SOFI

Silicon-Organic hybrid Fabrication platform for Integrated circuits

www.sofi-ict.eu

FP7-ICT-2009.3.8

SEVENTH FRAMEWORK PROGRAMME

GA No. 248609

Participants:

	Karlsruhe Institute of Technology (KIT), Germany	- Project coordination - Modulator design - Characterization
	Research and Education Laboratory in Information Technologies, Greece	- System application definition - Characterization
	Interuniversity Microelectronics Centre VZW- IMEC, Belgium	- Waveguide fabrication - Doping - Metallization
	Rainbow Photonics AG, Switzerland	- Nonlinear material deposition - Characterization
	GigOptix-Helix AG, Switzerland	- Nonlinear material - SiGe driver study - Characterization
	The University of Sydney, Australia	- Nonlinear material deposition - Characterization
	SELEX - Sistemi Integrati, Italy	- Prototype packaging - RF design - Characterization

Outline

- Today's High Speed Interconnects
- Vision : Convergence of Photonics & Electronics
- Silicon Photonics Technology
- Silicon-Organic Hybrid (SOH) Concept – SOFI
- Components
- Signal Monitoring and Detecting
- From components to integrated circuits
- Summary
- Publications in conference proceedings and journals
- Exchange with other projects
- Conclusions

Introduction

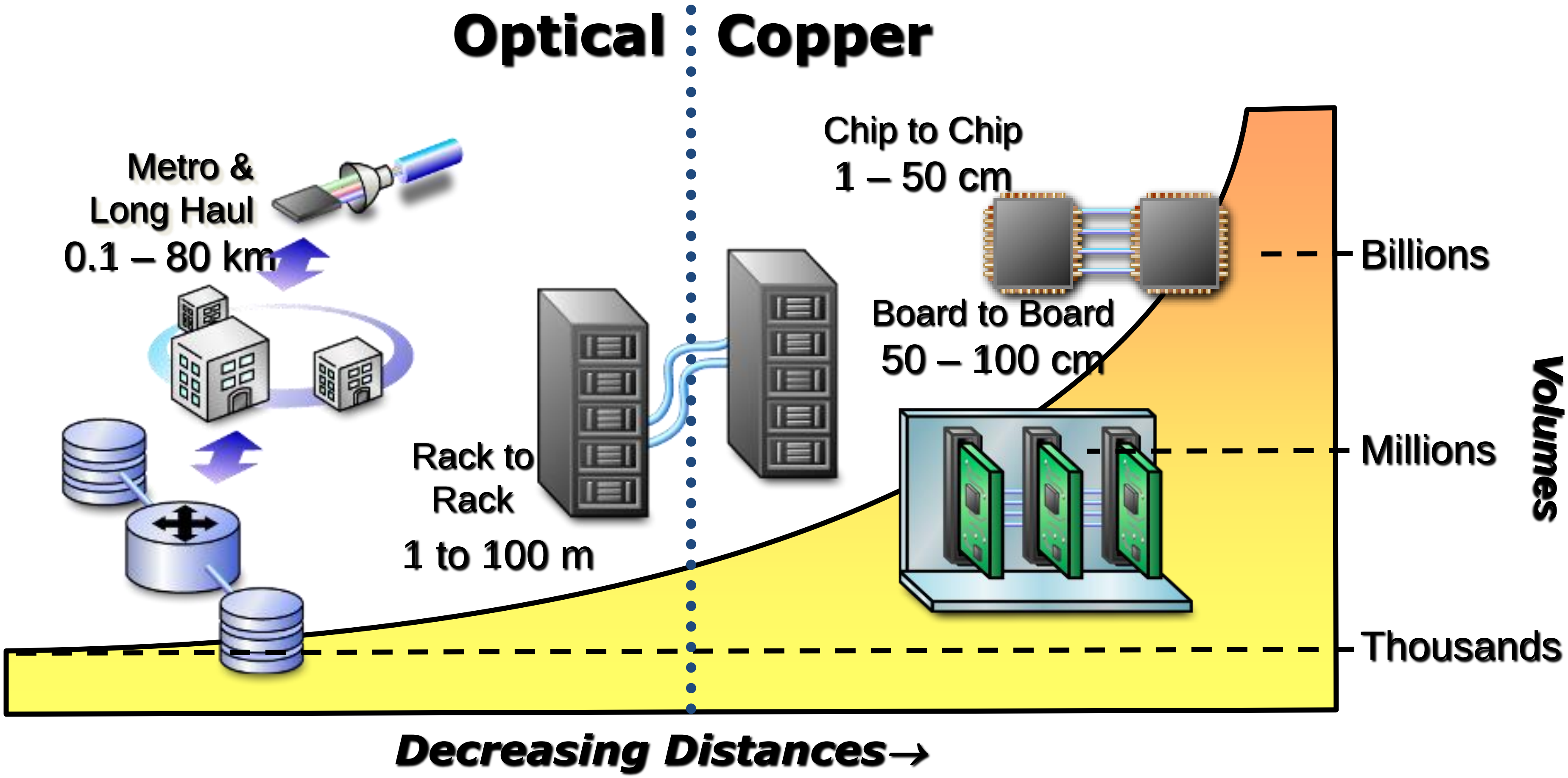
- The computing and communications industries face increasing challenges to deliver more data faster.

- Optical technology has always suffered from its reputation for being an expensive solution, due to its use of exotic materials and expensive manufacturing processes.

  → *Silicon photonics comes to change that reputation:*

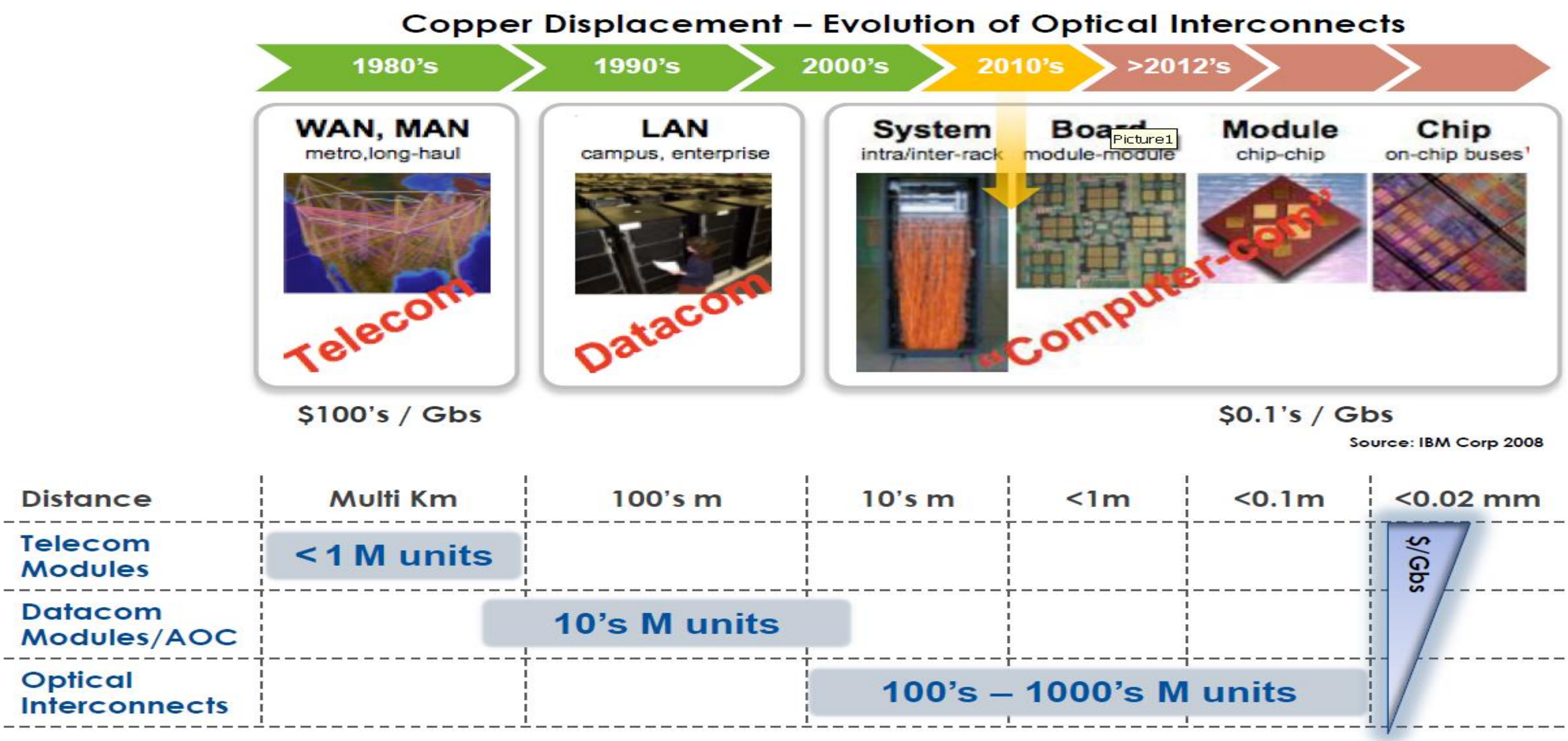
- Silicon photonics is an evolving technology on the low-cost CMOS process technology for fabrication of the optical components - allowing for the convergence of electronics with optics.

Today's High Speed Interconnects

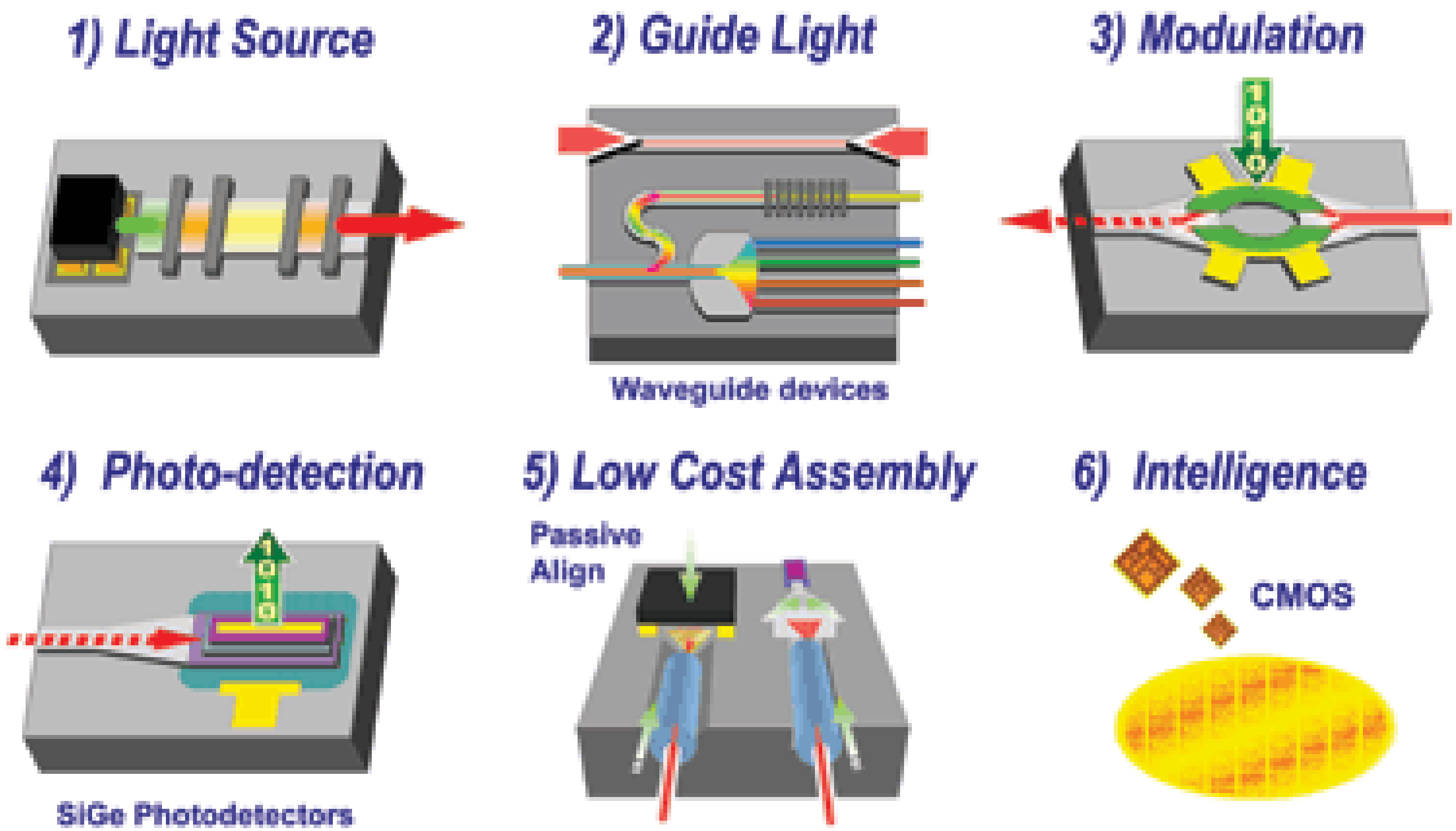


Goal: Drive optical to high volumes and low costs

Evolution of Optical Interconnects



Main building blocks for investigation



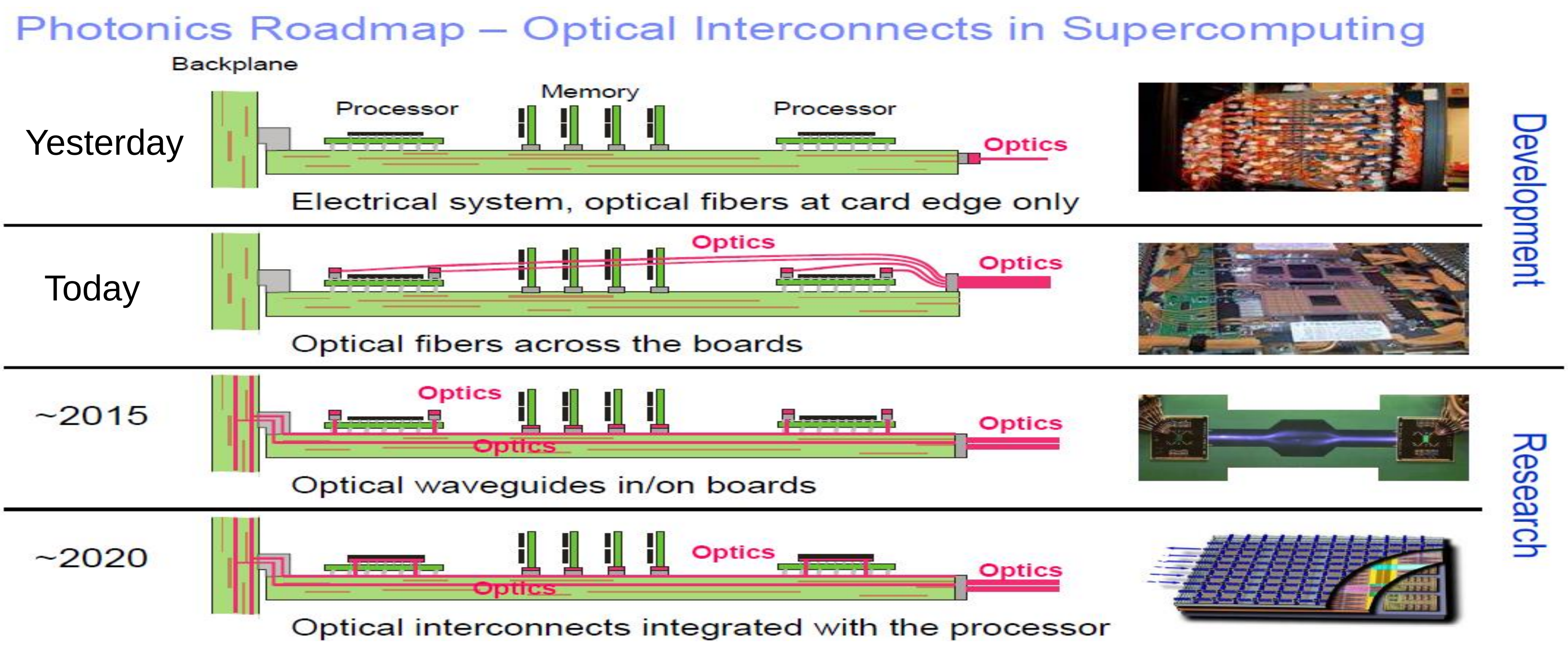
Role of silicon in optical communications/networking

- Silicon will win where it has unique advantages
  - Superb process control, extremely small feature sizes, uniformity
  - High confinement, compact waveguide structures
  - Potential for highly compact switching, multiplexing functions
  - CMOS electronics on board
- …but
  - Needs off board (or hybrid integrated) lasers
  - High performance modulators (high ER, high speed) still difficult
- Silicon should not compete with InP or VCSELs where these are strongest
- Opportunities for data communications in shorter span, high speed, very cost-sensitive applications –a very large market
- Optical switching networks will be of increasing importance

What does VLSI Photonics Require?

- > 100,000 electronic and photonic devices/die
- CMOS Integration
- Redundancy
- Self testing, flexible, software controlled IO formats
- High yield
- High reliability
- Laser, amplifier, modulator, photodetectors, low loss delay lines, optical buffers, AWGs, etc. integrated on chip

IBM Roadmap of Optics in Computing



The vision: Convergence of Photonics & Electronics

Large scale all-semiconductor approach

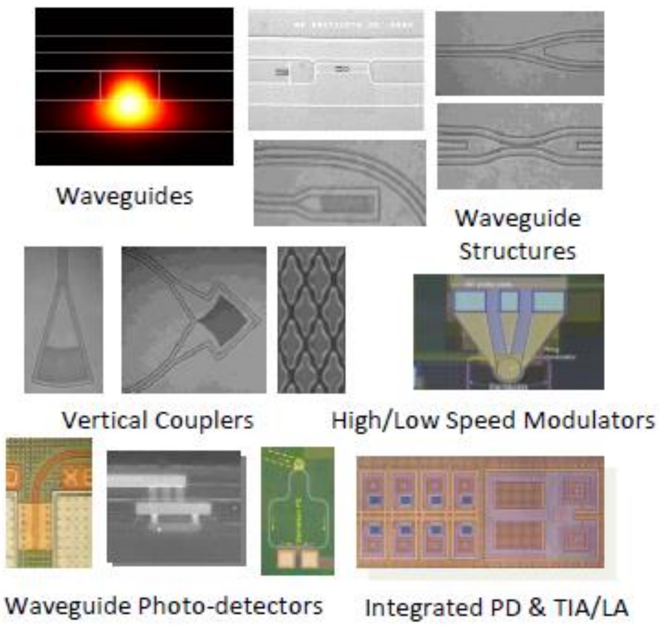
- All-CMOS approach + Ge hybrid integration
- Optics and electronics integrated → high cost, large volume required

Advantages of silicon

- Transparent to light at wavelengths longer than 1100 nm
  - Need transparency to build a waveguide
- High index contrast = miniaturization
  - Small form-factor
- CMOS compatible
- Low cost

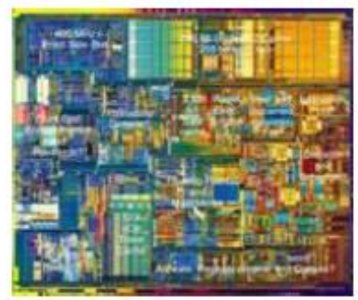
Silicon Photonics is expected to play a key role in future highly integrated optical circuits

Silicon Photonics Technology



CMOS Photonics Circuits

+



CMOS Analog & Digital Circuits

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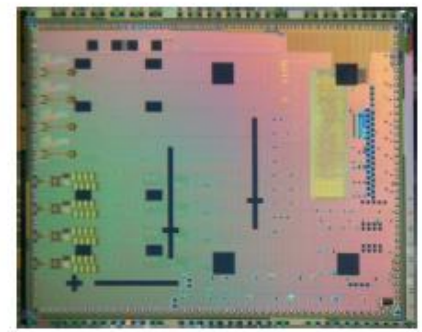


Integrated CMOS Photonic, Analog & Digital Circuits

Next Gen 100G Interconnect

Technical feasibility using Silicon Photonics

Luxtera

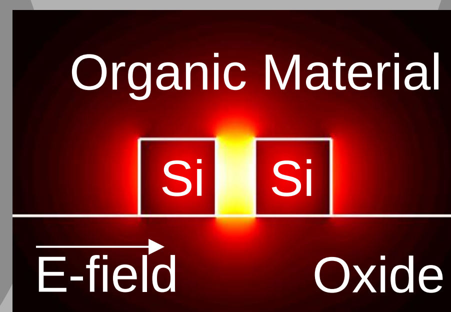
Silicon-Organic Hybrid Concept (SOFI)

Silicon

- CMOS infrastructure
- electrical properties (doping for conductivity)
- optical properties (high refraction index, transparent $\lambda > 1.1\ \mu m$)

Organic Materials

- $\chi^{(2)}$, $\chi^{(3)}$ nonlinear
- liquid crystals
- dyes for a variety of wavelengths



Hybrid
field enhancement in slot

A versatile fabrication platform with large application range

SOFI Approach

Silicon-organic hybrid (SOH) technology

- SOI waveguides & organic cladding

  → Superior and unique functionality

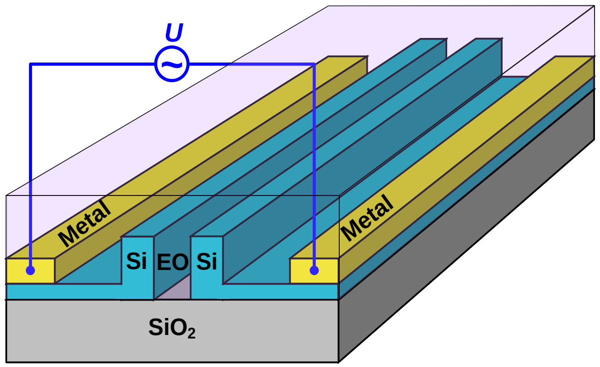
- Hybrid electronic co-integration

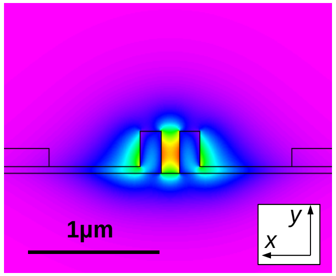
  → SiGe driver (supports higher speed at higher voltage swings)

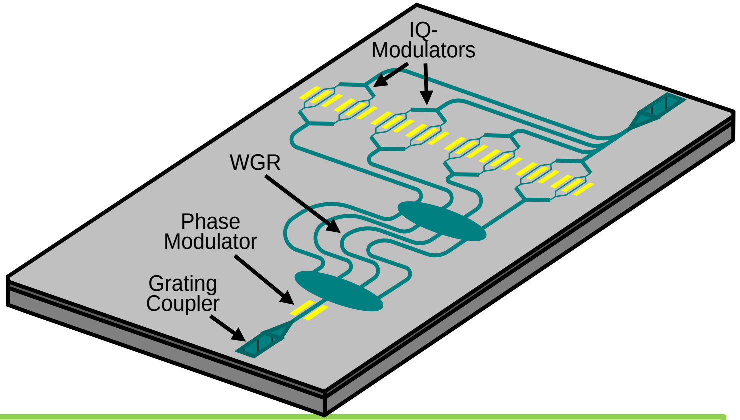
Project objectives

1. Development of a silicon-organic hybrid integrated optics platform
2. Realization of novel electro-optic waveguide, thereby tripling the state-of-the art modulation bandwidth
3. Realization of novel electro-optic waveguide with record low power consumption of 3 fJ/bit
4. Demonstration of a highly integrated optical circuit for high capacity signal transmission and signal processing capabilities exceeding the limits of electronics.
5. The evaluation of the silicon-organic hybrid technology for the realization of disruptive components by varying the organic cladding materials
6. Benchmarking in reference to other data/telecom technologies.

SOFI Goal-Achievements



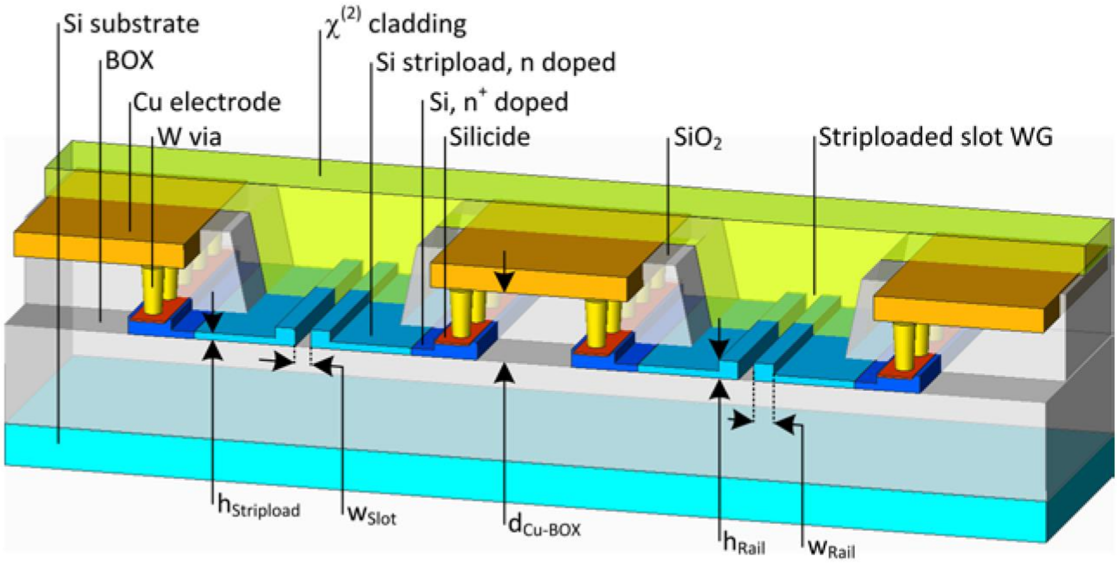




- Novel silicon-organic hybrid technology
- New active optical waveguides and integrated optoelectronic circuits
- Low-cost CMOS processing
- Low power consumption

•Data transmission capacity: SOH IQ modulators can operate at 28 GBd using QPSK for 56 Gbit/s or 16QAM to transmit 112 Gbit/s on a single channel and single polarization.
•Bandwidth: SOH phase modulators can exceed 100 GHz.
•Energy consumption: SOH Mach-Zehnder modulators (MZM) can consume <1.6 fJ/bit at 12.5 Gbit/s
•Driving voltage: A $V\pi L$ product of 0.5 V mm has been realized

The SOFI modulator



➢**Detailed cross section of MZM as implemented, showing two phase modulators with striploaded slot WGs, filled with nonlinear cladding;**
➢**length of 1.5 mm**
[Figure source: dx.doi.org/10.1364/OE.21.013219]

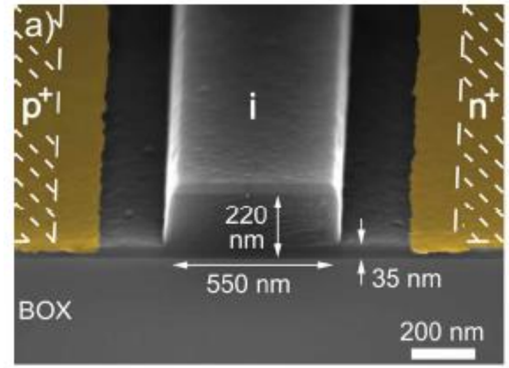
Optical Modulation – EO Conversion

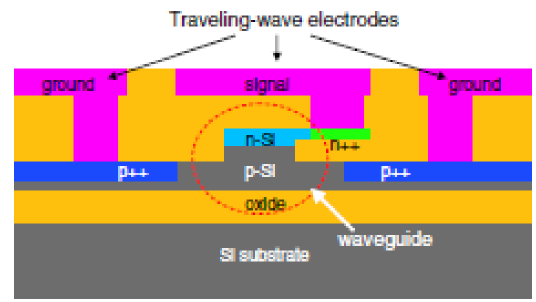
Silicon Plasma-Effect Modulator

- Carrier accumulation
- Carrier injection, 10 Gbit/s (IBM) [1]
- Carrier depletion, 40 Gbit/s (Intel) [2]
  50 Gbit/s (Surrey, CEA Leti) [3]

Drawbacks

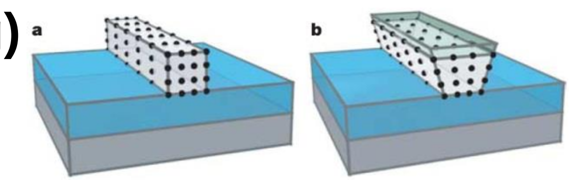
- Intrinsic speed limitation due to carrier dynamics
- Combination of phase and amplitude modulation





Electro-optic Modulator (Pockels effect)

- Strained silicon (DTU) [4]
- **Cladding with NL polymers (poling)**
- **Cladding with NL organic crystals (no poling)**



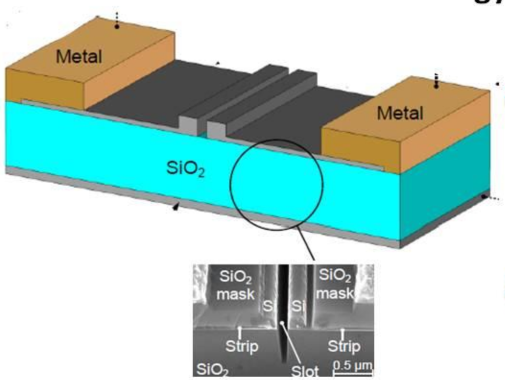
Advantages

- Pure phase modulation
- High bandwidth
- Low power consumption

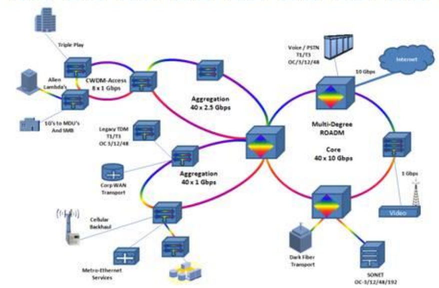
[1] Green, W. et al., Optics Express, 15, 17106-17113 (2007)
[2] Liao, L. et al., Electronics Letters, 43, 1196-1197 (2007)
[3] Thomson, D. et al. IEEE Photonics Technology Letters, 24(4), 234-236, (2012)
[4] Jacobsen, R. S. et al., Nature, 441, 199-202 (2006)

SOFI devices ideal for communications applications

Silicon Organic Hybrid modulator technology

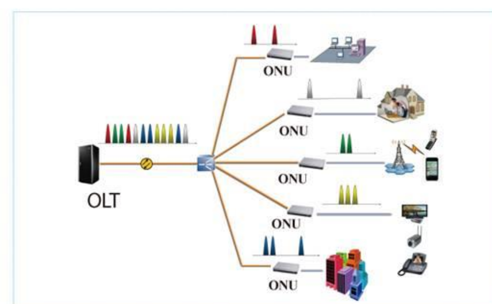


Specification definition structure of SOH modulator technology for long and short reach optical networks



Optical transport networks:

- 100G PM-QPSK (OIF standards)
- 1T super-channel OFDM (theoretical benchmarking against reported solutions)



Access networks:

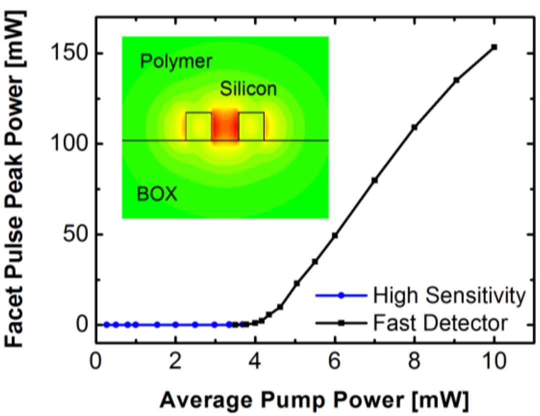
- OFDM PON (theoretical benchmarking against reported solutions)

Identified additional disruptive SOH application scenarios

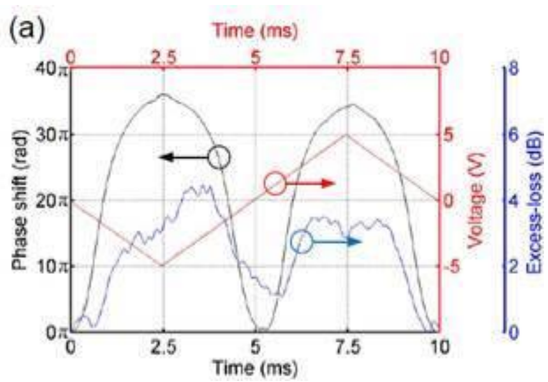
✓**The first SOH laser**

✓**Ultra-low power Liquid Crystal Phase Shifters phase shifters useful for adjusting inevitable phase deviations in the fabrication of IQ modulators and optical FFT circuits for OFDM**

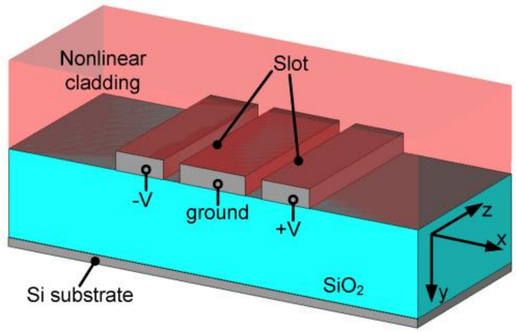
✓**Parametric Amplification**



SOH Laser emission. (a) Output pulse peak power in fiber vs. averaged pump. The inset shows the slot waveguide with simulated mode field



Measured phase shift of strip loaded slot waveguide filled with liquid crystals and driven with a 100 Hz triangular signal of 5 V

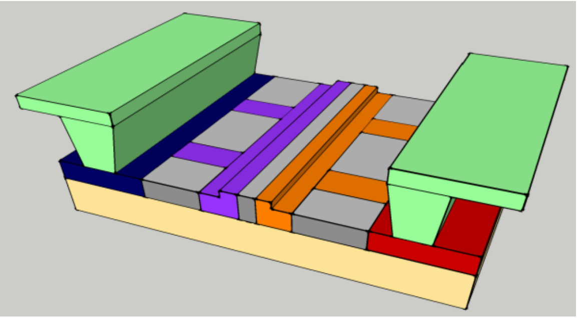


SOH) double slot waveguide for second-order nonlinear applications. The waveguide consists of three silicon strips on a glass substrate, it is multimode and dimensioned such that modal phase-matching is achieved

Detection – OE Conversion (at IR Wavelengths)

- Incorporating various materials
  - Bonding III-V material
  - Epitaxial growth of Ge J. Michel et al., Nature Photon. 4, 527 - 534 (2010)
  - (Mechanically transferring) graphene

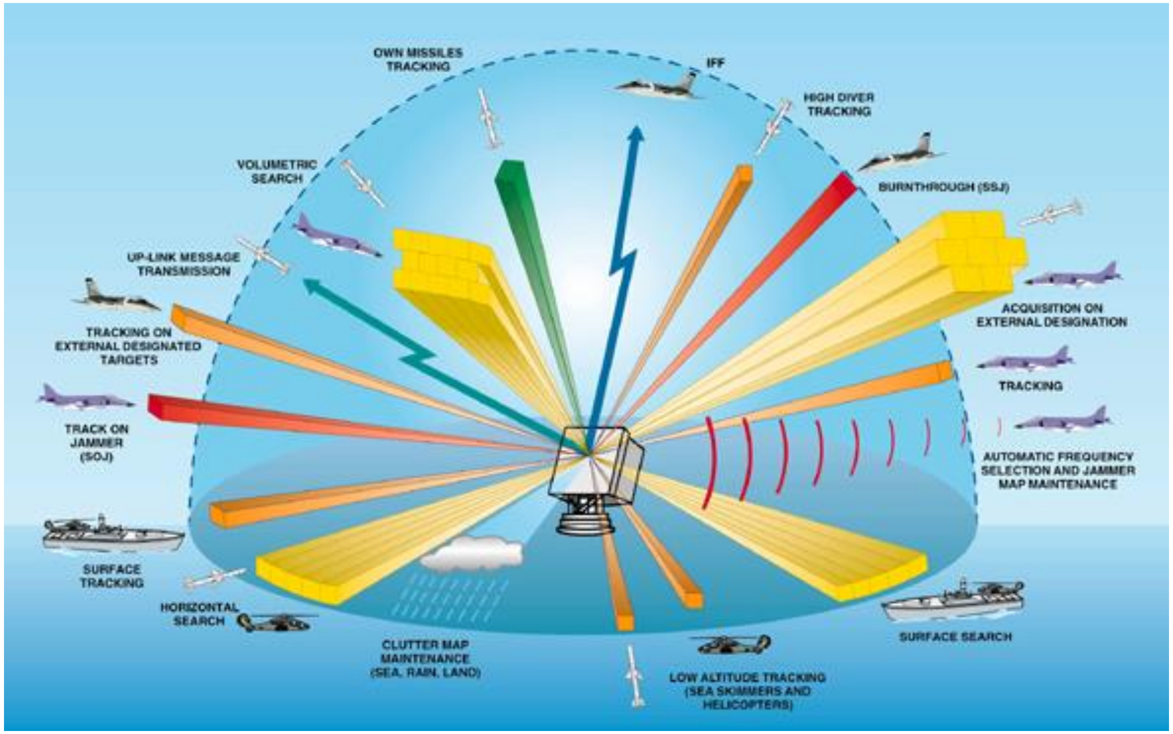
- Rely on silicon
  - Implant Si ions for defect mediated detection
    Geis et al., Optics Express 17, 5193-5204
  - **Implant other ions to create defects**
  - Polysilicon



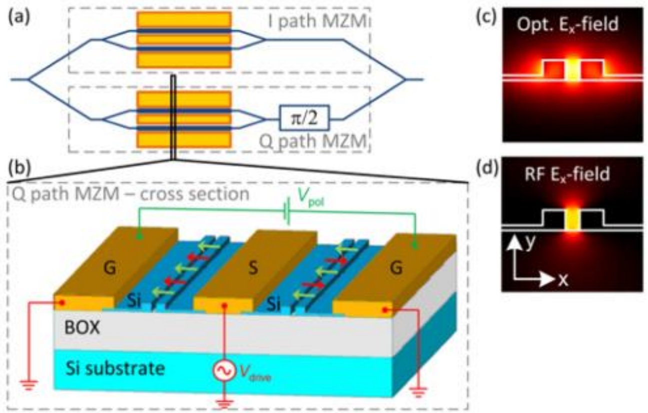
Aim: Easy processing, compatibility with SOH approach

Multifunction Phased Array Radars (M-PAR),

- The SOFI modulators are fundamental devices for already existing RADAR products (European Multifunction Phased Array Radar – EMPAR) as well as for future RADAR architectures (MORSE – EDA project)
- Integration of a large number of SOFI modulators within the same substrate and at the same time exploitation of several optical functions



SOH modulator characterization and benchmarking

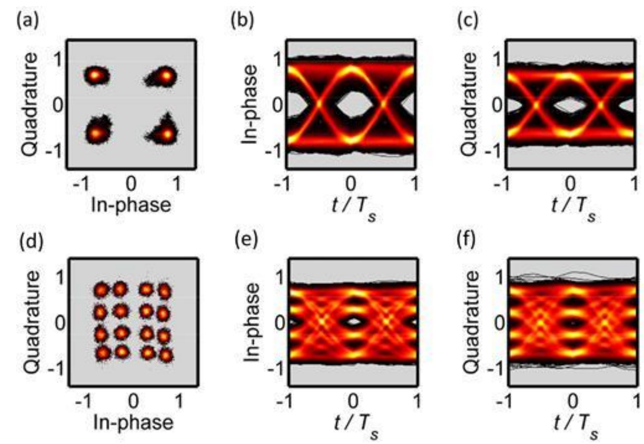


➢IQ modulator based on the SOH concept. (a) Topview of the IQ modulator with nested Mach-Zehnder modulators (MZM), displaying optical waveguides (WG) in blue and electrical lines in orange.

➢(b) Cross section of an SOH MZM, showing two silicon striploaded slot WGs, which act as phase shifters. They are filled and covered with a nonlinear cladding

➢(c) Color-coded dominant x-component |Ex| of the optical electrical field in the slot WG cross section.

➢(d) Modulating electrical RF field. Both fields are strongly confined to the slot, resulting in high modulation efficiency. [Figure source: dx.doi.org/10.1364/OE.21.013219]

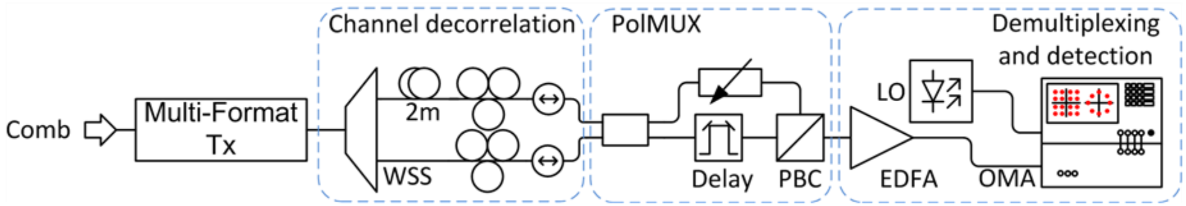


➢Data generation on a single channel and polarization with SOH IQ modulator at 28 GBd reaching 112 Gb/s confirmed that this device with a length of 1.5 mm performs well within the limits of standard forward error correction (FEC)

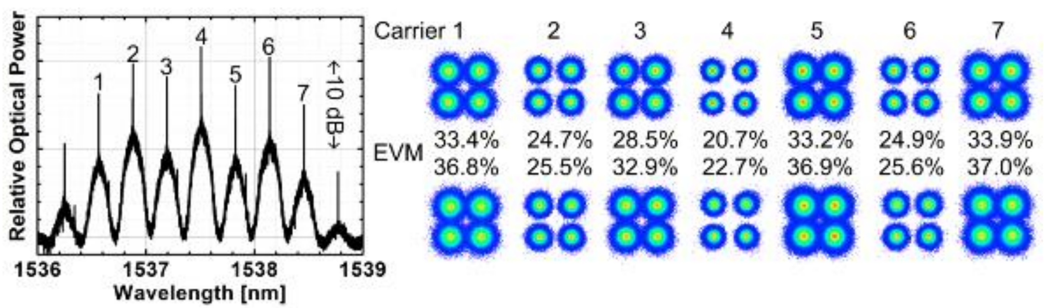
➢ The polymer produced by GigOptix has been used in this experiment.

➢ Error free operation is measured and displayed in (a) constellation and (b, c) eye diagrams. (d) Constellation and (b, c) eye diagrams as observed when employing an 8-tap (1 tap per symbol) pre-emphasis at the transmitter, and no equalization at the receiver. The BER is 1.2×10^{-3}, and the EVM is 10.3%. [Figure source: dx.doi.org/10.1364/OE.21.013219]

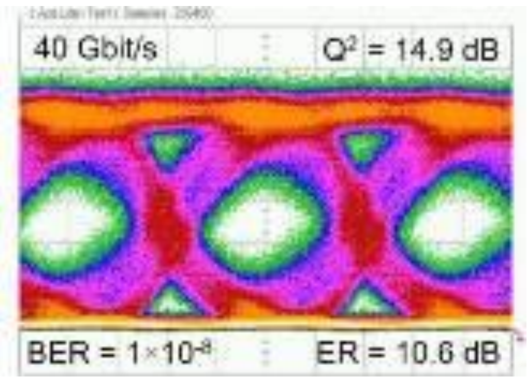
Comb line generation

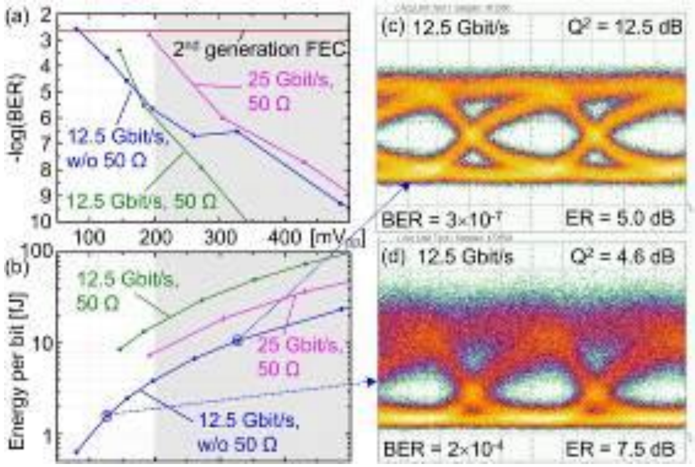


➢Frequency comb generated by SOH modulator to do WDM using a LN modulator
➢Data transmission of 784 Gbit/s using QPSK signals on 7 carriers generated by an integrated SOH comb source.
➢Comb spectrum (left) and constellation diagrams for all channels and both polarization are depicted along with measured EVM values.
➢BER below hard-decision threshold are achieved for all signals.
[Figure source: Weimann et al., "Silicon-Organic Hybrid (SOH) Frequency Comb Source for Data Transmission at 784 Gbit/s", ECOC 2013]



Energy efficient SOFI devices

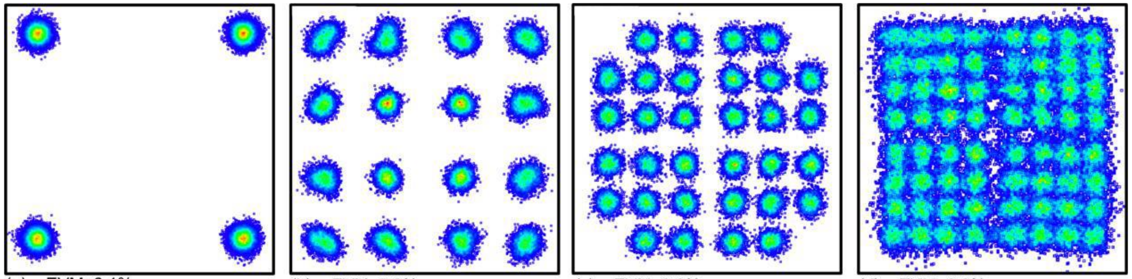




➢Eye diagram and energy consumption of a SOFI modulator when operated at low drive voltages.
➢(a) Measured BER as a function of drive voltage for data rates of 12.5 Gbit/s and 25 Gbit/s when the DUT is terminated by a 50 Ω probe (green, magenta) and for a rate of 12.5 Gbit/s for an unterminated device. Data points in the gray colored area were measured at quadrature.
➢(b) Corresponding energy per bit for the various drive voltages of (a).
➢(c) Optical eye diagram at 12.5 Gbit/s for an unterminated device at quadrature; V_{drive} = 320 mV_{pp}, W_{bit}=10 fJ.
➢(d) Optical eye diagram at 12.5 Gbit/s for an unterminated device below quadrature; V_{drive} = 125 mV_{pp}, W_{bit}=1.6 fJ. [Figure source: Palmer et al., "High-Speed Silicon-Organic Hybrid (SOH) Modulator with 1.6 fJ/bit and 180 pm/V In-Device Nonlinearity", ECOC 2013]

➢MZM from the SOFI project serves to illustrate that the dynamic extinction ratio can surpass 10.6 dB even at 40 Gbit/s.
➢NRZ OOK eye diagram at 40 Gbit/s measured at quadrature. Q^2-factor
➢Drive voltage 950 mV_{pp}.
➢The ER exceeds 10 dB up to 40 Gbit/s.
➢At 40 Gbit/s a BER of 1×10^{-8} was obtained for PRBS length 2^{31}-1.
[Figure source: Palmer et al., "High-Speed Silicon-Organic Hybrid (SOH) Modulator with 1.6 fJ/bit and 180 pm/V In-Device Nonlinearity", ECOC 2013]

Benchmarking studies



(a) EVM: 6.1%
BER (calculated): $< 10^{-18}$
BER (measured): error-free

(b) EVM: 7.0%
BER (calculated): $\sim 10^{-6}$
BER (measured): $< 8 \cdot 10^{-8}$

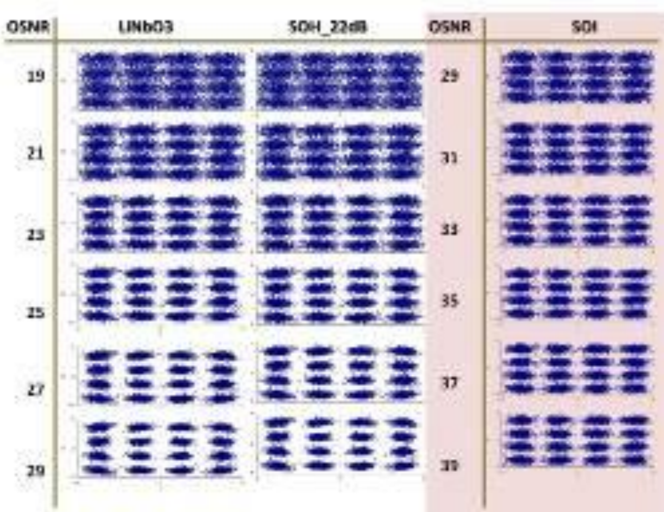
(c) EVM: 6.3%
BER (calculated): $\sim 5 \cdot 10^{-5}$

(d) EVM: 6.9%
BER (calculated): $\sim 1.1 \cdot 10^{-2}$

➢Reference research prototypes developed under the FP7 project GALACTICO

➢GaAs chips provided by the GALACTICO consortium were measured at KIT facilities by KIT and AIT researchers to compare their performance with the SOFI modulators.

➢A 3-dB bandwidth of about 32 GHz and constellation diagrams for up to 64QAM modulation at 25 GBd were obtained

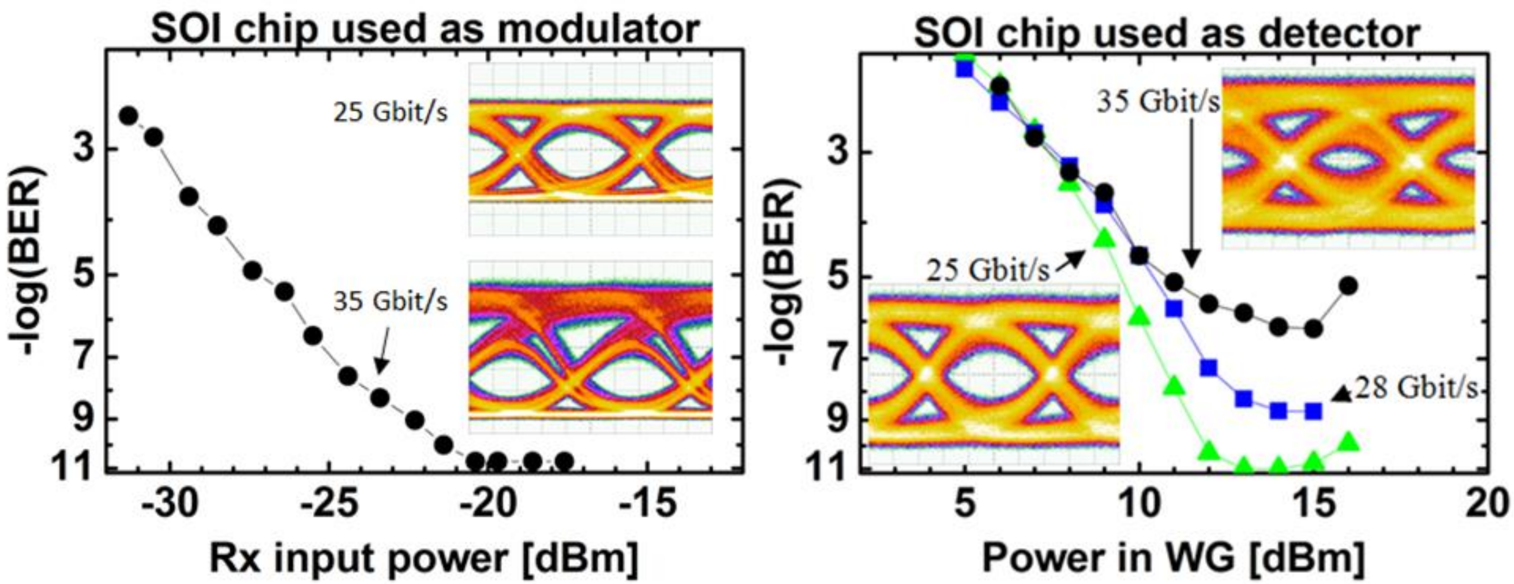


✓Benchmarking of the SOH modulator technology against commercially available electro-optic modulators (e.g. LiNbO3) and currently researched low-cost silicon modulator approaches was performed in the framework of transmission modeling studies

✓The studies showed that SOFI modulators will be capable to provide similar and superior performance with respect to state-of-the-art commercial technologies for long haul and access networks

✓A significant lower network energy requirement in the order of 22-25% can be achieved compared to standard transceiver solutions if SOFI's modulator technology is applied to a real network.

Lateral PN Junction – SOH Compatible Signal Monitoring

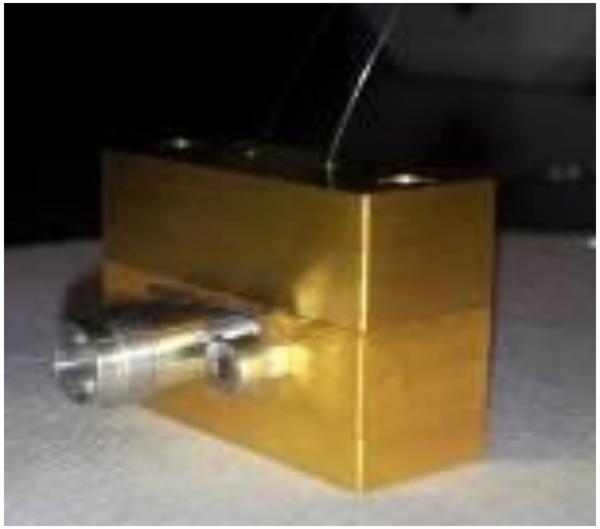


- High-speed modulation (5.7 V reverse bias, Vπ × L = 11.9 Vmm @ -1 V bias, DC) or detection (7.1 V reverse bias) using the same SOI waveguide, PRBS length 2^7–1
- Simple processing relying only on dry etching and ion implantation, fully compatible to SOH platform; no process flow extension

H. Yu et al., Optics Express, 20(12), p.12926-12938 (2012)
D. Korn et al., CTu1A.1, CLEO2012

Packaging of SOFI devices

- Specific tool for fiber alignment and pigtailing has been designed and realized
- Consists of suitable fiber holders, stages for movement, support capillaries and polarization maintaining fibers
- Main packaging difficulties stem from the integration of the SOI chip with the organic polymers that is used for the electro optic features
- The package has been designed as flexible as possible, in order to allow for both flip-chip and standard wiring



Comparison with state-of-the-art

targeted	achieved	state-of-the-art
Solution and melt deposition of single crystalline electro-optic organic materials on top of silicon chips. (Objective 1)	Single crystalline electro-optic thin layers of OH1 and BNA from melt, with single crystalline area of >10 mm^2 respectively, have been deposited on structured SOFI chips with silicon slot waveguides and electrodes. The thickness of the films depends on the growth conditions and can vary between 0.2 and 2 µm.	Not any other single-crystalline electro-optic materials grown directly on structured and electroded chips with silicon waveguides.
Si EO modulator based on SOH technology: 100 GHz bandwidth single channel phase modulator (Objective 2)	Single channel phase modulation - at 42.7 Gbit/s with BER smaller than 3×10^{-9} (almost error-free) - insertion loss 39 dB (including 2x 5 dB grating coupler) - drive voltage 4.1 V (peak-to-peak) - making this devices shorter and using a new polymer cover gives a bandwidth of 100 GHz Single channel MZM - 84 Gbit/s using 8-ASK - 1.6 fJ/bit at 12.5 Gbit/s using OOK at ER 7.5 dB Single channel IQ - 112 Gbit/s using 16QAM well below hard-decision limit for FEC (FEC allows to make error-free transmission)	→In silicon: '50-Gb/s silicon optical modulator' by Thomson *et al.* (Reed) in IEEE Photon. Technol. Lett. 24(4), 234–236 (2012). →Lithium niobate: Limited by walk-off and dispersion because of long structure. 40 Gbit/s at 5.5 V drive →All-organics: 100G modulator from GigOptix. →SOI modulator ER at 3…8 dB using 200 fJ/bit; T. Baehr-Jones et al., Optics Express 20(11):12014-12020, 2012 →IQ modulator from ALU, P. Dong, 224 Gbit/s PM-16QAM barely at limit for soft-decision FEC (too many errors to correct), presented as PDP at OFC 2013
Low-loss slot waveguides for SOH	Optimized etch process gives 10-15 dB/cm strip waveguides (wires) with 1.35-1.7dB/cm propagation loss Narrow slots of 80 nm have been produced. Slot waveguides with 100-130nm width yield around 10dB/cm	Typical loss figures for optically defined wires are around 3dB/cm. (Exception: IBM) E-beam defined wires are around 1dB/cm Standard slot width with DUV lithography is >100 nm Best reported losses are around 7dB/cm (U. Delaware)

Achievements with respect to project objectives – 1/2

❑Development of a silicon-organic hybrid integrated optics platform

- ✓The technology platform has been fully developed
- ✓The passive structures of IMEC have been functionalized with materials from RB and GO.
- ✓SOH modulators have proven useful in a number of scenarios, covering high-speed data transmission at >40 Gbit/s and frequency comb line generation.
- ✓Packaging of prototypes with two different methods (wire bonding, flip-chip bonding) has been investigated.

❑Realization of novel electro-optic waveguide, thereby tripling the state-of-the art modulation bandwidth

- ✓Phase modulator with 100 GHz bandwidth has been built
- ✓Advanced modulation formats have been applied.
- ✓A 112 Gbit/s single channel modulator using 16QAM has been demonstrated at 1540 nm.

❑Realization of novel electro-optic waveguide with record low power consumption of 3 fJ/bit

- ✓Demonstration of NRZ OOK at 40 Gbit/s measured at quadrature. Q^2-factor 14.9 dB, extinction ratio (ER) is 10.6 dB. Drive voltage is 950 mV_{pp}.
- ✓A SiGe driver supplying 0.6 V_{pp} was used to directly drive an SOH MZM. The switch of CMOS electronics to SiGe electronics was motivated in a study performed by GO, which pointed out the cost-advantage of SiGe at realistic initial production volumes.
- ✓An ultra-low power SOH MZM operating at 12.5 Gbit/s consuming only 1.6 fJ/bit has been demonstrated.

Achievements with respect to project objectives – 2/2

❑ Demonstration of a highly integrated optical circuit for high capacity signal transmission and signal processing capabilities exceeding the limits of electronics

- ✓**QPSK was demonstrated with an SOH IQ modulator at 56 Gbit/s. Polarization multiplexing of signals from SOH modulators was shown off-chip in a different experiment using 8-ASK at 2×84 Gbit/s.**
- ✓**All subcomponents necessary to generated and receive an OFDM signal all-optically have been demonstrated. This includes the SOH frequency comb line generator, the SOH data encoder on the transmitter side (Tx). At the receiver side (Rx), photonic integrated circuits for the DFFT have been experimentally shown.**
- ✓**A WDM experiment achieved 784 Gbit/s using an SOH comb source. The actual OFDM experiment was only simulated, due to low resources at the end of the SOFI project.**
- ✓**An experimental demonstration will be made in a different FP7 project, which will continue using the SOH platform developed in SOFI.**

❑ The evaluation of the silicon-organic hybrid technology for the realization of disruptive components by varying the organic cladding materials

- ✓**Successful chromophores deposited in host polymers, organic crystals, dyes in a polymer matrix, chalcogenides, and liquid crystals.**
- ✓**SOH laser**
- ✓**ultra-low power consumption phase shifters.**

❑ Benchmarking in reference to other data/telecom technologies

- ✓**The SOFI consortium characterized plasma-effect based pin-modulators developed in a different project at IMEC.**
- ✓**Collaboration with the FP7 project GALACTICO and performance evaluation of GaAs modulators**
Chalcogenides from CUDOS were measured on 2nd generation SOFI chips but did not show modulation.
- ✓**Each of these approaches has its merits in certain application scenarios. There is no clear winner**

Impact

✓SOH will be a competitive modulator technology that is capable to meet the specifications of new generation long haul and access networks which will require high speed modulators with ultra-high bandwidth

✓Superior performance with respect to commercial available technologies (e.g LiNbO3), low power consumption and reduced cost.

✓A total network energy lowering in the order of 22% is achievable using the SOFI devices leading to new more efficient subsystems and meeting the EU requirements for greener technologies.

✓Significant enhancement of the technology platform: The incorporation of high-quality exposed slot waveguides in a CMOS-compatible silicon photonics platform is not only relevant for high-speed and low-power modulators, but also for sensors. This can be a key differentiator of silicon photonics.

✓IMEC has recently started to offer the full platform in multi-project wafer (MPW) runs. The SOFI-specific modules are not yet a part of that offering, but if there is a clear demand for back-end opening, IMEC will consider to integrate this as a standard module in the platform. This injects the SOFI technology into the silicon photonics supply chain in Europe.

✓Within the SOFI project, silicon-organic hybrid modulation at a high speed has been demonstrated for the first time with organic crystals from Rainbow Photonics. This opens up a new opportunity for organic crystals to replace poled polymers in SOH applications

✓Organic electro-optic crystals developed by RB are very promising for THz-wave generation enabling a wide range of applications

✓Many commercial products prove that it is possible to design chromophores hosted polymers for durable, resilient products.

✓Novel materials of GigOptix Inc. have been used to produce SOH modulators. This is the very same material employed in Telecordia certified modulators sold by GigOptix. Also new polymers/chromophores can be further enhanced. Demand for high performing, energy efficient modulators will drive these developments in chemistry.

✓The potential applications from the output of the project envisaged by Selex-ES rely on both military and civil fields, that are mainly focused on the improvement of advanced generation of Multifunction Phased Array Radars (M-PAR).

From SOH Components to Integrated Circuits

How to integrate building blocks on one chip?

- Focus on SOH modulator and phase shifter
- Check material compatibility
- Find the right combination of solvents
- Encapsulate liquid crystals

How to integrate electronics?

- Use separate SiGe driver, faster than CMOS electronics:
  - Opens different application range, e.g. long haul
  - Allows smaller production volumes, easier product start

How to mount in a package?

- Adapt to wide choice of cover materials
- Use standard packaging approach for flexibility:
  - Pigtailing of grating couplers with active alignment of fibers
  - Wire bonding or flip-chip bonding
  - Rely on off-chip light source

Summary

✓Proof-of-concept implementation of ultra-fast, ultra-low energy optical modulators such as needed in optical communications and a wide range of other applications

✓Claddings made of polymers containing optically nonlinear chromophores have been used, as well as claddings of organic crystals.

✓The demonstrated prototypes address the most important principal challenges of today's optical communications

✓Data transmission capacity: SOH IQ modulators can operate at 28 GBd using QPSK for 56 Gbit/s or 16QAM to transmit 112 Gbit/s on a single channel and single polarization.

✓Bandwidth: SOH phase modulators can exceed 100 GHz.

✓Energy consumption: SOH Mach-Zehnder modulators (MZM) can consume <1.6 fJ/bit at 12.5 Gbit/s

✓Driving voltage: A $V_\pi L$ product of 0.5 V mm has been realized enabling efficient comb line generation.

✓In addition transmission using orthogonal frequency division multiplexing (OFDM) has been investigated.

✓highly energy efficient switches employing liquid crystals have been demonstrated.

✓Using dye molecules as cladding, SOH lasers surpass any other laser on silicon by an order of magnitude in peak output power.

Publications in Conference Proceedings and Journals

- Accepted and published papers:
  - ✓ **Over 30 conference & symposium papers** (OFC, SPIE Photonics, OSA, ICTON, CLEO, IEEE ICT, EOS, IEEE SOI, GFP, ECOC, FOTONICA)
  - ✓ **Over 20 journal papers** (JSTQE, Nature Photonics, Optics Express, PTL, Photonics Journal, Optics Letters)

❖ **A complete list of all publications can be found in D6.8: Final report on SOFI dissemination and promotion activities**

Collaborations with other EU projects

- GALACTICO
- NAVOLCHI
- ACCORDANCE

Conclusions

- Successful promotion in the scientific and industrial community.
- Establishment of contact with other groups (projects, companies).
- A lot of publications in scientific conferences and journals.
- A lot of exploitation activities have been made.

SOFI ideas achieved high visibility in the community and the project has successfully embedded in the research & the industry network.