Silicon photonics for broadband communication

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Cost of broadband optical components

- If manufacturing fabs for broadband optical components have no other market than telecom: chicken-and-egg problem
  - market volume is low → overcapacity → prices are high → market volume stays low
- If manufacturing fabs can manufacture for many markets:
  - telecom market volume is low, but there are other markets to fill the capacity → prices are compatible with market growth → market volume grows

Reasons for high optical component cost

- **high cost of packaging and assembly**
  - **sub-micron accuracy of alignment between objects**
  - **not fully automated**
  - **fiber-chip coupling through the edge of the chip**

- **photonic chips are made in**
  - **a variety of “exotic” materials**
  - **in low-volume but highly complex fabs**
  - **with low yield**

- **testing of chips prior to assembly is difficult**

Ways to tackle the problem

- lower cost of packaging and assembly
  - Integrate more and package less
  - Increase alignment tolerance by integrated spot-size converters
  - Do not couple through the edge of the chip
- photonic chips are to be made in
  - Silicon as much as possible
  - With built-up (back-end processed or hybridly integrated) “exotic” materials where needed
  - in high volume CMOS fabs
  - with high yield
- testing of chips prior to assembly is to become easy and automated
  - Wafer level testing (light has to come out from the surface)

Outline

Silicon Photonics: why and how?

Passive/active photonic functions in Silicon

Silicon photonics: what for?

Silicon photonics: the food chain

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Silicon Photonics: why and how?

Why?

- Functionality + performance
- Technology
- Cost

How?

- Wafer-level fabrication
- Packaging

Silicon photonics: functionality

Spectacular breakthroughs in last 2-3 years

- low loss waveguides (IMEC, NTT, IBM…)
- compact wavelength routers (IMEC…)
- ultra-compact PhC microcavities (U. Kyoto…)
- >>10 Gb/s receivers (LETI, UPS, …)
- 10 Gb/s modulators (INTEL, Luxtera, Cornell…)
- Raman Silicon laser (INTEL…)
- (velocity tunable) slow light (IBM…)
- all-optical switching + λ-conversion (NICT+IMEC…)
- integration with CMOS (Luxtera…)

No record performance but useful performance

Objectives

- Si nanophotonics with CMOS processes
- Application-specific EPIC
- New photonic devices in Si
  (lasers, wavelength converters, amplifiers, ...)

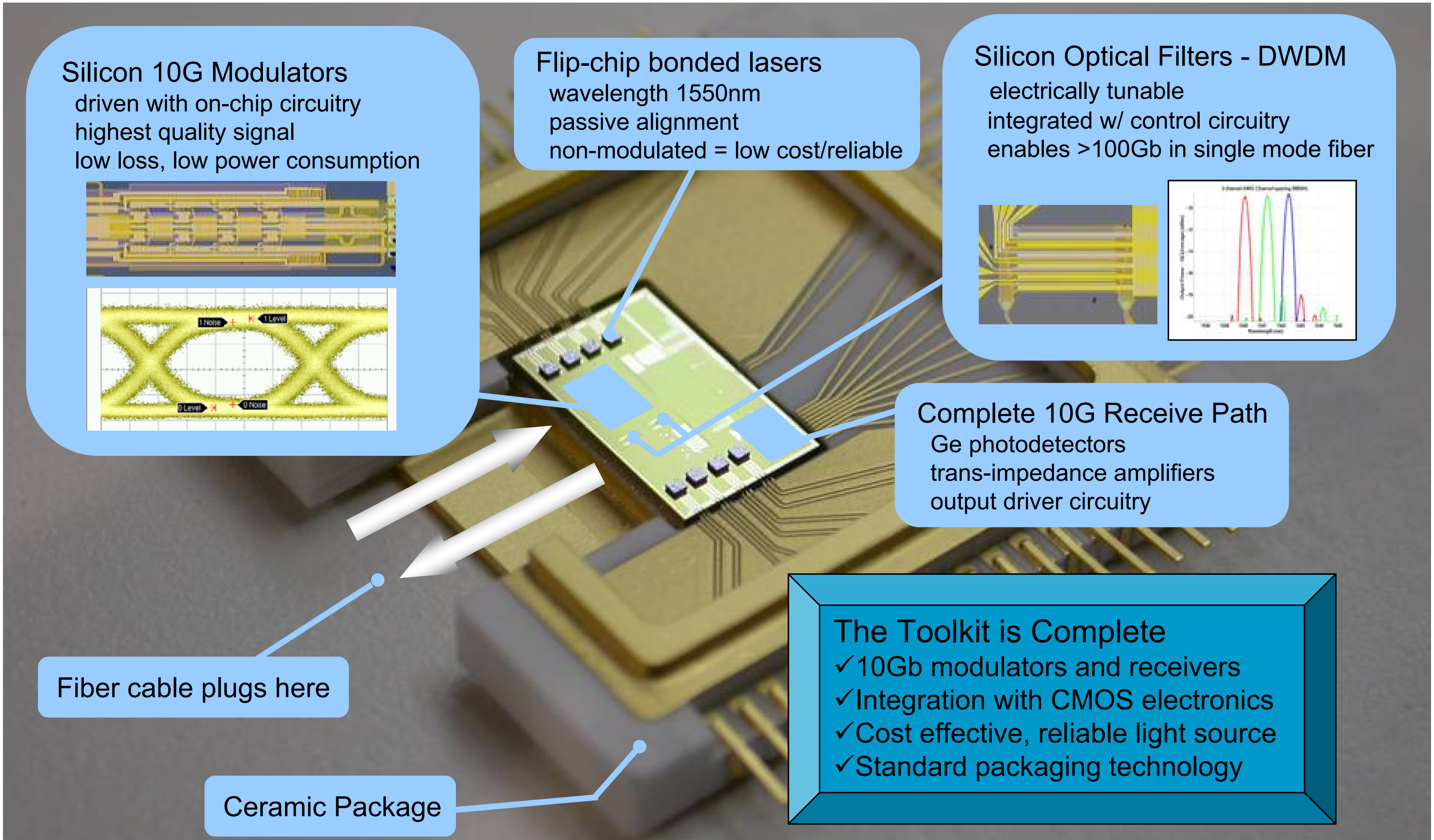
Partners

- MIT
- Luxtera
- Sun
- Freescale

Budget: 12M$

www.darpa.mil/mto/epic

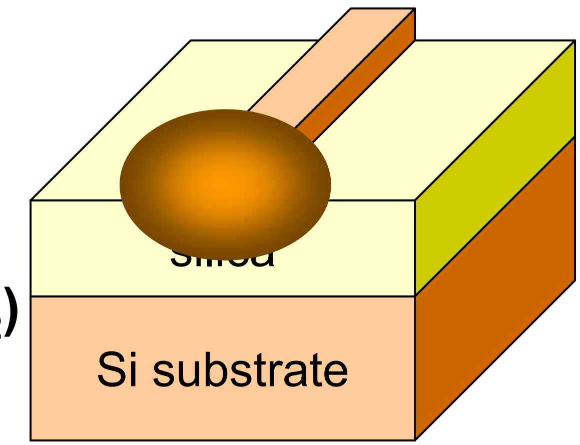
Luxtera CMOS Photonics Technology



Nanophotonic waveguides

Silicon on Insulator

- Transparent at telecom wavelengths (1.55μm and 1.3μm)
- High refractive index contrast
  - in-plane: 3.45(Si) to 1.0 (air)
  - out-of-plane: 3.45 (Si) to 1.45 (SiO_2)
- Typical dimensions:
  - Thickness: 200 nm
  - Width: 500 nm
  - Required accuracy: 1-10 nm
- Compatible with CMOS processes



Nano ?

- Feature size: a few 100nm
- Required accuracy of features:
- For wavelength-dependent stru

nm-scale wavelength accuracy : O(1nm) dimensional accuracy !

Fabrication ?

- Classical optical lithography → too low resolution
- E-beam lithography, focused ion beam → too slow

➔ Deep UV lithography (used for CMOS)

  - 248nm, 193nm
  - Fabrication in IMEC CMOS-pilot line
  - 200mm wafers

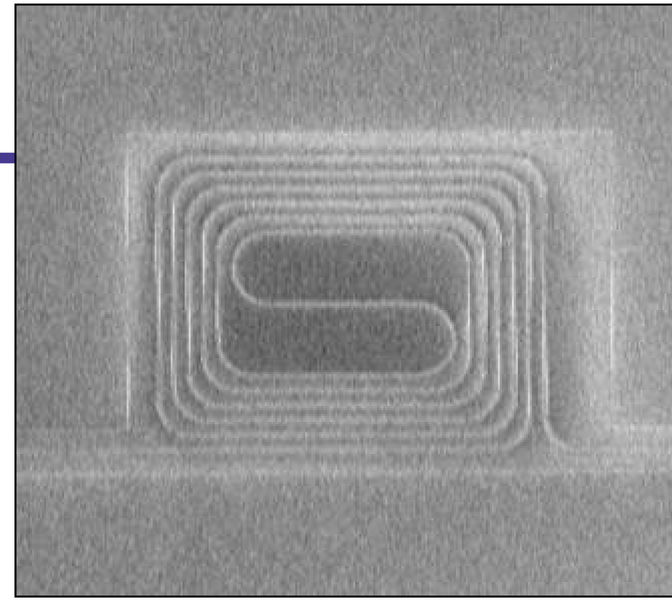
SOI-nanophotonic wires

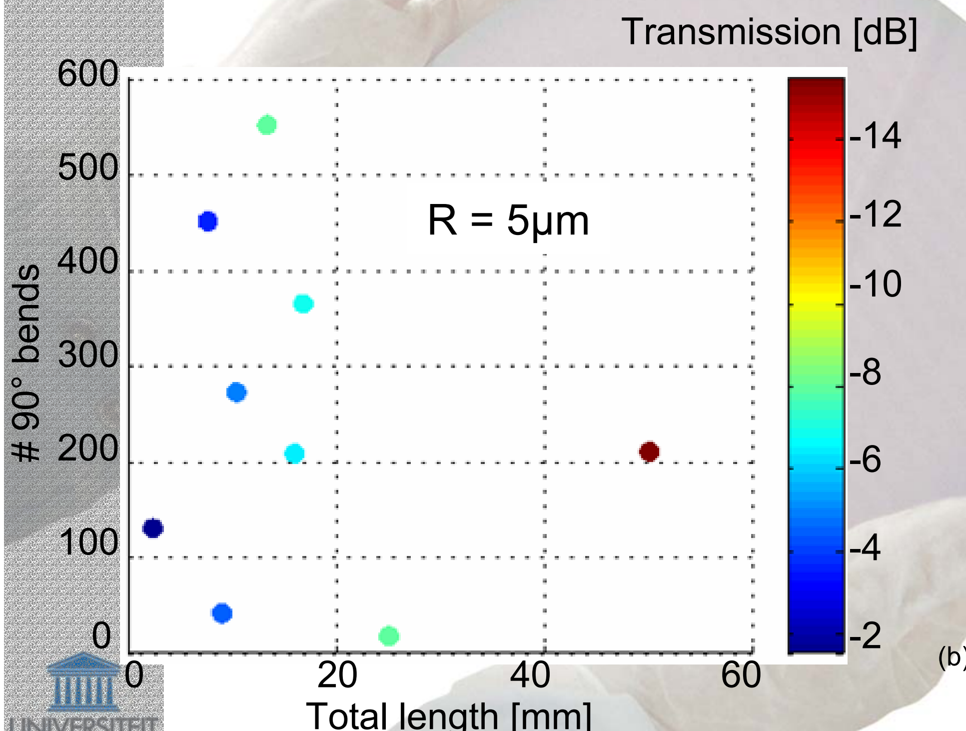
Group	Date	h [nm]	w [nm]	loss [dB/cm]	BOX [um]	top clad	Fab.
IMEC	Apr. '04	220	500	2.4	1	no	DUV
IBM	Apr. '04	220	445	3.6	2	no	EBeam
Cornell	Aug. '03	270	470	5.0	3	no	EBeam
NTT	Feb. '05	300 200	300 400	7.8 2.8	3	yes	EBeam
Yokohama	Dec. '02	320	400	105.0	1	no	EBeam
MIT	Dec. '01	200	500	32.0	1	yes	G-line
LETI / LPM	Apr. '05	300 200	300 500	15.0 5.0	1	yes	DUV
LETI	’06			5.0			DUV, a-Si
Columbia	Oct. 03	260	600	110.0	1	yes	EBeam
NEC	Oct. ‘04	300	300	19.0	1	yes	EBeam

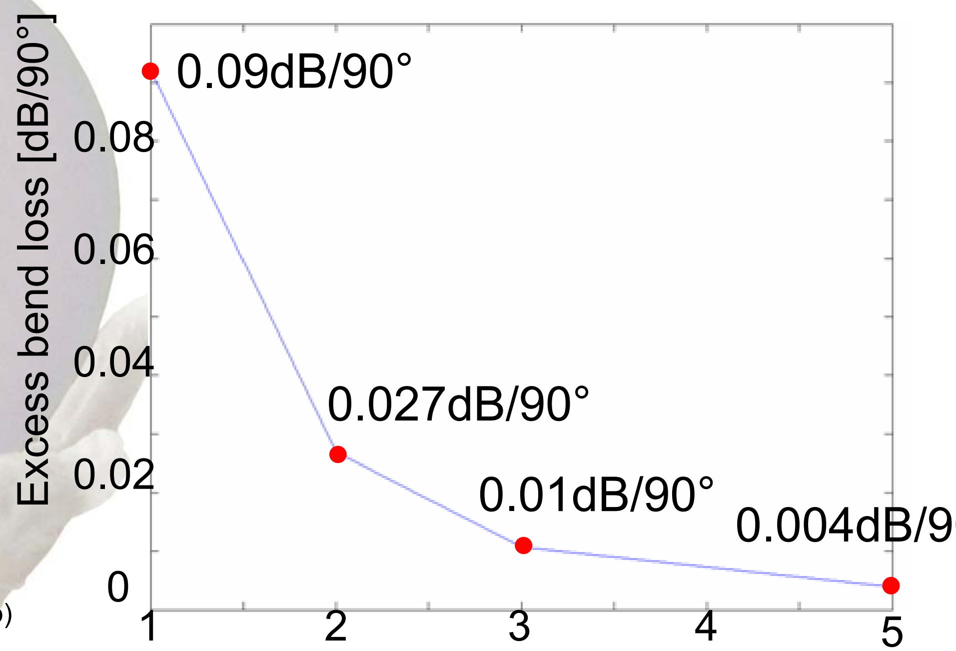
Waveguide bends

Spirals

- **Long waveguides (up to 50mm)**
- **Many bends (up to 560)**







Bends

Group	h [nm]	w [nm]	Radius [um]	Loss [dB/90]	Note
IBM	220	445	1.0 2.0 5.0	0.086 0.013 0	20 bends
IMEC	220	500	1.0 2.0 5.0	0.09 0.027 0.004	> 500 bends
NTT	300	300	2.0 3.0	0.46 0.17	24 bends
Yokohama	320	400	1.0	3	
MIT	200	500	1.0 resonant	0.5 0.3	12 bends poly-Si
LETI/LPM	220	500	2.0 5.0	0.15 0.05	40 40
Columbia	340	400	resonant	1.3	2 bends

(Table partly from Vlasov, McNab, Opt. Expr. '04, pp1630)

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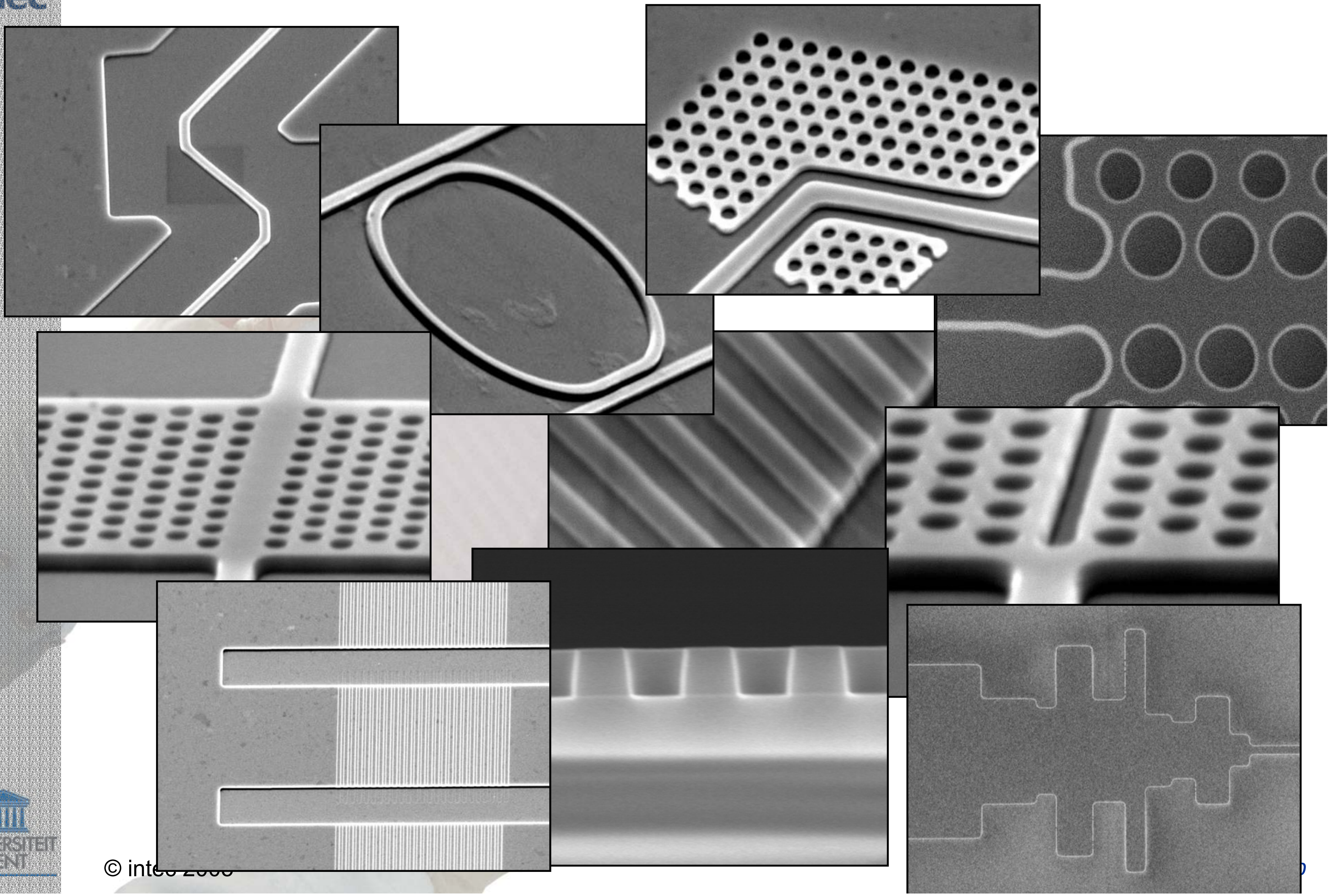
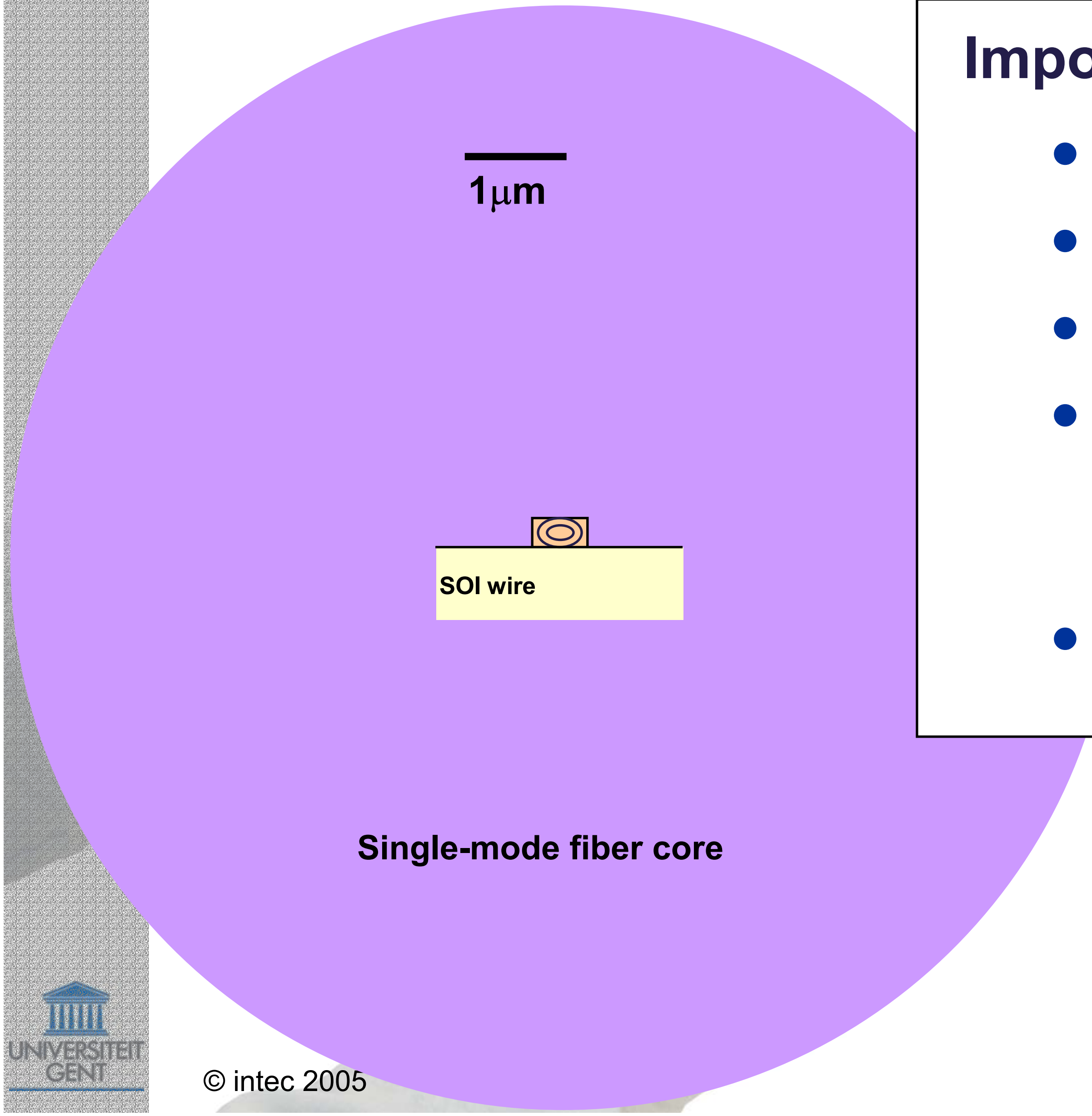
Fabricated Structures



Low cost

- **Wafer-scale fabrication on large wafers with high yield**
- **Wafer-scale testing**
- **Low cost packaging**

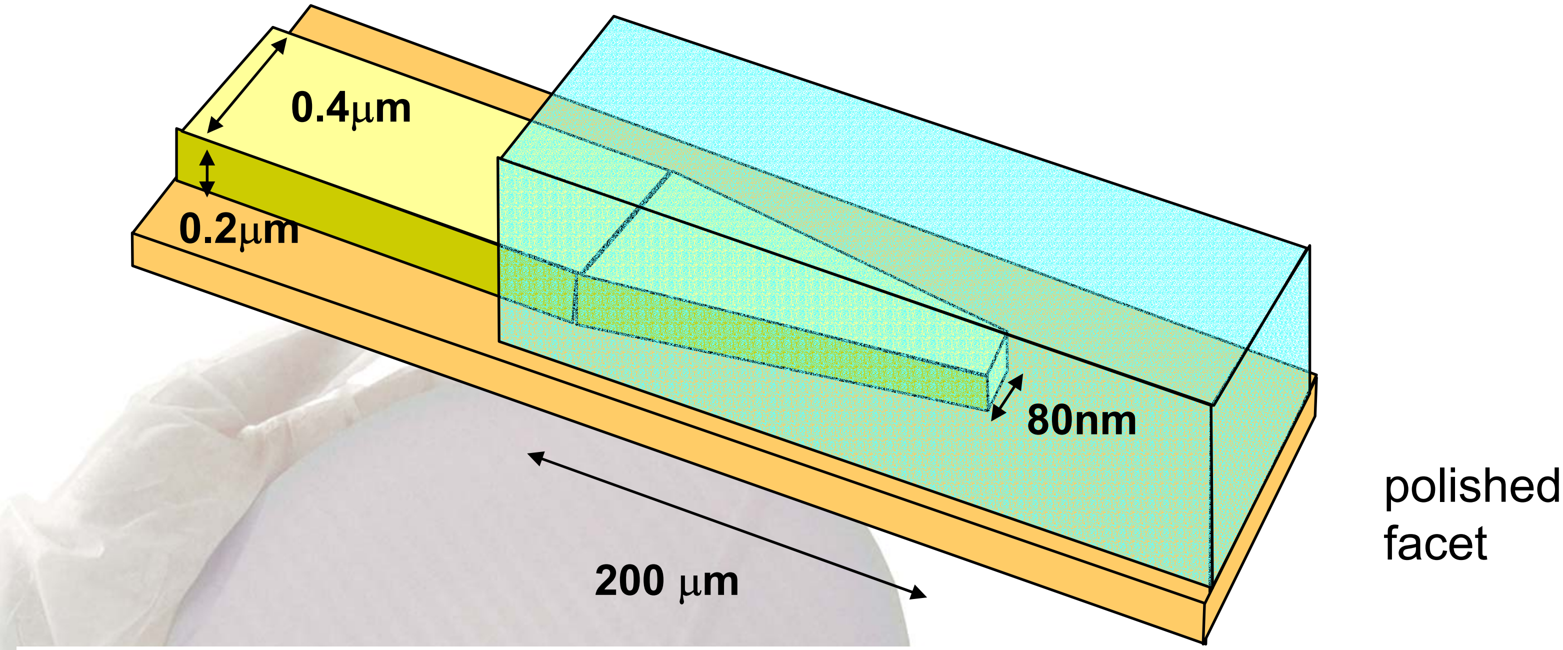
Coupling into SOI nanophotonics



Important:

- Low loss
- Large bandwidth
- Coupling tolerance
- Fabrication
  - Limited extra processing
  - Tolerant to fabrication
- Polarization

Coupling to fiber – Inverse taper



Group	h [nm]	w [nm]	L [um]	tip width [nm]	Cladding Material	Cladding Size	Loss
IBM (e-beam)	220	445	150.0	75.0	Polymer	2x2	< 1dB
Cornell (e-b)	270	470	40.0	100.0	SiO2	?x?	< 4dB
IMEC(DUV)	200	500	175.0	175.0	Polymer	3x1.3	< 2dB
NTT (ebeam)	300	300	200.0	60.0	Polymer/Si3N4	3x3	0.8

Coupling to fiber – Grating coupler

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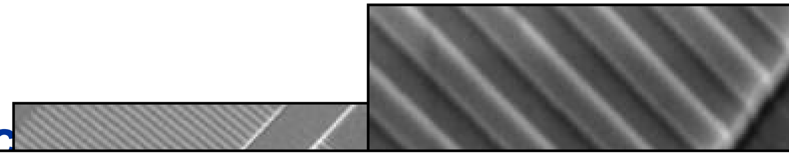
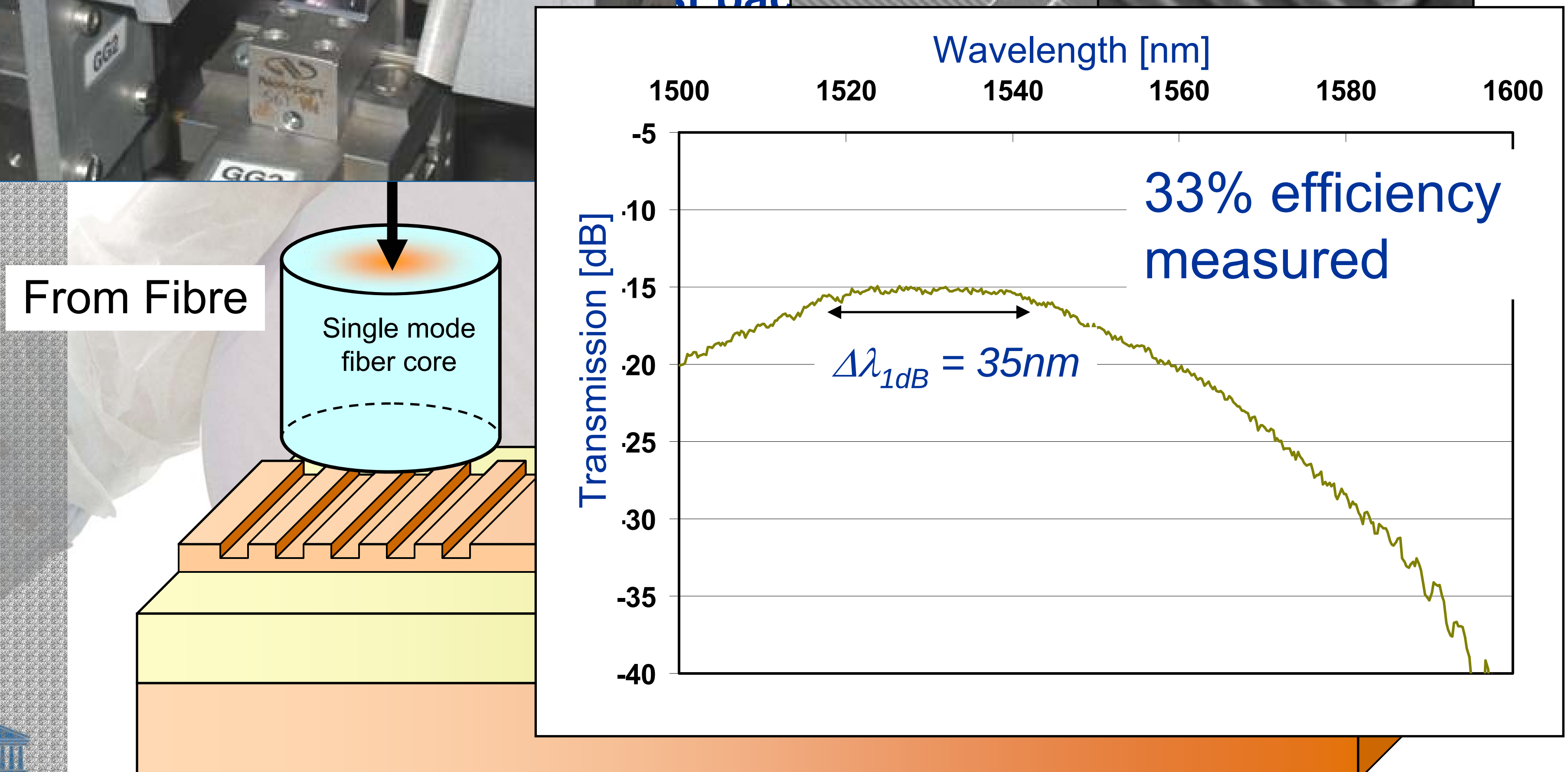
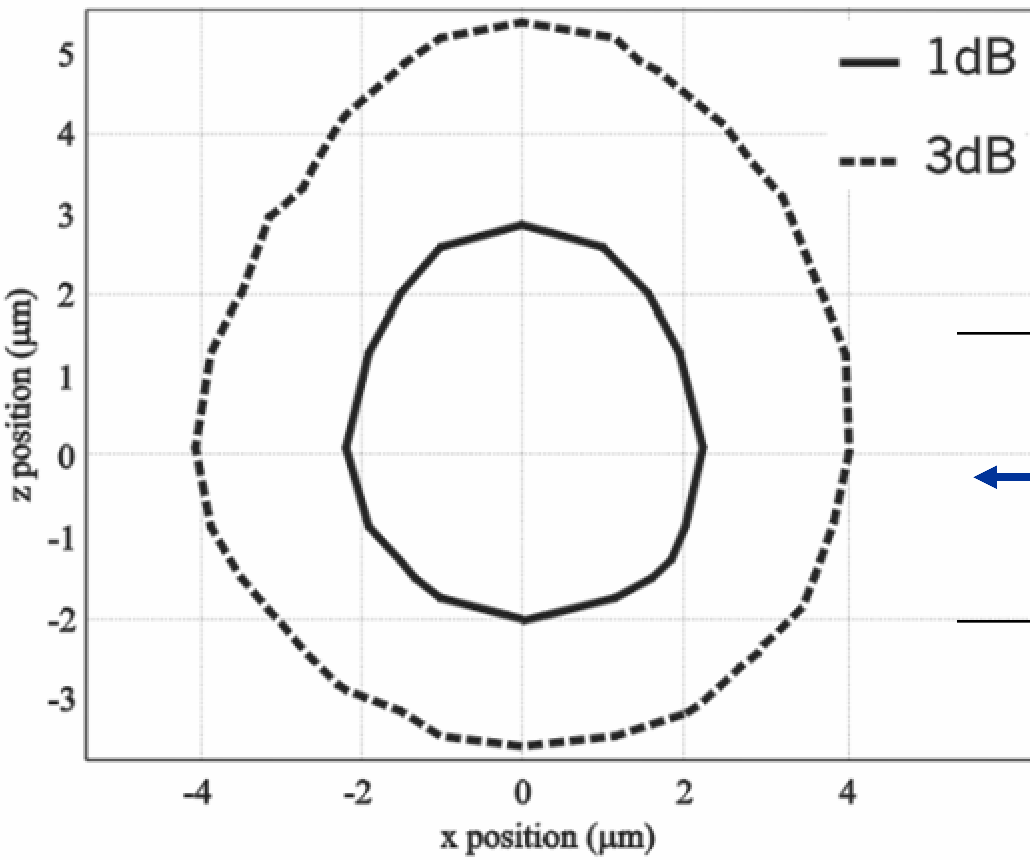
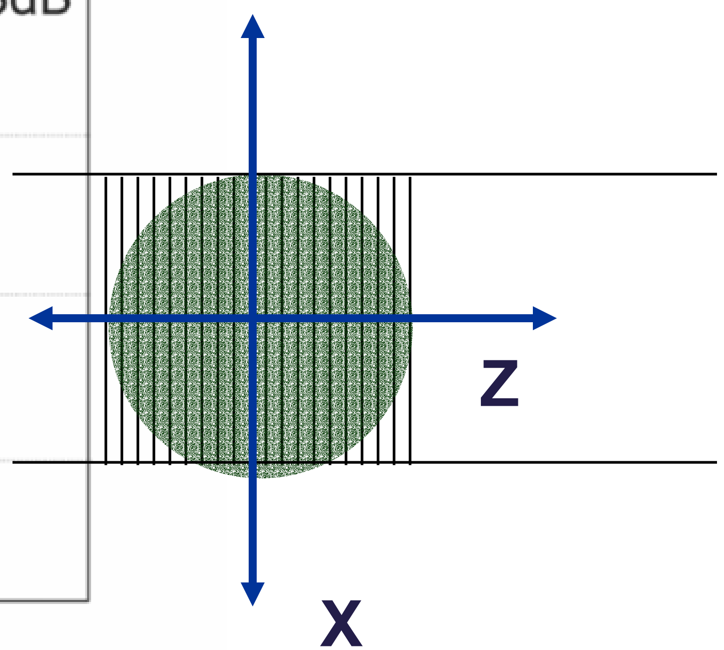




Alignment tolerances

- good alignment tolerances
- measurement of P/P_{max} versus fiber position



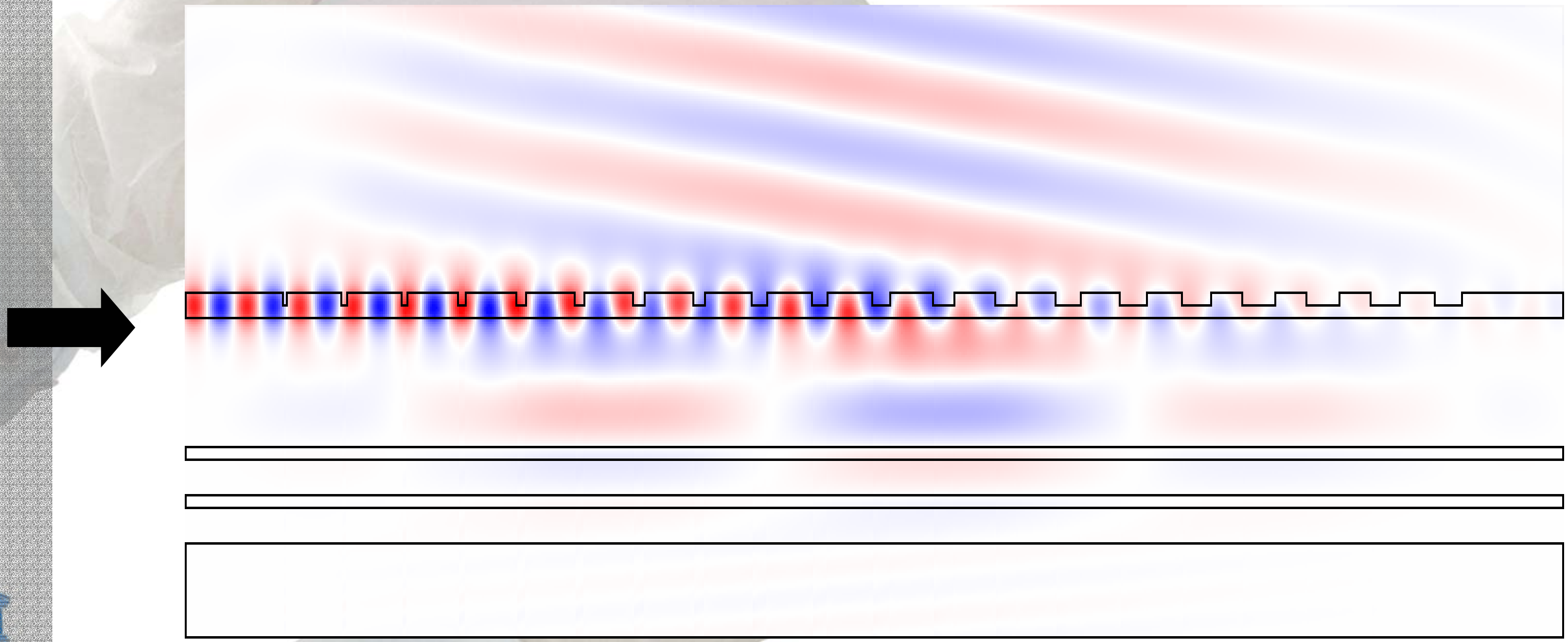


Taillaert et al, JQE 38(7), p. 949 (2002)

Coupling to fiber – Grating coupler

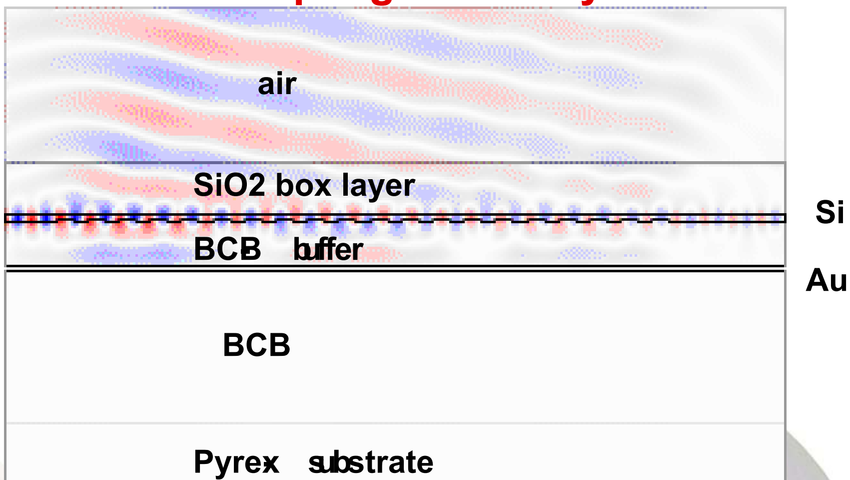
Improved design

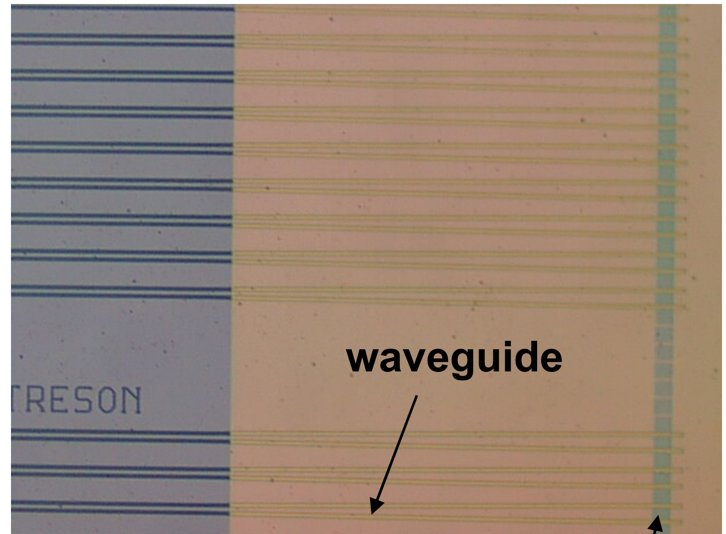
- **Apodise grating → efficiency 63%**
- **Add bottom reflector → efficiency over 90%**



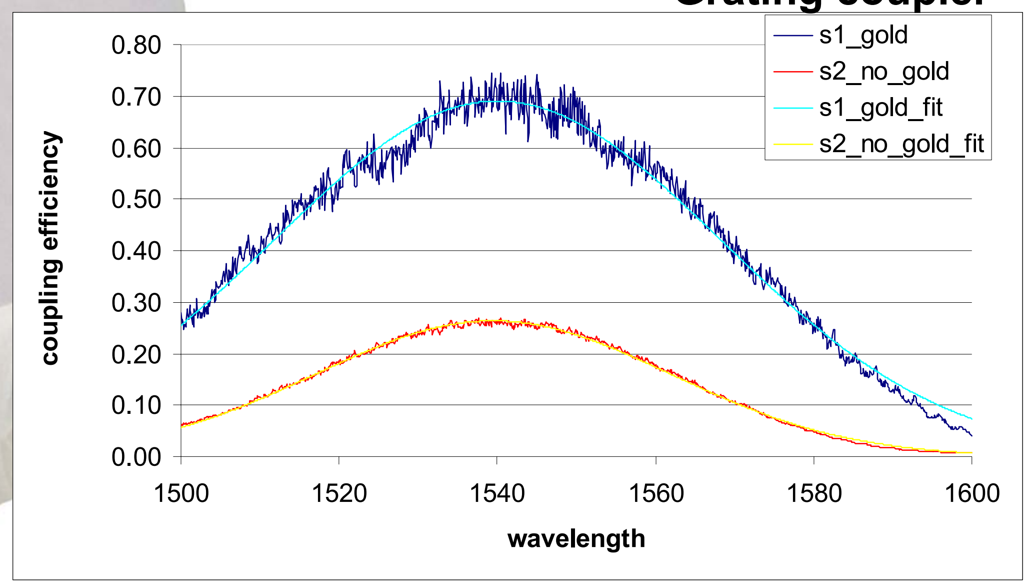
Bonded SOI-coupler with gold bottom mirror

Theoretical coupling efficiency 78%





Measured coupling efficiency:
69% (1.5 dB loss)

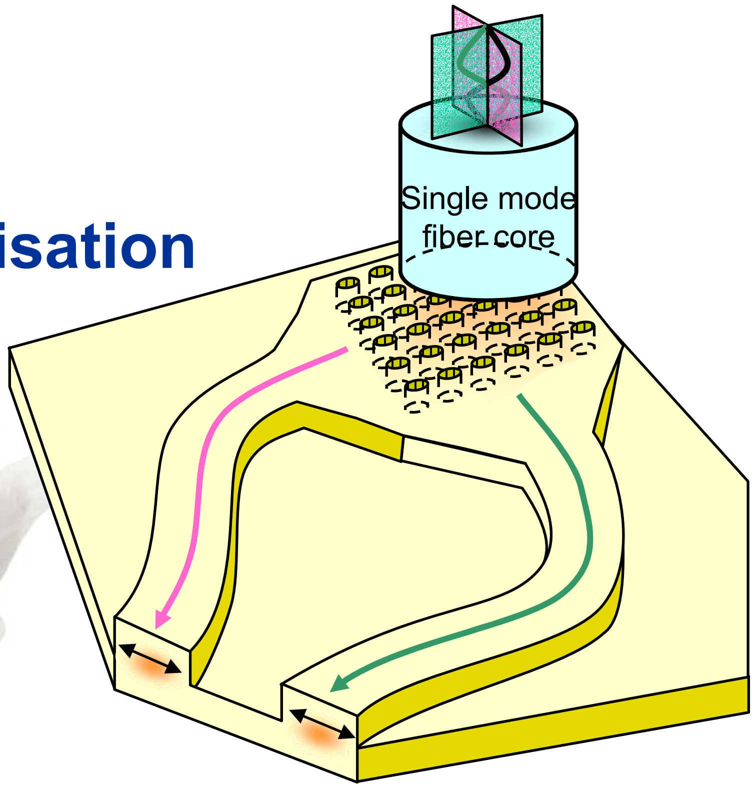


Polarisation problem

Problem: nanophotonic circuits are highly polarisation dependent

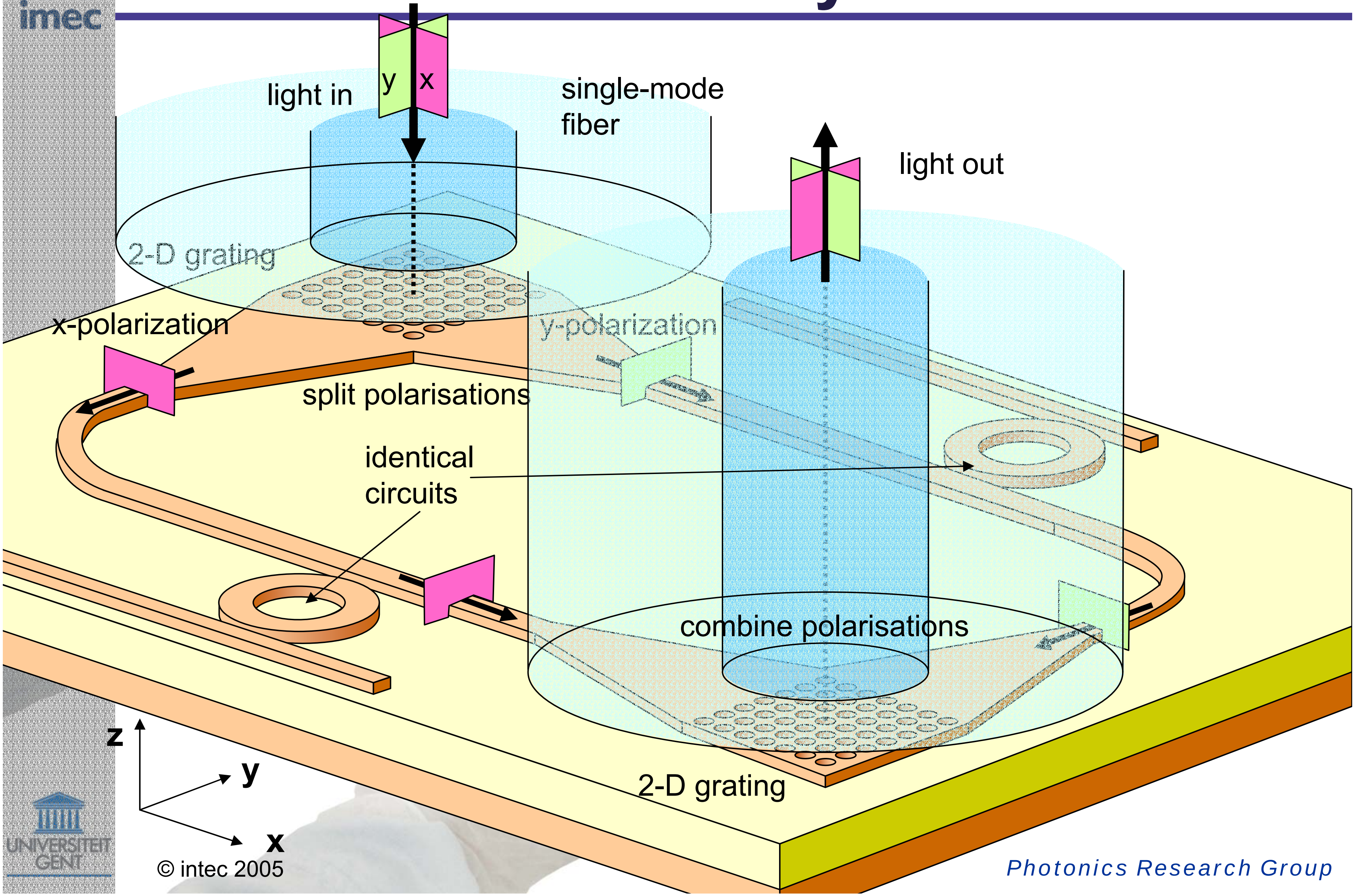
Our solution:

- **2D grating**
- **Couples each fiber polarisation in its own waveguide**
- **In the waveguides the polarisation is the same (TE)**
- **Allows for polarisation diversity approach**

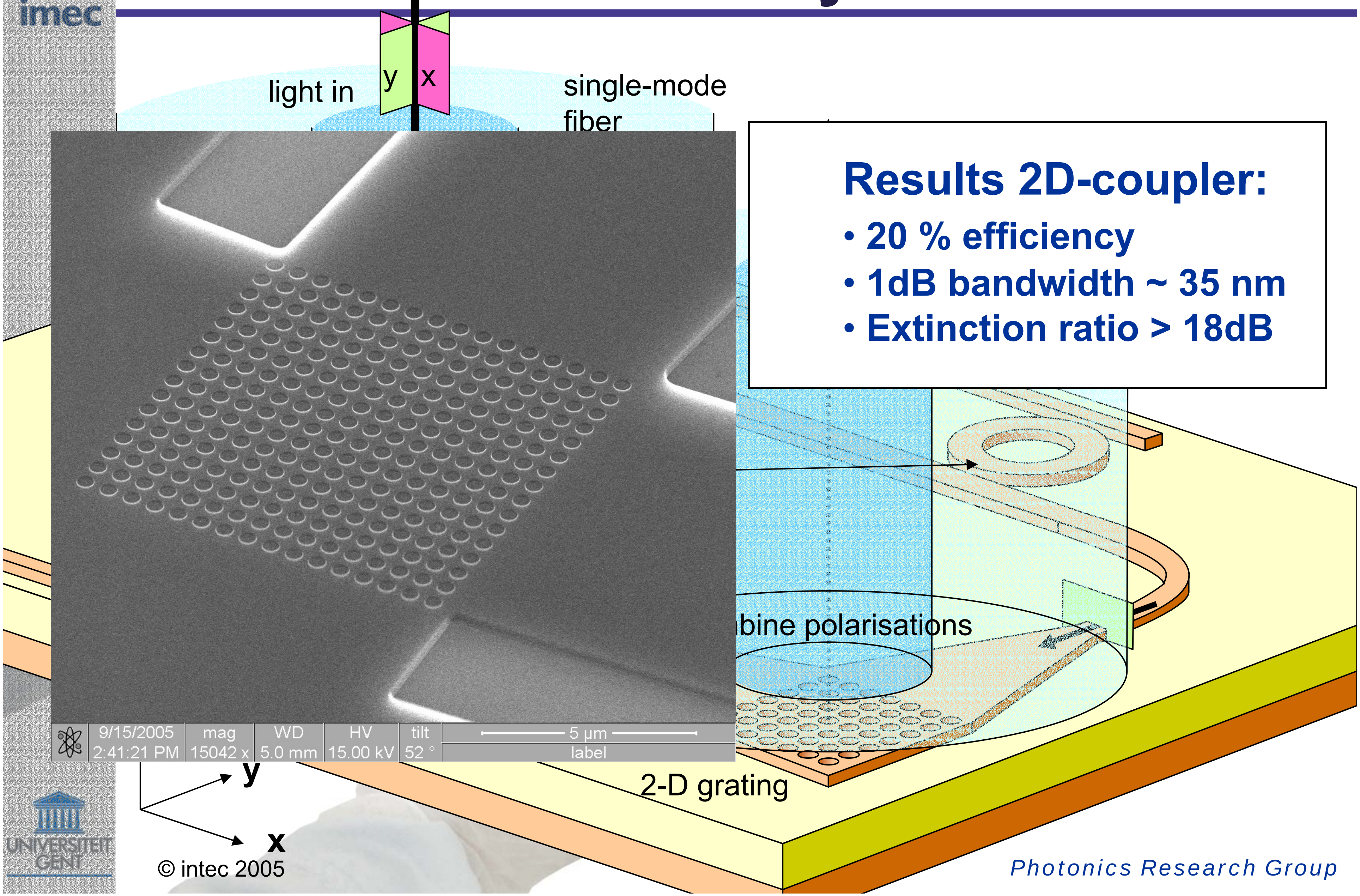


Taillaert et al. PTL 15(9) p. 1249 (2003)

Polarisation Diversity Circuit



Polarisation Diversity Circuit



Results 2D-coupler:

- 20 % efficiency
- 1dB bandwidth ~ 35 nm
- Extinction ratio > 18dB

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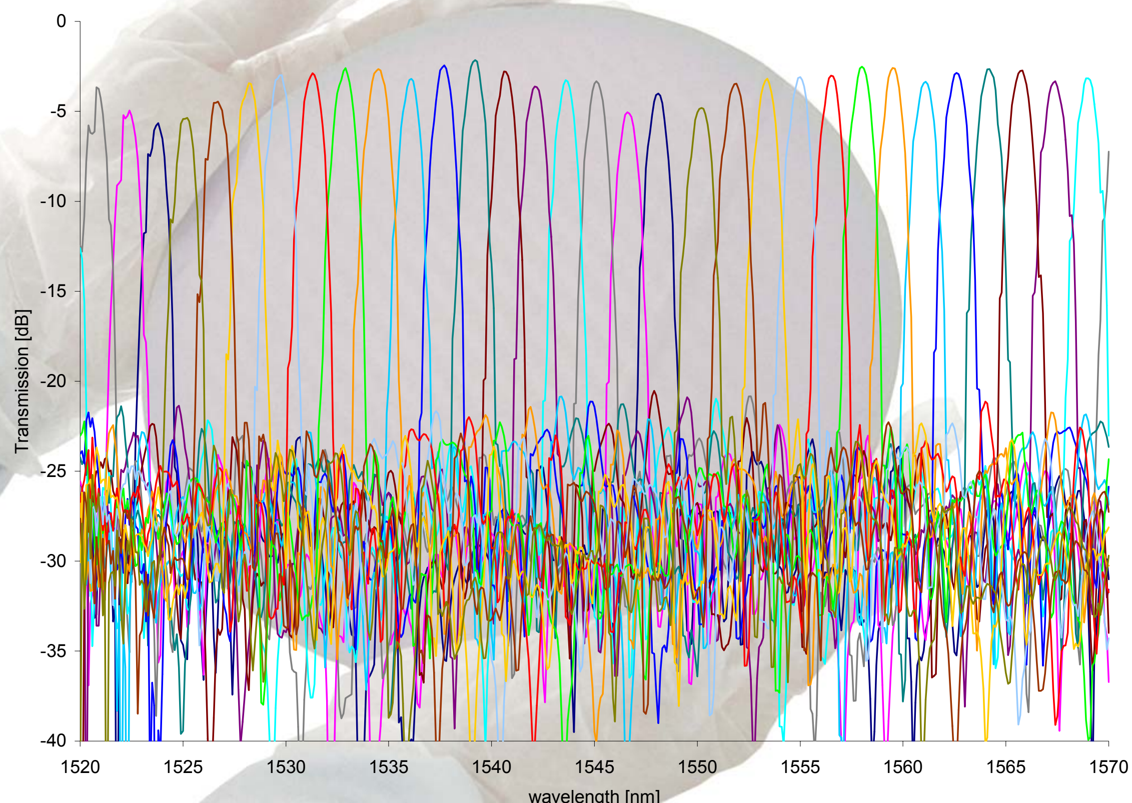
Silicon photonics: the food chain

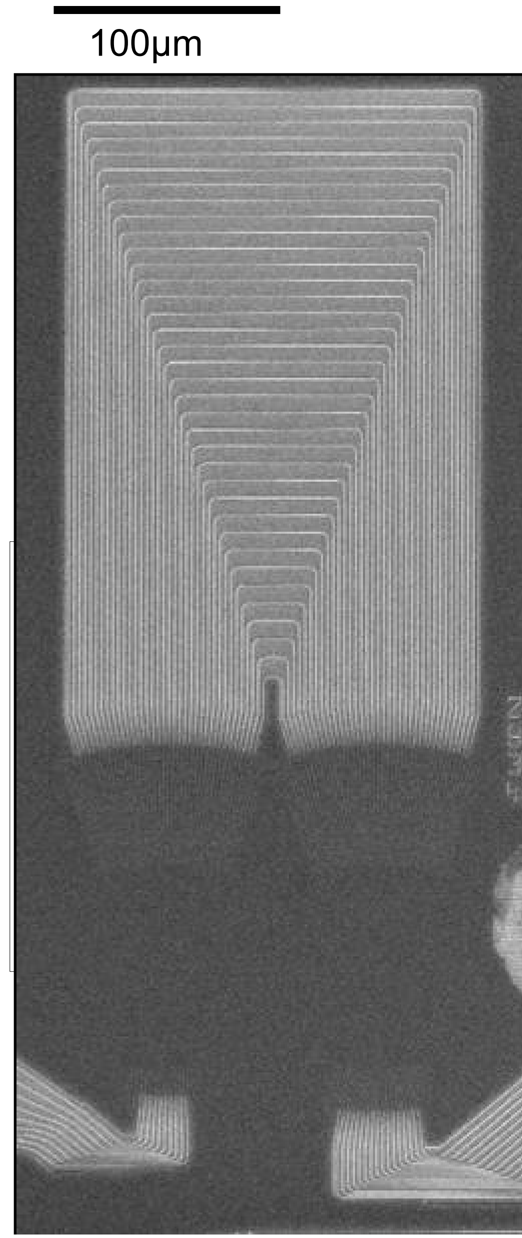
Arrayed waveguide grating

16-channel AWG, 200GHz

200µm x 500µm area

- **-3dB insertion loss**
- **-15dB to -20dB crosstalk**





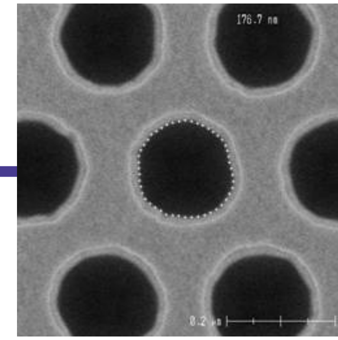
Active photonic functions

The options for modulation, switching, tuning, detection at high speed:

- **all Silicon approach**
  - **carrier density based optical effects + electric field induced carrier sweep away**
  - **All-optical approach using two-photon absorption**
  - **Strained Silicon : Pockels EO-effect**
- **Silicon + Germanium approach**
- **Silicon + III-V-membrane integration**
  - **Using ultra-fast carrier lifetime in III-V**
  - **Also allowing light emission, gain, detection**

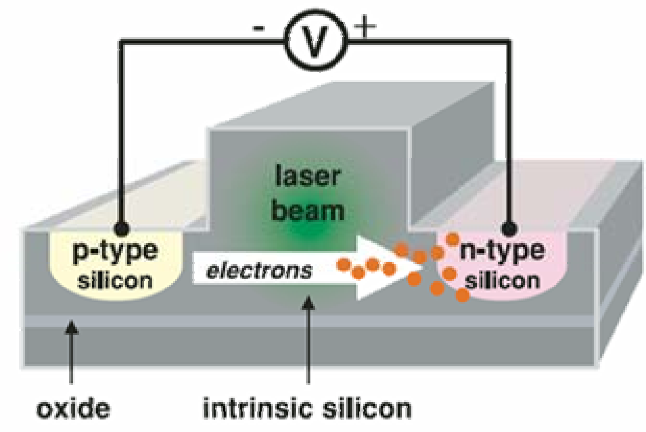
Silicon lasers & modulators

280nm pitch



intel

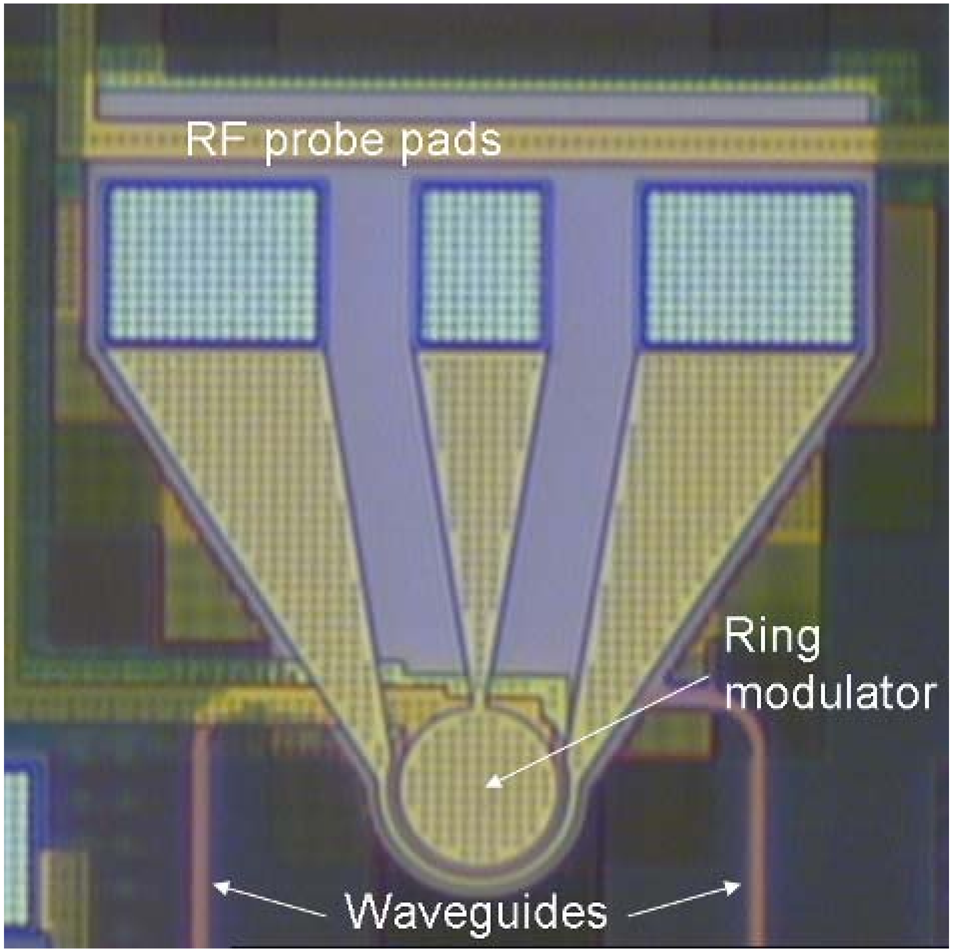
- Optical modulator @ 10GHz
- Silicon CW Raman laser:
  extract electrons using p-i-n diode
- SOI Photonic Crystal devices
  with 193nm Deep UV lithography

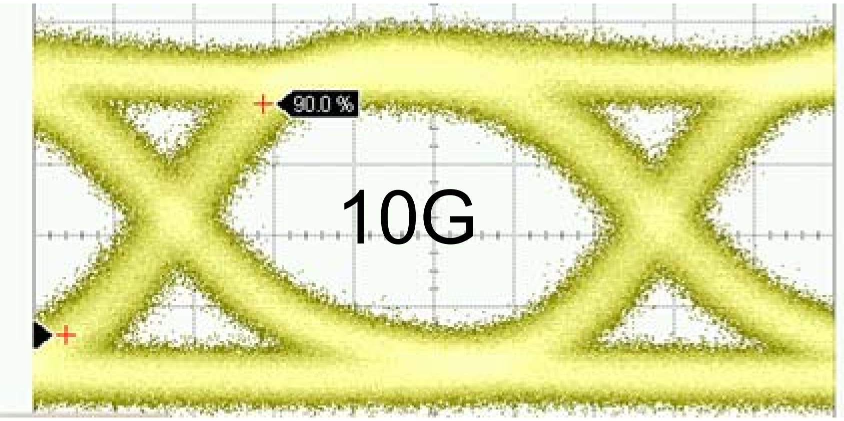


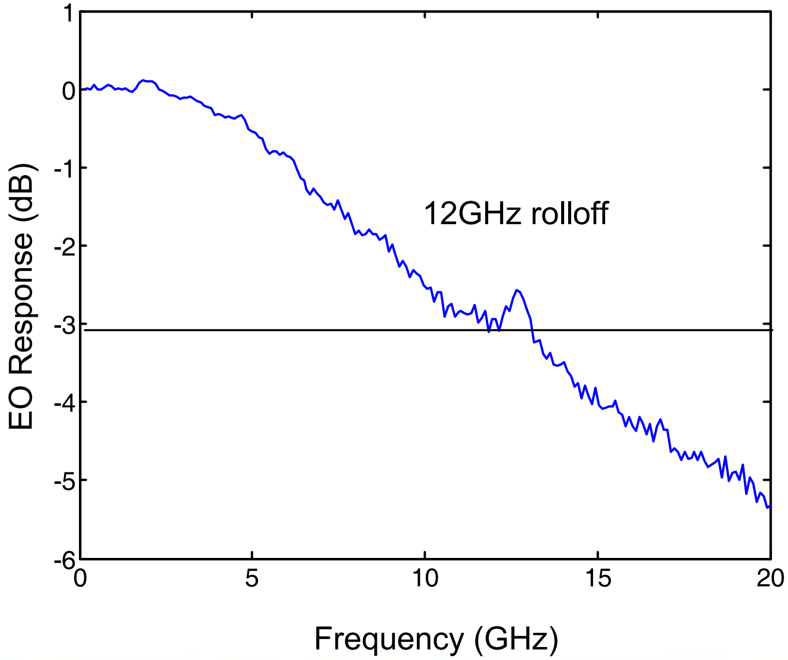
LUXTERA freescale semiconductor

- Fabless Silicon Photonics (Fabrication by Freescale)
- Integration of CMOS and photonic circuits
- 10Gbps Silicon modulator
- 40Gbps optical link for Sun’s Hero project
  (part of the DARPA HPSC programme)

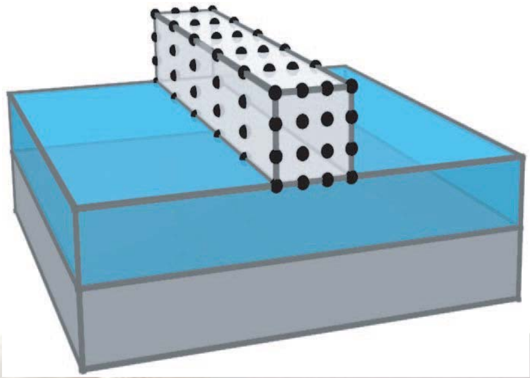
Ring Modulators Work at 10G

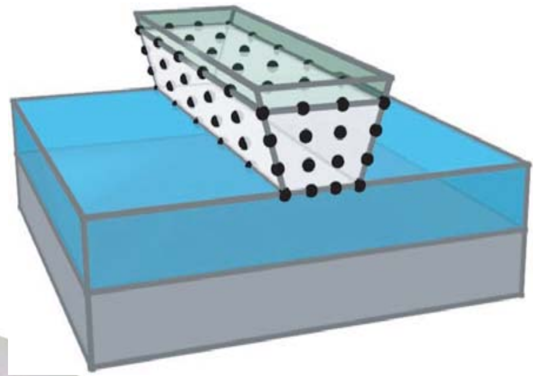




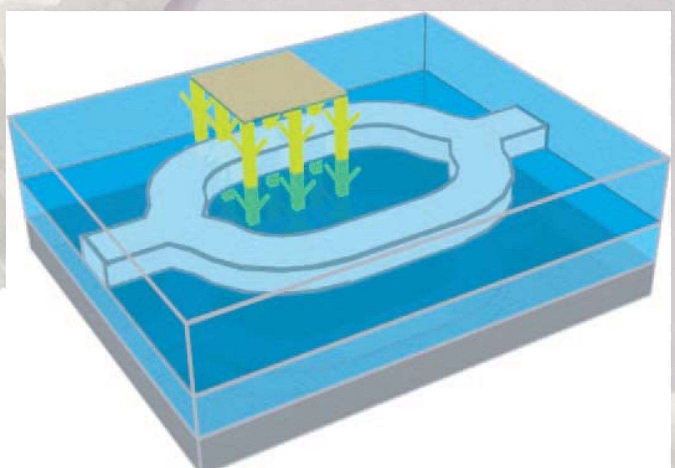


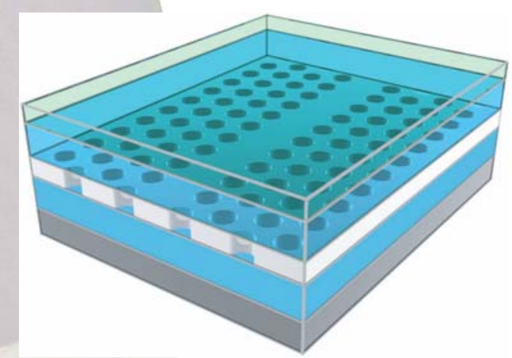
Strained Silicon for optical modulators





No Pockels effect Pockels effect

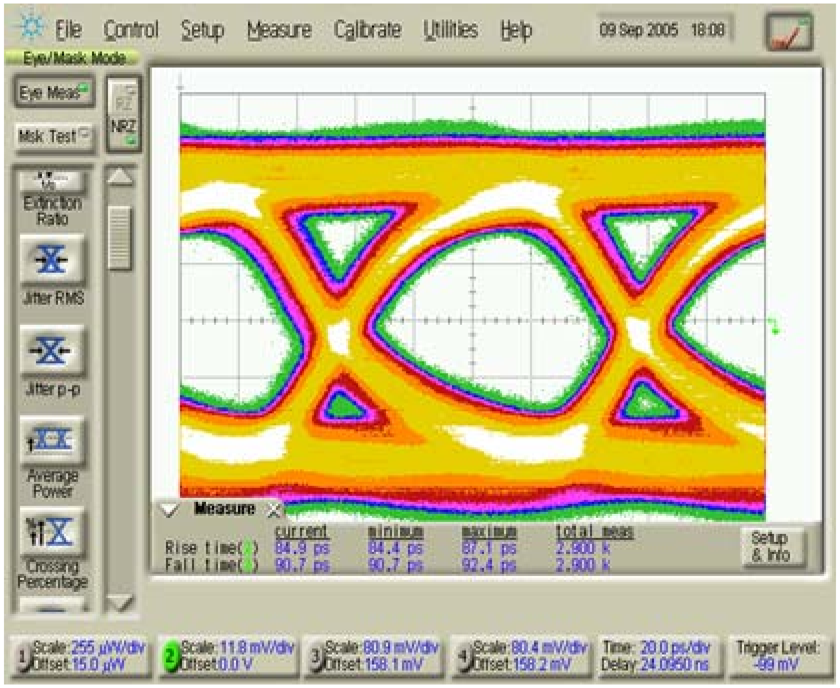




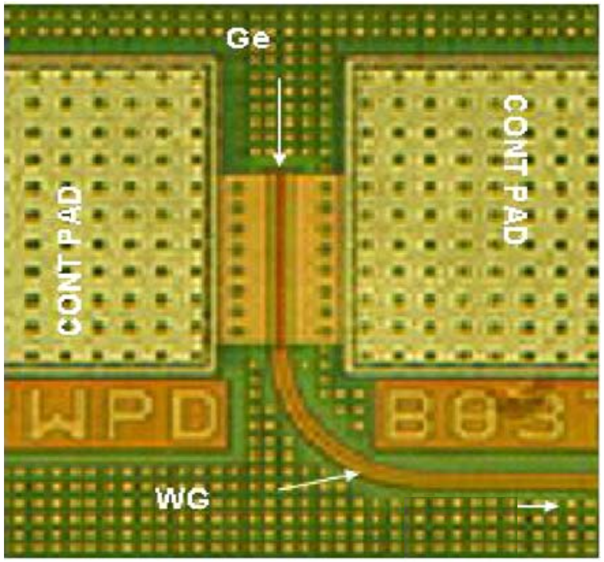
$\chi(2) \approx$ 15pm/V demonstrated

(R. Jacobson et al (TUD-COM), Nature, May 2006)

Ge detectors – 10Gbps



10Gb Eye



Top View

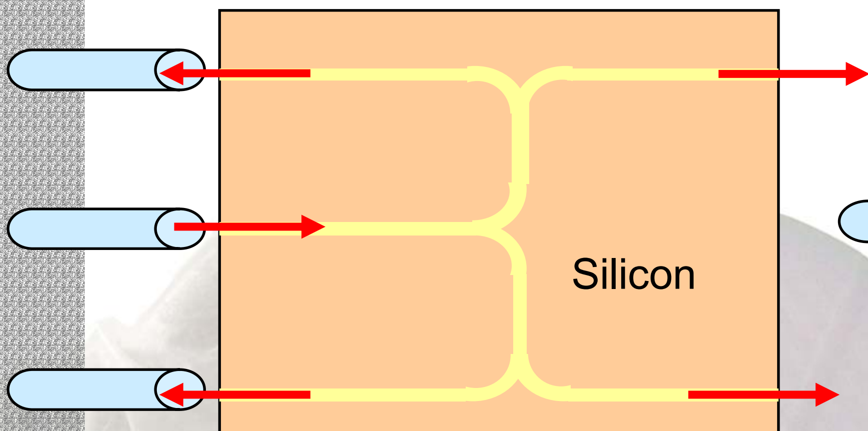
- Sensitivity better than discrete PDs
  - Receivers limited by kTC noise, C=10fF
  - No bondwires between PD and TIA

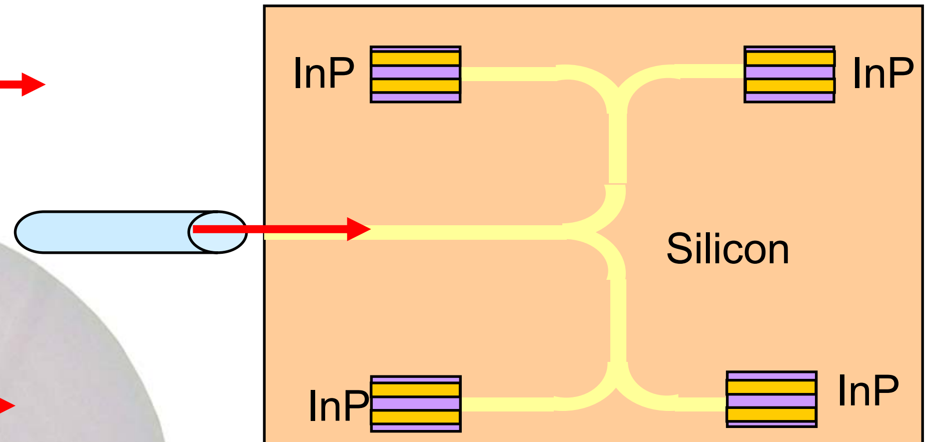
Heterogeneous integration

Silicon waveguide structure → *Heterogeneous circuit*

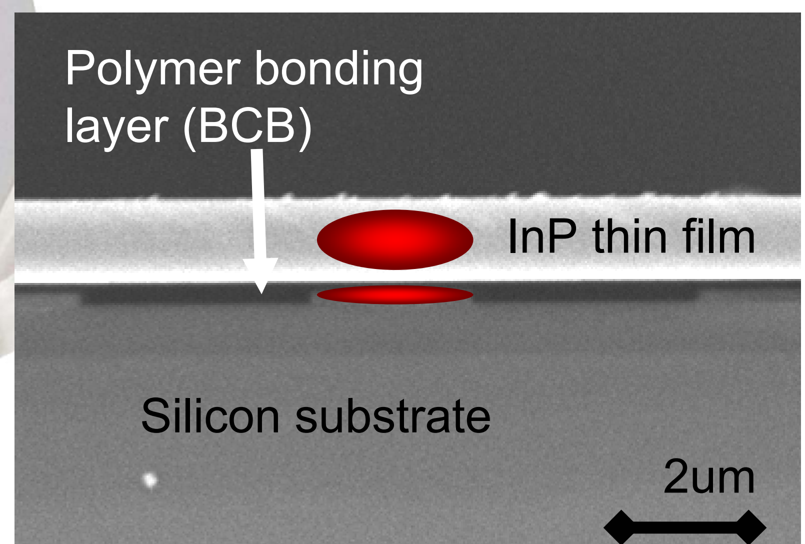
Passive only

Active + passive





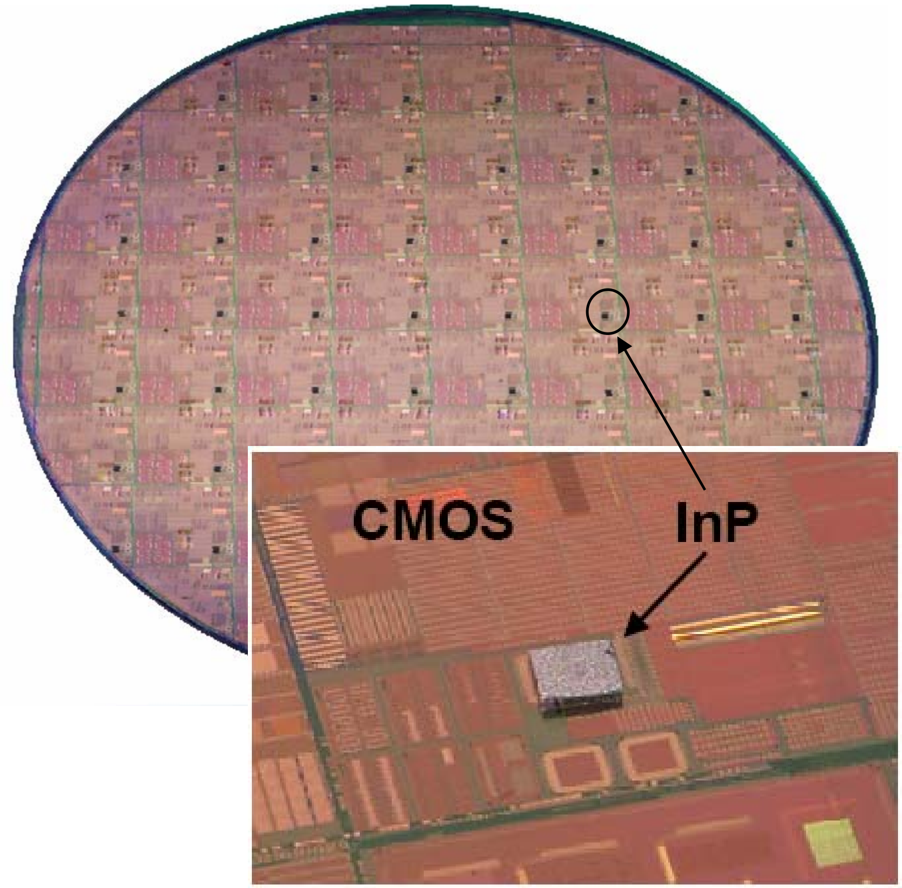
Bonded membranes of InP allowing for wafer scale planar processing



Die-to-wafer bonding

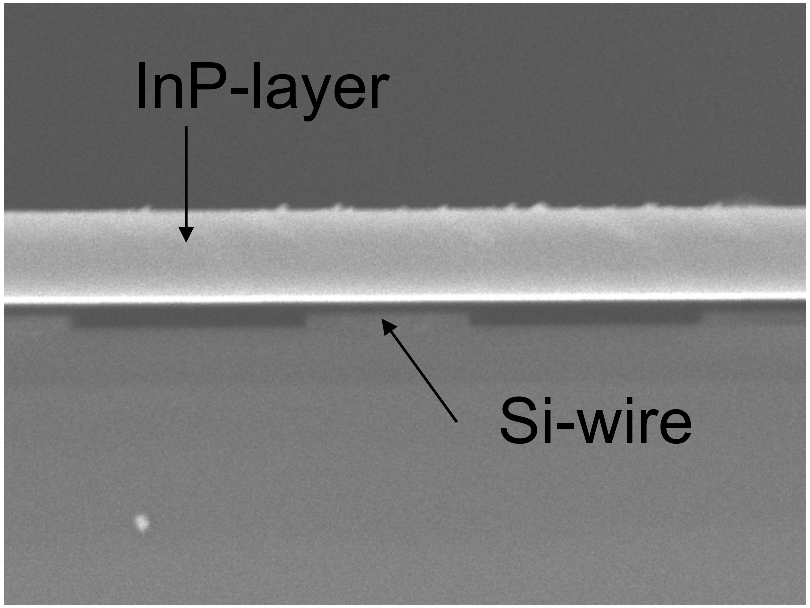
Molecular bonding

- InP on SOI-waveguides on CMOS demonstrated (LETI, TRACIT)

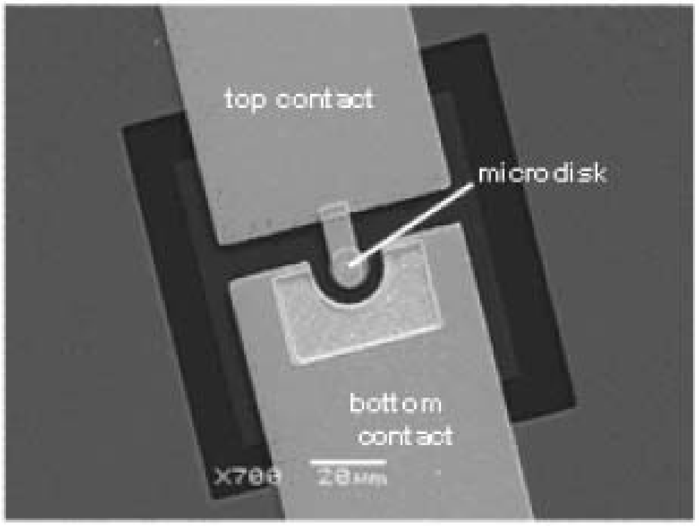


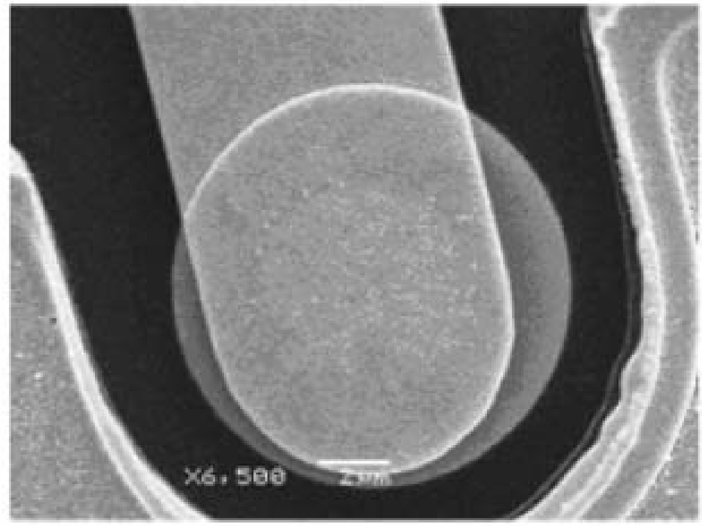
Polymer bonding

- Planarization and bonding in single step (IMEC)
- Ultra-thin bonding layers (sub 200nm demonstrated)

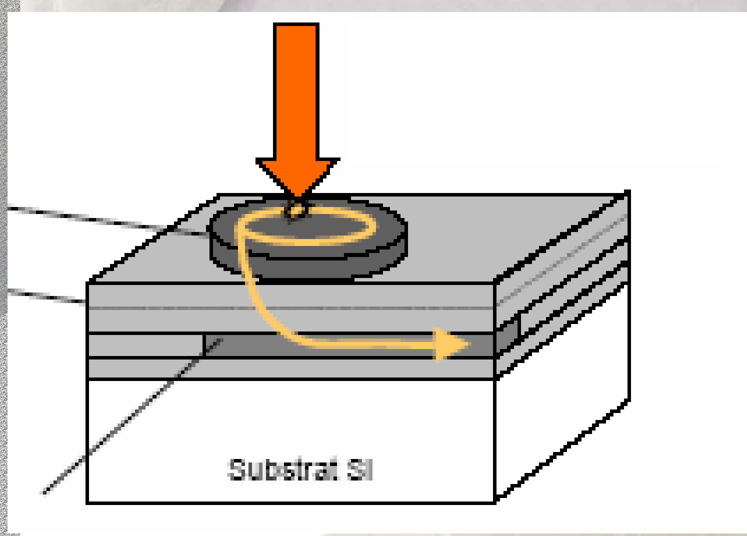


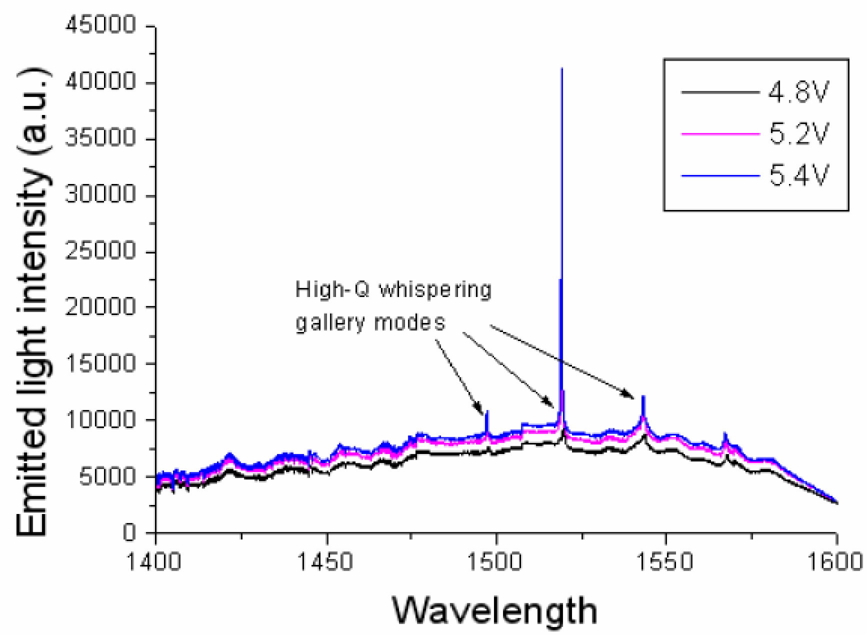
Electrically pumped InP microdisk laser



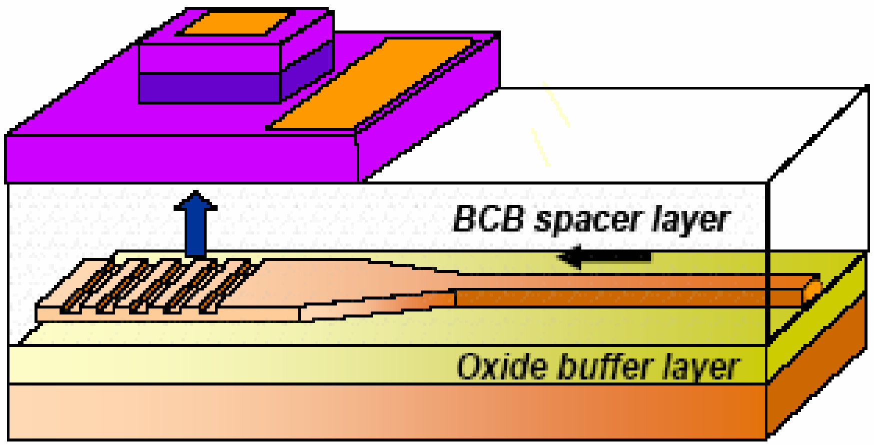


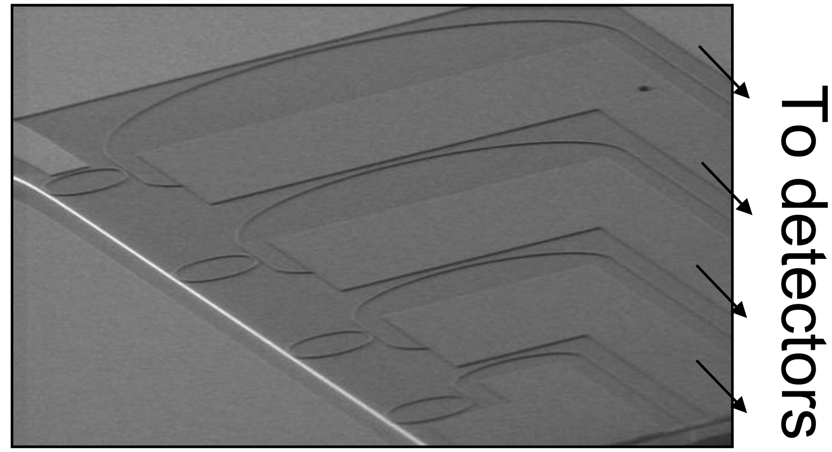
IMEC
EC Lyon
CEA/LETI

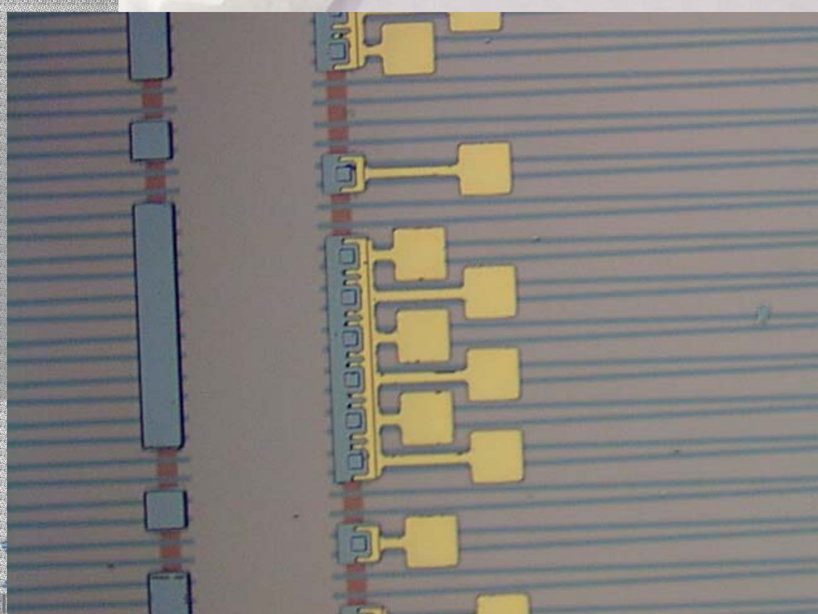




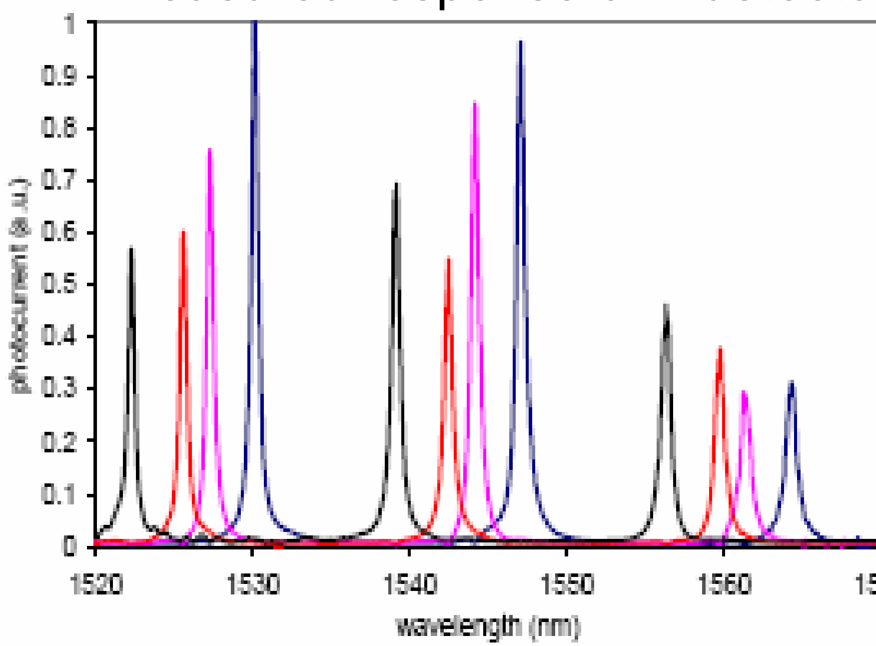
InGaAs Detectors on SOI







Measured response of 4 detectors



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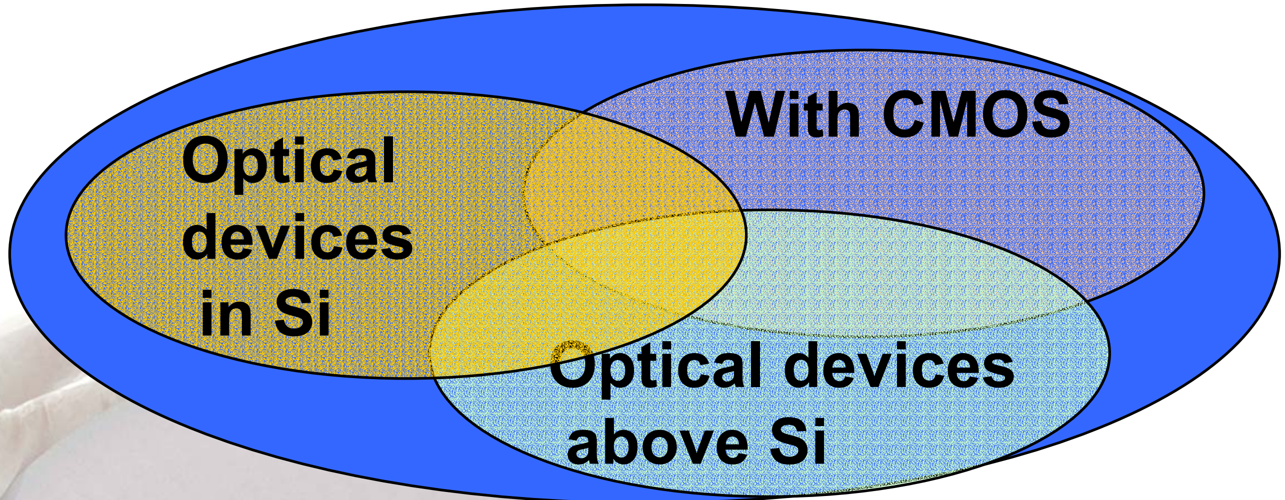
Silicon photonics: what for?

Silicon photonics: the food chain

Silicon photonics: what for?



- WDM components
- switches for high speed backplanes
- single chip high speed low power transceivers
- on-chip optical interconnect
- sensors
- labs on a chip

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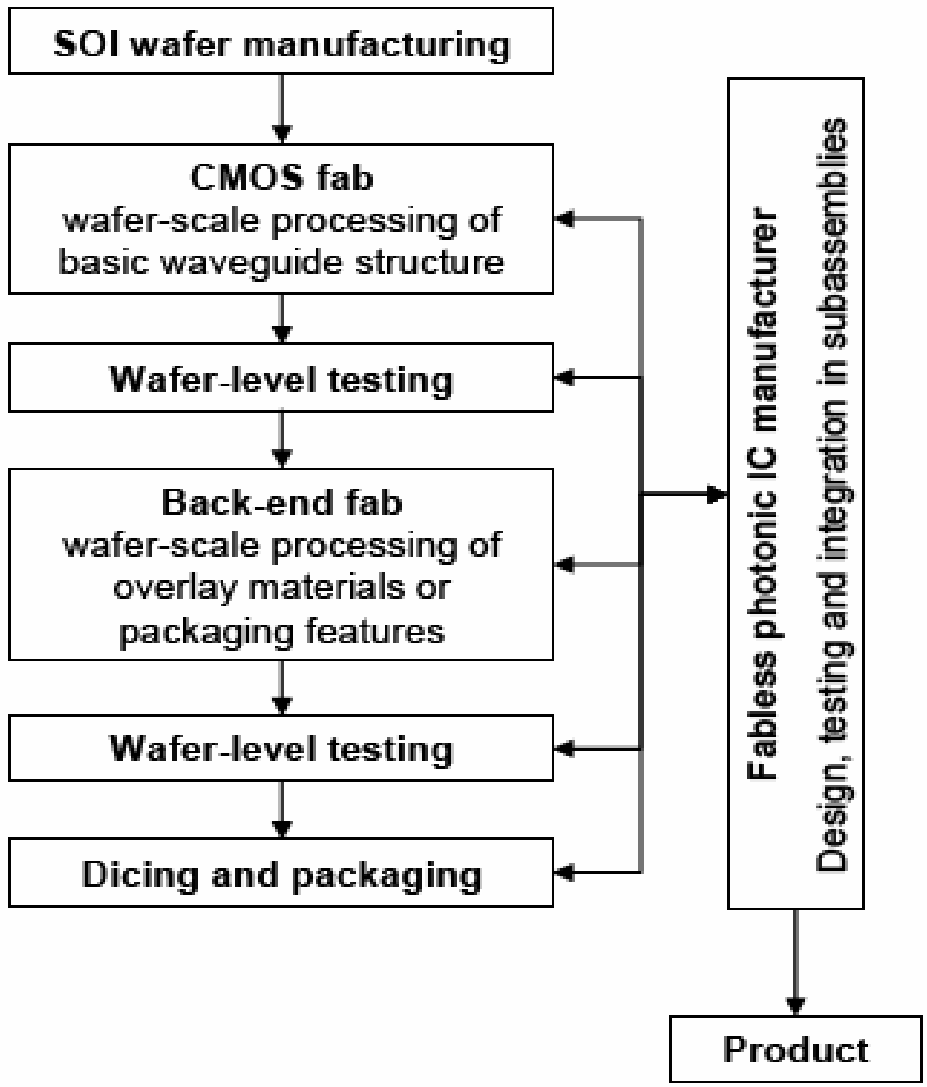
The fabless model



CMOS Photonics Foundry

Motorola's recently spun-out its fabs into Freescale (FSL)

Luxtera uses FSL's 0.13µm SOI process

- **Same process used to construct their PowerPC™ embedded microprocessors**
- **3000 wafers/week capacity**
- **Very high yield, high volume, mature process**

Design environment is Cadence at the system/subsystem level

- **Device design done on 200 node cluster running 3D FDTD**
- **Can perform LVS, DRC on optical circuits**

Philosophy: Started with existing electronics design manual, and make the optics fit – requires extensive characterization, simulation, compromise

But what about research?

A dedicated wafer run in a commercial fab will cost 100 k€ - 1 M€

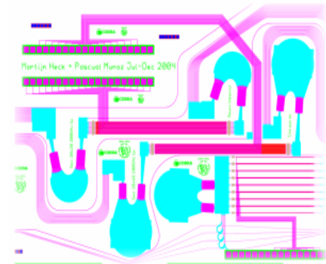
↓

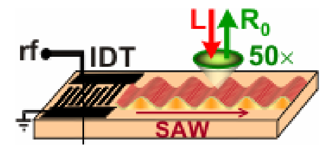
Too expensive for a typical academic research group.

↓

The research community needs to get organised

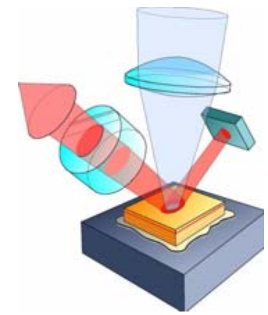
European Network of Excellence
on
Photonic Integrated Components and Circuits

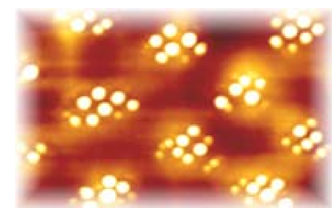




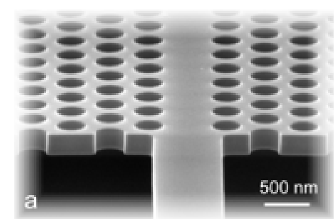
Figures:
- 2004-2008
- 32 partners
- 13 affiliate partners
- 300 researchers
- budget : 6 M€

Integration of research on:
- Technologies for photonic VLSI
- Photonic Signal Processing
- Integrated Light Sources
- Advanced Materials
- Nanophotonics





Through:
- Joint Research Activities
- Joint Education Programs
- Exchange of Researchers
- Dissemination of Knowledge



ePIXnet platforms

3 technology platforms

- InP monolithic integration platform
- Silicon photonics platform
- Nanostructuring platform

3 supporting platforms

- Photonic packaging platform
- Testing platform (high speed components)
- Modelling platform (using cluster/grid computing)

Silicon Photonics Platform

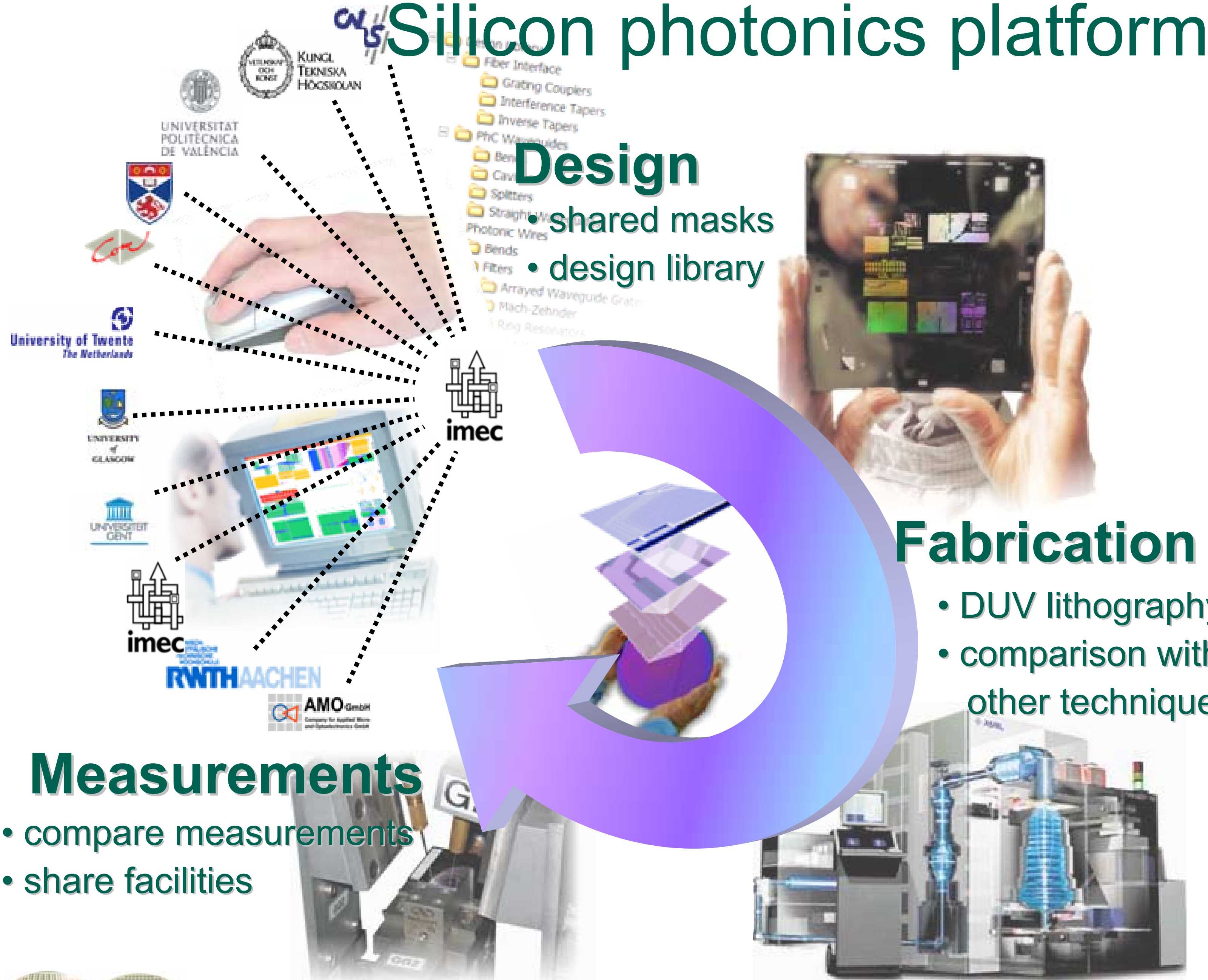
A framework to

- fabricate **Silicon Photonic** Circuits
- for **research** (projects) and prototyping
- using mature, **stable processes**
- **transferable** to a commercial CMOS fab
- at a **reduced cost** (sharing mask, processing)

Core partners

- IMEC (Belgium)
- CEA/LETI (France)

Silicon photonics platform



Design

- shared masks
- design library

Fabrication

- DUV lithography
- comparison with other techniques

Measurements

- compare measurements
- share facilities

Functionality of the Silicon photonics platform

Prototyping, low-volume fabrication

- Passive waveguides
- Ge-based active components

(Coordinate) Process development

- develop standardized fabrication modules:
  e.g. fiber couplers, integrated photodetectors, ...
- transfer of know-how
- expand platform portfolio

Support circuit design

- Design rules
- Design library
- CAD software through Europractice

Core Partners

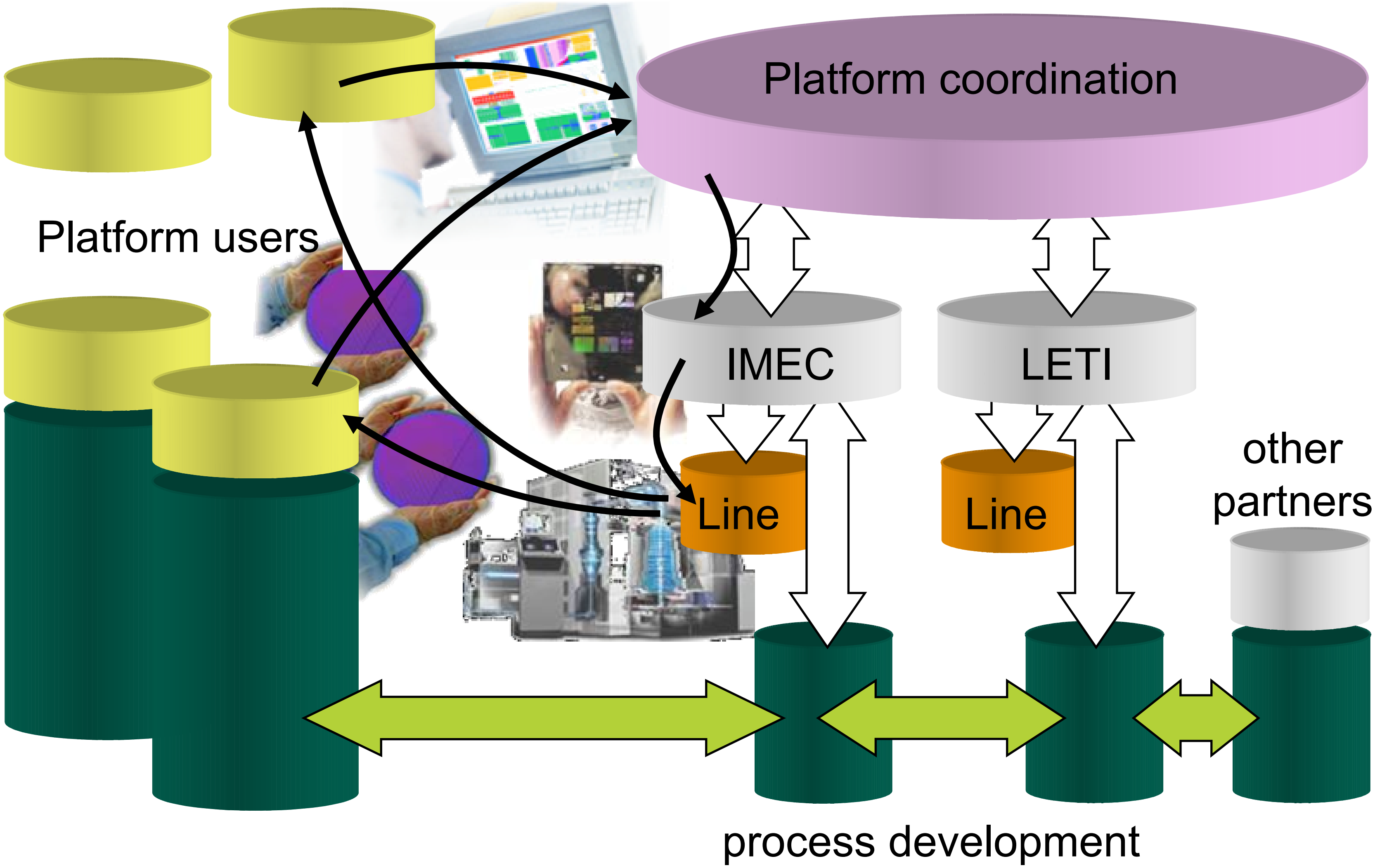
IMEC:

- Passive waveguides and photonic crystals in SOI:
  - 200mm SOI with a Si thickness of 220nm
  - Deep UV at 248nm (foreseen switch to 193nm)
  - Optional top oxide cladding
- Standard grating coupler for fiber
- Future: 193nm, amorphous SOI

CEA/LETI:

- Passive waveguides in SOI or amorphous SOI
  - 200mm SOI with a Silicon thickness of 50 to 400nm
  - 193 nm Deep UV lithography
  - Hard mask and side wall treatment
  - Optional top oxide cladding
- Epitaxy of SiGe or Ge films onto SOI
- Future: standard Ge photodetector module

The Silicon Photonics Platform



Silicon "CMOS" photonics?

☺ low loss waveguides
☺ compact functional devices
☺ WDM components
☺ easy coupling to fiber
☺ polarisation insensitivity
☺ >10 Gb/s optical modulators
☺ >10 Gb/s detectors

☹ light sources,
☹ amplifiers
☹ all-optical functions

Silicon “CMOS” photonics?

☺ low loss waveguides

☺ compact functional devices

☺ WDM components

☺ easy coupling to fiber

☺ polarisation insensitivity

☺ >10 Gb/s optical modulators

☺ >10 Gb/s detectors

+ overlay materials

☹light sources,

☹amplifiers

☹all-optical functions

Conclusion

Silicon photonics is a

generic technology

with a wide range of

high volume applications

for which the

industrial technology base

largely exists

today.

Acknowledgements

- The European Union
  - *IST-PICCO*
  - *IST-PICMOS*
  - *IST-ePIXnet*
- The European Space Agency
- The Belgian IAP-PHOTON network
- The Flemish Institute for the indust advancement of Scientific and Technological Research (IWT)
- The Flemish Fund for Scientific Research (FWO-Vlaanderen)
- The Photonic Research Group at Ghent University – IMEC
- The Silicon Process division at IMEC
- The P-line at IMEC
- Cary Gunn of Luxtera

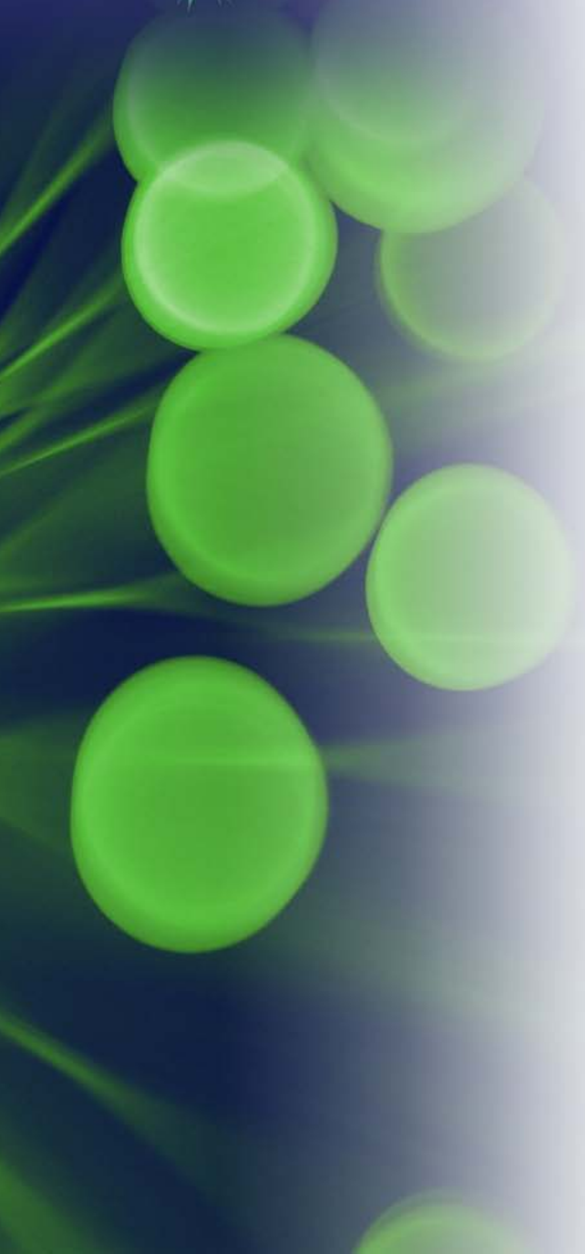
Technical Programme

Workshop on Photonic Components for Broadband Communication

City Conference Centre Stockholm
Norra Latin, Stockholm, Sweden
Wednesday–Thursday 28–29 June 2006

SPIE Europe

EPIC European Photonics Industry Consortium



Conference Chairs: **Pierre-Yves Fonjallaz**, Kista Photonics Research Ctr. (Sweden); **Thomas P. Pearsall**, European Photonics Industry Consortium (France)

Program Committee: **Pierre-Yves Fonjallaz**, Kista Photonics Research Ctr. (Sweden); **Silvio Abrate**, Istituto Mario Boella (Italy); **Dieter Bimberg**, Technische Univ. Berlin (Germany); **Markus Blaser**, Optospeed SA (Germany); **Andrew C. Carter**, Bookham Technology (United Kingdom); **Laurent R. Fulbert**, Commissariat à l'Energie Atomique (France); **Hans-Joachim Grallert**, Heinrich Hertz Institute (Germany); **Miroslaw Grudzien**, VIGO System S.A. (Poland); **Gerard Guillot**, Institut National des Sciences Appliqués de Lyon (France); **Michael Heuken**, AIXTRON AG (Germany); **Anders G. Larsson**, Chalmers Tekniska Hoegskola (Sweden); **Miguel Llera**, Haute Ecole ARC Ingénierie (Switzerland); **Daniel Milanese**, Politecnico di Torino (Italy); **Mario Musolino**, SAES Getters S.p.A. (Italy); **Christoph Peschke**, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); **Henning Schroeder**, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany); **Nicholas Traynor**, PERFOS (France); **Peter Van Daele**, INTEC Univ. Gent/Dept. of Information Technology (Belgium); **Egbert Woelk**, Rohm and Haas Electronic Materials (France)

Welcome! To survive and grow in a market correcting itself from short term over-investment and over-capacity, the optical communication and components industries are in a process of consolidation and cost reduction. However, in the last five years, the global demand for bandwidth has been increasing. Therefore, we believe it is the right time to evaluate the opportunities and needs for optical components and systems in broadband network applications.

In this workshop we will focus on the opportunities where optical communications can bring the greatest added value to existing network infrastructure. We will also identify component and system breakthroughs that will enable migration to profitable, manageable networks capable of supporting next generation broadband services. New products and processes will generate an increasing economic activity for the photonics industry into the 21st century. To achieve success, photonic components and systems must be reliable and inexpensive, generic and adaptable, offer superior functionality, be innovative and have strong IP protections, and be aligned to market opportunities.

Made up of selected invited and poster presentations, Photonic Components for Broadband Communication will focus on the global opportunities for cost effective functions that can be realised by photonic components and systems for use in broadband networks. The workshop will also focus on resources that European industry needs to capitalise on those opportunities, including support from European and national R&D programmes.

The goal is to strengthen the strategies developed in the Technology Platform Photonics21 to reinforce the European position in the manufacturing of photonics components and systems. Poster presentations will propose technology solutions from new materials and components to system designs. Participants will join focus working groups to develop specific recommendations for R&D priorities and continuing actions.

We welcome your participation!

spie.org/events/eoc

Conference 6350 • Room: Pillarhall

Wednesday–Thursday 28–29 June 2006 • Proceedings of SPIE Vol. 6350

Wednesday 28 June

Welcome and Introduction

Room: Pillarhall . . . . Wed. 08.40 to 09.00

Thomas P. Pearsall, European Photonics Industry Consortium (France); Pierre-Yves Fonjallaz, Kista Photonics Research Ctr. (Sweden)

SESSION 1

Room: Pillarhall . . . . Wed. 09.00 to 10.00

Plenary Session

Chair: **Pierre-Yves Fonjallaz**, Kista Photonics Research Ctr. (Sweden)

09.00: **A review of the FP6-project on photonics components for telecom** *(Invited Paper)*, H. J. Rajbenbach, European Commission (Belgium) . . . . . [6350 01]

09.30: **The strategic research agenda of the Technology Platform Photonics21: preparation of FP7 and reinforcement of European component industry** *(Invited Paper)*, L. ThylÈn, Kungliga Tekniska Hˆgskolan (Sweden) . . . . [6350 02]

SESSION 2

Room: Pillarhall . . . . Wed. 10.00 to 11.00

High-Performance Devices

10.00:**20-Gb/s direct modulation of 980-nm VCSELs based on submonolayer deposition of quantum dots** *(Invited Paper)*, F. Hopfer, A. Mutig, G. Fiol, M. Kuntz, Technische Univ. Berlin (Germany); S. S. Mikhrin, I. L. Krestnikov, D. A. Livshits, A. R. Kovsh, Nanosemiconductor GmbH (Germany); C. Bornholdt, Fraunhofer-Institut f¸r Nachrichtentechnik Heinrich-Hertz-Institut (Germany); V. Shchukin, N. N. Ledentsov, Technische Univ. Berlin (Germany) and Nanosemiconductor GmbH (Germany); D. Bimberg, Technische Univ. Berlin (Germany) . . . . [6350 03]

10.20: **High-speed travelling-wave electro-absorption modulators** *(Invited Paper)*, U. Westergren, Kungliga Tekniska Hˆgskolan (Sweden); Y. Yu, Zhejiang Univ. (China); L. ThylÈn, Kungliga Tekniska Hˆgskolan (Sweden) . . . . [6350 04]

10.40: **High-brilliance photonics bandgap crystal lasers** *(Invited Paper)*, V. A. Shchukin, Nanosemiconductor GmbH (Germany) . . . . [6350 05]

Poster Session, Part I

Room: Pillarhall . . . . Wed. 11.00 to 12.00

Part I of the Workshop Poster Session will take place on Wednesday in the Conference Room. Coffee and refreshments will be served in order to encourage full discussions and networking. For presentation detail, please reference the poster presentation list following the oral agenda listing of the Workshop.

Lunch Break . . . . 12.00 to 13.00

SESSION 3

Room: Pillarhall . . . . Wed. 13.00 to 14.00

Low-Cost Devices

13.00: **Uncooled lasers for high data rates** *(Invited Paper)*, M. M. Meliga, Avago Technologies (Italy) . . . . [6350 06]

13.20: **Low-cost single-mode fibre connectors for better implementation of SMFs in the access networks** *(Invited Paper)* . . . . [6350 07]

13.40: **Advanced packaging concepts for low-cost optoelectronic devices** *(Invited Paper)*, S. Bernabe, Intexys Photonics (France) . . . . [6350 08]

SESSION 4

Room: Pillarhall . . . . Wed. 14.00 to 15.00

Fibre in the Access (FTTH)

14.00: **Fiber in access: a challenge for a new breed of optical devices** *(Invited Paper)*, P. Ghiggino, Marconi SpA (United Kingdom) . . . . [6350 09]

14.20: **Berlin Access, an initiative of Berlin SMEs and research for new FTTH technologies** *(Invited Paper)*, W. Doeldissen, N. Keil, M. Moehrle, W. Schlaak, H. Yao, C. Zawadzki, Fraunhofer Institute for Telecommunications - Heinrich Hertz Institut (Germany) . . . . [6350 10]

14.40: **FTTH: bringing the services the end users** *(Invited Paper)*, G. N. van den Hoven, Genexis (Netherlands) . . . . [6350 11]

Poster Session, Part II and Reception

Room: Pillarhall . . . . Wed. 15.00 to 16.00

Part II of the Poster Session will take place on Wednesday in the Conference Room with authors present at their posters for discussion. A reception with drinks and refreshments will accompany the event. Poster authors may set up their posters on Wednesday from 8.00 for all-day viewing. It is the authors' responsibility to remove their posters at the end of the day Thursday. SPIE assumes no responsibility for posters left up after the end of the poster session. For presentation detail, please reference the poster presentation list following the oral agenda listing of the Workshop.

SESSION 5

Room: Pillarhall . . . . Wed. 16.00 to 17.00

Future Devices, Systems and Networks

16.00: **Options for FTTP in Europe and implications for optical components** *(Invited Paper)*, D. B. Payne, R. Davey, BT Exact (United Kingdom) . . . . . [6350 12]

16.30: **Silicon photonics for broadband communication** *(Invited Paper)*, R. G. Baets, Univ. Gent (Belgium) . . . . [6350 13]

Room: Pillarhall . . . . Wed. 17.00 to 18.00

General Discussion

The general discussion will aim to summarize Day One of the workshop, and will focus on comparison between oral and poster presentations, discussions on general issues, including additional subjects for breakout discussions and working groups for Day Two.

Poster—Wednesday

✔ **InP/InGaAsP electrically controlled Bragg modulator for over 40-Gbit/s modulation speed**, A. Irace, G. Breglio, M. De Laurentis, Univ. degli Studi di Napoli Federico II (Italy) . . . . [6350 14]

✔ **Electrically pumped InAs single quantum dot emitter**, A. Lochmann, E. Stock, O. Schulz, F. Hopfer, Technische Univ. Berlin (Germany); A. I. Toropov, A. K. Bakarov, A. K. Kalagin, Institute of Semiconductor Physics (Russia); M. Scholz, S. B¸ttner, O. Benson, Humboldt-Univ. zu Berlin (Germany); V. A. Haisler, Institute of Semiconductor Physics (Russia) and Technische Univ. Berlin (Germany); D. Bimberg, Technische Univ. Berlin (Germany) . . . . [6350 15]

✔ **GaIn(N)As/GaAs VCSELs emitting in the 1.1 to 1.3-µm range**, L. Grenouillet, P. Duvaut, O. Nicolas, P. Gilet, P. Grosse, S. Poncet, P. Philippe, E. Pougeoise, L. R. Fulbert, A. Tchelnokov, CEA-LETI (France) . . . . [6350 16]

✔ **Integration of silicon photonics on a CMOS circuit**, J. FÈdÈli, L. R. Fulbert, CEA-LETI (France) . . . . [6350 17]

✔ **Photodiodes with integrated optical filters for passive optical network applications**, C. Petit, M. Blaser, Albis Optoelectronics AG (Switzerland) . . . . [6350 18]

✔ **A novel electrical and optical confinement scheme for surface emitting optoelectronic devices**, R. Marcks von W¸rtemberg, J. Berggren, Z. Zhang, M. Hammar, Kungliga Tekniska Hˆgskolan (Sweden) . . . . [6350 19]

✔ **Optical filters in SOI: design considerations for devices based upon strip and rib waveguides**, B. D. Timotijevic, G. T. Reed, Univ. of Surrey (United Kingdom); R. Jones, Intel Corp. (USA); A. Michaeli, Intel Corp. (Israel); G. Z. Mashanovich, Univ of Surrey (United Kingdom) . . . . [6350 20]

✔ **Tunable acoustooptic filters for WDM applications**, V. Y. Molchanov, O. Y. Makarov, Moscow State Institute of Steel and Alloys Technological Univ. (Russia) . . . . [6350 21]

✔ **Self-organized quantum dots for 1.3-μm photonic devices**, M. Laemmlin, G. Fiol, C. Meuer, M. Kuntz, F. Hopfer, N. N. Ledentsov, Technische Univ. Berlin (Germany); A. R. Kovsh, Nanosemiconductor GmbH (Germany); D. Bimberg, Technische Univ. Berlin (Germany) . . . . [6350 22]

✔ **Recent advances in quantum dot materials for lasers and amplifiers at 1.55 μm**, B. Dagens, Alcatel Research & Innovation (France) . . . . [6350 23]

✔ **10-gigabit colourless reflective amplified modulator for access network**, C. Kazmierski, Alcatel Research & Innovation (France) . . . . [6350 24]

✔ **Low-cost enhanced performance DFB Lasers**, M. Mˆhrle, W. Brinker, L. Mˆrl, A. Sigmund, N. Grote, Fraunhofer-Institut f¸r Nachrichtentechnik Heinrich-Hertz-Institut (Germany) . . . . [6350 25]

✔ **Dense central office solution for point-to-point fibre access including a novel compact dual bi-directional fibre optical transceiver**, G. Arvidsson, S. Junique, Acreo AB (Sweden); K. Persson, Ericsson AB (Sweden); E. Sundberg, TeliaSonera AB (Sweden) . . . . [6350 26]

✔ **Optical toggle flip-flop**, M. R. Sayeh, J. W. Park, Southern Illinois Univ. (USA) . . . . [6350 28]

✔ **Fiber To The Home: Next Generation Network**, C. Yang, Consultant (USA) . . . . [6350 29]

✔ **Determination of the optical constants of thin film from reflectance spectra by improved Flexible Tolerance method**, Q. Chan, Y. Xie, University of Electronic Science and Technology of China (China) . . . . [6350 30]

✔ **An improved FD-BPM imaginary-distance propagation method**, X. Yi, University of Electronic Science and Technology of China (China); C. QIAN, Z. Jianhong, University of Electronics Science and Technology of China (China) . . . . [6350 31]

Banquet on the Boat:

Wednesday 28 June 18.30 to 22.00

18.15: departure for banquet

18.30-22.00: Banquet on a historical ship, M/s Östanå

We invite you to view the city from its canals: see the pearl of Lake Mälaren, Drottningholm Palace, the residence of the Swedish royal family. The tour will continue around different islands so that you can enjoy some of the beautiful archipelago houses and cottages.

All attendees are invited to relax, socialise, and enjoy the conference dinner and the cruise.

Please remember to wear your registration badges.

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Wednesday Morning Coffee Break Sponsor:

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Thinking optical solutions

Thursday 29 June

Workshops

Rooms: Pillarhall and
Rooms 251, 252, 254, 255, 352 . . . . Thurs. 9.15 to 12.30

Photonic Components for Broadband Communication

9.00 to 9.15: **Introduction**

Moderators: **Pierre-Yves Fonjallaz,** Kista Photonics Research Ctr. (Sweden); **Thomas Pearsall,** European Photonics Industry Consortium (France)

9.15 to 12.30: **Workshops**

10.30 to 11.00: **Coffee Break**

The following sessions will provide an exciting opportunity for every participant to play an active role in developing photonics components for broadband communication in Europe. The workshop will be divided into four break-out groups, each focusing on a specific area:

- **Components for access networks**
- **Components for the trunk networks**
- **Business aspects**
- **Manufacturing and infrastructure in Europe**

12.30 to 13.30: **Lunch Break**

13.30 to 14.30: **Presentations preparations**

14.30 to 15.30: **Presentations from groups**

14.30 to 14.45: **Components for access networks**

14.45 to 15.00: **Components for the trunk networks**

15.00 to 15.15: **Business aspects**

15.15 to 15.30: **Manufacturing and infrastructure in Europe**

15.30 to 15.45: **Coffee Break**

15.45 to 16.30: **Discussion**

16.30: **Closing Remarks** Thomas P. Pearsall, European Photonics Industry Consortium (France)

Proceedings of SPIE

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Vol# 6350 **Workshop on Optical Components for Broadband Communication**
(P.-Y. Fonjallaz/T. P. Pearsall) . . . . Prepublication Price $60

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General Information

Symposium Location

Workshop on Photonic Components
for Broadband Communication

City Conference Ctr. Stockholm
Norra Latin
Drottninggatan 71B
107 26 STOCKHOLM
Tel: 08 - 506 166 00
Fax: 08 - 21 69 71
info@stoccc.se
www.stoccc.se

Registration Hours

Wednesday 28 June, 07.30 - 18.00 hrs
Thursday 29 June, 08.30 - 15.30 hrs

Coffee and Lunch Breaks

Coffee Breaks

Wednesday 28 June, 11.00 - 12.00 and 15.00 - 16.00
Thursday 29 June, 10.30 - 11.00 and 15.30 - 15.45

QuickLunch Coupon

Full conference technical registrants will receive on QuickLunch coupon redeemable for a lunch on Wednesday and Thursday. Some restrictions apply. Please refer to the coupon you receive in your registration packet.

Poster Sessions and Reception

Two interactive poster sessions will be held on Wednesday 28 June. The authors will be able to set up their poster papers starting 8.30 Wednesday morning. Supplies for posting papers will be available in the poster session area. The viewable size of the poster board is ~1.25 m high x 0.96 m wide. Attendees can preview the posters during the day before the formal reception. Authors need to be present at their posters for discussion with attendees during the formal sessions from 11.00 to 12.00 and 15.00 to 16.00 hrs. It is authors' responsibility to remove their posters at the end of the day on Wednesday. SPIE Europe assumes no responsibility for presentations left up after this time. Attendees are requested to wear their conference registration badge to gain access to the interactive poster session and reception.

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For copyright reasons, video or digital recording of any conference session, short course, or poster is strictly prohibited without prior written consent from each specific presenter to be recorded. Individuals not complying with this policy will be asked to leave a given session and to surrender their film or disc. It is the responsibility of the presenter to notify SPIE or SPIE Europe if consent is given.

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Stockholm A - Z

About Stockholm

Stockholm is one of the world's most beautiful cities. This is not news.

What's new is that in recent years Stockholm has been identified as one of the world's most creative and exciting urban scenes. These daysk Stockholm attracts an intercontinental set of visitors who come to sample its selection of contemporary cosmopolitan culture - for the same reasons they might otherwise travel to London, Paris, New York, Milan or Tokyo. Whether your passion is art, music, fashion, design, food, shopping, nightlife or big-city trends, Stockholm has plenty to offer even to the most discerning globetrotter.

Accessibility

Most museums, attractions, stores and restaurants are wheelchair-accessible. For information on the accessibility of a particular destination, contact the Stockholm Tourist Centre on +46 8 508 28 508.

Rentals

You can rent bicycles, canoes and inline skates in Stockholm to discover the city at your own speed. Rental companies can be found on www.stockholmtown.com.

Shopping

Stores are generally open from 10am to 6 or 7pm Monday to Friday, 10am to 4pm on Saturdays and 12 noon to 4pm on Sundays. Shopping centres and department stores may be open longer. To buy wine or spirits, visit a Systembolaget store, open normal store hours from Monday to Friday, and until 3pm on Saturdays.

Tax free / Duty free

Tax Free Shopping means that non-EU residents who buy goods in Sweden can receive a cash refund of up to 17.5%. The amount of the purchase must exceed SEK200 including VAT. The refund is paid when the visitor leaves the EU.

Tipping

In Sweden, tips are included in the prices you pay in restaurants, bards, and cafes. However, Stockholmers do tip if they are happy with the service. The customer is free to decide the amount of the tip, but it is customary to tip around 10%.

For more information about tourist attractions in Stockholm,

go to www.stockholm.se/english/