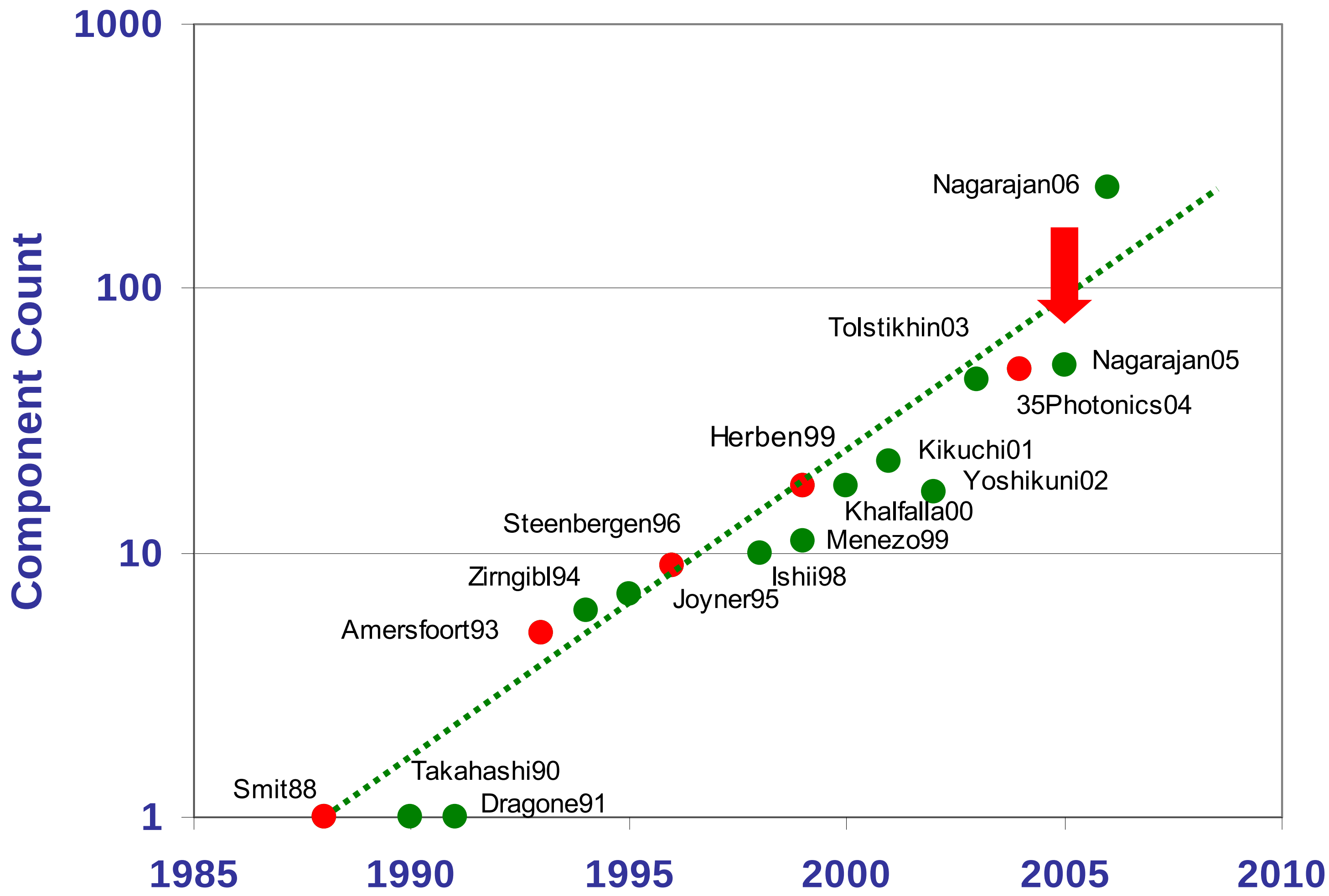
Towards LSI: Infinera WDM circuits







Moore’s law for WDM PICs



What went wrong?

- **Since 1990 worldwide more than 1 B$ invested in development of integration technologies**
- **Almost all research was application driven**
- **Therefore almost as many technologies as applications**
- **For most of them: market too small for payback of investments**

- **(By far too) many degrees of freedom**
  - **many different materials and technologies**
  - **many different component types**
  - **many different wavelength ranges and applications**

The (only?) way out

- **Develop a limited number of generic wafer-scale integration technologies, that can support a broad range of functionalities and applications**
- **Move to a generic foundry model (as in CMOS)**
  - **Convergence of technologies**
  - **Decouple design (IP) from technology (IP)**
  - **Set up libraries and tools for ASPIC design**
  - **Organize training and design support for fabless users**
- **Work on market development (new applications)**

ePIXnet

COBRA

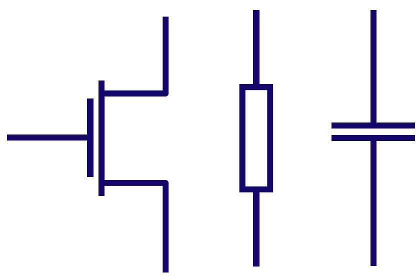
TU/e Technische Universiteit Eindhoven University of Technology

Outline

- The Past / Moore's law in Photonics
- The Future / 1 Generic Integration Technology
- The Future / 2 Nanophotonic Integration Technology

Generic Integration philosophy

Electronic integration
3 basic elements

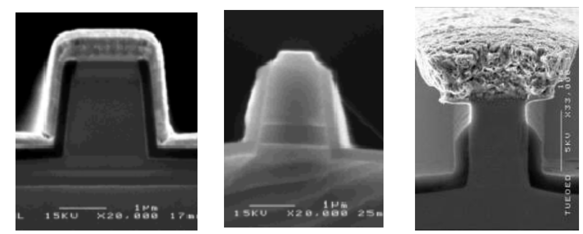


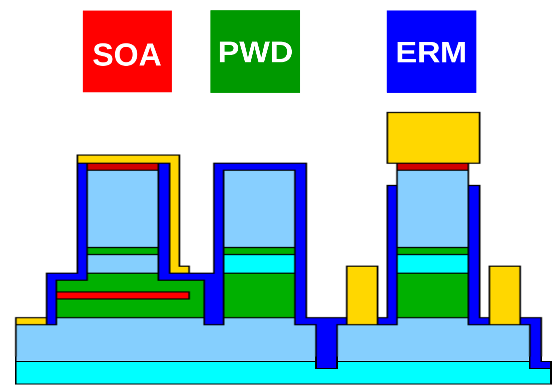
Photonic integration
3 basic elements

PWD — Waveguide

ERM — φ — Phase control

SOA — A — Amplitude control

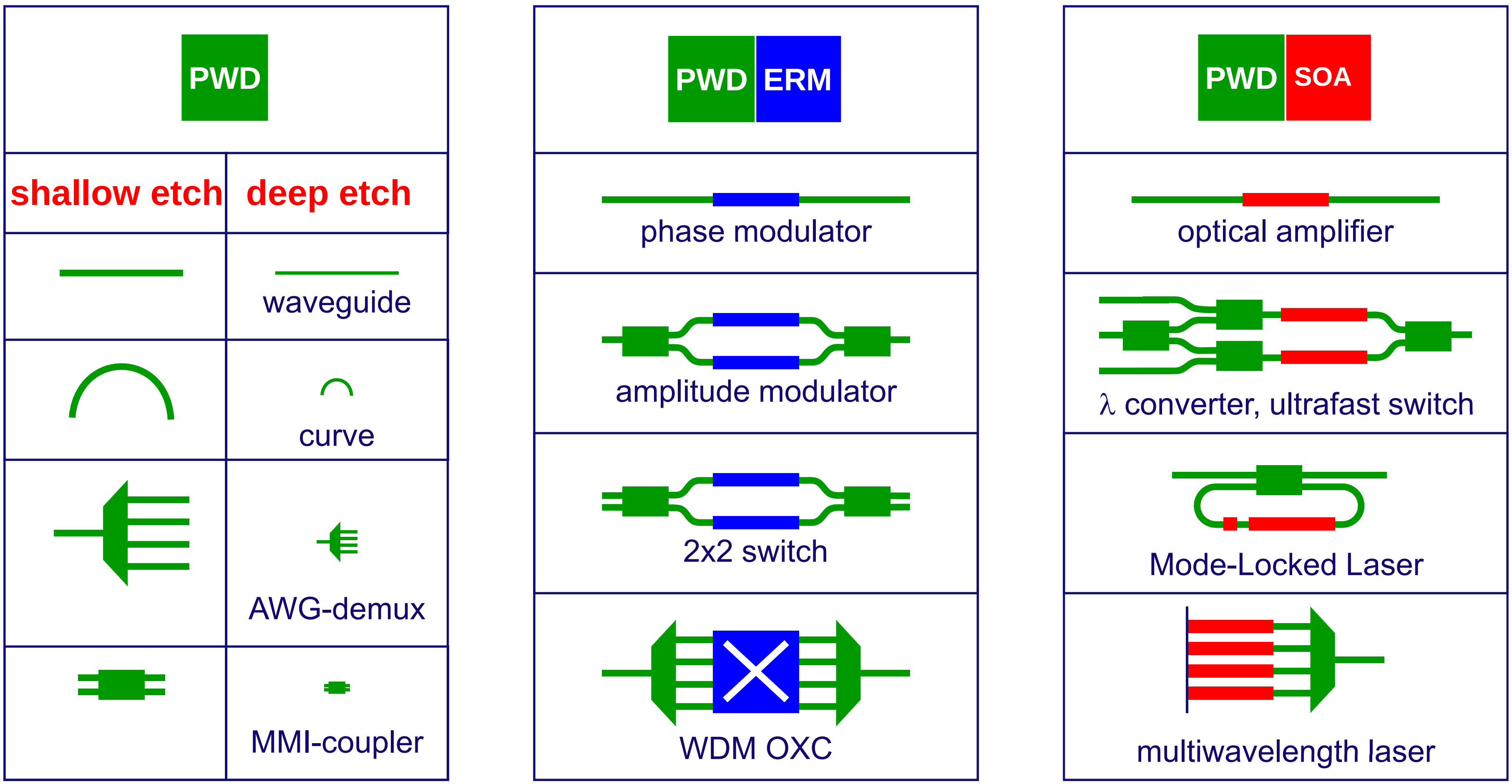




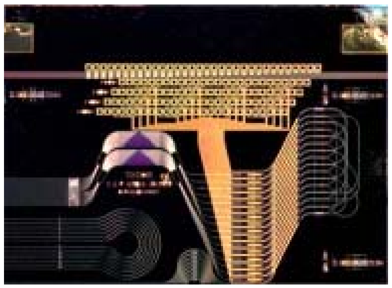
COBRA

Technische Universiteit Eindhoven University of Technology

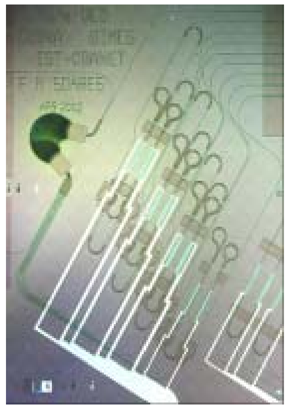
Photonic Integration
with 3 basic building blocks (BB)



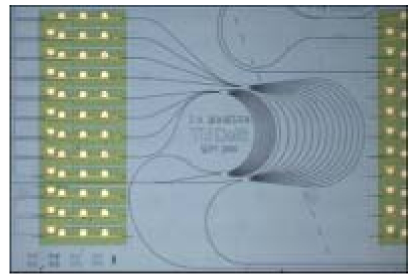
Examples



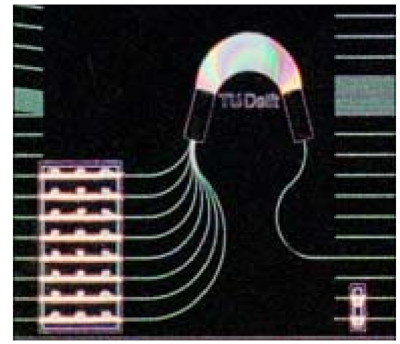
optical crossconnect



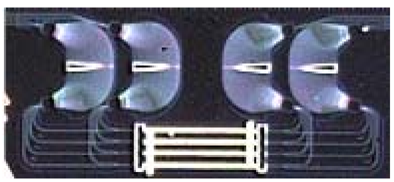
WDM-TTD switch



Cascaded WDM laser

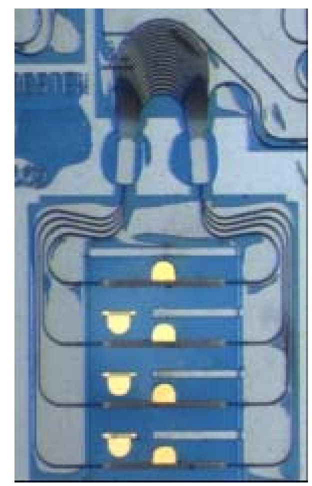


multiwavelength laser

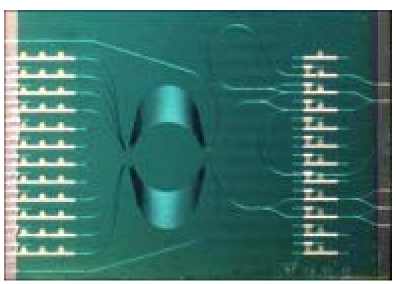


optical crossconnect

tunable multiwavelength laser



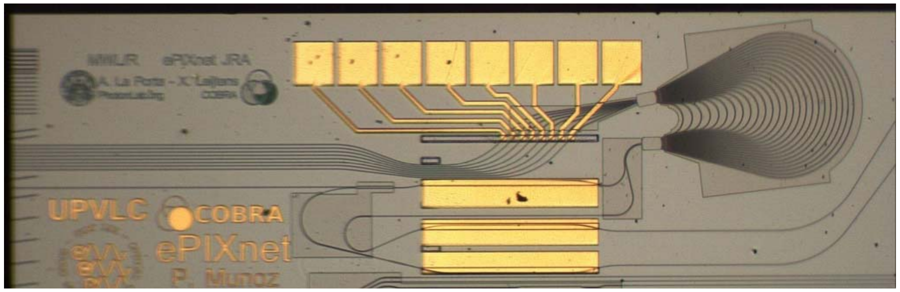
WDM ring laser



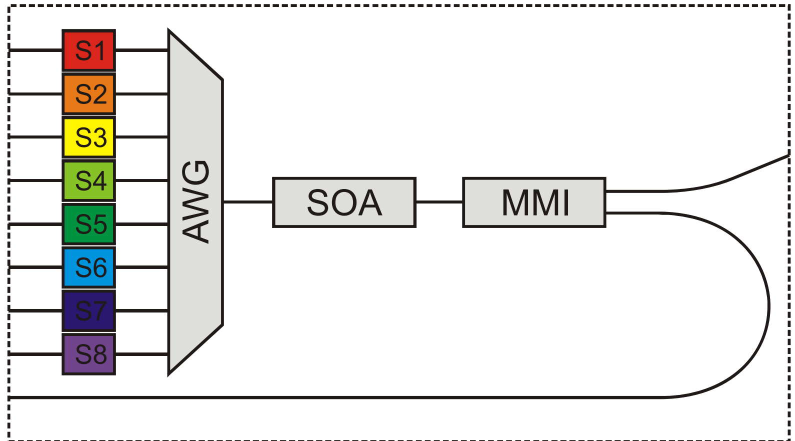
wavelength converter

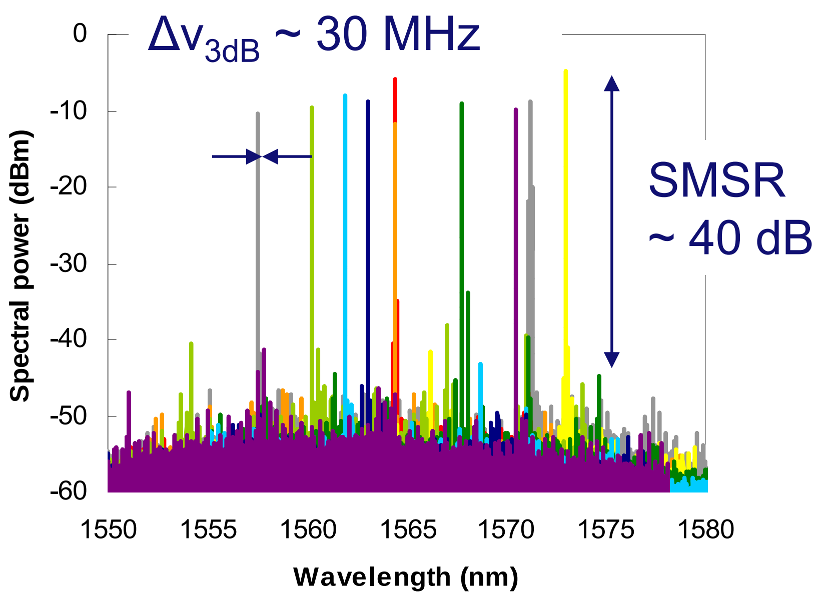
picosecond pulse laser

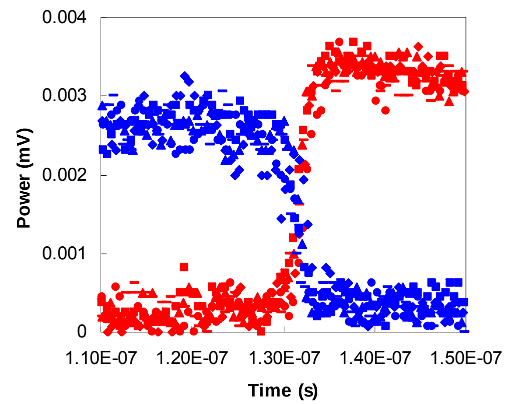
New: A fast tunable AWG-laser



AWG channel spacing 100 GHz







Switch-on time: 3 ns

Switch-off time: 4 ns

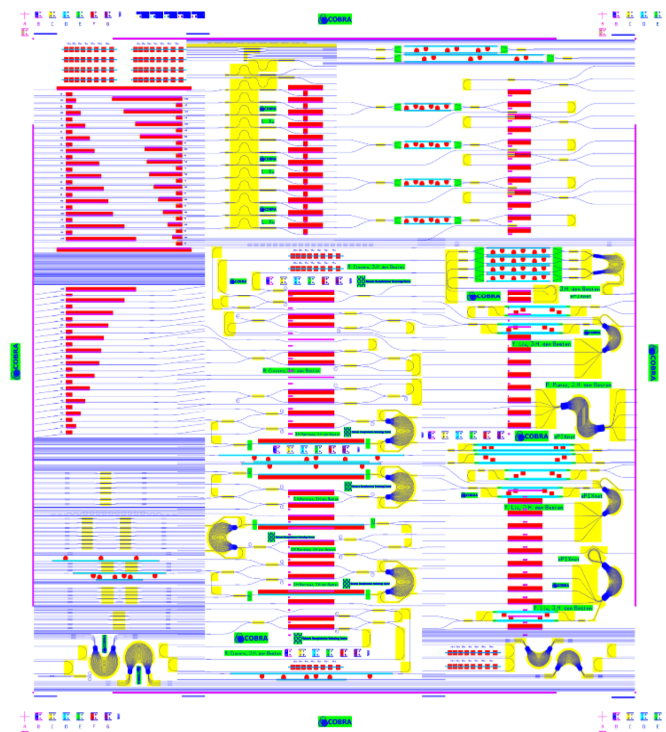
A Generic Integration Platform

JePPIX:

Joint European Platform for InP-based Photonic Integration of Components and Circuits

JePPIX

Industrial partners:	Bookham, CIP, Cedova, Alcatel-Thales III-V Lab, u2t, FhG-HHI, Svedice ASML, Aixtron, OPT
Photonic CAD:	Phoenix, Photon Design, Filarete
Universities:	COBRA –TU/e, Cambridge, KTH, COM, CNRS
Coordination:	COBRA



Step 1: Small-scale access to the COBRA process for research purposes (proof-of-concept)

Step 2: Feasibility of an industrial foundry (EuroPIC)

COBRA

TU/e Technische Universiteit Eindhoven University of Technology

Entry costs for different production models (1)

Vertical integrated fab

Cleanroom cost >100 M€

> 1 Mchips for chip cost < 100 €/chip

Custom foundry

cleanroom costs shared by all customers

custom process development cost > 3 M€

> 30,000 chips for chip cost < 100 €/chip

Entry costs for different production models (2)

Generic foundry

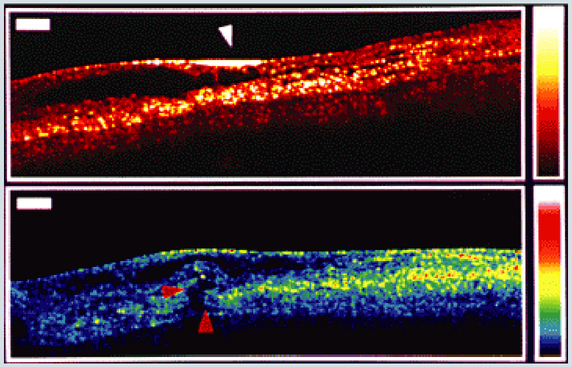
- **Cleanroom costs shared by all customers**
- **Process development costs shared**
- **Process qualification costs shared**

- **Cost of shared infrastructure for large volumes: a few €/mm^2**

- **Entry cost reduction**
  - R&D time shortened by dedicated ***software design kit with accurate models for the building blocks***
  - R&D cost reduced by ***Multi-Project wafer Runs*** (MPR)
  - chip testing costs reduced by ***building-block approach***
  - R&D cost < 300 k€, 1 trial < 100 k€ (interesting for SME’s)
  - ***> 3000 chips for chip cost < 100 €/chip***
  - ***> 300 chips for chip cost < 1000 €/chip***

- **Develop generic packaging and testing approaches**

non-telecom applications

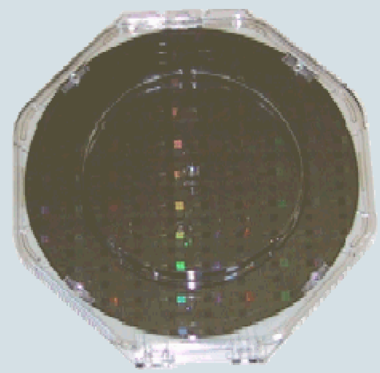


Optical Coherence Tomography

Skin analysis equipment

Fibre strain sensor for
construction integrity monitoring

Compact
Frequency comb-generators
for metrology



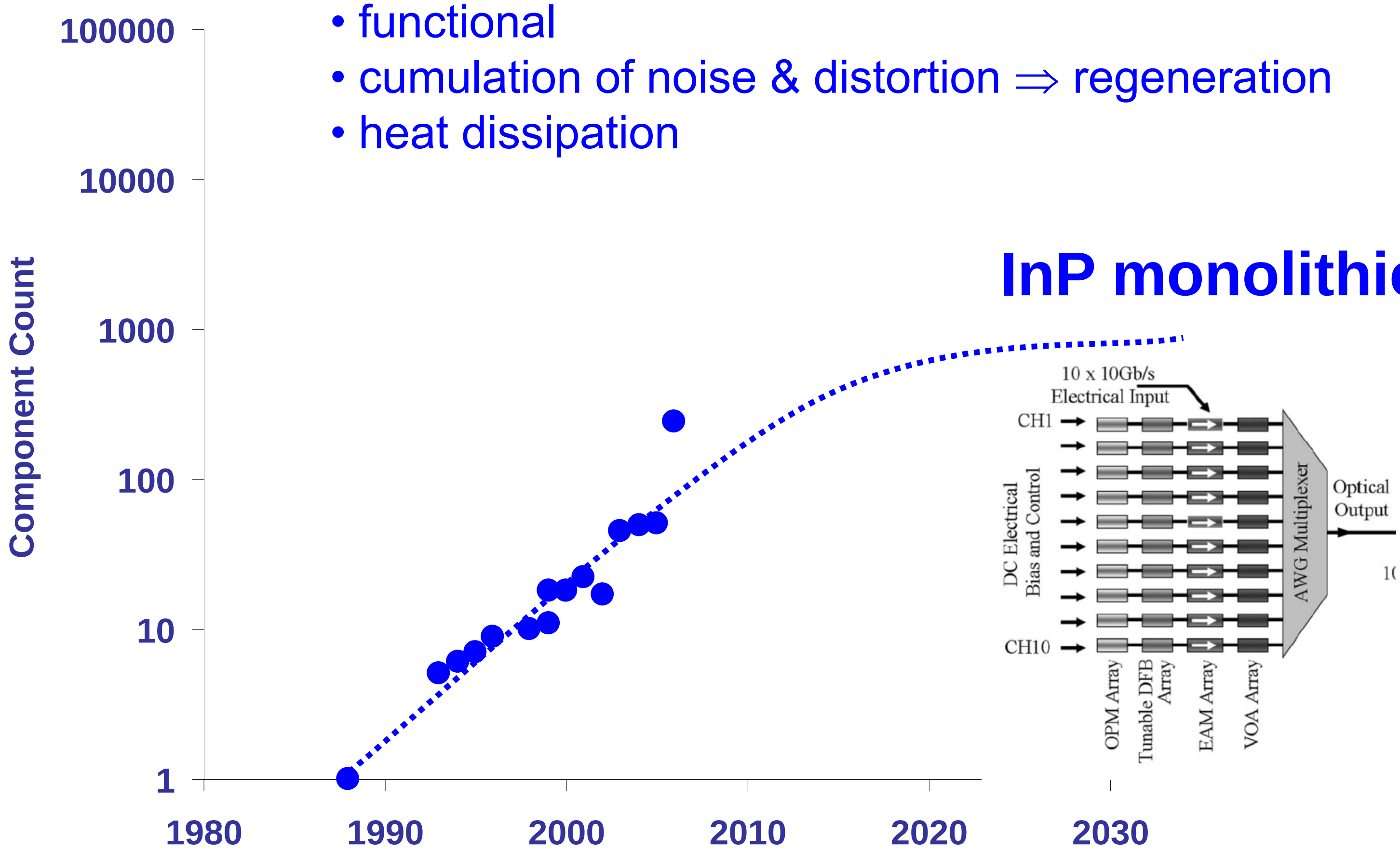
Outline

- Introduction
- Past / Moore's law in Photonics
- Future / 1 Generic Integration Technology
- Future / 2 Nanophotonic Integration Technology

Saturation?

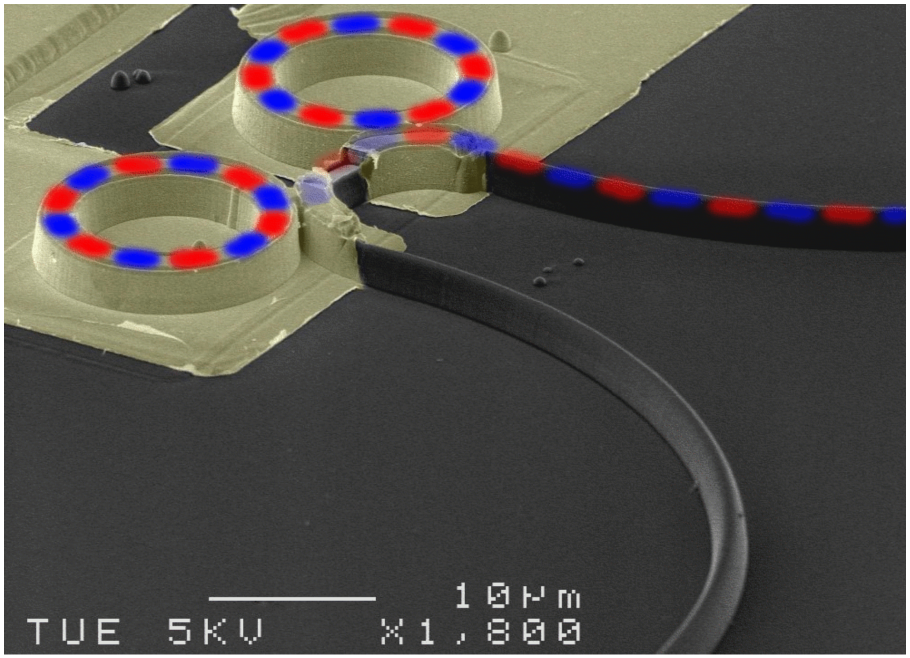
Limitations for scaling

- functional
- cumulation of noise & distortion ⇒ regeneration
- heat dissipation



From analog to digital

Martin Hill et al.,
Nature, Vol. 432, 11 Nov. 2004, pp.206-209



Digital photonic flip-flop based on coupled micro-lasers

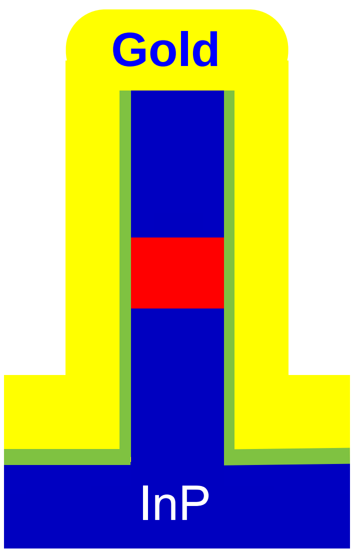
Dimensions	< 20 x 40 μm^2
Switching time	< 15 ps
Switching energy	< 6 fJ

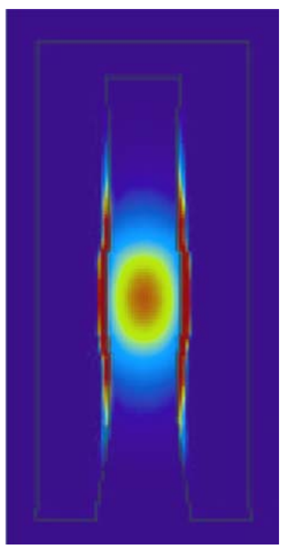
Track 2: Metallic and Plasmonic lasers

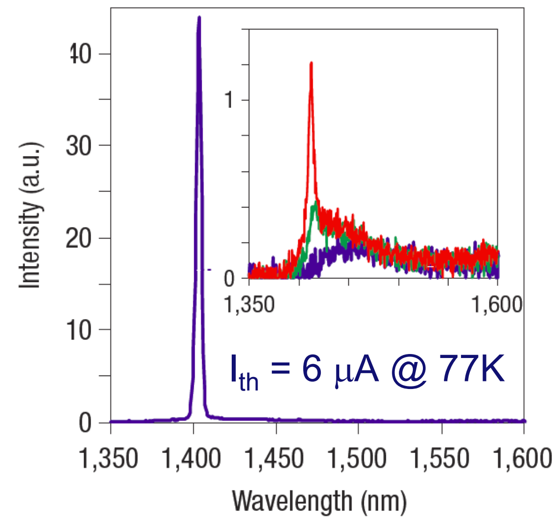
A BREAKTHROUGH
The world's smallest electrically injected laser (diameter 250 nm)

small active volume means low power and high speed

Martin Hill et al., Nature Photonics, October 2007

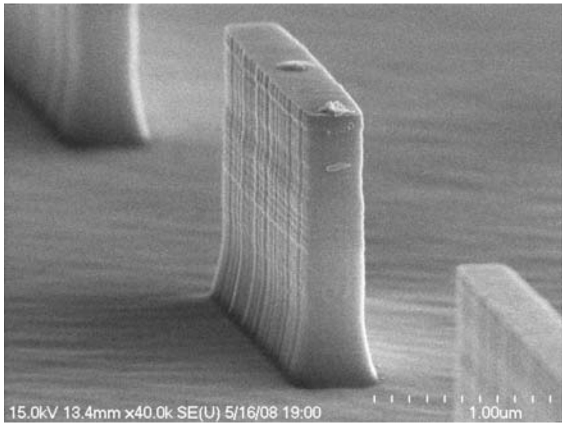


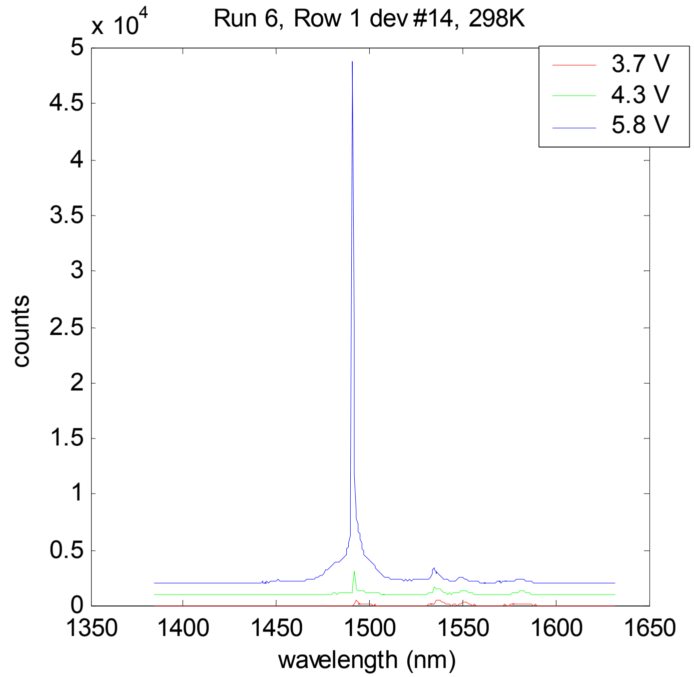




Latest Results for MIM structures

- **Most devices from 80-300 nm worked pulsed at 250K**
- **For ~300 nm semiconductor core size**
  room temperature (298K) operation (pulsed)
- **Life time issues at higher temperatures**
- **Higher threshold current**
- **But, just beginning, not optimized**
- **Much room for improvement**

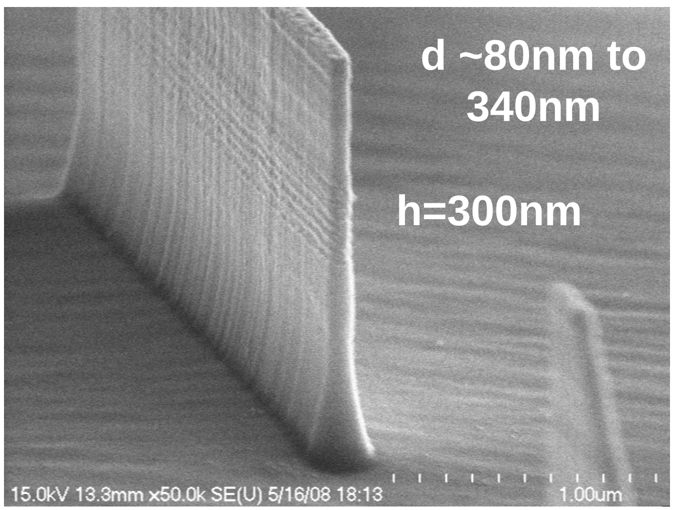


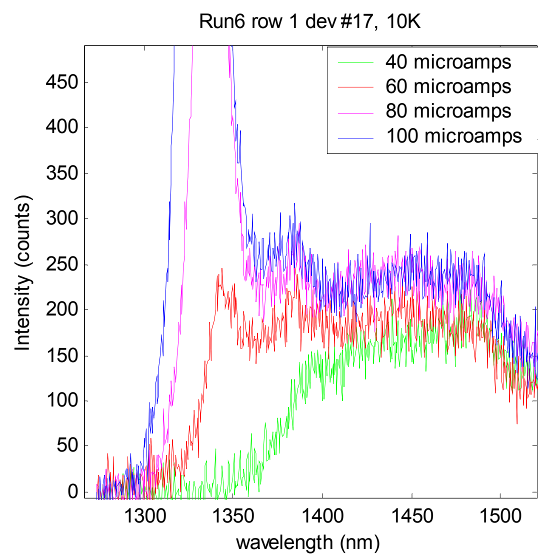


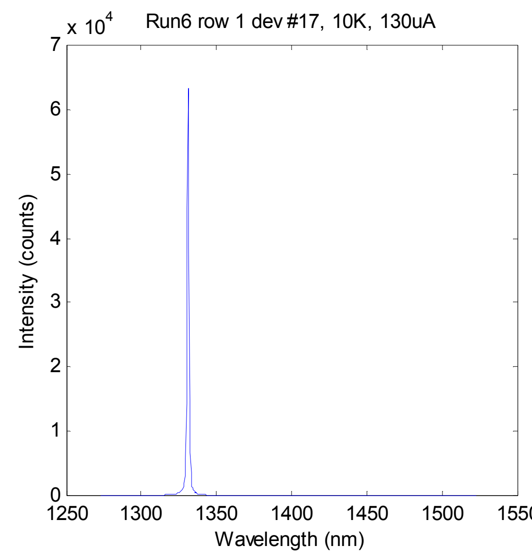
Confidential

Record small MIM Devices

- **rectangular pillars 3 and 6 micron long**
- **core width 80nm**

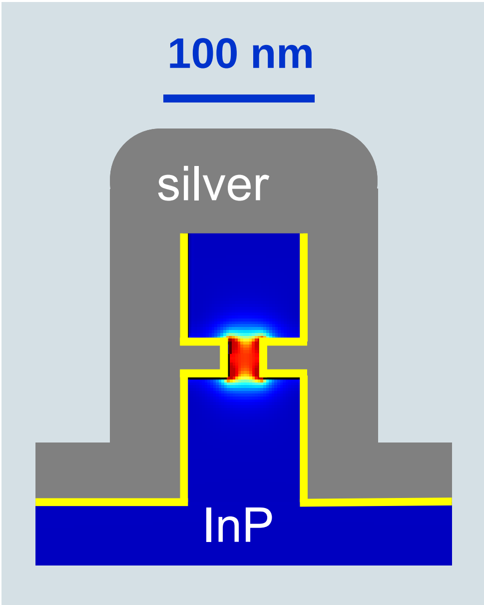


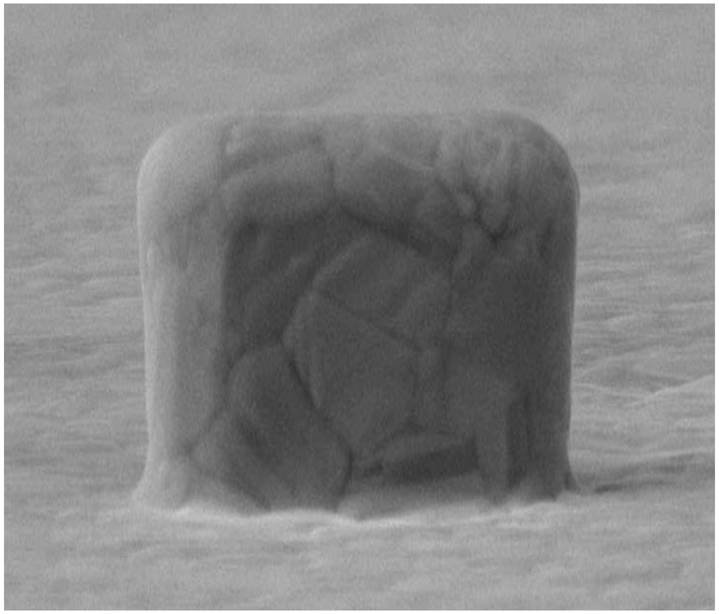




Confidential

Potential

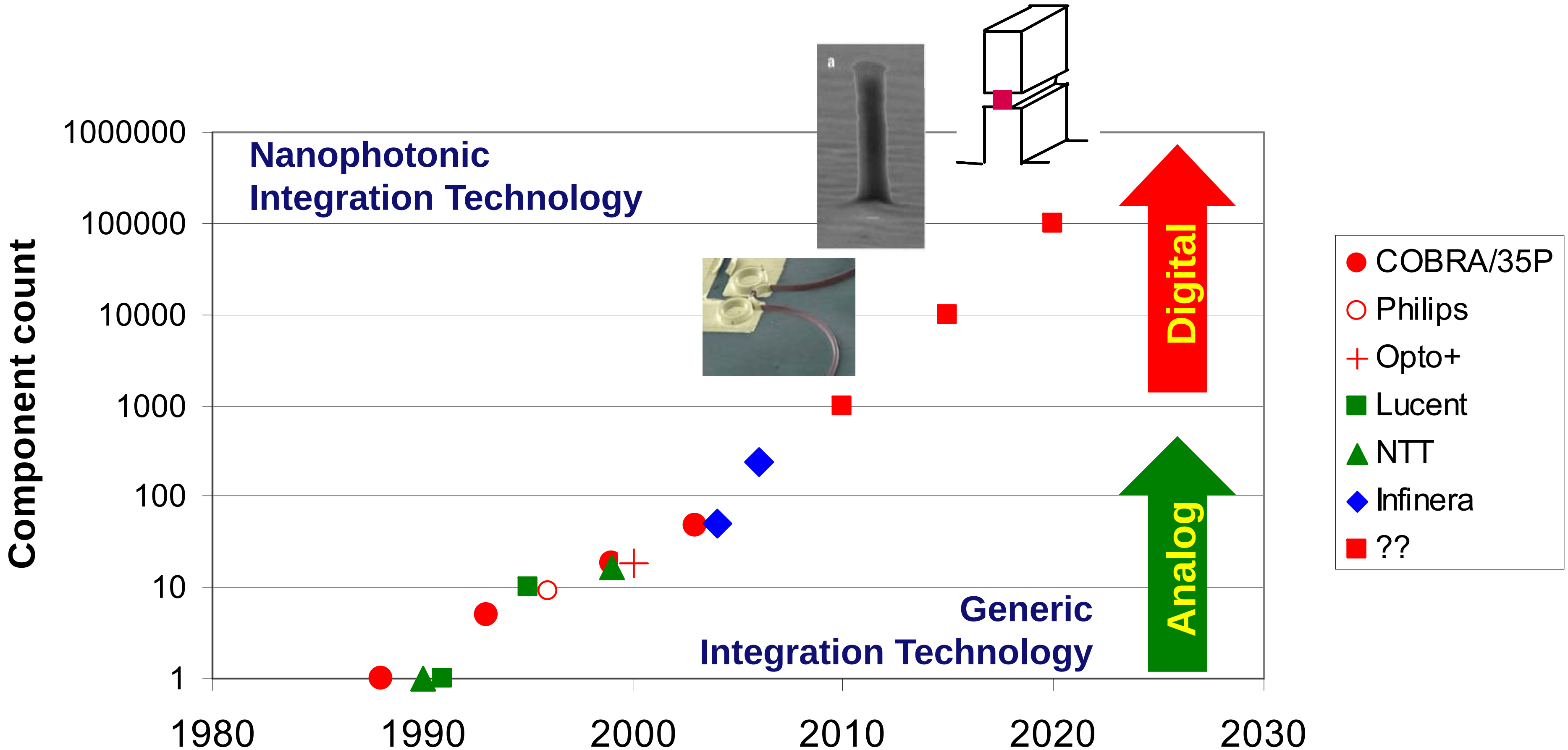




- Integration of more than 100,000 lasers on a chip
- Operating at speeds well beyond 1 THz

Superior to high-speed transistors for ultrafast signal processing

Complexity of InP Photonic ICs?



COBRA

Technische Universiteit Eindhoven University of Technology