The Generic Foundry Vision

- Towards a Generic Foundry Model

  Glass, Silicon and InP

- (Generic) Circuit approach

  Building Blocks, Design rules, Design kits

- Opportunities

  Jeppix, ePIXfab, OpSIS …

The current model in difficulties…

(vertical integrated fab)

Since 1990 worldwide several B$ invested in development of photonic integration technologies

Market share of PICs is still small for payback investments

- Almost all research was strongly application driven
- No coordination in technology development
- Therefore, almost as many technologies as applications
- No knowledge and cost sharing advantage
- For most companies entry costs too high

➢ Move to a few generic technologies that support a broad range of functionalities

➢ *Apply the methodology of CMOS to photonics*

Someting is going wrong ....

- Up to now almost all research has been Application driven
- Therefore almost as many technologies as applications (almost everything is reinvented)
- For most of them: market too small for payback investments
- Huge fragmentation, unsustainable fragments
- (in electronic) Huge market served by a small set of integration technologies
- (in photonic) Small market served by a huge set of integration technologies

~~A fully optimized technology for a succesfull application~~

Too many degree of freedom, Too many materials, Too many technologies, Too many component types, too many packaging types

No standards

Towards a generic foundry model…

… that support a broad range of functionalities

Limit the number of possibilities (technologies, devices, materials, dimensions, …)

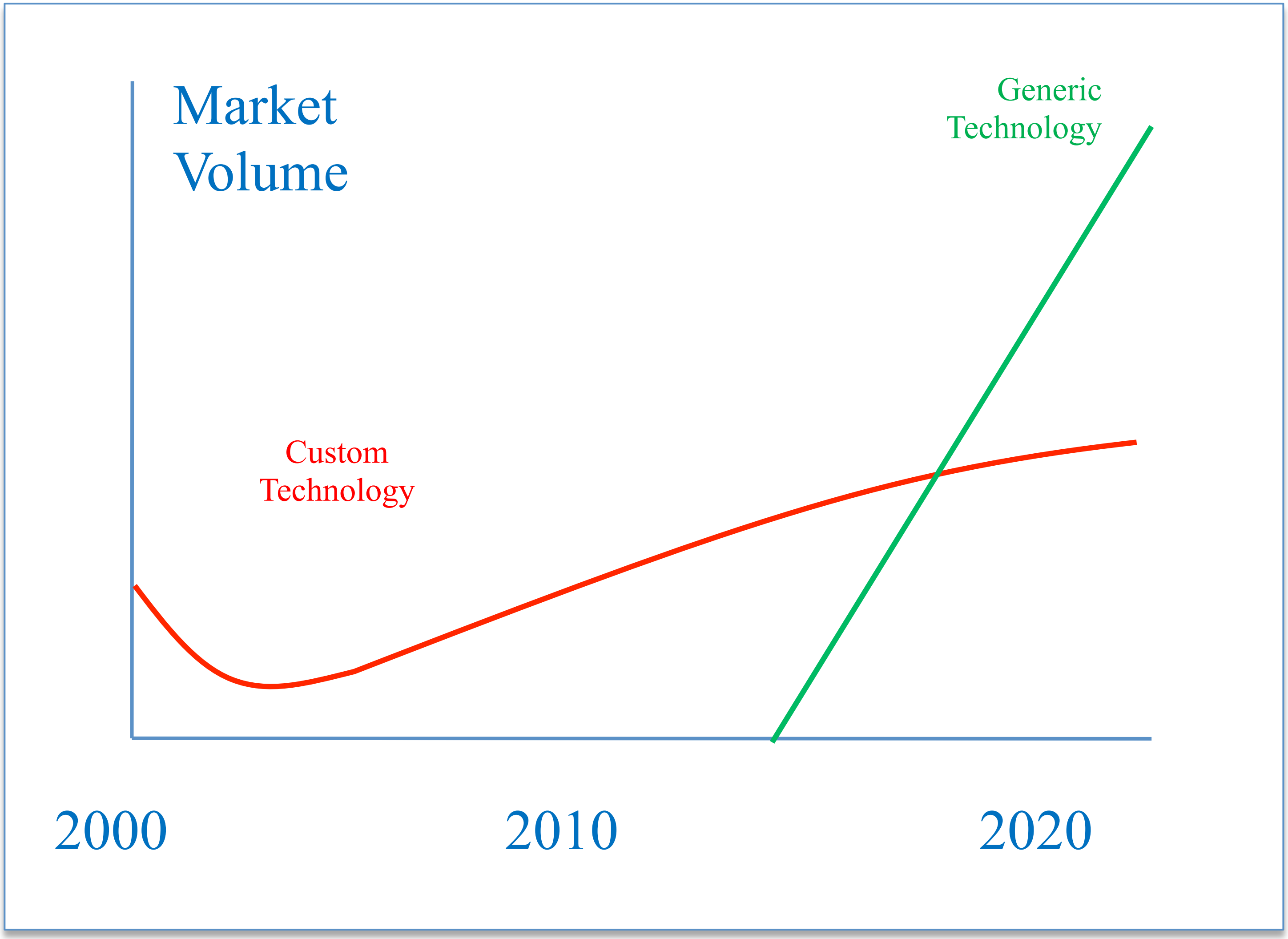
Move to a Generic Foundry Model means

- *Convergence of technologies*
- *Decouple design and technology (IP)*
- *Reduce cost (entry, development, qualification, multi-projects…)*
- *Use standard Building Blocks*
- *Set up libraries, design kits, circuit design tools*
- *Generic packaging*

Fabless companies, new market, design houses, high quality foundries, reduced time to market, no custom design…

Towards a generic foundry model…

… that support a broad range of functionalities



A paradigm shift needed

Move from *application specific* technology development

to *generic* technologies that apply to a broad range of functionalities

Apply the methodology of microelectronics to photonics

Knowledge and cost sharing

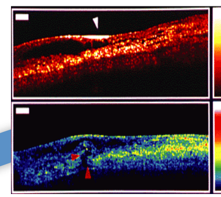
	Vertical Integrated Model	Custom Foundry Model	Generic Foundry Model
Cleanroom fab	NO	YES	YES
Integration process	NO	NO	YES
Design Kit	NO	NO	YES
Component Library	NO	NO	YES
Packaging	NO	NO	YES
Qualification and testing	NO	NO	YES

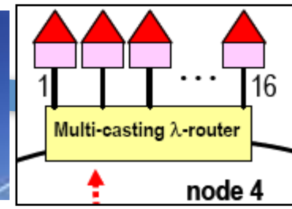
The generic foundry model (in Europe)

PARADIGM

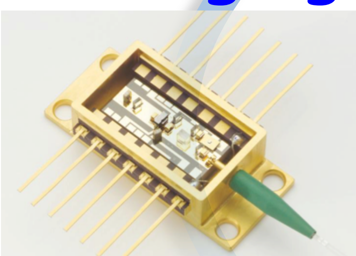
euroPIC

Users



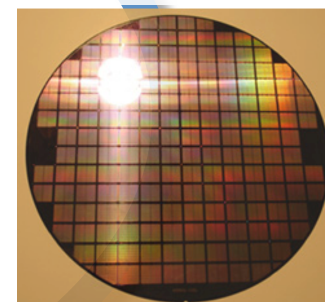


Packaging

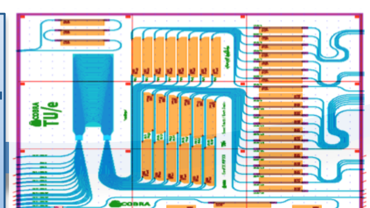


Building Blocks
Design rules
Design kits
Software

Foundries



Design Houses

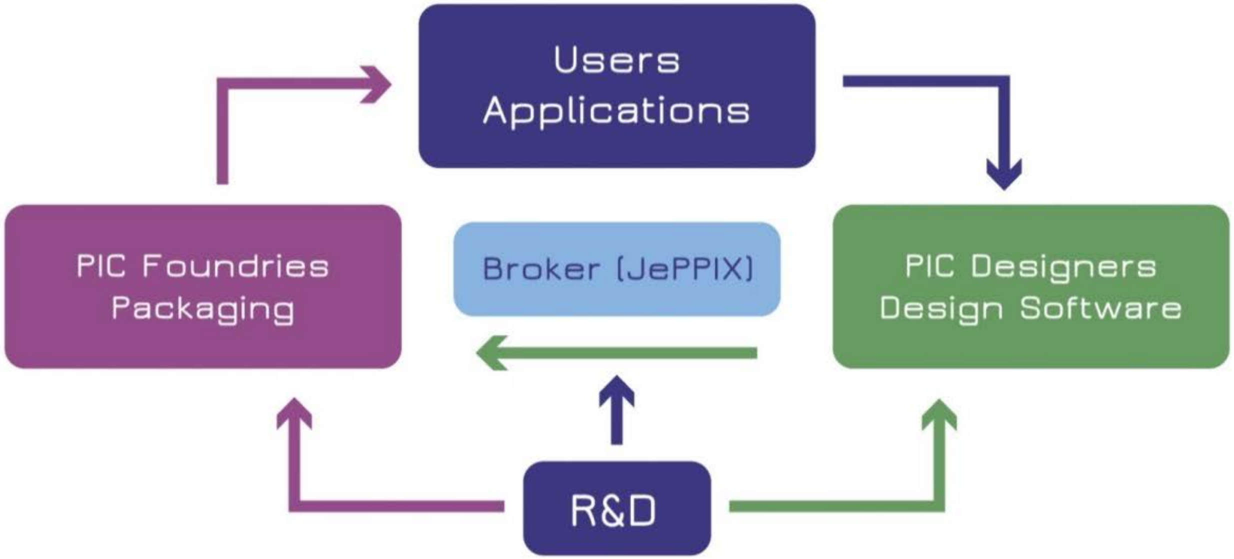


HELIOS
pHotonics ELectronics functional Integration on CMOS

Memphis
Merging Electronics and Micro & Nano-Photonics in Integrated Systems

PhotonFAB Support Action

Eco-system for InP foundry model



Fraunhofer Heinrich Hertz Institute
OCLARO
SMARTPhotonics III-V foundry services
LioniX
LINKRA Networks
Technobis ipps

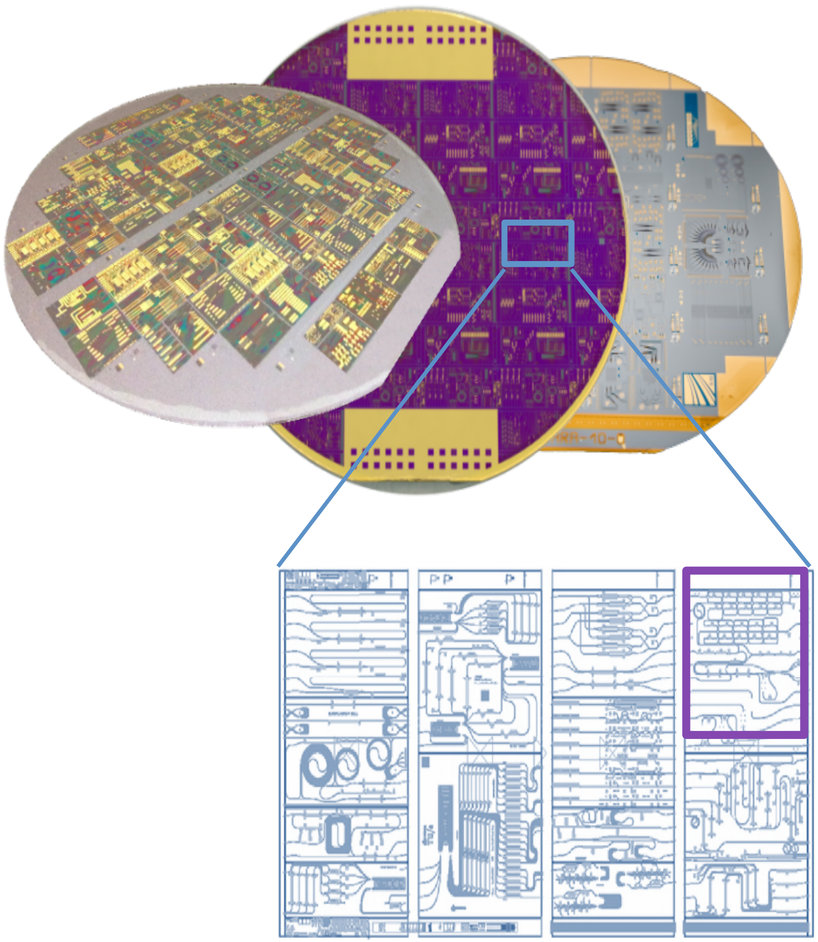
PhoeniX Software Solutions for Micro and Nano Technologies
Aspic design
Photon Design
BRIGHT Integrated PHOTONICS
VLC PHOTONICS

JePPIX: broker InP and TriPleX

TU/e Technische Universiteit Eindhoven University of Technology

Value chain for photonic ASICs prototyping

Multi-Project Wafer (MPW) runs



Generic foundries offer **standardized and general-purpose fabrication technologies** to external users. The ecosystem of **fabless player** can focus on new circuital solutions rather than technological issues.

Learning from **integrated electronics**

- Access to a cutting-edge photonic technology
- Sharing wafer: sharing fab costs
- Simple and cheap way of prototyping
- Fabless business model

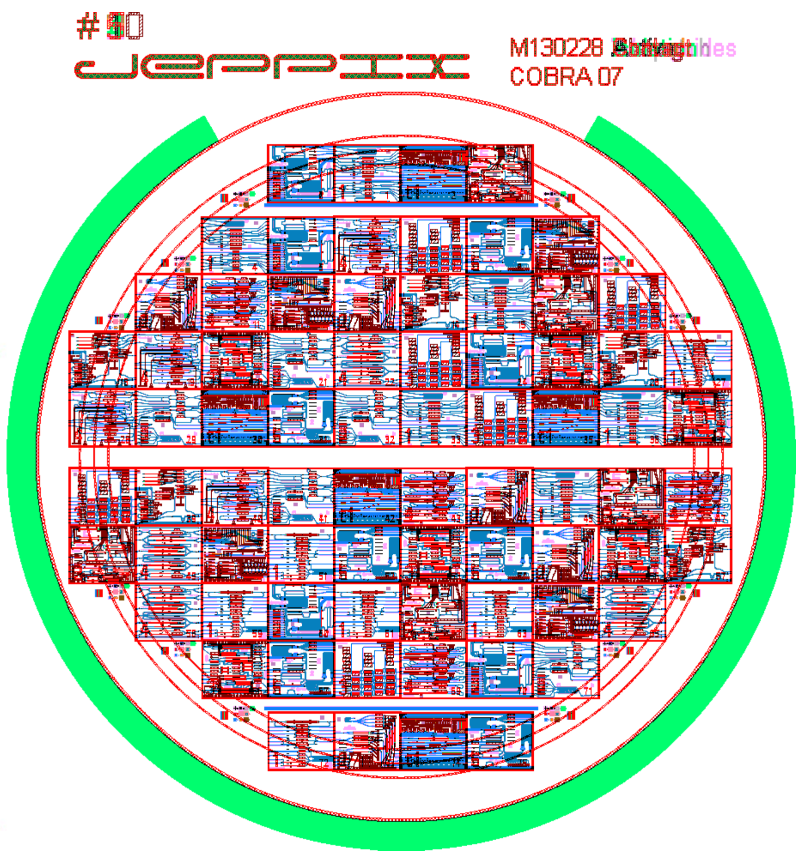
Increasing complexity

Increase of complexity:

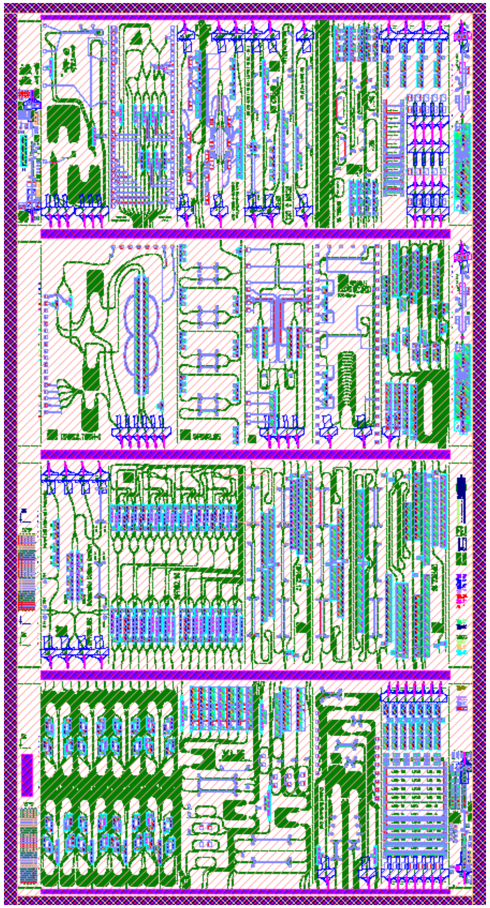
- At the ASPICs level
- At the mask/reticle level

Examples:

2005-2006

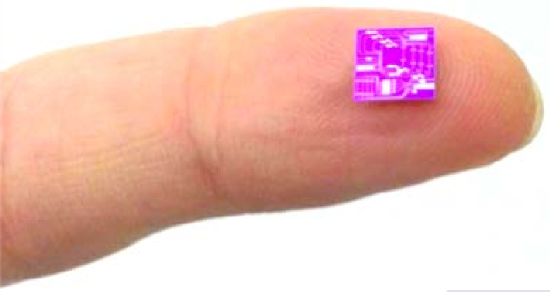


2011-2012



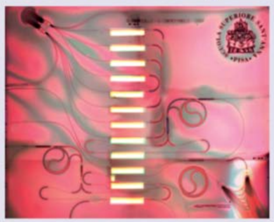
2014-2015

Photonic ICs : variety of applications

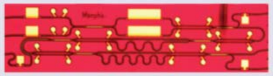


> 350 ASPICs fabricated in MPW runs

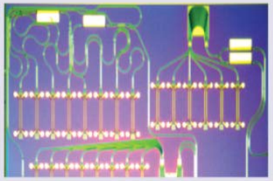
Optical data handling



All-optical regenerator for constant envelope WDM signals

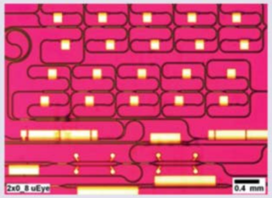


WDM to TDM Trans-Multiplexer

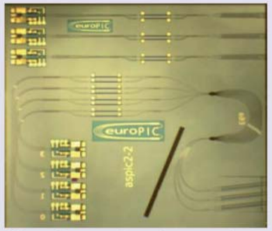


Pulse serialiser

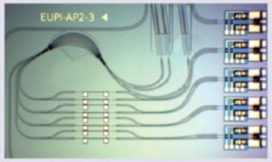
Fiber sensor readout



Brillouin strain sensor readout

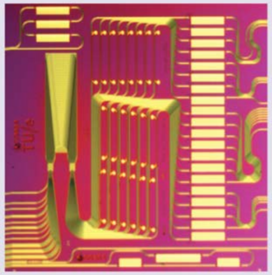


Fiber Bragg Grating readout

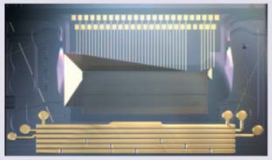


Fiber Bragg Grating readout

Medical and bio-imaging

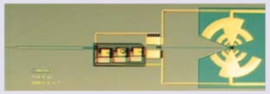


Pulse shaper for bio-imaging

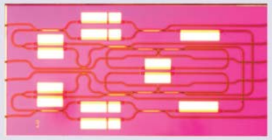


Integrated tunable laser for optical coherence tomography

THz Optical to RF converter

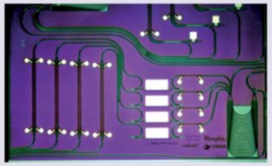


Variety of lasers



Widely tunable ring laser

Variable repetition rate pulse laser

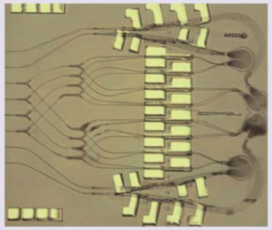


Filtered-feedback multi-wavelength laser

tunable laser with integrated MZI modulator

QPSK receiver

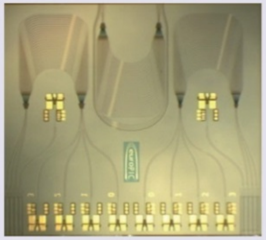
Optical switching



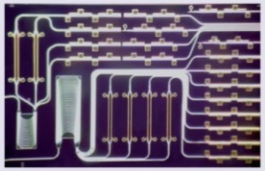
4x4 space and wavelength selective switch

Fast optical switch matrix

Fiber to the home



WDM receiver



WDM transmitter

Major Generic foundries

ePIXfab
The silicon photonics platform

http://www.epixfab.eu

Institute of Microelectronics
A*STAR

GLOBAL FOUNDRIES

amf
ADVANCED MICRO FOUNDRY

JePPIX

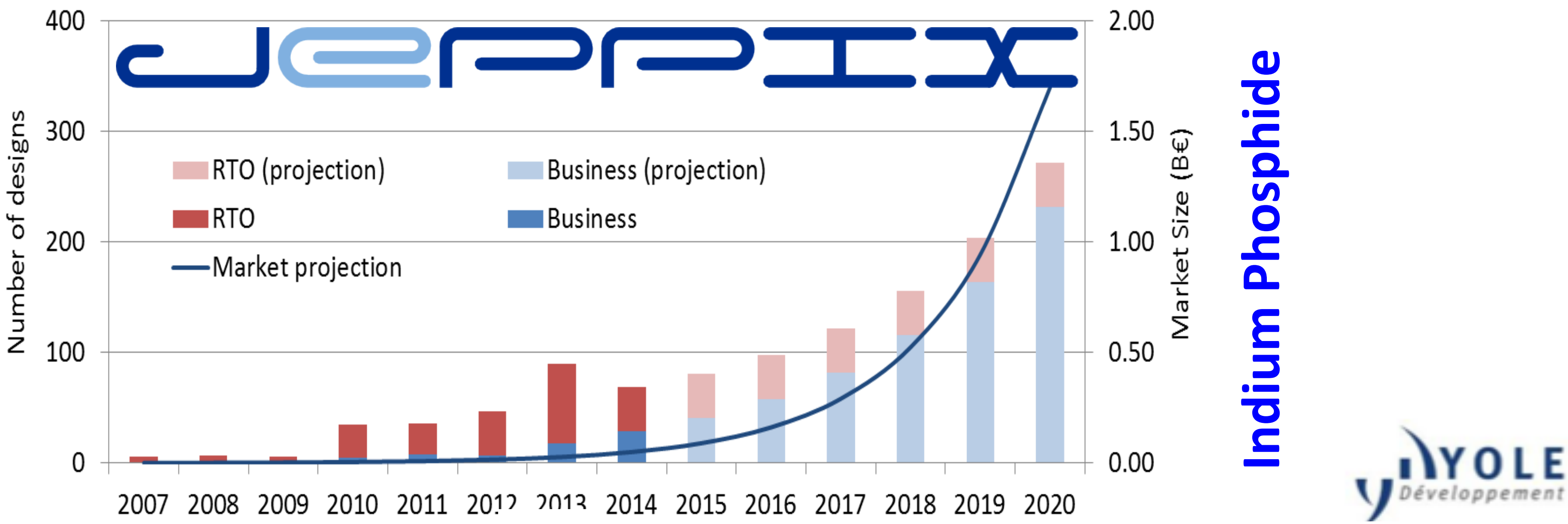
Indium Phosphide

http://www.jeppix.eu

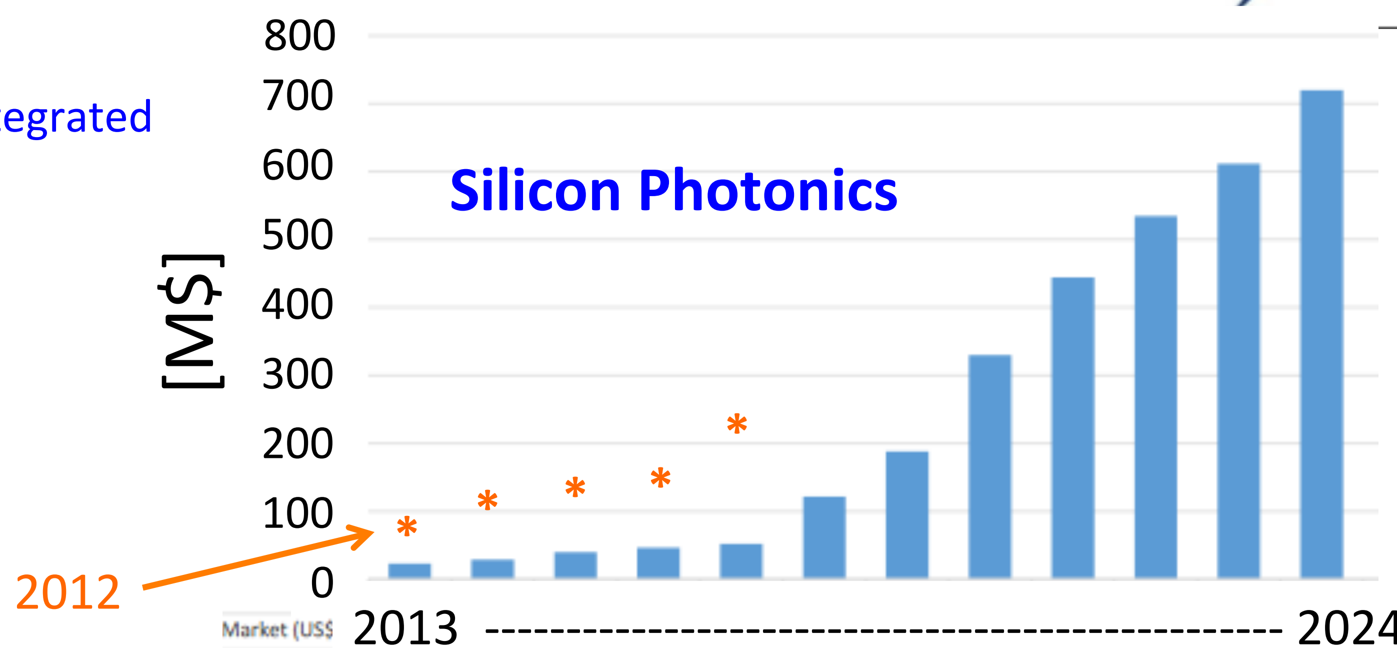
GLOBALFOUNDRIES Capacity: ~7M Wafers/Yr*

East Fishkill, New York	Malta, New York	Burlington, Vermont	Dresden, Germany	Singapore
				
TECHNOLOGY				
90nm–22nm	28nm, ≤ 14nm	350nm–90nm	45nm–22nm	180nm–40nm
CAPACITY IN WAFERS/MONTH				
14,000 (300mm)	Up to 60,000 (300mm)	40,000 (200mm)	60,000 (300mm)	68,000 (300mm) 93,000 (200mm)

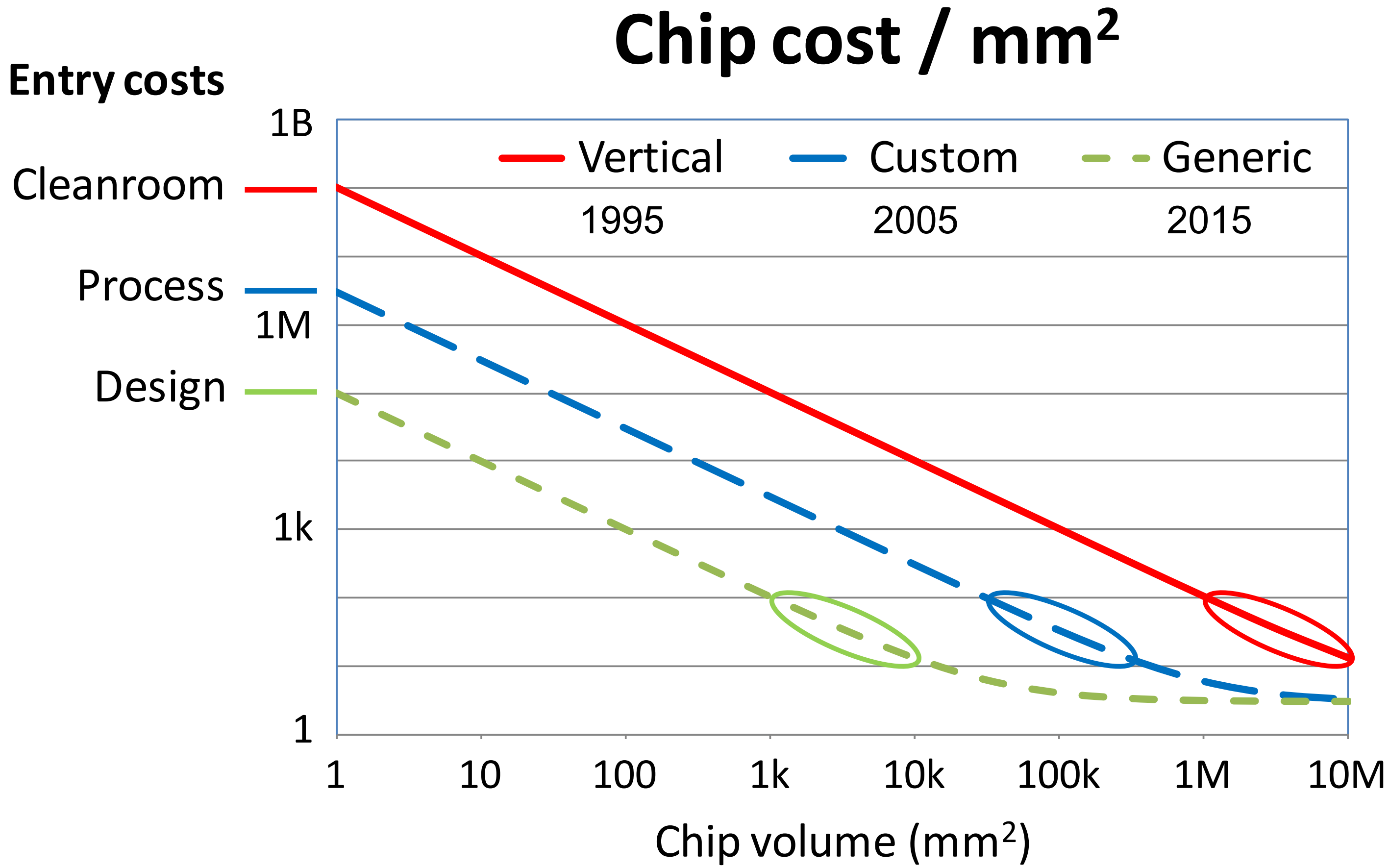
The (potential) market forecast



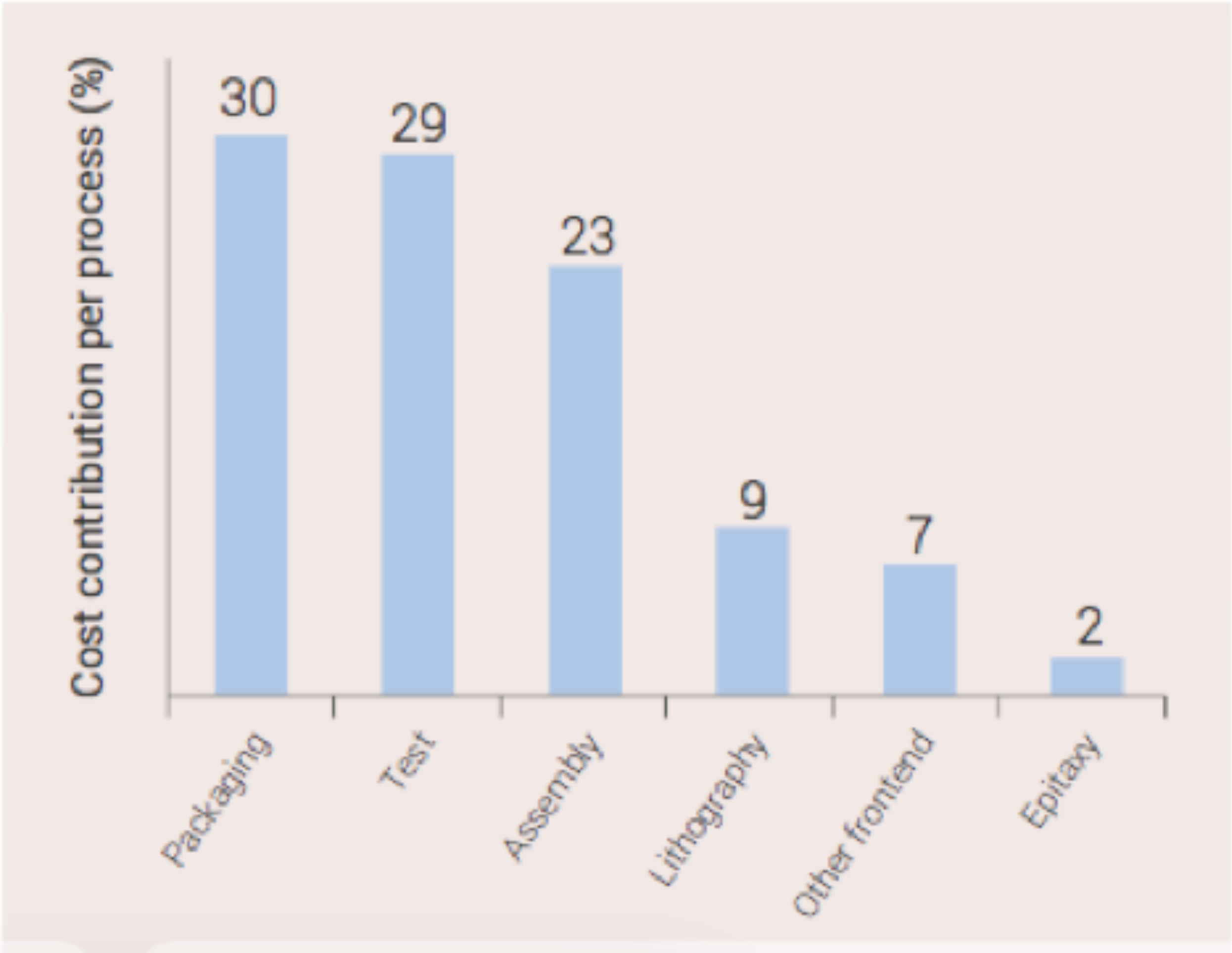
JePPIX Roadmap
Using Generic Integrated Photonics



Chip cost in different fab models



Manufacturing cost distribution (InP)



Market silicon photonics

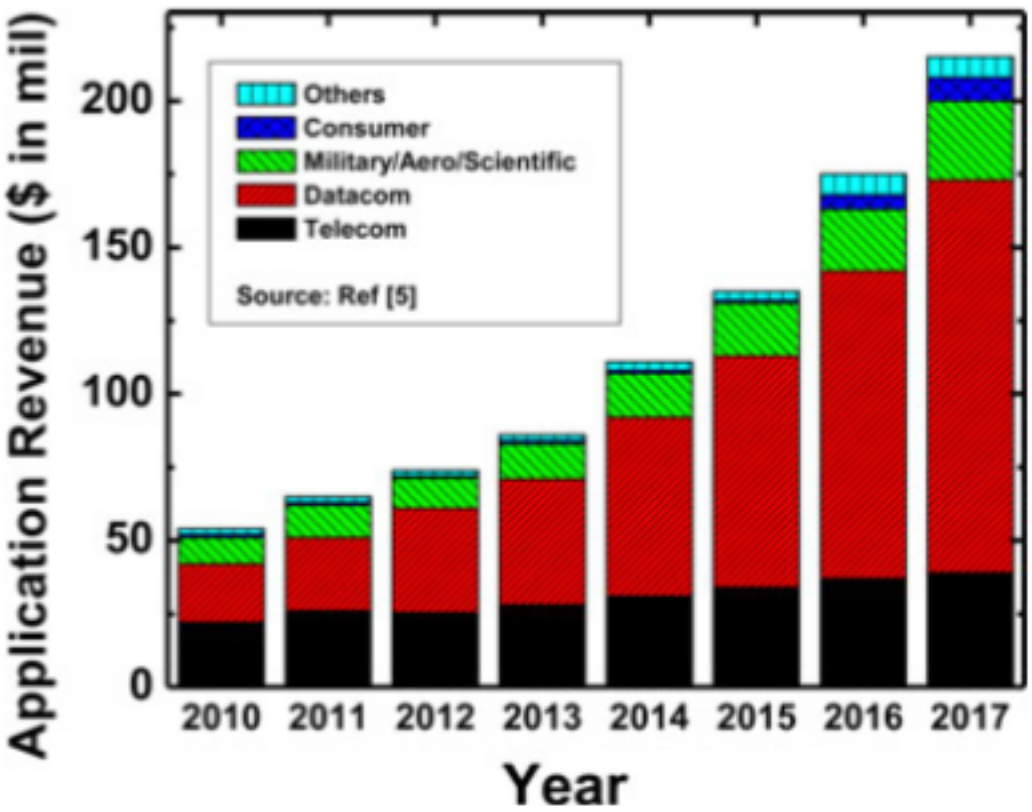


TABLE I

COMPARISON OF FULLY INTEGRATED SILICON PHOTONICS MPW PLATFORM (WITH PASSIVES AND ACTIVES) AVAILABLE IN R&D FOUNDRIES

	IME/OpSIS	IMEC/ePIXfab	CEA-LETI/ ePIXfab
Passives	Si passives with 60nm, 130 nm and 220 nm etch depths	Si passives with 70nm, 130 nm and 220 nm etch depths, extra poly-Si layer	Si passives with 70nm, 130 nm and 220 nm etch depths
Photodetector	Ge vertical *pin*	Ge vertical *pin*	Ge lateral *pin*
Modulator	Si MZ, Si ring	Si MZ, Si ring	Si MZ
Heater[1]	doped Si	doped Si	---
Couplers	Vertical and edge	Vertical	Vertical
Wavelength Supported[2]	1310 and 1550 nm	1310 and 1550 nm	1550 nm
CAD Tools	Mentor Graphics/ Lumerical	Mentor Graphics/ IPKISS/Phoenix	Mentor Graphics/ Phoenix
Packaging	PLC Connections/ Chiral	Tyndall National Institute	Tyndall National Institute
Pricing[3]	\$1800 - 2200 USD/mm^2	\$1330 – 1550 EUR/mm^2	\$1400 – 2500 EUR/mm^2

ROADMAP • FREE ARTICLE

Roadmap on silicon photonics

David Thomson[1,10,11], Aaron Zilkie[2], John E Bowers[3], Tin Komljenovic[3], Graham T Reed[1], Laurent Vivien[4], Delphine Marris-Morini[4], Eric Cassan[4], Léopold Virot[5,6], Jean-Marc Fédéli[5,6]

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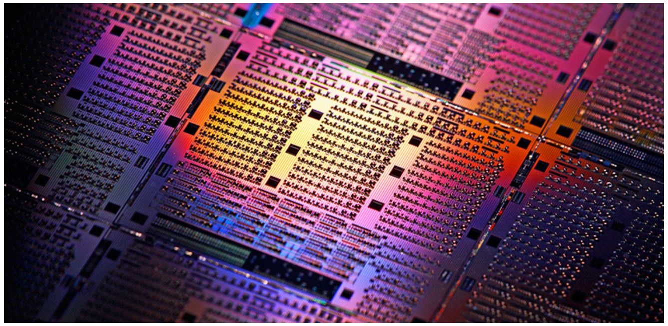
http://www.jeppix.eu

IPSR ROADMAP

https://aimphotonics.academy/roadmap/ipsr-roadmap



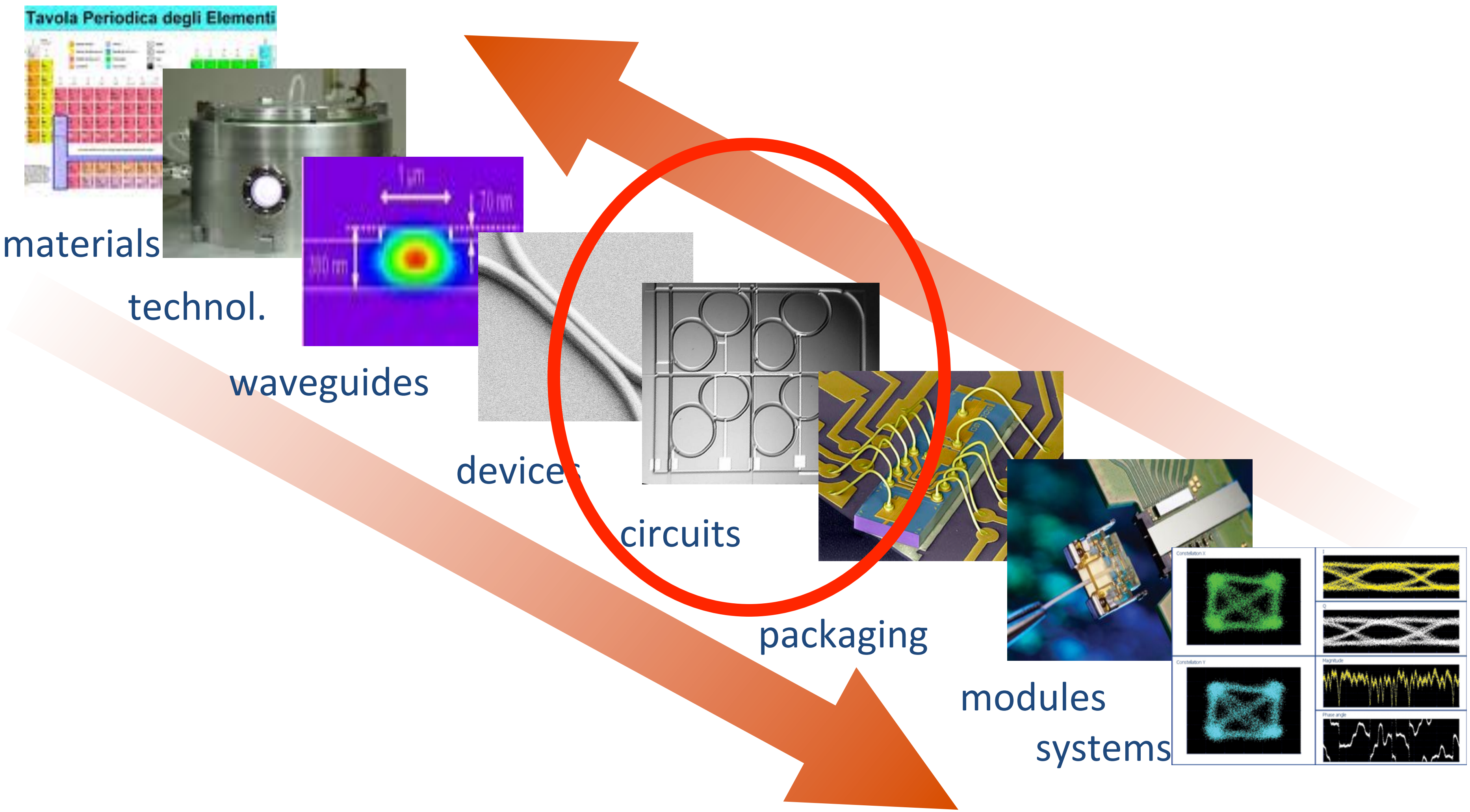
Dipartimento di Elettronica, Informazione e Bioingegneria
Politecnico di Milano – ITALY
Filarete srl - Milano

New Horizons for Integrated Photonics: from design to applications

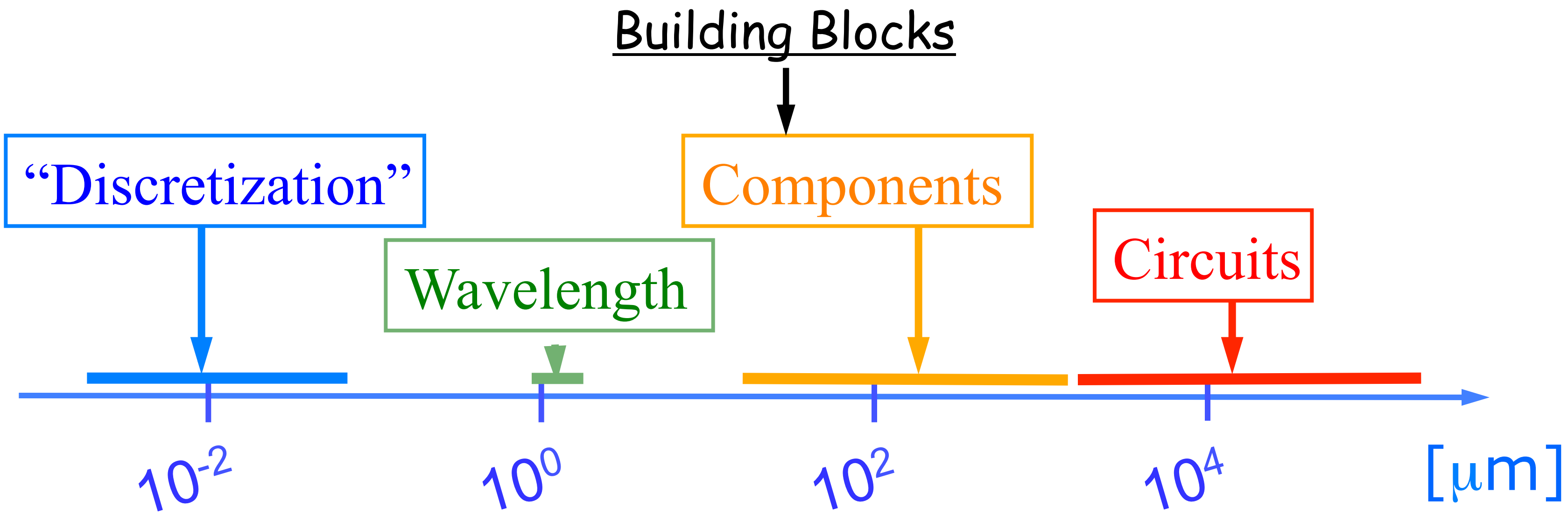
CIRCUIT APPROACH

A. Melloni

Logical process flow



Analysis, design, study of large and complete optical circuits



- The key point is the 'model', which describes the behavior of the circuits' building blocks
- The BBs are described by models that collect all the microscopic details and to be used at macroscopic level

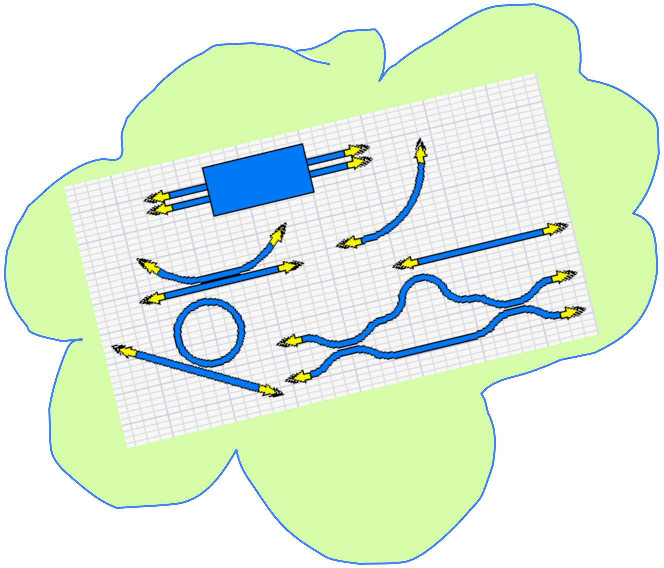
Electromagnetic approach (physical modeling) vs Circuit approach (high abstraction level)

$$\nabla \times \mathbf{E} = -j\omega\mathbf{B}$$

$$\nabla \times \mathbf{H} = j\omega\mathbf{D} + \mathbf{J}$$

$$\mathbf{B} = \mu\mathbf{H}$$

$$\nabla \bullet \mathbf{D} = \rho$$



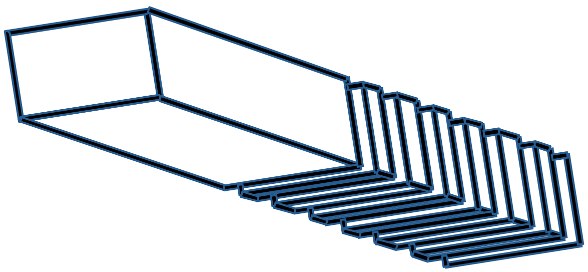
- flexible (no modeling required)
- needs and gives physical parameters
- large time and memory requirements
- suitable for small elements

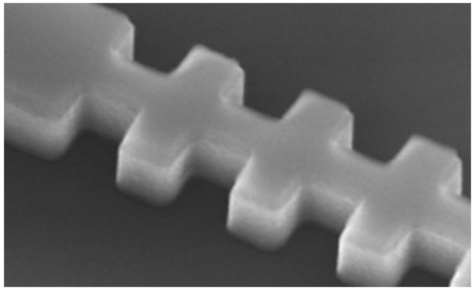
- requires a modeling
- non information on geometry & materials
- access only to input/output port waves
- very fast, suitable for large circuits

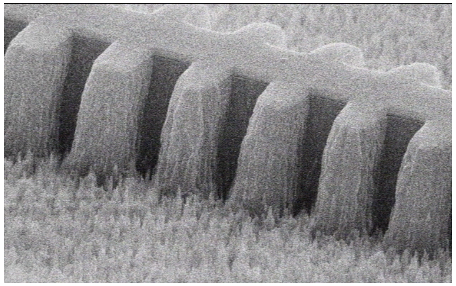
Accuracy

The wave equation: $$\nabla^2 \mathbf{E_t} + \nabla(\mathbf{E_t} \cdot \nabla \ln \varepsilon) + (\boldsymbol{\omega^2} \varepsilon \boldsymbol{\mu_0} - \boldsymbol{\beta^2})\mathbf{E_t} = \mathbf{0}$$

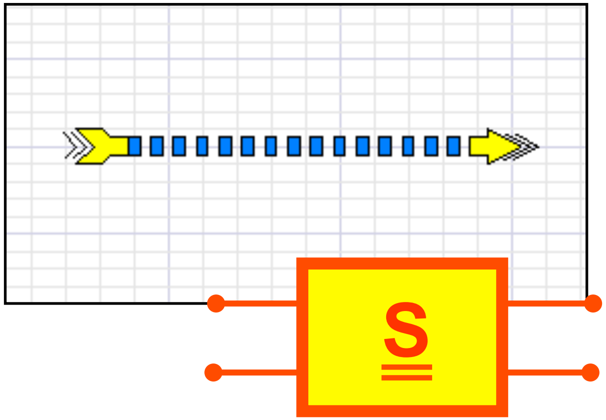
BPM, FDTD, FEM, EME, MoL, MM, IE, ….





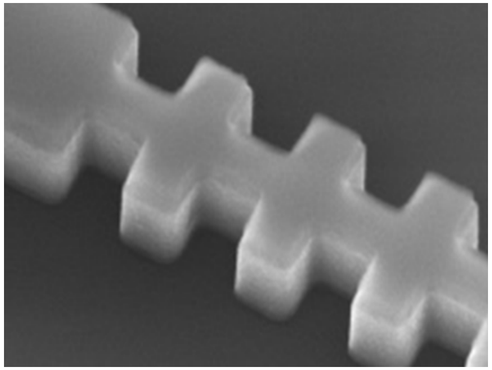


The model / BB / S matrix



- higher abstraction level
- model (preprocessing)
- single/multi mode
- measure/datasheets/EM results

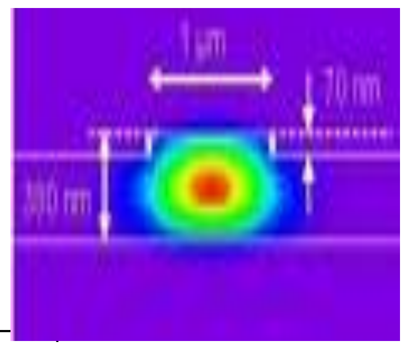
Modelling of photonic Building Blocks



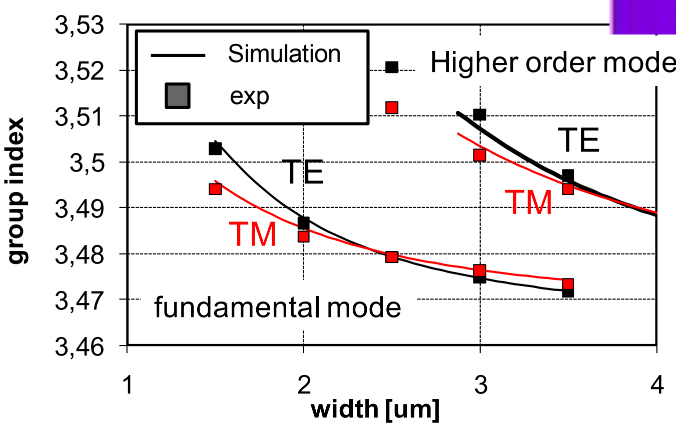
EM analysis

$$\nabla \times \mathbf{E} = -j\omega\mathbf{B}$$
$$\nabla \times \mathbf{H} = j\omega\mathbf{D} + \mathbf{J}$$
$$\mathbf{B} = \mu\mathbf{H}$$
$$\nabla \bullet \mathbf{D} = \rho$$

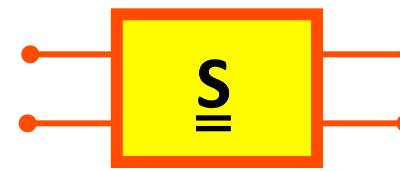
Numerical simulations



Characterization



BB model

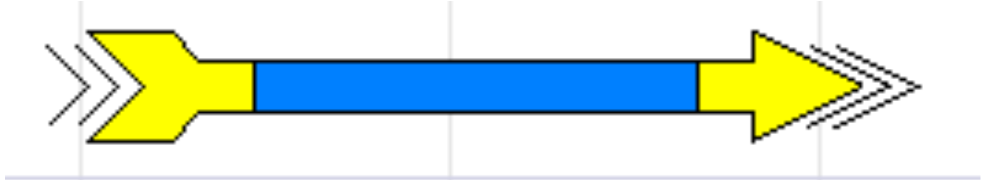


Circuit approach

(high abstraction level)

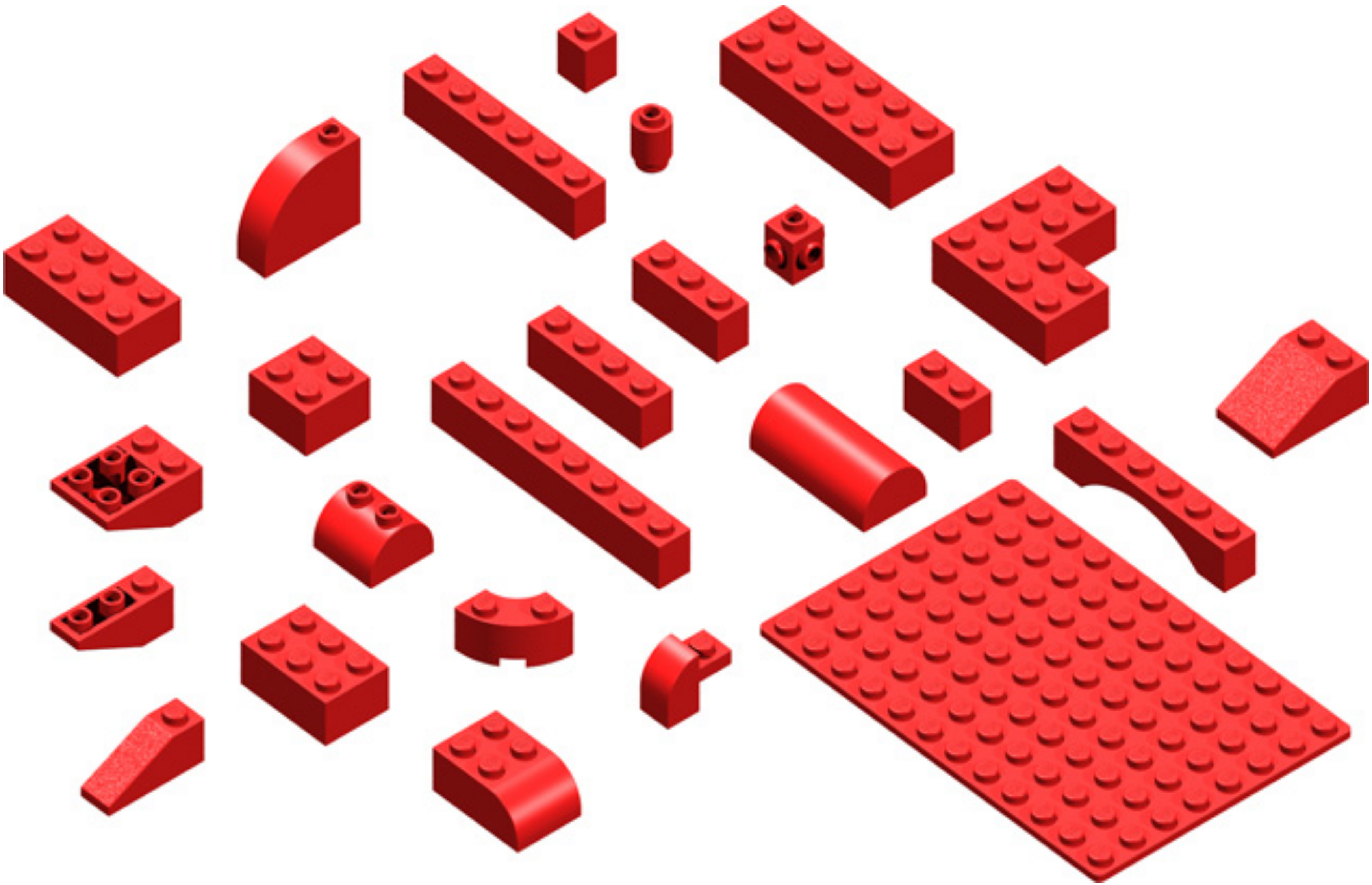
- realistic model
- no information on geometry & materials
- access only to input/output port waves
- very fast, suitable for large circuits

The model of a straight waveguide

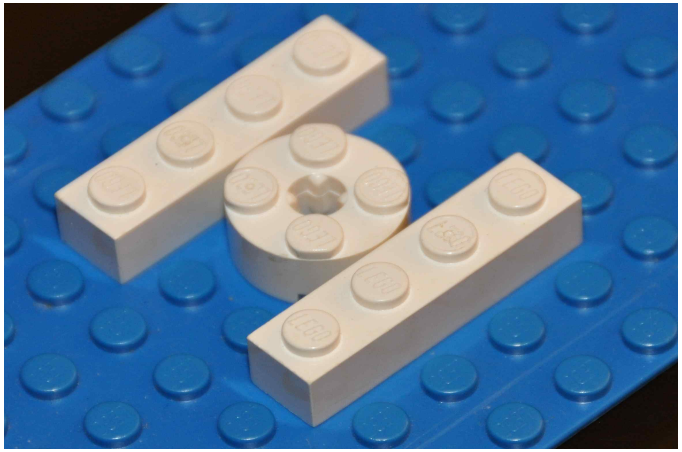


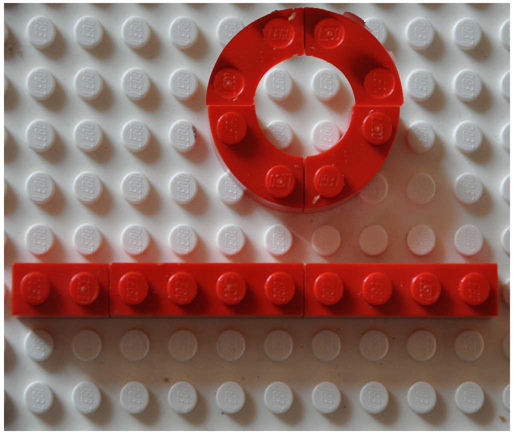
- *1*
- $e^{-\alpha L - j\beta L}$
- *α , β f (λ, temperature, I, V, E and H field, statistics, aging … solar wind, radioactivity !)*
- *TE / TM: birefringence, multimode, mode coupling,…*
- *Input/output modal mismatch*
- *Parasitic interactions, backscatter*
- *Nonlinearities*

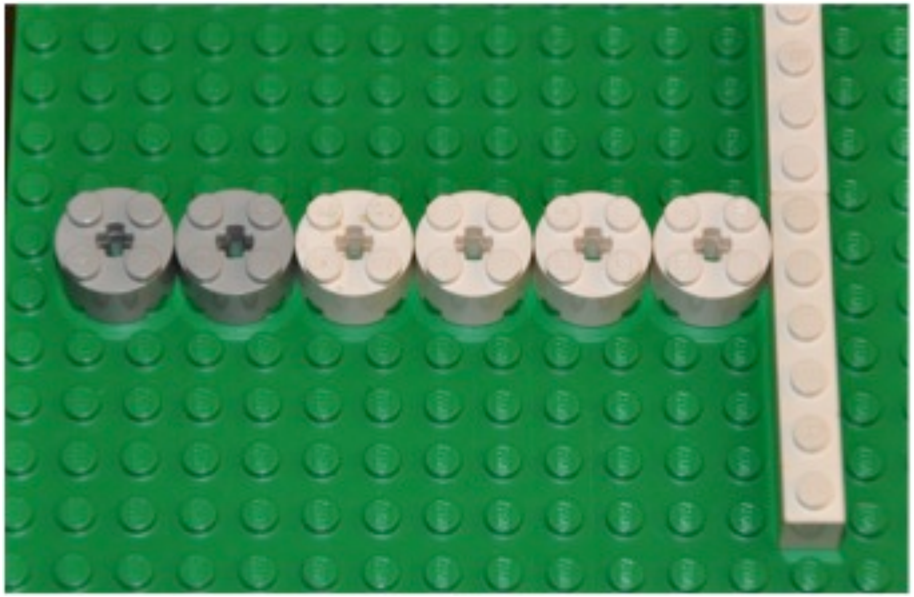
The Building Blocks

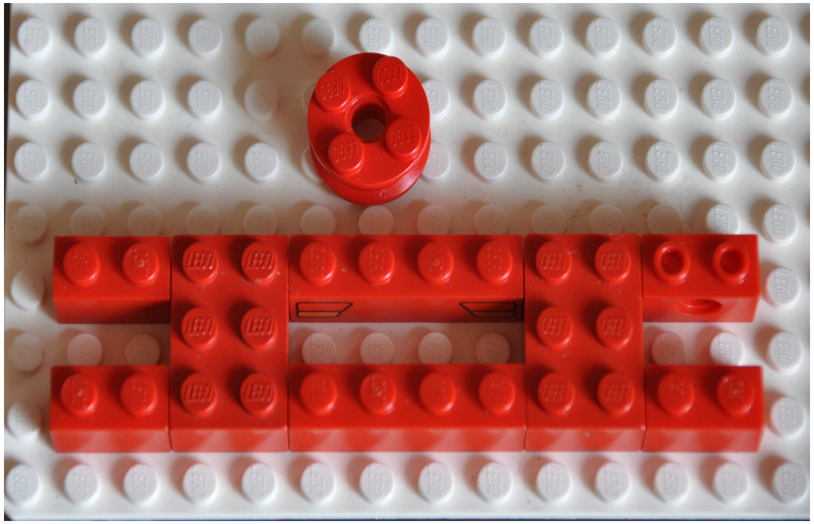


The Composite Building Blocks

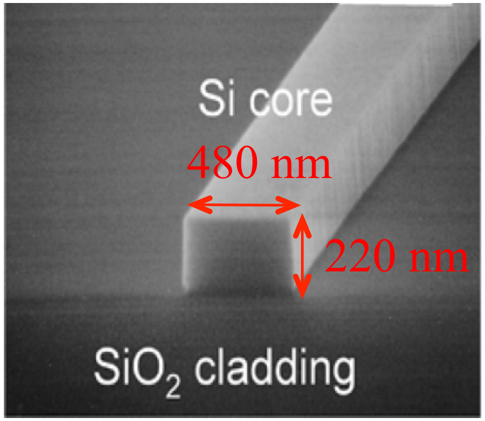


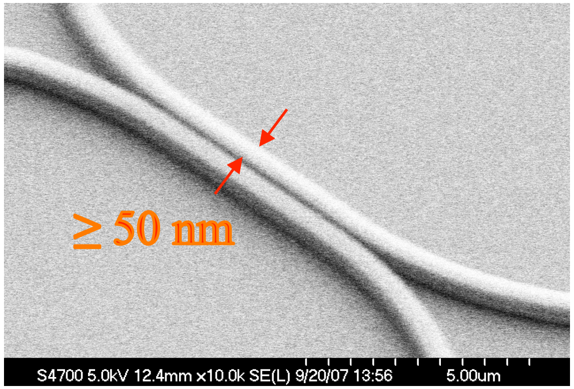






Some physical Building Blocks

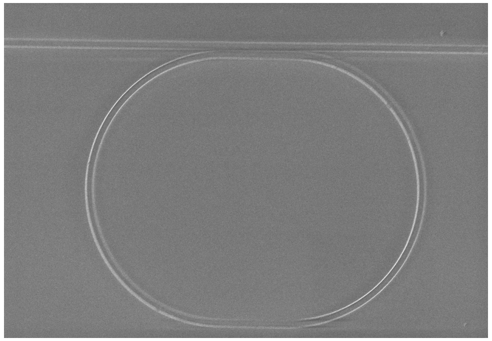


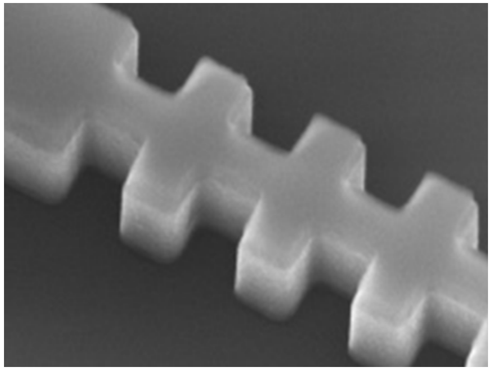


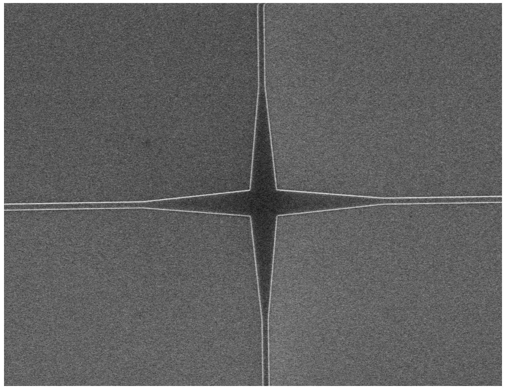
TU/e

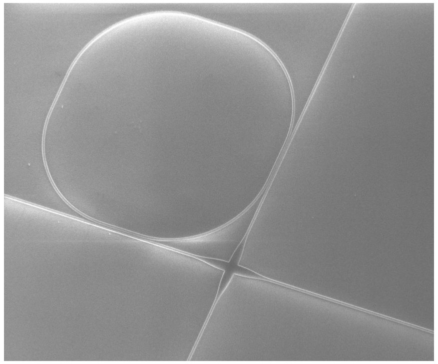
HHI

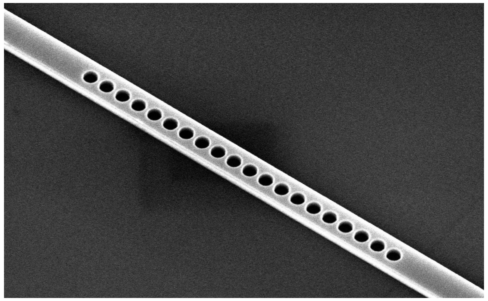
oclaro

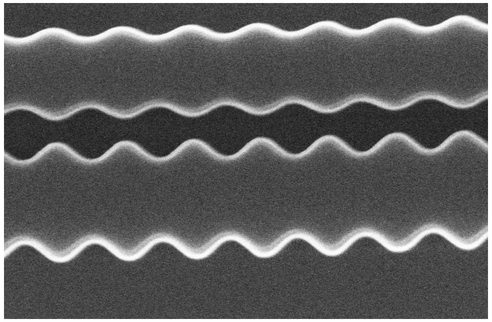




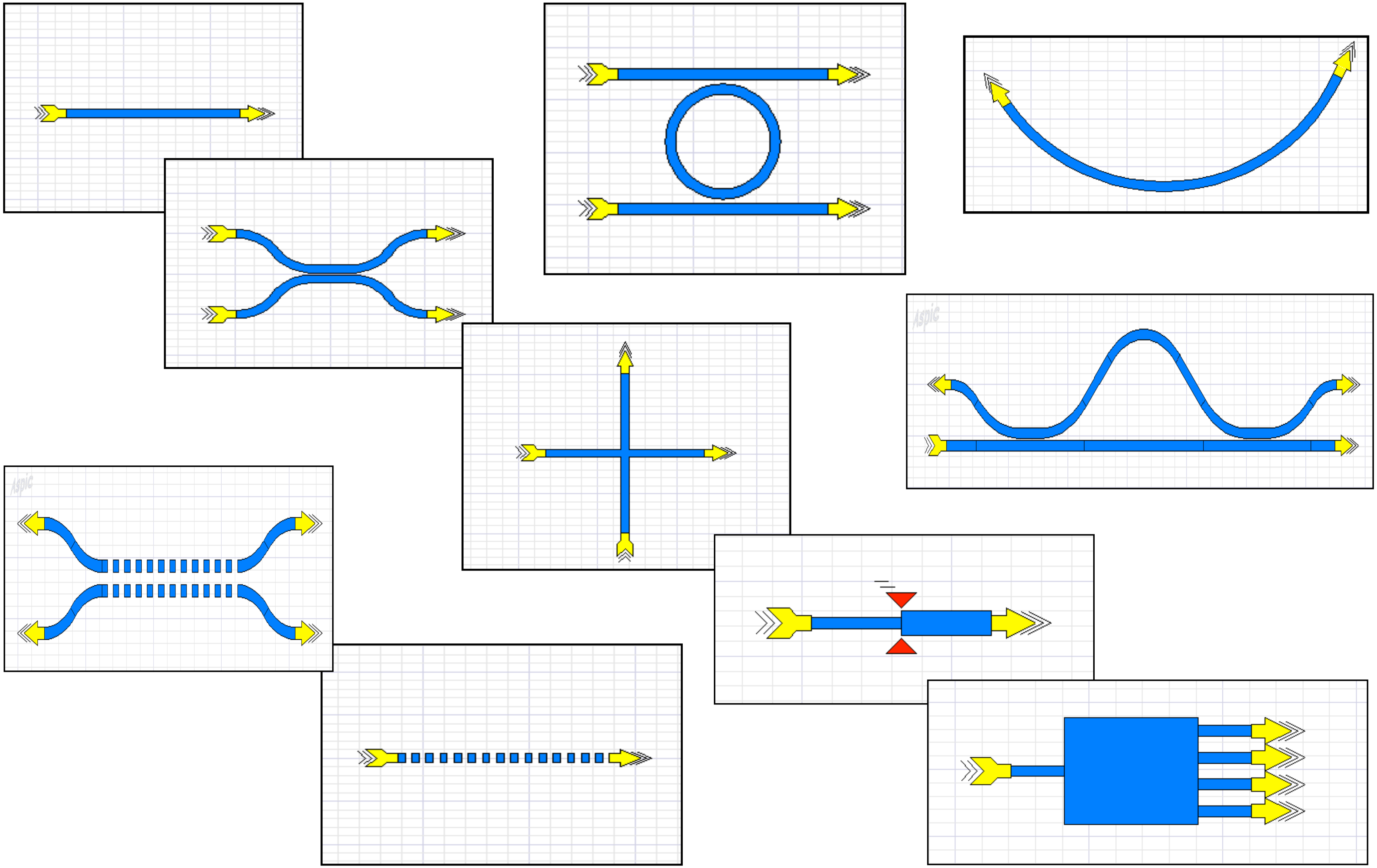




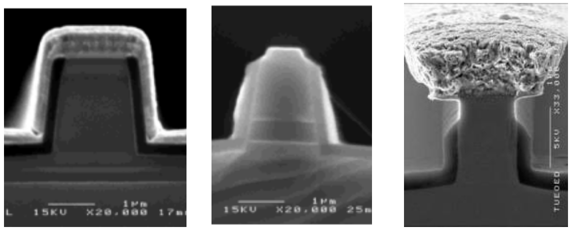




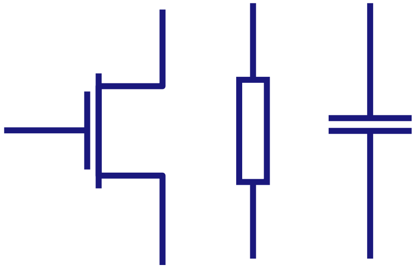
The (SOI) Building Blocks Library



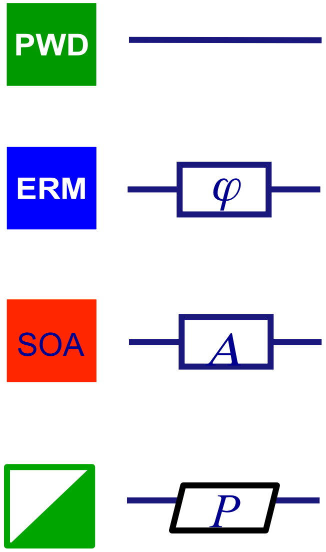
Generic Integration philosophy



Electronic integration
3 basic elements



Photonic integration
4 basic elements

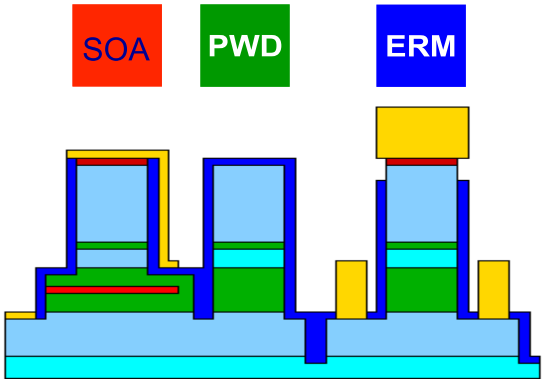


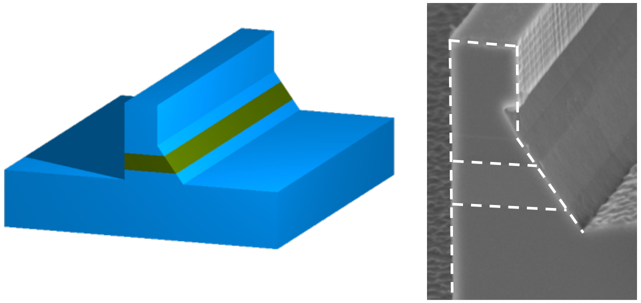
Waveguide

Phase

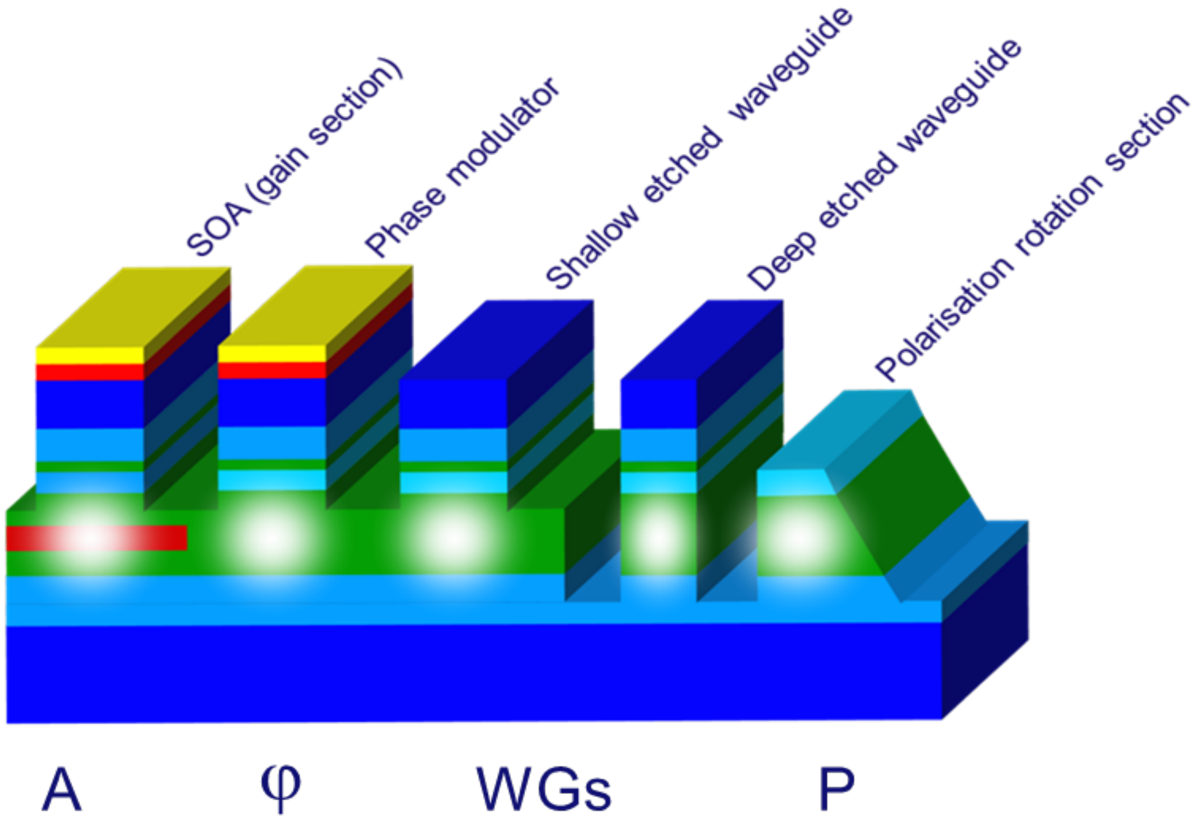
Amplitude

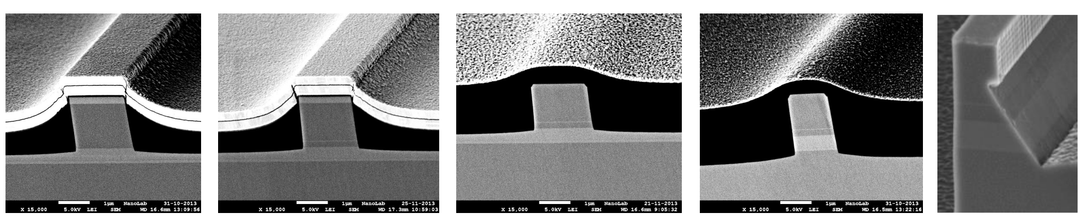
Polarisation





Integration of building blocks in a single chip

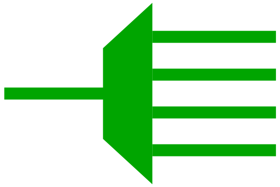




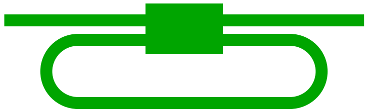
All kinds of passive devices …

MMI-couplers and filters

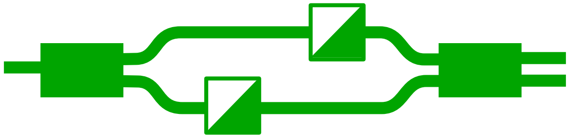
MMI-reflectors



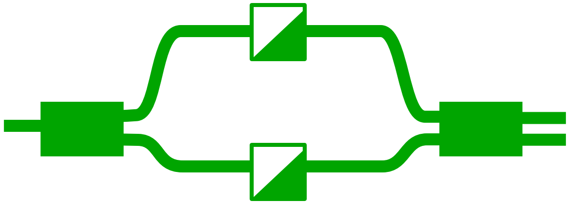
AWG-demux



ring filters

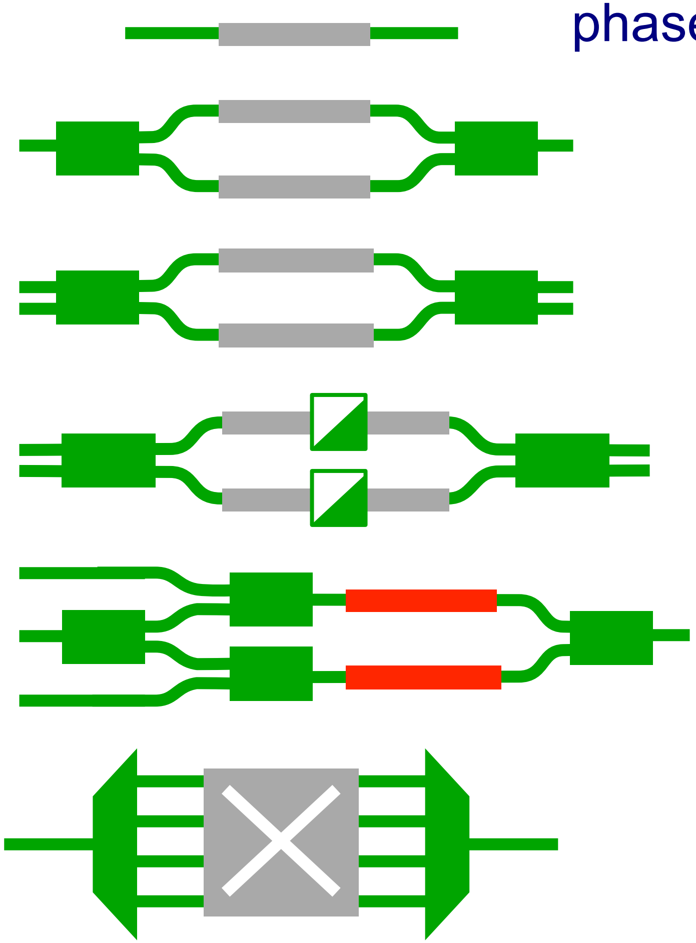


polarisation splitters
polarisation combiners



polarisation independent
differential delay lines

switches and modulators …



phase modulator

amplitude modulator

fast space switch

polarisation independent 2x2 switch

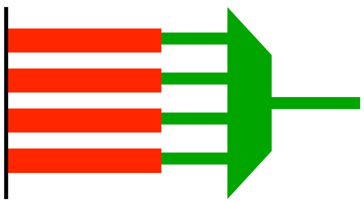
ultrafast switch

WDM crossconnect
WDM add-drop

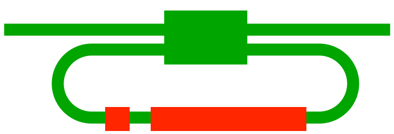
All kinds of lasers …

Fabry-Perot lasers

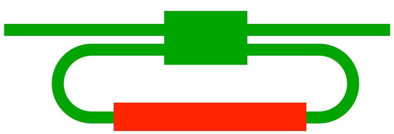
tunable DBR lasers



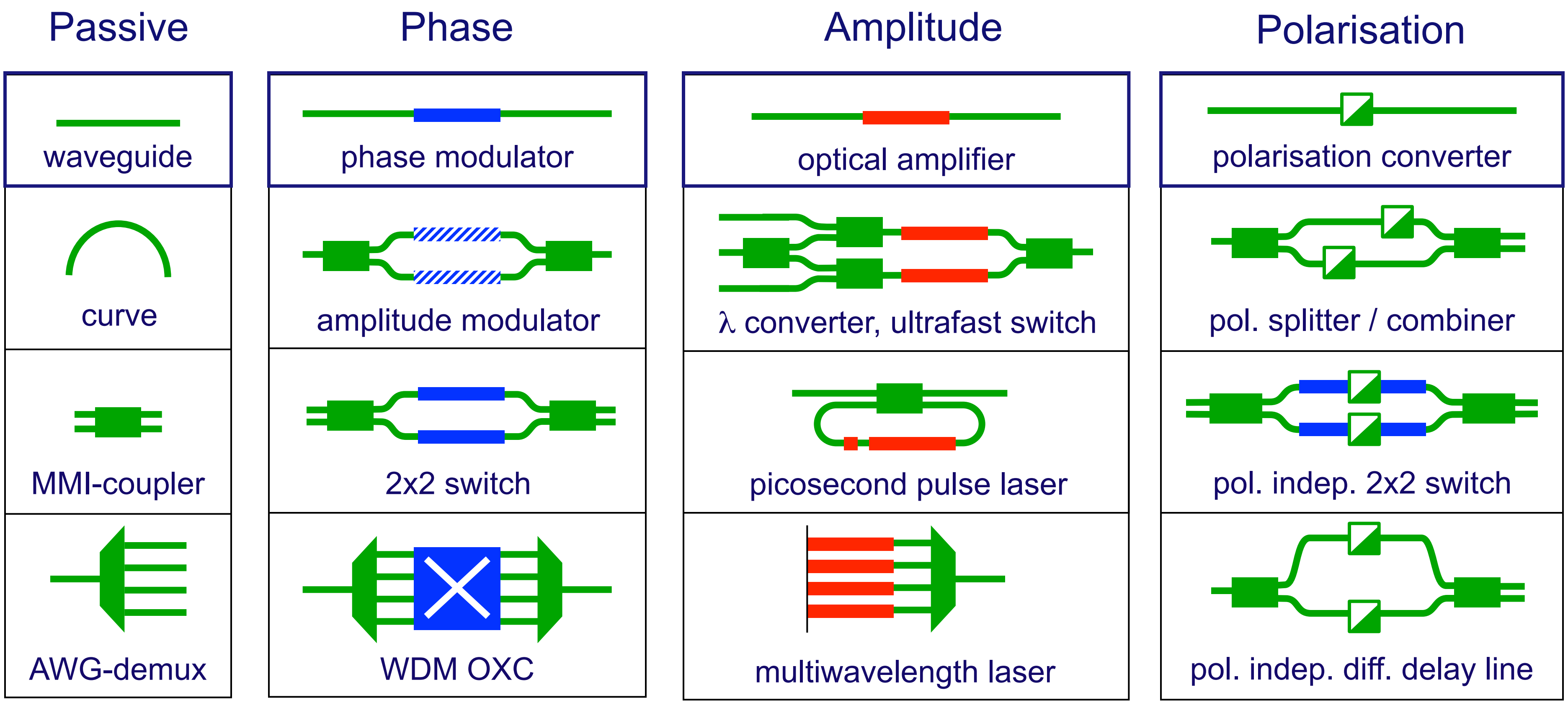
multiwavelength lasers



picosecond pulse laser

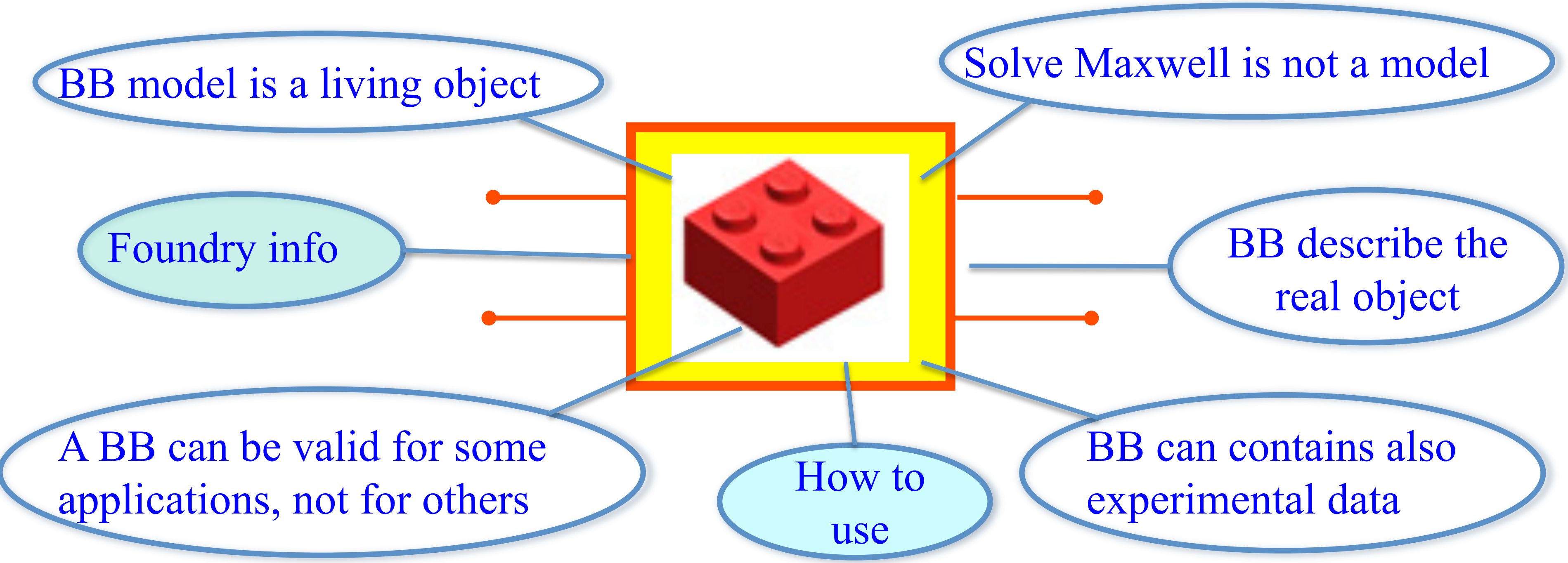


ring lasers


Passive
Phase
Amplitude
Polarisation
waveguide
phase modulator
optical amplifier
polarisation converter
curve
amplitude modulator
λ converter, ultrafast switch
pol. splitter / combiner
MMI-coupler
2x2 switch
picosecond pulse laser
pol. indep. 2x2 switch
AWG-demux
WDM OXC
multiwavelength laser
pol. indep. diff. delay line

Building blocks and Design kits

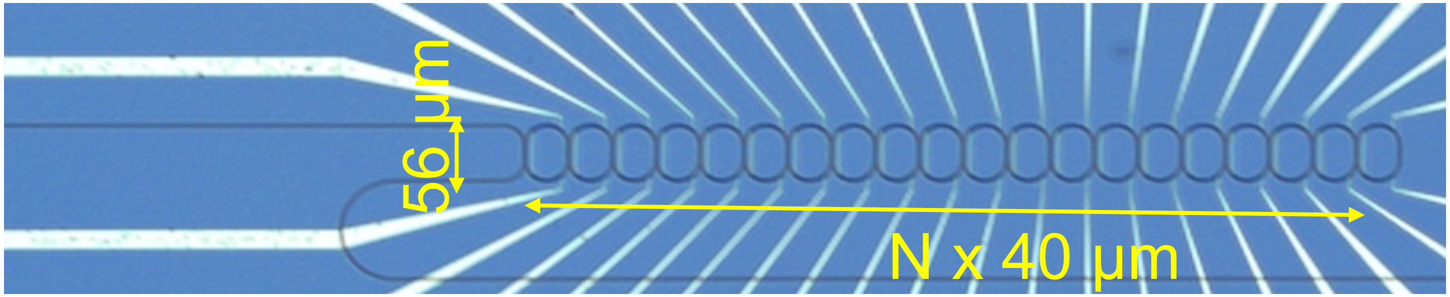
BB comes from a cooperation:
Foundry + Designer + BB builder



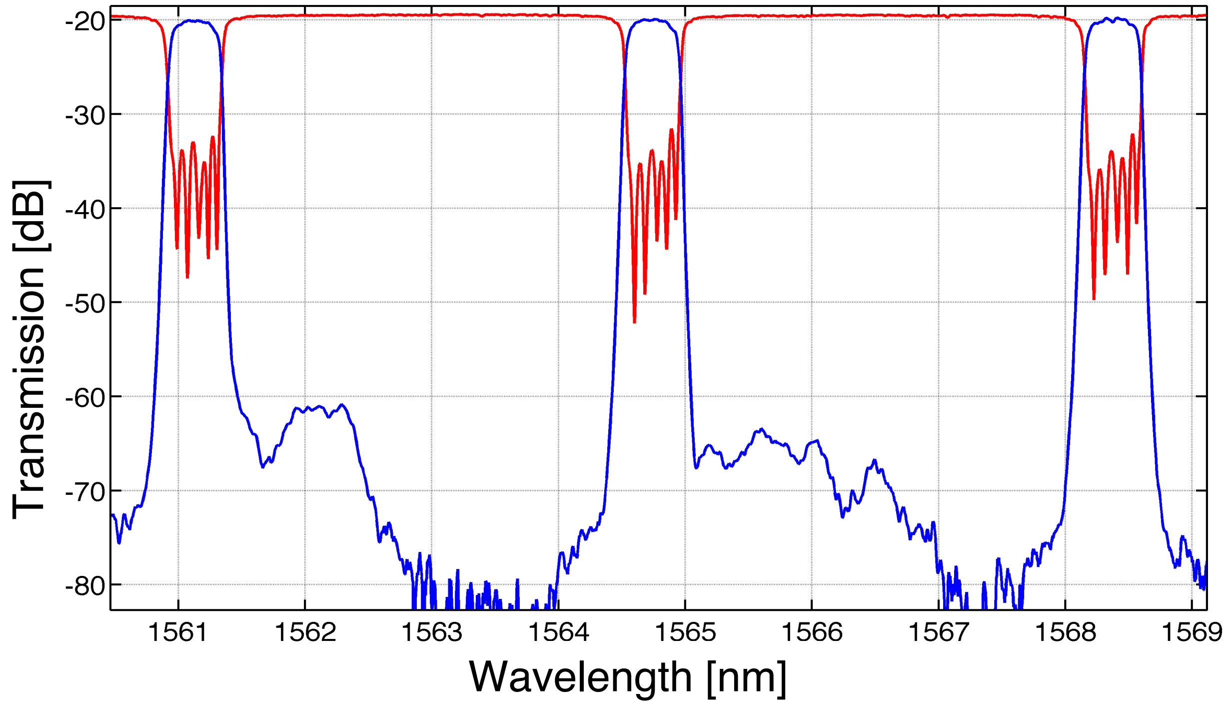
Effective index n_{eff} is the most important parameter

Effective index n_{eff} is useless !

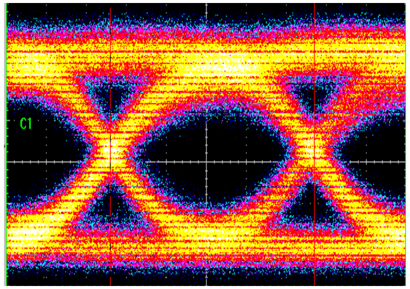
Circuit = Σ Building Blocks



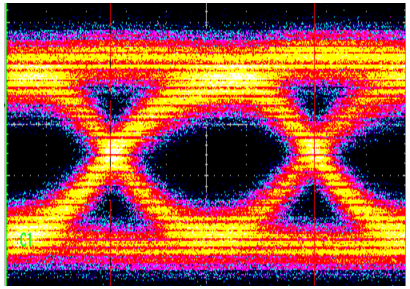
Tunable delay line 0÷8 bit @ 10…100 Gbit/s

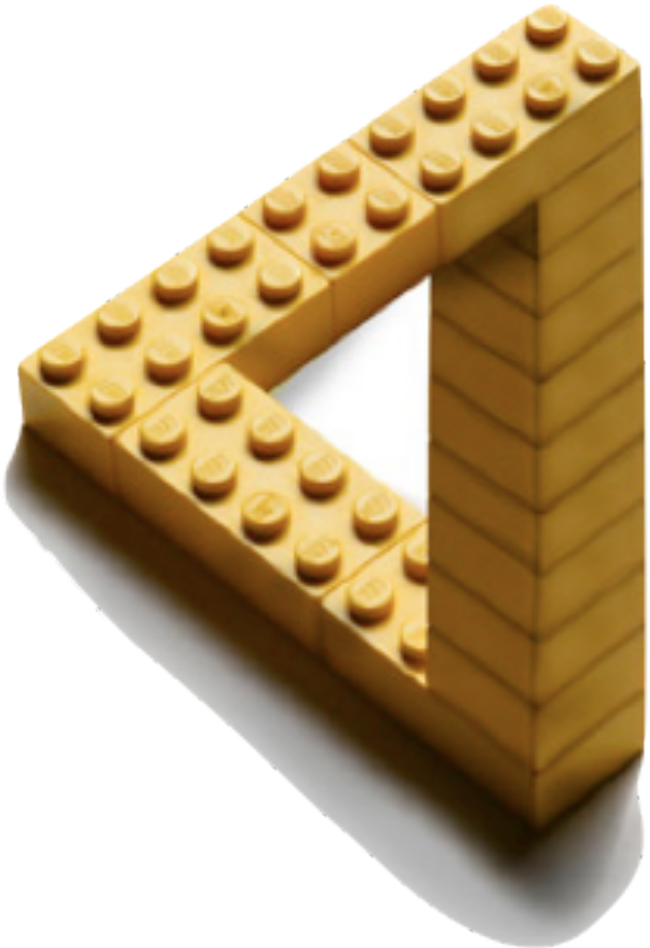


OOK, 10 Gbit/s



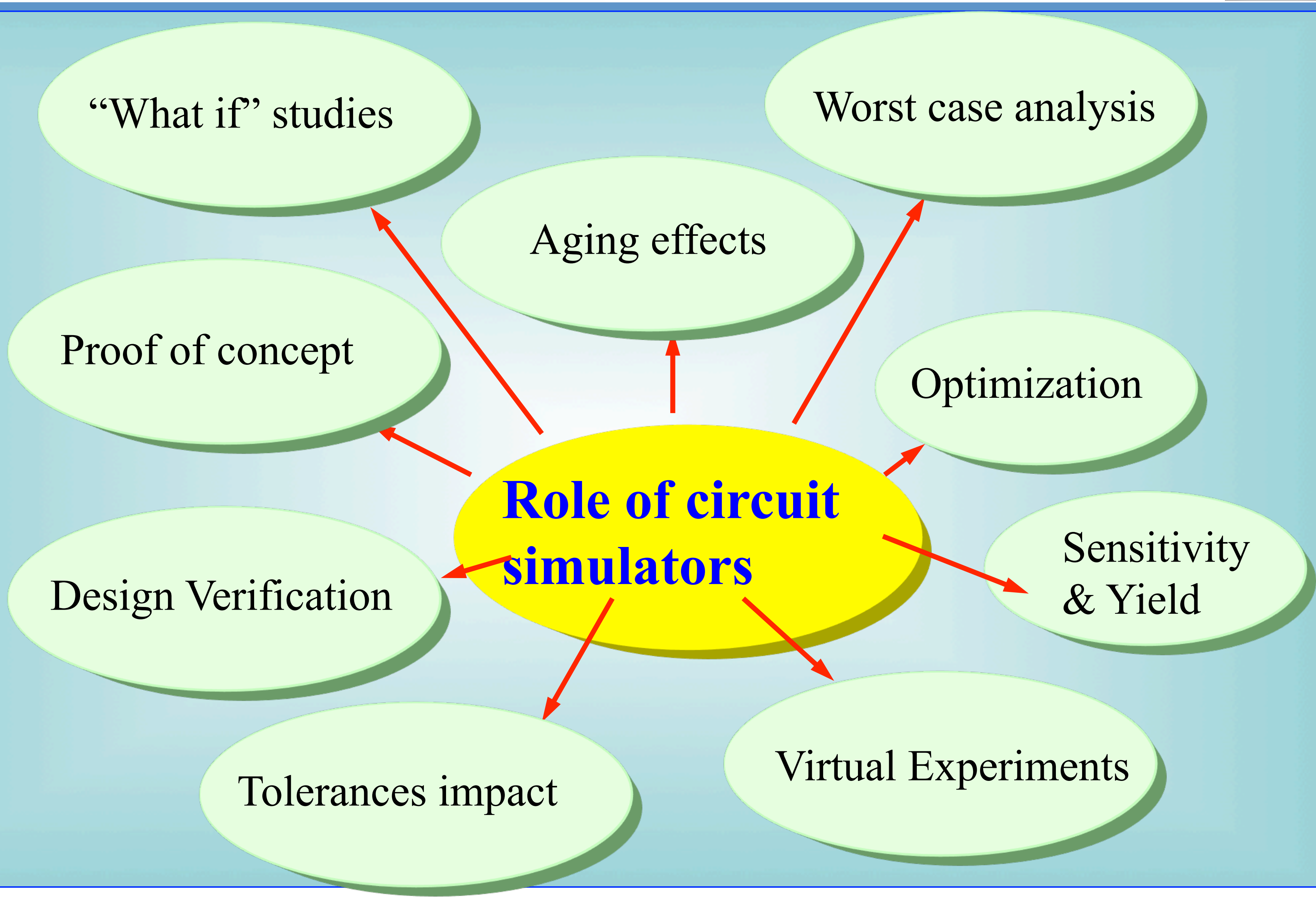
Delay: 50 ps





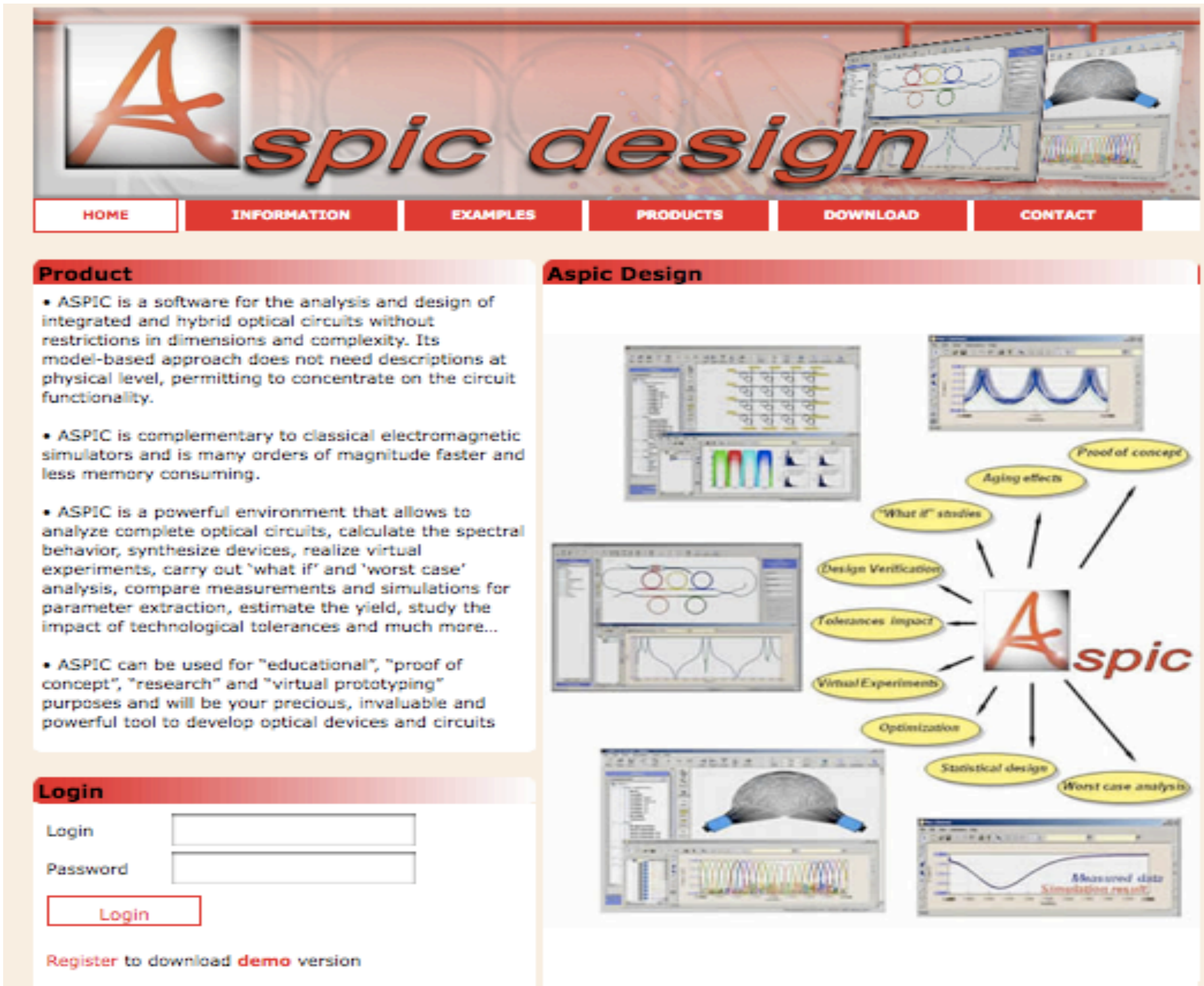
Functionality → Topology

Fill the gap between components and systems



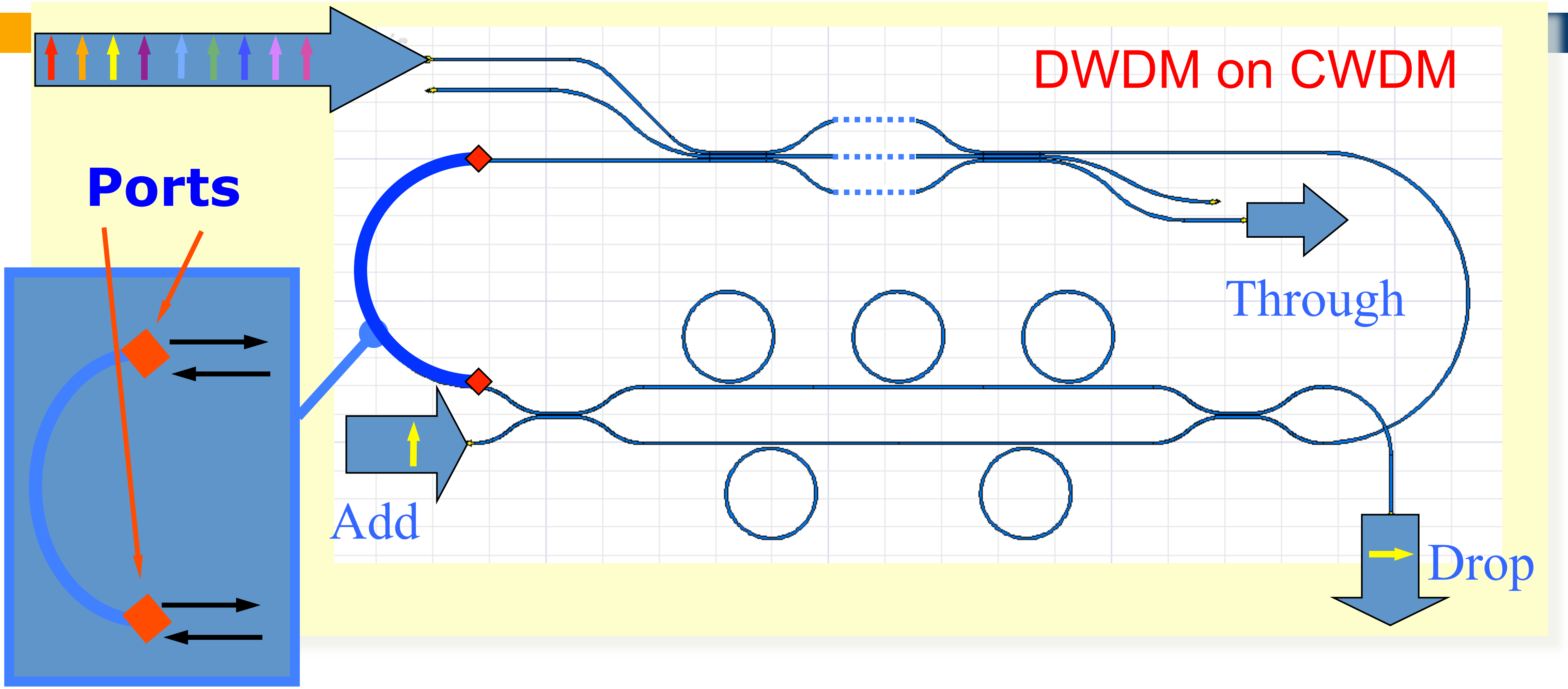
CITCUIT SIMULATOR

www.aspicdesign.com



www.phoenixbv.com

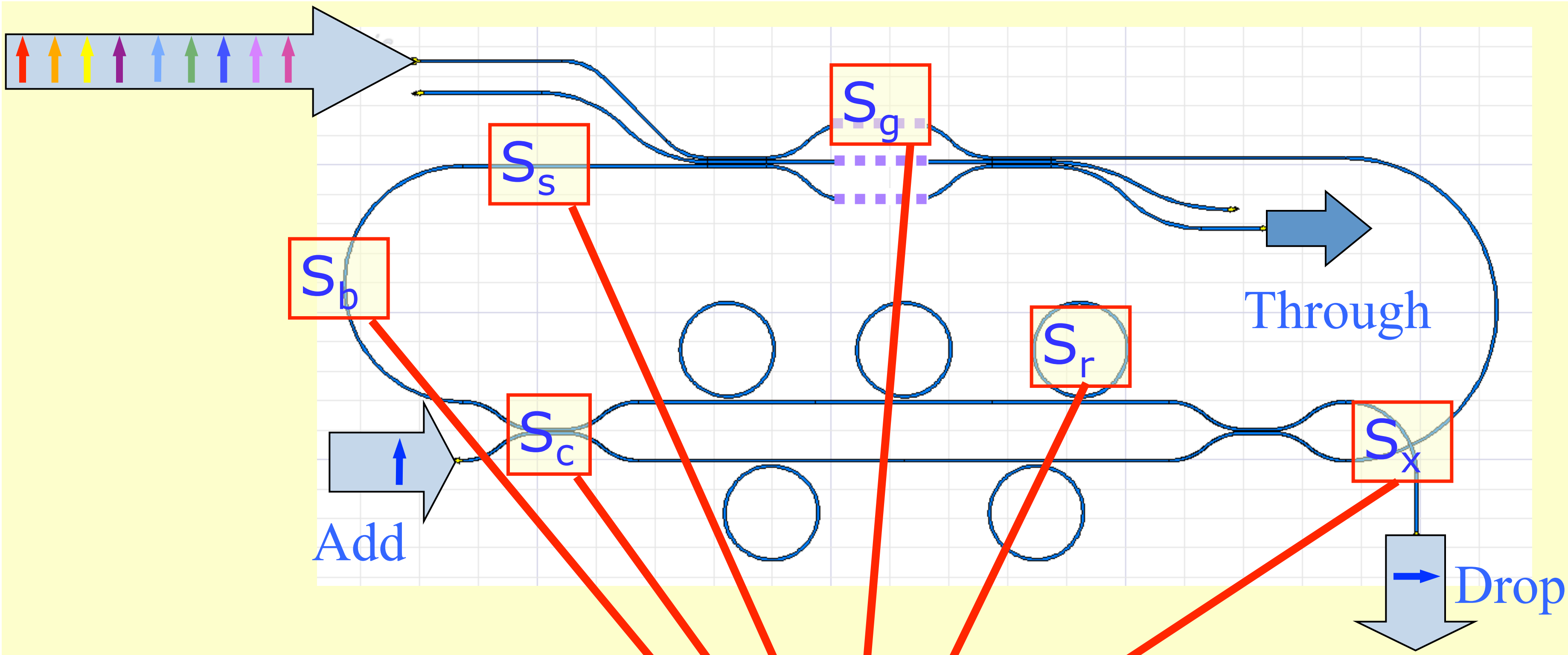
Analysis of the circuit



Each element of the circuit has N ports where the complex amplitudes of input and output waves are specified.

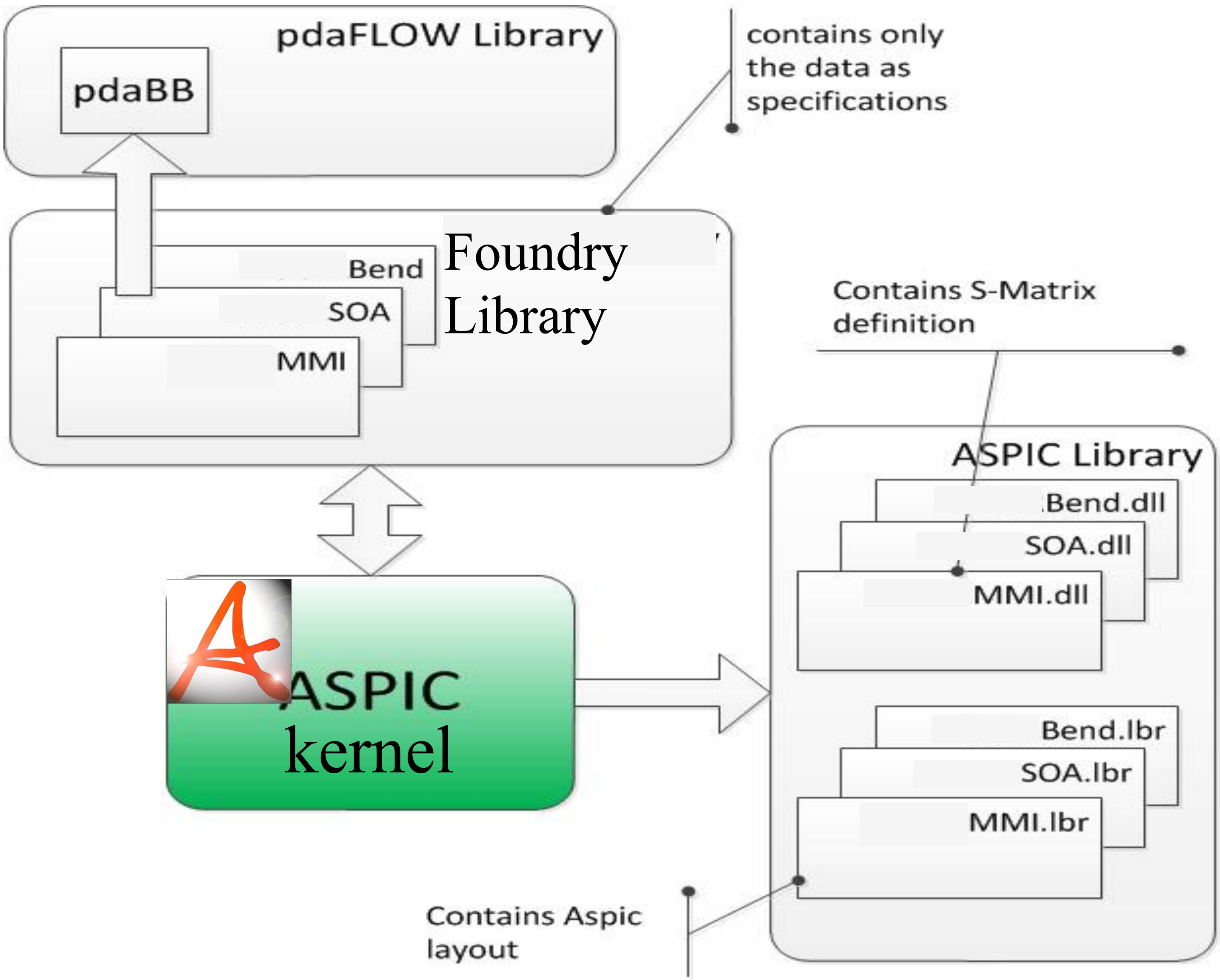
Each element is described by a Scattering matrix

Matrix description of the circuit



$$Out=[S]\cdot In$$

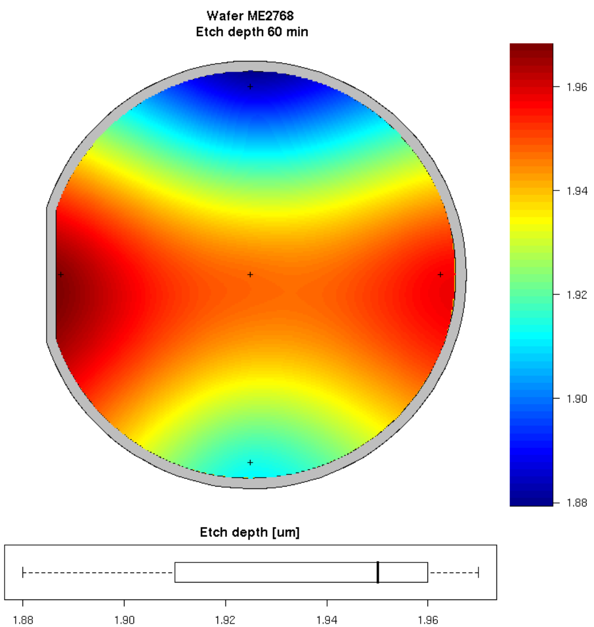
Structure of a circuit simulator (ASPIC)



Statistics of parameters…

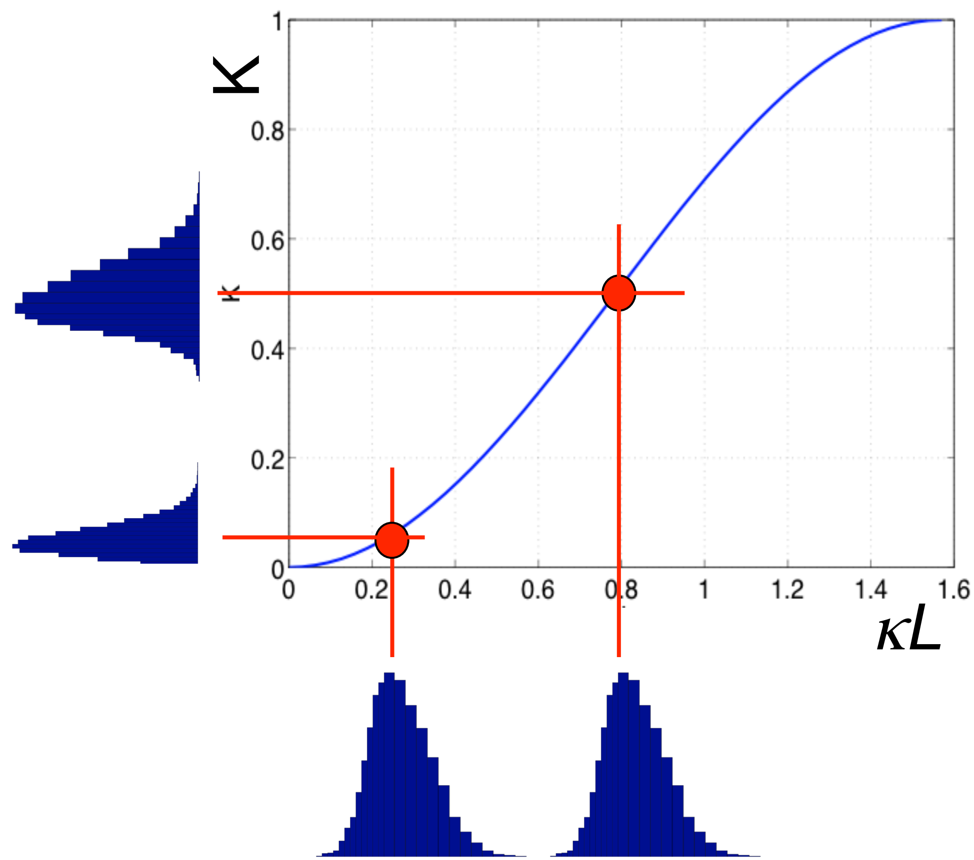
n_{eff}

Etching depth
Layers thickness
Material homogeneity
Stress & Strain
Linewidth

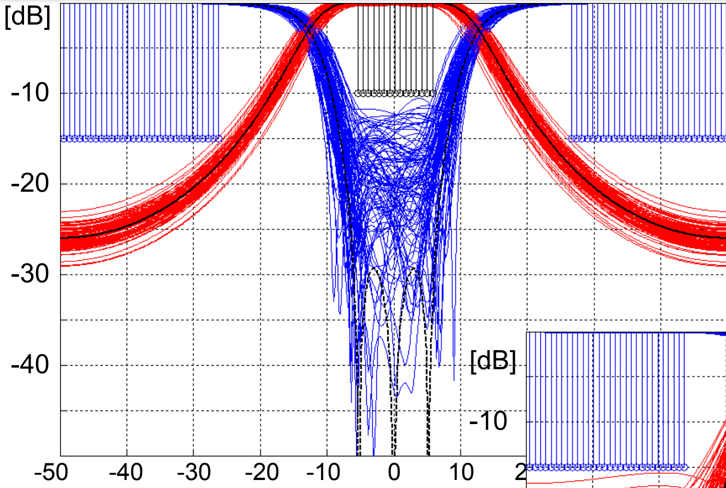


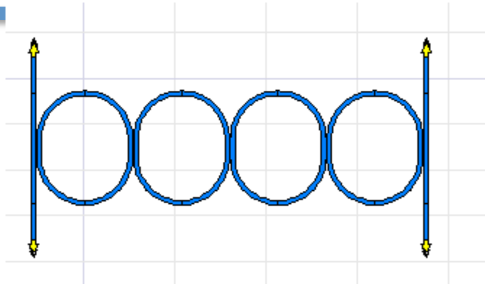
Directional couplers

$$K = \sin^2(\kappa L) = \sin^2(\kappa_0 e^{-g/d} L)$$

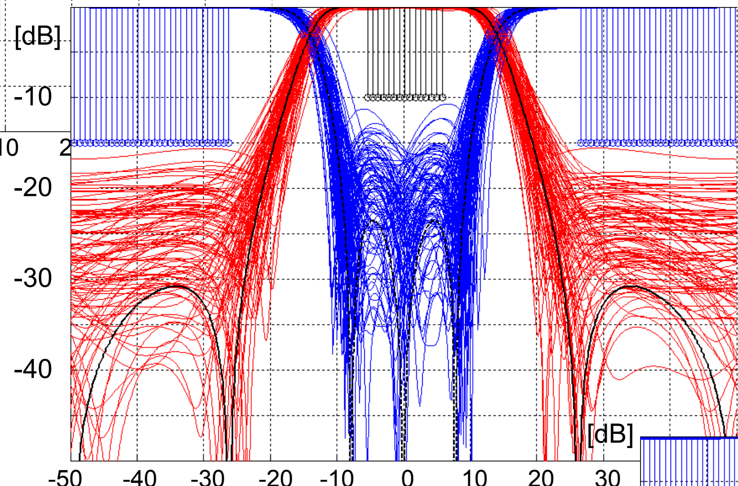


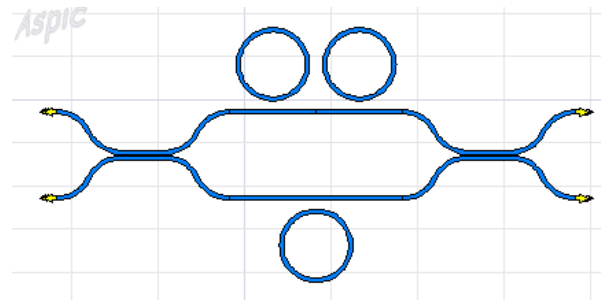
Tolerance impact on filters (δn_{eff}, δk)



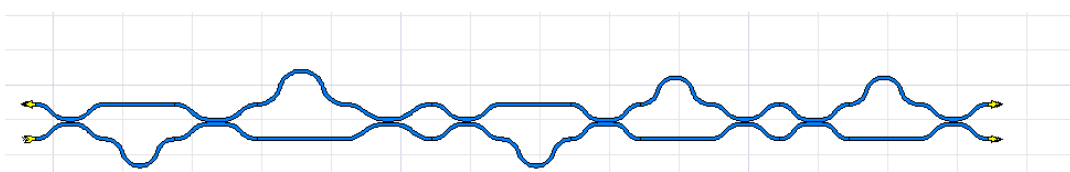


N=4

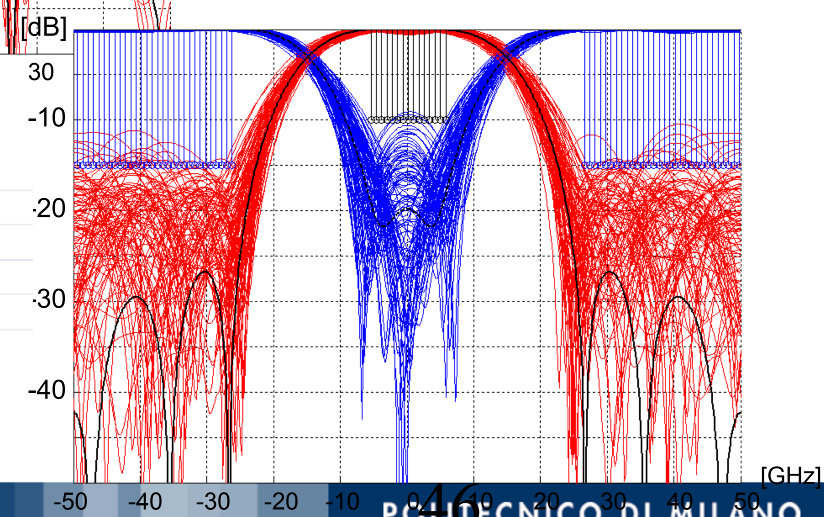




N=3

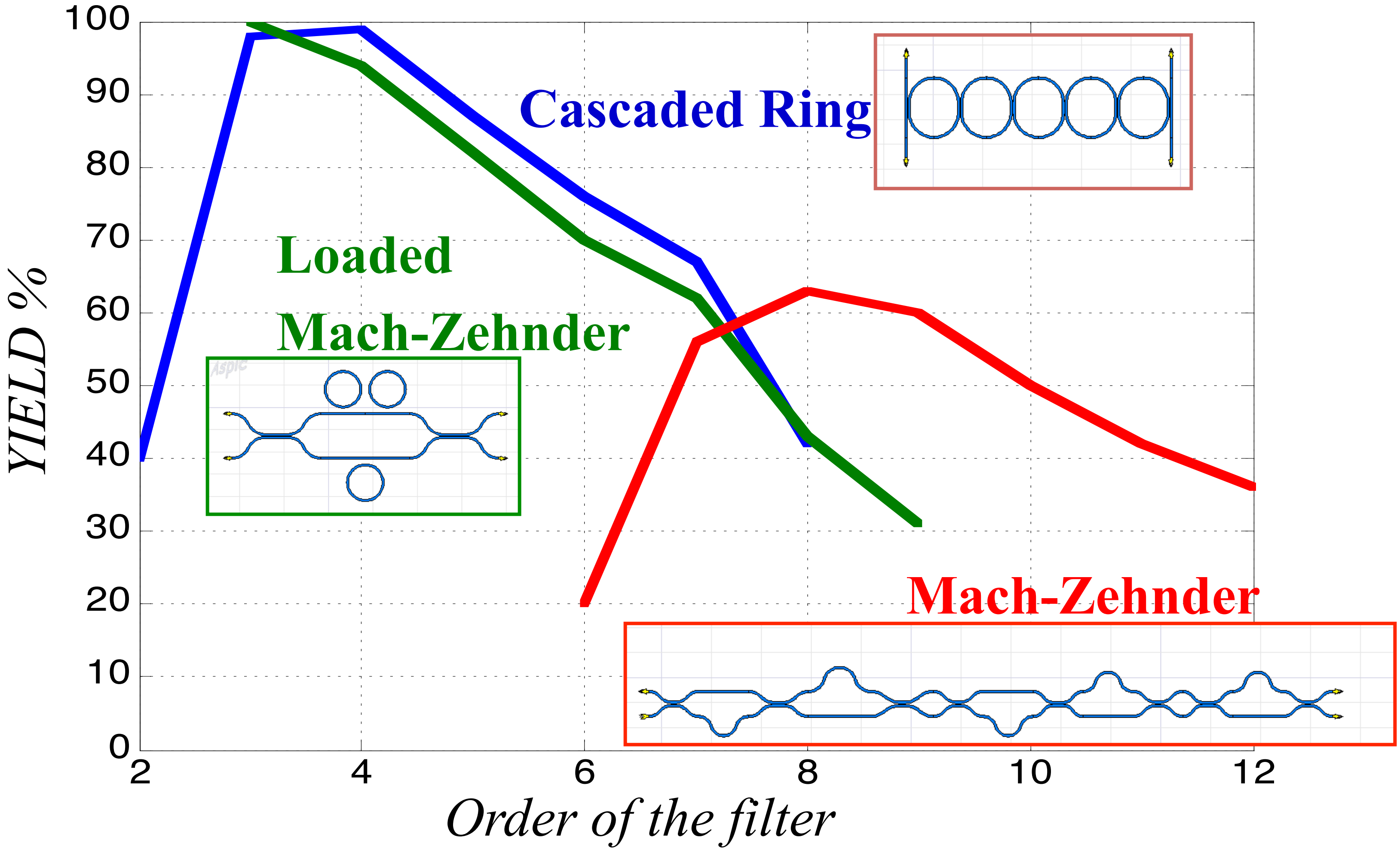


N=8



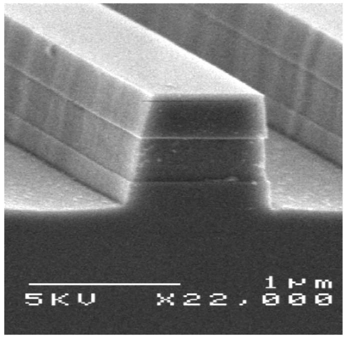
Optimized filters comparison

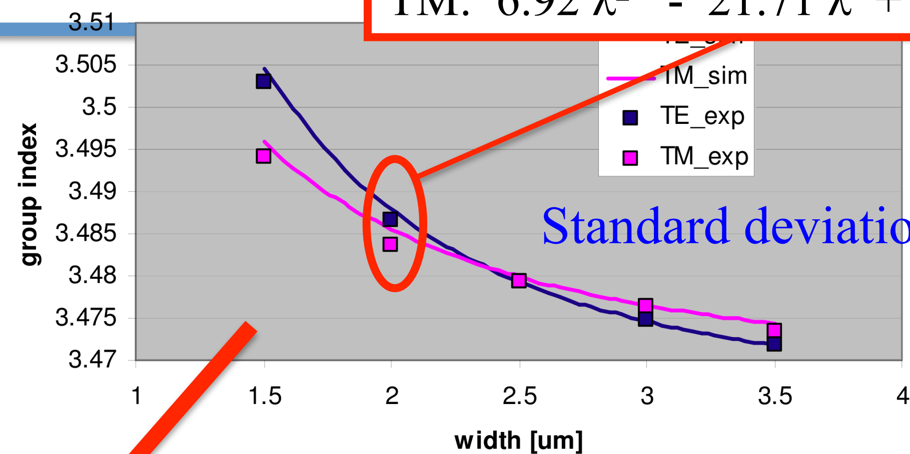
Tolerance on coupling coefficients and effective index



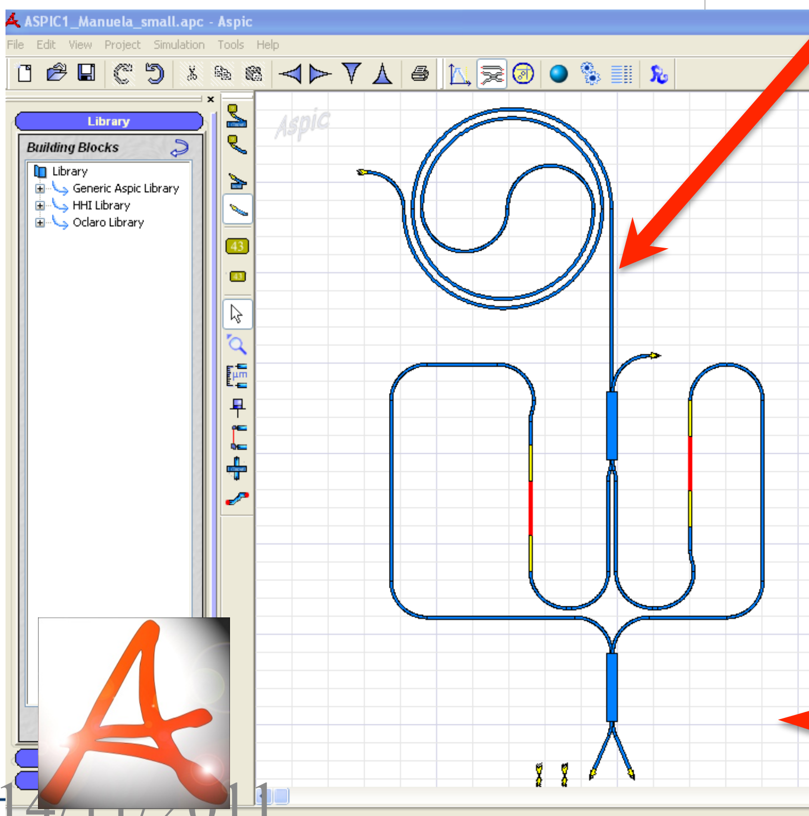
TE: $4.79\lambda^2 - 15.10\lambda + 15.39$

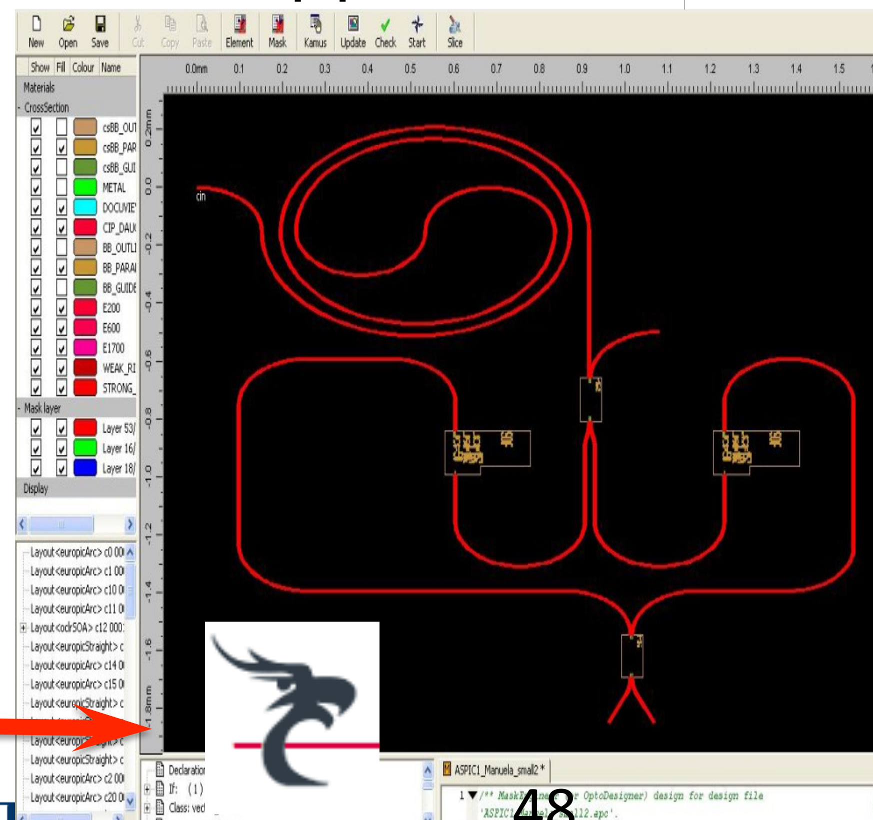
TM: $6.92\lambda^2 - 21.71\lambda + 20.49$



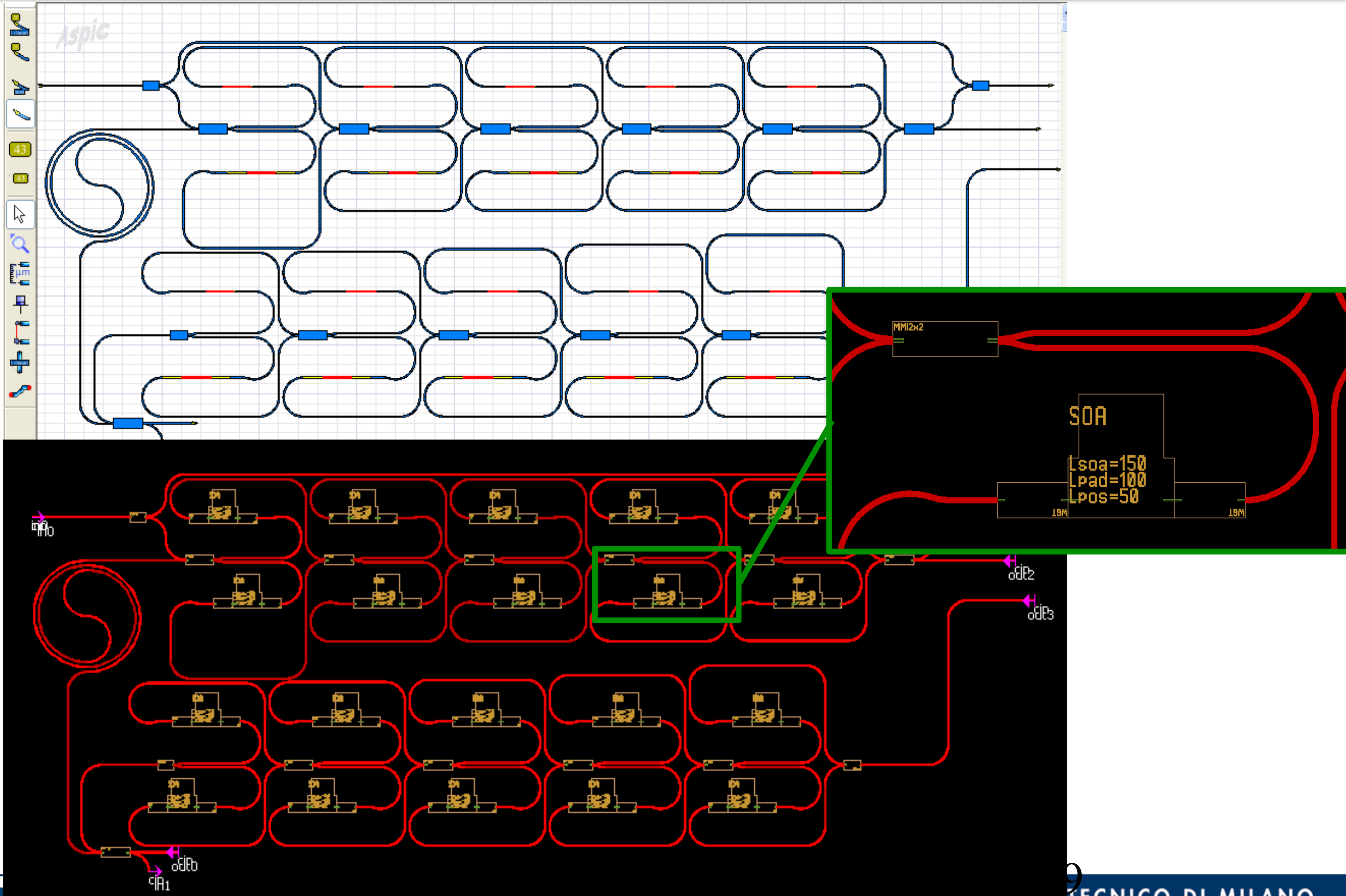


Standard deviation: 0.006



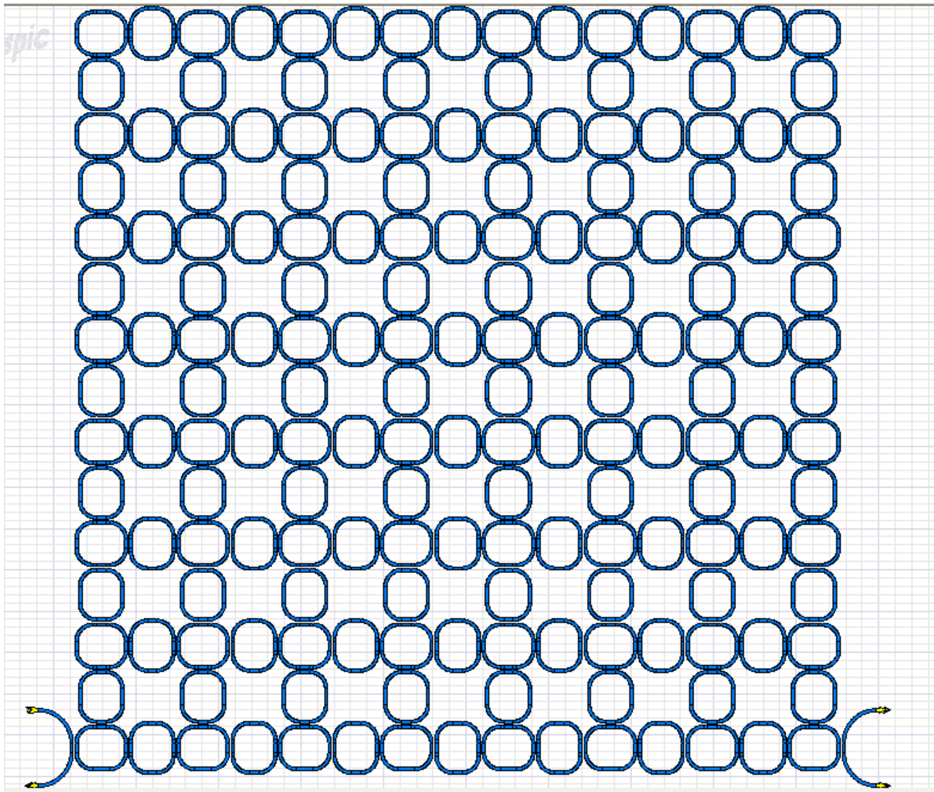


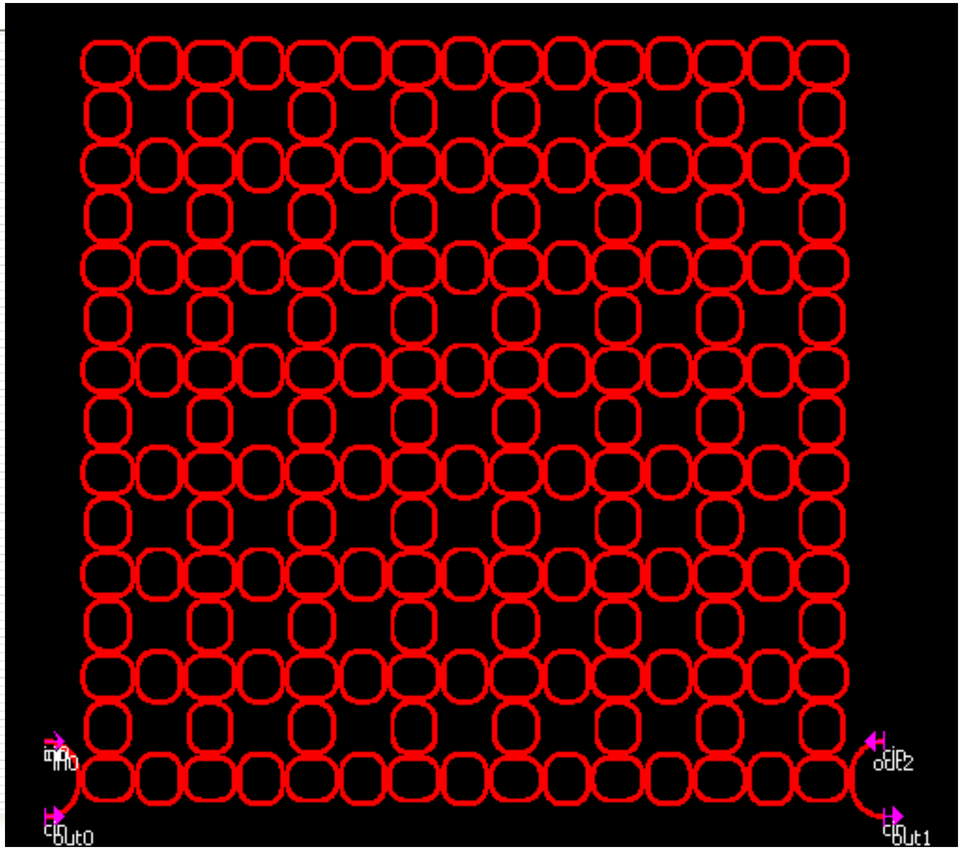
Tunable delay line



A matrix of rings…

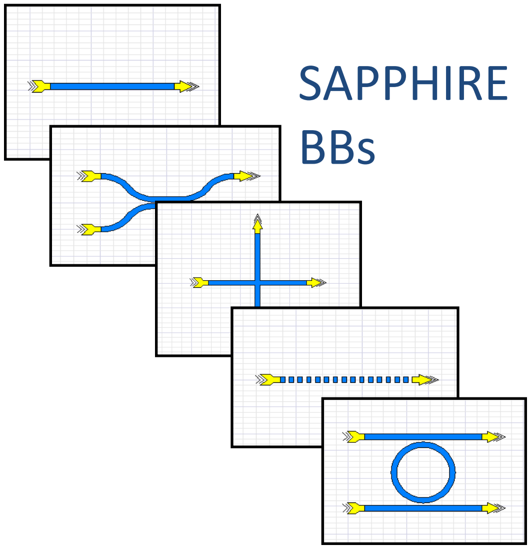
Robust optical delay lines with topological protection
M. Hafezi, NATURE PHYSICS, VOL. 7, NOVEMBER 2011



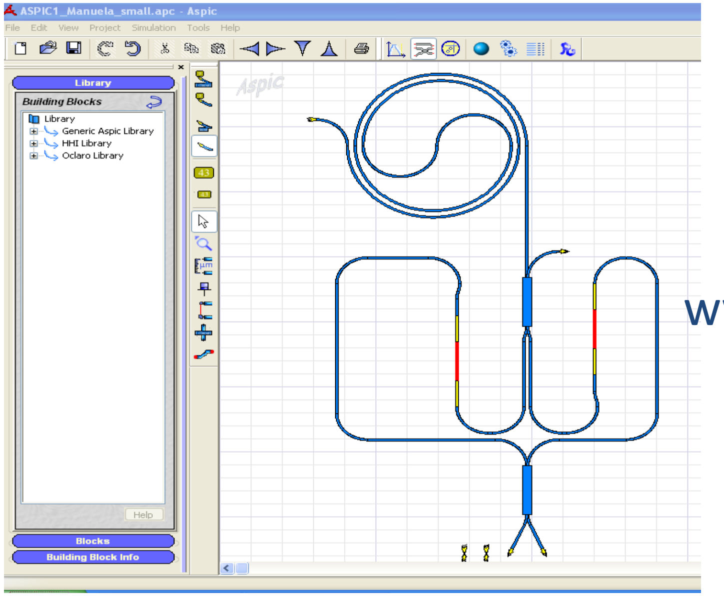


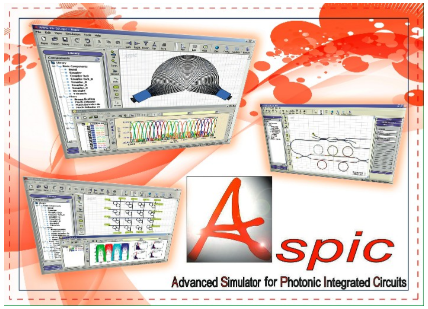
1656 Building Blocks, 3760 ports, 18 nested variables

Libraries for ASPIC^{TM} simulator



SAPPHIRE BBs

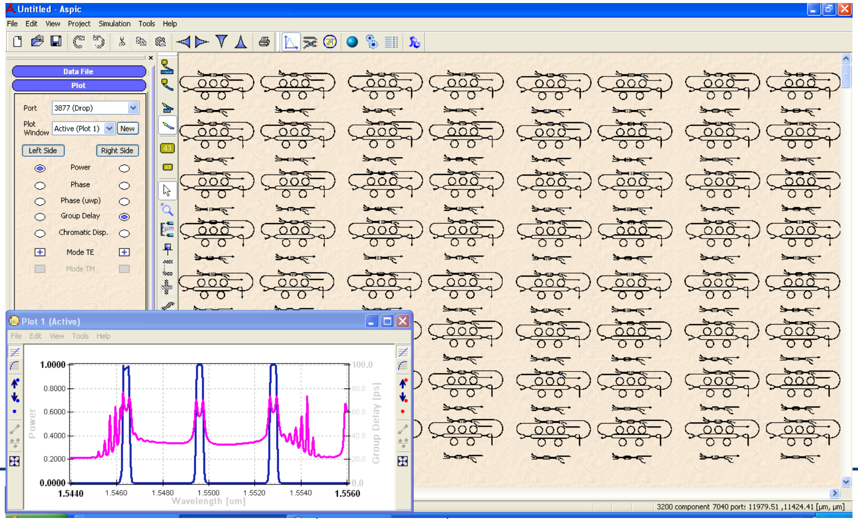




www.aspicdesign.com

Use realistic BB

1600 BBs; 100 lambda points → 1 min



Direct export to mask layout