PROJECT PERIODIC REPORT

Grant Agreement number: 288869

Project acronym: NAVOLCHI

Project title: Nano Scale Disruptive Silicon-Plasmonic Platform for Chip-to-Chip Interconnection

Funding Scheme: Collaborative Project

Date of latest version of Annex I against which the assessment will be made:

2011-06-03

Periodic report: 1st

Period covered: from 2011-11-01 to 2013-04-30

Name, title and organisation of the scientific representative of the project's coordinator[1]:

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.
[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [3]:

  ☐ has fully achieved its objectives and technical goals for the period;

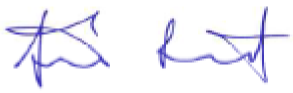
  X has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable

  X is up to date

  ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator:. Juerg Leuthold.



Date: ...25../ ..June.../ 2013.

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism and in that case, no signed paper form needs to be sent

Contents

1 Introduction

The report here present summarizes the results and achievements during the first 18 months of the NAVOLCHI project. It is the First Periodic Activity Report out of a list of four major reports during the project:

- First Intermediate Report after 9 months,
- First Periodic Activity Report after 18 months,
- Second Intermediate Report after 27 months and
- Second Periodic Activity Report after 36 months.

Additionally, a final report will follow in the end of the project.

As usual for periodic reports, this document contains a section 'Summary' which can be published by the EC. Details about the results reached so far, including the achievement of deliverables and milestones, are located in the section 'Core of the Report', where each work package is discussed separately. Man power and financial situation of the beneficiaries are attached at the end of the report.

2 NAVOLCHI Midterm Summary

The Project

The NAVOLCHI project explores, develops and demonstrates a novel nano-scale plasmonic chip-to-chip and system-in-package interconnection platform to overcome the bandwidth, foot-print and power consumption limitations of todays electrical and optical interconnect solutions. The technology exploits the ultra-compact dimensions and fast electronic interaction times offered by surface plasmon polaritons to build plasmonic transceivers with a few square-micron footprints and speeds only limited by the RC constants. Key elements developed in this project are monolithically integrated plasmonic lasers, modulators, amplifiers and detectors on a CMOS platform. The transceivers will be interconnected by free space and fiber connect schemes. The plasmonic transceiver concept aims at overcoming the challenges posed by the need for massive parallel interchip communications. Yet, it is more fundamental as the availability of cheap miniaturized transmitters and detectors on a single chip will enable new applications in sensing, biomedical testing and many other fields where masses of lasers and detectors are needed to e.g. analyze samples. Economically, the suggested technology is a viable approach for a massive monolithic integration of optoelectronic functions on Si substrates as it relies to the most part on the standardized processes offered by the silicon industry. In addition, the design and production cost of plasmonic devices are extremely low and with the dimension 100 times smaller over conventional devices they will require much lower energy to transfer data over short ranges of multi-processor cluster systems. The project is disruptive and challenging, but it is clearly within the area of expertise of the consortium. It actually builds on the partners prior state of the art such as the demonstration of the first nano-scale plasmonic pillar laser. This project has the potential to create novel high-impact technologies by taking advantage of the manifold possibilities offered by plasmonic effects.

Project Status

During the first period up to month 18 of the NAVOLCHI project, the analysis of chip to chip interconnect requirements and needs as well as the modelling and beginning of fabrication of plasmonic devices has been of major concern. The plasmonic physical layer comprises

- the transmitter, consisting of the metallo-dielectric laser and the modulator, and
- the receiver, subdivided into the amplifier and the QD-photodetector.

While the analysis part is handled in WP2, the WPs 3 and 4 deal with the devices. The realization of the optical and electrical interfaces for the plasmonic interconnection platform is focused in WP5. As core tasks in this project, these work packages 2-5 will be discussed in more detail.

Naturally and according to plan, minor activities have been carried out in WP6, which handles characterizing of the devices.

The project is accompanied by the management WP1 and by WP7, which cares for publication and dissemination work.

WP1 (Project Management) Summary

As all relevant objectives for the first period up to month 18 have been achieved and no future problems are expected, the project partners are keen to continue the project facing the final goal of a well operating demonstrator device. Based on intense communication between the project partners, no critical situations occurred so far.

Details of the results achieved up to now are discussed in the following sections of WP2-WP7.

On the NAVOLCHI-WEB-Site www.navolchi.eu further information can be obtained.

WP2 (Interconnect Specifications) Summary

WP2 investigates the new plasmonic device technology for chip-to-chip interconnection. In the context of WP2, the requirements and needs for chip-to-chip interconnects have been reviewed. Initial benchmarking has been performed. In view of the benchmarking review, industrial partner’s ST input and all partner’s contributions, targeted specifications have been set for the system in order for the plasmonic interconnect to be competitive and, eventually, outperform competing technologies. The future of multicore computing depends on the capability of interconnects to transmit great amounts of data from chip to chip, but electric interconnects are reaching their bandwidth limitations. The need for a chip-to-chip interconnect that can offer great bandwidth in combination with low latency and power consumption has surfaced, as expected. In this context, plasmonics technology appears to be very promising for overcoming the challenges at hand. Optical interconnects with plasmonic transceivers can be smaller than existing conventional photonic systems while retaining the bandwidth capabilities of photonic systems. Initial definitions of the subsystem devices have been set. System design scenarios have been selected. A simulation platform has been prepared for helping with the convergence of system goals and subsystem properties.

WP3 (Plasmonic Transmitter) Summary

- The main objective of WP3 for the reporting period was to investigate via simulations the plasmonic transmitter, which consists of a plasmonic/metallic laser and a plasmonic modulator, as well as to show significant progress in the fabrication of the transmitter.
- The modelling of both, a Fabry Perot plasmonic laser and a metallo-dielectric nanolaser has been carried out. The fabrication of the metallo-dielectric nanolaser has started.
- A III-V wafer to fabricate the lasers has been grown and sent to Ghent University for its bonding to a silicon substrate.
- Modelling of both, a plasmonic phase modulator and a plasmonic absorption modulator has been performed.

- The fabrication of a plasmonic phase modulator has been carried out.

WP4 (Plasmonic Receiver) Summary

A large database of Quantum Dot (QD) geometries and compositions (characterized optically) is available to be employed as the gain materials in plasmonic amplifiers. QDs of different types were dispersed in (lithographic) polymers like PMMA and SU8 (ligand exchange is necessary in this case), as the most promising host materials, and optical waveguiding with (saturating) gain using optical pumping was demonstrated. Electrically pumped nanocrystal light sources based on electric-field excitation have been successfully demonstrated of both visible and near-infrared electroluminescence. This is due to AC electroluminescence by charge tunneling between neighbouring quantum dots. Polymer based symmetric and antisymmetric Insulator-Metal-Insulator (IMI) waveguides (planar geometry) were fabricated and modelled, and found a significant advantage of the first over the second design. Net gain is measured with gain limitations possibly due to Auger processes in QDs. New QD infrared materials will be synthesize to overcome these limitations. Further advantages in propagation length are foreseen by using ridge IMI waveguides of finite width. We carried out also a modelling and fabrication for the hybrid silicon-plasmonic amplifier. QDs (whose absorption is enhanced in very thin layers by dipole-dipole interactions in QD superlattices forming these layers) interact with the optical mode of the waveguide. A Layer-by-Layer technology to deposit conducting QD layers for photo-detectors was developed successfully. The internal quantum efficiency (IQE) can be controlled by the ligands used in this method and optimizing the synthesis of QDs with metal excess. In Schottky/heterostructure photodetectors an IQE = 1 is measured at visible wavelengths, where most of the light is absorbed at the QD layer, corresponding to Responsivities of the order of 0.7 A/W. These achievements will be translated to 1550 nm by using thicker and more uniform thin films of PbS or PbSe QDs. A nanocomposite based on conductive polymer in a photolithographic resist has been developed and optimized by doping with Cu-salt and Au-salt; in this case the Au-salt is also acting as precursor for in-situ synthesis of Au-nanoparticles have been grown in-situ. These materials exhibit photoconductivity and seem to be higher when incident light coincides with the plasmon resonance of the nanoparticles. A parallel strategy, patternable (now dielectric) polymers containing metal salts, have been used to create Ag nanostructures on the basis of e-beam lithographied patterns and a chemical metal regrowth technique.

WP5 (Optical and Electrical Interfaces) Summary

WP5 focusses on the development of the photonic and electronic interfaces required to integrate all individual device together. During this period several new interfaces were designed and/or fabricated. This included the design and fabrication of novel couplers to interface standard silicon waveguides with plasmonic modulators and steerable grating couplers to interface silicon waveguides with optical fibers. Novel compact optical filters for suppressing noise in the optical signal before the receiver were demonstrated. Finally, the design of the electronic signal generation module was completed and its implementation was initiated.

WP6 (Integration, Characterising and Testing) Summary

During the first 18 months the following activities have been carried out:

- Testing and characterization of all the passive and active plasmonic devices such as plasmonic laser, modulators, amplifiers and photodetectors has started under the control of AIT.
- In order to estimate the coupling losses of metal taper mode converters, KIT has fabricated plasmonic phase modulators with various lengths. Moreover a 34 µm long plasmonic phase modulator with 200 nm wide metallic slot has been electro optically characterized; the device exhibits flat optical transmission with a 13 dB insertion loss and flat frequency response up to at least 45 GHz.
- ST has developed a Transaction Level Model (TLM) view of the platform that will be used for the final validation of the system. This platform, allowing generating the stimuli for the system to be validated, will be used in a first phase for the validation of the RTL VHDL view of the overall system, and in a second phase for the validation of the system mapped onto FPGA.

WP7 (Exploitation and Dissemination) Summary

Dissemination and exploitation of ideas and results is of high importance in the project. There is substantial dissemination action concerning project activities. In particular, NAVOLCHI partners have already produced 14 high quality scientific journal and 37 conference publications (papers/presentations/talks). In addition, they provided the May 2013 cover article for scientific magazine Optics & Photonics News on plasmonic communications (invited); and they published a white paper on innovation potential online. Importantly, a NAVOLCHI workshop has been organized at ICTON 2012 (Warwick, UK), where partners presented their initial results and future plans, and communication was established with another EU-funded project related to plasmonics, the PLATON project. A workshop has also been organized for ICTON 2013 (late June, Spain). The project website (www.navolchi.eu) has been implemented and uploaded online, disseminating the NAVOLCHI activities further. A press release and an advertising brochure have been issued.

On the exploitation front, 1 patent has been submitted successfully, and several Master and PhD theses on NAVOLCHI technology have been initiated at partners' institutes.

3 Core of the Report

3.1 Project Objectives for the Period

WP1 (Project Management) Objectives

- Performing common project management tasks
- WEB-site preparation and continuous update,
- Preparation of Project Reference Manual,
- Project Quality Assurance Manual and
- Intermediate progress report after month 9.

WP2 (Interconnect Specifications) Objectives

- Initial benchmarking.
- To define optical interconnection system environment and parameters within which the plasmonic devices have to function and that will be used for evaluating its performance with respect to chip to chip communication.
- To develop a cycle accurate VHDL model of serializer/deserializer.
- Device definitions.
- System modeling.

WP3 (Plasmonic Transmitter) Objectives

The main objectives of WP3 for the reporting period were to investigate via simulations the plasmonic transmitter as well as to show a significant progress on the transmitter fabrication. This component consists basically of two devices, which are a plasmonic or metallic laser and a plasmonic modulator. Concerning the plasmonic modulator, the numerical modelling of a plasmonic phase modulator and a plasmonic absorption modulator, as well as their comparison were performed. The fabrication of the phase modulator was carried out. Regarding the laser source, the modelling of a plasmonic laser and a metallo-dielectric was performed. First fabrication results are reported as well.

The milestones corresponding to WP3 in the reported period are:

- Milestone 8: Decision on an optimized structure for metallic/plasmonic nanolaser and its coupling to Si waveguide.
- Milestone 9: Decision on an optimized structure for plasmonic modulator.
- Milestone 10: Grown wafer structure for plasmonic lasers

- Milestone 11: Fabrication of plasmonic modulator on a SOI platform
- Milestone 12: Decision on an optimized structure for plasmonic modulator with a maximum loss of 20dB
- Milestone 13: Initial characterization of unbounded plasmonic lasers

WP4 (Plasmonic Receiver) Objectives

Plasmonic Amplifier:

- Modelling (Surface Plasmon Polariton physics and loss compensation).
- IR Quantum Dots (wavelength tunable, high QY).
- Plasmonic Amplifier concept by using polymers doped with QDs (optical injection).
- Si based Plasmonic Amplifier platform (electrical injection).

Photodetectors using QDs and metal nanostructures

- - Photoconductors based on QD solids: Schottky/heterestrocture vs nanogap/microgap devices.
- - Patternable conductive polymers containing metal nanostructures.
- - Metal nanostructures based on e-beam patternable polymers doped with metal nanoparticles.

WP5 (Optical and Electrical Interfaces) Objectives

- Fabrication of coupling scheme of Si waveguide to plasmonic waveguide: tapered couplers and side couplers
- Fabrication of optical filters for optical receiver
- Fabrication of beam shapers
- Design of signal generation module

WP6 (Integration, Characterising and Testing) Objectives

- Characterization and testing of first active and passive plasmonic devices

WP7 (Exploitation and Dissemination) Objectives

- Dissemination through paper submission to high quality and high impact scientific journals, magazines and white papers.
- Promotion of the project outputs through the participation in conferences and symposia.
- Organizing workshops/seminars on NAVOLCHI technology.

- Interaction with other EU-funded and national projects.
- Issuing of press releases and brochures.
- Generation of intellectual property (patents portfolio).
- Theses at the partners' institutes on NAVOLCHI technology.
- Provide input to industrial partners based on scenarios of the proposed solutions.
- Maintenance of the project web site which will be used for information and result dissemination purposes.
- Work Progress and Achievements

3.1.1 Work Package 1: Project Management

Please refer to chapter 3.2 for a detailed description of the activities concerning the project management.

3.1.2 Work Package 2: Inter Connect Specifications

This work package investigates the new plasmonic device technology for chip-to-chip interconnection.

General status

The progress of WP2 is generally on track. All deliverables (namely, D2.1 and D2.2) were completed on time. Milestones MS 1, MS2 and MS3 were met, while milestone MS4 is in progress and currently delayed.

Up to month 18, only Tasks T2.1, T2.2 and T2.5 have been active. Task 2.1 has been completed, while T2.2 and T2.5 are in progress. Objectives have been met.

Task 2.1 Work Progress

(Analysis of chip to chip interconnect requirements and needs (bandwidth, latency, power consumption, noise immunity [M1-M6])

Task 2.1 has been completed successfully. The objective of this task was to define the interconnect system, as well as analyze and understand requirements and needs in terms of bandwidth, latency, power consumption, and size of chip-to-chip communication for systems split over more dice, implementing real applications. Device definitions have been performed, as has preliminary benchmarking to aid the definitions. The work on the system level was based on prior know-how of partners, review of the interconnect field, and direct input by industrial partner STMicroelectronics. The work on subsystem devices was based on the conclusions of the system report, as well as device leader expertise and research.

Initial Benchmarking

Initial benchmarking was carried out and the basic operation targets were set for the system specifications. Such benchmarking has been included in Deliverable 2.2 (month 12). It was used, along with system considerations, to set the initial desired targets for subsystem device specifications. Since then, additional benchmarking activities have been carried out and the total results are listed below.

Important specifications of industry or research interconnects are listed below, both for electrical and optical interconnects.

Link	Type	Throughput	Latency	Power	Pins
Intel 50G Link [1]	Opt.	50 Gb/s (12.5x4)			
UNIC [2]	Opt.	10 Gb/s*		~ mWs**	
TI C2C [3]	Electr.	6.4 Gb/s	50 ns		16
MIPI LLI [4]	Electr.	5.8 Gb/s	80 ns	15 pJ/bit	4
MIPI UniPort [4]	Electr.	3.2 Gb/s (0.8x4)	high	15 pJ/bit	4

* 2011 results; ** 530 fJ/bit without laser source

Tab. 1: Interconnect data.

Note that the MIPI data are specifications of the MIPI Alliance and not products. More information on each interconnect follows.

Intel 50G Link

Intel's 50G Silicon Photonics Optical Link [1] uses lasers to transmit data between two silicon chips, a transmitter and a receiver chip. It is composed of four optical channels, each running at 12.5 Gbit/s, which are combined onto a single fiber to transmit data up to 50 Gbit/s.

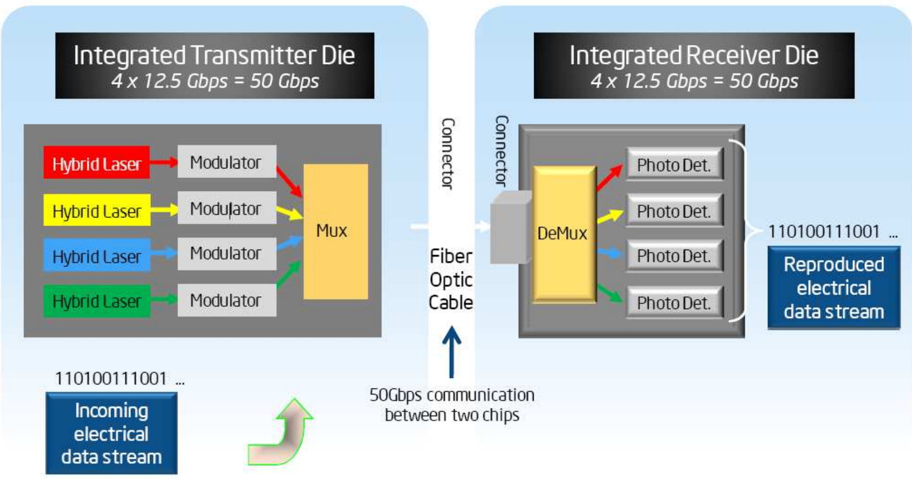


Fig. 1: Schematic of the Intel 50 G Link (taken from [1]).

The light sources are 4 hybrid silicon lasers, created by fusing a layer of InP (Indium Phosphide) onto the silicon waveguides during the manufacturing process. Integrated silicon modulators are utilized that use interference to place the data onto the light beam. The 4 light beams are multiplexed into one beam by passive multiplexers. At the receiver, a demultiplexer separates the 4 streams of data again and sends them to the photodetectors so that the initial electrical signals are reproduced. Intel plans to reach 1 Tbit/s in the future by utilizing 25 channels with 40 Gbit/s modulators.

Modulator Speed (Gbps)	Number of Channels	Data Rate
12.5	x4	50Gbps
12.5	x8	100Gbps
25	x16	400Gbps
40	x25	1Tbps

Fig. 2: Future targets for Intel 50G Link (taken from [1]).

Because it is developed using silicon manufacturing methodologies, the link can be utilized for high volume applications with minimal process complexity or cost.

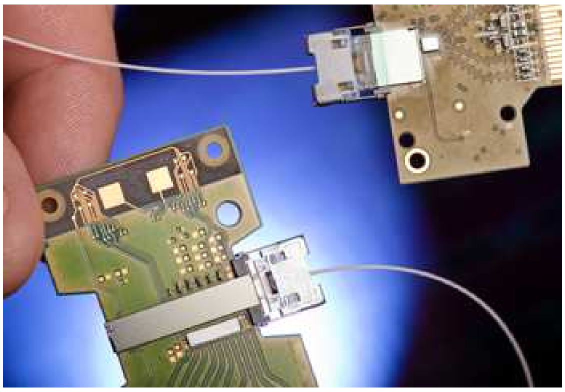


Fig. 3: Intel 50 G Link (taken from [1]). Note the size.

Applications:

- Computing applications, from Gigabit to Terabit
- Cloud data-centers
- Throughput intensive applications in scientific computing
- Ultra-high resolution 3D applications for future consumer electronics

TI C2C

TI C2C (available since 2010) contains technology from Texas Instruments and Arteris [2]. It was created to allow DRAM memory sharing for reduced eBoM (electronic bill of materials) cost through a very low latency interface. C2C does not require a PHY, as it just uses 2 DDR pads. C2C requires about 30 pins total in a mobile phone use model (16 transmit pins, 8 receive pins, plus clock and power pins). Round trip latency is 100 ns. It requires 1.2 or 1.8 volts and has throughput of 6.4 Gbit/sec at 200 MHz DDR speeds and using 16 pins. C2C's primary purpose is to connect a mobile phone applications processor to a mobile phone modem.

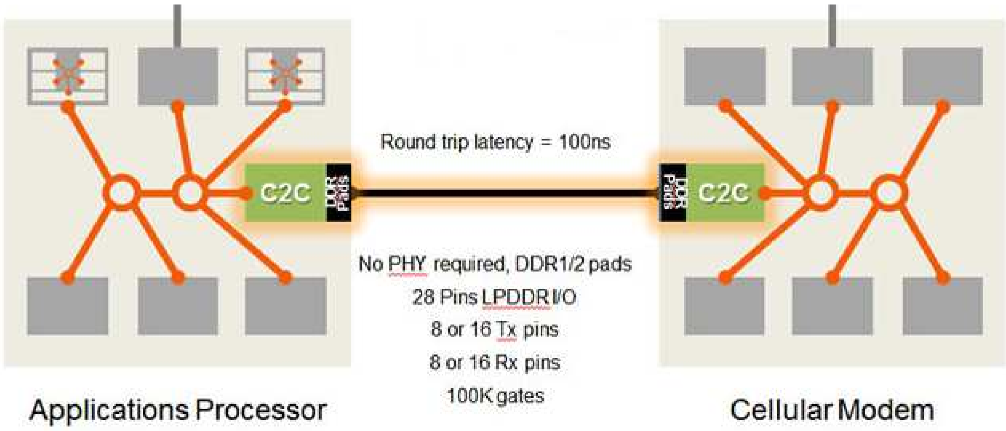


Fig. 4: TI C2C (taken from [2]).

MIPI UniPort

MIPI Alliance [3] is a global, collaborative organization comprising companies that span the mobile ecosystem and are committed to defining and promoting interface specifications for mobile devices.

The UniPro specification was first released in 2007. It defines a layered protocol for interconnecting devices and components within mobile device systems. It is applicable to a wide range of component types including application processors, co-processors and modems, as well as different types of data traffic including control messages, bulk data transfer and packetized streaming. UniPort is UniPro combined with a MIPI D-PHY or M-PHY. It supports a maximum data rate of 800 Mbit/s per lane, for 1 to 4 lanes. UniPro is not low latency enough for RAM sharing.

MIPI LLI

The MIPI LLI specification [3] was released in 2011, but we only have targeted specs. Its primary purpose was to allow sufficient performance to enable sharing a DRAM memory. The main motivation was electronic bill of materials (eBoM) cost reduction.

Round trip latency was targeted to be 80 ns using 8 pins in Gear 3. Unidirectional throughput is 2.9 Gb/s per lane using Gear 2.

UNIC

The Ultra-performance Nanophotonic Intrachip Communication (UNIC) [4] is a DARPA funded project that involves Sun/Oracle, Kotura and Luxtera. It started in 2008 and finishes in 2013. UNIC aims to achieve "unprecedented high-density, low-power, large bandwidth, and low-latency optical interconnect for highly compact supercomputer systems", considering both on- and off-chip communication. UNIC first-year achievements included a 320 fJ/bit hybrid-bonded optical transmitter and a 690 fJ/bit hybrid-bonded optical receiver. The project utilizes silicon photonics and assumes an external laser. In 2010, the power consumption target for 2012 was 300 fJ/bit, about two orders of magnitude lower than state-of-the-art optical transceivers.

UNIC builds on the success of a previous project called EPIC. A table showing some of the targets follows.

Device Example (w/drivers)		EPIC Demonstrated	UNÍC Requirements	Required Improvement
10+ Gb/s Modulator	Area	700 μm^2	28 μm^2	25 X
	Power	330 mW	0.8 mW	825 X
WDM Filter	Area	0.6 mm^2	0.005 mm^2	120 X
	Power	73 mW (tuning)	0 mW ?	???
10+ Gb/s Detector	Area	0.16 mm^2	0.01 mm^2	16X
	Power	36 mW	1 mW	36 X

Tab. 2: UNIC targets (taken from [5]).

In 2011, a 10 Gbit/s hybrid integrated silicon photonic transmitter and receiver interconnect system was presented by UNIC consortium members [6]. An off-chip laser source was used. For transmitter, a depletion racetrack ring modulator with greater than 25 pm/V EO efficiency from a CMOS compatible photonic foundry was developed. This device was hybrid integrated to a cascaded 2 V modulator driver in an advanced 40 nm CMOS process using 25 μm bonding pads, and 10 Gbit/s performance was demonstrated with better than 7 dB extinction ratio at a power consumption of 1.35 mW, or 135 pJ/bit in energy efficiency. Similarly, an SOI CMOS Ge waveguide PIN photodetector with 12 GHz bandwidth and 0.8 A/W responsivity was hybrid integrated with a low power receiver circuit in a 45 nm CMOS process to build an energy-efficient silicon photonic receiver. The resulting all-CMOS receiver achieved 17 dBm sensitivity for a BER of 10^{-12} at 10 Gbit/s. Careful sizing with accurate characterization of SNR resulted in a power consumption of 3.95 mW, or 395 fJ/bit.

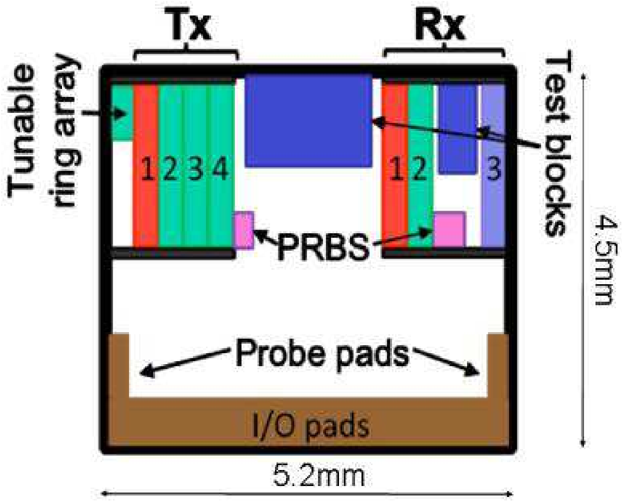


Fig. 5: Silicon photonics transceiver built by UNIC consortium (taken from [6]).

Comparisons: Electrical, Optical, Plasmonic Interconnects

In high power computing, data centers, and multicore processor-memory communication, data rates have been increasing due to increased needs and system scaling. This has been the best way to improve cost per transmitted bit [7]. Electronics has been dominating the industry for several decades now, but electrical interconnects are getting harder to design as needs increase (especially for data rates approaching or exceeding 10-25 Gbit/s); this is because of frequency-dependent losses (due to skin effect), crosstalk and frequency resonance effects [8]. Losses can be mitigated by using thicker wires, but this method worsens the wiring surface-area problem.

In the near future, very thick or multiple electrical wires may be able to cater for very short distances. However, these methods increase costs and also do not scale indefinitely. Wire thickness is eventually limited by chip size (see e.g. [9] for an argument of how required wire thicknesses exceed square centimeters(!) for petascale bandwidths); multiple thin wires are similarly limited by chip area and also by crosstalk between neighboring wires.

Optical interconnects [7, 10-12] allow for better signal integrity, reduced cable bulk for high data rates (e.g. an optical fiber with a diameter of more than 100 μm can transmit tens of Tbit/s), reduced electromagnetic interference for closely packed wiring, lower jitter, lower dispersion, simple impedance matching, speed-of-light signal propagation, and minimization of the needs for high-power equalization and pre-emphasis [7, 13-15]. This means that optical interconnects are especially fitting to cater for the 100s of Tbit/s off-chip bandwidths that will dominate systems in less than a decade [14].

Therefore, photonics is a good candidate to resolve the issues that electrical interconnects are facing as bandwidth needs increase. However, photonic devices are generally much bulkier than electronics. Photonics compactness is limited by the diffraction limit of optical signals, i.e. a signal of wavelength λ cannot be smaller than $\lambda/(2n)$ [16] in any dimension (where n is the refractive index of the material). For example, for transmission in glass (n=1.5) at telecom frequencies (λ=1550 nm), the signal in a conventional photonic device cannot be smaller than 0.5 μm in any dimension. Currently, photonic devices are typically much larger, but this is a hard limit that they cannot beat with conventional methods. According to the theory of diffraction, smaller wavelengths can lead to linearly more compact signals, but propagation losses increase significantly as we move to higher frequencies. If we compare this size with current dimensions of IC transistors (~ a few tens of nanometers), then it becomes evident that there is a size gap between electronics and photonics that makes their cooperation in integrated chips problematic.

Plasmonics [17-20] is a technology that can bridge the size gap between electronics and photonics. Plasmonic devices utilize surface-plasmon polaritons (SPPs) as signal carriers, i.e. charge-density oscillations at the interface between insulators and metals (or, to be more precise, between materials of positive and negative permittivity) that are induced by and coupled with electromagnetic waves. In effect, light can travel along such interfaces retaining all its advantages for communication applications. In addition, a major advantage of plasmonics is that SPPs are not bound by the diffraction limit. The size advantage of plasmonic devices over conventional photonics can be broken down to 2 distinct effects:

a) In transverse dimensions, SPPs can beat the diffraction limit and plasmonic devices can potentially reach sizes < 100 nm. Also note that signal compactness allows for devices that are closely packed together in integrated circuits without major crosstalk effect between neighboring waveguides.

b) Because of the strong light intensities caused by (a), plasmonic devices that utilize nonlinear effects can be shorter than their photonic counterparts.

Consequently, plasmonic devices can in principle beat conventional photonics in size by up to 2 orders of magnitude.

Yet, plasmonics retains other major advantages of photonics; the great bandwidths, speed-of-light transmission for reduced latency, and possibility for reduced power consumption. In addition, plasmonic devices offer a convenient practical solution for hybrid electrical/optical integrated circuits, as they utilize metals; these metals can be used to transmit both electrical signals and SPPs.

Note that the final benchmarking, along with the techno-economic evaluation, will take place in Task 2.4 in the last year of the project, as determined in Annex I of the proposal.

<u>System Definition and Requirements</u>

Definition and a detailed analysis of chip-to-chip interconnect requirements has been presented. In addition, an analysis has been presented on the future requirements of silicon devices that will host several processors and memory modules and will require high bandwidth and low latency interconnects. In D2.1, we analyzed the future requirements of high speed interconnects both in systems-on-chip (SoC) and systems-in-packages (SiP). Furthermore, we described the state-of-the-art solutions for these interconnects, such as electrical interconnects and silicon photonics, and we discussed the limitations of these solutions.

In particular, it was shown that on-chip performance has been increasing much more rapidly than off-chip communication bandwidth because both on-chip transistor density and clock frequency are increasing faster than off-chip input/output density and frequency. This difference occurs because off-chip bonding and wiring are about two orders of magnitude larger than on-chip wiring: on-chip wiring pitch is on the order of 1 micron, while off-chip wiring and ball-bond pitches are on the order of 100 microns. The performance gap between on-chip and off-chip bandwidth makes off-chip bandwidth a performance bottleneck. Advanced high speed interfaces handle the transfer of large amounts of data between embedded processor cores and main off-chip memories in digital multimedia applications. These approaches support hundreds of Gigabits per second of aggregate I/O bandwidth but they require high power consumption and large chip area occupation.

Industry needs and NAVOLCHI targets

The emerging field of plasmonics promises the generation, processing, transmission, sensing and detection of signals at optical frequencies along metallic surfaces, in dimensions much smaller than the wavelengths they carry. Plasmonic technology has applications in a wide range of fields, including biophotonics, sensing, chemistry and medicine. But perhaps the area where it will have the most profound impact is in optical communications, since plasmonic waves oscillate at optical frequencies and thus can carry information at optical bandwidths.

Industry needs have been partially covered in the “Comparison” section above. We will now add a few comments by industrial partner STMicroelectronics on the cellular industry - where time to market, cost, size and performance are primary drivers- as the cellular industry can be claimed to drive the electronics system market.

Beyond the miniaturization trend, talk and standby times have been key selling points for cellular phone manufacturers, driving the pressure on IC suppliers to offer highly integrated but low-power consumption devices that do not strain handset battery lifetimes. Cellular phones are becoming increasingly small, dense and power-hungry, offsetting the size and energy density advances offered by the lithium-ion battery sources powering them.

In short, battery development has not kept pace with Moore’s law and its subsequent power demands. As new applications and services become available, it is anticipated that the computing power available to incorporate into mobile devices will always be limited by finite power sources. As a consequence, mobile phone board designers are looking for every opportunity to save every milliamp of current in order to extend battery life as much as possible.

Another aspect to take into account is that both communications and digital IC technologies are moving progressively towards higher frequencies, such that the limiting factor for many wireless components is often the package parasitic effects, not the IC itself. Packaging parasitic factors can limit the frequency response or signal integrity of an otherwise robust design, preventing it from reaching its operation speed potential. Reducing inductance and capacitance of interconnections would help reduce time delays and improve electrical performance. Dielectric technology must then be chosen to ensure both low dielectric constant and low dielectric loss.

Combining what we have talked about in the "Comparison" and this section, and taking into account other important publications in the field, we can conclude the following:

Today

Bandwidth:

7.2 Gbit/s (see [21]).

Footprint:

In chip technology, it is important to try to bridge the size gap between electronics and photonics. In view of this, NAVOLCHI aims to produce plasmonic transceivers of size on the order of tens of μm^2. Typical photonic transceivers for chip interconnection are on the order of 0.1 mm^2 [12].

Power Consumption:

Optics may be able to save energy in interconnection because it is not necessary to charge the line to the operating voltage of the link [9]. To be competitive with the current state of the art in electrical off-chip interconnects, the system energy per bit should be ~1 pJ, and to offer sufficient energy advantage for optics, it should be ~100 fJ/bit or lower [9, 10]. Due to the huge power consumption in data centers, it has been argued in [9] that it would be very difficult to introduce a new technology for interconnection unless it is competitive in terms of low environmental impact.

Latency

8.8 ns @450 MHz clock [21]. Lower latencies are needed at higher clock rates.

In the Future

"The goal is propagating terabits/second at femtojoules/bit." [22]

Bandwidth:

230 - 780 Tb/s of off-chip bandwidth will be required in 2022 [9, 11]. In 2015, the need is for 82 Tbit/s.

Footprint:

Another important aspect of interconnects is the required interconnect density and the available (cross-sectional) area for it. The required number of channels is on the order of thousands to tens of thousands, assuming that next generation system architectures operating at data rates of 1’020 Gbit/s will require around 780 Tbit/s per chip [9, 12]. Given that one chip surface is typically used for heat removal, footprint should be as small as possible so that chip space suffices for 100s or 1000s of channels.

Power Consumption:

Presuming 50% of CPU power is in the interconnects, and taking the lower estimate of 27% of the server power in the CPU means that, in the United States, server interconnect power exceeded the total power generated from solar energy in 2007 [9]. To meet the demands of off-chip interconnects out to the ITRS projections of 2015, ~500 fJ/bit would suffice. In 2022, system energies per bit of 100 fJ/bit may be sufficient, but to sustain the number of bytes/FLOP in the later years will require 50 fJ/bit or lower system energy [9, 14]. Such system energy per bit argues for optical output device energies in the scale of 10 fJ/bit to a few tens of fJ/bit.

Latency:

Unclear. As low as possible in order to support increased performance and scalability.

Tab. 3 sums up requirements for chip-to-chip interconnects now and in the future. NAVOLCHI aims to achieve current targets and show potential for achieving future targets as well.

	Now	2022
Data Rate	7.2 Gbit/s/channel	230 – 780 Tbit/s
Latency	8.8 ns @ 450 MHz	?
Power Consumption	1 – 15 pJ/bit	50 – 100 fJ/bit
Footprint	~100 μm^2	subwavelength (device level)

Tab. 3: Requirements for chip-to-chip interconnects now and in the future.

The targeted specs are such that the final product a) fits the systems of industrial partner ST for consumer applications such as Set Top Box, HDTV, etc., and b) is competitive with respect to competing technologies.

Task 2.2 work progress

(Modeling of devices and system for communications application [M13-M36])

The aim of this task is to give device specifications for the novel disruptive plasmonic Si-photonic devices and its application in the chip-to-chip interconnection environment.

Subsystem considerations

Task 2.2 includes both system and subsystem considerations, i.e., initial definitions of the devices that will eventually make up the chip-to-chip interconnect transceivers. In this context, partners discussed and then contributed the targeted specs for the devices they are responsible for, under the prerequisites of the system requirements that had been set previously. In addition, open issues were narrowed down and technological decisions were made. Materials and architectures were set (e.g., gold is going to be the metal material for the amplifier) and the operating wavelength of the devices was narrowed down to the spectral region 1.5-1.55 microns.

Parameter	**Targeted Value**
SOI device layer thickness	220 nm
Silicon waveguide width	500 nm
Plasmonic slot width	50 nm
Distance *d*	75 nm
Angle θ	36°
Efficiency of a single coupler	87%

Tab. 4: Example of targeted device specs from deliverable 2.2. Shown are the targeted specs for the waveguide coupler.

The targeted specs for the devices were written down in Deliverable 2.2. Additional specs are given in the relative WPs of this report. Moreover, system simulations will take place so that the devices specs will converge to the desired system specs.

System perspective

Given the estimations for the achievable parameters on a device level, here are some notes on the system targeted specs and anticipated issues:

- Data Rate: 7.2 Gbit/s per channel seems achievable with no problems expected.

- Latency: The photodetector is currently expected to add huge delay (> 50 ns) to system latency, while the target is for 8.8 ns system latency. Ways to alleviate this problem are being looked into.

- Power Consumption: The modulator and the amplifier are expected to consume significant amounts of energy (15 and 10 pJ/bit, respectively, while the target is to reach 1-15 pJ/bit for whole system within project duration). Ways to alleviate these problems are being looked into. The amplifier may be left out of the final system if laser produces enough power to do without.

The actual interconnect system planned in NAVOLCHI and the expected level of integration is shown in the following figure. Note that there are 2 implementations considered (flip-chip connection and fiber connection) as well as a contingency plan.

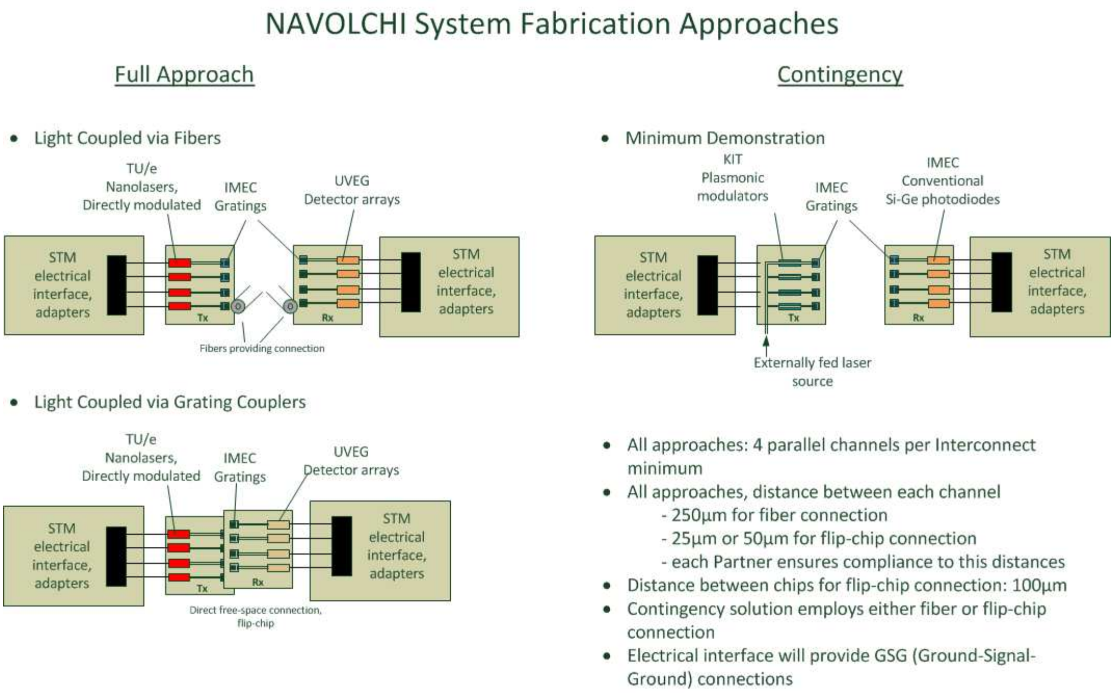


Fig. 6: The NAVOLCHI interconnect system.

The interconnect system will be simulated in VPI photonics, as presented in Milestone 3. An example of a simulation scenario is presented on Fig. 7.

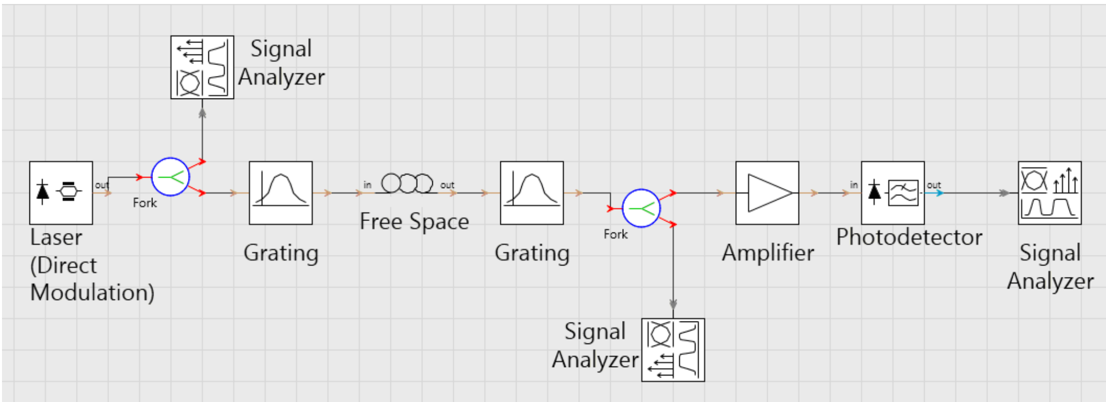


Fig. 7: Simulation scenario in VPI Photonics.

The first results of the simulations will be presented in D2.3 (month 24).

Task 2.3 work progress

(Value analysis in terms of cost and green aspects. [M25-M30])

This Task starts on month 25.

Task 2.4 work progress

(Techno-economical evaluation and benchmarking [M24-36])

This task starts on month 24.

Task 2.5 work progress

(VHDL modeling on plasmonic interconnect and CMOS interface circuits [M10-M24])

The objective of this task is the implementation of behavioral models of the plasmonic devices (emitter, detector, modulator, transmission medium) and the CMOS mixed analog/digital circuits responsible for interfacing the digital modules with the plasmonic devices.

Two important activities have been carried out so far in this context:

a) a Verilog-A training has been followed by Alberto Scandurra (ST) on January the $30^{th}/31^{st}$ at the Agrate site of STMicroelectronics;

b) the VHDL model of a configurable serializer/deserializer has been implemented .

Verilog-A is a Hardware Description Language (HDL) extending the classical Verilog language, specific for VLSI digital system, with capabilities for modeling analog electronic devices, as well as photonic, mechanical and thermal systems. This language will be used for modeling the plasmonic devices in terms of both functionality and physical effects conditioning their behavior (such as temperature variation impact on performance, etc.), and the analog electronic components allowing the digital electronic system to interact with the plasmonic devices, such as emitter/modulator driver, Trans-Impedance Amplifier (TIA), voltage level adjusters, and so on.

The serializer and the deserializer implemented in VHDL are parametric building-blocks, with configurable input and output size, allowing for getting in a fast and easy way a specific serializer/deserializer pair, already verified and characterized in terms of area occupancy and operation frequency. The parametric approach will allow for carrying out architectural exploration by simply changing the values of the parameters; for example, understanding, by means of simulation results, what is the optimum width of the off-chip data stream, what in turn determines the number of plasmonic emitter/modulator/detectors to be used in order to get specific performances.

The next step is to exploit Verilog-A language to implement the model of the required plasmonic devices and the analog electronic building-blocks, and integrate them together with the VHDL model of the serializer/deserializer in order to obtain complete interface circuits enabling the communication between digital systems exploiting the plasmonic physical layer.

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Deliverables until month 18

D2.1 Definition of chip-to-chip interconnection system environment and specification (month 3) – Completed.

D2.2 Definition of plasmonic devices (month 12) – Completed.

Upcoming deliverables

D2.3 Investigation of chip-to-chip interconnection-level specifications employing new plasmonic devices (month 24) – No delay expected

D2.4 Interface and plasmonic interconnect models and reports (month 24) – No delay expected

D2.5 Techno-economical evaluation with respect to the cost efficiency and green aspects (month 36) – No delay expected

Milestones until month 18

MS 1 Definition of chip-to-chip interconnection system environment and specification (month 3) – Completed.

MS 2 Definition of plasmonic devices and material properties for chip-to-chip interconnection (month 6) – Completed.

MS 3 Development of a system and device simulation platform (month 18) – Completed.

MS 4 Definition Derivation of the interconnection level specification (month 18) – Delayed (estimated date: July 2013)

Upcoming Milestones

MS 5 Digital domain to plasmonic domain interface specification and VHDL modeling (month 21) – No delay expected.

MS 6 Plasmonic interconnect VHDL modeling (month 24) – No delay expected.

MS 7 Investigation of the cost and power consumption efficiency of the developed plasmonic devices and systems (month 28) – No delay expected.

Use of resources

Use of resources has been according to plan. The table below gives a review of partners' contribution.

Partner	**Person Months**	**Main Contributions**
KIT	1.3	System design
IMEC	0	-
TU/e	2	Transmitter design
AIT	5.25	Device definitions, systems requirements, system design
UVEG	1	Receiver design
ST	4.5	System requirements, VHDL modelling, interface circuits
UGent	0	-

Tab. 5: Use of resources in work package 2.

3.1.3 Work Package 3: Plasmonic Transmitter

Task 3.1. Modelling of plasmonic laser and its coupling

It is one of the aims of WP3 to develop a laser with a metallic cavity coupled to a silicon waveguide. This report describes the design of a plasmonic and a metallo-dielectric laser, both coupled to an InP waveguide. For technological feasibility reasons, the laser is coupled as a first step to an InP waveguide on a silicon substrate. The coupling to a Si-waveguide will be done in a second stage, by tapering the InP-based waveguide to couple the optical mode down to an underlying Si waveguide. This approach to integrate III-V active devices with silicon waveguides has been recently demonstrated [1]. A detailed study of the laser modelling has been reported in deliverable 3.1.

Fabry-Perot plasmonic laser

The laser structure proposed is shown in Fig. 8, which is based on previously reported plasmonic lasers [2]. The laser consists fundamentally of a MISIM (metal-insulator-semiconductor-insulator-metal) waveguide forming a Fabry Perot resonator coupled to a dielectric waveguide, fabricated on an InP-membrane. The top n-contact and the lateral p-type contact provide the electrical pumping for the InGaAs active medium, which has a bandgap of $1.65\ \mu m$.

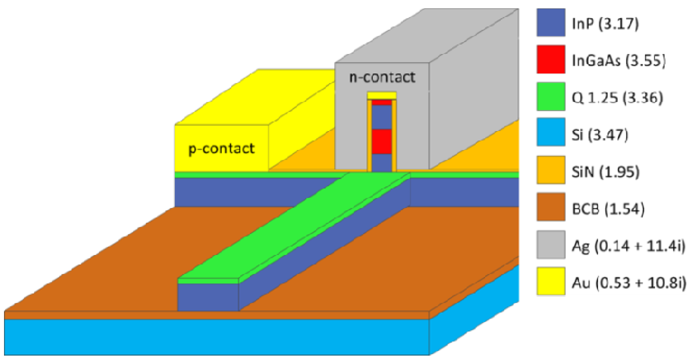

Fig. 8: Schematic representation of a plasmonic laser coupled to a dielectric waveguide. The refractive index of each material at $1.55\ \mu m$ is shown in parenthesis. Optical absorption in InGaAs has been neglected for the simulations.

As it can be seen in Fig. 8, there is a thin insulating layer of SiN between the semiconductor layer stack and the metal cladding, which serves to insulate the structure horizontally and therefore allow a top-down current flow. The quaternary ($Q\ 1.25$) layer acts as the ohmic contact layer for the p-contact. The back side of the Fabry Perot cavity is completely terminated by metal to achieve a strong reflection, whereas it has an open facet at the frontal end to improve the coupling.

The intensity distribution of the hybrid surface plasmon polariton mode with lowest loss in the cavity is shown in Fig. 9b. Due to its plasmonic nature, it has a dominant E_x component and is mainly confined within the insulation layer, which leads to a poor overlap with the active region. The structure geometry shown in Fig. 9a was optimized for a low modal loss and high waveguide coupling efficiency.

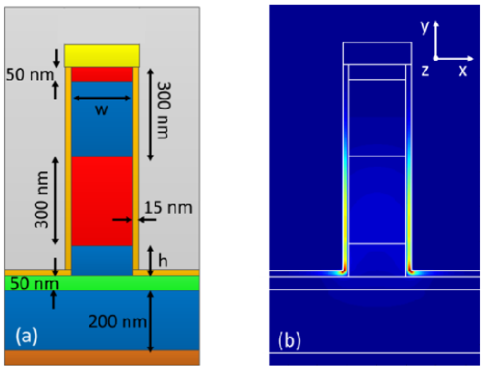

Fig. 9: (a) Cross section of the plasmonic laser cavity with the dimensions used for the simulations. (b) Optical intensity of the plasmonic mode at $1.55\ \mu m$. Blue: low intensity. Red: high intensity.

To estimate the threshold material gain g_{th} shown in Fig. 10, we obtained via simulations the propagation loss α, the confinement factor Γ, and the facet reflectivities R_1 and R_2. Lasing in a cavity with length L is achieved when

$$g_{th}\Gamma = \alpha + \frac{1}{2L} ln\left(\frac{1}{R_1 R_2}\right).$$

Fig. 10 shows both, optical and differential quantum efficiencies, as well as the threshold gain required to overcome losses. For example, assuming a laser length of $50\ \mu m$ and considering a cavity with $w = 200\ nm$ and $h = 100\ nm$, it gives $\alpha = 0.16\ dB / \mu m$, $\Gamma = 0.23$, $R_1 = 0.65$ and $R_2 = 0.98$, resulting in a threshold gain of $g_{th} = 1796\ cm^{-1}$ with only 5% of differential quantum efficiency, which is possible at room temperature under a high injected carrier density above $6 \cdot 10^{18}\ cm^{-3}$ [3].

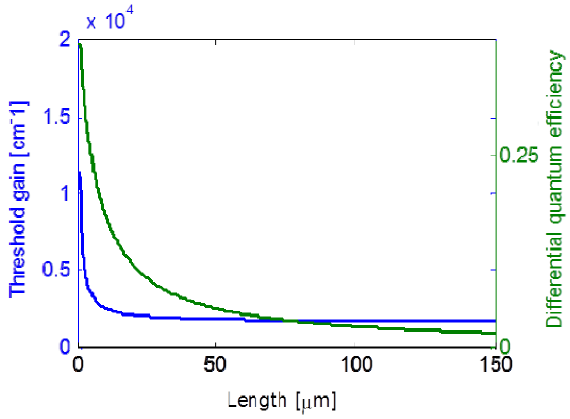

Fig. 10: Threshold gain and differential quantum efficiency assuming unity internal quantum efficiency.

Metallo-dielectric nanolaser

In this section, the design of a metallo-dielectric laser with higher performance is presented. The combination of dielectric and metallic confinement can lead to strong optical confinement of a dielectric mode with relatively low loss, and has been used to demonstrate room-temperature lasing in a subwavelength cavity [4]. However, efficient coupling to a waveguide has not been demonstrated yet. In Ref. [5] the coupling of a III-V metallo-dielectric nanopillar laser to a Si/SiO_2 waveguide was proposed. In this report, a metallo-dielectric cavity laser coupled to a waveguide on a III-V membrane bonded with BCB to silicon is described and studied.

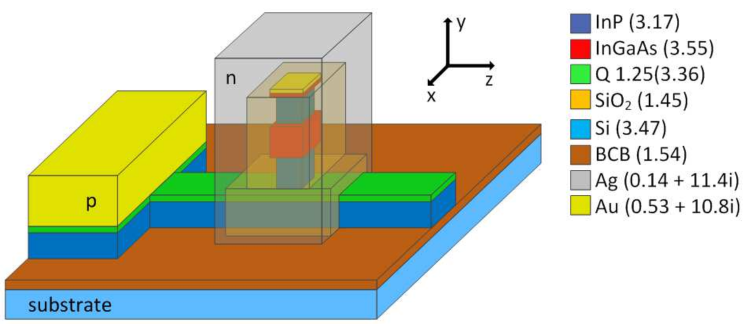

Fig. 11: Model of the metallo-dielectric laser coupled to an InP-membrane waveguide. The refractive index of each material at $1.55\ \mu m$ is shown in parenthesis.

The proposed laser structure is shown in Fig. 11. The semiconductor laser pillar lies on top of a thin InP waveguide and it is insulated with a SiO_2 layer from a metallic cladding. A lateral p-contact is electrically connected to the pillar through a highly p-doped quaternary (InGaAsP) layer. The metallic cladding acts itself as the n-contact allowing a top-down current flow. For simplicity, Fig. 11 does not show the ohmic contact layers Ti/Pt/Au, however they were included in the simulation model in order to account for their optical loss.

The optical design of the laser cavity and its coupling to an InP-waveguide was performed with three-dimensional finite-difference time-domain simulations. The cavity supports a TE-polarized mode with high quality factor. The optimized parameters are highlighted in Fig. 12a, where t is the SiO_2 dielectric thickness, h is the height of the InP bottom post and s is an undercut. A thick dielectric decreases the absorption into the metal, but also increases the radiative leakage due to a poor confinement. The bottom post controls the Q-factor as well as the coupling to the waveguide. A short post enhances the laser optical efficiency at the expense of a Q-factor decrease. The undercut is introduced to increase the Q-factor, while maintaining a relatively short post to simplify the fabrication process. The optimum values of these parameters were found to be $t = 175\ nm$, $h = 400\ nm$, $s = 60\ nm$. The detailed design is described in [6].

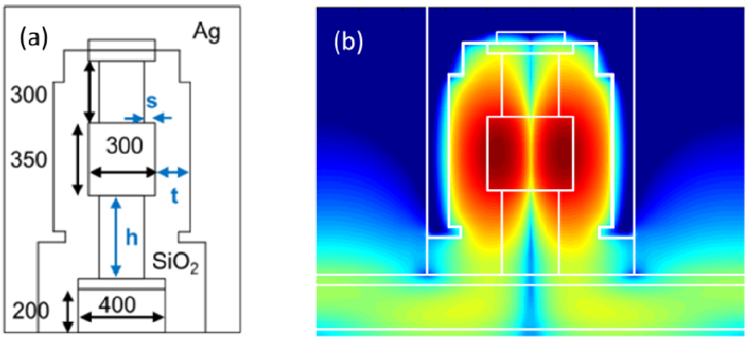

Fig. 12: (a) Transversal cross section of the parameterized cavity with dimensions in nanometers. (b) Colour plot of $\log(|E|^2)$ showing the coupling between the lasing mode and the waveguide along the longitudinal cross section.

After the optimization of a symmetric pillar cavity, the longitudinal dimension (along the outcoupling waveguide) of the pillar was increased to enhance the waveguide coupling, which in turns enhances the differential quantum efficiency. The differential efficiency is defined as the number of photons injected into the waveguide divided by the total number of photons generated in the cavity. Furthermore, the resonant wavelength can be adjusted, since it increases linearly with the cavity length. As it can be seen in Fig. 13, a cavity length of $400\ nm$ results in a resonant wavelength near $1.55\ \mu m$, a Q-factor exceeding 500 and a differential efficiency of 0.16. Considering a confinement factor of 0.33, the threshold gain is calculated to be $815\ cm^{-1}$, which is expected to be achievable at room temperature.

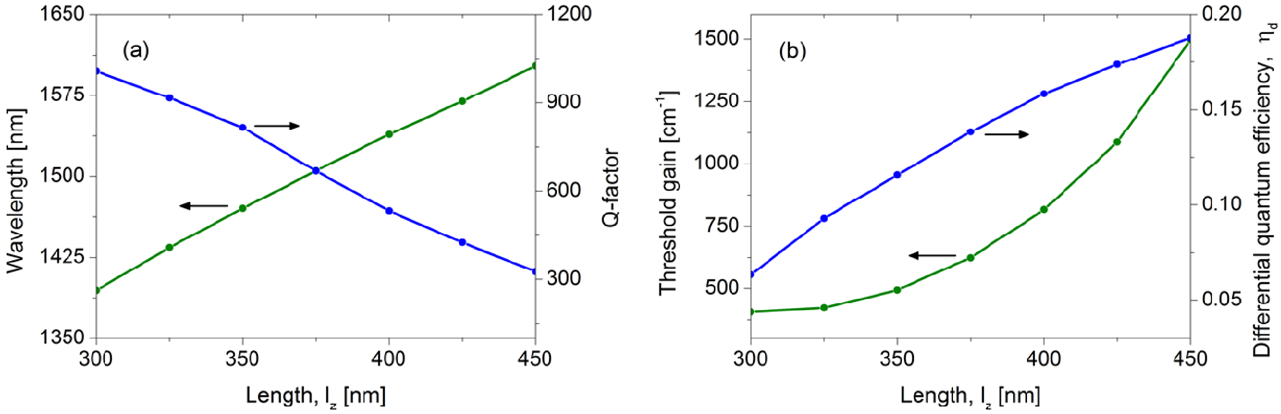

Fig. 13: (a) Resonant wavelength and Q-factor as a function of cavity length. (b) Threshold gain and differential quantum efficiency, assuming a unity internal quantum efficiency.

Electrical simulations were carried out with the self-consistent Poisson solver nextnano++ to determine the threshold current. A detailed description of such simulations can be found in [7]. Tab. 6 shows the semiconductor layer stack considered for the electrical simulations.

Thickness [nm]	Material	Doping [1/cm³]
50	n-InGaAs	$1\cdot10^{19}$
200	n-InP	$5\cdot10^{18}$
100	n-InP	$1\cdot10^{18}$
350	i-InGaAs	-
100	p-InP	$3\cdot10^{17}$
100	p-InP	$5\cdot10^{17}$
100	p-InP	$1\cdot10^{18}$
100	p-Q1.25	$2.4\cdot10^{19}$

Tab. 6: Semiconductor layer stack considered for electrical and thermal simulations.

Using nextnano++, the dependence of the Fermi levels in valence and conduction bands as a function of current density can be calculated. This allows to calculate the optical material gain with Fermi's golden rule at a temperature of $300\ K$ [8]. The resulting gain spectra are presented in Fig. 14a for current densities ranging from 20 to $200\ kA/cm^2$. The material gain at $1550\ nm$ is plotted in Fig. 14b as a function of the current density. The threshold gain of $815\ cm^{-1}$ determined by the optical simulations is reached with a current density of $100\ kA/cm^2$ corresponding to a threshold current $I_{th} = 120\ \mu A$ for the nanolaser with an active area cross section of $300x400\ nm^2$.

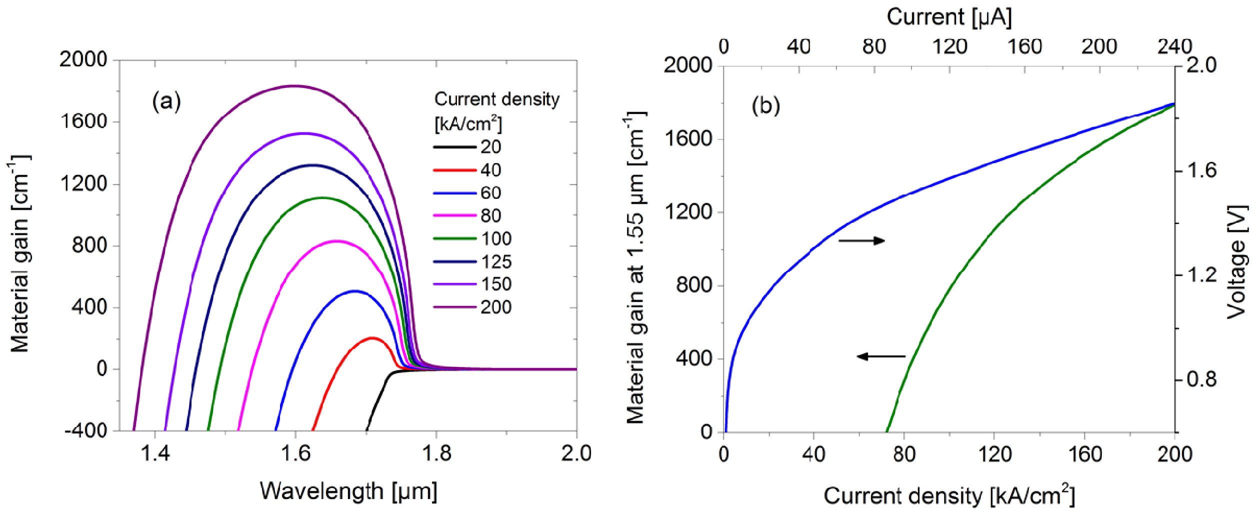

Fig. 14: (a) InGaAs material gain for different current densities. (b) Material gain at 1.55 µm and voltage through the device as a function of current.

The current-voltage characteristics of the diode are plotted in Fig. 14b. The device has a total resistance of $2.25\ k\Omega$. This is a combination of the p-side contact ($400\ \Omega$), where the current is transported in a $100\ nm$ thin quaternary layer on top of the waveguide, the p-doped region of the laser diode ($1000\ \Omega$) and the ohmic contact on the n-doped side of the pillar ($850\ \Omega$), where we assume a contact resistance of $1 \cdot 10^{-6}\ \Omega cm^2$. When driving a current through the device the high resistive regions contribute to heat generation as it is shown in the inset of Fig. 15, while the optical absorption in the metal coating of the cavity can be neglected.

If no self-heating is considered, the optical output power grows linearly with the drive current I as $P_{out} = \eta_d (I - I_{th})\, hc/\lambda e$ as it is plotted in Fig. 15. Here, $\eta_d = 0.16$ is the differential quantum efficiency and $I_{th} = 120\ \mu A$ is the threshold current for an emission wavelength of $\lambda = 1.55\ \mu m$. Fig. 15 also shows the temperature in the laser as a function of the drive current for one laser per 800, 1500, and $3000\ \mu m^2$, calculated with a three-dimensional finite element model. To calculate the laser temperature we assume packaging with a high performance heat sink as described in reference [9] with a junction-to-ambient heat transfer coefficient of $7000\ W/(m^2\ K)$. In the linear model, an optical output power of nearly $40\ \mu W$ is reached for a current of $425\ \mu A$ and a voltage of $1.98\ V$ corresponding to an efficiency of 4.8%. In a real laser device, the self-heating produces a clamp in the output power. Additionally, since the heat dissipation in realistic packaging is limited, a compromise between integration density and available optical power will need to be found. Fig.

16 shows the temperature increase in the laser core as a function of the integration density for a fixed output power.

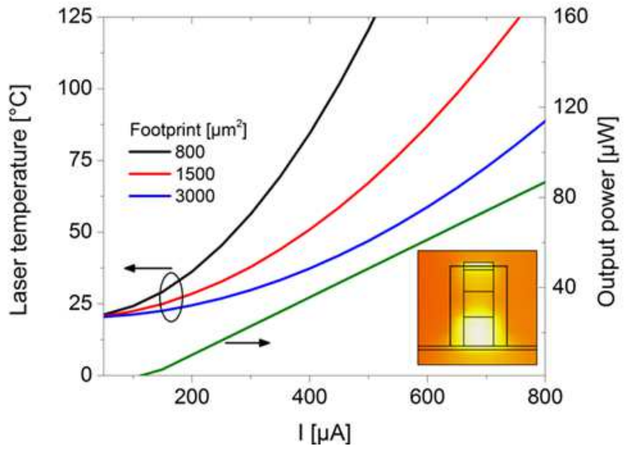

Fig. 15: Laser temperature and estimated output power as a function of drive current. The inset shows a colour plot of the temperature distribution in the cavity. White: high temperature. Orange: low temperature.

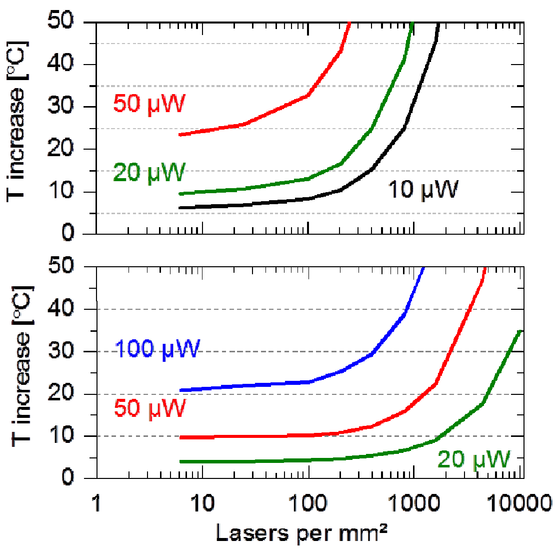

Fig. 16: Temperature increase in the laser core as a function of integration density. Top: assuming fan cooling (7 mW/mm^{2}K [9]). Bottom: assuming water cooling (95 mW/mm^{2}K [10]).

The design of a metallo-dielectric nanolaser was presented. Optical, electrical and thermal simulations were carried out to predict the performance of such a laser, resulting in a cavity Q-factor of 532 with a threshold gain of 815 cm^{-1} and a threshold current of 120 μA. Using a high performance heat sink, output powers of 40 μW seem feasible at a voltage of 1.98 V and a current of 425 μA. A compromise between the device footprint and the maximum output power was identified. This laser device was the design of choice to fabricate since it offers a better performance while maintaining reduced physical dimensions.

Task 3.2. Modelling of Si-plasmonic modulators

The plasmonic phase modulator consists of two metal taper couplers and the metallic slot waveguide in between, see Fig. 17. The metallic slot is filled with electrooptic polymer with an electrooptic coefficient of r_{33} = 70 pm/V. Light guided through the silicon nanowire is adiabatically squeezed into the metallic slot waveguide where the phase of SPP is modulated by the voltage applied between two electrodes. Details of the modelling of the plasmonic modulators can be found in the Deliverable 3.2 and Milestones MS9, MS11 and MS12.

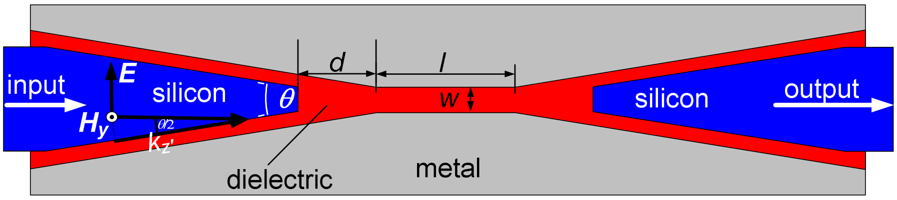

Fig. 17: Design of the plasmonic phase modulator. Light guided through silicon nanowire is adiabatically squeezed and launched into metallic slot waveguide.

Integration of the plasmonic phase modulator in a system can be done in two different scenarios employing either a Mach-Zehnder-Interferometer or a ring resonator, see Fig. 18. In both scenarios, the phase-keyed signal after the plasmonic phase modulator is converted to an intensity modulated signal which can be detected by the photodetector in the receiver side. Both integration architectures and their influence on the entire system performance will be studied within the task 2.2 of WP 2.

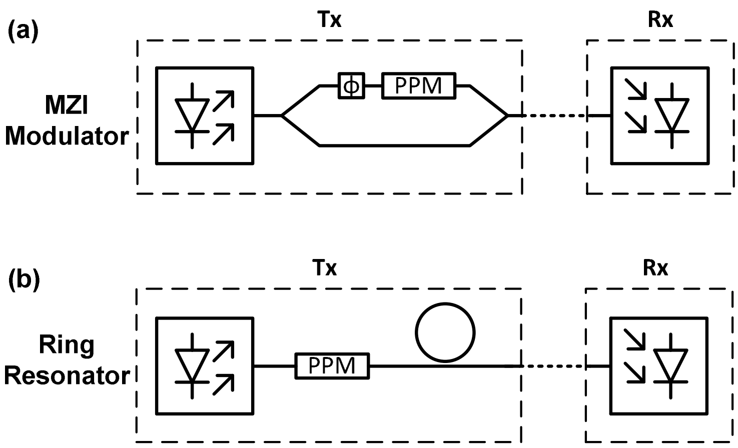

Fig. 18: Integration of the plasmonic phase modulator (PPM) in a system. Using either a Mach-Zehnder-Interferometer (a) or a ring resonator (b), the phase-keyed signal after the PPM is converted to an intensity modulated signal for direct detection with a photodetector.

Task 3.3. Fabrication of plasmonic/metallic laser

The device fabrication consists in a complex series of steps. It involves different processes, such as: electron beam lithography, optical lithography, plasma-enhance chemical vapour deposition techniques, reactive ion etching processes, wet-chemical etching, thermal and electron-beam evaporation of metals, rapid thermal annealing, etc. Among the most critical steps are: the vertical etching of the pillar cavity, the creation of an undercut to achieve high cavity Q-factor and the alignment of the overlay lithography to fabricate the laser pillar on top of the waveguide.

Initial fabrication runs carried out to find suitable lithographic processes to fabricate the most critical structures in the laser device (i.e. the waveguide and the nanopillar). Two different masking schemes were determined to properly etch these structures in InP wafers. Later, these processes will be used to fabricate the device in a III-V wafer with the real layer stack. Fig. 19 shows a picture taken with a scanning electron microscope of our current efforts to fabricate the device.

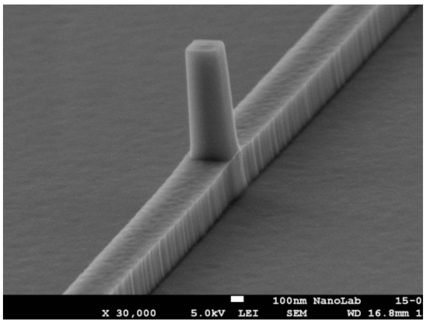

Fig. 19: InP-semiconductor pillar on top of an InP-waveguide structure.

In order to start with the fabrication of the metallo-dielectric laser in a wafer with the real layer stack, a III-V wafer was grown as reported in Milestone 10. Its growth was carried out with metalorganic vapour phase epitaxy. Tab. 7 shows the details of its layer stack.

Material	Thickness [nm]	Doping
InP	50	N > $5x10^{18}$
InGaAs	50	N > $1x10^{19}$
InP	100	N > $5x10^{18}$
InP	100	N = $5x10^{18}$
InP	100	N = $1x10^{18}$
InGaAs	350	n.i.d.
InP	100	P = $3x10^{17}$

InP	100	P = $5x10^{17}$
InP	50	P = $1x10^{18}$
Q 1.25	50	P = $2.4x10^{19}$
InP	100	P = $1x10^{18}$
InP	100	n.i.d.
InP	Substrate	n.i.d.

Tab. 7: Layer stack of the wafer indicating materials, thicknesses and doping levels.

Among other experimental activities that have been performed, the silver annealing has been investigated to produce a more homogeneous silver. Its annealing is important to increase the grain size since a non-homogeneous metal (i.e. small grain size) will result in high metal loss. Fig. 20 shows the result of the silver annealing optimization carried out to produce silver layers with larger metal grains. The thickness of the metal is not a fundamental problem for the device operation, since the light at 1.55 µm cannot penetrate more than tens of nanometers into it, but a more practical issue, nevertheless metal layers thinner than 1 µm with acceptable homogeneity seem feasible.

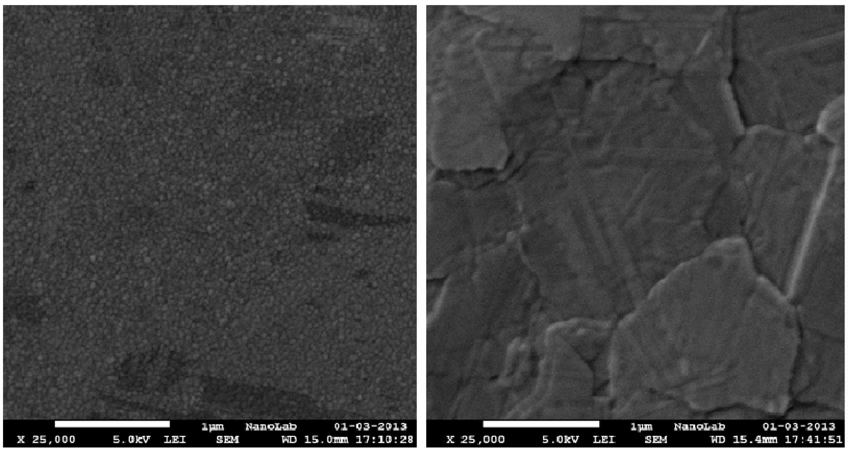

Fig. 20: Silver depositions on flat samples by electron-beam evaporation. Left: sample without annealing. Grains of about 30 nm are formed during Ag deposition. Right: sample annealed with optimized recipe to form grains larger than 1 µm.

Task 3.4. Fabrication of Si-plasmonic modulators

Fabrication of the plasmonic phase modulator consists of 3 main steps:

1) Fabrication of passive silicon on insulator platform
2) Fabrication of the metal taper couplers and the metallic slot waveguide by standard lift-off process

3) Coating with electrooptic polymer

IMEC has fabricated the passive silicon on insulator chip designed by KIT. Last two steps of the fabrication have been completed by KIT. The optical microscope image of an array of the plasmonic phase modulators with various lengths are given in Fig. 21. The photograph is taken before coating with electrooptic material. The scanning electron microscope picture of the 1µm long device is given as an inset.

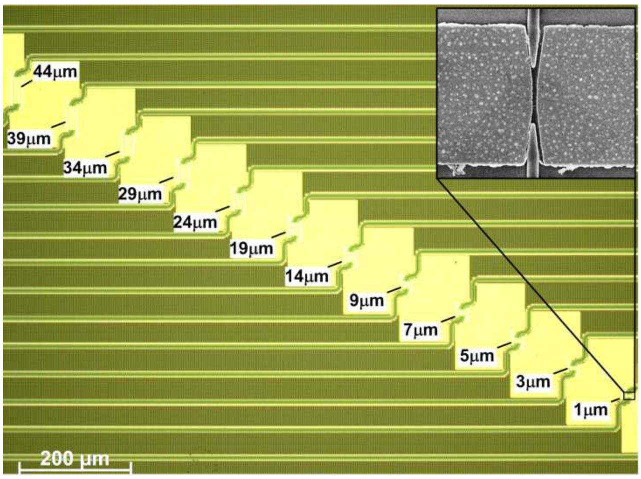

Fig. 21: The optical microscope image of the plasmonic phase modulator with various lengths

We characterized the electrooptic response of the modulators by measuring the modulation index for driving RF sinusoidal signal with 0.8 V amplitude and a frequency of f_m = 1…45 GHz. *The results are presented in the WP6 part of the current report.*

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[9] B. Guenin, “Thermal Interactions Between High-Power Packages and Heat Sinks”, Electronics Cooling, 16(12), 2010.
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Deliverables in first reporting period (month 1 – month 18)

Deliverable	Name of deliverable	Responsible partner	Delivery date
D3.1	Report on studies of optimized structure for metallic/plasmonic nano-laser and its coupling to Si waveguide	TU/e	10/2012
D3.2	Report on modelling of the modulator structure	KIT	10/2012

Upcoming deliverables

Deliverable	Name of deliverable	Responsible partner	Delivery date
D3.3	Fabrication of plasmonic laser device	TU/e	10/2013
D3.4	Report on fabrication of modulators	KIT	10/2013

Milestones in first reporting period (month 1 – month 18)

Milestone	Name of milestone	Responsible partner	Delivery date
MS8	Decision on an optimized structure for metallic/plasmonic nano-laser and its coupling to Si waveguide	TU/e	04/2012
MS9	Decision on an optimized structure for plasmonic modulator.	KIT	04/2012
M10	Grown wafer structure for plasmonic	TU/e	10/2012

	lasers		
M11	Fabrication of plasmonic modulator on a SOI platform	KIT	01/2013
MS12	Decision on an optimized structure for plasmonic modulator with a maximum loss of 20dB	KIT	04/2013
MS13	Initial characterization of unbounded plasmonic lasers	TU/e	04/2013

Upcoming Milestones

Milestone	Name of milestone	Responsible partner	Delivery date
MS14	Initial testing and characterization of plasmonic modulators	KIT	07/2013
MS15	Initial testing of bonded plasmonic laser	TU/e	10/2013

Use of resources

Use of resources has been according to plan. The table below gives a review of each partners contribution.

Partner	Person months	Main contribution
TU/e	14.7	Modelling and fabrication of metallo-dielectric nanolaser
KIT	25.4	Modelling and fabrication of plasmonic modulator
IMEC	0.8	Bonding of III-V wafer to silicon wafer

Tab. 8: Use of resources in work package 3.

3.1.4 Work Package 4: Plasmonic Receiver

Task 4.1 Design and modeling of plasmonic pre-amplifier

a) Polymer based version

The work started simulating symmetric (PMMA-Au-PMMA) and asymmetric (PMMA-Au-SiO_2) plasmonic waveguides, and the effect of considering gain in the dielectric. The simulation consists of finding the modes able to be propagated in the structures in TE and TM polarizations, and in particular the Surface Plasmon Polariton (SPP) which only can be propagated in TM. Then, the work is extended by considering a complete structure with a Si substrate and air. So, the waveguides analysed up to now are:

- 1D asymmetric IMI waveguide asymmetric (PMMA-Au-SiO_2) and (PMMA-Au-PMMA).
- 1D symmetric IMI waveguide asymmetric (Fig. 22a) and symmetric (Fig. 22b) with semiinfinite Si and air layers on the top and the bottom.
- Effect of gain in the PMMA by doping the polymer with colloidal QDs.
- Bilayer structure on the top of the gold (Fig. 22c) composed by thin a nanocomposite and a PMMA.
- 2D rectangular waveguide to simulate metal stripes and dielectric loaded waveguides.

The following methods were utilized for modelling:

- Müller's method for 1D structures for waveguides with three layers.
- Graphical methods in order to ensure that Müller's method converges to the desired mode.
- Transfer matrix method for 1D structures with an arbitrary number of layers.
- Finite Difference Frequency Domain (FDFD) method for simulation of 2D structures.
- A modified Effective Index Method (EIM) for 2D geometries.

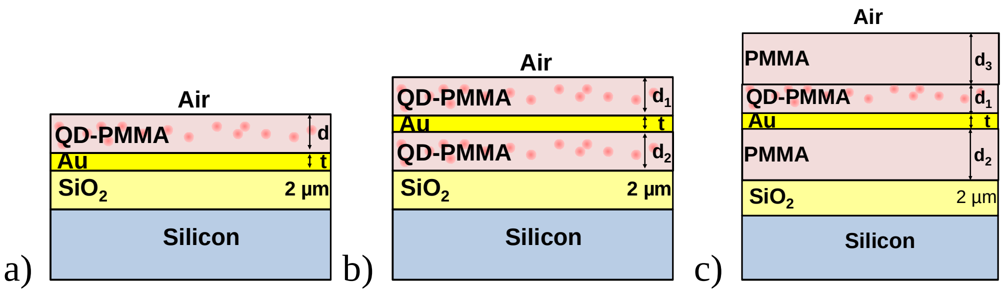


Fig. 22: Design of plasmonic amplifiers. a) Asymmetric waveguide. b) Symmetric waveguide. c) Symmetric waveguide with a cladding.

Two operation wavelengths have been tested. First, waveguides were analysed at 600 nm as a probe of concept because the gain and plasmonic propagation at 1550 nm is more challenging. Then, the work has been extrapolated to IR wavelengths.

Key findings:

- At 600 nm asymmetric structure seems to be optimum, while at 1550 nm the symmetric one becomes necessary.
- A gold thickness of 30 nm is good compromise between propagation lengths and mode confinement.
- In asymmetric and symmetric structures the dielectric layers should be chosen to avoid high order TM modes: 1 µm at 600 nm and 3 µm at 1550 nm.
- A gain of 12.1 cm^{-1} can compensate the losses at 1550 nm.
- A bilayer waveguide structure can improve the pumping conditions and the integration of the device, because it allows the coupling of the pump beam from the input edge of the sample.
- 2D waveguides are expected to improve the mode confinement. They are now under study.

b) Hybrid silicon plasmonic amplifier

A hybrid silicon-plasmonic amplifier is also contemplated in WP4 as an alternative to the polymer amplifier. The structure consists of a silicon waveguide with a stack consisting of insulating AlOx layers with embedded quantum dots and an Au layer on top. This gold layer has a dual function: through the plasmonic effect it concentrates the light in the quantum dot layer and at the same time it allows to apply an electric field over the quantum dots, allowing for electrical pumping of the

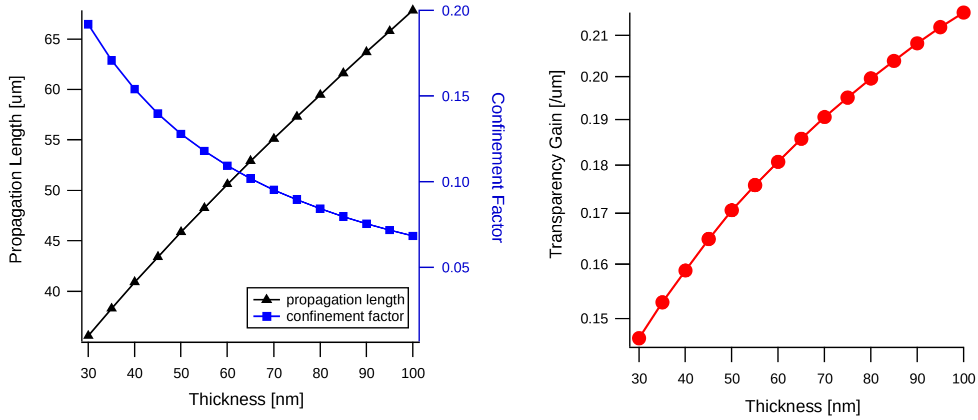


Fig. 23: Simulation output (at 1550 nm) for hybrid Au/Silicon waveguide: (left) propagation length and confinement factor and (right) transparency gain for varying slot thickness.

quantum dots (AC injection, see previous report). The most important parameters of the structure were scanned (width, influence of etch depth, layer thickness) and their effect evaluated. A detailed description is given in deliverable D4.1. Some typical results are given in Fig. 23. This input was used for realizing mask sets for the fabrication of the hybrid silicon plasmonic amplifier.

Task 4.2 Modelling of plasmonic QD polymer based photodetectors

Most of the modelling work on this WP4 was concentrated on plasmonic amplifiers and experimental optimization of photodetection materials. Attending to optical properties of PbS QD layers (absorption coefficient in PbS layers in the range 3000-4000 cm^{-1} at the ground exciton transition) and experimental quantum efficiencies (EQE ≈ 10^{-3}) in Schottky photodiodes, one could deduce that thicker layers (> 1 μm) are needed to increase significantly EQE, even if also needed to obtain a QD-solid with higher carrier mobilities.

Plasmonic effects in nanogap devices are being modelled at the moment, as the strategy to increase photoconductive gain by the electromagnetic field enhancement.

Task 4.3 Colloidal quantum dots with optimized gain and electrical injection scheme

a) Synthesis of PbX/CdX heterostructures by cationic exchange

Cationic exchange: from CdS QRs into PbS QRs. Initial CdS rods are prepared by a seeded growth method. The exchange into PbS rods is done in two steps. In the first step, CdS rods are mixed with a Cu (I) salt dissolved in methanol. A Cu^{+}:Cd^{2+} excess of 20:1 is used. The reaction is performed inside a nitrogen-filled glovebox at room temperature. After washing the sample, the Cu_2S rods obtained are transformed into PbS rods by injecting a mixture of lead acetate and tri-n-butylphosphine. The final product is washed twice with methanol and stored in toluene under vacuum.

PbS/CdS multiple dot-in-rod synthesis. PbS QRs synthesized as outlined above are exposed to a solution of Cd oleate in toluene at 65°C for 1 hour. This initiates a cationic exchange reaction where Pb cations are replaced by Cd cations. The resulting heteronanostructure features a series of multiple PbS dots in a single CdS rod and can have – depending on the synthesis conditions – photoluminescence quantum yields of 45-55%.

Fig. 24 gives an overview of the full procedure. Samples of prepared particles have been delivered to UVEG and IMCV.

Other PbX/CdX (X=S,Se) hetero-nanostructures. A similar procedure can be used to form PbSe/CdSe multiple dot-in-rods or the form a CdS nanorod with a single PbS quantum dot at its end.

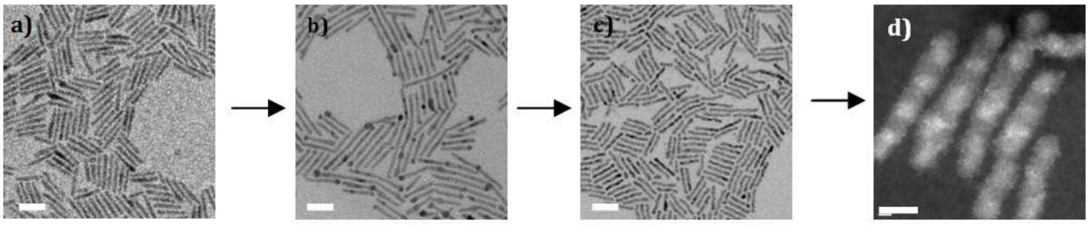


Fig. 24 TEM overview images of the different steps of the cationic exchange procedure. a) CdS initial rods. Scale bar 20 nm. b) Cu2S rods. Scale bar 20 nm. c) PbS rods. Scale bar 20 nm. d) STEM-

HAADF image of PbS/CdS multiple dot-in-rods, showing the PbS dots as bright spots relative to the background of the CdS rod. Scale bar 5 nm.

b) Light absorption in hybrid silicon-on-insulator/quantum dot waveguides

To fully understand the interaction of colloidal quantum dot layers with silicon waveguides, we analyzed the absorption coefficient of planarized silicon-on-insulator waveguides coated by close packed mono- and multilayers of colloidal PbS/CdS quantum dots (QDs), as shown in Fig. 25. The results are discussed in detail in D4.2. Experimental data clearly show the influence of the QDs on the waveguide absorbance around 1500 nm, where we find that QDs absorb stronger in thicker layers (Fig. 26a). To simulate the absorption coefficient of QD functionalized waveguides, the QD layer is replaced by an effective medium with a dielectric function determined by dipolar coupling between neighbouring QDs (Fig. 25). Using the host dielectric constant εh as an adjustable parameter, excellent agreement with the experimental results is obtained. In this way, the increase in absorption cross section with layer thickness can be traced back to an increasing εh (Fig. 26b). This reflects the decreasing influence of the surroundings on the εh, which therefore evolves from an extrinsic property for monolayers to a more intrinsic film property for multilayers. The results of this study were submitted to Phys. Rev. This model helped us better understand the interaction between closed packed quantum dot layers and silicon waveguides and was used as input for improving the design of the hybrid silicon-plasmonic amplifier (Task 4.1, D4.1).

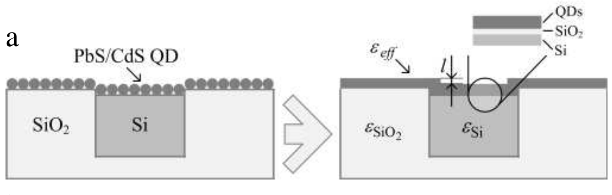


Fig. 25: Schematic representation of the replacement of the real QD film on top of an SOI planarized waveguide by an effective medium. Indicated are the height difference *l* between the top surface of the PWG and its silica cladding and the native silica layer in between the PWG top surface and the effective medium representing the QD film.

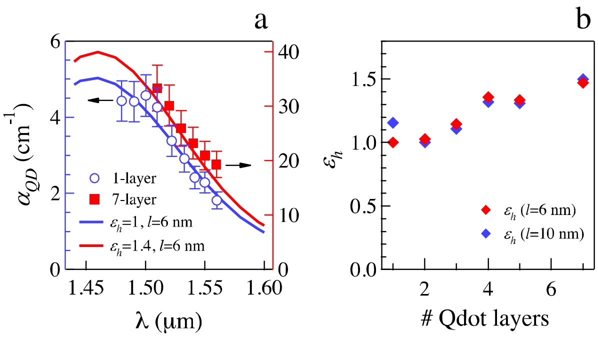


Fig. 26: (a) Comparison of the experimental and simulated αQD spectrum of a silicon waveguide coated with (blue) a QD monolayer and (red) a QD seven layer. The respective axes are scaled by a

factor of 7 to allow for a direct comparison of the absorbance per number of layers. (b) Evolution of εh values needed to match experimental and simulated absorption co-efficient calculated for the extreme case of (red) l = 6 and (blue) l = 10 nm.

c) Gain characterization in solution

In collaboration with the TU Delft (Delft, Netherlands, Prof. L. Siebbeles, Dr. A. Houtepen) white-light transient absorption spectroscopy was used to characterize the ultrafast optical properties of the nanorods developed in task 4.3.a. Samples were prepared under nitrogen at band gap optical densities of 0.1. The samples are pumped at 700 nm under varying laser fluence. Due to the large absorption cross section of the nanorods typical excitation densities are higher than 1 exciton per particle.

A typical near-infrared difference spectrum is shown in Fig. 27a below. We can distinguish a region of bleach (blue) and of photo-induced absorption (red). Typical picosecond time-scales are indicative of fast multi-exciton decay. Spectral cuts were taken at 3 ps (just after excitation from the pump) and 3 ns. We can see the initial broad bleach band decays to an absorptive background after all multi-excitons have decayed.

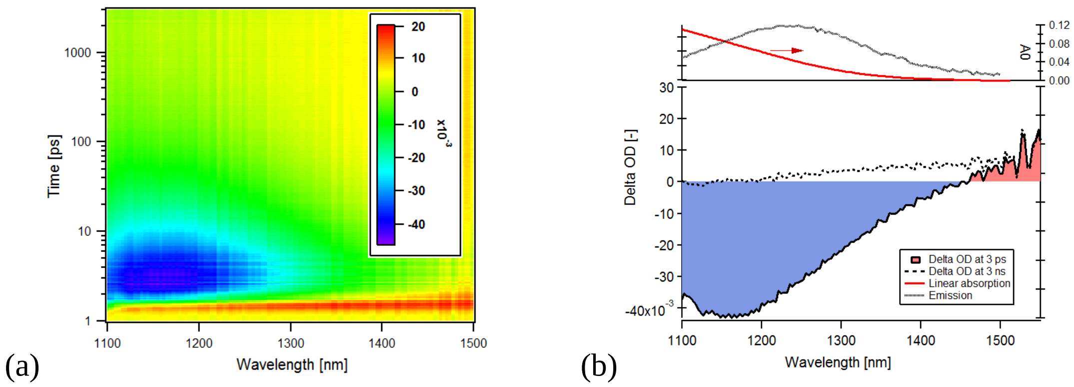


Fig. 27: (a) differential spectrum as a function of time for 4 x 12 nm nanorods. (b) spectral cuts at 3 ps and 3 ns compared to linear absorption and emission spectrum.

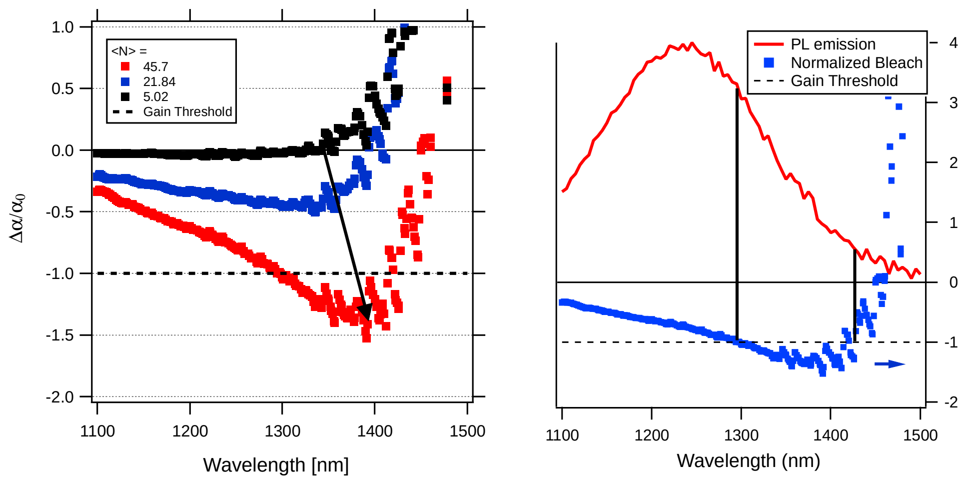


Fig. 28: (left) Normalized bleach spectrum for short PbS nanorods under different excitation fluences, expressed in absorbed pump photons per nanorod <N>. The spectra are obtained 2.5 picoseconds after photo-excitation at 700 nm. (right) Normalized bleach spectrum with gain band extrapolated to steady state photoluminescence spectrum.

Of all samples investigated, only the short rods show optical gain, i.e. normalized bleach $\Delta\alpha = \frac{\alpha}{\alpha_0} - 1$ below -1. A typical (normalized) bleach spectrum is shown in Fig. 28. However, we only cross the transparency threshold under extremely high fluence laser excitation. Moreover, the transparency only lives for ca. 10 ps (see Fig. 29). The normalized bleach spectrum indicates that optical gain develops on the low energy side (longer wavelengths) of the steady state emission spectrum. This correlates to a fine structure splitting, where carriers would indeed cool to the lowest energy states, yielding the bleach at the low energy side of the spectrum. We do not observe a decrease in gain threshold value, nor a significant shortening of the Auger lifetime.

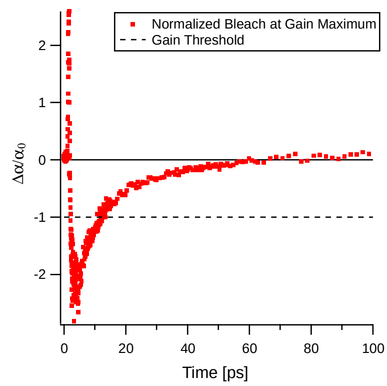


Fig. 29: Normalized bleach as a function of time (or equivalent probe delay) for a fluence of 56 absorbed photons per nanorod.

Gain characterization in dielectric films

The gain of the different nanoparticles has been measured by fabricating dielectric waveguides spin coating the nanocomposite (polymer+QDs) on a SiO_2/Si. Tab. 9 summarizes the different semiconductor nanostructures studied up to now with its absorption and emission wavelengths. The work started with CdSe spherical QDs with emission at 600 nm. These QDs had a reduced Stokes shift and hence it was difficult to obtain net gain due to reabsorption effects. Core-shell QRs have a large Stokes-shift and could provide such a gain. Then, different types of QRs (PbS-CdS, PER, PbS-CdSe) with emission in the IR have been tested, taking spherical PbS QDs for comparison.

Nanoparticle	λ_{abs} (nm)	λ_{PL} (nm)
CdSe QDs (UVEG)	580	600
PbS QDs(UGent)	1490	1500
PbS/CdS QRs(UGent)	600	1300
PERQRs(UGent)	450	1200
PbS/CdSe QRs(UGent)	1200	1500

Tab. 9: Colloidal nanoparticles.

Gain and losses of nanocomposite films were characterized with Variable Length Stripe method (described in D4.1). For all nanostructures PL intensity increases with stripe excitation length and then it arrives to saturation for stripe lengths close to 300 µm. This behaviour can be modelled considering an exponential dependence in the gain (see D4.1). It is important to note that gain increases with the concentration of the nanoparticles in the polymer. However, in the case of spherical QDs losses increase in a similar proportion due to reabsorption effects and hence net gain is practically zero. A first strategy to avoid reabsorption losses is the use of semiconductor nanostructures with large Stokes Shift like QRs (see Tab. 9). Fig. 30 shows the gain and losses characterization in samples with PER-QRs dispersed in PMMA with two different concentrations. For the largest QR concentration, the growth of the PL intensity until a stripe length ≈ 300 µm is represented by $g_0 \approx 300$ cm^{-1} (Fig. 30a), whereas losses are not too high, $\alpha \approx 50$ cm^{-1} (Fig. 30b). A similar behaviour is observed for PbS-CdS and PbS-CdSe QRs for which we deduce $g_0 \approx 180$ and 350 cm^{-1}, respectively, for similar filling factors as in the case of PER-QRs, whereas losses are slightly larger ($\alpha \approx 70$ and 150 cm^{-1}, respectively). These results are discussed in more detail in D4.2.

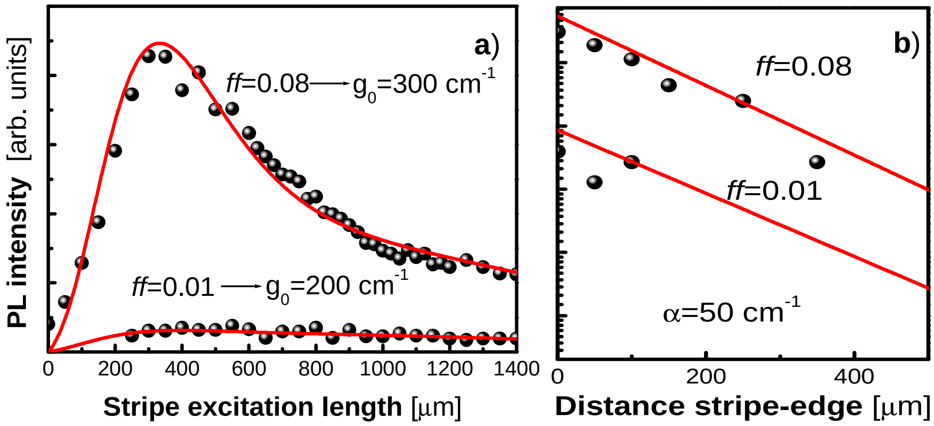


Fig. 30: (a) PL intensity as a function of the stripe excitation length for two different filling factors of PER QRs in PMMA. (b) PL intensity as a function of the distance between the stripe and the edge of the sample for the same samples. The values of g0 and α are indicated in the figures.

Task 4.4 Fabrication and characterization of QD-based plasmonic amplifiers

a) Polymer based version

Gain and losses of plasmonic waveguides were investigated with the variable stripe length method (more details on results and discussion is presented in D4.1). According to the modelling, the waveguides working in the visible (600 nm) were prepared by using the asymmetric structure (Fig. 22a) with $d_1=1\ \mu m$ and $t=30\ nm$. Fig. 31 shows the gain and losses measured under TM polarization (that propagating the SPP) in samples with different filling factors of CdSe in PMMA. Again PL intensity increases with the stripe excitation length before saturating for lengths of about 300 µm, but for these samples the PL intensity growth is sharper than that observed in dielectric waveguides, probably due to the reflection of the pump beam by the gold layer. Again, losses increase with concentration due to reabsorption avoiding their use for amplification purposes. In any case, these results are useful to study the coupling of the light to the SPP and test the designs. It is worth noting that losses are bigger in TM than TE due to the fact that the SPP mode is centred at the gold layer, whilst the dielectric TE modes are centred at the dielectric active layer, where losses are less important. Fig. 32 shows the pump beam (blue) and PL (red) under TE and TM polarizations at the output edge of the waveguide when the samples are pumped using the VSL method. On the one hand, the pump beam seems to be coupled to TM mode probably due to scattering by the gold surface roughness. On the other hand, the PL is coupled to both polarization modes, but TM mode exhibits a narrower cross section, accordingly to the influence of the SPP propagation on this mode.

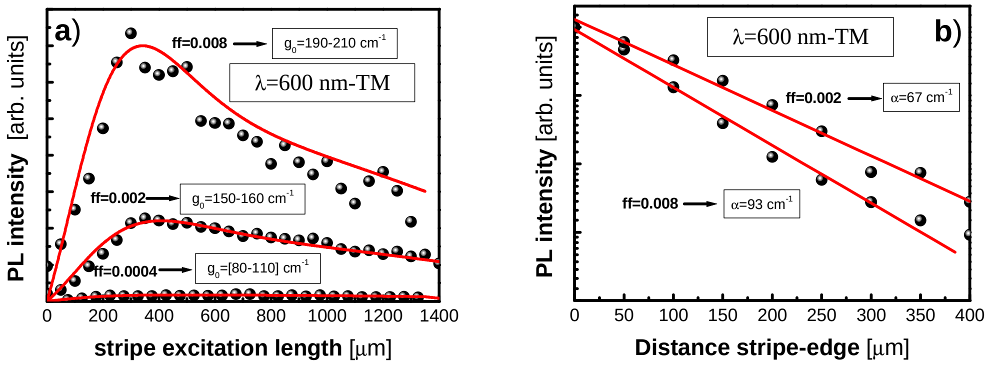


Fig. 31: a) PL as a function of the stripe length. b) PL as a function of the distance between the edge of the sample and the stripe (kept constant). Graphic refers for TM polarization and three different filling factors.

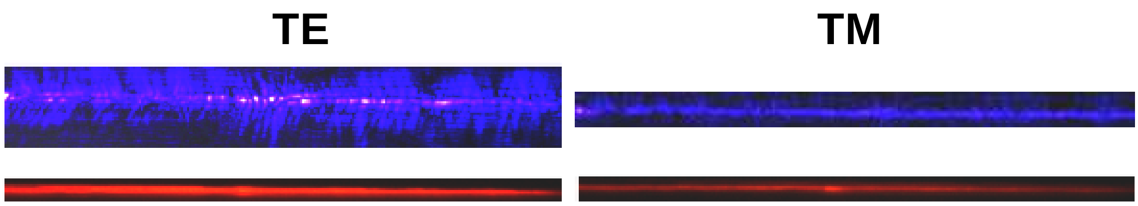


Fig. 32: CCD images of the modes under TE and TM polarizations.

Similar characterization was made in asymmetric waveguides (Fig. 22a), where a 2 μm thick PMMA layer containing QR-nanostructures (table 1) was deposited on top of the 30 nm thick gold layer. PL intensity curves (gain and losses) have a similar behaviour under TE and TM polarizations, probably due to the fact that the asymmetric waveguide does not hold the propagation of the SPP at IR wavelengths. The values of g_0 measured in this kind of samples with $ff \approx$ 0.01 were, for example, 300-400 for PER-QRs (losses around 60 cm^{-1}). Symmetric waveguides (Fig. 22b) were only studied with available spherical PbS QDs. In this case losses are larger for the TM mode, which shows a narrower cross section confirming the presence of the SPP.

Finally, samples with the modified symmetric bilayer structure shown in Fig. 22c have been tested by fixing the thickness of the active nanocomposite (d_1) and bottom dielectric layer (d_2), and varying the thickness of the top cladding layer (d_3). Losses of dielectric modes decrease with the thickness of the cladding, as expected theoretically. Moreover, it is possible to couple the pump beam from the input edge of the waveguide in order to increase the power excitation density of the active nanocomposite layer. As an example, Fig. 33 shows the propagation of TE and TM modes in a sample with d_1=700 nm, d_2=2 μm, t=30 nm and d_3=2.3 μm, characterized by coupling a pump beam (533 nm laser) from the input edge of the sample, and collecting the waveguided PL from the output edge. TM has less intensity and narrower vertical cross section, as expected from its plasmonic nature.

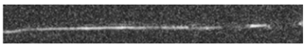
a)  b) 

Fig. 33: Images of TE (a) and TM (b) modes in a symmetric bilayer structure registered with an infared camera.

b) Hybrid silicon version

During the first reporting period we reported on a first attempt at fabricating the hybrid silicon amplifier. Due to a non-optimised mask set there were large misalignments in the waveguide and the contacts, leading to very low transmission. We now have prepared a new mask set (Fig. 34) and fabrication has started: the silicon base waveguides (shallow etch type instead of deeply etched as first time) were fabricated and fabrication of the quantum-dot layer on top has started. Results will form the input for D4.4 (month 30).

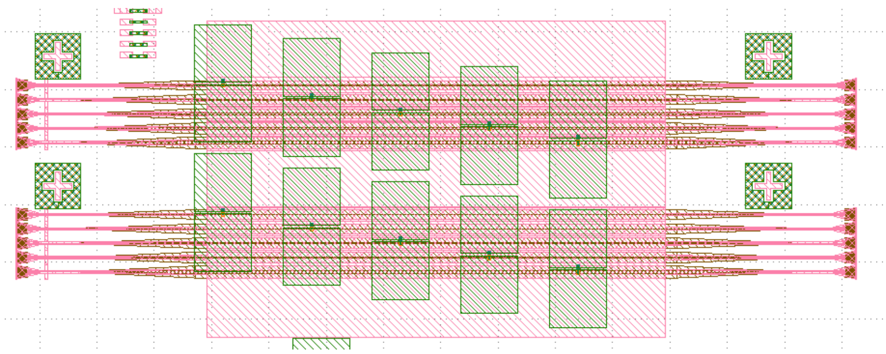


Fig. 34: Layout of contact mask for device fabrication. The SOI waveguides are depicted in pink and the device contact area is depicted in green.

Task 4.5 Fabrication of plasmonic polymer QD based photodetectors

a) Layers of IV-VI QDs

The production of PbS and PbSe QD-solids is based on a solution-processing method called Layer-by-Layer (LbL), as described in detail in Milestone-18 and Deliverable 4.2. This approach allows the fabrication of smooth and crevice-free QD films directly from the colloidal solution. The key step of this method consists in a ligand exchange reaction to replace the insulating oleyamine (2 nm long) for shorter ligands, as the case of 3-Mercaptopropionic acid (MPA) used in the most representative results presented below. We have produced PbS QD films on glass (for micro-gap photoconductors) and glass/ITO/PEDOT (for Schottky/heterostructure photovoltaic photodetectors) substrates. These layers and devices maintain their good electro-optical properties stable in air during weeks.

In Schottky photodiodes we have measured the I(V) characteristics under dark and illumination conditions at different wavelengths, as plotted in Fig. 35. Clearly, they are limited by a series resistance of the order of 2500 Ω that yields $\rho = 7.10^5$ Ω□cm if we attribute that series resistance to the resistivity of the PbS QD film. Further improvement could be attained if using metals with higher work function for the top metal electrode, as the case of Al and LiF thin layer between the QD film and the metal electrode to improve the Schottky contact, other than thicker films and smoother surface. Given the limitation imposed by the series resistance of the diode the resulting open circuit voltage, V_{OC}, filling factor and efficiency (8.5 mV, 0.28 and 0.3 % at 560 nm, respectively, for an incident power of 4.4 μW) are seriously compromised, as observed in Fig. 35. Photocurrent (short circuit current), reaches reasonable values, given that responsivity ($R = I_{ph} / P_i$) reaches high values at visible wavelengths where most of the incident flux can be absorbed by the QD film (see curves in Fig. 36a).

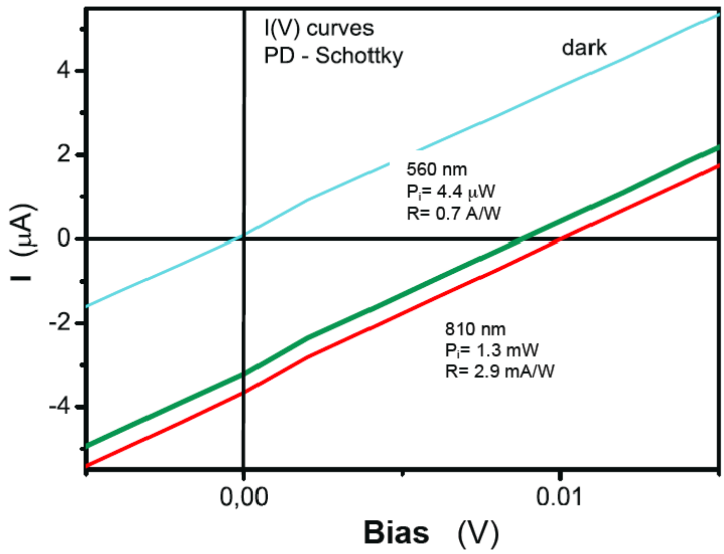


Fig. 35: I(V) characteristics of the best ITO/PDOT/PbS-QD-solid(360 nm)/Ag photodiode under dark (cyan line) and illumination at 560 (green line) and 810 (red line) nm.

The highest responsivity curves in Fig. 36a were reached in the case of photodiodes prepared for the thickest QD-solid film (360 nm) and using PbS QDs synthesized with excess of Pb. The highest Responsivity, *R = 0.7 A/W*, takes place at around 520 nm, whereas decreases up to 1 mA/W at the region close to the PbS QD-film absorption edge. The maximum responsivity corresponds to an EQE ≈ 1 that means all absorbed photons are contributing to charge generation, whereas at the infrared $\alpha d << 1$ and hence the EQE decreases significantly (10^{-3} at 900 nm). Again, thicker films would lead to better results, now regarding absorption and signal at infrared wavelengths.

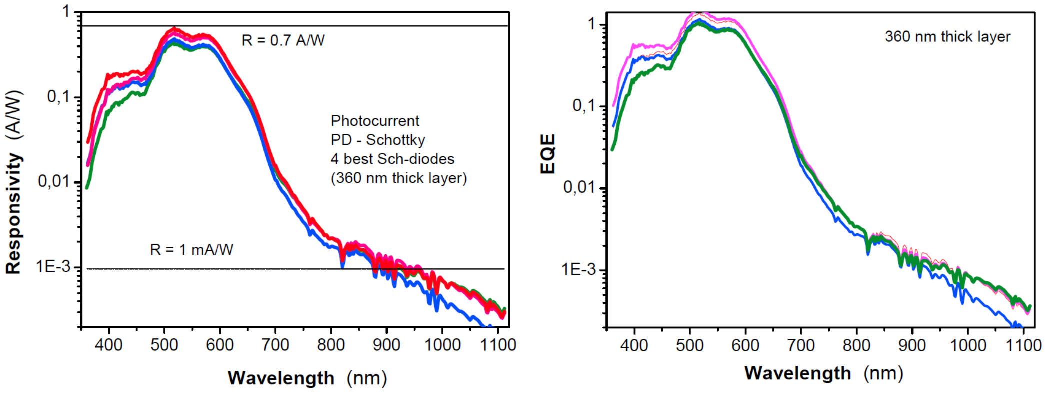


Fig. 36: Responsivity spectra (left) and External Quantum Efficieny (right), EQE, measured in different glass/ITO/PEDOT/QD-film/Ag photodiodes of the same sample.

Using micro- and nano-gap separated electrodes much important photoconductive gain is expected after improving the QD-solid curing and/or its surface isolation (in photodiodes the surface is covered by the metal electrode). Given that technical difficulty to achieve nano-gap distances and the possible difficulties to couple sufficient light leaving the plasmonic amplifier into this photoconductive device, we also considered the study of micro-gap photoconductors. Preliminary results in micro-gap devices with 45 μm distance between electrodes are not giving such expected high photoconductive gain values, possibly because this distance is large in comparison to diffusion length. The resistance measured in the 1 V range was around 1 GΩ in a QD film 300 nm thick (12 LbL cycles), that is, a resistivity of 7.10^5 Ω.cm, equal to that estimated in a photodiode configuration through its series resistance losses. The responsivity curve of a micro-gap photoconductor (45 μm distance between electrodes) measured at 1.5 V bias is about 2 orders of magnitude below that obtained from photocurrent spectrum in a Schottky photodiode made on a PbS QD film with similar thickness and preparation conditions (Fig. 37). Such a difference can be attributed to the still long distance between electrodes as compared to diffusion length of the material and the small in-plane electric field, even if responsivity at 500 nm increases a factor 20 from 1 to 5V bias.

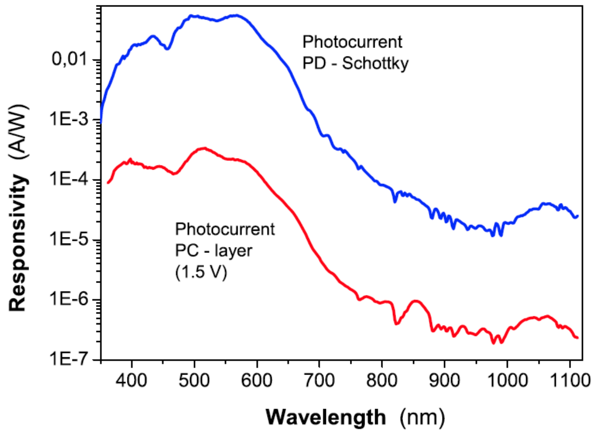


Fig. 37: (a) Responsivity curve of a PbSe QD-solid micro-gap photoconductor (red line) 280 nm thick as compared to that measured through the short circuit photocurrent in a glass/ITO/PEDOT/QD-film(280 nm)/Ag photodiode (blue line).

b) Patternable conductive polymers (PCP)

Most important results on multifunctional PCP were reported in MS19 and D4.2. We have optimized the in-situ polymerization of 3T with $Cu(ClO_4)_2$ inside several host polymers. Particularly, Novolak photoresist was properly formulated to preserve as far as possible its negative lithographic characteristics and generate conductive (10^{-2} S/cm) micropatterns by means of UV lithography, as shown in Fig. 38.

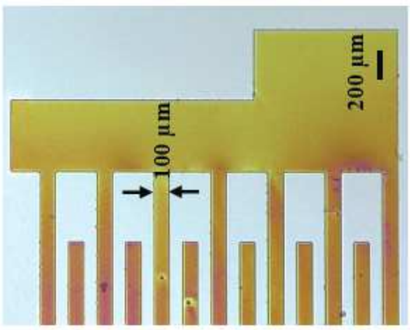


Fig. 38: Example of UV-photolithography patterning using a PCP.

c) Plasmonic PCP

In this case, we have also developed a novel patternable conducting nanocomposite containing gold nanoparticles (NPs) for its possible application in plasmonic based photodetectors, where light absorbed by these nanoparticles due to their characteristic Localized Surface Plasmon Resonance (LSPR) can be transformed into an electrical current (through electron injection). Similar to the Novolak-based nanocomposite, the electrical conductivity of this metal-polymer nanocomposite also exhibits a percolating behaviour and reaches values of the order of 10 S/cm. Currently, the lithographic performance of this material is being optimized, but preliminary results are promising.

The best result for the photoconductivity measured in these nanocomposites deposited on glass (100 nm thick) and using two electrodes separated 45 μm a give responsivities of the order of 4.10^{-4} A/W at 1 V and 0.02 A/W at 20 V (the resistivity of the film was 10 Ω.cm), as shown in Fig. 39.

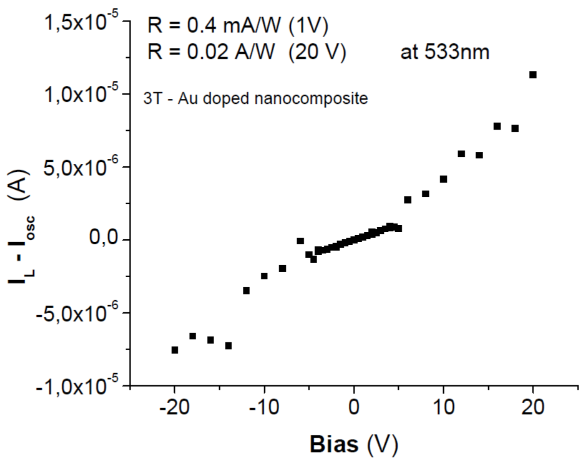


Fig. 39: Photocurrent measured as a function of the applied bias under 533 nm illumination (0.5 mW, approximately).

d) Development of metallic microstructures by a chemical regrowth of metal NPs: towards prepatterned plasmonic nano- and micro-structures.

We have developed an alternative method for the fabrication of metal micro- and nano-structures from metal-polymer nanocomposite resists and their subsequent wet chemistry metallization. The process consists of three simple steps: (1) fabrication of macro-/micro-/nano-patterns by means of lithography or any other direct printing technologies (inkjet, microplotter, ...), (2) in-situ synthesis of metal NPs during a post-bake step and (3) wet chemistry (non-electrochemical) metallization of nanocomposite patterns. The novelty of our approach is that both metal NPs are embedded into the polymer pattern and act as seeds for the reduction of Ag(I) when immersed into a solution of the corresponding precursor metal salt ($AgNO_3$) and an appropriate reducing agent. As a result, metal NPs grow significantly into the nanocomposite structure until the pattern is completely metallized.

In addition to the optical and morphological characterization, we also carried out the electrical characterization of the layers and confirmed that bulk conductivities of silver (gold in other experiments) were achieved. Given that the progress of plasmonics is closely related to the advancement of material research and fabrication technology, we believe that this fabrication method may be very useful for the fabrication of future plasmonic (waveguides for Surface Plasmon Polariton) and optolectronic (electrodes) devices. See for example e-beam nanopatterns fabricated by using the Ag-PVA nanocomposite (Fig. 40).

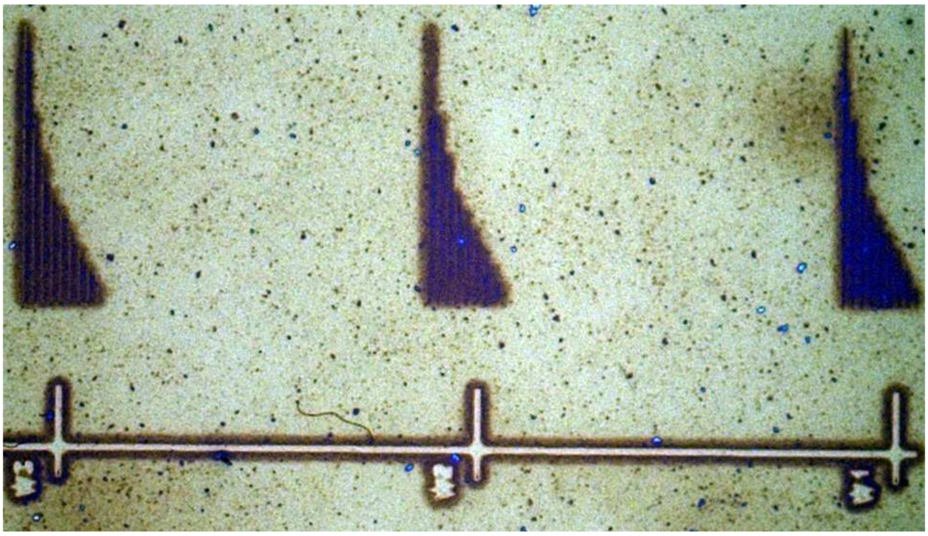


Fig. 40: Optical microscope image of Ag-PVA nanostructures fabricated by e-beam lithography before the metallization process.

Status deliverables and milestones

MS16, MS17, MS18 and MS19 have already sent and approved by the consortium. MS20 was sent recently. We had difficulties in fabricating the nanogap and then we reported our preliminary results with microgap. The fabrication of the nanogap design will be undertaken in collaboration with other partners (TU).

MS16	Demonstration of decision on optimized structures for plasmonic amplifiers	4	UVEG	12	10/2012
MS17	Synthesis of nanoparticles with gain at 1550 nm	4	Ugent	12	10/2012
MS18	Demonstration of conductive QD layers with photoconductive properties	4	UVEG	15	01/2013
MS19	Demonstration of metal-(lithographic) polymer and QD metal-(lithographic) polymer nanocompo-sites	4	UVEG	15	01/2013
MS20	Demonstration and decision on photodetector operation: nano-gap (MIM) vs. Schottky / heterostructure	4	UVEG	18	04/2013
MS22	Demonstration of plasmonic amplifiers with optical pumping exhibiting 10dB gain	4	IMCV	21	07/2013
MS23	Operation of QD based photodetector with responsivity > 0.1 A/W	4	UVEG	24	10/2013
MS24	Demonstration of SPP amplifiers with electrical injection exhibiting 10dB/cm gain	4	UVEG	30	01/2014

Comments on upcoming milestones:

MS22: Plenty of work has already been performed.

MS23: This task of the project is advanced as well.

Deliverables D4.1 and 4.2 are under final revisions.

D4.1	Designs of plasmonic amplifiers	4	UVEG	18	04/2013
D4.2	Report on optical properties of QDs layers and polymer nanocomposites	4	UVEG	18	04/2013
D4.3	Designs of plasmonic photodetectors	4	UVEG	24	07/2013
D4.4	Report on SPP amplifiers by using QDs	4	IMCV	30	10/2013
D4.5	Report on plasmonic photodetectors	4	UVEG	33	01/2014

D4.3: Some designs are being considered for nanogap devices, other than optimization of Schottky heterostructures.

D4.4: Several measurements have been already carried.

Use of resources

Use of resources has been according to plan. The table below gives a review of each partners contribution. More efforts on person months are justified by the UVEG group without increase of costs (salary reductions in the last two years).

Partner	**Person power**	**Main contribution**
UVEG	20.6	Fabrication and characterization of polymer plasmonic amplifiers, study of quantum dot detectors
UGent	15.5	Synthesis of colloidal nanoparticles, fundamental particles properties characterization, study of electrical injection
IMEC	9	Fabrication and characterization of silicon hybrid plasmonic amplifier, study of electrical injection
KIT	1.8	Support of modelling plasmonic waveguide and detector
AIT	9	Modelling of polymer plasmonic waveguides

Tab. 10: Use of resources in work package 4.

3.1.5 Work Package 5: Optical and Electrical Interfaces

Task 5.1 Modelling and fabrication of coupling Si waveguide to plasmonic waveguide

Tapered Couplers: Metal taper couplers are necessary for the excitation of surface plasmon polariton in a vertically aligned metallic slot structure. After numerically optimization of these couplers, the structures have been fabricated and tested. The characterization results are shown in WP6 part of the current report.

Side Couplers: Horizontal metallic slot waveguide can be excited with a directional coupler configuration. In this coupling scheme, the photonic mode propagating through the silicon nanowire is phase matched with the SPP in a horizontal slot waveguide. SPP is then excited with the photonic mode propagating through the silicon nanowire similar to the conventional directional couplers, see Fig. 41.

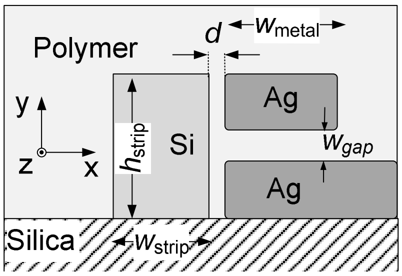


Fig. 41: The cross section of the coupling section consisting of silicon nanowire and horizontal metal slot separated with a distance *d*.

We have used eigenmode expansion method to find the geometrical parameters leading to the highest excitation efficiency of the SPP at the horizontal slot structure. Excitation efficiency γ and the coupling length *L*, versus separation *d* and slot size w_{gap} are given in Fig. 42 Other geometrical parameters are fixed: It can be seen that more than 85% coupling efficiency is possible for the metal slots larger than 60 nm, see Fig. 42a. We also calculated the length *L* of the coupling section leading to maximum SPP excitation efficiency which is given in Fig. 42b.

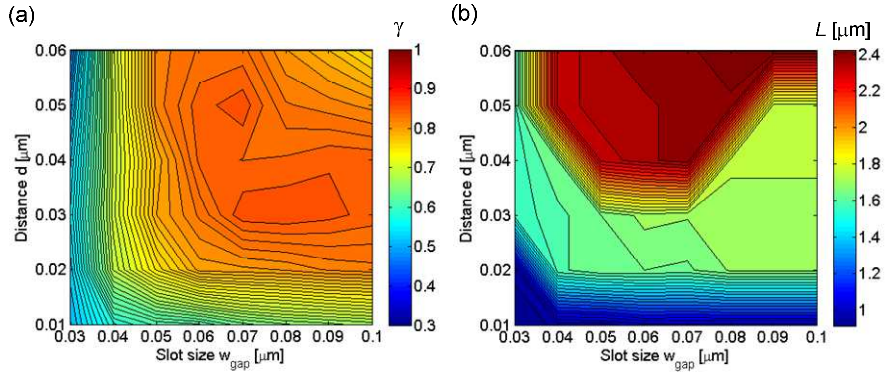


Fig. 42: SPP excitation efficiency and the coupling length *L*. (a) The coupling efficiency of the SPP for various slot size w_{gap} and distance *d*. SPP in a horizontal slot larger than 60nm can be excited with more than 85%. (b) The length of the coupler *L* leading to the maximum SPP excitation efficiency.

This coupling scheme not only provides large excitation efficiency but also is compact with maximum length of 2.4 μm. Such compact couplers are necessary in order to keep the size and loss of the modulator small.

Task 5.2 Design and fabrication of Si beam shaper

As discussed in the first periodic report, in this task we focused on the development of movable grating couplers, which will allow to steer a beam or actively align a beam using electro-mechanically actuation. Previously we reported on out-of-plane tilting grating couplers which allow to direct the beam at several angles. In the second period we focused on in-plane moving grating couplers, which are actuated through capacitive comb-actuators. A global view of the structure and a detailed view of the comb actuators is shown in Fig. 43 a and b respectively. To realize these structures the etching process to release the moving gratings from the substrate had to be optimized. We developed a vapor HF based process, which is less susceptible to stiction problems. This resulted in the completion of milestone MS21. The fabricated structures were charachterised by applying voltages to the different actuators. Lateral movement in the order of 1 micrometer could be demonstrated unambiguously. Such a shift is sufficient to compensate for typical misalignment errors occurring in fiber-chip coupling processes or in VCSEL-grating coupler alignment. Detailed results will be reported in D5.3 (month 21).

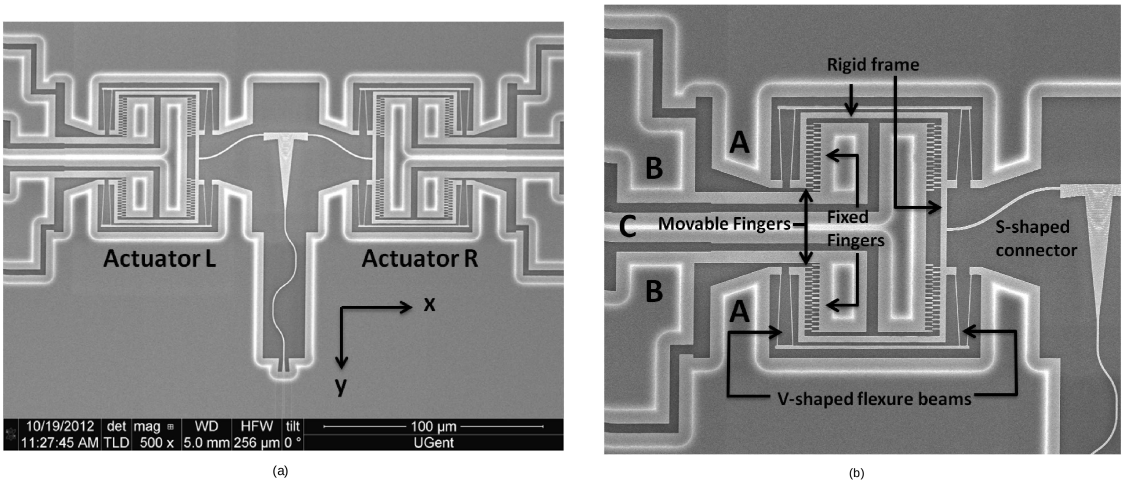


Fig. 43: (a) SEM picture of the top view of the planar moving devices showing the two actuators on both the sides of the FGC (a), and close-up view of the specific actuators and the different components of it (b).

Task 5.3 Design and fabrication of passive ultra-compact components as filters

During the first reporting period we already realized and characterised AWG-based filters with a standard Gaussian response fulfilling the specifications set forward in the DoW. We also reported on the design of a second class of filters, based on ring resonators. During the second period, these filters were now fabricated and characterized. An example is of the response for a single ring resonator and a double ring resonator is given in Fig. 44. These ring resonators included thermal phase shifters which allow to tune the response to a desired wavelength. Compared to the AWG filters demonstrated earlier the ring resonators show a sharper filter response and better crosstalk suppression. Through this work we now have available a library of possible filter designs for incorporation in the final system. The filter to be included in the final system will be determined based on system simulations in WP6.

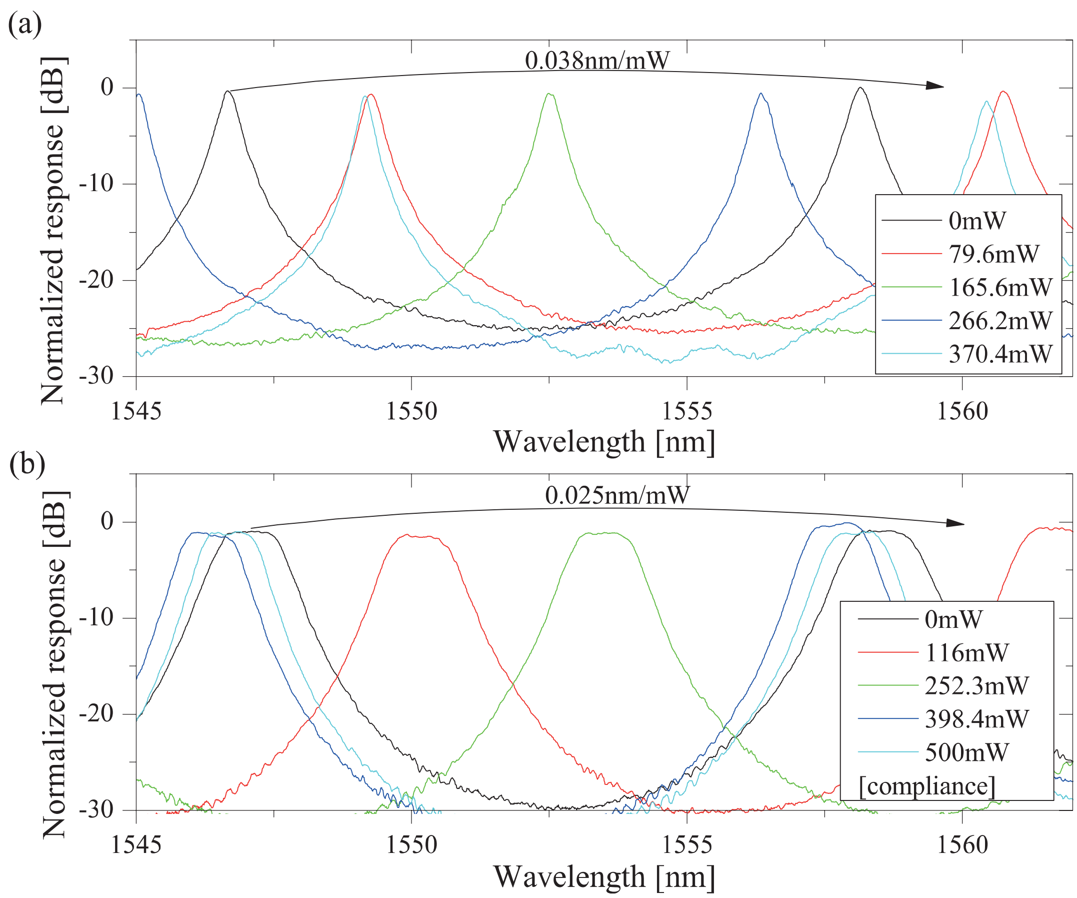


Fig. 44: Filter response for single and double ring resonators, including heaters for shifting wavelength to desired position.

<u>Task 5.4 Signal generation module design</u>

The signal generation module, called DDCM (Dual Dice Communication Module) has been specified and implemented in VHDL, synthesized and characterized in terms of area and timing. A flow for its characterization also in terms of power consumption has been developed. The DDCM has been implemented as parametric module (number of external interfaces, internal storage (FIFOs) size, Quality of Service (QoS) policy, operating frequencies) in order to be configured in different ways according to the requirements of the system that needs to use it. In its first version it employs a classical physical layer consisting of 16 wires over which data flow at the speed of 450 MHz. The whole system is able to run at up to 400 MHz. Its area depends on the internal storage size as well as on the number of external modules supported. The database containing the design and the verification environment of the DDCM has been delivered in time (month 12) as deliverable D5.2.

The next deliverable ST is in charge of is D5.4: Generic DDCM compatible with plasmonic-based PHY specification document. This is expected during month 24.

In the first half of the second year the following activities linked to this deliverable have been carried out:

- a Verilog-A training has been followed by Alberto Scandurra (ST) on January the $30^{th}/31^{st}$ at the Agrate site of STMicroelectronics;
- the VHDL model of a configurable serializer/deserializer has been implemented.

Verilog-A, a Hardware Description Language (HDL) with capabilities for modeling analog electronic devices, as well as photonic, mechanical and thermal systems, will be used for modeling the plasmonic devices in terms of both functionality and physical effects conditioning their behavior (such as temperature variation impact on performance, etc.), and the analog electronic components allowing the digital electronic system to interact with the plasmonic devices, such as emitter/modulator driver, Trans-Impedance Amplifier (TIA), voltage level adjusters, and so on.

The serializer and the deserializer implemented in VHDL are parametric building-blocks, with configurable input and output size, allowing to get in a fast and easy way a specific serializer/deserializer pair, already verified and characterized in terms of area occupancy and operation frequency. The parametric approach will allow to carry out architectural exploration simply changing the values of the parameters, for example understanding, by means of simulation results, which is the optimum width of the off-chip data stream, what in turn determines the number of plasmonic emitter/modulator/detectors to be used in order to get specific performances.

All the building-blocks modeled in Verilog-A and in VHDL will allow to generate a high-level model of the complete chip-to-chip interface and, according to simulation results, define the optimum architecture that will be described in the specification document (D5.4). Such a high level model is called “executable specification” and is something re-enforcing and validating the concepts described in the system specification document.

The system specified will be implemented and used as reference for the project demonstration (D5.6).

Task 5.5 Signal Generation Module implementation via FPGA

The Transaction Level Model (TLM) view of the whole platform has been developed and version v1.0 has been released.

This platform allows generating the stimuli for the system to be validated. In this first phase the RTL VHDL view of the overall system can be stimulated and validated. In a second phase the system will be mapped onto FPGA and it will be stimulated and validated re-using the same platform.

At first the system will include classical electrical PHY (wires) implementing the chip to chip communication. Then the electrical PHY will be replaced with the novel PHY exploiting plasmonic components, that will be available as discrete components mounted on small boards driven by the digital parts mapped onto FPGA.

The FPGA equipment (Zebu) has been already available in ST since more than one year.

Deliverables in first reporting period (month 1 – month 18)

D5.2 – DDCM with electrical PHY design and verification data base (month 12): Completed in time

Upcoming deliverables:

D5.3 - Compact optical filters (2nm bandwidth, >30nm FSR) and first generation beam shapers (month 21) → No delay expected

D5.4 - Generic DDCM compatible with plasmonic-based PHY specification document (month 24) → No delay expected

D5.5 - Report on plasmonic waveguide couplers (month 24) → No delay expected

Milestones in first reporting period (month 1- month 18)

MS26 - Fabrication of plasmonic waveguide couplers with less than 3 dB coupling loss (month 12) → Completed

MS27 - Design of first generation beam shapers and compact optical filters (month 12) → Completed

MS28- DDCM with electrical PHY design and verification (month 12) → Completed

MS29 - Data codecs for power consumption reduction (month 15) → Completed

MS30 - Decision on plasmonic waveguide couplers with less than 3 dB coupling loss (month 15) → Completed

MS31 - Fabrication of compact optical filters and first generation beam shapers (month 18) → Completed

MS32 - Data codecs for error detection and correction → Activity already started and ongoing, no delay expected.

Upcoming milestones

MS33 - Design of second generation beam shapers (month 24) → Design is ongoing, no delay expected.

MS34 - Generic DDCM compatible with plasmonic-based PHY (month 24) → Activity already started and ongoing, no delay expected.

Use of Resources

Use of resources is according to plan

Partner	Person months	Activity
IMEC	6.5	WP-leader Fabrication and characterization of ring resonator filters Development of stiction free underetch process for fabrication of steerable grating couplers Characterisation of steerable grating couplers
ST	24.5	Signal generation module design and start of implementation
KIT	4.9	Argishti Melikyan

Tab. 11: Use of resources in work package 5.

3.1.6 Work Package 6: Integration, Characterising and Testing

Task 6.1 Characterization of active and plasmonic devices

Objective of this task, led by AIT, is testing and characterization of all the passive and active plasmonic devices such as plasmonic laser, modulators, amplifiers and photodetectors. AIT will also define the testing procedures and the required characterization data that need to be collected and provide feedback to studies in WP2.

This task has been started during the first project year in month 7. AIT has been in contact with all partners regarding the goals set for their devices, as this is work that has been started in WP2 (see the report on WP2, which is also led by AIT).

The list of the required characterization data has been compiled. To this end, AIT has developed trial simulation tools using Matlab, so that the required parameters are known in advance. Once the trial simulations has finished, the final required data list has been given to partners.

AIT is involved also in the definition of the testing procedures, so that the required characterization data can be gathered. For example, the trip to Valencia happened in May was important in that the AIT researcher and the UVEG team could reach better understanding on their common goals.

During the first half of the second year, in order to estimate the coupling losses of metal taper mode converters, KIT has fabricated plasmonic phase modulators with various lengths as described in WP3 part of the same report. The linear fit of the optical transmission dependence on device length gives the estimation for the coupling losses.

Fig. 45 gives the normalized optical transmissions of devices with a length of 5 µm, 9 µm, 24 µm, 29 µm, 34 µm and slot width of 140nm. It can be seen that the coupling loss is less than 3 dB per metallic taper coupler.

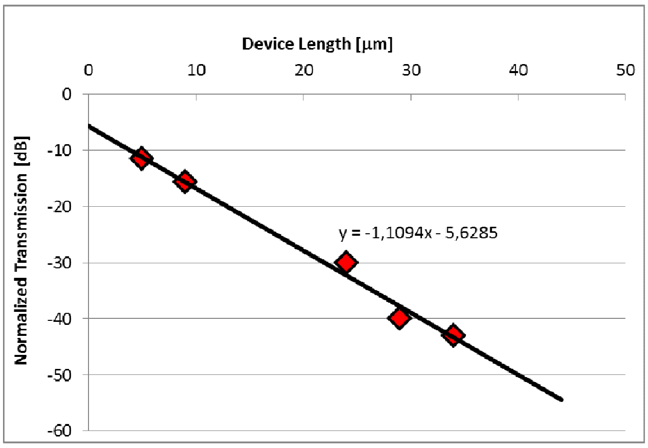


Fig. 45: Normalized optical transmission versus device length. Linear fit gives an estimate for the propagation losses in the metallic slot and total coupling losses

A 34 µm long plasmonic phase modulator with 200 nm wide metallic slot has been electro optically characterized. The device exhibits flat optical transmission with a 13 dB insertion loss. To characterize electrooptic response of the modulator, the modulator itself has been driven with a sinusoidal RF signal with frequencies up to 45 GHz and the modulation index has been measured. It has been found that the device exhibits flat frequency response up to at least 45 GHz.

Task 6.2 Assembly and packaging of plasmonic devices into System-in-Package

The goal of this task, led by KIT is to integrate plasmonic transmitter and receiver in a unique device, test and characterize it.

Task 6.3 Plasmonic chip to chip interconnect prototype testing and evaluation

This task, led by AIT, aims at integrating plasmonic devices and building a full plasmonic interconnect.

Task 6.4 System-in-Package integration and characterization

The objective of this task is to integrate a simple but complete SiP, exploiting the electronic parts developed by ST and the plasmonic devices developed by the other partners.

The main activity carried out in ST during the first 18 months of the project, linked to the integration of the demonstrator SiP, is the development of a Transaction Level Model (TLM) view of the platform that will be used for the final validation of the system.

This platform, allowing generating the stimuli for the system to be validated, will be used in a first phase for the validation of the RTL VHDL view of the overall system, and in a second phase for the validation of the system mapped onto FPGA.

At first the system will include classical electrical PHY (wires) implementing the chip to chip communication. Then the electrical PHY will be replaced with the novel PHY exploiting plasmonic components, that will be available as discrete components mounted on small boards driven by the digital parts mapped onto FPGA.

Deliverables in first reporting period (month 1 – month 18)

No deliverables expected in this reporting period.

Upcoming deliverables:

D6.1 – Report on characterization results of all plasmonic devices (month 27)
→ No delay expected

D6.2 – Report on characterization results of all optical interface plasmonic passive components (month 27)
→ No delay expected

D6.3 – DDCM Report on chip to chip interconnect characterization (month 36)
→ No delay expected

D6.4 – Report on plasmonic system-in-package interconnect prototype testing and evaluation (month 36)
→ No delay expected

Milestones in first reporting period (month 1- month 18)

No milestones expected in this reporting period.

Upcoming milestones

M6.1 - Plasmonic active device characterization results allowing for decision on best combination of devices (month 24)
→ No delay expected so far

M6.2 - Plasmonic passive components characterization results allowing for decision on best coupling and beam shapers (month 24)

→ No delay expected so far

M6.3- Concept for system integration developed (month 27)
→ No delay expected so far

M6.4 - Chip to chip interconnect characterization (month 36)
→ No delay expected so far

M6.5 - Individual plasmonic devices characterization, testing and evaluation (month 36)
→ No delay expected so far

M6.6 - Fabrication Plasmonic components integration to demonstrate chip-to-chip interconnect (month 36)
→ No delay expected so far

M6.7 - Plasmonic chip-to-chip interconnect prototype testing and evaluation (month 36)
→ No delay expected so far

MS38 Plasmonic passive components characterization results with a 1dB coupling loss (M21)

The submission of the milestone will be in time.

Use of Resources

Use of resources is according to plan

Partner	Person power	Activity
ST	2.5 MM	DDCM TLM platform development
KIT	1.4 MM	
IMEC	0 MM	
TUE	0 MM	(3 MM planned)
AIT	2.24 MM	Collection of required characterization data, implementation of a devices simulator using Matlab
UVEG	0 MM	

Tab. 12: Use of resources in work package 6.

3.1.7 Work Package 7: Exploitation and Dissemination

General Status

During the first half of NAVOLCHI, Task 7.1 (Dissemination) and Task 7.2 (Exploitation) have been officially active, while Task 7.3 (Promotion) starts on month 24. A major dissemination and promotion activity has already taken place in the form of a NAVOLCHI workshop at ICTON 2012 (Warwick, UK) and another one is taking place at ICTON 2013 (Cartagena, Spain – June 2013). In addition, NAVOLCHI partners have contributed several publications to high-quality scientific journals, magazines and conferences disseminating project results. One of the publication highlights was when project partners (led by Prof. Leuthold) contributed the cover article for the May 2013 issue of the scientific magazine Optics & Photonics News. Communication has been established with another plasmonics-related EU-funded project (PLATON). The NAVOLCHI consortium is committed to the continuation of the dissemination and exploitation effort.

In the first 18 months of the project, there were three milestones to be met. Two have been met successfully (MS44, MS45), while MS46 is currently delayed. There were 4 deliverables to be submitted (D7.1, D7.2, D7.3, D7.4), and have been submitted successfully.

Task 7.1 Dissemination

Dissemination of ideas and results is of high importance in the NAVOLCHI project. The partners of NAVOLCHI are top research organizations with proven track records in their field and are very active in disseminating research results in a worldwide range to scientists, industry, and the public.

Dissemination activities this far

There has been significant dissemination action concerning NAVOLCHI activities and results. In particular:

- 14 journal and 37 (talks/papers/abstracts) conference publications disseminating the project have been published by NAVOLCHI partners.
- In addition, a cover article on plasmonic communications has been published in the May 2013 issue of Optics & Photonics News.
- A white paper on the innovation potential of plasmonic interconnects has been published online.
- A NAVOLCHI workshop on plasmonics-based components has been organized at the ICTON 2012 conference at Warwick (UK), attracting more than 50 attendees. Another NAVOLCHI workshop has been scheduled for ICTON 2013 (June 2013, Cartagena, Spain).
- Communication has been established with plasmonics-related EU-funded project PLATON (http://www.ict-platon.eu).
- The project website is up and running.

- A brochure on NAVOLCHI activities and goals has been issued.
- A press-release on the start of the project has been issued and another one has been submitted to the Photonics Unit newsletter.

In particular, the dissemination activities that have taken place are analyzed below per partner:

AIT is the AIT is the leader of WP7. As such, AIT has already performed several activities related to the dissemination and promotion of the project results and technology. In the context of Milestone 45, AIT issued an official press release announcing the start of the project to the public. AIT designed and issued a brochure advertising NAVOLCHI. A white paper led by AIT and ST (where all partners contributed) on the innovation potential of plasmonic interconnects was prepared and posted online in the 1st year of the project. AIT organized and chaired (along with KIT) the NAVOLCHI workshop at the ICTON 2012 conference (Warwick, UK) which was a major dissemination activity in this period. The workshop featured 4 presentations from consortium partners as well as presentations from research groups outside the consortium. Specifically, there was a presentation from a group representing EU-funded project PLATON (a project that also involves plasmonic technology) and communication ties were established. There is also a NAVOLCHI workshop organized for June at ICTON 2013 by AIT and KIT.

AIT actively contributed to disseminating and promoting NAVOLCHI in the following conference works:

- *"Surface plasmon-polariton amplifiers"*, I. Suarez et al., ICTON 2012 (UK). Led by UVEG.
- *"Chip-to-chip plasmonic interconnects and the activities of EU project NAVOLCHI"*, A. Melikyan et al, ICTON 2012 (UK). Led by KIT.
- *"Colloidal QDs/PMMA nanocomposites as material to provide gain in surface plasmon polaritons"*, I. Suarez et al., CEN 2012 (Spain). Led by UVEG.
- *"Geometries for surface plasmon-polariton amplification in the context of the EU project NAVOLCHI"*, E. P. Fitrakis et al, Micro&Nano 2012 (Greece). Invited, led by AIT
- *"Light coupling from active polymer layers to hybrid dielectric-plasmonic waveguides"*, I. Suarez et al, ICTON 2013 (Spain). Led by UVEG.
- *"Optimization of colloidal quantum dots-PMMA nanocomposites to provide gain to surface plasmon-polaritons in the visible and the infrared"*, I. Suarez et al, SPP6 Conference (Canada). Led by UVEG.

In early 2013, AIT organized an Open Seminar on plasmonic technology in Peania, Attiki (Greece), titled "Plasmonic communications and innovation". The seminar was a success, attracting around 40 attendees, mainly professionals and students. Finally, AIT contributed to the Optics & Photonics News cover article of May 2013 that was led by KIT.

KIT implemented the project website on which the ideas of the project are published and established a common platform for the partners where useful information is gathered. Therefore the WEB-site is separated into a public part containing:

- basic project information,
- an introduction into the project partners,
- the list of publications, and
- offers of employment within the project,

as well as a part with limited access for project partners only. The latter covers the following subtopics:

- a collection of presentations given from the partners in meetings and phone conferences.

Beneath archiving purposes, this collection is helpful during the phone conferences for distributing the presentations to all partners.

- Two lists containing deliverables and milestones including their actual state. Both lists can be ordered by deliverable/milestone respectively or by date.
- A page with a full contact list, e-mail lists and useful information how to join phone conferences.
- A page with documents important for internal use, mainly the ‘Project Reference Manual and the ‘Quality Assurance Manual’. Templates for internal documents are also available on this site.
- A further site holds the documents for the Grant Agreement and the Consortium Agreement. Additionally, templates for progress reports can be found here.
- Finally, a page announces next meetings or other important target dates.

The website can be found on http://www.navolchi.eu. It was started immediately at the beginning of the project and is updated continuously.

KIT participated in two international conferences, disseminating NAVOLCHI information and results. In particular, this happened at OFC and ICTON with the following works:

- A. Melikyan, L. Alloatti, A. Muslija, D. Hillerkuss, P. Schindler, J. Li, R. Palmer, D. Korn, S. Muehlbrandt, D. Van Thourhout, B. Chen, R. Dinu, M. Sommer, C. Koos, M. Kohl, W. Freude, and J. Leuthold, "Surface Plasmon Polariton High-Speed Modulator," in *CLEO: 2013*, PDP paper CTh5D.2

- A. Melikyan, C. Gaertner, K. Köhnle, A. Muslija, M. Sommer, M. Kohl, C. Koos, W. Freude, and J. Leuthold, "Integrated Wire Grid Polarizer and Plasmonic Polarization Beam Splitter", in Optical Fiber Communication Conference, OSA Technical Digest (Optical Society of America, 2012), paper OW1E.3
- A. Melikyan, M. Sommer, A. Muslija, M. Kohl, S. Muehlbrandt, A. Mishra, V. Calzadilla, Y. Justo, J. P. Martinez-Pastor, I. Tomkos, A. Scandurra, D. Van Thourhout, Z. Hens,

M. Smit, W. Freude, C. Koos, J. Leuthold, "Chip-to-chip plasmonic interconnects and the activities of EU project NAVOLCHI," *Transparent Optical Networks (ICTON), 2012 14th International Conference on* , vol., no., pp.1,3, 2-5 July 2012.

In the post-deadline paper at CLEO 2013 in San Jose, KIT presented its recent results on the high speed plasmonic phase modulator.

In the OFC talk, an ultra-compact, low loss, high extinction ratio polarization beam splitter integrated on SOI platform was proposed. The device is 3.5 μm in length and provides more than 11dB extinction ratio with less than 1dB plasmonic losses.

At ICTON, the concept and goals of the NAVOLCHI project were presented.

KIT also co-chaired (with AIT) the NAVOLCHI workshop at ICTON 2012 and is co-chairing the NAVOLCHI workshop at ICTON 2013.

KIT, and Prof. Leuthold in particular, also led a review work on plasmonic communications featured as the cover article in the May 2013 issue of the scientific magazine Optics & Photonics News:

- J. Leuthold, C. Hoessbacher, S. Muehlbrandt, A. Melikyan, M. Kohl, C. Koos, W. Freude, V. Dolores-Calzadilla, M. Smit, I. Suarez, J. Martínez-Pastor, E.P. Fitrakis, and I. Tomkos, "Plasmonic Communications: Light on a Wire", Optics & Photonics News 24, 24-35 (2013). Cover article.

Finally, there was a paper published from Prof. Leuthold:

- J. Leuthold, "Ultracompact CMOS-compatible Modulators," in *Frontiers in Optics 2012/Laser Science XXVIII*, OSA Technical Digest (online) (Optical Society of America, 2012), paper FTu4A.1.

TU/e contributed to the plasmonic communication Optics & Photonics News cover article and the interconnect ICTON paper that were led by KIT (see section on KIT) and also participated in the following conferences, from which the last two in the list were by invitation:

- V. Dolores-Calzadilla, A. Fiore, M. K. Smit, *"Towards plasmonic lasers for optical interconnects"*, IEEE Proceedings of the 14th International Conference on Optical Transparent Networks, 2012.
- V. Dolores-Calzadilla, D. Heiss, A. Fiore, M. K. Smit, *"Metallo-dielectric nanolaser coupled to an InP-membrane waveguide"*, Proceeding of the Proceedings of the 17th Annual Symposium of the IEEE Photonics Society Benelux Chapter, 2012.
- D. Heiss, V. Dolores-Calzadilla, A. Fiore, M. Smit, *"Design of a waveguide-coupled nanolaser for photonic integration"*, Integrated Photonics Research, Silicon and Nano-Photonics, 2013. Submitted.

- V. Dolores-Calzadilla, D. Heiss, A. Fiore, M. K. Smit, *"Waveguide-coupled nanolasers in III-V membranes on silicon"*, IEEE Proceedings of the 15th International Conference on Optical Transparent Networks, 2013. Accepted to be presented.
- V. Dolores-Calzadilla, D. Heiss, A. Fiore, M. K. Smit, *"Nanometallic lasers for optical interconnects"*, The 18th OptoElectronics and Communications Conference/Photonics in Switching, 2013. Accepted to be presented.

UVEG has been very active disseminating the activities related to plasmonic amplifiers in 8 journal publications and 9 conference participations through conference papers, talks and poster. UVEG also contributed to the Optics & Photonics News cover article that was led by KIT, and to the white paper that was led by AIT. In particular, UVEG's dissemination activities in this period were:

- Poster contribution at the ITC (Lisboa, Portugal) 01/2012. P. Rodríguez-Cantó, Rafael Abargues, Raúl García-Calzada, and Juan P. Martínez-Pastor, *"In-situ synthesis of conducting polymers into patternable polymer matrices"*.
- Poster contribution at the European Conference of Integrated Optics ECIO (Barcelona, Spain) 04/2012. I. Suárez, H. Gordillo, P. Rodríguez-Cantó, R. Abargues, S. Albert and J. Martínez-Pastor, *"Multicolor wave-guiding in polymer/quantum dot nanocomposite waveguides"*.
- Poster contribution at Conference on Laser Ablation and Nanoparticle Generation in Liquids Taormina ANGEL2012 (Sicilia, Italy) 05/2012. R. García-Calzada, P. Rodríguez-Cantó, V. Chirvony, R. Abargues, J. Martínez-Pastor, *"Gold nanoparticles obtained by pulsed laser ablation in liquids: formation of monolayers on chemically functionalized patterns/substrates"*.
- Talk at the International Conference of Transparent Optical Networks ICTON (Warwick, England) 06/2012. I. Suárez, E. P. Fitrakis, P. Rodriguez-Cantó, R. Abargues, I. Tomkos and J. Martinez-Pastor, *"Surface plasmon-polariton amplifiers"*.
- Poster contribution at the Spanish Conference of Nanophotonics CEN2012 (Carmona, Spain) 09/2012. H. Gordillo, I. Suárez, P. Rodríguez-Cantó, R. Abargues, S. Albert and J. Martínez-Pastor, *"Waveguides based on Colloidal QDs embedded in PMMA and SU8"*.
- Talk contribution at the Spanish Conference on Nanophotonics CEN2012 (Carmona, Spain) 09/2012. I. Suárez, E. P. Fitrakis, P. Rodriguez-Cantó, R. Abargues, H. Gordillo, I. Tomkos and J. Martinez-Pastor, *"Colloidal QDs/PMMA nanocomposites as a material to provide gain in surface plasmon polaritons"*.
- Poster contribution at the Spanish Conference on Nanophotonics CEN2012 (Carmona, Spain) 09/2012. M. L. Martinez-Marco, P. J. Rodriguez-Canto, R. Abargues, V. Latorre-Garrido and J. P. Martinez-Pastor, *"In - situ synthesis of conducting polymers and gold nanoparticles into PMMA"*.
- Talk at the SPIE advanced lithography (California, EEUU) 02/2013. R.Abargues, M. Martínez-Marco, P. J. Rodríguez-Cantó, J. Marqués-Hueso, J. Martínez-Pastor, *"Metal-polymer nanocomposite resists: a step toward in situ nanopatterns metallization"*.

- Talk at the SPIE advanced lithography (California, EEUU) 02/2013. J. Rodríguez-Cantó, M. Martínez-Marco, R. Abargues, V. Latorre-Garrido, J. P. Martínez-Pastor, *"Novel patternable and conducting metal-polymer nanocomposite: a step toward advanced multifunctional materials"*.
- Journal paper. Henry Gordillo, Isaac Suarez, Rafael Abargues, Pedro Rodriguez-Cantó, Sandra Albert y Juan Martinez-Pastor, *"Polymer/QDs nanocomposites for wave-guiding applications"*, Journal of nanomaterials, 2012, 960201 (2012).
- Journal paper. A. Bueno, I. Suárez, R. Abargues, S. Sales and J. Martínez-Pastor, *"Temperature sensor based on colloidal Quantum Dots-PMMA nanocomposite waveguides"*, IEEE sensors, 12, 3069-3074 (2012).
- Journal paper. R. Abargues, P. J. Rodríguez-Cantó, R. García-Calzada and J. Martínez-Pastor, *"Patterning of conducting polymers using UV lithography: the in-situ polymerization approach,"* Journal of Physical Chemistry C, 116 17547-17553 (2012).
- Journal paper. I. Suárez, H. Gordillo, R. Abargues, P. Rodríguez-Cantó and J.P. Martínez-Pastor, *"Color tuning and white light by dispersing CdSe, CdTe and CdS in PMMA nanocomposite waveguides"*, IEEE Photon. J. 5, 2201412 (12 pgs) (2013).
- Journal paper. H. Gordillo, I. Suárez, R. Abargues, P.J. Rodríguez-Cantó, and J.P. Martínez-Pastor, *"Color tuning and white light by dispersing CdSe, CdTe and CdS in PMMA nanocomposite waveguides"*, submitted (under revision) to IEEE Photonics J.
- Journal paper. P.J. Rodríguez-Cantó, R. Abargues, R. García-Calzada, and J. Martínez-Pastor, *"UV-Patterning of In-Situ Synthesized Conducting Polymers for Polymeric Display Devices"*, submitted to the Synthetic Metals J.
- Journal paper. P. J. Rodriguez-Canto, M. L. Martinez-Marco, R. Abargues, V. Latorre-Garrido, J. P. Martinez-Pastor, *"Novel patternable and conducting metal-polymer nanocomposite: a step toward advanced mutlifunctional materials"*, submitted to the *SPIE Journal*.
- Journal paper. R. Abargues, M. L. Martinez-Marco, P. J. Rodriguez-Canto, J. Marques-Hueso, J. P. Martinez-Pastor, *"Metal-polymer nanocomposite resists: a step toward in situ nanopatterns metallization"*, submitted to the SPIE Journal.

STMicroelectronics collaborated closely with AIT on the white paper concerning the innovation potential of plasmonic interconnects. In addition, ST contributed to a conference paper at ICTON 2012 led by KIT. Lastly, a section on NAVOLCHI appeared in the ST internal magazine. In 2011, in the Catania site of STMicroelectronics, Alberto Scandurra did a seminar dealing with Systems on Chip and Systems in Package, highlighting the need for novel communication solutions exploiting advanced physical links in order to get the required performance and integration level. In this context, the solutions based on plasmonics so as targeted by NAVOLCHI project have been described.

IMEC* and *UGent have produced jointly several journal and conference publications. They are listed below (works where IMEC and UGent have acted independently follow later in the report).

- Journal. Pieter Geiregat, Yolanda Justo, Sofie Abe, Stijn Flamee, Zeger Hens, "*Giant and Broad-band absorption enhancement in colloidal quantum dot monolayers through dipolar coupling*", ACS Nano, 7(2),987-993.
- Journal. Yolanda Justo, Bart Goris, John Sundar Kamal, Pieter Geiregat, Sara Bals, and Zeger Hens, "*Multiple Dot-in-Rod PbS/CdS Heterostructures with High Photoluminescence Quantum Yield in the Near-Infrared*", Journal of the American Chemical Society 2012, *134*, 5484–5487.
- Journal. B. De Geyter, Houtepen, Arjan J., Carrillo, Sergio, P. Geiregat, Gao, Yunan, Ten Cate, Sybren, Schins, Juleon M., D. Van Thourhout, Delerue, Cristophe, Siebbeles, Laurens D.A., Hens, Zeger, "*Broadband and Picosecond Intraband Relaxation in Lead-Based Colloidal Quantum Dots*", accepted for ACS Nano 2012 July, 24;6(7):6067-74, **DOI:** 10.1021/nn301149x (2012).
- Journal. B. De Geyter, K. Komorowska, E. Brainis, P. Emplit, P. Geiregat, A. Hassinen, Z. Hens, D. Van Thourhout, "*From fabrication to mode mapping in silicon nitride microdisk with embedded colloidal quantum dots*", Applied Physics Letters, 101(16), p.161101~4 (2012).
- Journal. Abdoulghafar Omari, Pieter Geiregat,Dries Van Thourhout and Zeger Hens, *"Light Absorption in Hybrid Silicon-On-Insulator/Quantum Dot Waveguides"* , submitted to Phys Rev.
- Conference. P. Geiregat, B. De Geyter, S. Carillo, A. Houtepen, Y. Gao, S. Ten Cate, J. Schins, D. Van Thourhout, C. Delerue, L. Siebbeles, Z. Hens, "*Broadband and Picosecond Intraband Relaxation in Lead Chalcogenide Nanocrystals*", International Quantum Dot Conference 2012, (2012).
- Conference. B. De Geyter, P. Geiregat, A. J. Houtepen, D. Van Thourhout, L. Siebbeles, Z. Hens, "*Ultrafast Photoinduced Intraband Absorption in PbS, PbSe and PbSe/CdSe Core/Shell Nanocrystals for near-Infrared to Mid-Infrared All-Optical Signal Processing*", MRS Fall Meeting 2011, United States, (2011).
- Conference. Pieter Geiregat, Yolanda Justo and Zeger Hens; "*Giant Absorption Enhancement in Close Packed Monolayers of Colloidal Quantum Dots through Dipolar Coupling Effects*", MRS Fall Meeting, Boston (US), 2011.
- Conference. Q. Lu, P. Geiregat, D. Van Thourhout, Zeger Hens, "*Design of Nanocrystal Light Source for Silicon Photonics*", IEEE Photonics Annual Meeting 2011, WP4, United States, p.527-528 (2011).
- Conference. P. Geiregat, Y. Justo, Z. Hens, "*Giant Absorption Enhancement in Colloidal Quantum Dot Supercrystals*", International Quantum Dot Conference 2012, United States, (2012).
- Conference. Pieter Geiregat, Floris Tallieu, Philippe Smet, Kilian Devloo – Casier, Sreeparvathi Warrier, Dries Van Thourhout and Zeger Hens, "*Integrated light source for silicon photonics using colloidal nanocrystal light emitters under AC field excitation*", submitted for ELOPTO 2012.

- Conference. Bram De Geyter, Pieter Geiregat Yunan Gao, Sybren ten Cate, Arjan J. Houtepen, Juleon M. Schins, Dries Van Thourhout[3] Laurens D.A. Siebbele , Zeger Hens, "*Broadband and Ultrafast Intraband Absorption in Lead based Colloidal Quantum Dots"*, NaNaX 5, Fuengirola (Spain), 2012.
- Conference. Bram De Geyter, Pieter Geiregat, Arjan Houtepen, Dries Van Thourhout and Zeger Hens, *"Ultrafast Photoinduced Intraband Absorption in PbS, PbSe and PbSe/CdSe Core/shell Nanocrystals for Near-infrared to Mid-infrared All-optical Signal Processing"*, ICTON, Warwick (UK), 2012.
- Conference. Dries Van Thourhout, *"Silicon Photonics: short course (3 hours)"*, CLEO Europe 2013, May 2013, Munich.
- Conference. B. De Geyter, P. Geiregat, K. Komorowska, A. Hassinen, E. Brainis, D. Van Thourhout, Z. Hens, *"Embedding Colloidal Nanocrystals in Silicon Nitride Micro-Disk Resonators: From mode-mapping to single dot spectroscopy"*, E-MRS Spring Meeting (2013).
- Conference. P. Geiregat, Y. Justo, A. Omari, S. Abe, S. Flamee, Z. Hens, D. Van Thourhout, *"Giant And Broadband Absorption Enhancement in colloidal nanocrystal monolayers through dipolar coupling"*, E-MRS Spring Meeting (2013).
- Conference. P. Geiregat, Y. Justo, A. Omari, S. Abe, S. Flamee, Z. Hens, D. Van Thourhout, *"Absorption Enhancement in 2D Nanocrystal Superlattices through Near-Field Dipolar Coupling: A Novel Optical Phenomenon at the Nanoscale"*, CLEO (USA), (2013)
- Contribution to KIT's ICTON conference paper (see KIT's section).

IMEC also contributed to the following conference:

- Dries Van Thourhout, *"Colloidal quantum dots for silicon photonics"*, invited presentation at NANAX 5, 7-11 May 2012, Fuengirola (Spain).

UGent also contributed the following journal and conference publications:

- Journal. Yolanda Justo, Bart Goris, John Sundar Kamal, Pieter Geiregat, Sara Bals, and Zeger Hens, "*Multiple Dot-in-Rod PbS/CdS Heterostructures with High Photoluminescence Quantum Yield in the Near-Infrared"*, Journal of the American Chemical Society 2012, 134, 5484–5487.
- Conference. P. Geiregat, Y. Justo, Z. Hens, "*Giant Absorption Enhancement in Colloidal Quantum Dot Supercrystals"*, International Quantum Dot Conference 2012, United States, (2012).
- Conference. Pieter Geiregat, Yolanda Justo and Zeger Hens; "*Giant Absorption Enhancement in Close Packed Monolayers of Colloidal Quantum Dots through Dipolar Coupling Effects"*, ICTON 2012 (UK).

- Conference. Yolanda Justo, Bart Goris, John Sundar Kamal, Pieter Geiregat, Sara Bals and Zeger Hens, "*PbS/CdS core/shell nanorods, highly luminescent anisotropic near infrared nanomaterials by cationic exchange*", NaNaX 5, Fuengirola (Spain), 2012.
- Conference. Pieter Geiregat, Yolanda Justo, Zeger Hens, "*Absorption enhancement in colloidal quantum dot monolayers through coherent dipolar coupling*", NaNaX 5, Fuengirola (Spain), 2012.

Dissemination plans for the future

NAVOLCHI members have made some further plans on their future dissemination activities.

In particular:

AIT plans to contribute at least another 2 publications in scientific journals and magazines as well as at least another 2 conference papers and presentations. A NAVOLCHI workshop organized and chaired by AIT is taking place at Cartagena, Spain, in June 2013, in the context of ICTON 2013. A newsletter contribution is planned in the 3rd year concerning NAVOLCHI achievements, as well as at least one more press release (month 36). AIT leads the dissemination workpackage, and therefore will interact with all partners on their dissemination activities and plans.

KIT expects to have 4-5 journal publications and 4-5 conference abstracts until the end of the project. One of the publications of the near future will be on the coupling between horizontal metal slot and silicon nanowire waveguides. KIT will continue to disseminate project activities through the NAVOLCHI website, as was described in the previous section.

TU/e: Once the fabrication of the first nanolaser is achieved, TU/e will publish a journal paper on the first waveguide-coupled nanolaser operating at room temperature. It might happen at the end of the second year or early during the third year of the project. After this first demonstration, the fabrication of further nanolasers with novel designs and new features will be done, such as designs with improved coupling efficiency or coupled to a silicon waveguide, from which additional journal papers are expected. Additionally, TU/e will participate in at least two international conferences during the third year of the project.

UVEG will pursue plentiful journal and conference-related dissemination activities on the NAVOLCHI results in the next 18 months. In particular, UVEG estimates to contribute to plenty conferences as usual and also have journal publications on high-impact factor scientific journals on the following:

- A paper about plasmonic coupling is expected to be submitted within this year.
- A paper about gain in colloidal QDs-PMMA dielectric and plasmonic waveguides is the goal of the project.
- A paper explaining the dispersion of QDs in SU-8 and its application in waveguiding will be submitted this year.
- A paper about QD-Photodetectors will be prepared for consideration of publication.
- Several manuscripts about different patternable conducting polymers containing Au nanoparticles are being prepared for journal submission.

In addition, UVEG plans to issue press releases through their university service in the 3rdyear of the project, when the amplifier and receiver platforms will be (or will be close to be) a reality.

STMicroelectronics: See Task 7.2 below for more information on ST planning.

The primary focus of ***IMEC*** with regard to disseminating NAVOLCHI results is on international journals and conferences. Next to the general activities in this sense, members of the imec team are (co)chairing several workshops at international conferences focusing on the topic of “hybrid silicon photonics”, whereby the silicon PIC’s are “enhanced” through the addition of extra materials (III-V’s, polymers, or in this case plasmonics and quantumdots). Besides the standard scientific dissemination, the photonics group of imec is also strongly involved in student education through the organization of an international Erasmus mundus master program in Photonics. Integrated photonics devices are an important part of the regular course program of that master and every year several master students are carrying out a master thesis related to the topics covered in this project.

The primary focus of ***UGent*** with regard to disseminating NAVOLCHI results is on international journals and conferences. Besides the standard scientific dissemination, the Physics and Chemistry of Nanostructures group of UGent is also strongly involved in student education in Chemistry, Physics and Applied Physics. Master thesis projects on colloidal nanomaterials for optical applications – topics in close connection with the Navolchi project – are yearly proposed to students in their 1st master year, and typically attract 1-2 students.

Task 7.2 Exploitation

The main objective of this task is to explore the research outcomes of the NAVOLCHI project and promote market penetration of the end products. Due to the early stage of plasmonic technology, it is difficult to prepare for commercial products within or shortly after the timeframe of the project. At the same time, this early stage also means that project partners have the opportunity to lead the way in the technological advancement in their respective fields. In NAVOLCHI, this is mainly expressed through patent opportunities and innovative research through theses at the Master's and PhD level of participating institutions.

Note that industrial partner STMicroelectronics has gone through deep reorganization recently. The Interconnect Systems Group has been moved from a product division to a central organization responsible for technology R&D and design services, and its current activities, including the NAVOLCHI project, will be presented to the new management soon. In consequence, there have been no exploitation activities from STMicroelectronics this far. On the other hand, the new ISG collocation fits much better with the objectives of the project, and the possibility that NAVOLCHI is better followed, sponsored and encouraged is concrete.

For a detailed list of exploitation activities, see D7.2. The main points are also summarized below.

- (UVEG) Patent: "Method to obtain metallic structures of nano- and micro-metric size from lithographic resists based on nanocomposites„ (P201201282).
  ("Método de obtención de estructuras metálicas de tamaño nano y micrométrico a partir de resinas litográficas basadas en nanocomposites)

- Theses (KIT, UGent, IMEC, UVEG):
  - (KIT) Calus Gaertner,"Plasmonic Modulators" (master thesis)
  - (UVEG) Henry Gordillo Millán, PhD thesis on Fabrication and characterization of polymer doped with quantum dots for photonic applications.
  - (UVEG) Mari Luz Martínez Marco, PhD thesis on conducting polymers containing metal nanoparticles and metal nano- and micro-structures using polymer-based patterns.
  - (UVEG) Víctor Latorre Garrido, "Propiedades Eléctricas y Ópticas del PMMA 3T-Au" ("Optical and electrical properties of PMMA-3T-Au") (master thesis)
  - (UGent) Sukumar Rudra, "Diffractive Micro-Electromechanical Structures in Si and SiGe" (PhD Thesis).
  - (IMEC/UGent) Floris Taillieu, "Broadband colloidal quantum dot LED for active plasmonics" (master thesis).
  - (IMEC/UGent) Qi Lu, "Colloidal Nanocrystal Light Sources on Silicon", (master thesis).
  - Other exploitation activities include the development of numerical tools of general interest (AIT), and several invitations to partners for papers and talks on NAVOLCHI technology (all).

- Exploitation plans at this point involve mainly attention to patent opportunities for the devices developed in the project, e.g.: TU/e-metallo dielectric laser, KIT-modulator, UVEG/AIT-amplifier, IMEC-filers, etc. In addition, the consortium awaits the decisions on the new strategy at STMicroelectronics for further exploitation activities. See D7.2 for more information.

Task 7.3 Promotion

Task 7.3 starts on month 24 of the project.

Deliverables in reporting period month 1 – month 18

D7.1 First report on NAVOLCHI dissemination and promotion activities (m18) – submitted.

D7.2 First report on NAVOLCHI exploitation activities (m18) - submitted.

D7.3 Mirror Deliverable of D7.1, which will be available to the public on the website (m18) – submitted.

D7.4 Intermediate report on recent achievements (m18) – submitted.

Upcoming deliverables:

D7.5 Reports on the impact and outcome of organized promotion events (m36) –no delay expected.

D7.6 Final report on NAVOLCHI dissemination and promotion activities (m36) –no delay expected.

D7.7 Dissemination kit (m36) – no delay expected.

Milestones in reporting period month 1 - month 18

MS44 Dissemination of activities in the project's website and continuous update (m1) –met (ongoing ever since).

MS45 Press release on start of project distributed to the public (m2) –met.

MS46 Identification of possible contributions to the industrial partners for commercialization (m15) –delayed due to the reorganization process at ST.

Upcoming milestones

MS47 Organization of workshop on silicon photonics interface for chip-to-chip communication (m34) –no delay expected.

MS48 Public website for NAVOLCHI prepared to stay open for at least another year (m36) –no delay expected.

MS49 Press release distributed comprising key results with a public target audience (m36) – no delay expected.

Use of resources

Use of resources has been according to plan. The table below gives a review of partners' contribution.

Partner	**Person Months**	**Main Contributions**
KIT	1.31	OPN article, papers, conferences, workshops co-chairing, website
IMEC	0.2	Papers, conferences
TU/e	0.4	Conferences
AIT	2.51	WP7 lead, white paper, 2 workshops organized and chaired, seminar, conferences
UVEG	0.5	Patent, papers, conferences
ST	1.72	White paper co-lead, conferences, seminar
UGent	0	Papers, conferences

Tab. 13: Use of resources in work package 7

3.2 Project Management (Work Package 1)

Beneath common management functions as

- Strategic management at project level,
- Control of work package activities, including technical quality control,
- Organisation of project reporting and meetings,
- Control of deliverable preparation,
- Conflict management,

the WP1 leader KIT is responsible for the quality management within the project during the complete projects run-time. The detailed list of management activities is given below.

3.2.1 Administrative Boards and Structure

One of the first tasks for the coordinator was to implement the main administrative boards of the project, i.e. the General Assembly and the Project Management Committee. Additionally, a Technical Project Manager had to be appointed.

General Assembly:

The General Assembly as the prime board in this project is responsible for all major decisions within the project and consists of one representative of each party. It is chaired by the coordinator, the members are listed in Tab. 14.

Karlsruhe Institute of Technology, Germany	KIT	Manfred Kohl
Interuniversity Microelectronics Centre VZW-IMEC, Belgium	IMEC	Dries Van Thourhout
Eindhoven University of Technology, Netherlands	TU/e	Meint Smit
Research and education laboratory in information technologies, Greece	AIT	Ioannis Tomkos
University of Valencia, Institute of Materials Science, Spain	UVEG	Juan Martinez Pastor
ST-Microelectronics, Italy	ST	Alberto Scandurra
Ghent University, Belgium	Ugent	Zeger Hens

Tab. 14: General Assembly.

Technical Project Manager:

PD Manfred Kohl (KIT) was elected as the Technical Project Manager for NAVOLCHI at the Kick-Off meeting in Karlsruhe (see below). He chairs the Project Management Committee and coordinates all technical issues.

Project Management Committee:

Chair: Technical Project Manager: Manfred Kohl (KIT)

Coordinator: Juerg Leuthold (KIT)

WP 1 Leader	KIT	Manfred Kohl
WP 2 Leader	AIT	Emmanouil-Panagiotis Fitrakis
WP 3 Leader	TU/e	Meint Smit
WP 4 Leader	UVEG	Juan Martinez Pastor
WP 5 Leader	IMEC	Dries Van Thourhout
WP 6 Leader	ST	Alberto Scandurra
WP 7 Leader	AIT	Dimitrios Klonidis

Tab. 15: Project Management Committee.

3.2.2 Management Deliverables

Deliverables covered by work package 1 with delivery dates are:

D1.1	Project web site with .eu domain (M01) and continuous update	11/2011
D1.2	Project reference online manual	01/2012
D1.3	Project quality assurance manual	04/2012

All have been prepared in time, for access to the WEB-site and the manuals please follow the links.

3.2.3 Communication: Meetings and Phone Conferences

Up to now, two meetings and six phone conferences have been held:

Meetings:

1) Kick-Off meeting in Karlsruhe, Germany, February 3rd 2012.
2) Intermediate Meeting in Warwick, Great Britain, July 6th 2012.
3) Pre-Review Meeting in Ghent, Belgium, November 26th 2012.
4) Midterm Meeting in Karlsruhe, Germany, April 26th 2013

To provide a short reaction time on possible problems, it was decided that phone conferences will be held every month if applicable, typically on the first Monday of every month.

Phone Conferences:

1) November 16th, 2011
2) December 12th, 2011
3) March 12th, 2012
4) April 2nd, 2012
5) May 7th, 2012
6) June 4th, 2012
7) September 3rd, 2012
8) October 8th, 2012
9) November 5th, 2012
10) November 16th, 2012
11) December 11th, 2012
12) January 14th, 2013
13) February 4th, 2013
14) March 3th, 2013
15) April 8th, 2013
16) May 13th, 2013

Detailed documentation of partner presentations, results obtained and decisions made during the meetings and phone conferences can be found in the minutes-files available on our WEB-site (please follow the link).

3.2.4 Relevant Decisions

An issue regarding the processing of the nanolaser raised when starting its fabrication. Initially, it was planned to perform the fabrication on III-V wafers and then, in a second stage, do their fabrication in III-V wafers bonded to silicon. Nevertheless, a more suitable fabrication scheme was found where only III-V wafers bonded to silicon are used. Therefore, milestone 13 (*Initial characterization of unbounded plasmonic lasers*) is not valid anymore. For this reasons, we are not able to report the characterization of unbounded lasers in such milestone, instead we report characterization studies on the technology that we are developing to fabricate the lasers, showing a significant progress in this respect.

For the second half of the project time it is planned, that Prof. Jürg Leuthold (Coordinator, up to now) and PD. Dr. Manfred Kohl (Technical Project Manager, up to now) will change their positions within the General Assembly.

3.2.5 Legal Status

No changes.

3.2.6 WEB-site

Since project start in November 2011, the WEB-site is available under www.navolchi.eu and is updated periodically. A detailed description can be found in the deliverable D1.1.

During the first one and a half year, the WEB-site has been opened at least 1155 times by 468 different visitors. (Including visits by the project partners itself.)

Broken down by country, Tab. 16 shows - beneath visits from project partners - also visits from China, US, Great Britain, Canada and others.

Additionally, and not listed in the table aside, about 1300 accesses from at least 22 different automated 'robots' like Yandex (Russian),

GoogleBot (US) and BaiDuSpider (Chinese) have been observed.

Country	Domain	2012	2013	Summe
Germany	de	204	35	239
China	cn	93	60	153
Belgium	be	75	10	85
Netherlands	nl	57	3	60
Greece	gr	48	18	66
Spain	es	31	0	31
United States	us	24	10	34
Luxembourg	lu	12	1	13
France	fr	10	1	11
Great Britain	gb	7	0	7
Switzerland	ch	5	1	6
Israel	il		6	6
Japan	jp	2	3	5
Italy	it	1	3	4
Canada	ca	1	2	3
Sweden	se	1	2	3
Romania	ro		3	3
Cyprus	cy	2	0	2
Lithuania	lt	2	0	2
Ireland	ie	1	1	2
Finland	fi	1	1	2
Singapore	sg		1	1
Unknown		309	108	417
Summe		**886**	**269**	**1155**

Tab. 16: Visits of www.navolchi.eu itemised by country.

3.2.7 In Total

As stated in the reports concerning the work packages 2-7, all deliverables and milestones of the first report period have been accomplished successfully. Problems for the next months are not expected. Therefore, changes in overall strategy are not necessary.

3.3 Deliverables and Milestones Tables

3.3.1 Deliverables

Status levels:	finished	in progress	due	critical

Deliverable		WP	Partner	Type	Diss	Delivery	
Nr.	Title					Mnth	Date
D1.1	Project web site with .eu domain (M01) and continuous update	1	KIT	O	PU	1	11/2011
D1.2	Project reference online manual	1	KIT	O	RE	3	01/2012
D2.1	Definition of chip-to-chip interconnection system environment and specification	2	ST	R	RE	3	01/2012
D1.3	Project quality assurance manual	1	KIT	O	RE	6	04/2012
D5.1	DDCM specification document	5	ST	R	CO	6	04/2012
D1.4	Intermediate progress report (1)	1	KIT	R	PU	9	07/2012
D2.2	Definition of plasmonic devices	2	AIT	R	RE	12	10/2012
D3.1	Report on studies of optimized structure for metallic / plasmonic nano-laser and its coupling to Si WG	3	TU/e	R	CO	12	10/2012
D3.2	Report on modelling of the modulator structure	3	KIT	R	CO	12	10/2012
D5.2	DDCM with electrical PHY design and verification data base	5	ST	R	CO	12	10/2012
D4.1	Designs of plasmonic amplifiers	4	AIT	R	CO	18	04/2013
D4.2	Report on optical properties of QDs layers and polymer nanocomposites	4	AIT	R	PU	18	04/2013
D7.1	First report on NAVOLCHI dissemination and promotion activities	7	ST	R	RE	18	04/2013
D7.2	First report on NAVOLCHI exploitation activities	7	AIT	R	RE	18	04/2013
D7.3	Mirror Deliverable of D7.1, which will be available to the public on the website.	7	TU/e	R	PU	18	04/2013
D7.4	Intermediate report on recent achievements.	7	AIT	R	PU	18	04/2013

Tab. 17: Deliverables of the NAVOLCHI project, ordered by delivery date3.

[3] **Diss:** **PU** = Public

PP = Restricted to other programme participants (including the Commission Services).

RE = Restricted to a group specified by the consortium (including the Commission Services).

3.3.2 Milestones

Status levels: finished | in progress | due | critical

Milestone		WP	Partner	Delivery	
Nr.	**Title**			**Mnth**	**Date**
MS44	Dissemination of activities in the project's web site and continuous update	7	KIT	1	11/2011
MS45	Press release on start of project to the public distributed	7	AIT	2	12/2011
MS1	Definition of chip-to-chip interconnection system environment and specification	2	AIT	3	01/2012
MS2	Definition of plasmonic devices and material properties for chip-to-chip interconnection	2	AIT	6	04/2012
MS8	Decision on an optimized structure for metallic/plasmonic nano-laser and its coupling to Si waveguide	3	TU/e	6	04/2012
MS9	Decision on an optimized structure for plasmonic modulator	3	KIT	6	04/2012
MS25	Decision on optimized plasmonic waveguide couplers	5	KIT	6	04/2012
MS10	Grown wafer structure for plasmonic lasers	3	IMEC	12	10/2012
MS16	Decision on optimized structures for plasmonic amplifiers	4	UVEG	12	10/2012
MS17	Synthesis of nanoparticles with gain at 1550nm	4	Ugent	12	10/2012
MS26	Fabrication of plasmonic waveguide couplers with less than 3 dB coupling loss	5	KIT	12	10/2012
MS27	Design of first generation beam shapers and compact optical filters	5	IMEC	12	10/2012
MS28	DDCM with electrical PHY design and verification	5	ST	12	10/2012
MS37	Plasmonic active device characterization results	6	KIT	12	10/2012
MS11	Fabrication of plasmonic modulator on a SOI platform	3	KIT	15	01/2013
MS18	Demonstration of conductive QD layers with photoconductive properties	4	UVEG	15	01/2013
MS19	Demonstration of metal-(lithographic) polymer and QD metal-(lithographic) polymer nanocompo-sites	4	UVEG	15	01/2013

CO = Confidential, only for members of the consortium (including the Commission Services).

MS29	Data codecs for power consumption reduction	5	ST	15	01/2013
MS30	Decision on plasmonic waveguide couplers with less than 3 dB coupling loss	5	KIT	15	01/2013
MS46	Identification of possible contributions to the industrial partners for commercialization	7	ST	15	01/2013
MS3	Development of a system and device simulation platform	2	AIT	18	04/2013
MS4	Definition of the interconnection level specification employing developed plasmonic photonic devices	2	ST	18	04/2013
MS12	Decision on an optimized structure for plasmonic modulator with a maximum loss of 20dB	3	KIT	18	04/2013
MS13	Initial characterization of unbonded plasmonic lasers	3	TU/e	18	04/2013
MS20	Demonstration and decision on photodetector operation: nano-gap (MIM) vs. Schottky / heterostructure	4	UVEG	18	04/2013
MS21	Electroluminescence from QD stack embedded within conductive oxides (>1µW)	4	IMEC	18	04/2013
MS31	Fabrication of compact optical filters and first generation beam shapers	5	IMEC	18	04/2013
MS32	Data codecs for error detection and correction	5	ST	18	04/2013
MS5	Digital domain to plasmonic domain interface specification and VHDL modelling	2	ST	21	07/2013
MS14	Initial testing and characterization of plasmonic modulators	3	KIT	21	07/2013
MS22	Demonstration of plasmonic amplifiers with optical pumping exhibiting 10dB gain	4	IMEC	21	07/2013

Tab. 18: Milestones of the NAVOLCHI project, ordered by delivery date.

Comment to MS8: A suitable structure based on a plasmonic laser was designed, however further investigations are being carried out to design a metallic laser, which might offer a better performance.

Comment to MS46: Delayed due to reorganization of ST management. To be finished within July 2013.

Comment to MS13: To be discussed at the review meeting.

3.4 Explanation of the Use of the Resources and Financial Statements

	WP1		**WP2**		**WP3**		**WP4**		**WP5**		**WP6**		**WP7**		**Total**	
	Real	Plan	Real	Plan	Real	Plan	Real	Plan	Real	Plan	Real	Plan	Real	Plan	Real	Plan
KIT	9.8	16	1.3	2	25.4	26	1.8	3	4.9	12	1.4	4	1.3	3	45.9	66
IMEC	0	1	0	1	0.8	3	9	11	6.5	14	0	3	0.2	1	16.5	34
TU/e	0.4	1	2	6	14.7	29	0	0	0	0	0	3	0.4	1	17.5	40
AIT	1.1	2	5.3	18	0	0	9	9	0	0	2.2	10	2.5	8	20.1	47
UVEG	1	2	1	2	0	0	20.6	32	0	4	0	2	0.5	1	23.1	43
ST	0.5	2	4.5	12	0	1	0.2	1	24.5	30	2.5	22	1.7	10	33.9	78
UGent	0	0	0	0	0	0	15.5	24	0	0	0	0	0	0	15.5	24
Total	12.8	24	14.1	41	40.9	59	56.1	80	35.9	60	6.1	44	6.6	24	172.5	332

Tab. 19: Total Person-Month Status Table. Real: Actual state for months 1-18; Plan: Total for months 1-36.

	actual claimed costs Reporting Period M1 – M18	planned costs Funding Period 1 M1 – M18	actual requested funding Funding Period 1 M1 – M18	planned requested funding Funding Period 1 M1 – M18
KIT	408 387 €	308 317 €	334 069 €	247 808 €
IMEC	217 400 €	256 608 €	163 050 €	193 007 €
TU/e	181 645 €	238 877 €	138 620 €	181 112 €
AIT	115 425 €	200 776 €	88 302 €	152 494 €
UVEG	188 244 €	205 240 €	143 772 €	155 770 €
ST	376 807 €	401 620 €	191 622 €	206 150 €
UGent	98 942 €	85 280 €	74 206 €	63 960 €

Tab. 20: Costs claimed in the reporting period versus the costs planned in the first funding period.

Summary Financial Report - Collaborative Project - Planned Eligible Costs

Project acronym	NAVOLCHI	Project n°	288869	Reporting period from	11/01/2011	to	04/30/2013	Page	1/1
Funding Scheme	CP								

Beneficary n°	If 3rd Party, linked to beneficary	Adjustment (Yes/No)	Organization Short Name	Type of Activity: RTD (A)		Demonstration (B)		Management (C)		Other (D)		Total (A+B+C+D)		
				Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Receipts
1			KIT	484.074	363.055	-	-	132.560	132.560	-	-	616.634	495.615	
2			IMEC	508.818	381.613	-	-	4.400	4.400	-	-	513.218	386.013	
3			TUE	462.120	346.590	-	-	15.634	15.634	-	-	477.754	362.224	
4			AIT	386.251	289.688	-	-	15.300	15.300	-	-	401.551	304.988	
5			UVEG	395.760	296.820	-	-	14.720	14.720	-	-	410.480	311.540	
6			ST	781.880	390.940	-	-	21.360	21.360	-	-	803.240	412.300	
7			UGent	170.560	127.920	-	-	-	-	-	-	170.560	127.920	
			Sum	3.189.463	2.196.626			203.974	203.974			3.393.437	2.400.600	

Summary Financial Report - Collaborative Project - Actual M18 Eligible Costs

Project acronym	NAVOLCHI	Project n°	288869	Reporting period from	11/01/2011	to	04/30/2013	Page	1/1
Funding Scheme	CP								

Beneficary n°	If 3rd Party, linked to beneficary	Adjustment (Yes/No)	Organization Short Name	Type of Activity: RTD (A)		Demonstration (B)		Management (C)		Other (D)		Total (A+B+C+D)		
				Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Total	Max EC Contribution	Receipts
1			KIT	297.270	222.952	-	-	111.117	111.117	-	-	408.387	334.069	
2			IMEC	217.400	163.050	-	-	-	-	-	-	217.400	163.050	
3			TUE	172.100	129.075	-	-	9.545	9.545	-	-	181.645	138.620	
4			AIT	108.490	81.367	-	-	6.935	6.935	-	-	115.425	88.302	
5			UVEG	177.886	133.414	-	-	10.358	10.358	-	-	188.244	143.772	
6			ST	370.370	185.185	-	-	6.437	6.437	-	-	376.807	191.622	
7			UGent	98.942	74.206	-	-	-	-	-	-	98.942	74.206	
			Sum	1.442.458	989.249			144.392	144.392			1.586.850	1.133.641	

Tab. 21: Planned costs (above) and actual costs after month 18 (below). The pre-financing generated an interest of 3.674 € (see FormC of KIT).

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 1 (KIT) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
1-7	Personnel direct costs	219 904 €	Salaries
	Travels	11 757 €	Project meeting Warwick, project meeting Karlsruhe (2x), Review Meeting Brussels
	Other direct costs	316 €	Chemicals, other
	Indirect costs	176 410 €	Overhead
TOTAL COSTS		408 387 €	

Tab. 22: Personnel, subcontracting and other major cost items of beneficiary 1 (KIT) for the period 01/11/2011 – 30/04/2013.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 2 (IMEC) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
WP3/4/5/7	Personnel direct costs	86 362 €	Salaries
WP3/4/5/7	Travels	1 623 €	Project meeting Warwick, project meeting Karlsruhe (2x), dissemination Lyon
WP3/4/5/7	Other direct costs	7 494 €	Masks, Fabrication of SOI-wafers …
WP3/4/5/7	Indirect costs	121 921 €	Overhead
TOTAL COSTS		217 400 €	

Tab. 23: Personnel, subcontracting and other major cost items of beneficiary 2 (IMEC) for the period 01/11/2011 – 30/04/2013.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 3 (TUE) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
RTD	Personnel direct costs	73 220 €	Salaries of V. M. Dolores Calzadilla and M. Smit
RTD	Travel	3 455 €	Karlsruhe, Sitges, Warwick, Gent, Mons
RTD	Other Costs	17 333 €	
RTD	Indirect Costs	78 092 €	Overhead
MAN	Personnel direct costs	7 093 €	Salary of M. Smit
MAN	Indirect Costs	2 451 €	Overhead
	TOTAL COSTS	181 645 €	

Tab. 24: Personnel, subcontracting and other major cost items of beneficiary 3 (TU/e) for the period 01/11/2011 – 30/04/2013.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 4 (AIT) FOR THE PERIOD 01/11/2011 – 30/04/2013						
Work Package	Item description	Amount	Explanations			
WP 2.4.6.7 WP 1	Personnel costs	61 943 € 3 521 €	Resulting from 19.00 PMs of RTD effort performed by 6 persons Resulting from 1.08 PMs of MGT effort performed by 3 persons			
WP 1.2.4.6.7	Travel & Meeting Costs		**Name**	**Date of travel**	**Destination** (Country, City)	**Purpose of Travel**
		563 €	FYTRAKIS	02-03/02/2012	GERMANY-KARLSRUHE	PROJECT MEETING
		936 €	FYTRAKIS	13-19/05/2012	SPAIN-VALENCIA	EXPERIMENTAL ACTIVITY
		1 362 €	TOMKOS	01-06/07/2012	UK-COVENTRY	ICTON 2012, CONFERENCE
		1 090 €	FYTRAKIS	25-27/11/2012	BELGIUM-GHENT	REVIEW MEETING
		1 010 €	KACHRIS	15-18/04/2013	FRANCE-BREST	ONDM CONFERENCE
		806 €	FYTRAKIS	25-26/04/2013	GERMANY-KARLSRUHE	PROJECT MEETING
	Conference registration fee	638 € 350 €	ICTON 2012, I. TOMKOS ONMD CONFERENCE, C. KACHRIS			
	Total Direct Costs	72 219 €				
	Indirect Costs	*43 206 €*	*Overheads*			

Tab. 25: Personnel, subcontracting and other major items for Beneficiary 4 (AIT) for the period 01/11/2011 – 30/04/2013.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 5 (UVEG) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
2, 4,7 1	Personnel direct costs	88 439 € 4 799 €	22.1 Person Months for RTD (2 permanent staff and 2 posdocs: partial time) 1 PM for MGT (permanent staff)
1,4	Major cost "Meetings and Conferences"	8 811 € 1 550* € (*registration cost in Conferences)	Kick-off meeting (Feb. 2012, Karlsruhe) 8th Conf. on thin-film Transistors (Lisbon, 30-31 Jan 2012) ECIO2012 (Barcelona, 18-20 April 2012) ICTON2012 (COVENTRY, UK, 2-5 July 2012) + Techn. Meeting Spanish Conf. of Nanophotonics (Sevilla, 1-4 Octobre 2012) Review Meeting Gent-Brussels Nov. 2012 SPIE Advanced Lithography Conf. (San José, USA, 24-28 February 2013)
4	Major cost: "Optical equipment" "Optics/Optomechanics"	521 € 7 737 €	ND:YAG laser head, delay generator, pulsed diode laser head, infrared camera (< 25% of the cost charged to the project). Total charged to the project: 6 821,95 --- after depreciation (520,80 €) --- Optomechanical for waveguide light coupling, optomechanical for Nd:YAG doubling and "photonic fiber" pumping (supercontinuum generation), lenses and objectives, colour/neutral filters.
4	Major cost "Chemicals-gases" "Si/SiO2 wafers"	4 814 €	Chemicals and gases for chemical lab: preparation of polymers doped with QDs, Layer-by-Layer deposition of QDs (including ligand exchange), Si-SiO2 wafers for preparation of samples (waveguides based on QD doped polymers and metal + waveguides)
4	Remaining direct costs	982 €	Electrical, electronic, informatics, DHL, …
	Indirect costs	70 591 €	
TOTAL COSTS		188 244 €	

Tab. 26: Personnel, subcontracting and other major cost items of beneficiary 5 (UVEG) for the period.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 6 (ST) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
2, 4, 5, 6, 7	Personnel direct costs	151 663 €	Salaries of 1 project manager and 5 senior researchers for a total of 33,42 p/m
1	Personnel direct costs	2 914 €	Salaries of 1 project manager, for a total of 0.54 p/m
	Indirect costs	222 230 €	
	TOTAL COSTS	376 807 €	

Tab. 27: Personnel, subcontracting and other major cost items of beneficiary 6 (ST) for the period 01/11/2011 – 30/04/2013.

PERSONNEL, SUBCONTRACTING AND OTHER MAJOR COST ITEMS FOR BENEFICIARY 7 (UGENT) FOR THE PERIOD 01/11/2011 – 30/04/2013			
Work Package	Item description	Amount in €	Explanations
4	Personnel direct costs	56 739 €	Yolanda Justo, Phd, 01/11/2011 - 30/09/2012 (11 PM) --- Yolanda Justo, researcher, 01/10/2012 - 31/12/2012 (3 PM) --- Chiluka Laxmi Kishore Sagar, PhD, 15/03/2013 - 30/4/2013 (1.5 PM)
4	Consumables	3 504 €	lab instruments and reagents (propanol, tetracloroethylene, lead acetate trihydrate, ...)
4	Travel	1 596 €	Prof. Hens, ICTON Conference, London UK), 6/07/2012 (1140 €) --- Prof. Hens, Geiregat, Justo, Kick-off meeting NAVOLCHI, Karlsruhe (Germany), 02-04/02/2012 (456,01 €)
	Indirect costs	37 103 €	
	TOTAL COSTS	98 942 €	

Tab. 28: Personnel, subcontracting and other major cost items of beneficiary 7 (UGent) for the period 01/11/2011 – 30/04/2013.

4 Attachments

As determined in the projects "Description of Work", the milestones (refer to chapter 3.4.2) achieved so far are delivered with this report. To avoid redundant lengthening of this document, the milestones are delivered as separate files. Additionally, you can find them on our web site www.navolchi.eu .

4.1 Explanation of the use of the resources and financial statements

The tables and forms presented at the following pages are taken from the NEF database provided by the EC.

Use of Resources

Period 1 (1 - 18)
(01-11-2011 - 30-04-2013)

Project Number	288869	Project Acronym	NAVOLCHI

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 1 for the period. Karlsruher Institut fuer Technologie				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 3	Other direct cost	269 €	Costs for Kick-off meeting	Other
WP 1	Other direct cost	1,015 €	1 person Radcliffe 05.-07.07.2012 Project meeting	Traveling
WP 1	Other direct cost	2,760 €	1 person Warwick 02.-07.07.2012 Project meeting	Traveling
WP 3	Other direct cost	1,845 €	1 person Anaheim 16.-23.03.2013 Conference	Traveling
WP 3	Other direct cost	47 €	Laboratory Equipment and Chemicals	Consumables
WP 3	Other direct cost	208 €	1 person Frankfurt 07.03.2013 Conference	Traveling
WP 1	Other direct cost	694 €	1 person Karlsruhe 11.-15.06.2012 Project meeting	Traveling
WP 1	Other direct cost	215 €	1 person Zürich 10.-12.01.2013 Project meeting	Traveling
WP 1	Other direct cost	926 €	2 persons Gent 25.-26.11.2012 Project meeting	Traveling
WP 2 WP 3 WP 4 WP 5 WP 6	Personnel costs	152,251 €	WP2: 1,3 PM Technican/ WP3: 7,3 PM Young researcher; 11,5 PM Technican; 3,3 PM PhD-Student; 3,3 PM Student / WP4: 1,3 PM Technican; 0,5 PM PhD-Student / WP5: 2,5 PM Technican; 2,4 PM PhD-Student / WP6: 1,4 PM PhD-Student / WP7: 1,3 PM Senior researcher	and WP7
WP 1	Other direct cost	1,207 €	2 persons Gent, Brüssel 26.-27.11.2012 Project meeting	Traveling

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 1 for the period. Karlsruher Institut fuer Technologie				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 1	Other direct cost	746 €	1 person Karlsruhe 07.-11.05.2012 Project meeting	Traveling
WP 1	Other direct cost	1,512 €	1 person Aberdeen 25.-28.09.2012 Project meeting	Traveling
WP 1	Other direct cost	629 €	1 person Karlsruhe 16.-20.07.2012 Project meeting	Traveling
WP 1 WP 7	Personnel costs	67,653 €	WP1: 9,8 PM senior researcher	only WP1
	Indirect costs	176,410 €		
	TOTAL COSTS	408,387 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 2 for the period. INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 3 WP 4 WP 5 WP 7	Personnel costs	86,362 €	Personnel cost - RTD/Innovation	personnel cost for 2 senior technicians and 4 engineers for a total of 16.50 MM
WP 3 WP 4 WP 5 WP 7	Other direct cost	1,623 €	travel	02-03/02/12 Karlsruhe, project meeting 05-06/07/12 Warwick, project meeting 06/12/12 France, meeting at EC-Lyon 25-26/04/13 Karlsruhe, project meeting
WP 3 WP 4 WP 5 WP 7	Other direct cost	7,494 €	consumables and other costs	mask, fabrication of LETI-07 run, IEEE Photonics membership
	Indirect costs	121,921 €		
	TOTAL COSTS	217,400 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 3 for the period. TECHNISCHE UNIVERSITEIT EINDHOVEN				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
	Personnel costs	73,220 €	Personnel Costs	2MM WP2 + 14.7MM WP3 V. M. Dolores Calzadilla and M. Smit
WP 2 WP 3	Other direct cost	20,788 €	Other Direct Costs	WP2, WP3

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 3 for the period. TECHNISCHE UNIVERSITEIT EINDHOVEN				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
	Personnel costs	7,094 €	Personnel Costs	0.4 MM WP1 M. Smit
	Indirect costs	80,543 €		
	TOTAL COSTS	181,645 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 4 for the period. RESEARCH AND EDUCATION LABORATORY IN INFORMATION TECHNOLOGIES				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 2 WP 4 WP 6 WP 7	Personnel costs	61,943 €	Resulting from 19 PMs of RTD effort performed by 6 persons	
WP 2 WP 4 WP 6 WP 7	Other direct cost	563 €	FYTRAKIS 02-03/02/2012 GERMANY-KARLSRUHE PROJECT MEETING	
WP 2 WP 4 WP 6 WP 7	Other direct cost	936 €	FYTRAKIS 13-19/05/2012 SPAIN-VALENCIA EXPERIMENTAL ACTIVITY	
WP 2 WP 4 WP 6 WP 7	Other direct cost	1,362 €	TOMKOS 01-06/07/2012 UK- COVENTRY ICTON 2012, CONFERENCE - TRAVEL COSTS	
WP 2 WP 4 WP 6 WP 7	Other direct cost	1,010 €	KACHRIS 15-18/04/2013 FRANCE-BREST ONDM CONFERENCE - TRAVEL COSTS	
WP 2 WP 4 WP 6 WP 7	Other direct cost	806 €	FYTRAKIS 25-26/04/2013 GERMANY-KARLSRUHE PROJECT MEETING	
WP 2 WP 4 WP 6 WP 7	Other direct cost	638 €	Conference registration fee - ICTON 2012, I. Tomkos	
WP 7 WP 6 WP 4 WP 2	Other direct cost	350 €	Conference registration fee, ONMD Conference , C. Kachris	
WP 1	Personnel costs	3,521 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 4 for the period. RESEARCH AND EDUCATION LABORATORY IN INFORMATION TECHNOLOGIES				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
			Resulting from 1.08 PMs performed by 3 persons	
WP 1	Other direct cost	1,090 €	FYTRAKIS 25-27/11/2012 BELGIUM- GHENT REVIEW MEETING	
	Indirect costs	43,206 €		
	TOTAL COSTS	115,425 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 5 for the period. UNIVERSITAT DE VALENCIA				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 2 WP 4 WP 7	Personnel costs	88,439 €	Personnel	Part of the salarie of researchers for time devoted to project: J. Martinez (3,52 PM; 17463,20 €), J. Sanchez (6 PM; 24810,15 €), I. Suarez (7,39 PM; 25615,76 €), P. Rodriguez (5,20 PM; 20549,41 €).
WP 2 WP 4 WP 7	Other direct cost	521 €	Durable	Part of the equipment depretiation corresponding to period for the purchase of: LASER Nd: Yag PULSED; SRS DELAY GENERATOR (STANFORD RESEARCH) MOD. DG535/01; LASER LDH-P 780; INFRARED CAMERA CHILLED.
WP 2 WP 4 WP 7	Other direct cost	13,533 €	Consumable	Cost for purchase of : Precision Optical and Optomechanical Elements (8.001,17 €); Gases and chemical (2.558,53 €); Other Optical and Optomechanical Elements (982,02 €); Substrates (1.991,00 €).
WP 2 WP 4 WP 7	Other direct cost	7,136 €	Travel	1) 8th International Thin-Film Transistor

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 5 for the period. UNIVERSITAT DE VALENCIA				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
				Congress; Lisbon (Portugal); Pedro J. Rodriguez; 29-31/01/2012 (562,73); 2) Congress CEN 2012; Mª Luz Martinez and Isaac Alvarez; Carmona (Spain); 1-4/10/2012 (632,25); 3) ECIO2012 Congress; Isaac Alvarez; Barcelona (Spain); 18-20/04/2012 (481,36); 4) ICTON 2012 Congress; Isaac Alvarez; Coventry (UK); 2-5/07/2012 (1590,56); 5) Project Kick-off Meeting; J. Martinez, I. Alvarez, P. Rodriguez; KARLSRUHE (Germany); 2-4/02/2012 (1815,48); 6) SPIE Advanced Lithography 2013 Congress; P. Rodriguez; San Jose-California (USA); 24-28/02/2012 (2053,33).
WP 7 WP 2 WP 4	Other direct cost	1,550 €	Other costs	Registration costs for the following events: 8th International Thin-Film Transistor Congress, Lisbon (Portugal): P. Rodriguez (170,00 €); Congress CEN 2012, Carmona (Spain): Mª Martinez and I. Alvarez (440,00 €); ECIO2012 Congress, Barcelona (Spain): Isaac Alvarez (416,67 €); SPIE Advanced Lithography 2013 Congress, San Jose-California

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 5 for the period. UNIVERSITAT DE VALENCIA				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
				(USA): P. Rodriguez (522,84 €).
WP 1	Personnel costs	4,799 €	Personnel	Part of the salarie of researchers for time devoted to project: J. Martinez (0,89 PM; 4427,79 €), I. Suarez (0,11 PM; 371,24 €)
WP 1	Other direct cost	1,675 €	Travel	Project Review Meeting in Brussels-Gante (Belgium); Isaac Alvarez and Juan Martinez; 25-27/11/2012 (1674,9 €);
	Indirect costs	70,591 €		
	TOTAL COSTS	188,244 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 6 for the period. STMICROELECTRONICS SRL				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 2 WP 6 WP 7 WP 5 WP 4	Personnel costs	151,663 €	Salaries of 1 project manager and 5 senior researchers for a total of 33,42 p/m	
WP 1	Personnel costs	2,914 €	Salaries of 1 project manager, for a total of 0.54 p/m	
	Indirect costs	222,230 €		
	TOTAL COSTS	376,807 €		

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 7 for the period. UNIVERSITEIT GENT				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
WP 4	Personnel costs	56,739 €	Yolanda Justo, Phd, 01/11/2011 - 30/09/2012 (11 PM) --- Yolanda Justo, researcher, 01/10/2012 - 31/12/2012 (3 PM) --- Chiluka Laxmi Kishore Sagar, PhD, 15/03/2013 - 30/4/2013 (1.5 PM)	personnel
WP 4	Other direct cost	1,596 €	Prof. Hens, ICTON Conference, London	travel

Table 3.1 Personnel, subcontracting and other Major cost items for beneficiary 7 for the period. UNIVERSITEIT GENT				
Work Package	**Item description**	**Amount in €**	**Explanation**	**Free Text**
			(UK), 06/07/2012 (1140 €) --- Prof. Hens, Geiregat, Justo, Kick-off meeting NAVOLCHI, Karlsruhe (Germany), 02-04/02/2012 (456,01 €)	
WP 4	Other direct cost	3,504 €	lab instruments and reagents (propanol, tetracloroethylene, lead acetate trihydrate, ...)	consumables
	Indirect costs	37,103 €		
	TOTAL COSTS	98,942 €		

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		

Legal Name	Karlsruher Institut fuer Technologie	Participant Identity Code	990797674
Organisation Short Name	KIT	Beneficiary nr	1

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	152,251	0	67,653	0	219,904
Subcontracting	0	0	0	0	0
Other direct costs	12,073	0	0	0	12,073
Indirect costs	132,946	0	43,464	0	176,410
Total costs	297,270	0	111,117	0	408,387
Maximum EU contribution	222,952	0	111,117	0	334,069
Requested EU contribution					334,069

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

3. Declaration of interest yielded by the pre-financing (to be completed only by the coordinator)

Did the pre-financing you received generate any interest according to Art.II.19 ?	Yes
If yes, please mention the amount (in €)	3,674

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligible costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Manfred Kohl / Bernhard Dasselaar
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW	Participant Identity Code	999981149
Organisation Short Name	IMEC	Beneficiary nr	2
Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	86,362	0	0	0	86,362
Subcontracting	0	0	0	0	0
Other direct costs	9,117	0	0	0	9,117
Indirect costs	121,921	0	0	0	121,921
Total costs	217,400	0	0	0	217,400
Maximum EU contribution	163,050	0	0	0	163,050
Requested EU contribution					163,050

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Hannelore Marain
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	TECHNISCHE UNIVERSITEIT EINDHOVEN	Participant Identity Code	999977269
Organisation Short Name	TU/e	Beneficiary nr	3
Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	73,220	0	7,094	0	80,314
Subcontracting	0	0	0	0	0
Other direct costs	20,788	0	0	0	20,788
Indirect costs	78,092	0	2,451	0	80,543
Total costs	172,100	0	9,545	0	181,645
Maximum EU contribution	129,075	0	9,545	0	138,620
Requested EU contribution					138,620

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Drs. S. Udo
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	RESEARCH AND EDUCATION LABORATORY IN INFORMATION TECHNOLOGIES	Participant Identity Code	999582382
Organisation Short Name	AIT	Beneficiary nr	4
Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	61,943	0	3,521	0	65,464
Subcontracting	0	0	0	0	0
Other direct costs	5,665	0	1,090	0	6,755
Indirect costs	40,882	0	2,324	0	43,206
Total costs	108,490	0	6,935	0	115,425
Maximum EU contribution	81,367	0	6,935	0	88,302
Requested EU contribution					88,302

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	ATHANASIOS ZESIMOPOULOS
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	UNIVERSITAT DE VALENCIA	Participant Identity Code	999953019
Organisation Short Name	UVEG	Beneficiary nr	5
Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	88,439	0	4,799	0	93,238
Subcontracting	0	0	0	0	0
Other direct costs	22,740	0	1,675	0	24,415
Indirect costs	66,707	0	3,884	0	70,591
Total costs	177,886	0	10,358	0	188,244
Maximum EU contribution	133,414	0	10,358	0	143,772
Requested EU contribution					143,772

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Inmaculada Santaemilia Alcacer
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	STMICROELECTRONICS SRL	Participant Identity Code	999977657
Organisation Short Name	ST	Beneficiary nr	6
Funding % for RTD activities (A)	50.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	151,663	0	2,914	0	154,577
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	218,707	0	3,523	0	222,230
Total costs	370,370	0	6,437	0	376,807
Maximum EU contribution	185,185	0	6,437	0	191,622
Requested EU contribution					191,622

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Alberto Scandurra - Roberto Silva
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	288869	Funding scheme	Collaborative project
Project Acronym	NAVOLCHI		
Period from	01/11/2011	Is this an adjustment to a previous statement ?	No
To	30/04/2013		
Legal Name	UNIVERSITEIT GENT	Participant Identity Code	999986096
Organisation Short Name	Ugent	Beneficiary nr	7
Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	56,739	0	0	0	56,739
Subcontracting	0	0	0	0	0
Other direct costs	5,100	0	0	0	5,100
Indirect costs	37,103	0	0	0	37,103
Total costs	98,942	0	0	0	98,942
Maximum EU contribution	74,206	0	0	0	74,206
Requested EU contribution					74,206

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Geert Van de Gucht
	Date & signature