# Silicon-Organic hybrid Fabrication platform for Integrated circuits

## At A Glance

www.sofi-ict.eu

**Project Coordinator**
Prof. Juerg Leuthold
Tel: +49-721-608-42480
Fax: +49-721-608-49097
Juerg.Leuthold@kit.edu

Karlsruhe Institute of Technology
Kaiserstrasse 12
D-76131 Karlsruhe
GERMANY

**Timeline**
Start Date: 01/01/2010
End Date: 31/12/2012

**Budget**
Overall Cost: >3.5 M€
EC Funding: 2.5 M€

**Proof-of-concept of**

- The silicon-organic hybrid fabrication platform, which is to be created
- Implementation of high speed electro-optic modulator to show the platform's potential
- Looking into applications beyond data / telecom domain, enabled by this platform

**Project Partners**

- Karlsruhe Institute of Technology (KIT), DE
- Selex Sistemi Integrati SPA, IT
- IMEC, BE
- Rainbow Photonics AG, CH
- GigOptix-Helix AG, CH
- Research And Education Laboratory In Information Technologies (AIT), GR
- The University of Sydney (CUDOS), AU

## Vision & Aim

In the SOFI project, new active optical waveguides and integrated optoelectronic circuits based on a novel silicon-organic hybrid technology are introduced. **The technology is based on the low-cost CMOS process technology for fabrication of the optical waveguides - allowing for the convergence of electronics with optics. It is complemented by an organic layer that brings in new functionalities** so far not available in silicon. Recent experiments have shown that such a technology can boost the signal processing in silicon far beyond 100 Gbit/s - which corresponds to a tripling of the state-of-the art bitrate.

**SOFI focuses on a proof-of-concept implementation of ultra-fast, ultra-low energy optical phase modulator waveguides** such as needed in optical communications. These devices will ultimately be used to demonstrate an integrated circuit enabling the aggregation of low-bitrate electrical signals into a 100 Gbit/s OFDM data-stream **having low energy consumption.**

However, the SOFI technology is even more fundamental. By varying the characteristics of the organic layer one may also envision new sensing applications for environment and medicine.

The suggested approach is practical and disruptive. It combines the silicon CMOS technology and its standardized processes with the manifold possibilities offered by novel organic materials. This way, for instance, the processing speed limitations inherent in silicon are overcome, and an order-of-magnitude improvement can be achieved. More importantly, the new technology provides the lowest power consumption. The potential for low power consumption is attributed to the tiny dimensions of the devices and to the fact, that optical switching is performed in the highly nonlinear cladding organic material rather than in silicon.

## Main Objectives

1. Development of a silicon-organic hybrid (SOH) integrated optics platform
    - Overcome silicon related limitations such as the missing electro-optic effect
    - Deal with all technological aspects such as deposition of organics, poling, metallization & prototype packaging
2. Realization of EO phase modulator with 100 GHz electro-optic bandwidth at 1550 nm
    - This will ultimately increase optical processing speeds beyond today's limits of silicon
3. Demonstration of integrated optical circuit for higher order signal modulation formats at 100 Gbit/s
    - Mach Zehnder modulator configuration
    - Aiming for 50 Gbit/s QPSK, 100 Gbit/s OFDM in system application scenario
4. Look into silicon-organic hybrid technology for other purposes than data / telecom applications
5. Benchmarking with respect to other data / telecom technologies
    - Evaluate potential of organic material with respect to inorganic material (i.e. chalcogenides)
    - Comparison to state-of-the-art LiNbO3 modulators

## Technical Approach and Achievements

Within its 1st year the SOFI project demonstrated the world's first high-speed (>10 GHz) **silicon electro-optic modulator based on the Pockels effect.** To confirm its performance, **data transmission at 42.7 Gbps with a bit-error-ratio (BER) smaller than $3 \times 10^{-9}$** has been shown and published (*40 Gbit/s Silicon-Organic Hybrid (SOH) Phase Modulator* presented at ECOC 2010). Above 2 GHz, the **frequency response is essentially flat (less than 3dB decrease between 2 GHz and 60 GHz)** suggesting that data rates could be extended well beyond the 42.7 Gbit/s limit of our equipment. Moreover, this response is wavelength-independent over the C-band.

For accomplishments like this the interplay of SOFI partners is crucial and is described in the brief summary below.

To guide SOFI **to address actual challenges of commercial relevance, *AIT* has identified a number of potential applications of SOFI devices** which exploit electrical and linear / nonlinear optical properties of SOH waveguide structures. Currently, *AIT* has built a simulation platform to study the impact of characteristics and device parameters of SOFI modulators on the systems performance in network systems scenarios, e.g. 56 QPSK systems, 112 Gbit/s DP-QPSK systems and 100 Gbit/s optical OFDM. A block diagram of the 50 Gbit/s QPSK transmitter and receiver is shown in Figure 1.

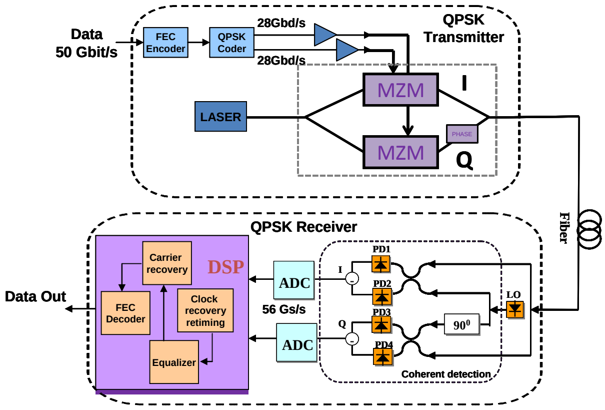


**Figure 1** Schematic of simulated 50 Gbit/s QPSK transmitter and coherent receiver, which will incorporate modulators fabricated in SOFI.

**Design of the optical waveguides and high-speed RF-electrodes is led by *Karlsruhe***

***Institute of Technology (KIT)***. During this core development stage, simulations and design decisions have been made, which determine the performance of the SOH modulators. The devices measured so far have been designed by *KIT* and owe their exceptional properties to a so-called socket waveguide geometry, see Figure 2. Characterization and performance analysis (system experiment) have also been done at *KIT* leading to the result summarized in the box above.

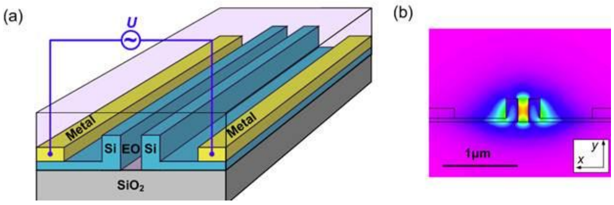


**Figure 2** Socket waveguide to be covered with nonlinear optical material, which changes its refractive index when a voltage is applied across the slot. The slot geometry is chosen for having a large amount of light propagating in the nonlinear material; see (b), which shows the electrical field in a profile cut of the waveguide.

The fabrication **of silicon-on-insulator waveguides in a CMOS line is done by *IMEC***, where the 1st SOFI dedicated run is currently in process. Ion implants as well as metallization are developed for use with integrated circuits of optical waveguides.

To give SOFI devices their functionality a cladding is deposited on top of the silicon waveguides.

→ Organic crystal cladding: ***Rainbow Photonics* has developed new techniques for the deposition of single-crystalline electro-optic organic thin films** of OH1 (2-(3-(4-hydroxystyryl)-5,5-dimethyl-cyclohex-2-enylidene)malononitrile) on various structured substrates. OH1 is a relatively new organic material with very high electro-optic figures of merit, $n^3r$ = 530 pm/V at 1319 nm, as well as a high thermal stability allowing for melt-based processing. Since the lattice matching between organic and inorganic materials is in general not possible in the same way as for inorganic-only hybrids and in several cases the desired substrates are amorphous or consist of different materials, we refer to our deposition processes as quasi-epitaxial. The next figure shows examples of single crystalline organic thin films deposited on top of various inorganic substrates.

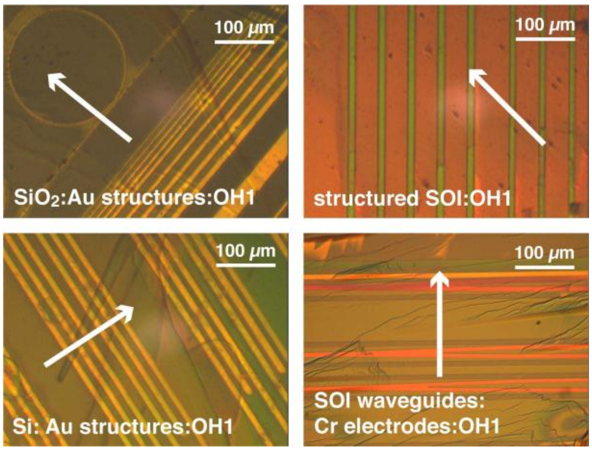


**Figure 3** OH1 thin electro-optic films (0.5–5 µm thick) grown on various structured substrates; photos have been taken between crossed polarisers in reflection microscope; arrows indicate the polar *c* axis of OH1 crystals.

→ Polymer cladding: ***GigOptix-Helix'* main contributions are the provision of the electro-optic polymers**, by coordinating the exchange of sample material and work instructions between GigOptix Bothell and the consortium, **as well as the exploitation and dissemination activities**. Furthermore, *GO* contributed to the identification of emerging applications. The first year focussed on selecting the proper existing material and process steps to enable the deposition of EO polymers while filling the narrow slot of the waveguide, see next figure.

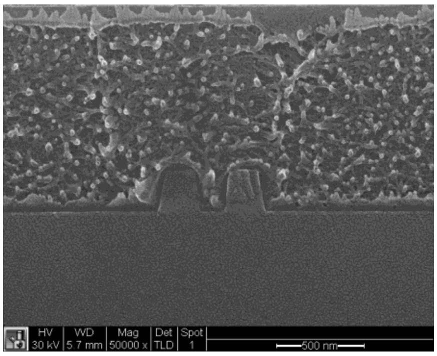


**Figure 4** Picture showing the EO polymer filling the waveguide slot, an essential requirement to make the modulator work.

→ Inorganic cladding: To evaluate the potential of organic materials with respect to inorganic materials ***CUDOS (University of Sydney)*** **is currently looking into the deposition of chalcogenides**.

To assure the potential of commercial applicability of devices developed in SOFI, **SELEX addresses packaging and RF design**. One possibility currently pursued is described here: The work flow for the wedge-bonding technique directly in a standard packaging module (Figure 5) consists of three main steps:

1. After the chip has been fixed and glued to the metallic enclosure, the electrodes are bonded to the 50 Ohm load and to the RF input connector. A microstrip alumina transition from coaxial connector to coplanar waveguide electrodes could be adopted.
2. The fibers are aligned to the In/Out grating couplers, glued and UV cured.
3. Finally the cover is mounted on the package and the fibers, passing through it by way of two slits, are fixed with an epoxy resin.

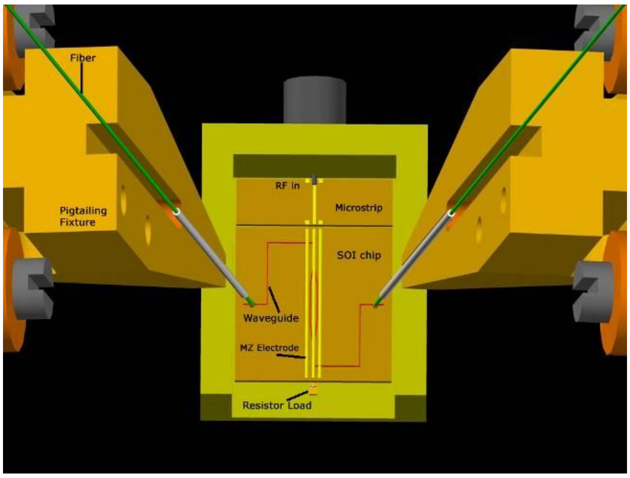


**Figure 5** Fiber to grating couplers alignment procedure

## Expected impact

Technical results will come to the benefit of the participating industrial partners and people reading our publications. However, the impact of the project must be seen in the wider context of several European and international incentives in the domain of Silicon Photonics.
Among the other projects in the European Silicon Photonics Cluster (see www.siliconphotonics.eu) **SOFI will answer the question, whether a silicon organic hybrid platform contributes a viable technology to face today's global questions on capacity of communication channels** (be it long distance connections for the internet or some optical port to connect PCs, servers) and their related **energy consumption**.
Given the fact that huge microelectronics companies are driving research in this field, **SOFI creates know-how especially in Europe** in a field where nobody yet can claim leadership.
Considering the almost infinite range of applications which come into view at the moment of convergence between electronics and photonics, **SOFI identifies which particular set of applications can be served best by using the silicon organic hybrid approach**. In this sense, SOFI is a piece in an ensemble of European projects driving innovation in Silicon Photonics in Europe and thereby creating potential for employment and wealth in general.

**Please visit www.sofi-ict.eu**