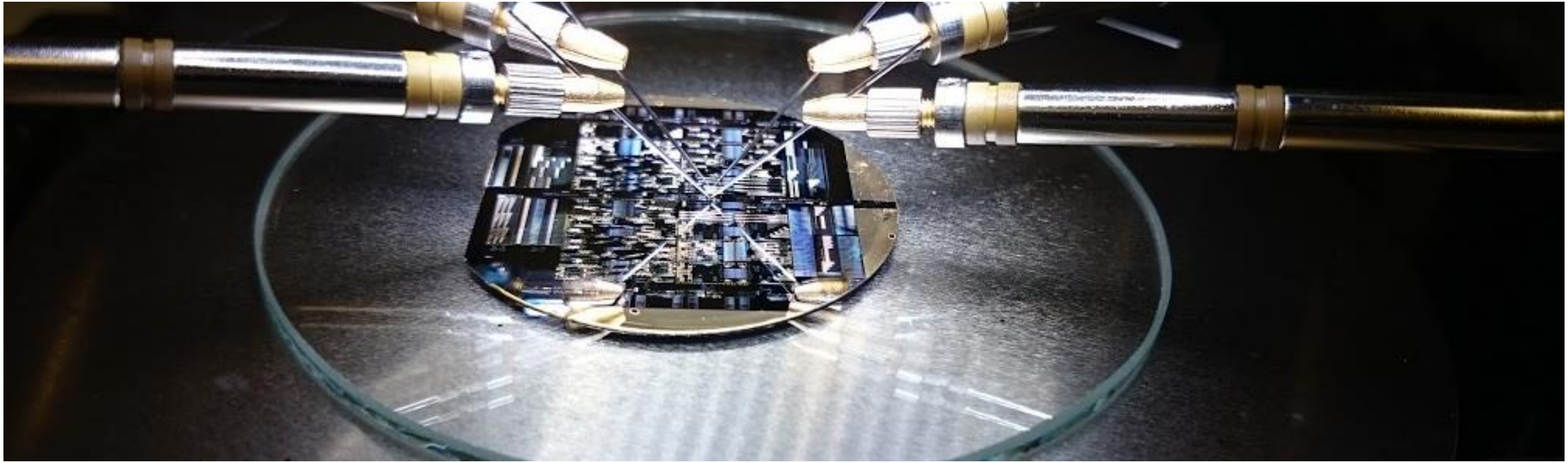
Photonic Integrated Circuits in InP for Sensing Applications

Moritz Baier



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Fraunhofer HHI

Outline

- Integrated Photonics ≠ Silicon Photonics
- Our Open Access PIC Foundry
- Example Building Blocks
- Example PICs
- Q&A

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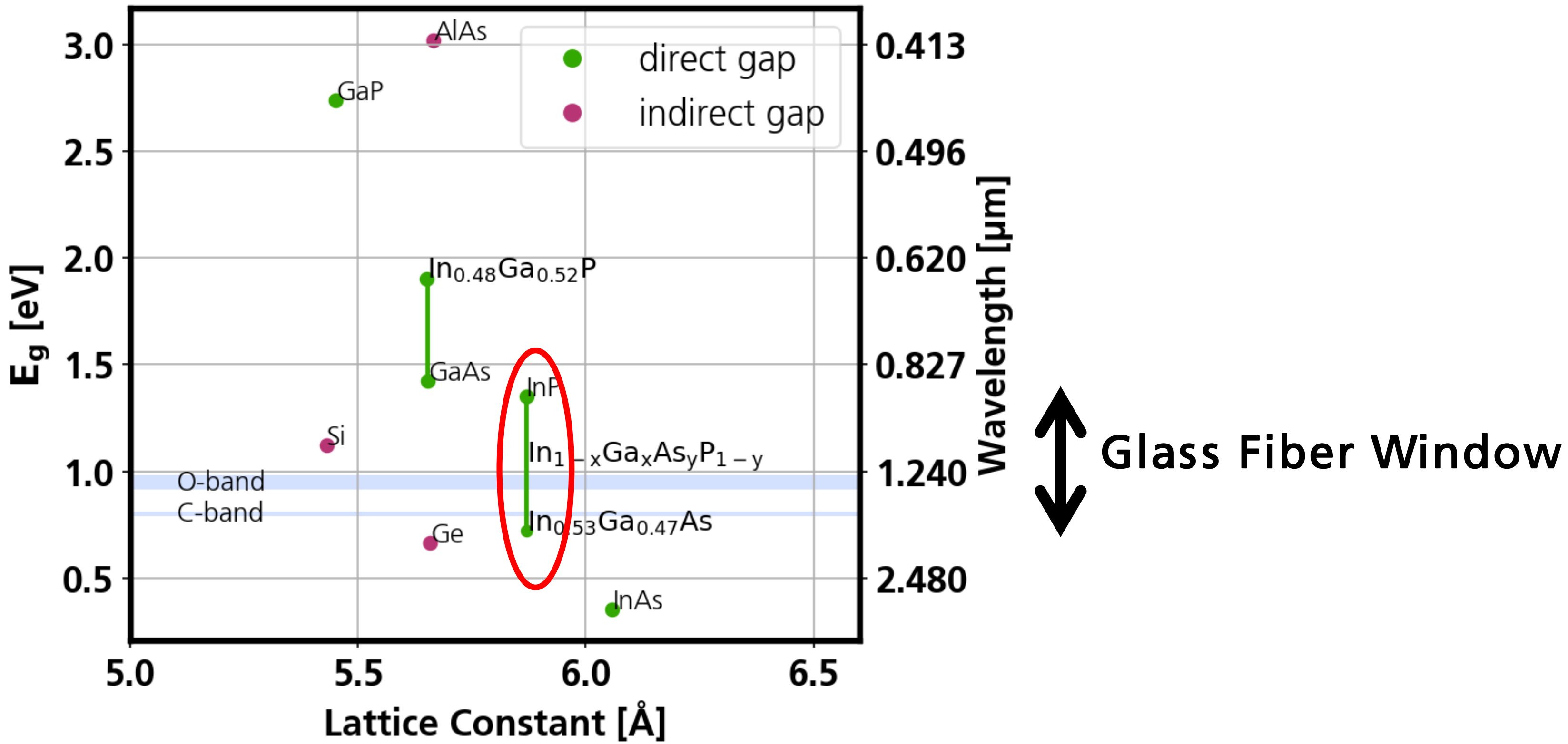
Our Material System of Choice



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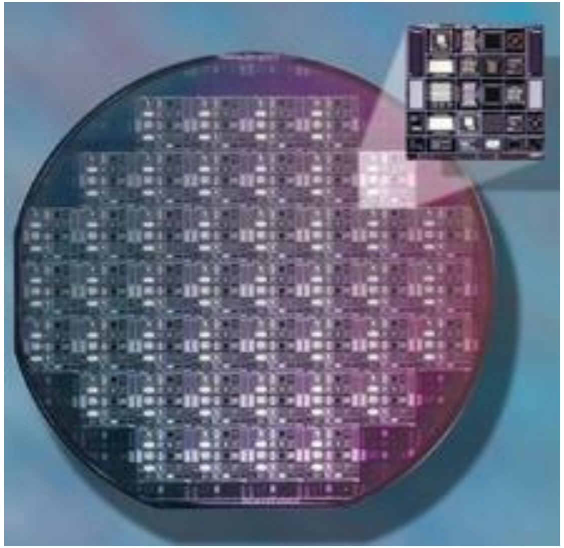
The Multi-Project Wafer (MPW) Model

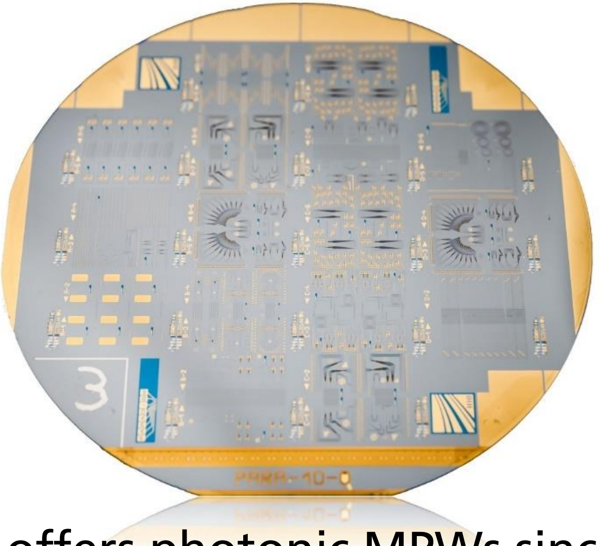
Sharing The Wafer – Sharing the Cost

Si Electronics



MOSIS pioneered MPWs in 1981

InP Photonics



HHI offers photonic MPWs since 2016

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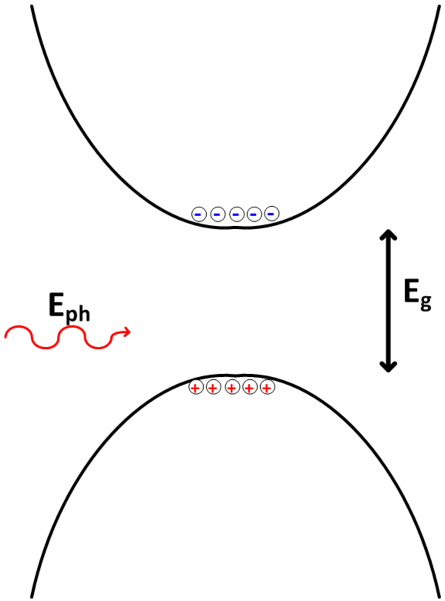
One Bandgap for Each Application

- Let's assume we use photons of energy E_{ph}
- Let a device's bandgap be E_g

Functionality	Bandgap Condition
Low-loss waveguide	$E_g >> E_{ph}$
Gain	$E_g = E_{ph}$
Detector	$E_g < E_{ph}$



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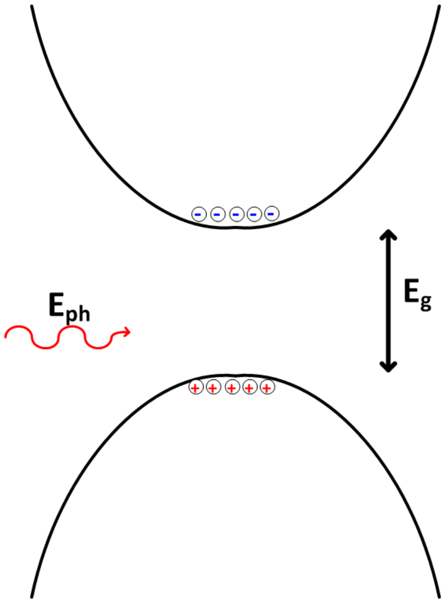
One Bandgap for Each Application

- We want a solution for the C-band

  →E_{ph} = [1530,1570] nm

Functionality	Bandgap
Low-loss waveguide	~1100 nm
Gain	~1550 nm
Detector	1650 nm



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Challenges for Integration

- How to implement all of them?
- We chose a combination of:
  - Vertical evanescent coupling
  - Selective regrowth

Functionality	Bandgap
Low-loss waveguide	~1100 nm
Gain	~1550 nm
Detector	1650 nm

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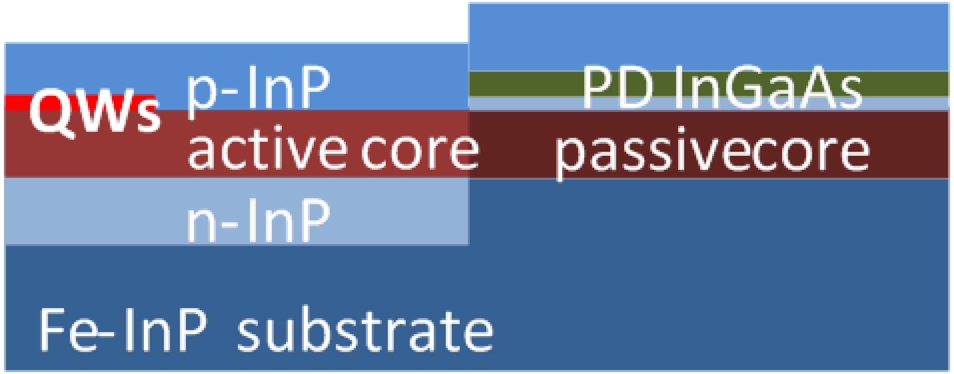
Butt-Joint Growth



Functionality	Bandgap
Low-loss waveguide	~1100 nm
Gain	~1550 nm
Detector	1650 nm

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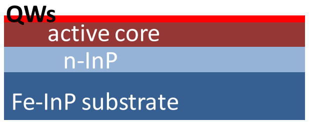
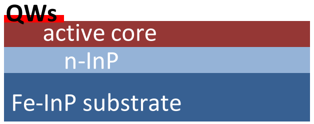
Process Flow

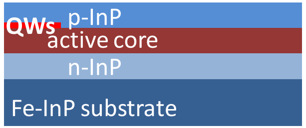
1) epi-growth n-InP & QW layer



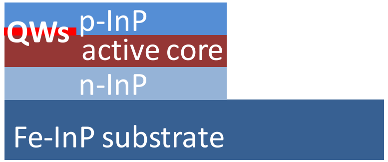
2) define QW regions & gratings



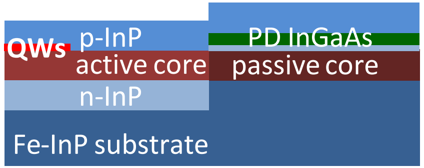
3) epi-growth p-InP



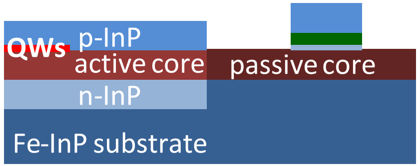
4) Define active mesas outside of active regions



5) selective-area growth of WG & PD layers



6) patterning



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Overall Process Flow

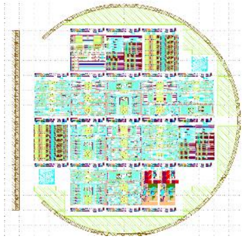
tape out
- design submission
- feedback from HHI

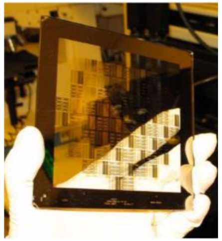
mask assembly
- wafer layout
- reticle fabrication

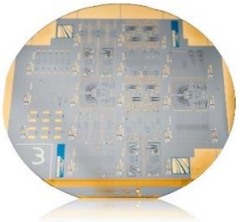
wafer fabrication
- 3 epitaxial steps
- 22 lithographic masks
- eBeam for gratings
- passivation & metallization

backend process
- cleaving & coating
- dicing
- visual inspection

end of line
- bar level measurements
- measurement report
- shipment







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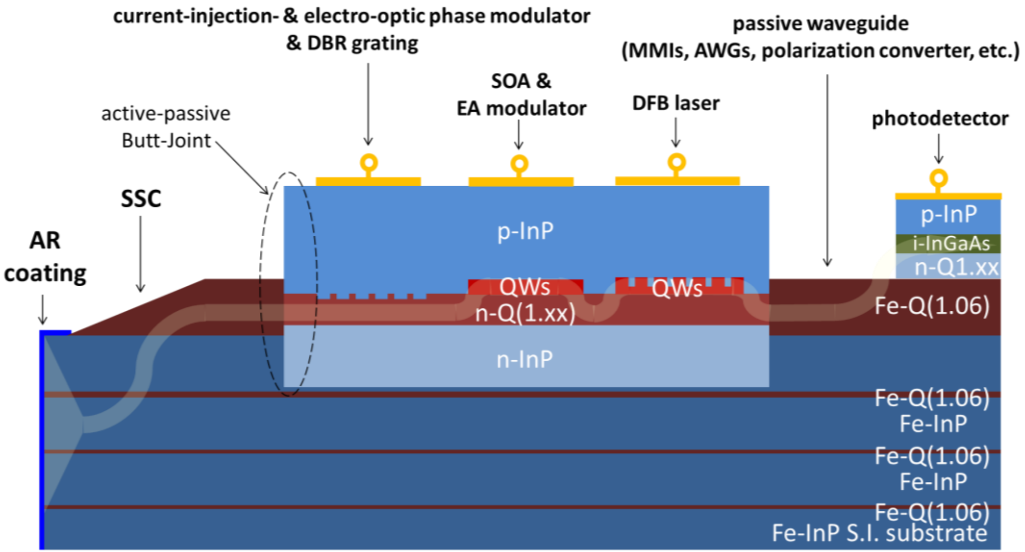
Technology

Overview and Capabilities



Passive	Tx	Rx
Bends	Tunable Gratings	Photodiodes
Couplers	Amplifiers, Phase Sections	Balanced Diodes
Pol. Elements	Lasers	
TO MZIs	EA Modulators	RF tracks, crossings

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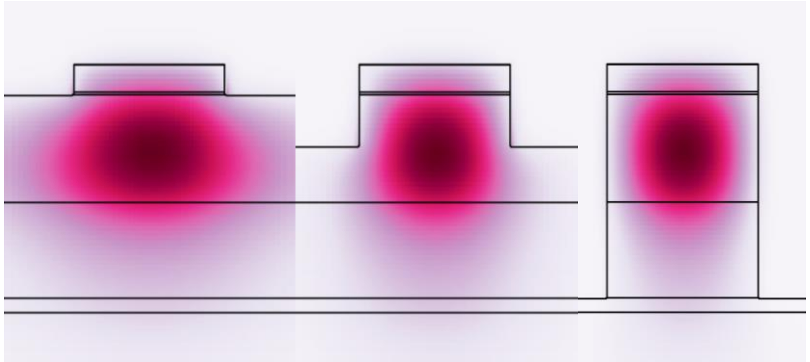
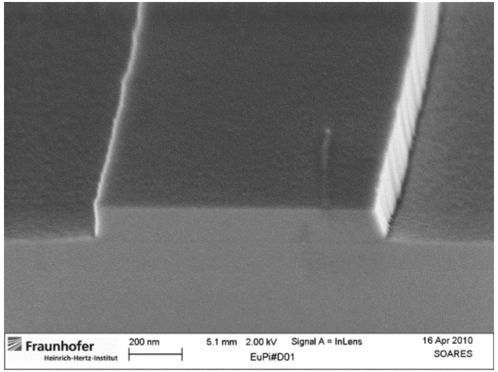
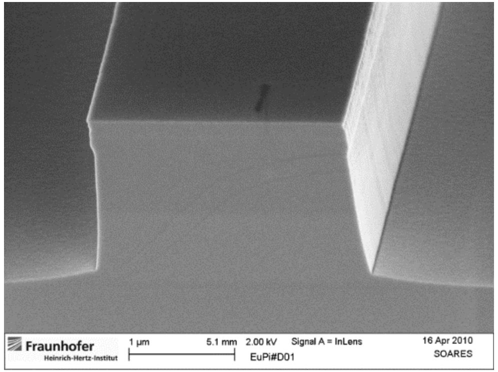
Passive Waveguides

- 1 dB/cm
- 150 µm bend radius
- Can be used for couplers, AWGs, etc.







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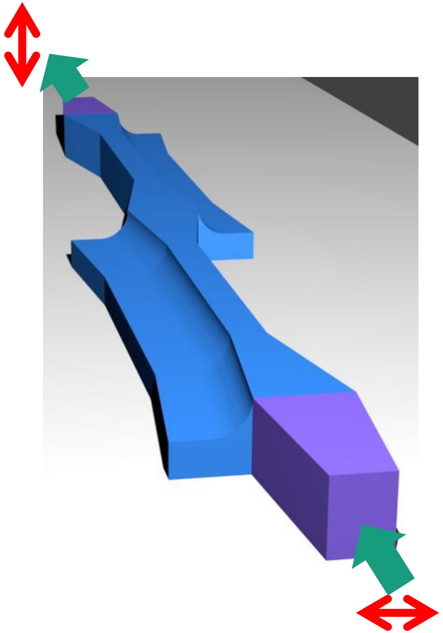
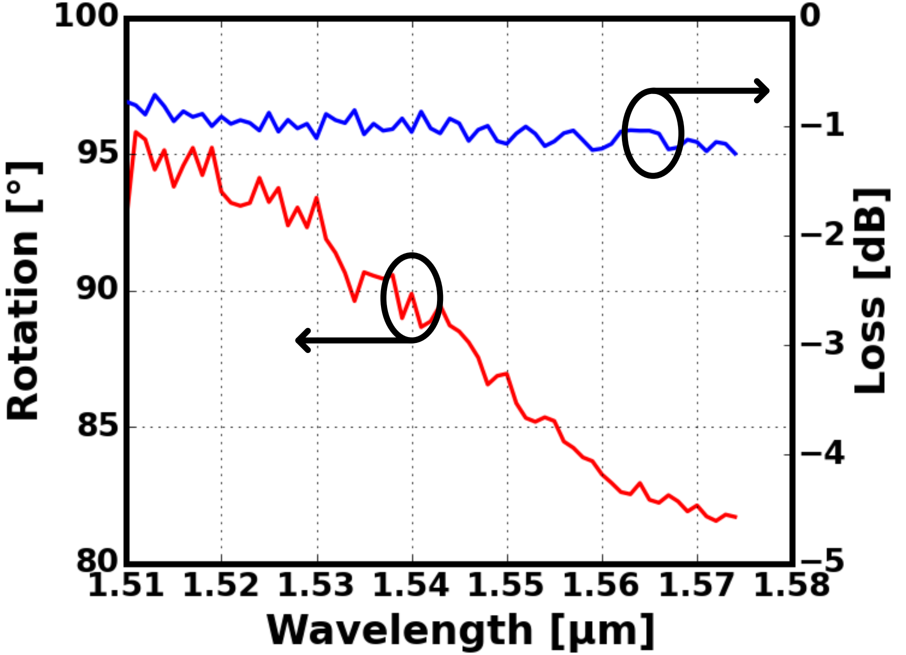
Polarization Converter

- >20 dB PER from 1510-1555 nm, >16 dB until 1575 nm
- 1 dB loss





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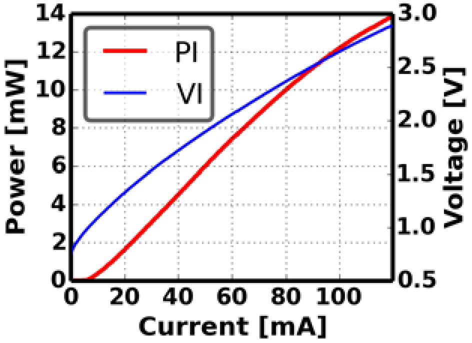
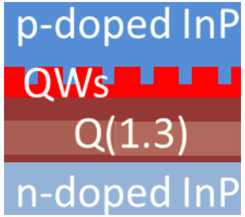
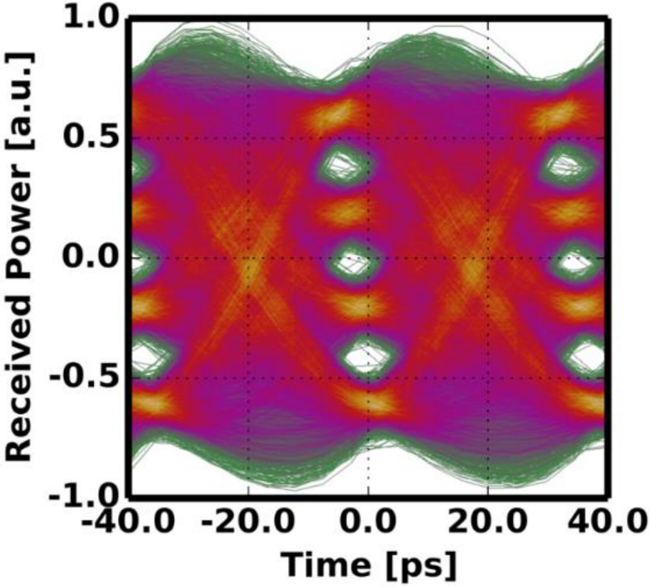
DFB

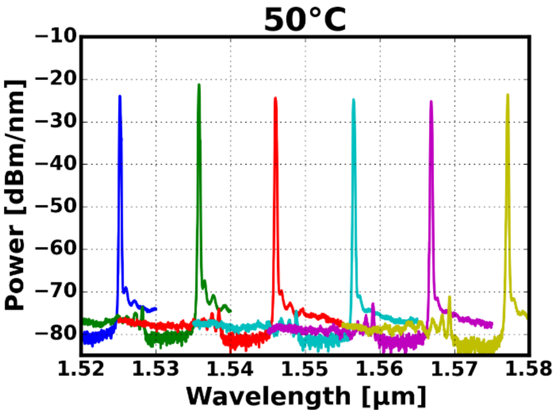




50Gbit/s



M. Baier et al., CSW 2015, WE2O7.3



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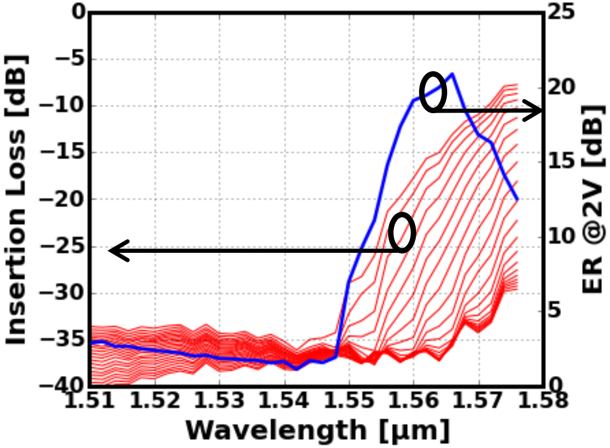
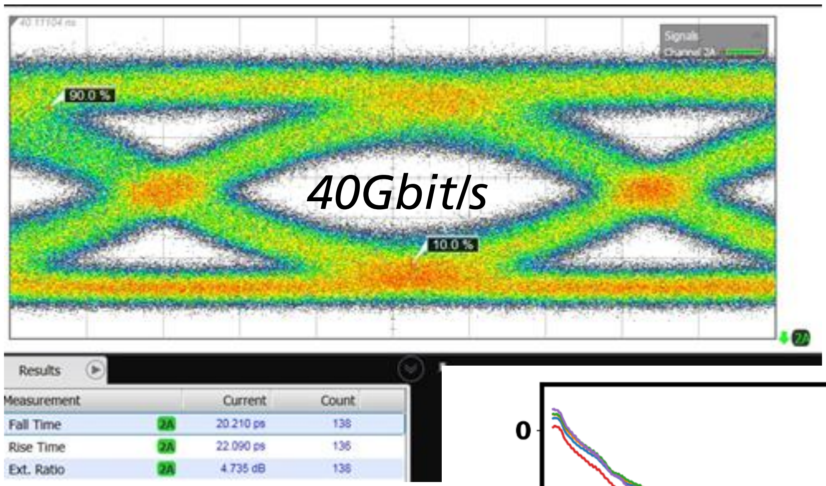
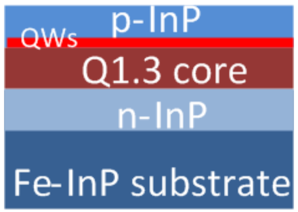
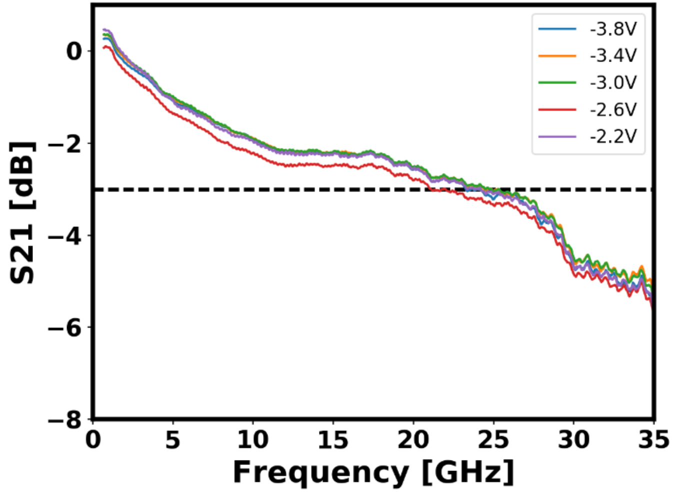
EAMs









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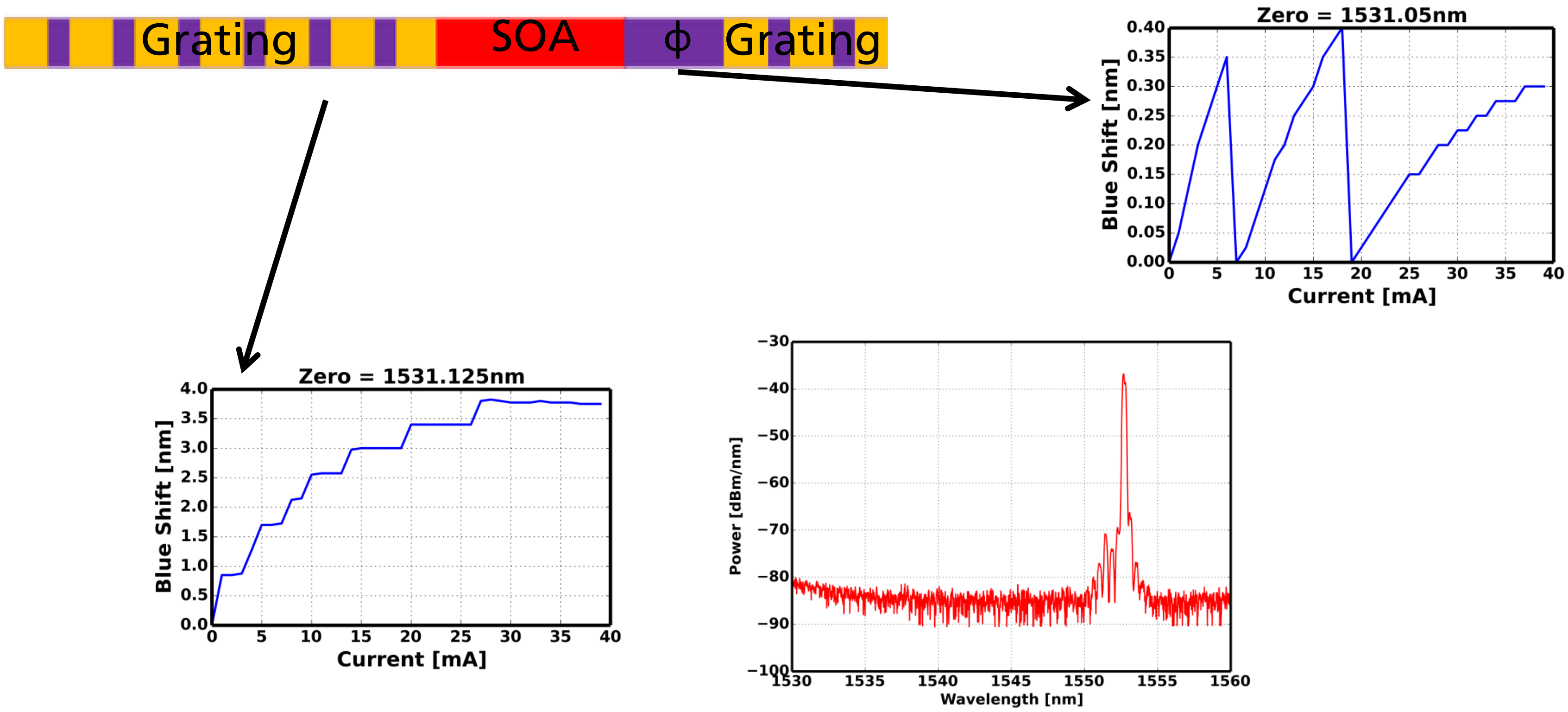
Compound BB: 4-Section DBR



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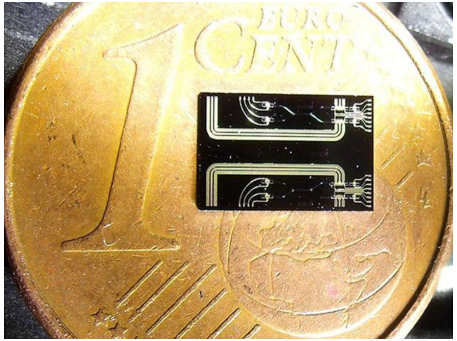
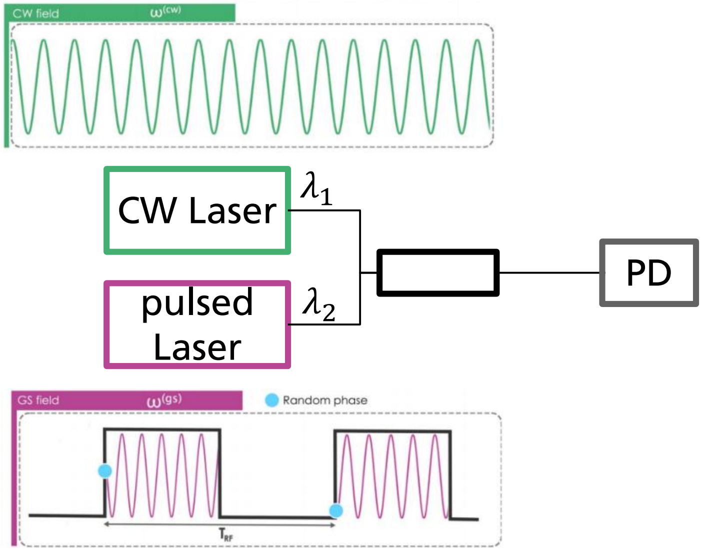
Quantum Entropy

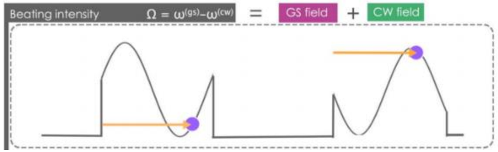
Randomness Guaranteed by Quantum Mechanics

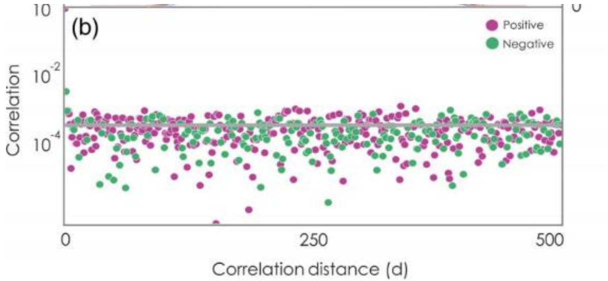




Phase noise of laser gets imprinted on phase noise of beat signal.

Phase of beat signal gives entropy





QUSIDE

C. Abellan et al., "Quantum entropy source on an InP photonic integrated circuit for random number generation" Optica, Sep. 2016.

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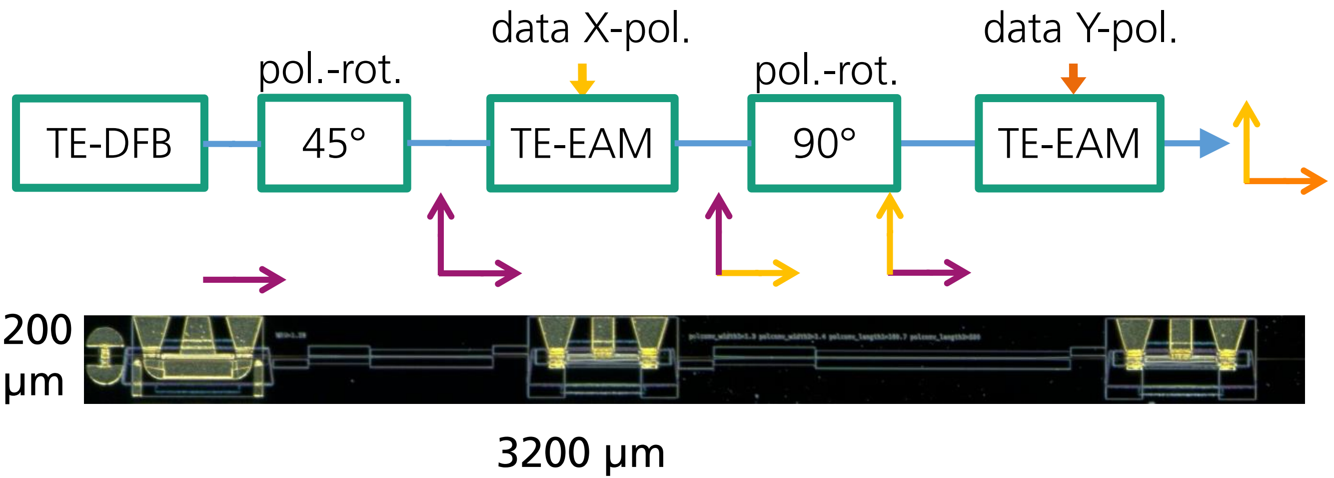
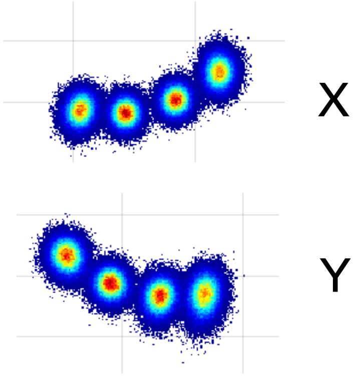
Dual-Polarization Tx

Slim Design – Easy to Make Arrays



- 112 Gbit/s w/o on-chip laser
- 40 Gbit/s with on-chip laser
- Potential for 200 Gbit/s



M. Baier et al., "New Polarization Multiplexed Externally Modulated Laser PIC," *ECOC* 2018

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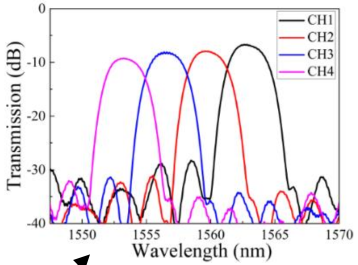
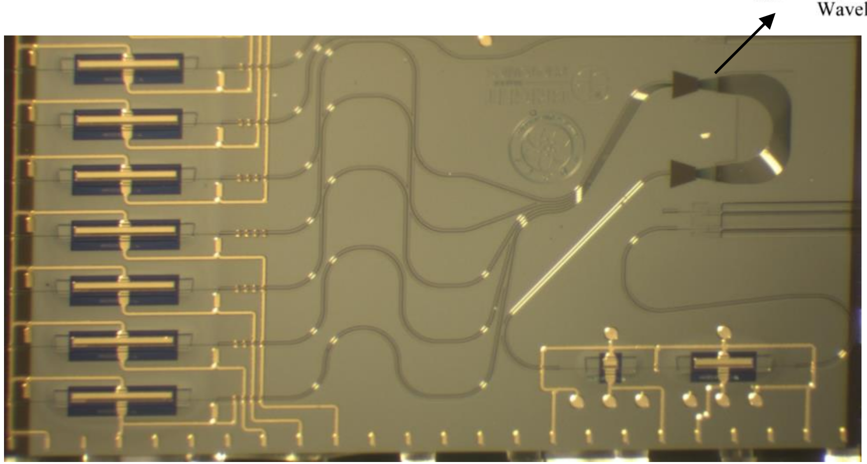
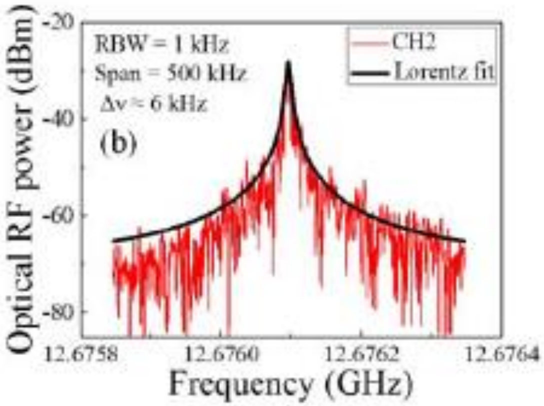
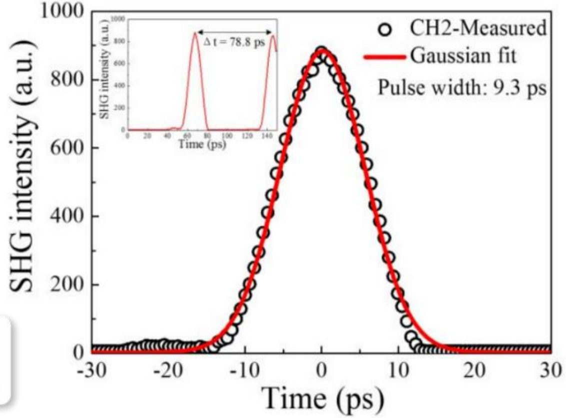
Mode Locked Laser

9 ps Pulses @12 GHz









S. Liu *et al.*, "AWG-Based Monolithic GHz Multichannel Harmonically Mode-Locked Laser" *IEEE Photonics Technology Letters*, 2016

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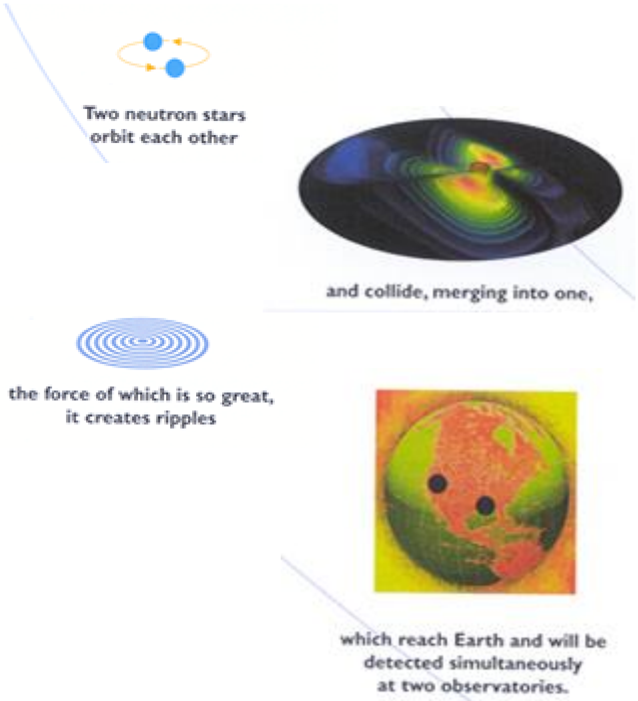
R&D: High Quantum Efficiency Planar Detectors (1064nm, ϕ = 3 mm)

For LIGO, Laser Interferometer Gravitational Wave Observatory

www.space.com/28409-ligo-generations-the-film-hd-video.html



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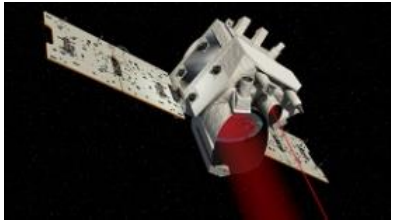
Eagleyard charms Small Satellite MERLIN

Low Linewidth Laser PICs for Methane Sensing



eagleyard Photonics GmbH enables SpaceTech GmbH/Immenstaad to build the LIDAR Frequency Reference Unit for German-French small satellite mission MERLIN (*Methane Remote Sensing LIDAR Mission*) -helping measuring methane gas concentration for a better understanding of climate change.

With a scheduled launch for 2021, the German-French satellite mission is laid out to measure methane gas concentration by means of a LIDAR instrument (Light Detection And Ranging) sending laser light pulses into the atmosphere and determining the gas concentration by the characteristics of the reflected light.

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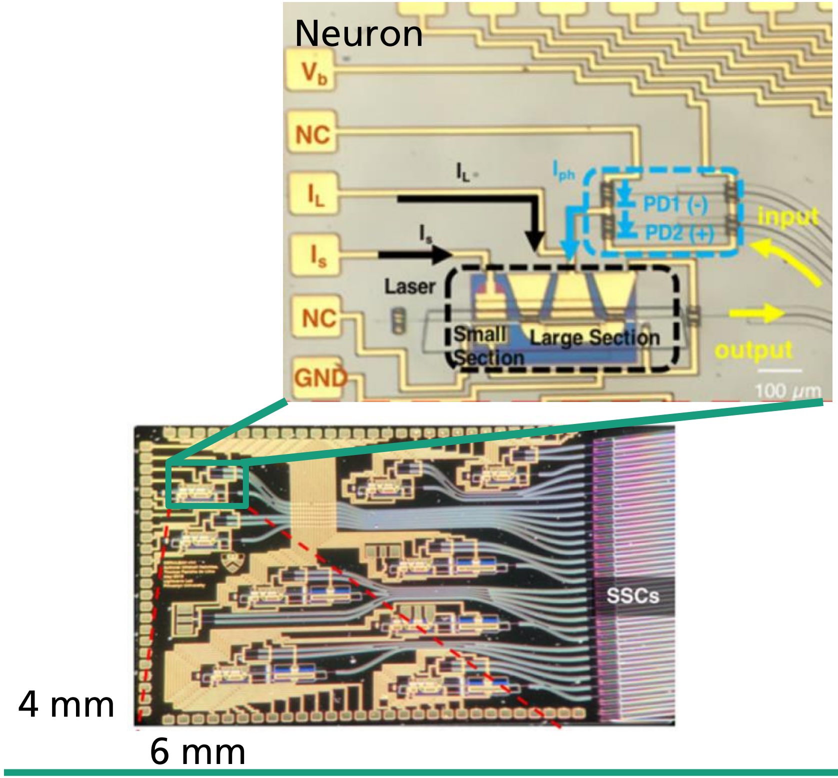
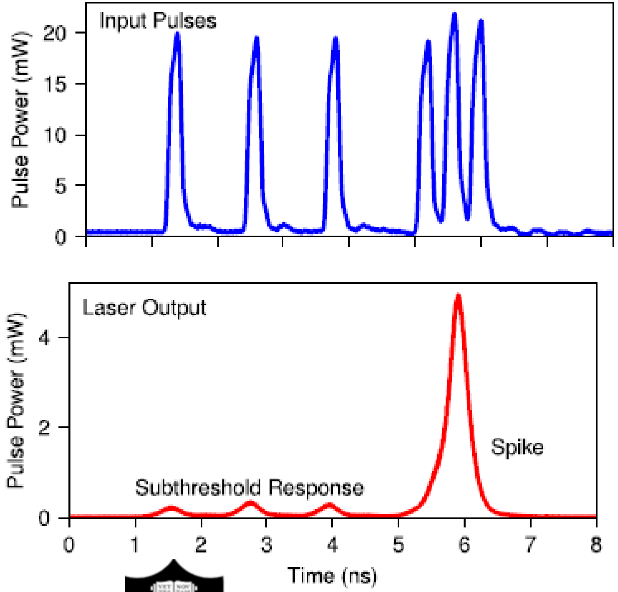
All-Optical Neuron for Computing

Breaking von-Neumann Bottlenecks



spikes encode the timing between input pulses



H.-T. Peng et al. "Neuromorphic Photonic Integrated Circuits" *IEEE JSTQE*, 2018

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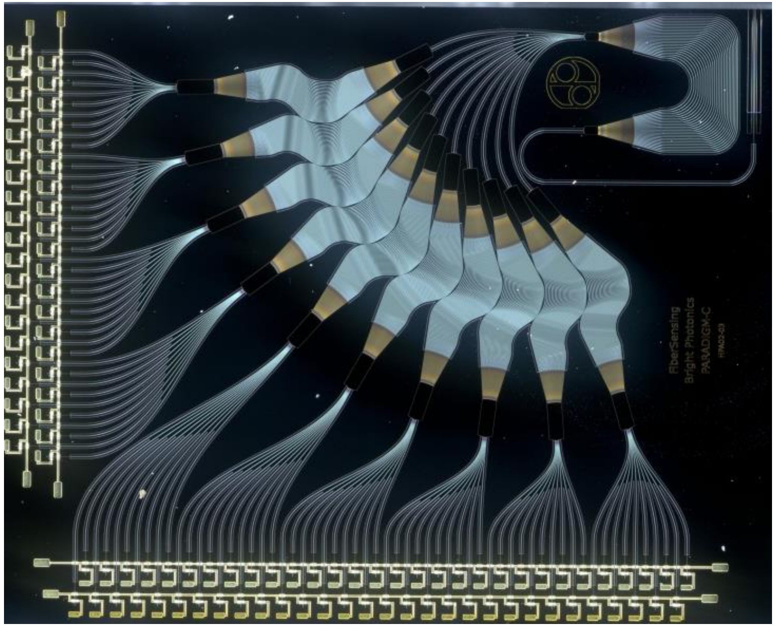
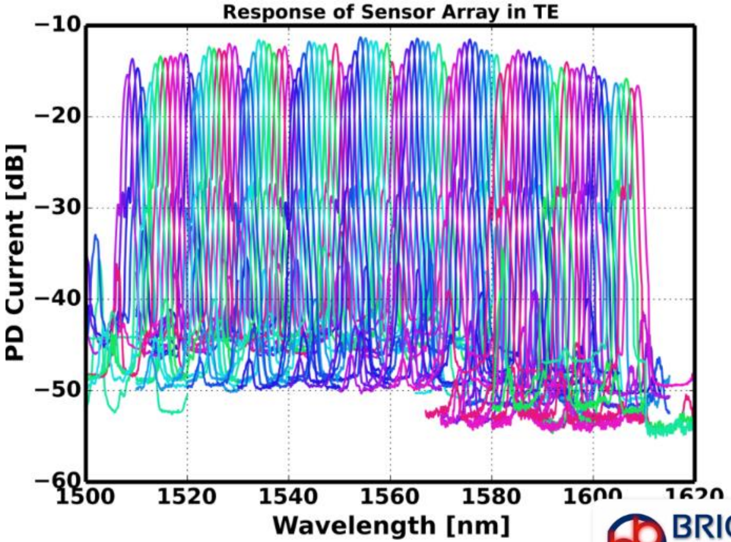
WDM Receiver

Bragg Interrogator for 100 sensors on One Chip





Baier et al., 100-Channel WDM Rx-Type PIC on InP for Use of Low-Cost and Low Power Consumption Electronics,ECOC 2014

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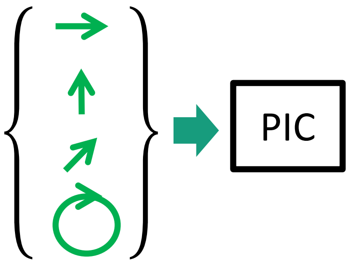
Stokes Vector Rx

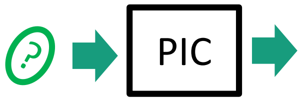
Fully Integrated Polarimeter with 45 GHz Bandwidth

1)

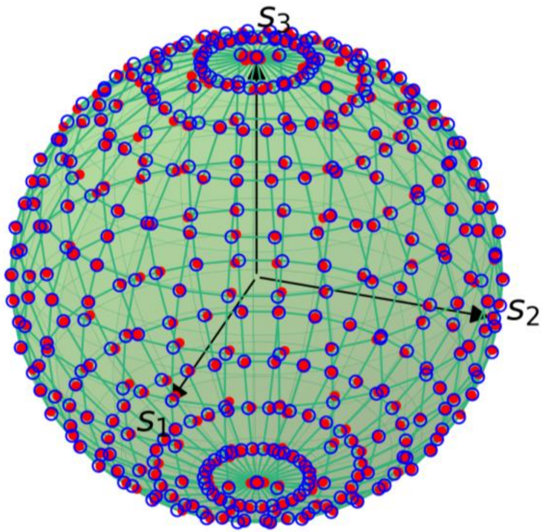


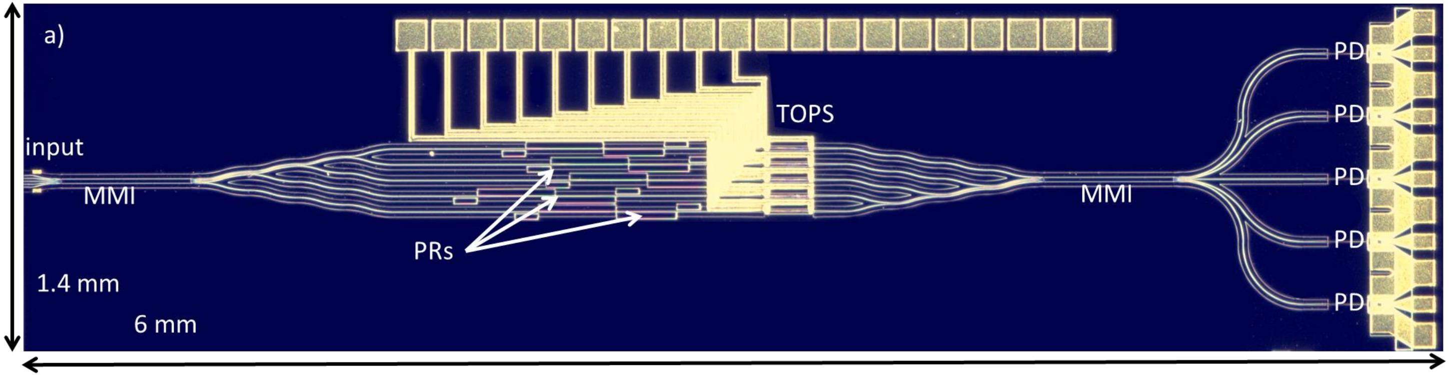
$$\begin{Bmatrix} \vec{P}_{TE} \\ \vec{P}_{TM} \\ \vec{P}_{45°} \\ \vec{P}_{LHC} \end{Bmatrix}$$

2)



$$\vec{s} = \underline{Z}^{-1} \cdot \vec{P}$$





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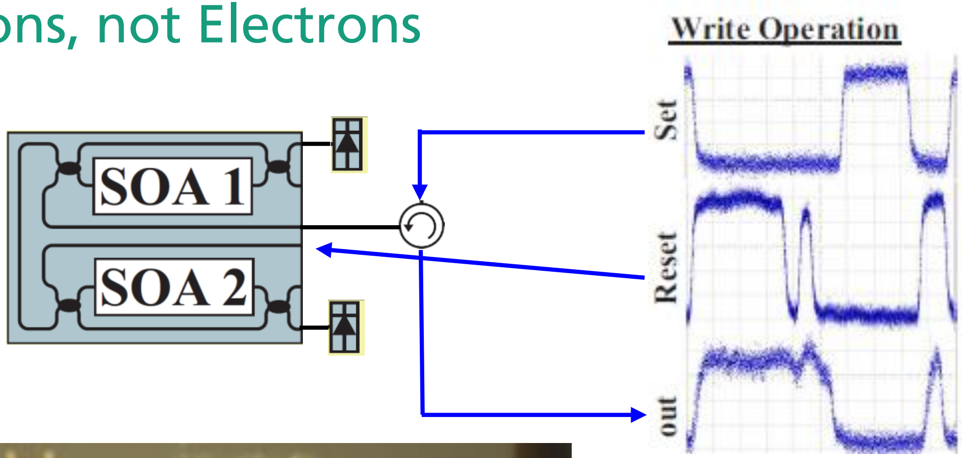
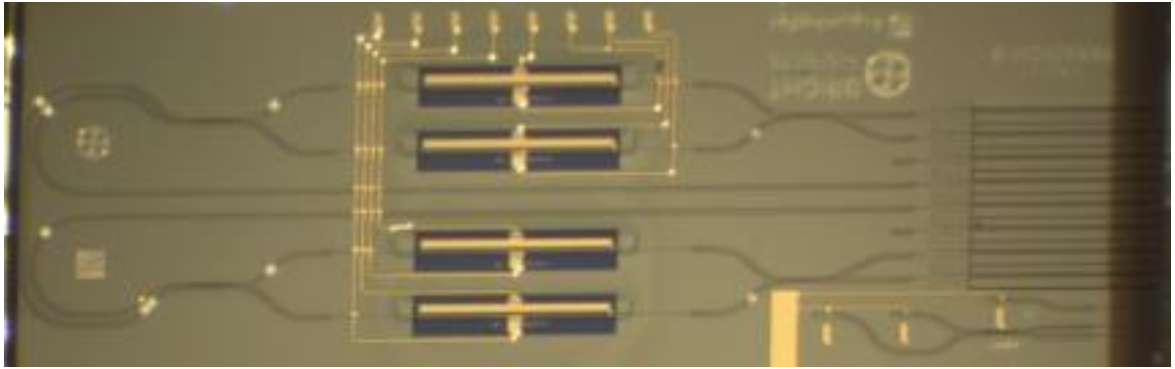
All-Optical Memory

Flip-Flops Based on Photons, not Electrons





G. Mourgias-Alexandris, et al., “All-optical 10Gb/s ternary-CAM cell for routing look-up table applications,” *Opt. Express*, Mar. 2018.

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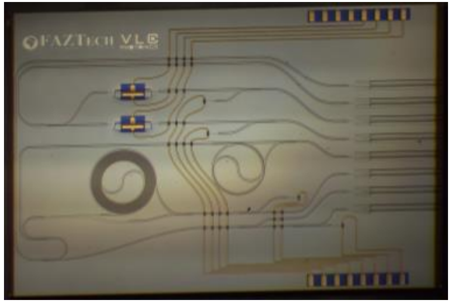
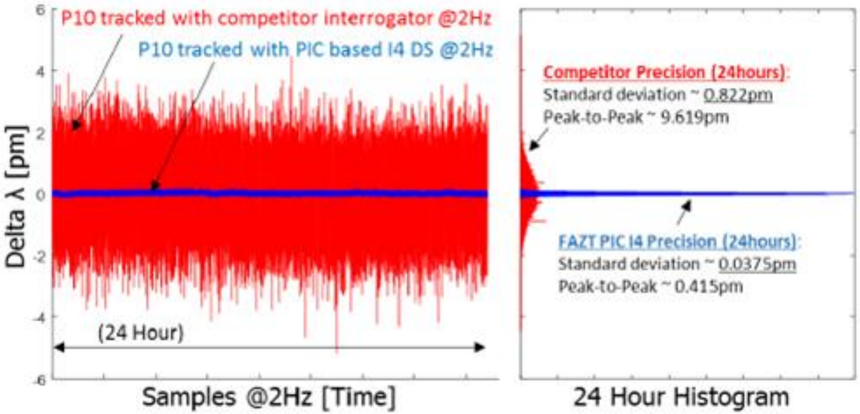
Bragg Sensors Interrogator

Optical Sensors for Spark-Free Systems

160x100 mm²

67x30 mm²





S. K. Ibrahim et al., "Design of a photonic integrated based optical interrogator" in *Photonic Instrumentation Engineering IV*, 2017

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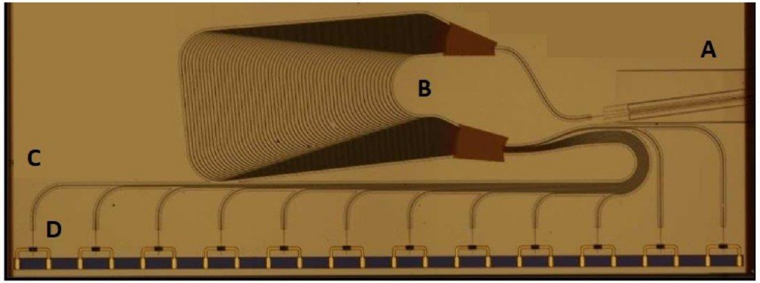
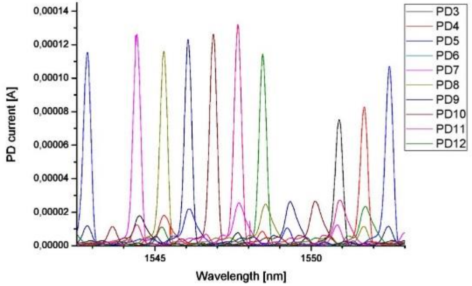
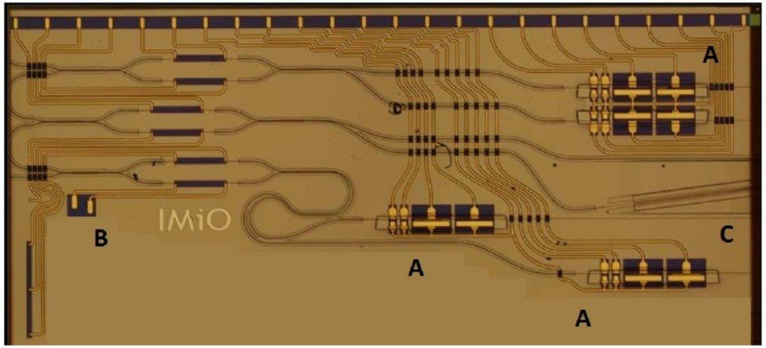
Bragg Sensors Interrogator

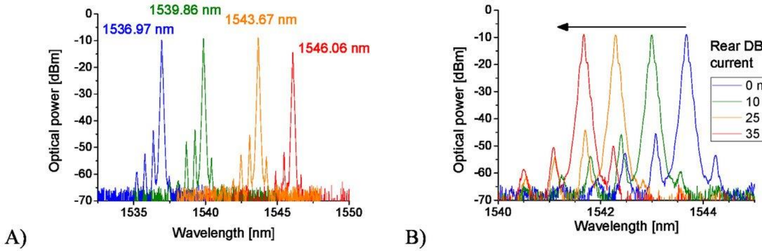
Optical Sensors for Spark-Free Systems





A. Kaźmierczak et al., "Integrated interrogator circuits for fiber optic sensor network in generic InP photonic integrated circuit technology," *Optical Sensing and Detection V*, 2018





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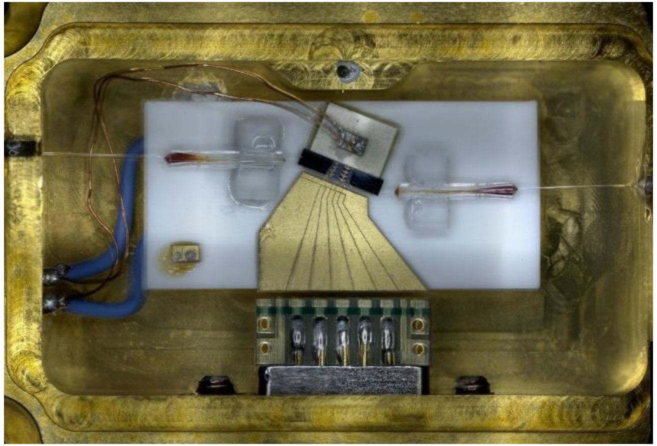
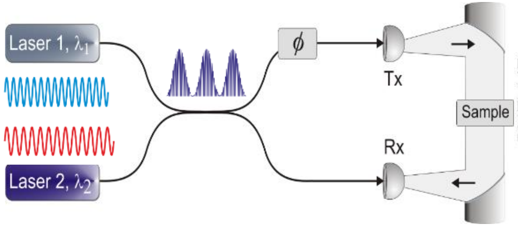
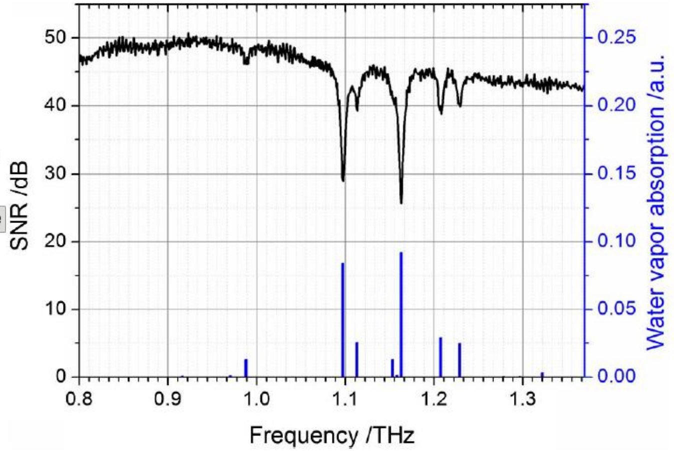
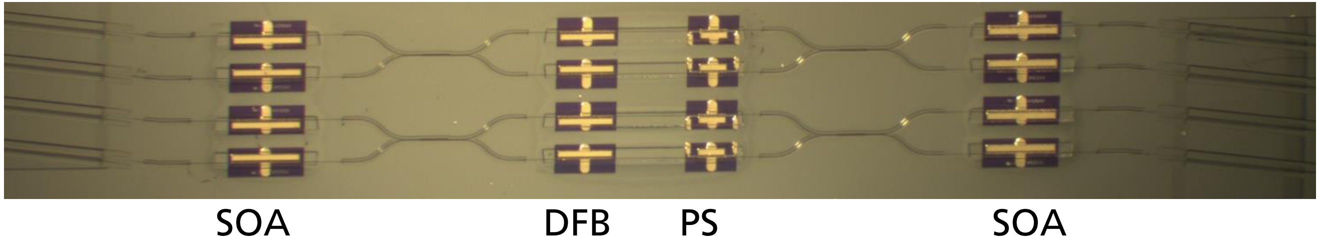
Optical Driver for CW THz Tx

THz Signal Tunable over 570 GHz









M. Theurer *et al.*, "Photonic-integrated circuit for continuous-wave THz generation," *Opt. Lett., 2013*

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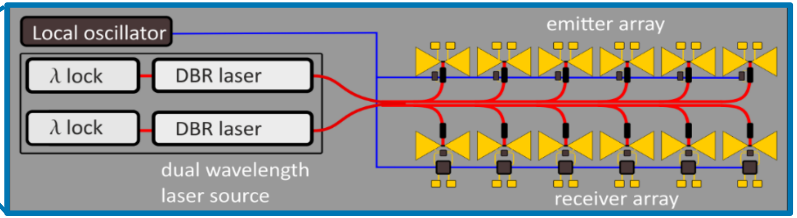
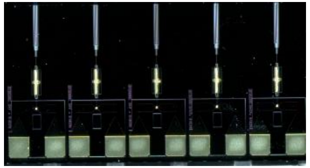
Ongoing research: Broadband on-chip THz systems

Driven by photonic/hybrid integration

On-chip terahertz system





Features:

- Electronic and photonic integration
- Multiple THz bandwidth
- Beam steering via phased arrays

Applications:

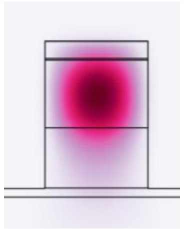
- Gas spectroscopy
- Layer thickness measurements
- Quality inspection

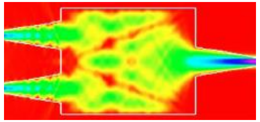
Full Ecosystem for PIC Design

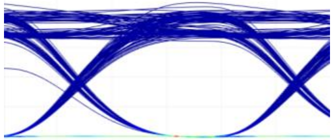
- Design Kit: fab building blocks
- Design Manual
- Physical simulation
- Circuit simulation
- Mask layout generation

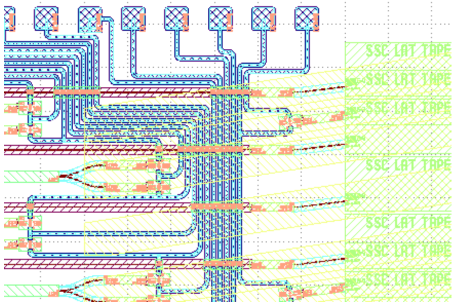
Models

Type	Description
HHI_1x2_MMI	1x2 MMI Coupler
HHI_2x2MMI	2x2 MMI Coupler
HHI_BJ	Butt-Joint Coupler
HHI_DBR	Distributed Bragg Reflect...
HHI_DFB	Distributed Feedback Laser
HHI_E1700	E1700 Waveguide
HHI_E200	E200 Waveguide
HHI_E200-E1700	Transition E200-E1700
HHI_E200-E600	Transition E200-E600
HHI_E600	E600 Waveguide
HHI_E600-E1700	Transition E600-E1700
HHI_EAM	Electro-absorption modu...
HHI_GRAT	Current Injection Tunabl...
HHI_ISO	Active Isolation
HHI_MZI	Mach-Zahnder Interfero...
HHI_PD_DC	DC Photodetector
HHI_PD_RF	Fast Photodetector
HHI_PM_CI	Current Injection Phase ...
HHI_PM_TO	Thermo-Optic Phase Mo...
HHI_PolCH	Polarization rotator
HHI_PolSplitter	Polarization Beam Splitter
HHI_SOA	Semiconductor Optical A...
HHI_SSC	Spot Size Converter for fi...









Nazca design™
photonic IC design framework

VPIphotonics
DESIGN AUTOMATION

lumerical

Photon Design®

SYNOPSYS®

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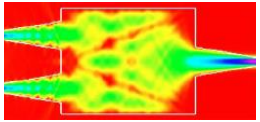
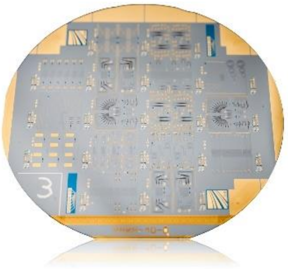
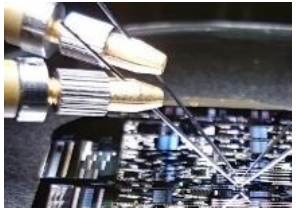
How to Get Started?

From Signature to Tested PIC in Six Months

User Agreement, Design Kit License → PIC design → Fabrication (~4 months) → Testing → Proven Prototype







Jeppix

HHI / Design House[1]

HHI

HHI / other partner[2]

1) e.g. Bright Photonics, VLC, etc
2) e.g. VLC, Jeppix technology center

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Prices

MPW runs

4 copies per chip

Tape out every 3 months

Size	Price
2x6 mm²	2,900 €
4x6 mm²	5,800 €
12x12 mm²	17,400 €

dedicated wafer run

quote depends on specifications

inquiries:

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