FP7 - 224312

HELIOS

pHotonics ELectronics functional
Integration on CMOS

D101 – HELIOS roadmap first version

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Abstract: This deliverable gives the first version of HELIOS roadmap. It focuses on the identification of different field of applications of Silicon Photonics on the analysis of pertinent product/Technology roadmap and on a first HELIOS roadmap crossing Helios Building Blocks development and products needed in the different field of applications identified.

Keyword list: HELIOS Silicon Photonics Roadmap

Table of Contents

1- Introduction

1.1- Goal of deliverable

Road mapping activity will be developed along the whole HELIOS project duration and will be reported successively within 4 deliverables:

- D101: First version of HELIOS roadmap@ T0+12 –This deliverable-
- D104: Second of HELIOS Roadmap@ T0+24.
- D106: Up date of HELIOS Roadmap@ T0+36
- D108: Final version of HELIOS Roadmap@ T0+48

First step of "Road mapping" activity and goal of this deliverable is:

- To start identification of the different field of applications (§2: Competition product & "technology" state of the art in the field of Si Photonics).
- To analyse -thanks to HELIOS industrial partners vision- an expected product roadmap where photonic on Si could be the most "pertinent" technological platform
- To "plug" these products (or applications) needs on a first HELIOS roadmap (§3: HELIOS roadmap first version).

1.2- Road mapping methodology & first template

To prepare first HELIOS roadmap, following methodology has been used:
A general/standard description of the different "levels" for technology platform development is used. Figure 1.1 shows the different & detailed levels of this development.
For HELIOS roadmap only step 1 "Basic principles observed and reported" to step 7 "System prototype demonstration in an operational environment" is considered.

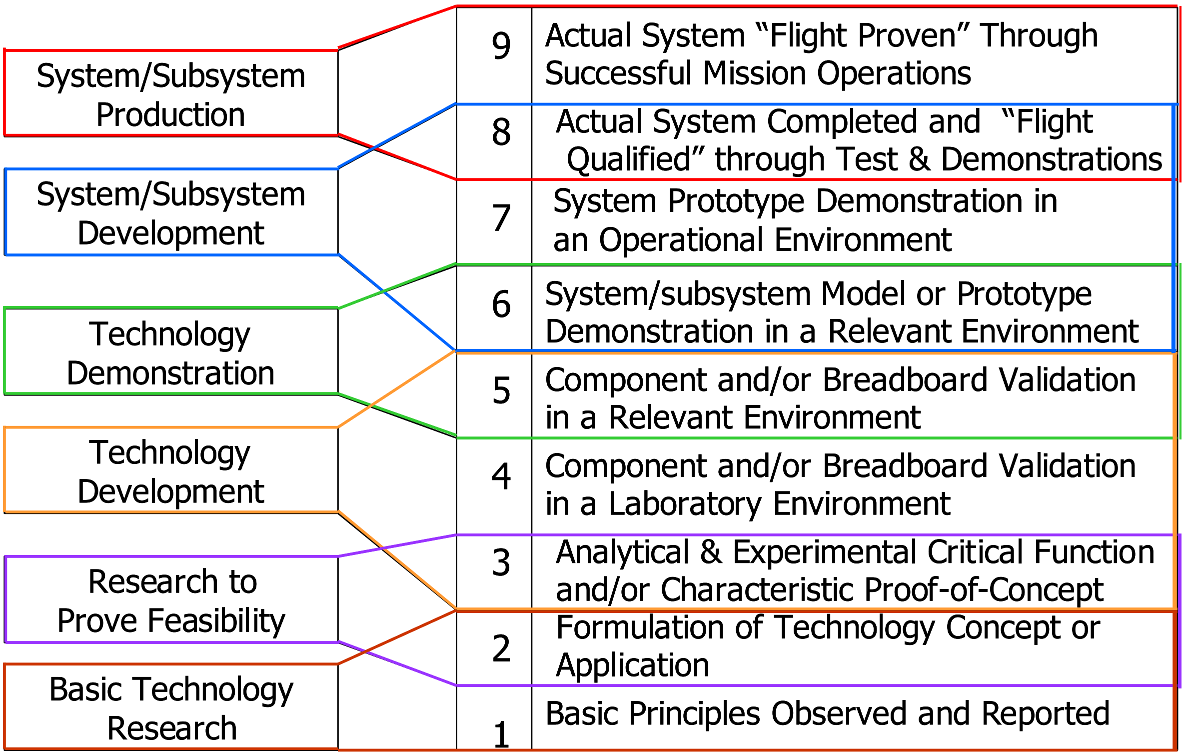


Figure 1.1: Technology readiness level

Using these definitions, Figure 1.2 shows Building blocks development within HELIOS project targeting Level 4 completion at the end of project [Component validated in a laboratory environment].

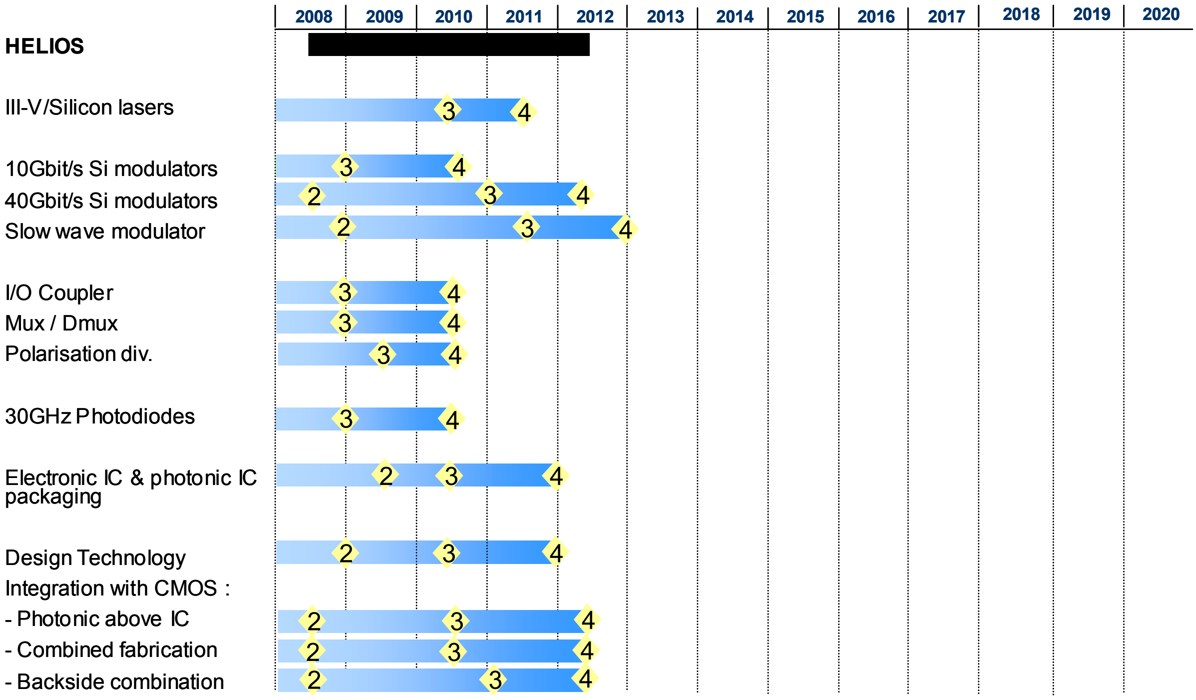


Figure 1.2: HELIOS Building blocks roadmap targeting level 4

While Figure 1.3 shows Building blocks development within HELIOS project targeting Level 3 completion at the end of project.

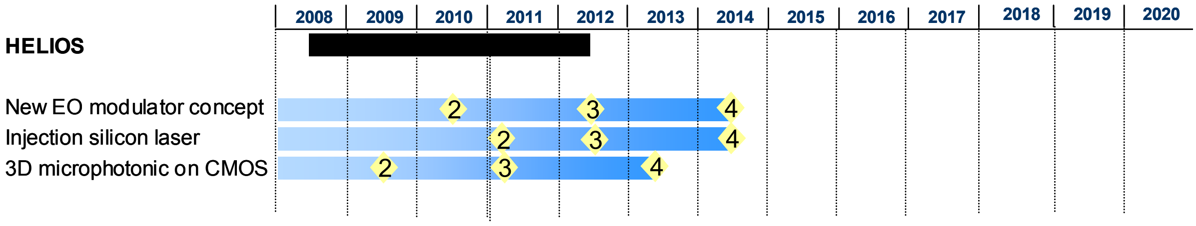


Figure 1.3: HELIOS Building blocks roadmap targeting level 3

Using this methodology and assuming a sufficient “visibility” on considered application first HELIOS roadmap will combine Helios BB roadmap and potential products or technology expected using these Building (See §3).

2- Competition product & Technology state of the art

2.1- OE modules for Metro/Access transceivers

Despite the development of many integration technologies and many examples of publications in this field [1] [2] today photonic integration has seen only limited use in a few optical interface applications.

State of the art:

Although first generation implementations will certainly use discrete components technologies long term requirements for significant reduction in cost, size & power of 40 & 100Gb/s transceivers will lead to a broad demand for photonic integration. Especially new draft of IEEE standards in this field are important to consider [40GBASE-LR4 & 100GBASE-LR4 & ER4 for reaches of 10 to 40km [3]

Product development is made in a “pragmatic” manner and several technologies (complementary/or competitive) have been reported. Prototypes or pre-products have been claimed as using “PIC” platform for such applications mainly by 3 companies : Kotura, Infinera, Luxtera.

However it is important at this stage to have a clear understanding of the key differences between these approaches.

Kotura [4] claimed APD/VOA & Modulator (based on MZ on SOI technology /VOA) and 10x10 Gbit/s CWDM transceivers based on a PIC technology. These products are based on integration on PLC using Si as a “motherboard”.This approach is a Silicon Photonics approach in a “broad” sense but there is no compatibility with CMOS technology and thus the integration scheme is based on mounting technologies on Si leading to a non “collective” approach leading to cost limitation for large volumes.

Infinera [5] developed/published on TX & RX for Nx10Gb/s (40 & 100Gb/s) and Nx40 Gbit/s based on PIC approach. Infinera used an InP integration platform while hybrid packaging is used (InP Components and associated drivers and piece parts reported in a package (Figure 2.1). Performances could be adapted for applications in this field. (Despite an unknown yield of this approach) but a poor compacity resulted with such approach.[See detailed description in D601 Helios]

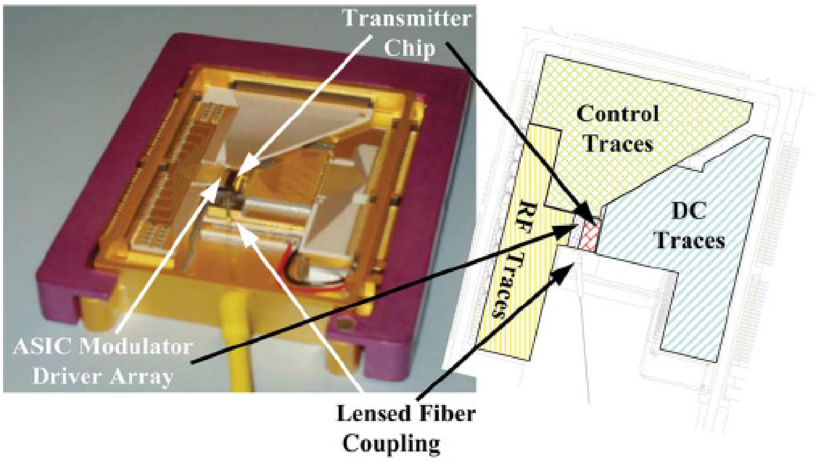


Figure 2.1: Infinera PIC 10x10Gb/s prototype

Luxtera [6] developed/published on transceiver for Datacom applications (Figure 2.2). Here the approach is clearly a photonic on Si based approach using Si CMOS platform and available Building blocks (Modulators, photodetectors, Electronic). For datacom applications, hybridisation of VCSEL emitters is used (See § 2.6.4). However to extend Si Photonics technology platform applications to Access Metro a breakthrough in performances is needed. Hybridisation of edge lasers is mandatory which is a difficult task addressed in HELIOS BB development roadmap.

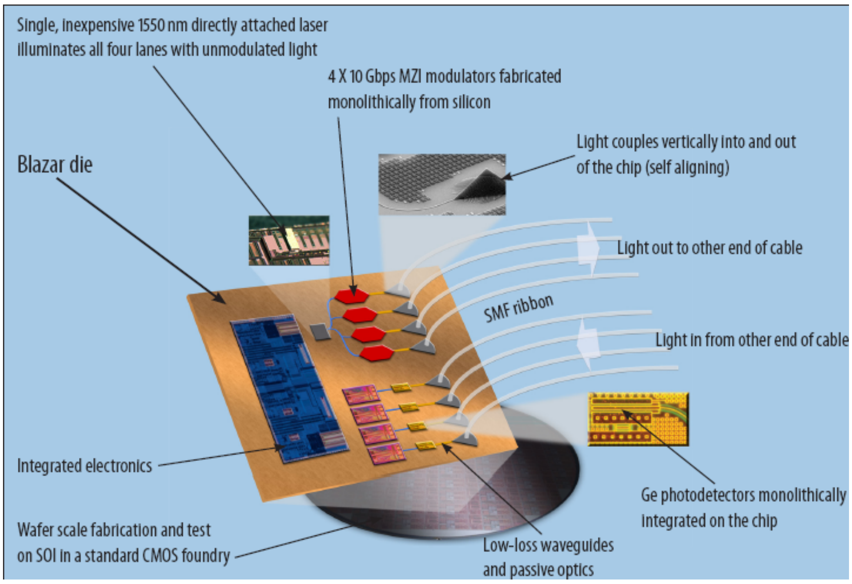


Figure 2.2: Luxtera Integrations scheme for transceiver 4x10Gb/s

2.2- Modulators for telecom applications

The market of telecom modulator has been structured for 15 years now. In the middle of the 90's the telecom modulator market dealt mostly with 2,5Gb/s modulators, and CATV fibre networks with analogue transmission (TV on RF carriers). At the end of the 90's, the DWDM high data rate fibre communications networks dominates and requires external and low chirp optical modulators. For the last 10 years the numbers of external modulators deployed in systems is between 60000 and 100000 pieces each year. The present aimed data rate is still 10 Gb/s (12.5Gb/s with FEC: forward error correctors).

State of the art:
Three main technologies have emerged.

2.2.1- Electro absorption modulators:

The first one deals with electro-absorption modulators [7-10]. These devices are miniaturized components integrated in cascade with DFB lasers. They are compact, low cost, low consumption. Due to high insertion loss they cannot be found easily as discrete components and are generally associated with the lasers sources on the same chip. The driving power is low enough with 3V of driving voltage and the bandwidth in the range of 10GHz. The extinction ratio is limited to 10dB. Due to the high residual chip, the transmission is limited to 80kms. The characteristics are strongly dependent on the wavelength.

EAM's are a more performing solution than direct modulation of laser, but cannot fulfil the conditions required for long haul and ultra long haul transmissions (transoceanic distances up to 10,000 kms)

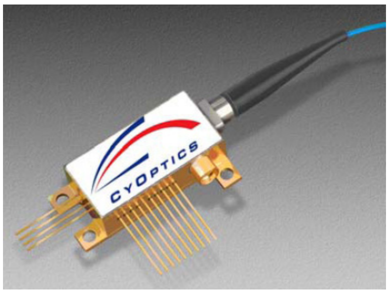


Fig 2.3 External EA modulator & laser from Cyoptics

The main competitors are Cyoptics, Oki in Japan offers products up to 40Gb/s with DER of 20dB and insertion loss in discrete modules of 7dB

2.2.2- InP Mach-Zehnder modulators:

Due to their optical properties and potential for Optoelectronics integration, Indium phosphide (InP) and gallium arsenide (GaAs) semiconductors [11-14] are playing a major role for future optical communications. One of their properties is the lack of symmetry of the crystal structure (Zinc Blende). In other words, III-V semiconductors of the GaAs or InP family possess a linear electro-optic effect. Thus, it is possible to take advantage of this property to design high-speed intensity modulators.

Despite the relative poor value of the only non-zero bulk electro-optic coefficient (r41=1.4pm/V), the high refractive index (n≅3.4) joined with a nearly 100% overlap between the optical and electrical field give a good electro-optic efficiency (comparable to existing lithium niobate devices). Semiconductors are often used for different applications in Optoelectronics (light emission and detection, electro-absorption effects), III-V semiconductor intensity modulators based on the linear electrooptic effect constitute a particular class of component with a good potential for high-speed operations.
These modulators are mostly fabricated by Oclaro (Ex Bookham). Due to high insertion loss, they cannot be found as discrete components and are systematically associated in cascade with the laser source(tunable laser). The driving voltage is smaller than 5V and the bandwidth is larger than 30GHz. The sizes are small compared toi lithium niobate and they can be easily integrated in butterfly package.

2.2.3- Lithium niobate Mach-Zehnder modulators:

Lithium niobate is the most mature technologies and the most widely deployed [15-18]. It is a reliable and mature technology offering high performances with discrete modules thanks to extremely low insertion loss (<3dB) extremely low chip and very high extinction ratio compared to other technologies. It islimited by large sizes compared with semicondutor technologies with chip in the range of 50mm instead of some mm with EA modulators. The driving voltage is typically 4-5V with bandwidh of 14 Ghz at 10Gb/s up to 32GHz at 40Gb/s. The three main competitors are JSU, Oclaro (Ex Avanex) and Sumitomo which offer each the largest families of telecom modulators. Fujitsu is also a competitor in telecom applications in particular for QPSK configurations. EOSpace and Photline are smaller competitors addressing new markets opportunities in the telecom and outside the telecom, for instance in the field of sensors, defense & aerospace and industrial fiber lasers.

The lithium niobate modulator are widely integrated in 4" x4" transceivers and transponders, but their sizes do not allow lithium modulator to be integrated in small form factor subsystems such as XFP

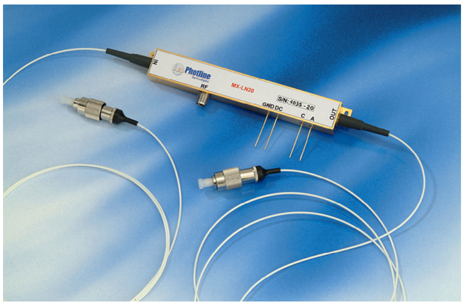


Fig 2.4 Photline : Telecom modulator

2.3- Wireless modules

There is no commercial deployment of integrated silicon photonics for wireless modules at the moment.

State of the art: Free-Space Optics (FSO) vs. milimetre wave technology

In parallel to radio communication links using millimetre-wave frequencies for Gb/s connectivity, FSO technology also provides wireless communications with Gb/s capacity. It is claimed that FSO has the potential to deliver 10 Gb/s capacity [20], but up to the present moment commercially available products are able to provide 622 Mb/s. The main disadvantage of FSO is the huge fog attenuation, which in the worst case results to be in about 225 dB/km [21], providing connectivity up to a few tens of meters. The following table resumes the state-of-the-art status of FSO and millimetre-wave links.

Table 1: Key comparison criteria to evaluate millimetre-wave vs. FSO case

	Free space optics	**Millimetre wave**
Bit-rate	Up to 10 Gb/s	> 10 Gb/s
Clear air attenuation	< 1 dB/km	< 1 dB/km
Worst case attenuation	225 dB/km (thick fog)	50 dB/km (rainfall 150 mm/hr)
Typical distance 99.999%	< 200 m	< 2 km
Link outage	High risk of link outage due to bath blockage or mount misalignment	Broader beam width provides stable connectivity
Equipment durability	Laser transceivers deteriorate with temperature fluctuations	MMIC based mm-wave components are reliable

2.4- Intrachips and chip to chip applications

There is no commercial deployment of integrated silicon photonics for chip-to-chip (distance < few 10cm) and on-chip communications at the moment

State-of-the-art:

On-chip optical interconnect is not expected before 2018-2022 in commercial applications. However a lot of research effort is currently going on in Europe (ICT WADIMOS project), VS (consortia led by IBM, SUN, INTEL, HP) and Japan.

Off-chip optical interconnect is now mainly being pursued using vertically emitting VCSELs + vertically receiving detectors in <1um wavelength range. However, it is expected that by 2018 the required datarate will increase to a level (several 10s of TB) such that wavelength division multiplexing is required to reach the desired data density.

2.5- Sensors and bio-photonic applications

At this moment there is to our knowledge no commercial deployment of integrated photonic silicon circuits being used for biosensing. There is considerable research activity however, e.g. in Europe through the EU projects SABIO, OPTISENS and INTOPSENS.

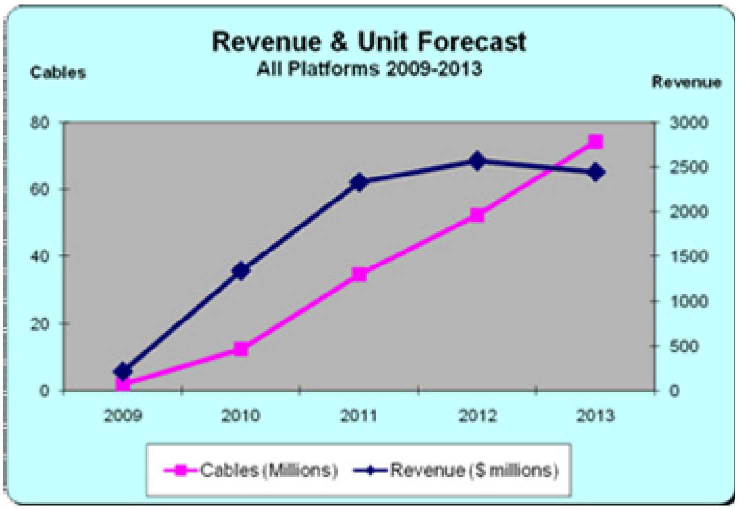
State-of-the-art:
The use of silicon platform for the development of sensing devices attracts lot of interest nowadays and a huge potential is envisaged. Some portable easy-to-use diagnosis products have already been developed, although photonic technology is not mainly used for the sensing mechanism. A very interesting product is the Abbott's i-STAT system, a hand-held blood analyzer capable of performing cartridge-based blood tests at the patient's side in two minutes. The analyser cartridge contains micromachined biosensor arrays which integrate biochemical and silicon chip technologies. The sensors are micro-fabricated thin film electrodes (not photonic sensor), but this kind of high-performance handheld product give us a great view about the possibilities of using compact CMOS-compatible silicon technology for biosensing purposes.

Figure 2.5: Abbott i-STAT.

Figure 2.6: Disposable sensing cartridges for Abbott i-STAT.

2.6- High power computer/Active cable

Active Optical Cables (AOC) are communication links using digital electronics interfaces, while Optics/Electronics conversion is made inside the connectors.
AOC are well adapted to links running at or above 5Gbps, as well as to applications demanding extended cable lengths beyond 2-5 meters at these speeds. It is already well understood that copper-based cables are experiencing significant challenges in this performance range, thus offering significant copper displacement sales opportunity for AOC providers. As shown in Figure 2.7, very high volume are expected in the coming years.



Source: IGI Active Optical Cables Market Report 2009

Figure 2.7 revenue and unit forecast for Active optical Cables

AOC are expected to generate significant business growth over the next five years in several key segments: Mainframe/Supercomputer, Desktop and Notebook/Portable Personal Computers and High-definition Television and Consumer Electronics devices.

2.6.1- Mainframe/Supercomputer

Multicore computing dominates the High Power Computing. These cluster architectures require extremely high data traffic. Optics provides better datarate, latency, power consumption, and smaller volume compared to copper based solutions. Several standards are existing, InfiniBand being mostly used.
For this specific application, there is a broad market potential for short distances (<100m) optical interconnects.

Courtesy of IBM

Figure 2.8: IBM roadrunner - #1 in the world. This HPC is constituted of 19172 processors. More than 5000 actives cables are used (Infiniband DDR @ 4x5 Gbps), with a total length of 90 km

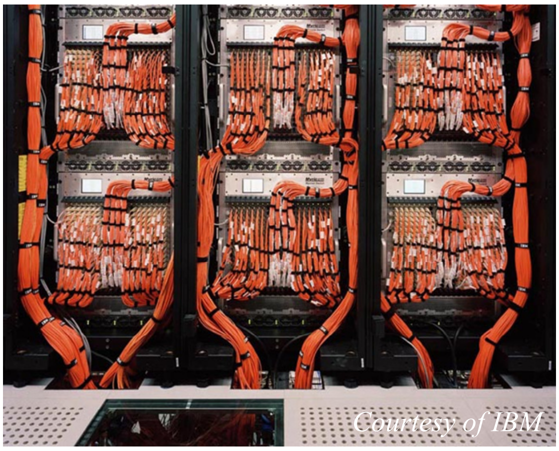


Figure 2.9: IBM MareNostrum central switch rack, with 1700 fiber cables/rack

2.6.2- Desktop and Notebook/Portable Personal Computers

The recently adopted standard USB 3.0 exhibits a datarate of 4.8 Gb/s, with the possibility for optical interconnect.

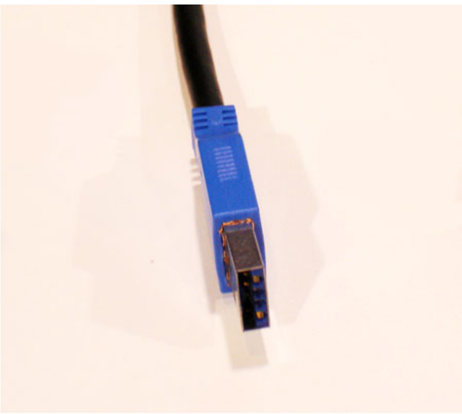


Figure 2.10: USB 3.0 connector

2.6.3- High-definition Television and Consumer Electronics devices

High speed links between video content sources (PC, Blu Ray DVD player, storage unit) and display devices (HD TV set, video projector) request datarates above 10 Gb/s. Two main standards are existing:

- HDMI 1.3 : 340 Mpixel/s, 10.2 Gb/s link, compatible with DVI interface
- DisplayPort: 10.8 Gbit/s forward link channel supports high resolution monitors up to 2560×1600 with single cable. 600 millions consumer products with DisplayPort interface expected in 2012 (source In-Stat, 2008).

Figure 2.11: HDMI 1.3 (left) and DisplayPort (right) connectors

2.6.4- Technology state-of-the art

Most of today active cables are based on 850 nm VCSELs laser sources. Discrete elements as VCSELs, driver, photodiode and TIA are assembled together and placed inside the connector.
Luxtera is the only company developing a silicon photonics technology platform for active cables. Its Balzar is an AOC containing 4 complete fiber optic transceivers per end, eac operating at data rates up to 10.5 Gb/s and supporting a reach up to 300 meters. The cable is electrically compliant with the SFP+ interface supporting Infiniband, Ethernet, Fiber Channel and other applications.

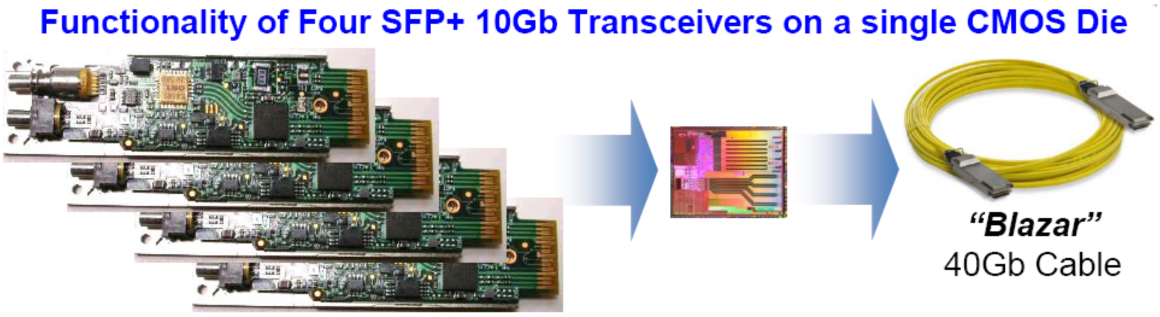


Figure 2.12: Luxtera Blazar Active Optical cable

3- Product & technology Helios roadmaps first versions

3.1- OE modules for Metro/Access transceivers product roadmap

Today's Metropolitan networks are based on TDM 10 Gb/s single transponders for the Client side and the multiplexing of up to 40 individual coloured transponders whose wavelengths are 100GHz spaced on the Network side.
DWDM has allowed huge network capacity increase by deploying existing discrete components based on Direct Modulated Laser (DML) or Electro-absorption Modulated Laser (EML) available technology mature enough to manufacture in large volumes.

Long term requirement on capacity and port density increase, power consumption and size drastic reduction in order to reduce cost, are pushing optical components and modules manufacturers to migrate from discrete single 10Gb/s products to hybrid and ideally full integrated technologies to provide 40Gb/s and 100Gb/s Ethernet solutions.

Moreover, the recent adoption of IEEE draft standards for 40 and 100Gb/s Ethernet on single mode fibre (IEEE 802.3) will also highly contribute to the acceleration of the development of transponder or transceiver modules based on monolithic InP Photonic Integrated Circuit (PIC).
Each emitter chip should integrate multiple DFB or EML 10Gb/s laser array with associated driver and potentially locker electronics array whose signal will be multiplexed into a wave guide (AWG or MMIC) to deliver N*10Gb/s optical signals into a single optical output.
For the receiver chip, the same level of integration must be also applied with multiple PIN or APD 10Gb/s array with associated Trans-impedance circuits (TIA) array aligned in front of an optical Demultiplexer to receive N*10Gb/s optical signals also into a single optical output.

PIC developments will require high photonic integration degree and expertise in order to enable good yield monolithic chips manufacturing: this is by far the key challenge and not the least one that PIC developer and manufacturer must overcome during the next 5 years.

Today's, PIC technologies are mainly pushed by Data Centers' interconnection large bit rate requirements.

But Infinera recent commercial success in the DWDM 10Gb/s Metropolitan space has accelerated the Telecom Equipment and Network manufacturers interest to such technologies in order to potentially use them for DWDM 50 or 100GHz spacing 10Gb/s Metropolitan applications in replacement of standalone

10Gb/s DWDM transponders and transceivers.

Figures 3.1 & 3.2 show the product roadmap respectively in the field of 40Gb/s and 100Gb/s applications.

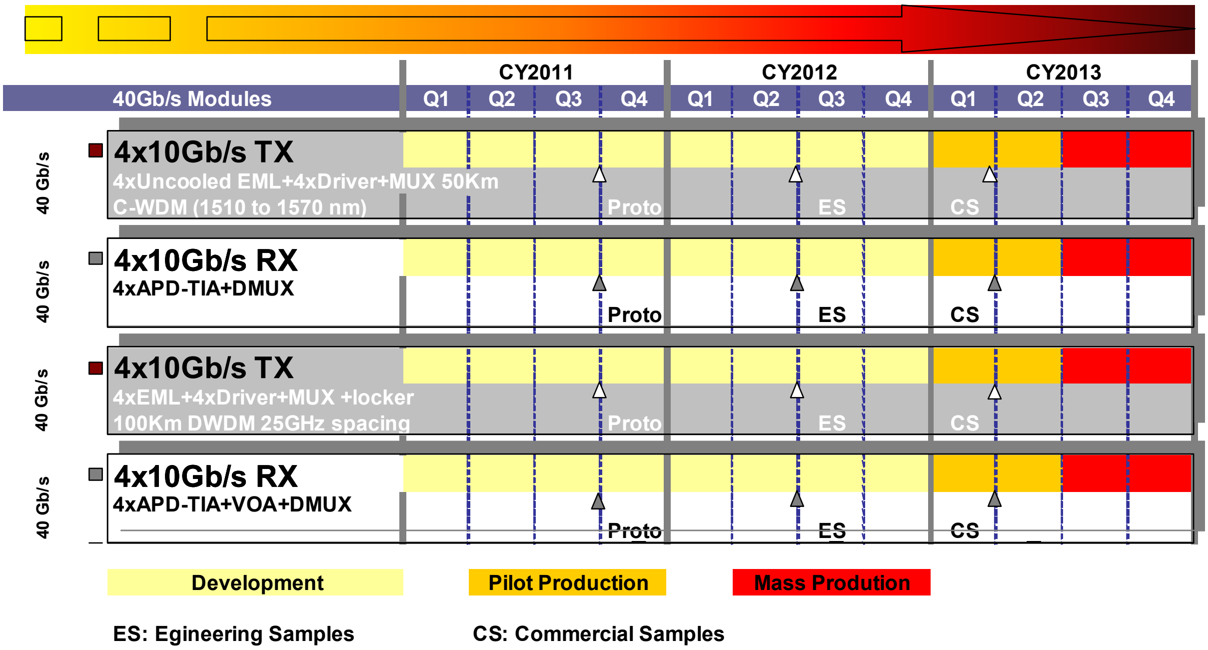


Figure 3.1: 40Gb/s TX/RX modules for transceiver roadmap

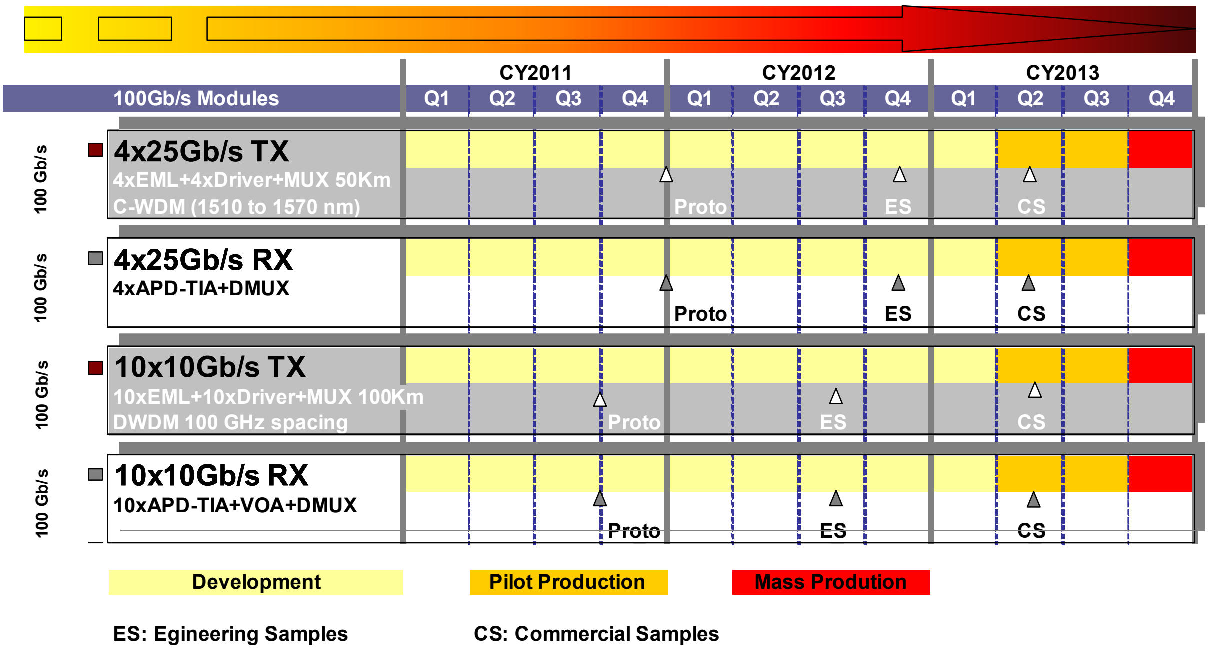


Figure 3.2: 100Gb/s TX/RX modules for transceiver roadmap

Even if future PIC based transceivers are of interest for Telecommunication manufacturers, development of tunable small form factor transceivers is a key driver to support their effort to constantly reduce cost, power and size.
Tunable laser sources based on DBR technology have already had to use photonic integration of multi-section to fit into a butterfly package.
Today's tunable laser source monolithic integration is moving a step head in the integration of the modulator and SOA functionalities to further push the module compactness while maintaining existing performances.

Once tunable integrated modulator laser technologies will be mature enough, next step will be to mix them with PIC N*10Gb/s technologies to ultimately propose a tunable N*10Gb/s PIC transceiver module. Figure 3.3 shows the product roadmap for such tunable PIC

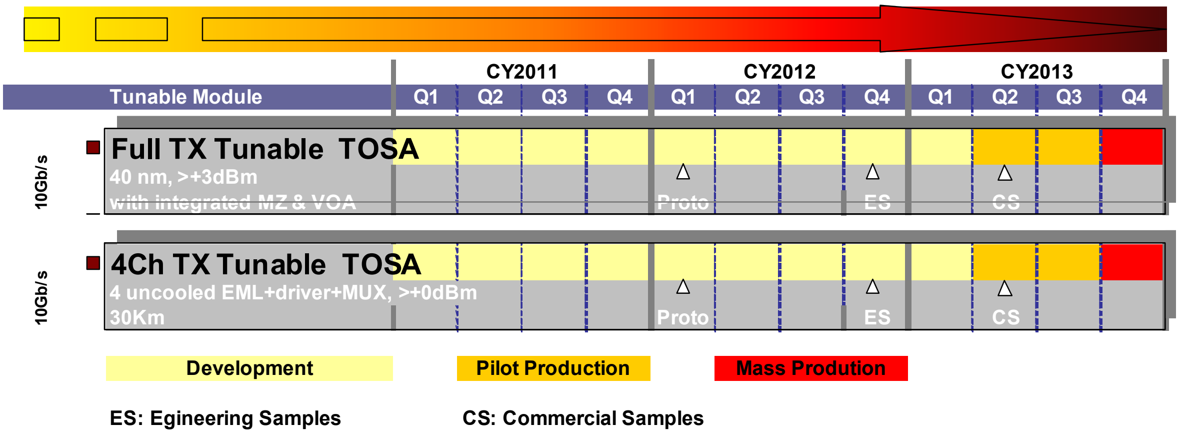


Figure 3.3: Tunable modules for Nx10Gb/s PIC transceiver roadmap

Considering product roadmap needs (Figures 3.1, 3.2 & 3.3) and HELIOS Building Block development roadmap following HELIOS roadmap for OE modules for Metro/Access transceivers can be derived (Fig 3.4)

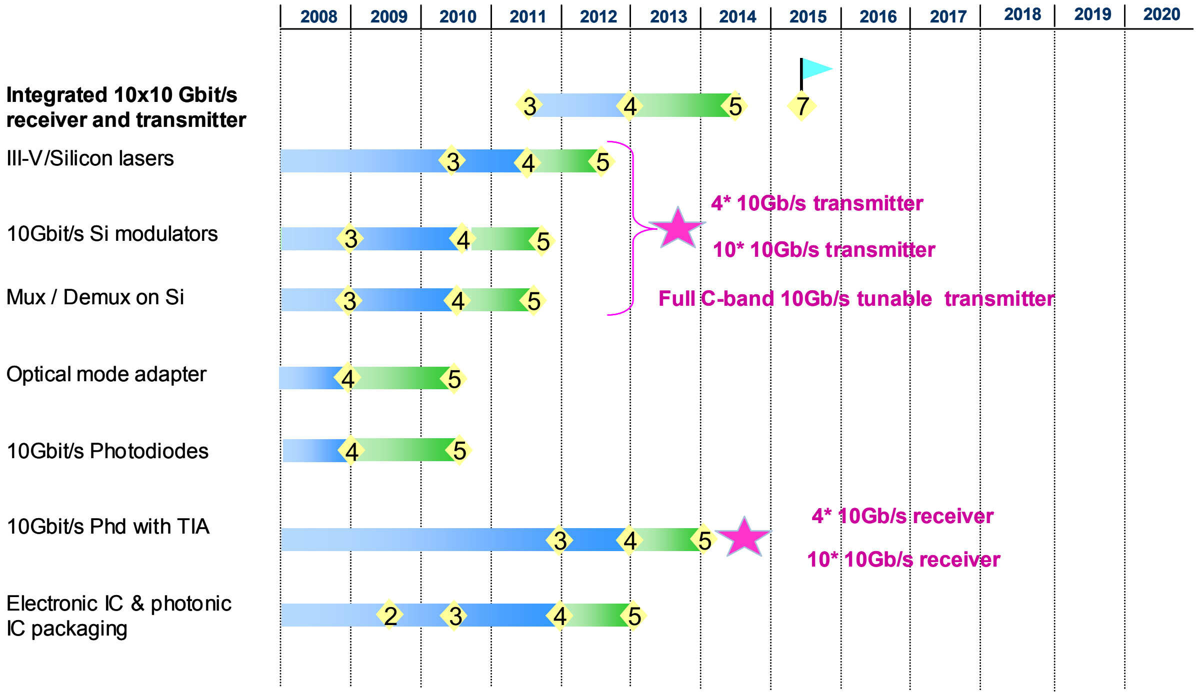


Figure 3.4: HELIOS roadmap on OE modules for Metro/access application

For access networks, silicon photonics can penetrate to the optical network units (ONU) at the user side, In particular, low-cost 10 Gbit/s ONU transceivers can be realized with silicon photonics. Such a transceiver chip consists of a III-V laser element emitting at 1270 nm, a modulator, an avalanche photodiode operating at 1577 nm, a wavelength multiplexer and a mode adapter easing coupling with an optical fiber. The avalanche photodiode becomes mandatory in order to ensure a power budget compatible for access applications. Considering product roadmap needs (Figures 3.1, 3.2 & 3.3) and HELIOS Building Block development roadmap following HELIOS roadmap for OE modules for Metro/Access transceivers can be derived (Fig 3.5)

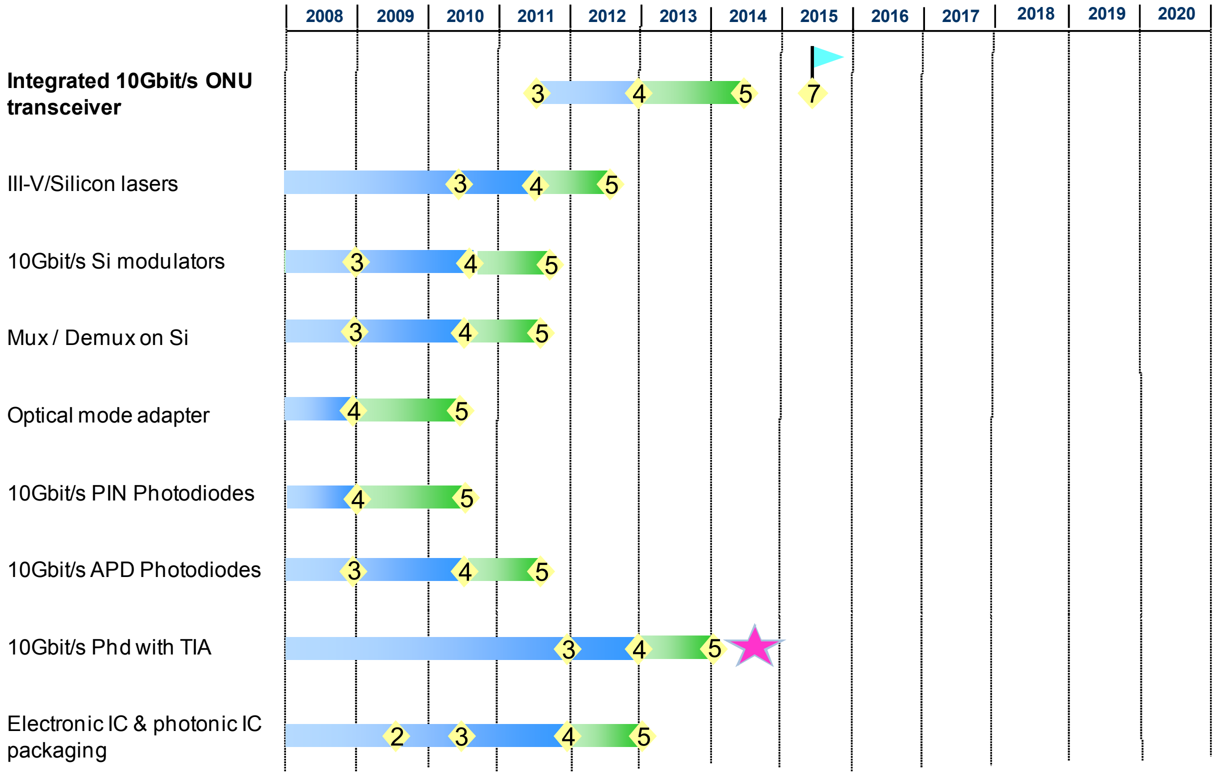


Figure 3.5: HELIOS roadmap on ONU 10 Gbit/s transceivers for access networks

3.2- Modulator for telecom applications product roadmap

Telecom silicon modulators are required in long haul but also in short reach with very high data rates, both for communications network based on SDH hierarchy but also for Gb/s Ethernet. The driving voltages aimed at 1550nm wavelength are smaller than 5V with bandwidth of more then 12GHz at 10Gb/s and near 30GHz at 40Gb/s. Extinction ratio are close to 13dB and insertion loss in individual modules is better than 10dB. For long haul, the chirp should be close to 0.

Such modulators should be miniaturized with the ability to fulfil new format of modulations (QPSK) Mach-Zehnder modulator is thus the suitable design for these applications. Small form factor package (XFP, DXF) transceivers and transponders will always be preferred in the future than larger modules of the previous generation (300pin transponders). That is why miniaturized modulators is maintained as a key challenge for the next generation of modulators fore telecom. All silicon modulators functionalities have to be integrated in one single miniaturized packaged, with a SMD format (surface mounted device) in order to be easily implemented.

During the Helios project, the feasibility should be demonstrated both with optical and electronic performances, but also in the field of packaging. Once validation is got, and depending on the market evaluation, industrialisation could be studied from the first prototypes at the end of the project and year 4.

Half a year should be required to make the final technical evolution from the 1st demonstrator to a 1st prototype in order to meet the updated requirements of the market, and to identify all contract manufacturers both at the chip level, at the package supply, and at the packaging integration level. 1st series can be validated by identified end user, and it has to be checked that the final design of packaging is compatible with small form factor next generation of transceivers / transponders.

In parallel, environmental tests have to be engaged in order to meet the requirements of telcordia recommendations.

During the next year, an industrial flow chart has to be managed with the channel of manufacturing contractors and developments of specific automatic tools for test and fibre connections, electrical connections, hermetical packaged to reach the pre industrial level. This step can last one year, and will require a specific business plan and a dedicated marketing approach of end user as a market evaluation with identification of the segments of market that could be addressed and an appropriate estimation of the costs that have to be reached.

3.3- Transceivers for Multifunction Antennas product roadmap

The expected product roadmap in this area is presented below figure 3.6, pilot production by mid of 2013, that corresponds to steps between TRLs 4 to 7, component and device working in a relevant environment toward working in an operational environment. The production post can be launched once the TRL7 level has been reached (component working in an operational environment).

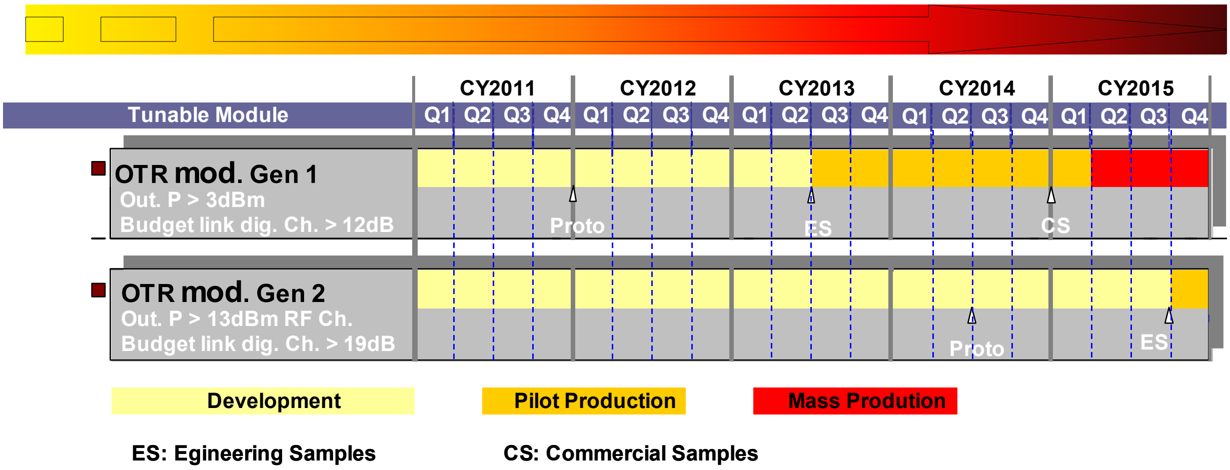


Figure 3.6: Product roadmap for optical TRM

The following figure 3.7 presents the roadmap of the different technologies that will be used in the optical TRM for future multifunction antenna systems.

In Helios two types of transceivers will be realised. They will be based on the association of an array of single mode WDM lasers, SOI modulators, an array of photodiodes and an AWG to multiplex and demultiplex the incoming and outgoing optical signals. In the first family of transceivers, one of the SOI modulators is dedicated to the distribution of a reference analogue RF signal, while in the second family; one of the photodiodes is used to detect the RF reference signal.
The stars seen on this roadmap highlight some possibility of very simple function that can also be used in a preliminary step in future systems.

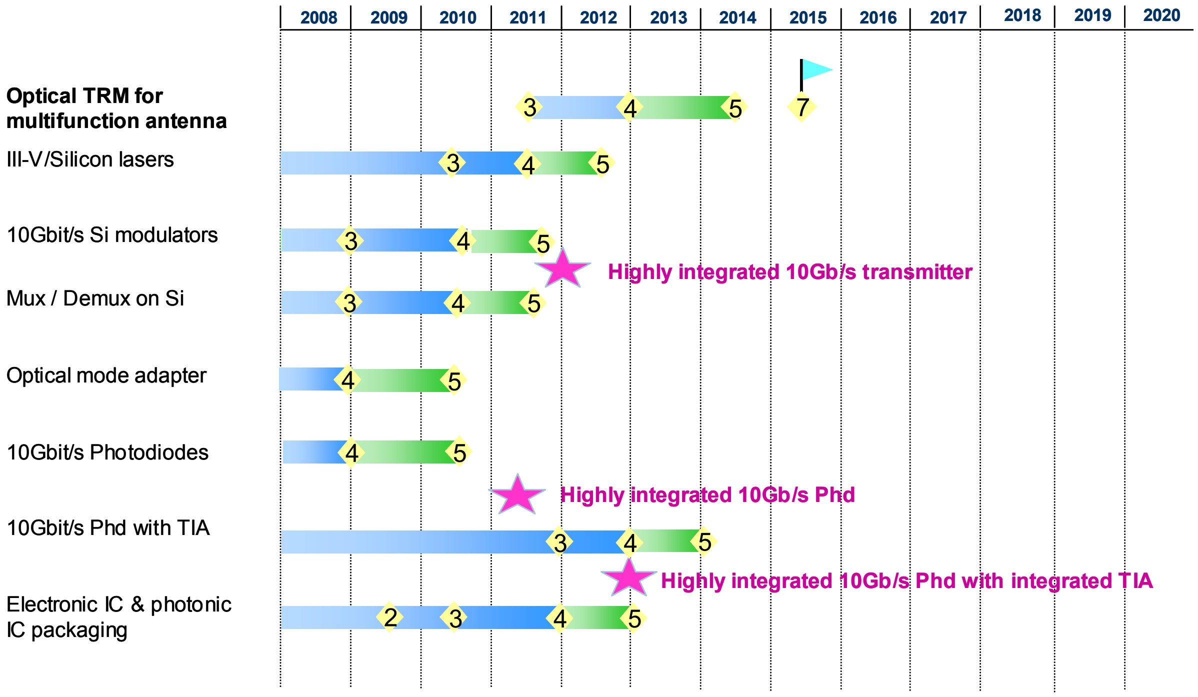


Figure 3.7: Helios Road-Map for multifunction antenna (Gen1)

Figure 3.8 presents roadmap of the optical TRMs for multifunction antenna. Two generations of products are expected, in the first one, the target is a point-to-point budget link in excess of 12dB with an output RF power per channel in the range of 5dBm. While for the second generation, the budget link mut be at least 19dB and the output RF power 13dBm.

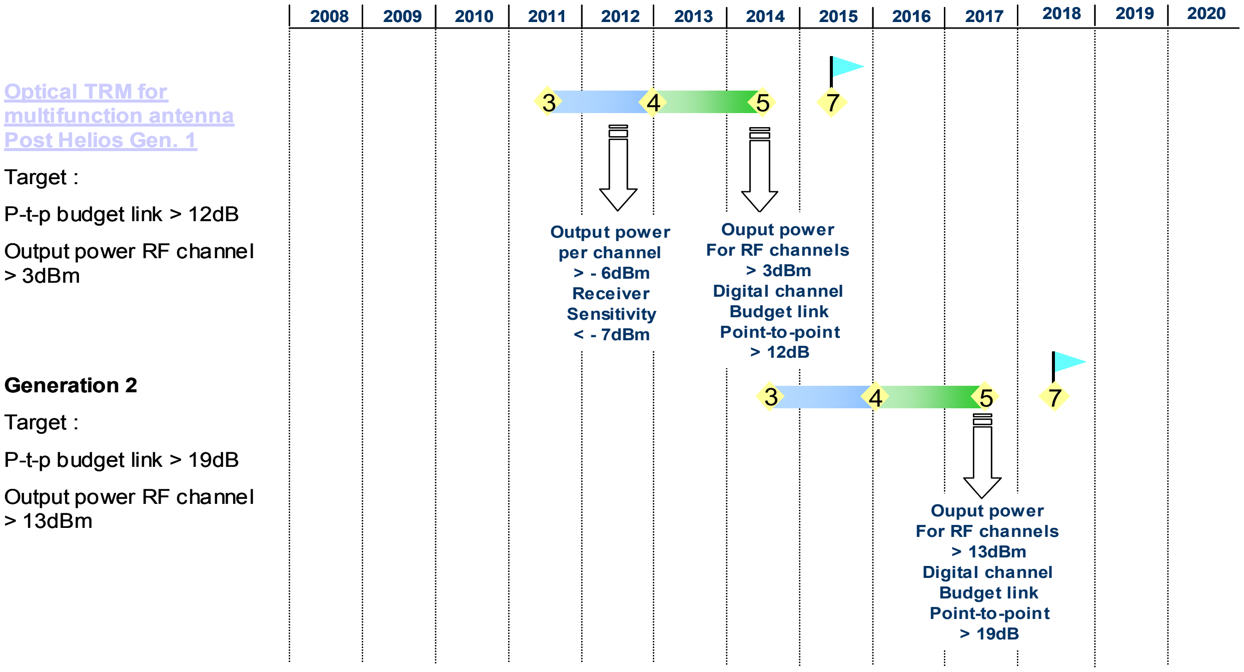


Figure 3.8: Gen2 (Post-Helios) Road-Map for multifunction antenna

3.4- Wireless modules product roadmap

The deployment of optical fibre networks imply considerable costs in CAPEX/OPEX for dedicated use, especially when considering the connection of new users in emerging economies like China or India with extremely large populations, or in small towns, rural areas with low density of population and underdeveloped countries. Wireless technologies are well known to provide reduced CAPEX/OPEX costs suitable both for urban and developed areas, as well as rural and emerging markets, allowing to break the digital trench between these two worlds. Moreover wireless clearly plays a major role in disaster recovery operations, as high-speed wireless links can be easily deployed connection with the nearest available access to the Internet, several kilometres away. By today, the objective of 1 Gb/s has been proposed as forthcoming updates for WiMAX-m, LTE-Advance and IMT-Advanced. But broadband wireless technologies have inherent limitations, in particular when dealing with bandwidth and capacity, and traditionally wired capacity has always led the wireless capacity by an order of magnitude. Also, the convergence and interoperability of these systems with FTTH is in an early stage.

In the past year a great effort has been devoted to wireless systems at Gb/s capacity operating at the millimetre-wave frequency band. The EU funded ICT projects IPHOBAC, FUTON, ALPHA and OMEGA, with an overall budget about 57 Meuros, have dealt with broadband wireless systems, convergence, interoperability and delivery through optical-fibre infrastructure. Several companies such as E-band Communications Corp., ELVA-1, Bluwan, ARC Electronics, BridgeWave, or Research Institutes like CSIRO are already offering prototypes and products for Gb/s point-to-point wireless links operating at the 40, 60 and 70/80 GHz bands. Recently Asyrmatos has introduced the first wireless transceiver at 10 Gb/s operating at the 40, 70/80, 94 and 140 GHz bands. The standards IEEE 802.16 WiMAX and ETSI BRAN HiperMAN and HiperAccess have specified air interfaces for broadband wireless access in the 10 to 66 GHz band, and the IEEE 802.15.3c is evaluating the millimetre-wave band for multi-Gb/s.

Although these efforts are showing their potential, there are key open issues that have to be addressed in a coordinated approach to achieve the goal of 10G Everywhere: a transparent wired and wireless technology providing ubiquitous broadband connectivity at 10Gb/s. Key challenges are:

- Compatibility of multi-Gb/s wireless systems with the 10G-EPON on-going standard for FTTH and EFM.
- Optimised technology for 10 Gb/s wireless systems operating at the millimetre-wave frequency band, especially at the E-Band.
- Highly spectral-efficient modulation and demodulation wireless technologies at 10 Gb/s at the millimetre-wave frequency band

The following figure 3.9 presents Helios the roadmap of the different technologies that can be used to build integrated 10Gbps wireless emitters and receivers

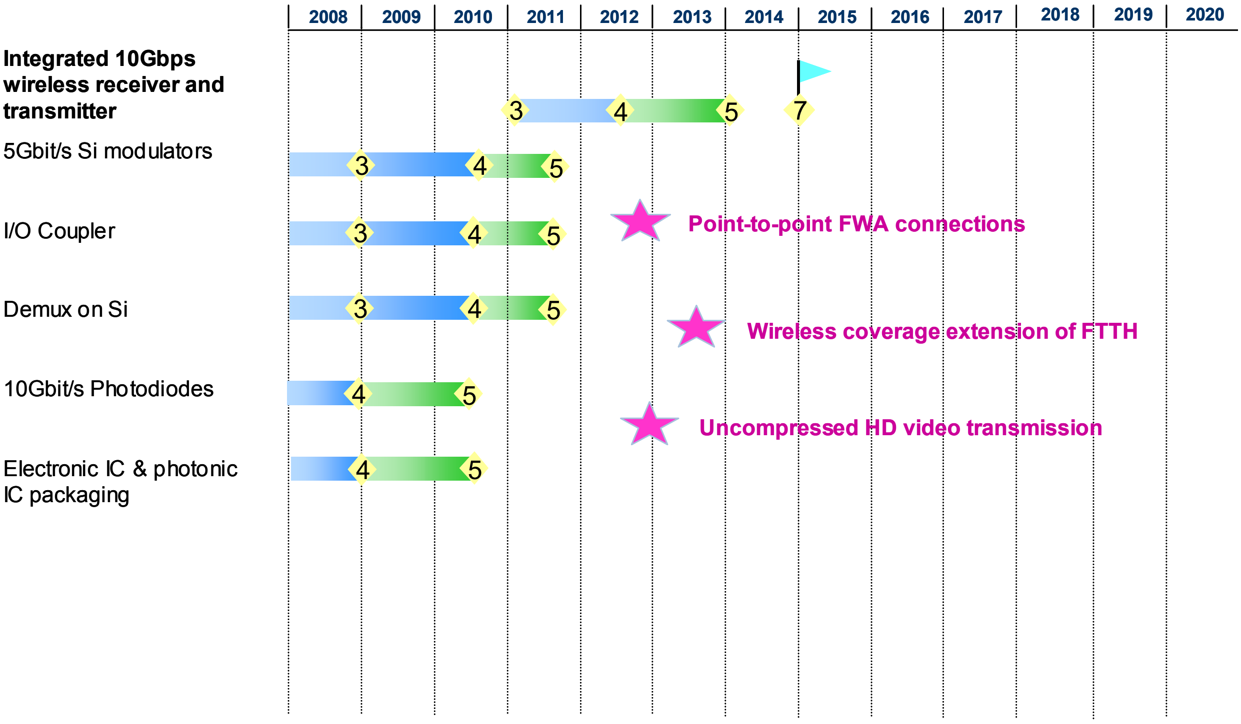


Figure 3.9: Integrated 10Gb.s wireless receiver and transmitter Road-map.

3.5- Intrachips and chip to chip applications

Application requirements:
More and more optical links are also being considered for chip-to-chip (distance < few 10cm) and even on-chip communications. To be viable the optical links have to be able to compete with electrical links in terms of cost, performance and power consumption. Fig. 3.10, 3.11, 3.12 give some of the relevant numbers, taken from [19]. In particular the requirements in terms of power consumption are very low. The total power consumption for the optical link (including optical parts + electrical drive circuitry should be only a few 100fJ/Bit to some pJ/Bit (or even lower), to fulfil projected demands. That means that the power consumption for the individual components (detector, source, modulator) is even an order of magnitude lower.

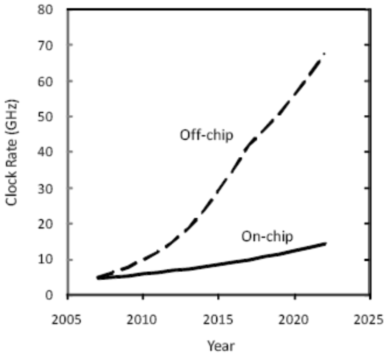


Fig. 3.10: Projected on-chip clock rate and the projected offchip rate required to drive the chip input and output, according to the ITRS roadmap.

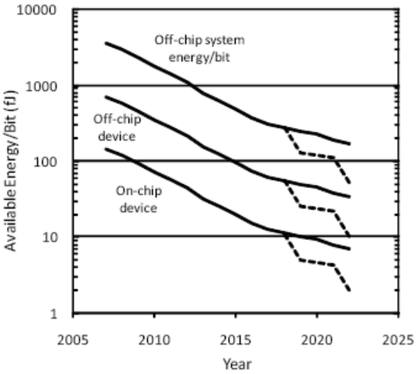


Fig. 3.11: The available energies per bit for interconnects.

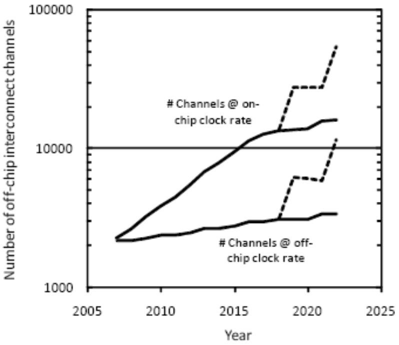


Fig. 3.12: Number of channels required to support the ITRS off-chip interconnect bandwidth.

Wavelength multiplexed optical links will require:

- Efficient optical transmitters: 2-100fJoule/bit, < 100um^2. Options include:
    - Directly modulated lasers, e.g. as being pursued in the EU WADIMOS project. However further scaling to smaller active volumes will be required.
    - External laser + modulators
- Efficient detectors: capacitance < few fF
- Low loss passive waveguides and filters with controlled passband
- Low loss out-off chip couplers

Helios does not develop components which can be directly reused for on-chip or chip-to-chip applications: the power consumption and dimensions of the components are simply too big (except maybe for the detectors). However, much of the technology developments can be reused:

- III-V on silicon integration (or all silicon sources)
- Off-chip couplers
- Integration optics/electronics
- Passive filters
- Photonic crystal cavities

3.6- Sensors and bio-photonic applications

For the biosensor application, typically arrays of optical resonators are envisaged. When a species attaches to the acceptors on the resonator, the effective optical index will shift, which can be measured.

The important subparts are:

- High quality array of optical resonators
- Optical couplers
- Optical readout system
- Chemistry for adhesion

The innovative part resides mainly in the latter two points. The first two are more-or-less available now.
Integrated photonic structures for biosensing application are mainly based on the detection of changes in the refractive index of the cladding material. When any target analyte to be detected is placed near to the photonic structure, a variation of the refractive index of the structure takes place, producing a variation in the response of the photonic structure, which will be used to carry out the detection. The suitability of these structures for label-free biosensing has also been demonstrated in the last years. The capability of developing bioassays where no marking of the target biomolecules is needed (e.g., fluorescent, magnetic,… markers) avoids the influence of the marker over the measurement and allows for simpler and faster procedures, what definitively opens the door to this technology for potential applications in several fields such as clinical diagnosis, drug discovery, or environmental monitoring.

Photonic structures with high sensitivities have already been experimentally demonstrated, but this characteristic can be improved even more. High efficiency optical couplers are also a need for this kind of photonic sensing structures.

However, the major issues to be addressed for the commercial development of photonic biosensors are related with other fields such as biochemistry, microfluidics or readout systems (not photonics). The development of high performance microfluidics systems, efficient biochemical functionalization procedures and simple and cheap readout systems are a need in order to obtain interesting commercial biosensing products based on photonic technologies.

HELIOS does not develop specific components for bio-sensing. However, several of the technology developments can be reused as well.

- Efficient optical resonators
- Efficient out-off-chip couplers

4- Conclusion

Thanks to complementary of HELIOS Consortium partners a first version of HELIOS roadmap has been proposed based on the identification of different field of applications for Silicon Photonics & on the analysis of pertinent product/Technology roadmap. This roadmap has been established for the applications where actual vision/maturity is still sufficient.
Next steps will be to complete this roadmap on the other applications and in coordination with the other deliverables (Exploitation plan & System and performance requirements) to analyse how potential products identified on this roadmap could be “differentiated” from other approaches in term of performances, size and cost.

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6- Glossary

AOC	Active Optical Cable
APD	Avalanche PhotoDiode
BER	Bit Error Rate
DBR	Distributed Bragg Reflector Laser
DFB Laser	Distributed Feed Back Laser
DML	Direct Modulated Laser
EML	Electro-absorption Modulated Laser
FEC	Forward Error Correction
FSO	Free Space Optics
MZ	Mach-Zehnder
NRZ	Non Return to Zero
PIC	Photonic Integrated Circuit
PLC	Planar Lightwave Circuit
Rx	Receiver Optical Sub Assembly
SOA	Semi-Conductor Optical Amplifier
TDM	Time Division Multiplexing
TIA	Trans-Impedance Amplifier
Tx	Transmitter Optical Sub Assembly
VOA	Variable Optical Attenuator
VCSEL	Vertical Cavity Semi-conductor Emitting Laser
DWDM	Dense Wavelength Division Multiplexing
SFP	Small Form factor Pluggabble (MSA)
FP-E	Small Form factor Pluggabble- Extended (MSA)