PROJECT FINAL REPORT

Deliverable D1.7: Final Publishable Summary Report

Grant Agreement number:	*224375*
Project acronym:	*BOOM*
Project title:	*Micro and Nano-scale silicon photonic integrated components and sub-systems enabling Tb/s-capacity, scalable and fully integrated photonic routers*
Funding Scheme:	*Collaborative Project*
Period covered:	***from*** *01-May-08* **to** *30-Sept-11*

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Section A- Final publishable summary report

1. Executive summary

BOOM has been a photonic integration concept aiming to develop compact, cost-effective and power efficient silicon photonic components for high capacity routing applications. The project has focused on a hybrid integration technology allowing Si manufacturing with III-V material processing for the implementation of a wide range of optical functionalities, including high speed optical transmission, modulation and wavelength conversion, on the silicon-on-insulator substrate.

BOOM has invested on the micro-solder fabrication technique for the hybridization of active components on silicon boards. The Au-Sn bumping process has reached adequate level of optimization during the BOOMing years. A key-milestone success has been the flip-chip bonding of SOAs and EML transmitters on the SOI boards with placement accuracy down to submicron level enabling the fabrication of silicon-on-insulator hybrid components with good electrical/optical properties. This has been a major achievement since it proved that the current flip-chip assembly technology could certainly provide mounting capabilities well below the multi-mode fiber limit. Compared to other techniques, BOOM micro-soldering technology has been more flexible and compatible with advanced III-V processing steps.

BOOM has advanced the state-of-the-art in photonic wavelength conversion devices developing scalable all-optical wavelength converters (AOWCs) with record integrated line-rate performance. In contrary with silica-on-silicon demonstrations, BOOM converters have increased aggregate switching capacity by a factor of 4, assisting for first time data rates up to 160Gb/s. In terms of footprint, silicon wavelength converters have been more compact devices (10 times squeeze) due to their high refractive index material. With respect to energy consumption, BOOM devices consumed less power (by a factor of 7) compared to Mach-zehnder interferometric structures due to the utilization of only one active element for the wavelength conversion process.

The InP-photodetectors developed in BOOM have been in direct competition with Ge-detectors for integration with silicon waveguides. Their hybridization has been performed with the heterogeneous wafer-scale integration technique. A persistent difficulty with this approach has been the high series resistance and the non-uniformity BCB layer thickness limiting the high-speed optical transit time of the detectors. From a fabrication point of view, a key success has been an adaptation in the flow process mechanism in order to minimize contamination of the surface prior to metal deposition ensuring good metal/semiconductor contact. From the design point of view, a significant improvement has been performed in the III-V epitaxial growth so as the photodetector to be more transit time limited than RC limited. The new technological methodology has been proved reliable and fully extendable to other materials and other wavelength ranges.

As general conclusion, BOOM has offered mature technology setting the basis for large scale implementation of cost-effective and power-efficient silicon components. BOOM has faced difficulties but eventually succeeded in demonstrating reliable and state-of-the-art components. In our opinion, BOOM has been a highly successful project that turned silic*o*n photonics into a stable and powerful integration platform.

BOOM

Terabit-on-chip: micro and nano-scale silicon photonic integrated components and sub-systems enabling Tb/s-capacity, scalable and fully integrated photonic routers

Grant Agreement No. 224375
Project duration: 41 months
Project website: http://www.ict-boom.eu

2. Introduction

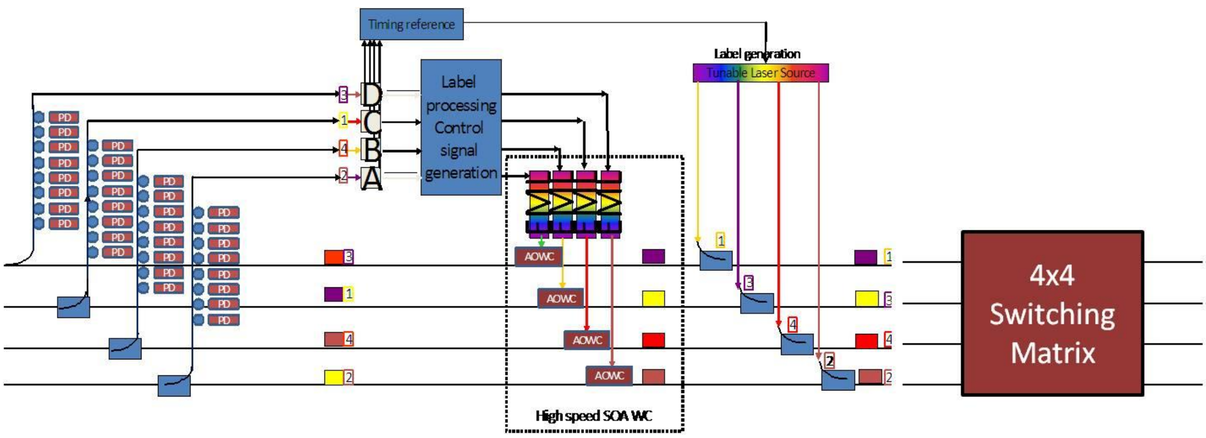
Power efficiency, physical size and equipment cost are key issues in Telecommunication Networks for the development of the next generation telecommunication hardware. The energy saving checklist includes broadband core networks, which now appear to be significantly energy consuming, since electronic carrier routing systems consume and dissipate large amounts of electrical power and heat respectively. The growing demand on the other hand for bandwidth hungry internet applications is stressing the available capacity and performance of current optical core networks. Network operators are responding with the expansion of their electronic infrastructure and the deployment of new transmission and switching equipment. However, the lack of compactness, the increased power consumption and the rack inter-connectivity issues raise prime concerns for the configuration and practical operation of modern central offices. The turn towards photonic technology has initiated multi-million investments worldwide for the development of optical systems that prove the potential of ”casting the light” into electronic data routing systems. R&D has been focused on the development of integrated transceivers and optical interconnection of electronic router racks - however this is not the end of the story. Photonics are being prepared for going deeper into the heart of electronic systems and perform the switching signal processing and routing processes.

Monolithic InP integration has been dominant in the fabrication of photonic integrated circuits (PICs) for signal processing such as all-optical wavelength converters (AOWCs) and multi-port optical switches. With the continuous progress of photonic integration, the assembly of the InP chips with passive silicon or silica waveguide circuits has become feasible, realizing even more demanding functionalities such as optical packet synchronization and buffering. Now the new trend is to bring both InP and silicon components on the same integration platform in order to address loss-coupling issues and obtain functional PICs with optimum yield management and InP utilization. In this context new power-efficient component designs and new optical routing components based on the hybrid silicon photonic platform are now being attempted combining both the processing speed of InP and the cost-effective silicon fabrication.

3. Project description summary and objectives

The European BOOM project has focused on the development of a photonic routing platform relying on hybrid silicon-on-insulator (SOI) integrated PICs to implement all the routing functionalities; label detection, control signal generation, wavelength conversion and wavelength routing. Hybridization of Semiconductor optical amplifiers (SOAs), electro-absorption modulated lasers (EMLs), photodetectors and electronic driver ICs has been pursued through flip-chip bonding and heterogeneous wafer scale integration techniques on top of rib and strip waveguide silicon boards respectively. With these technologies BOOM targeted to a new family of hybrid-silicon integrated components such as ultra-fast all-optical wavelength converters, EML transmitters, WDM photo-detectors and micro-ring based cross-connects on silicon substrates. The final goal was to assemble these components in a routing machine with >160 Gb/s aggregate capacity.

The envisaged BOOM photonic routing architecture is depicted below. Synchronized labeled packets are launched at different wavelengths. Payloads have an on-off-keying packet format and carry data rates up to 160 Gb/s. Labels on the other hand are NRZ optical pulses with duration of a few nanoseconds. The switching process starts with packets arriving at the node at predefined time-slots and three sub-systems are employed for routing the packets. The first performs label detection through Ultra-Dense Wavelength Division (UDWDM) demultiplexers that filter out the optical labels. The generated electrical signals are subsequently delivered for further electronic processing. The electronic processor – which can be typically a FPGA - generates the control signal that gates the all-optical wavelength conversion subsystem. The latter includes EMLs and high-speed AOWCs. The EMLs have the DFB and electro-absorption (EAM) section and by gating the EAM, E/O conversion of the control signal is accomplished. The optical control signals are subsequently used to feed the wavelength converters changing the wavelengths of the incoming data packets and assisting the wavelength routing process. The ultra-fast AOWCs consist of semiconductor optical amplifiers (SOAs) and a pair of cascaded DIs. The SOAs serve for cross gain and phase modulation while the cascaded interferometers for chirp filtering and polarity inversion respectively. According to the wavelength of the labels, a different group of photodetector, EML and wavelength converter is enabled changing the color of the initial packet streams. The wavelength converted packets enter the 4x4 switching matrix and are routed to specific



The BOOM routing architecture

outputs according to their new wavelength color. Packet routing configurability can be performed using heating elements on top of ring-based switching matrix. The whole routing system was designed to support 160 Gb/s line rates with power consumption mainly determined by the wavelength conversion stages.

Relying on the previous architecture BOOM has introduced a silicon-on-insulator (SOI) hybrid integration platform that provides all-optical signal processing functions that are beyond the reach of silicon and traditional III-V integration on their own. The project aimed to develop fabrication techniques as well as flip-chip bonding and heterogeneous III-V silicon integration methods to fabricate and mount the complete family of III-V components on SOI boards including: Semiconductor Optical Amplifiers (SOAs), Electro-absorption modulated lasers (EMLs) and InGaAsP photodetectors. In component level BOOM aimed to realize:
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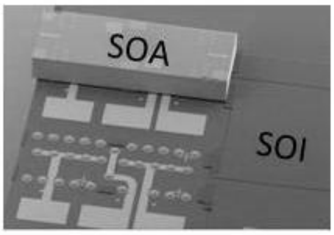
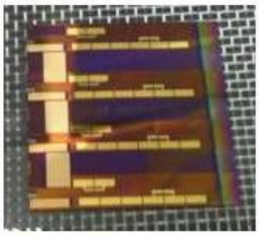
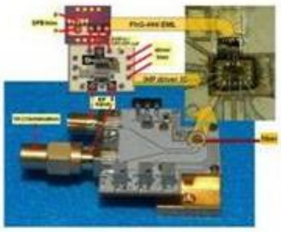
- A single All-Optical Wavelength Converter (AOWC) operating at 160Gb/s.
- A quadruple array of AOWCs fabricated on a chip size of 33x28 mm^2.
- A UDWDM photodetector with integrated ring resonator demultiplexers, heating elements and evanescent PIN detectors.
- A SOI EML transmitter integrated together with SiGe electronic drivers on a single chip.

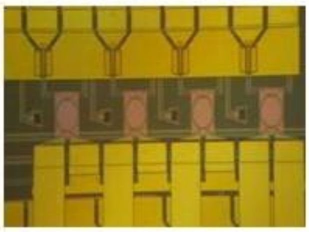
An additional goal for BOOM was to develop improved CMOS compatible waveguide technologies to fabricate ultra-small, low loss and fully reconfigurable wavelength routing switches. BOOM has pursued two planar waveguide concepts: the TripleXTM and SOI nanowire waveguide technology to fabricate higher order micro-ring and racetrack resonators for high-speed all-optical signal processing as well as switching matrixes for wavelength-based routing. Finally, BOOM has aimed to system integrate the fabricated hybrid components in rack-mountable cases developing customized electronic boards and user-friendly interfaces. The final target was to experimentally evaluate the prototype assembled platform in a lab environment and in a meshed optical network testbed for ultra-fast optical packet switching and video/audio streaming respectively.

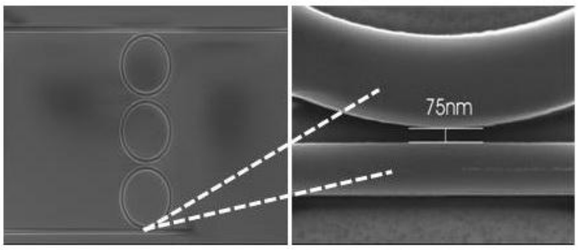


160Gb/s Hybrid AOWC

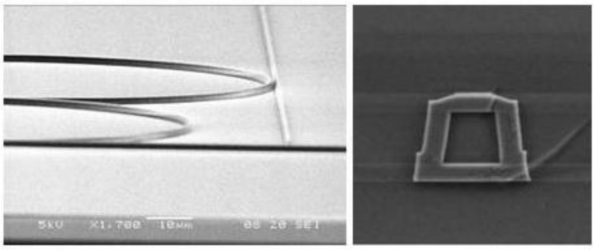

Quad Hybrid AOWC


EML transmitter


UDWDM photodetector



SOI Higher Order Rings


TriPleX Higher Order Rings

Consortium

Institute of Communications & Computer Systems/National Technical University of Athens

Heinrich-Hertz-Institut

Interuniversity Microelectronics Centre

University of Berlin

Technical University of Eindhoven

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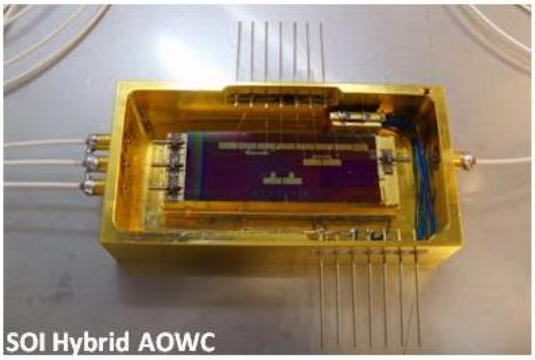
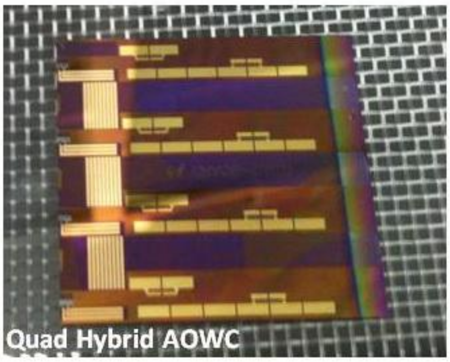
4. Work performed over the whole project

The main technical achievements of BOOM are summarized below:

- **Ultra compact, High-speed, SOI Hybrid Wavelength Converters and High density Wavelength Converter Arrays**

BOOM has pursued from the beginning of the project to hybrid integrate SOAs on silicon boards in order to form high-capacity wavelength converters. The fabrication method employed was the Au-Sn “sputtering” technique which allowed the flip-chip mounting of mature pre-fabricated active components on the silicon substrate. Through the years it has been a persistent difficulty to integrate the SOA chips on silicon motherboards with proper electrical and optical properties. After high-level optimization and a number of flip-chip attempts, placement accuracy has been achieved down to submicron level. This has been a key milestone success that enabled the fabrication and experimental evaluation of silicon-on-insulator all-optical wavelength converters (AOWCs) up to 160Gb/s. Compared to silica-on-silicon implementations, BOOM has advanced the state-of the-art worldwide demonstrating compact silicon converters with 4x higher throughput. Due to the utilization of only one active element for the wavelength process, these devices have been as well power efficient consuming 700mW of electrical power.

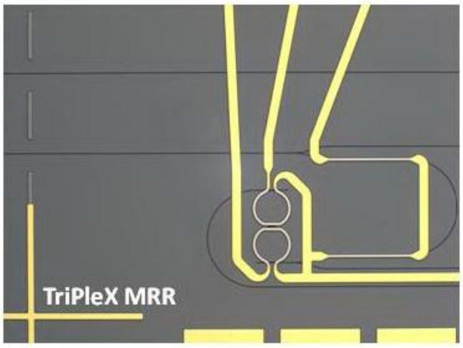


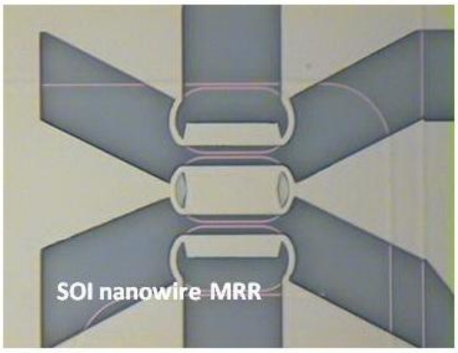


Note: Packaging for SOI Hybrid AOWC has been provided by Optocap

- **Micro-ring resonator technology for compact and functional wavelength converters**

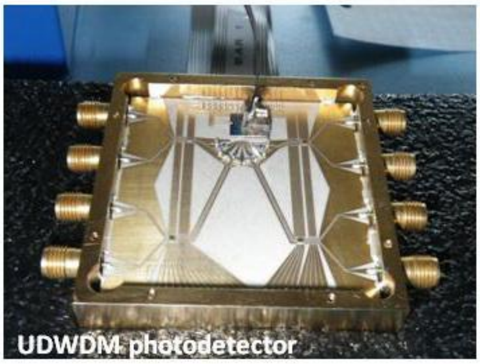
BOOM has explored two different waveguide platforms in order to integrate pulse-shaping wavelength selective switches. With the TriPleXTM approach, it has demonstrated a multi-channel wavelength conversion platform with integrated micro-ring resonators (MRRs) and delay interferometers (DIs). With low waveguide insertion loss (0.1dB/cm) and polarization independent behaviour, BOOM has reported 4x40Gb/s operation with 80mW electrical power per heating element. This has been a significant result for the implementation of large-scale photonic circuits with low tuning power consumption capabilities. With the SOI nanowire approach, higher order MRRs have been developed with coupling gaps <90nm, high resolution filtering profiles and SU8 tapered sections for efficient chip coupling. BOOM has demonstrated with the fabricated components wavelength conversion at data rates up to 160Gb/s. In order to alleviate the frequency mismatch observed in 3rd order structures, integrated heating elements have been incorporated for independent ring resonance wavelength tuning.

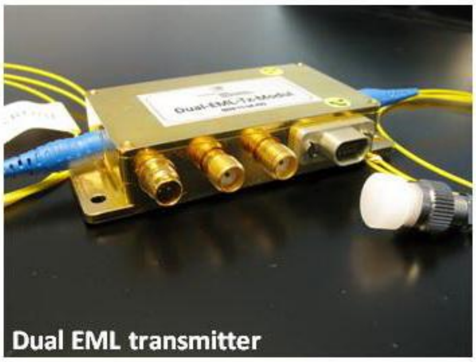




- **Compact, optoelectronic UDWDM photodetector and EML transmitters**

BOOM has systematically attempted to fabricate a hybrid UDWDM photodetector using the heterogeneous wafer scale integration technique and a dual EML transmitter employing the Au-Sn bumping approach. A persistent difficulty in the UDWDM development has been the high series resistance after the InGaAs detector hybridization limiting the overall performance of the device. After a series of fabrication tests, a process adaptation has been pursued minimizing contamination of the surface prior to metal deposition in order to ensure good metal/semiconductor contact. This has been proved very successful and system tests have shown operational performance up to 10Gb/s. The progress development of the hybrid dual EML transmitter has been a challenging task since it required the co-integration of the InP EMLs and SiGe electronic drivers on the same silicon platform. The whole process took more time than expected but in the end it succeeded showcasing the flexibility of the flip-chip bonding technique on integrating electro-optic components into silicon motherboards. DC measurements have verified good electrical and optical properties.

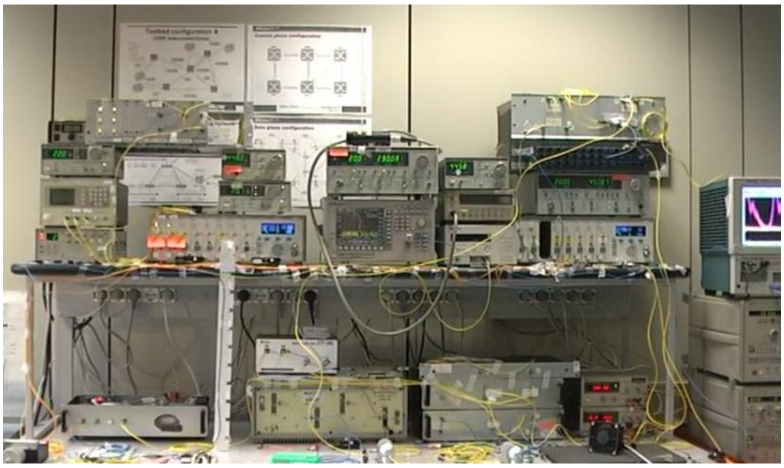


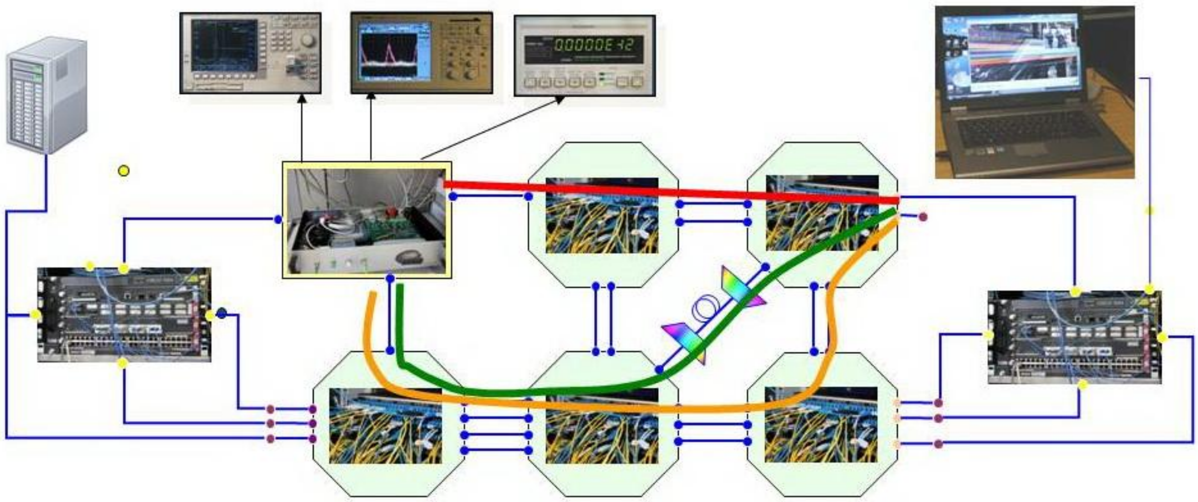


Note: Packaging for UDWDM photodetector has been provided by Fraunhofer IZM, Packaging for dual EML transmitter has been provided by PicoWave Berlin

- **System integration and evaluation**

BOOM has pursued to fabricate customized PCBs for driving the packaged and pigtailed components. These circuits have been constantly developed throughout the project meeting the electrical specifications set by the optical modules. The different piece parts have been successfully assembled and integrated in system enclosures, which in a second step have been monitored and controlled by user friendly interfaces. From the system level point of view, two major experiments have been performed in order to demonstrate the functionality of the fabricated elements. The first one took place in a lab environment showcasing 160Gb/s packet switching employing a 4-channel SOI demultiplexer, a high-speed wavelength converter and a hybrid integrated flip-flop. The second one was implemented in the network operator testbed, verifying the feasibility of the BOOM wavelength converter to transmit and route real data traffic. This has been a proof-of-principle experiment that verified the reliability of the BOOM silicon hybrid platform in next-generation routing interfaces.





Section B- Use and dissemination of foreground

BOOM project has developed integrated photonic circuits for implementing label detection, control signal generation, wavelength conversion and wavelength routing in the optical domain. Although BOOM hybrid integration methodology has been in its early development stage, it has ensured a stable platform that compares favorably in terms of volume/footprint with current state-of-the-art approaches.

Within BOOM project the integration of lasers, modulators, photodetectors and electronic drivers on the SOI board has enabled the assembly of fully functional transmitter/receiver modules applicable to metro/core networks. The arrays of micro-ring resonators due to their superior performance in terms of size, scalability and CMOS fabrication processes are finding the way to commercial application in WDM receivers and Reconfigurable Add-Drop Multiplexers as high-resolution DWDM filters. The developed SOI hybrid all-optical wavelength converters with 4x higher capacity than that of electronics set the basis for the assembly of high-capacity routing systems.

In BOOM project a number of technology solutions and processes have been developed and improved. Single process steps have been organized and assembled to process modules for dedicated network applications. The fabricated BOOM components are showcases of advanced technological processing offering new possibilities to a wide range of applications ranging from sensing systems in the visible light region to telecommunication devices at IR wavelengths. In this context BOOM has reinforced new integration concepts, starting up prototyping foundry services and licensing rules for mass photonic element production.

BOOM has carried out in the dissemination level a number of activities in order to increase the visibility of the project to a wide range of population groups, including the scientific community, students of different educational levels and the general public. By this time, BOOM has already significant impact to the scientific drift with presence to the most prestigious journals and photonic events. The project activities have been presented in international conferences, workshops, exhibition booths and silicon photonics forums attracting both research and industrial interest. BOOM project numbers 4 invited presentations, 28 conference presentations and 11 journal papers.

The network system tests performed within BOOM project have attracted the interest of large photonic companies. Experts have expressed positive comments for the developed BOOM hybrid technology, the routing architecture and the high end-to-end video performance quality. The final demo results have been summarised in a presentation video available in the BOOM website to disseminate the successful conclusion of the project and the future plans. An extract from the final video demo is on display in the internal Telecom Italia WEB TV, as an important innovation result for the company.

Photonics will eventually find its way into Tb/s routers and it is anticipated that the next generation systems will incorporate the best of both electronics and photonics. From the technology front, BOOM has presented a reliable integration approach for the development of CMOS compatible photonic components able to implement key functionalities with a scalable and straightforward manner.

List of dissemination activities

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS						
NO.	Title	Main author	Journal	Number	Year of publication	Relevant pages
1	*The European BOOM Project: Silicon Photonics for High-Capacity Optical Packet Routers*	*L. Stampoulidis*	*Selected Topics of Quantum Electronics*	*No 99*	*2010*	*pp. 1-12*
2	*Micro-ring resonator assisted, all-optical wavelength conversion using a single SOA and a 2nd order Si3N4–SiO2 ROADM*	*L. Stampoulidis*	*Lightwave Technology*	*No 4*	*2010*	*pp. 476-483*
3	*InGaAs PIN photodetectors integrated on silicon-on-insulator waveguides*	*Z. Sheng*	*Optics Express*	*No 18*	*2010*	*pp. 1756-1761*
4	*All-optical wavelength conversion at 160 Gbit/s using SOA and siliconon insulator photonic circuit*	*F. Gomez-Agis*	*Electronics Letters*	*No 45*	*2009*	*pp. 1132-1133*
5	*Clock-distribution with Instantaneous Synchronisation for 160 Gb/s OTDM Packets Transmission*	*F. Gomez-Agis*	*Optics Letters*	*No 35*	*2010*	*pp. 3255-3257*
6	*320-to-10 Gbit/s all-optical demultiplexing using sum-frequency generation in a PPLN waveguide*	*F. Gomez-Agis*	*Electronics Letters*	*No 46*	*2010*	*pp. 1008-1009*
7	*Packaging and assembly for integrated photonics - a review of the ePIXpack photonics packaging platform*	*L. Zimmermann*	*Selected Topics of Quantum Electronics*	*No 17*	*2011*	*pp. 645-651*
8	*Fabrication and Experimental demonstration of a four-channel x 40Gb/s TriPleX all-optical wavelength conversion platform*	*C. Stamatiadis*	*Lightwave Technology*	*No 29*	*2011*	*pp. 1886-1891*
9	*Silicon-on-insulator nanowire resonators for compact and ultra-high speed all-optical wavelength converters*	*C. Stamatiadis*	*Lightwave Technology*	*No 29*	*2011*	*pp. 3054-3060*
10	*Flip-chip compatible electroabsorption modulator for up to 40 Gb/s, integrated with 1.55 µm DFB laser and spot-size expander*	*J. Kreissl*	*Selected Topics of Quantum Electronics*	*No 47*	*2011*	*pp. 1036 – 1042*
11	*Silicon Microring Resonators*	*W. Bogaerts*	*Lasers and Photonics Review*	*-*	*2011*	*pp. 1-27*

A2: LIST OF SCIENTIFIC CONFERENCE PUBLICATIONS					
NO.	Title	Main author	Conference	Year of publication	Place
1	*The European ICT-BOOM project: Photonic Tb/s routers made of silicon*	*L. Stampoulidis*	*Photonic in Switching*	*2009*	*Pisa, Italy*
2	*Terabit-on-Chip: Enabling Ultra-high Capacity Photonic Networks*	*E. Kehayas*	*ECOC*	*2009*	*Vienna, Austria*
3	*The BOOM project: A new Generation of Photonic Routing Subsystems using Hybrid Integration on Silicon-on-Insulator Waveguide boards*	*L. Stampoulidis*	*SPIE Photonics Europe*	*2010*	*Brussels, Belgium*
4	*All-Optical Contention Resolution Using a Single-Optical Flip-Flop And Two-Stage All-Optical Wavelength Conversion*	*C. Stamatiadis*	*OFC*	*2010*	*San Diego, USA*
5	*High-order micro-ring resonator assisted wavelength converters for scalable and power efficient photonic routers*	*K. Vyrsokinos*	*ECOC*	*2009*	*Vienna, Austria*
6	*Investigation of evanescent coupling between SOI waveguides and heterogeneously-integrated III-V pin photodetectors*	*Z. Sheng*	*21st Conference on Indium Phosphide Materials*	*2009*	*Newport, USA*
7	*Silicon-on-insulator microring resonator for ultra dense WDM applications*	*Z. Sheng*	*6th Conference on Group IV Photonics*	*2009*	*Sorrento, Italy*
8	*SOAs and EMLs: Development of flip-chip compatible devices within BOOM*	*L. Moerl*	*European Semiconductor Workshop*	*2009*	*Vienna, Austria*
9	*Tutorial Silicon Photonics*	*Dries Van Thourhout*	*OFC*	*2010*	*San Diego, USA*
10	*SOI platform for high speed all optical wavelength conversion*	*K. Voigt*	*Group IV Photonics*	*2009*	*San Francisco, USA*
11	*Ultra-fast all-optical demultiplexer for 320 Gbit/s serial data exploiting sum-frequency generation in a PPLN waveguide*	*F. Gomez-Agis*	*ECOC*	*2010*	*Torino, Italy*
12	*160 Gbit/s packet clock distribution with instantaneous synchronization and low timing jitter*	*F. Gomez-Agis*	*ECOC*	*2010*	*Torino, Italy*
13	*Ultra-high Speed, all-optical wavelength converters using single SOA and SOI photonic*	*K. Vyrsokinos*	*Lasers and Electro Optics Society winter*	*2010*	*Mallorca, Spain*

	integrated circuits		*topical meeting*		
14	*Ultra-fast all-optical demultiplexer for 320 Gbit/s serial data exploiting sum-frequency generation in a PPLN waveguide*	*F. Gomez-Agis*	*ECOC*	*2010*	*Torino, Italy*
15	*Packaging of SOI motherboards for high-speed all optical router applications*	*L. Zimmermann*	*Group IV Photonics*	*2010*	*Beijing, China*
16	*Packaging and assembly for integrated photonics - the ePIXpack photonics packaging service*	*L. Zimmermann*	*Photonics Annual Meeting*	*2010*	*Denver, USA*
17	*The European ICT-BOOM project: Silicon photonic TB/s routers*	*A. Pagano*	*FOTONICA*	*2010*	*Pisa, Italy*
18	*All-Optical Wavelength Conversion at 160Gb/s Using an SOA and a 3rd Order SOI Nanowire Periodic Filter*	*C. Stamatiadis*	*Photonics Annual Meeting*	*2010*	*Denver, USA*
19	*4x40Gb/s All-Optical Wavelength Conversion using SOAs and integrated arrays of ring resonators and DIs*	*C. Stamatiadis*	*OFC*	*2011*	*Los Angeles, USA*
20	*High-precision flip-chip technology for all-optical wavelength conversion using SOI photonic circuit*	*L. Zimmermann*	*Group IV Photonics*	*2011*	*London, England*
21	*The European ICT-BOOM project: silicon photonics Tb/s routers for improved energy efficiency in optical networks*	*A. Pagano*	*SPIE*	*2011*	*Strasbourg, France*
22	*The ICT-BOOM project: Photonic routing on a silicon-on-insulatorhybrid platform*	*C. Stamatiadis*	*ONDM*	*2011*	*Bologna, Italy*
23	*1550 nm Flip-chip compatible electroabsorption-modulated laser with 40Gb/s modulation capacity*	*J. Kreissl*	*IPRM*	*2011*	*Berlin, Germany*
24	*"High-performance low-loss silicon-on-insulator microring resonators using TM-polarized light*	*P. De Heyn*	*OFC*	*2011*	*Los Angeles, USA*
25	*Optical coupling of SOI waveguides and III-V photodetectors*	*L. Moerl*	*French Symposium on Emerging Technologies for Micro-nanofabrication*	*2010*	*Paris, France*
26	*Improved intrinsic Q of Silicon-on-Insulator microring resonators using TM-polarized light*	*P. De Heyn*	*Annual Symposium of Photonics*	*2010*	*Benelux, Netherlands*
27	*III-V/silicon photonic integrated circuits for FTTH and optical*	*G. Roelkens*	*IB2COM*	*2010*	*Malaga, Spain*

	interconnectDevelopment of flip-chip compatible devices within BOOM				
28	*III-V/SOI photonic integrated circuit for FTTH central office transceivers in a PTP network configuration*	*D. Vermeulen*	*ECOC*	*2010*	*Torino, Italy*

A3: LIST OF DISSEMINATION ACTIVITIES

NO.	Activity	Leader	Event	Year of publication
1	*Project presentation*	*ICCS/NTUA*	*1st EURO-FOS Workshop on Photonics Systems*	*2009*
2	*Project presentation*	*ICCS/NTUA*	*Photonics Concertation Meeting*	*2009*
3	*Project presentation*	*ICCS/NTUA*	*Silicon Photonics Forum*	*2010*
4	*Booth Exhibition*	*ICCS/NTUA*	*ECOC*	*2009*
5	*Booth Exhibition*	*ICCS/NTUA*	*ECOC*	*2010*
6	*Booth Exhibition*	*ICCS/NTUA*	*ECOC*	*2011*
7	*Booth Exhibition*	*ICCS/NTUA*	*SPIE Europe*	*2010*
8	*Project participation*	*ICCS/NTUA*	*European Silicon Photonics Cluster*	*2010*
9	*Booth Exhibition*	*ICCS/NTUA*	*OFC*	*2011*