FABULOUS NEWSLETTER

FDMA Access By Using Low-cost Optical Network Units in Silicon photonics

Number 1

June 2013

European Commission

STREP Contract 318704

Objective ICT-2011-3.5: Core and disruptive photonic technologies

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FABULOUS at a glance:

Start date: 1st October 2012
Duration: 36months
Total project cost: 4,2M€
EU financing: 2,9M€

Welcome to the first issue of the Fabulous Newsletter!

It is my pleasure to open the first issue of FABULOUS project Newsletter with this Editorial! Well, being a "first issue" let me start by briefly describing what the project is about: FABULOUS is a European project of the Seventh Framework program (call FP7-ICT-2011-8, contract #318704) that passed the selections for STREP projects in the Photonic area approximately one year ago, and was ready to start on 2012, October 1st , with its kick-off meeting held in Turin, Italy. FABULOUS actually means "FDMA Access By Using Low-cost Optical Network Units in Silicon", an acronym that tries to summarize the keywords of our project, a balance between system- and component-oriented research.

From a system side, we propose an access architecture for next-generation passive optical networks where each lambda is shared by several users using a frequency-division multiplexing access (FDMA) approach, that allows to dynamically deliver to the final user just the "right amount" of spectrum it needs. Moreover, to avoid tunable laser at the user side, we implement a reflective transmission based on an innovative Mach-Zehender modulator that can support FDMA through advanced modulation formats. And this allows to introduce the second "pillar" of the project: the reflective modulator for the upstream will be designed inside the project using a Silicon-Photonic platform which will integrate all the required sub-components, and in particular a Mach-Zehender modulator, tunable optical filters, photodiode monitoring and optical amplification (by hybrid integration with two III-V SOAs).

This newsletter is going to be released periodically every nine months and will be made of many short articles that will try present all our latest research results with a "light" approach, hopefully without being too technical! Moreover, it will give updated overviews on what is "rolling" in the area of next-generation passive optical networks.

OK, the project manager gave me 250 words space and I am already way too long. So I stop here and see you again for the next issue. For the moment, I hope you will enjoy reading what we have "delivered" in the project first nine months.

Roberto Gaudino
Politecnico di Torino
Scientific coordinator

FABULOUS has started

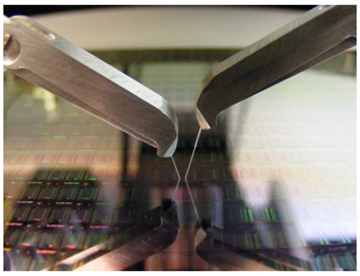
The FABULOUS European Project is a STREP (Small or medium scale focused research project) that was presented for evaluation to the EU commission on the 16th of January 2012, at the 8th call for proposals of the ICT sector of the 7th Framework Program (FP7), under the *Challenge 3.5: Core and Disruptive Photonic Technologies*. The proposal was in particular addressing the following objective: *Core photonic technologies, "Application-specific photonic components and subsystems"*, that was also addressing, for access networks, an "*affordable technology enabling 1-10Gb/s data-rate per client.*"

The proposal was awarded an evaluation of 14,5/15, and thus was called to negotiation in June 2012.

During this phase, no modification to workplan and project objectives has been asked for.

The kick-off meeting of the project took place in Torino, on the 1st and 2nd of October 2012. The project will last 3 years, and the second plenary meeting has taken place in Grenoble on the 5th and 6th of June 2013.

Silicon Photonics for access networks



Coupling of light from an external fiber to the silicon photonic wafer, by means of a surface grating coupler

"A practical solution to be implemented in CMOS technology with performances scaling with the requirements of Next Generation PONs is of tremendous value"

As optics is displacing electrical links on transmission distances that decrease continuously, Silicon photonics is expected to accelerate this shift in the next five years. This is because the main functions were demonstrated (transmitters and receivers) with equal performances as existing optical technologies (InP, LiNbO3, Si02), but also and mostly because this technology has unprecedented manufacturing capabilities. Silicon photonics technology is indeed developed to be fully compatible with the existing CMOS (Complementary Metal Oxide Semiconductor) infrastructure. Technological advances in CMOS design and manufacturing enable electronic devices with high integration complexity to be fabricated in very large scale and very low cost. The combination of CMOS electronics and CMOS photonics is further expected to leverage the Electro/Optic (E/O) devices performances due to the opportunity to tightly integrate the active photonic building blocks with their electronic driving and reading circuitries (analogue electronics), as well as with CMOS digital signal processing circuits.

The remaining challenges for silicon photonics to go from research to product are twofold:

development of fibre-packaging technologies with large volume production capabilities;

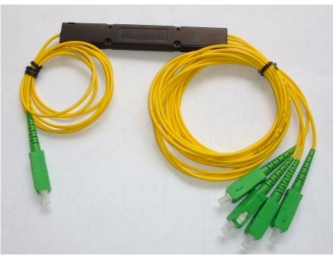
circuit integration: the effort for increasing the technology maturity level is about to pay off, allowing the successful integration of several devices on a same silicon photonic chip (modulators with photodetectors), including devices based on III-V heterogeneous integration.

Passive optical networks (PON) are mass market applications (~ a few million-range), where the constraints put on the optoelectronic transceivers are mostly cost constraints, while the requirements on transmission performances keep increasing. A practical solution that could be implemented with CMOS technologies and with performances scaling with the requirements of Next Generation PONs is of tremendous value.

Within Fabulous, the "Technology group' will be targeting the design and CMOS-fabrication of the full Optical Network Unit hardware, addressing the above mentioned technological challenges.

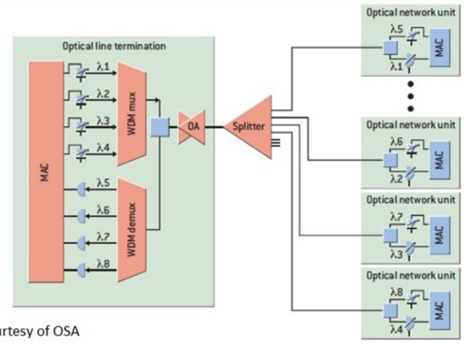
Sylvie Menezo
CEA-Leti
Benoit Charbonnier
France Telecom

ITU to standardise next generation PON solution chosen by FSAN



1x4 Optical Splitter

The standardisation process for the second next generation of PON transmission systems (a.k.a. NG-PON2) has recently started within ITU under the guidance of FSAN (Full Service Access Network). FSAN had first established a set of system level specifications in agreement with a consortium of telecom operators (in which France Telecom was involved). The target was thus set to ensure a broadband access capacity of 1Gbps per user in order to provide high quality of experience residential services and at the same time ensure a convergence between Optical Access Networks for residential and business users as well as with mobile telephony backhauling networks. The goal of FSAN was to identify a suitable technical solution to respond to these set of requirements and propose it for standardisation to ITU by 2015. After evaluating many



Courtesy of OSA

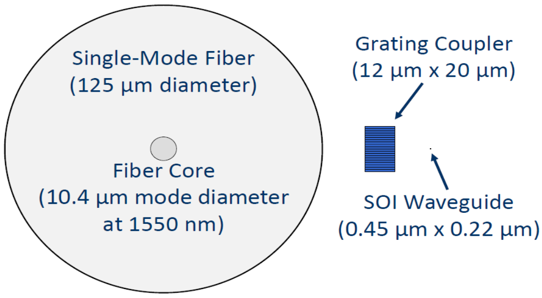
technical solutions proposed by different telecom equipment vendors (Alcatel-Lucent, Huaweï, ZTE, NEC, ADVA, etc...) and considering the foreseen technological advances, FSAN chose to promote a Time and Wavelength Division Multiplexed based system (TWDM PON) providing 40Gbps aggregated data rate in the downstream and 10Gbps (or 40Gbps as option) in the upstream with four wavelength pairs multiplexed per direction. One main characteristics of this system is the fact that it shall be compatible with the currently deployed splitter based infrastructures (up to 20km reach) and is susceptible to coexist with previous generations of PON systems (G-PON, XG-PON1 and XG-PON2) as well as with the RF TV systems. TWDM PON is now being standardised in ITU under reference G.898.

Benoit Charbonnier
France Telecom

Challenges of low-cost photonics packaging solutions

Unlike electronics where inexpensive packaging solutions have already been developed and implemented, in photonics packaging still constitutes a large percentage of the production cost, often as much as 90%. As a result, cost is a crucial factor to consider in the design of any photonic packaging and integration technology. The main contributor to this cost is the very precise alignment tolerance required to ensure efficient operation of optical components. In particular, when alignment tolerances fall below the micrometer level, slow and expensive active alignment processes are required. In these processes, light is passed through the optical components of a system and measured. The light can come from an external source or by driving a laser that is part of the system. While the measurement is taking place, the components are moved in sub-micrometer steps to gauge and maximize the system efficiency.

One of the key advantages of silicon photonics technology is the fact that it can integrate a wide range of photonic functions together into a single silicon die, resulting in very dense integration. A significant challenge however is that typical waveguide cross-sections have sub micrometer dimensions, which result in stringent alignment tolerances and thus high packaging costs. The size difference between silicon waveguides and standard components like single-mode fibers means that light cannot be directly coupled from one to the other without suffering significant power loss. Instead, a means for transitioning the size of the light mode (the spot size) in one device to its size in the other must be implemented. One way to do this is with a grating coupler. This sort of structure has the potential to ease alignment tolerances to a level where passive vision-based alignment can be used.



Relative sizes (in scale) of a single-mode fiber (cross-section, left), a grating coupler (top view, center) and a Si waveguide *(cross-section, right)*

Bradley Snyder, Nicola Pavarelli, Peter Ossieur, Peter O'Brien
Tyndall National Institute, University College Cork

> **"In photonics, packaging still constitutes a large percentage of the cost of production, often as much as 90%"**

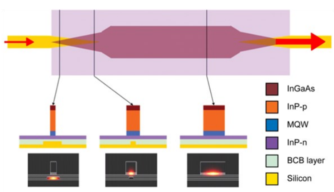
III-V heterogeneous integration on Silicon

Several functions have been demonstrated in Silicon Photonics technology, including wavelength demultiplexers, photodetectors, and modulators, all of which are gaining in performance and manufacturing maturity. In order to provide, electrically, the silicon photonic circuit with optical gain, heterogeneous integration architectures were proposed, allowing for an economical transfer of III–V gain-materials to silicon. Hybrid integration exactly means to combine different materials on one chip, to help getting the best performance out of each device; however, compared to monolithic integration, it often complicates the fabrication of a circuit and introduces interfaces that can cause losses and reflections if not carefully optimized. The challenge is to make the advantages win over the drawbacks. Within the FABULOUS project, we will demonstrate that this can be achieved with the hybrid III-V on silicon technology of CEA-Leti and 3-5 Lab. Light will be coupled between waveguides formed in silicon-on-insulator and waveguides based on indium phosphide. Using tapered structures, the transitions are made smooth and with a minimum of loss. Devices such as tunable lasers have already been demonstrated successfully using this approach.

The use of silicon as the host platform not only allows to exploit highly mature silicon photonics components, it ultimately enables the integration of CMOS technology and hence the implementation of photonic and electronic circuits in a single package.

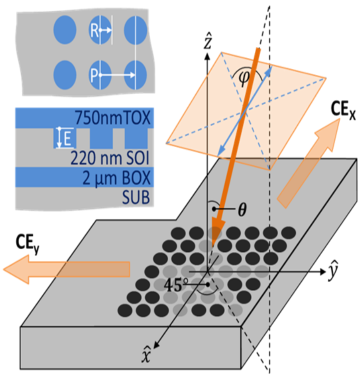
For the FABULOUS project, 3-5 Lab will develop a semiconductor optical amplifier (SOA) that can be seamlessly integrated with the reflective Mach-Zehnder modulator that constitutes the core element of the proposed NG-PON2 architecture. The integration of the optical amplification on the same chip will facilitate the assembly of the final network unit. It will reduce the cost and size of the final system and hence put it in a very favorable position for future industrial deployment.

Peter Kaspar, Guang-Hua Duan
III-V Labs
Sylvie Menezo
CEA-Leti



Schematic representation of a hybrid SOA, including top and side views of a mode transformer showing the transfer of light between silicon and III-V waveguides

Polarization diversity couplers: device optimization for FABULOUS



Scheme of the Polarization Diversity Coupler being studied for FABULOUS

Polarization-diversity couplers are an attractive solution to the problem of how best to couple light from a fibre optic into the silicon-on-insulator (SOI) waveguides of an all-optical circuit. Polarization diversity couplers, or PDCs, have much more relaxed alignment tolerances and lower footprints than so-called edge coupling schemes, but still provide good coupling efficiency and a useful bandwidth for telecom applications. These factors combine to make PDCs a promising and industrially scalable solution that bridge the large dimensional gap between the ≈10um mean-field diameter of single-mode telecom fibres and the typical 220nm x 500nm cross-section of SOI waveguides.

One goal of *FABULOUS* is to use a powerful computational technique known as 3D finite difference time domain (3D-FDTD) calculations to determine the best performing PDC that can be realized within the material and design constraints of the project. By using high fidelity simulations to test many hundreds of different PDC designs, we can rigorously identify the best possible combination of parameters for the photonic crystal array making up the active element of the PDC. In addition to optimizing the PDC performance, the 3D-FDTD calculations also answer important questions about the propagation and mode-profile of the light coupled from the fibre into the SOI platform. This is useful for the design of high performance tapers and waveguides in the all-optical circuit.

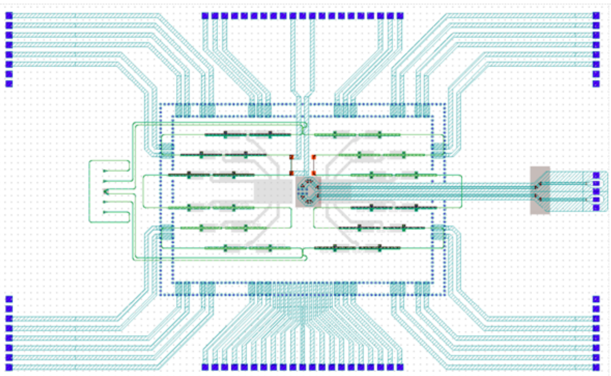
The research group at the University of Pavia, which is made up of a collaboration between the Physics and Engineering departments, has already identified a promising PDC design that exceeds the original *FABULOUS* specifications -4dB coupling efficiency, and is still working hard on improving the design further.

Lee Carrol, Dario Gerace, Ilaria Cristiani, Lucio Andreani
University of Pavia

"Polarization Diversity Couplers have much more relaxed alignment tolerances and footprint than edge coupling schemes"

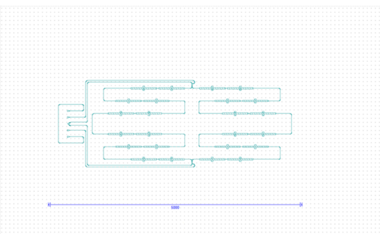
CMOS electro-optic circuit as the ONU modem

The ONU transmitter of FABULOUS is based on a Reflective Mach Zehnder Modulator (R-MZM) which is fed by a seeding Continuous Wave laser source sent from the Central Office (CO). When the R-MZM is biased at π, and when its two arms are driven by counter propagating RF waves, one can show that it operates as a Faraday rotator followed by a mirror. This enables coherent demodulation at the OLT side using the seeding laser source, and avoiding the need for any polarization diversity schemes. The objective of the Fabulous "technology group" is to demonstrate a full CMOS integrated solution that comprises photonic and electronic circuitries. The latter will be realized using standard CMOS technologies and will implement a distributed driving architecture, with 12 lumped driving stages per MZM arm, which delays are set to match the optical field propagation delay along the MZM. To maximize testing flexibility, the multistage driver can be reconfigured by independent stage power up and individual delay control. The photonic circuit will include itself a polarization splitter (made from a 2D surface grating coupler), a WDM filter, a modulator, and a photo-detector. Ultimately, the photonic circuit should comprise an SOA.



In the figure here inserted it is possible to see a top view of the first photonic test-chip, on which the electronic die will be bonded by means of 3D CMOS integration technologies (copper pillars). The overall footprint of the testchip, including the space required to shelter a five-fiber SMF ferrule, is 7 x 5 mm². This reduces down to 5 x 1.7 mm² when considering the R-MZM photonic core. The design trade-offs of both photonic and electronic circuits will be further reported.

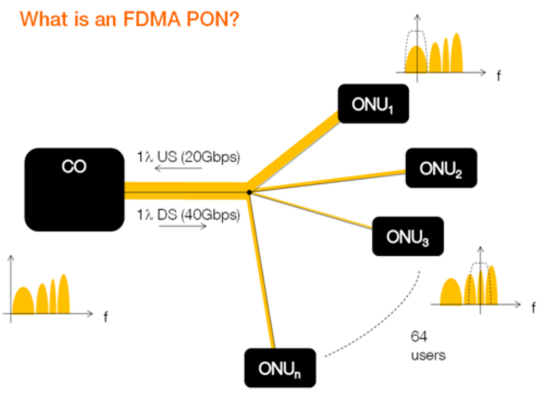
Sylvie Menezo
CEA-Leti
Enrico Temporiti
STMicroelectronics



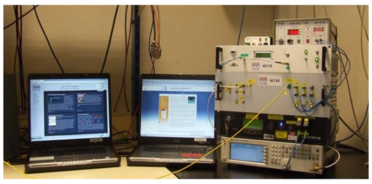
Overview of the photonic circuit (bottom chip; here above and in the article). DC Electrical wires are placed on the side of the chip to supply and allow verification tests of the flip chipped electronic circuit

FDMA PON demonstrates 40Gbps downstream and 20Gbps upstream on a single wavelength pair

Using commercially available off-the-shelf components, the FABULOUS team has demonstrated that a capacity as high as 40Gbps downstream and 20Gbps upstream could be transported over single wavelength pair over a 64-split optical infrastructure with a 20km span. As an added bonus, the Optical Network Unit (ONU – customer premises equipment) is completely colourless and the wavelength pair is managed from the Central Office (CO) side, simplifying multiple wavelength management and preventing rogue transmitters. These results prove that our solution can provide the necessary performance to ensure a sustained very high data rate per user (1Gbps) and ensure network convergence (with business and mobile networks). One of the inherent advantages of an FDMA PON is that the customer equipment – the ONU – has very low requirements on DSP and on its RF front end. Basically, all the necessary electronic equipment for a 1Gbps residential customer is similar to the one developed for wireless USB, designed for minimal cost and power consumption. On the other hand, some of the underlying complexity is transferred to the optical front end of the ONU. In order to prove the potential of our solution to respond adequately to the optical access market which is very sensitive to cost and manufacturability, the FABULOUS project has now to demonstrate the integration of the ONU optical components in Silicon in order to lower even more CAPEX and OPEX costs. Integration of the electronic drivers is also a strong requirement.



Benoit Charbonnier
France Telecom



Experimental setup at the France Telecom premises

Faraday rotation in the FABULOUS setup

The Faraday effect causes a rotation of the plane of polarization which is linearly proportional to the component of the magnetic field in the direction of propagation; a Faraday rotator is then a passive optical device designed to impose a desired rotation to the polarization of the incoming light.

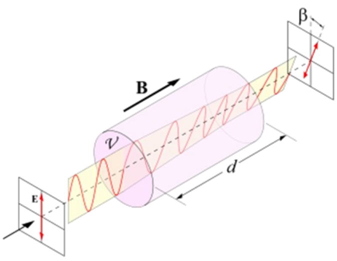
In a reflective Passive Optical Network (R-PON) scenario, a 90° rotation of the polarization of the modulated upstream signal (generated at the ONU side) with respect to the polarization of the CW downstream signal provides two important advantages: the mitigation of the Rayleigh backscattering (RBS) effects and a great simplification an eventual coherent receiver that might be used at the OLT side for improved performance.

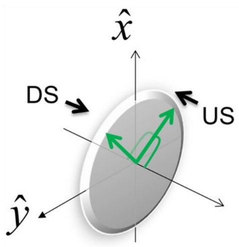
It is demonstrated that RBS tends to be (statistically) co-polarized with the counter-propagating signal that generates it. In a R-PON setup, this means that the RBS is mostly co-polarized with the CW feed signal, while the useful signal at the OLT receiver has an arbitrary polarization, due to random fiber's birefringence. The crosstalk system impact is maximum when these two polarizations are aligned, while it is null for a coherent receiver when they are orthogonal. If the polarization orthogonality between the up- and downstream signals is obtained at the ONU side, it is preserved in any ODN path section, regardless of fiber birefringence, due to its reciprocity. This means that, thanks to a Polarization Beam Splitter, the upstream signal can be totally provided to the coherent receiver, allowing self-coherent reception at the OLT, without polarization diversity nor polarization control, which would on the contrary imply duplication of high-cost resources such as optical hybrids and high end Digital Signal Processing units.

In the FABULOUS setup, the Faraday rotation effect is a natural consequence of the structure of the modulator and hence is obtained regardless of the incoming polarization (no polarization controllers needed), and is due to the interaction of co-propagating and counter-propagating waves of the two branches of the Mach-Zehender modulator, that thus have to be independently driven.

Stefano Straullu, Silvio Abrate
Istituto Superiore Mario Boella

"In a Reflective PON, a 90° polarization rotation provides a great simplification of the coherent receiver at the OLT side"





Faraday polarization rotation

info@fabulous-project.eu
+39 011 2276 302

Fabulous

A flexible architecture, compatible with current infrastructures, and low cost components and network units based on silicon photonics: the keys for mass Fiber-To-The-Home deployment.

The FABULOUS Project has been conceived and is being carried out by a balanced mix of *universities, research centers, industries and operators*; such a consortium is very heterogeneous, in order to cover all the many different technological aspects required by the work-plan. In particular, two main different category of aspects can be identified in the project structure:

- **System aspects**, main duty of Istituto Superiore Mario Boella, Politecnico di Torino and France Telecom
- **Optoelectronic, silicon photonics and packaging aspects**, main duty of CEA-LETI, II-V Labs, University of Pavia, Tyndall National Institute, STMicroelectronics.

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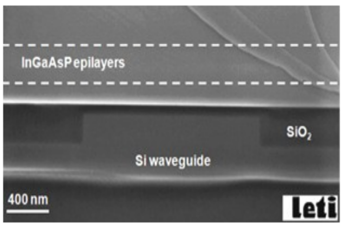
EVENTS and DISSEMINATION

Preparing for entering the clean rooms at CEA-Leti



SEM image of a III-V gain-device implemented on silicon

The partners of the FABULOUS consortium have partecipated to a number of dissemination events in this first 9-months of the project, in order to make the scientific community aware of the objectives of the project.

Silvio Abrate has partecipated to **Photonics West**, leading conference in the photonic sector organized by SPIE, held at the Moscone Center in San Francisco, in February 2013. He has given a presentation titled "*FDMA-PON architecture according to the FABULOUS European Project*".

OFC/NFOEC 2013, held in March at the Anaheim Convention Center (California), has seen a massive presence by the project partners with three invited presentation: in detail, "*Advantages of coherent detection in reflective PONs*" by Roberto Gaudino, "*France Telecom's PON deployment, learnt lesson and next steps*" by Benoit Charbonnier, "*III-V on silicon transmitters*" by Guang-Hua Duan; moreover, Sylvie Menezo has presented a poster paper titled "*Reflective silicon Mach Zehnder modulator with Faraday rotator mirror effect for self-coherent transmission*". During the same conference, the project partners have organized a meeting with the members of the **External Advisory Board**, in order to discuss objectives and results of their activity with representatives by *NEC*, *ZTE* and *ALPHION*.

More recently, in June Lee Carroll has presented a paper titled "*Optimizing silicon-on-oxide 2D-grating couplers*" at **ICTON**, held in Cartagena (Spain).

Next event to be attended: **ECOC** in London in September 2013