



Silicon-Organic hybrid Fabrication platform for Integrated circuits

Second public report on SOFI dissemination activities

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List of Partners concerned

Partner number	Partner name	Partner short name	Country	Date enter project	Date exit project
1 (coordinator)	Karlsruhe Institute of Technology (formerly University of Karlsruhe)	KIT	Germany	M1	M42
2	SELEX - Sistemi Integrati	SELEX	Italy	M1	M42
3	Interuniversity Microelectronics Centre - IMEC	IMEC	Belgium	M1	M42
4	Rainbow Photonics AG	RB	Switzerland	M1	M42
5	GigOptix-Helix AG	GO	Switzerland	M1	M42
6	Research and Education Laboratory in Information Technologies	AIT	Greece	M1	M42
7	The University of Sydney, Centre for Ultrahigh bandwidth Devices for Optical Systems	CUDOS	Australia	M1	M42

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1. Executive Summary

This deliverable reports the actions taken by the SOFI consortium in terms of dissemination of the project results during the 2nd reporting period of the project covering the period from January 2011 to June 2012 included.

In the second year of the SOFI project a significant amount of knowledge was generated in the specific topics related to the project.

While the actual exploitation activities and plans are detailed in Deliverable 6.5, it is worth mentioning the good results achieved during the second year suggest great potential for the further developments planned within SOFI and more so in view of the exploitation after the conclusion of the project.

To disseminate the project results and promote its visibility several actions were taken by the different partners:

- The project web site was updated providing summary of the activities performed over the first 2 years of the project, including list of publications and participation to events like conferences and trade shows.
- Significant presence at the most relevant optical conferences and symposiums in 2011 and in first half of 2012.
- Lead the preparation of a Silicon Photonics white paper to be published in 2012.

All partners have been very active in promoting the SOFI project in renowned scientific journals, magazines, conferences and seminars with great impact.

2. Dissemination of Knowledge

All partners of the SOFI consortium are committed to mobilize their contacts in the international research society and industry to promote the project results.

The participation in conferences, workshops and EU events not only falls in the project scope but it is one of the main project objectives.

Scientific contributions have and will continue to be submitted, throughout the project lifetime, for publication to journals/conferences, provided that they will enhance project visibility and release useful conclusions to the telecom community.

The dissemination plan includes the creation and maintenance of a professional project website containing all public information and facilitating contacts and exchanges with other research and industrial initiatives on the relevant topics. This consortium WEB site was created and is maintained by KIT with inputs from all partners.

In Sections 3.1 to 3.6 the activities per partner are listed.

2.1 RB Dissemination activities

Conferences and Symposiums

Rainbow Photonics was present at the following international exhibitions with the company booth, where we were also distributing a flyer promoting the SOFI project:

- SPIE Photonics West , Jan. 25-27 2011 in San Francisco USA
- Laser World of Photonics exhibition, May 22-26 2011 in Munich, Germany
- SPIE Photonics West exhibition, Jan. 24–26 2012 in San Francisco USA

RB presented the results of the activities within SOFI at the following international conferences:

- M. Jazbinsek, S.J. Kwon, P. Günter, "**Quasi-Epitaxial Single-Crystalline Organic OH1 Films with High Electro-Optic Activity on Inorganic Structures for Large-Scale Photonic Integration**", CLEO Europe, May 22-26 2011, Munich, Germany (oral presentation)

Abstract: We developed quasi-epitaxial deposition processes for organic OH1 crystals with high electro-optic figure of merit $n^3r=530$ pm/V at 1319 nm on top of glass, silicon-on-insulator and metal structures for high-speed, low-driving-voltage on-chip hybrid optical modulators.

- P. Günter, "**Organic and inorganic crystalline wires and thin films for hybrid integrated optics**" (Invited talk) Frontiers in Optics 2011 / Laser Science XXVII (16. - 21. 10. 2011) San Jose (U.S.A)

Abstract: Organic electro-optic thin films and nanowires intended for hybrid integration with Si have been prepared. The realization of optical microresonators based on these fast responding materials and on ion-sliced LiNbO₃ thin films will be presented.

- "**Organic single crystalline electro-optic films for hybrid integration with silicon photonic wires**" by P. Günter, B. Ruiz, M. Jazbinsek (Oral presentation), SPIE Photonics West (January 22–26, 2012), San Francisco USA

Abstract: Future high-speed and low-power silicon photonics modulators may benefit from hybrid integration of electro-optically active organic materials, which allow modulations bandwidths >100 GHz, beyond the limits of inorganic analogues. We developed new techniques for the deposition of single-crystalline electro-optic organic thin films of OH1 on inorganic substrates, including electroded silicon waveguides. OH1 is a new organic material with very high electro-optic figures of merit, $n^3r = 530$ pm/V at 1319 nm, and is the first highly nonlinear organic crystal allowing for melt-based processing, which is crucial for the fabrication of sub-100-nm structures required for on-chip photonics.

Journals

The following research paper has profited from Rainbow Photonics's activities within SOFI:

- Eun-Young Choi, Mojca Jazbinsek, Seung-Heon Lee, Peter Günter, Hoseop Yun, Soon W. Leed and O-Pil Kwon, "**Co-crystal structure selection of nonlinear optical analogue polyenes**", CrystEngComm, 2012, 14, 4306–4311

Abstract: We demonstrate co-crystallization of analogous phenolic polyene molecules that form non- isomorphic single-component crystal structures for nonlinear optical applications. The analogous polyene molecules form similar main supramolecular hydrogen-bond interactions with neighboring molecules resulting in polar linear molecular chains, but form different crystal space groups in single component crystals, which have a different orientation of these molecular chains due to subtle variations of weak intermolecular interactions. The resulting co-crystal structure is isomorphous with one of the single-component crystals. In co-crystallization with competition between two analogous crystal structures, the solubility plays an important role to select the equilibrium crystal structure of co-crystals. The phenolic polyene co-crystals retain optimal molecular ordering with large macroscopic nonlinearity of single component crystals for nonlinear optical applications.

2.2 AIT Dissemination activities

Conferences and Symposiums

AIT has prepared two conference papers that include the latest results from the studies performed under WP2 on the potentials of the SOFI devices in high speed telecom systems. These papers are:

- An invited presentation at ICTON conference 26-30 June 2011 Stockholm, Sweden 2011. *Mishra A.K. , Nellas I., Tomkos I., Koos C., Freude W., Leuthold J. "Comb generator for 100 Gbit/s OFDM and low-loss comb-line combiner using the optical inverse fourier transform (IFFT)"*
Paper abstract: "The generation of comb spectra is essential for optical OFDM transmitters. We describe a simple solution to this problem, feeding a dual drive Mach-Zehnder modulator with a 12.5 GHz sinusoidal at one arm and with a 25 GHz sinusoidal at the other arm separately. Up to eight optical subcarriers with 12.5 GHz spacing and a spectral flatness of < 1 dB can be produced. Much lower drive voltage swings are required than with other techniques reported so far. The modulated optical subcarrier fields are multiplexed to a compound field employing a lossless optical inverse Fourier transform circuit. Further, this circuit strongly suppresses inter-subcarrier cross-talk.
- A paper for the IEEE ICT-conference, 8-11 May 2011, Cyprus. *Mishra,A.K., Tomkos, I., "A novel cost-effective combline generation and cross-talk mitigation in optical OFDM signal using optical iFFT circuits"*
Paper abstract:" This paper is focused on the proposed novel techniques for cost-effective and high performance optical OFDM systems. We propose a novel cost-effective optical comb-line generation source to produce 8-sub-carriers with spectral flatness of <1dB with drive amplitudes of 1V_{pi} employing single dual-drive Mach-Zehnder-Modulator and show a comparison with other efficient comb-generator methods. We also propose a novel optical iFFT-based implementation for 87.5 Gbit/s optical NRZ-OFDM

generations. It is shown that the cross-talk introduced by imperfect WDM demultiplexer to separate sub-carriers for modulation can be significantly reduced.

AIT has organised a special session on silicon photonics at ICTON 2012 conference (2-5 July 2012, Warwick, UK) in collaboration with SOFI. This session will take place together with another EC-funded Project (FP7-ICT-NAVOLCHI) special session in a single workshop about silicon photonics and plasmonic technologies. The SOFI consortium has prepared a relevant invited paper about the project and its achievements (paper Th.A5.5). A preliminary agenda of the workshop is the following:

Preliminary Agenda of SOFI/NAVOLCHI workshop

- 9:30 Th.A5.1 Chip-to-chip plasmonic interconnects and the activities of EU project NAVOLCHI (Invited)
- 9:50 Th.A5.2 Surface plasmon-polariton amplifiers (Invited)
- 10:10 Th.A5.3 Low energy routing platforms for optical interconnects using active plasmonics integrated with silicon photonics (Invited)
- 10:30 Th.A5.4 Broadband and picosecond intraband absorption in lead based colloidal quantum dots (Invited)
- 10:50 Th.A5.5 Silicon-organic hybrid fabrication platform for integrated circuits (Invited)
- 11:10 Th.A5.6 Exploiting photosensitive As₂S₃ chalcogenide glass in photonic integrated circuits
- 11:25 Th.A5.7 Towards plasmonic lasers for optical interconnects

AIT contributed to the preparation of an invited paper about the SOFI project, its targets and achievements at ICTON 2012. The paper title is “Silicon-Organic Hybrid Fabrication Platform for Integrated Circuits”. This submission is a summary of the SOFI project objectives, targets and achievements.

Paper abstract: “The combination of CMOS compatible Silicon-On-Insulator (SOI) fabrication technology with organic cover materials constitutes the Silicon-Organic Hybrid (SOH) fabrication platform, which shows innovative functionality for the making of integrated optical circuits. We report on experimental demonstrations of essential building blocks for transceivers, while relying only on well-known SOI processing steps and simple post processing of the organic materials.”

Journals

AIT contributed to the preparation of the white paper on the European Silicon Photonics cluster with title “Silicon Photonics Progress in Europe”

Other Dissemination Activities

Each year AIT is organising a sequence of open research seminars with duration of 2 hours per seminar. In the frames of two seminars relevant to optical communications, a number of presentations to interested AIT graduate students and researchers about the SOFI technology platform with the AIT activities took place.

2.3 SELEX Dissemination activities

Presentation of the SOFI project and the silicon photonic potentiality within the focus group of photonics in the framework of MINDSH@RE, which is a FINMECCANICA activity aiming to promote scientific knowledge within the companies of the group.

2.4 GO Dissemination activities

Conferences and Symposiums

GigOptix was present at the following optical conferences and symposiums with its own corporate booth:

- OFC2011, Los Angeles, US, March 2011
- ECOC 2011, Geneva, Switzerland, September 2011
- OFC2012, Los Angeles, US, March 2012

A strong highlight has been given during the meetings at both conferences to GigOptix' technologies that relate to silicon photonics, namely GigOptix's EO material and chipset for optical interconnect and to the participation to the SOFI project.

Conferences

GigOptix contributed to the preparation to several papers presented at conferences by KIT. Please refer to Section 2.6 for the full listing.

Journals

- **42.7 Gbit/s electro-optic modulator in silicon technology.** Alloatti, L.; Korn, D.; Palmer, R.; Hillerkuss, D.; Li, J.; Barklund, A.; Dinu, R.; Wieland, J.; Fournier, M.; Fedeli, J.; Yu, H.; Bogaerts, W.; Dumon, P.; Baets, R.; Koos, C.; Freude, W. and Leuthold J.; Optics Express Vol. 19, pp. 11841-11851, June 2011, doi:10.1364/OE.19.011841

GigOptix has contributed to the preparation of the white paper on the European Silicon Photonics cluster with title "Silicon Photonics Progress in Europe".

2.5 IMEC Dissemination activities

IMEC will provide information about dissemination activities for the reporting period at a later stage of the project.

IMEC and KIT have a number of joint publications, see next section.

2.6 KIT Dissemination activities

KIT, as the coordinator of the project has been very active in the dissemination activities of the project, which are listed below. KIT is also keeping the SOFI webpage up-to-date.

Conferences

- **Silicon-Organic Hybrid (SOH) Lasers at Telecommunication Wavelengths.** Paper ID number is: 1360268. Matthias Lauermann; Dietmar Korn; Patrick Appel; Luca Alloatti; Wolfgang Freude; Juerg Leuthold; Christian Koos. 17-21 June, 2012 at the Cheyenne Mountain Resort, Colorado Springs, Colorado, USA.
- **First Silicon-Organic Hybrid Laser at Telecommunication Wavelength.** Dietmar Korn; Matthias Lauermann; Patrick Appel; Luca Alloatti; Robert Palmer; Wolfgang Freude; Juerg Leuthold; Christian Koos. Pres. number: CTu2I.1, CLEO: 2012 in San Jose, CA.
- **Detection or Modulation at 35 Gbit/s with a Standard CMOS-processed Optical Waveguide.** Dietmar Korn; Hui Yu; David Hillerkuss; Luca Alloatti; Christoph Mattern; Wim Bogaerts; Katarzyna Komorowska; Roel Baets; Joris Van Campenhout; Peter Verheyen; Johan Wouters; Myriam Moelants; Philippe Absil; Wolfgang Freude; Christian Koos; Juerg Leuthold. Pres. number: CTu1A.1, CLEO: 2012 in San Jose, CA.
- **Highly Efficient Strip-to-Slot Mode Converters.** Palmer, R.; Alloatti, L.; Korn, D.; Heni, W.; Schindler, P.; Bolten, J.; Karl, M.; Waldow, M.; Wahlbrink, T.; Freude, W.; Koos, C.; Leuthold, J.; CLEO 2012, San José (CA), USA, Paper CM4M1, May 2012
- **Nonlinear optics on the silicon platform.** Freude, W.; Alloatti, L.; Melikyan, A.; Palmer, R.; Korn, D.; Lindenmann, N.; Vallaitis, T.; Hillerkuss, D.; Li, J.; Barklund, A.; Dinu, R.; Wieland, J.; Fournier, M.; Fedeli, J.; Walheim, S.; Leufke, P. M.; Ulrich, S.; Ye, J.; Vincze, P.; Hahn, H.; Yu, H.; Bogaerts, W.; Dumont, P.; Baets, R.; Breiten, B.; Diederich, F.; Beels, M. T.; Biaggio, I.; Schimmel, Th.; Koos, C.; Leuthold, J.; Optical Fiber Communication Conference (OFC'12), Paper OTh3H.6 Los Angeles (CA), USA, 04.–08.03.2012 (**invited**).
- **Loss reduction of silicon slot waveguides with ALD-grown thin films.** Säynätjoki, A.; Karvonen, L.; Alasaarela, T.; Korn, D.; Alloatti, L.; Tervonen, A.; Palmer, R.; Koos, C.; Leuthold, J.; Freude, W.; Honkanen, S. K.; OPTO SPIE Photonics West - Society of Photo-Optical Instrumentation Engineers (OPTO-SPIE'12), San Francisco (CA), USA, Paper 8266-11 Jan. 21-26, 2012
- **Slotted Photonic Crystal Slow Light Modulators.** Leuthold, J.; Freude, W.; Koos, C.; Alloatti, L.; Korn, D.; Palmer, R.; Brosi, J. M.; Integrated Photonics Research, Silicon and Nanophotonics (IPRSN) 2011 paper: JTUA3 Slow and Fast Light (SL) Topical Meeting of the OSA, Toronto, Canada, June 2011 (**invited**)
- **Silicon nanophotonics and silicon-organic hybrid (SOH) integration.** Koos, C.; Alloatti, L.; Korn, D.; Palmer, R.; Vallaitis, T.; Bonk, R.; Hillerkuss, D.; Li, J.; Bogaerts, W.; Dumon, P.; Baetes, R.; Scimeca, M.L.; Biaggio, I.; Barklund, A.; Dinu, R.; Wieland, J.; Fournier, M.; Fedeli, J.; Freude, W.; Leuthold, J.; General Assembly and Scientific Symposium, 2011 XXXth URSI Istanbul August 2011 doi: 10.1109/URSIGASS.2011.6050595
- **Silicon-Organic Hybrid (SOH) Electro-Optical Devices.** Koos, C.; Alloatti, L.; Korn, D.; Palmer, R.; Hillerkuss, D.; Li, J.; Barklund, A.; Dinu, R.; Wieland, J.; Fournier, M.; Fedeli, J.; Yu, H.; Bogaerts, W.; Dumon, P.; Baets, R.; Freude, W. and Leuthold J.; Optical Society of America, Paper IWF1
- **Smooth and ultra-precise silicon nanowires fabricated by conventional optical lithography.** Palmer, R.; Alloatti, L.; Korn, D.; Moosmann, M.; Huska, K.; Lemmer, U.;

Gerthsen, D.; Schimmel, Th.; Freude, W.; Koos C. and Leuthold J.; CLEO 2011, Baltimore (Maryland), USA, Paper CThZ1, May 2011

Journals

- **Performance tradeoff between lateral and interdigitated doping patterns for high speed carrier-depletion based silicon modulators.** Yu, H.; Pantouvaki, M.; Van Campenhout, J.; Korn, D.; Komorowska, K.; Dumon, P.; Li, Y.; Verheyen, P.; Absil, P.; Alloatti, L.; Hillerkuss, D.; Leuthold, J.; Baets, R. and Bogaerts, W.; Optics Express, Vol. 20, Issue 12, pp. 12926-12938, June 2012, dx.doi.org/10.1364/OE.20.012926
- **42.7 Gbit/s electro-optic modulator in silicon technology.** Alloatti, L.; Korn, D.; Palmer, R.; Hillerkuss, D.; Li, J.; Barklund, A.; Dinu, R.; Wieland, J.; Fournier, M.; Fedeli, J.; Yu, H.; Bogaerts, W.; Dumon, P.; Baets, R.; Koos, C.; Freude, W. and Leuthold J.; Optics Express Vol. 19, pp. 11841-11851, June 2011, doi:10.1364/OE.19.011841
- **Reduced propagation loss in silicon strip and slot waveguides coated by atomic layer deposition.** Alasaarela, T.; Korn, D.; Alloatti, L.; Säynätjoki, A.; Tervonen, A.; Palmer, R.; Leuthold, J., Freude, W.; Honkanen, S.; Optics Express Vol. 19, pp. 11529-11538, June 2011 doi:10.1364/OE.19.011529

2.6 CUDOS Dissemination activities

CUDOS will provide information about dissemination activities at a later stage of the project.

2.7 The Silicon Photonics Cluster White Paper Initiative

In Brussels on April the 13th representatives of several European projects all active in the field of silicon photonics represented in the European Silicon Photonic cluster (<http://www.siliconphotonics.eu/>), including SOFI, have agreed to prepare a white paper to increase the public awareness regarding the ongoing activities in Europe and highlight the importance of European Community support to them.

The white paper will highlight the relevance Silicon Photonics will have for our societies and give a sense of the leadership Europe has in the field. The areas where the innovations related to Silicon Photonics are expected to be of relevance will also be discussed, including application to health sensors, environmental sensing, security, telecommunications, computing and datacom and even consumer.

The contributions will be kept as simple as possible from a scientific standpoint to broaden the audience.

In the reporting period the first draft for the white paper was completed and the internal review process was started. At present time a consolidation of the white paper content based on the comments on the first draft that was circulated is ongoing. It is expected that the white paper will be completed by September 2012.

3. Consortium future actions

The SOFI consortium will keep strong interaction with national and international initiatives through the activities independently carried on by the members of the consortium as one of the preferred ways to maximize synergies between the activities within the SOFI consortium and the scientific community as a whole.

A plan for using and disseminating knowledge is being maintained throughout the lifetime of the project.

The Final Plan for using and disseminating knowledge will describe the actual achievements for each participant in the consortium and their plans for the exploitation of the project results - for the consortium as a whole and for individual participants or groups of participants.

The Final Plan will also describe the dissemination strategies, the target groups and the strategic impact of the project in terms of improvement of competitiveness or creation of market opportunities for the participants.