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DIMENSION

Directly Modulated Lasers on Silicon

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First periodic report

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Authors	Ronny Henker, TUD with contributions from Niels Neumann, TUD Zaid Al-Husseini, TUD Marc Seifried, IBM Lars Zimmermann, IHP Benjamin Wohlfeil, ADV Michael Eiselt , ADV V. Vgenopoulou, AIT D. Klonidis, AIT
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Confirmation

Any work or result described in this report is either genuinely a result of this project or properly referenced. Any statements and results in the report reflect only the author's view and the European Commission is not responsible for any use that may be made of the contained information.

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Executive Summary

This deliverable report covers the publishable summary of the first periodic report of the DIMENSION project. It contains an overview of the tasks and achievements in the first project period from the project start in February 2016 to July 2017.

The report consists of four chapters which describe the overall project content and progress of the project. In the first chapter the background, motivation and basic idea, which is addressed by DIMENSION, are introduced. Furthermore, the overall objectives are described. In the second chapter, a summarized review of the progress and updates of all WPs is provided. In the third chapter, the project results' impact and progress beyond the state of the art are stated. Finally, the fourth chapter provides a brief outlook on the tasks and objectives of the second project period.

The project has been successfully launched, is on track according to the time plan and makes good progress. No deviations have occurred yet. The scheduled deliverables and reports were submitted according to the plan. The main tasks after the successful project launch include: establishment of communication and project management, technical and system specifications, first successful designs of electrical and optical components, fabrication start and measurements of first III-V laser designs, discussion and practical study of III-V-on-silicon integration approaches, initiate of first dissemination, standardisation and exploitation activities.

Detailed information on the project progress and results are provided with the first periodic project report and corresponding publications.

1 Summary of the context and overall objectives of the project

Optical interconnect technology is now widely applied as active optical cables for rack-to-rack links in datacenters for cloud-computing, big data, analytics and high-performance computing. Transceivers with a single mode silicon photonics electro-optical subassembly are emerging as an alternative to vertical-cavity surface-emitting laser (VCSEL) based multimode optical links. The longer distance of single mode interconnects and the ability to integrate optical functions such as wavelength division multiplexing and coherent transmission drive this trend. While silicon photonics integrates passive optical functions, it lacks a solution for a fully CMOS compatible integrated laser source. Consequently, today's commercial silicon photonics based transceiver subassemblies consist of at least three discrete chips; a passive silicon photonics chip, a laser and a (Bi)CMOS chip. These components are then aligned and assembled into a three dimensional stack. The cost of the components and the assembly procedure is a big challenge. The laser takes a substantial part of the bill of materials and the packaging cost of silicon photonics transceivers represents more than 60% of the total manufacturing expense. Furthermore, this discrete approach lacks design flexibility and functionality features that are required to further scale the performance and density of optical interconnects for future computing systems.
Various III-V on silicon integration approaches are explored in the state-of-the-art. Although excellent results were reported, the concepts do not provide a full integration of the III-V functionality in the CMOS process. This is hindered by for example the application of a polymeric bonding layer between the silicon and the III-V layer or by applying a III-V stack with a thickness of at least several micrometer. The latter prevents the application of the back-end of the line stack on a wafer with islands of III-V material.

DIMENSION establishes a truly integrated electro-optical platform, extending the silicon (Bi)CMOS and silicon photonics platform with III-V photonic functionality. The III-V integration concept is fully CMOS compatible and offers fundamental advantages compared to state-of-the art integration approaches. After bonding and growing ultra-thin III-V structures onto the silicon front-end-of-line, the active optical functions are embedded in between the front-end and back-end of line. This offers great opportunities for new innovative devices and functions at the chip-level but also for the assembly of such silicon devices. As processing takes place on silicon wafers, this project has the unique opportunity to bring the cost of integrated devices, with CMOS, photonic and III-V functionality, down to the cost of silicon volume manufacturing. Such a platform has the potential to allow Europe to take a leading position in the field of high functionality integrated photonics. Moreover, the project demonstrators adhere to standards such as IEEE802.3, 25G optical components and low-power electronics, thus opening a viable route towards ultra-low-cost high-performance optical transceivers for a new era of datacentres and cloud systems. DIMENSION will realise three demonstrators:

- A short-reach transmitter for intra-datacentre operation addressing the 400 GbE (IEEE 802.3bs) 2-km and 10-km reach requirements, making use of an array of directly modulated lasers, pulse-amplitude-modulation (PAM4) techniques and 8 wavelength channels in the telecom O-band.

- A medium-reach transmitter for inter-datacentre applications beyond the 400 GbE (IEEE 802.3bs) reach requirement by providing a tuneable coherent transmitter for inter-datacentre and metro applications for link lengths in excess of 10 km using a modulator integrated on the same chip.
- A novel laser directly grown on silicon photonics, operated at 25 Gb/s in the telecom O-band demonstrating the significant cost-saving potential of the technologies pursued in DIMENSION.

2 Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The objectives for the first project period are to find the concepts and final specifications for systems and components as well as first optical and electrical designs.

DIMENSION has been successfully started and established in February 2016. The work, the communication and collaboration among the project partners have been initiated. The project passed its first project period which contains the basic concepts, specifications and first designs. The findings of this phase are first component designs and measurements as well as process integration technologies. In detail the performed work in the several work packages (WP) is as follows:

In WP1 - Project management, the overall coordination and communication among the partners were arranged. The kick-off meeting (02/2016), the second (09/2016) and third (04/2017) project meetings were organized. Furthermore, webconferences with all or just few project partners on a regular three-weekly basis are scheduled and performed. A webpage has been created and is updated periodically to inform and promote the public about the project. A secured data sharing system is arranged which can be used to exchange information and documents among the DIMENSION partners. The handling of research data was defined in the data management plan (DMP). During the reported project period, 8 project deliverables and 2 milestones were achieved. Accordingly, deliverable reports have been prepared and submitted on time. All work packages are started and running according to the time plan. No deviations regarding time plan, resources and objectives have been observed yet. Thus, DIMENSION is currently well on track.

In WP2 - System requirements, transceiver specifications and benefits evaluation, the task T2.1 on system specifications and requirements has been started and successfully finished with the submission of the D2.1 report. This involves the study of the three system demonstrators with the focus on inter- and intra-DC communication. The system specifications have been defined on the basis of standardization and application aspects. Different modulation formats (PAM-4 and coherent formats such as 16QAM) have been listed which will be studied by system simulation. System and component modelling has been started for the performance simulation which reveals the target component parameters for optimal system performance. The conclusion of the study and derived component specifications are summarized in D2.2 report. A techno-economic evaluation and power consumption study of the transmission systems have been started in T2.3 and is in progress. Here, the system performance limitations for fixed grid, bit rate and transmission distance are identified.

In WP3 - Optical component design and fabrication, the fabrication of first silicon photonics devices was successful and reveals that there exists a good process control and fast turn-around time. First optically and electrically -pumped III-V laser were designed and experimentally studied for further improvement. Lasing was observed on the optically pumped devices. The electrically pumped devices show successful diode behaviour with corresponding electro-luminescence but have high turn-on voltage which finally led to an electrical break-down. This needs to be resolved for the final implementation in the silicon process technology. New approaches to achieve current confinement in the thin laser stacks for efficient electrical pumpung of the devices were developed by IBM. The III-V growth, silicon planarization and III-V on silicon bonding have been started. First epitaxial stacks were grown and a good planarization process control and successful bonding was shown. However, the direct growth of III-V on silicon has not been started yet and is planned from project month M25. The first designs of the III-V lasers are summarized in D3.1 report. Furthermore, new silicon photonics fabrication run was started with optical III-V to silicon couplers and higher order waveguide gratings in order to meet the critical dimensions of the IHP fabrication process.

In WP4 - Electronic design and electro-optic integration, information on the target technology for the drivers and modulators are exchanged and the technology access was arranged for TUD. Several circuit topologies for modulator drivers are studied at TUD. This includes also a study of the driver trade-offs for segmented and traveling wave modulators. Two modulator drivers for these modulator types were designed. The segmented driver was taped-out in April 2017 and is under fabrication. The traveling wave driver design is finished and goes to fabrication in August 2017. Both designs are capable of 40 Gb/s and provide a differential output voltage swing of 7.6 Vpp. However, using a segmented approach implies much higher power consumption. For the III-V laser on silicon integration the process flow for both technologies has been stated. To achieve required coupling between the III-V device and Si waveguide several processes in the BiCMOS technology flow were adapted. An additional SiN layer was successfully integrated and tested with photo detector fabrication at IHP.

WP5 - Packaging and characterization and evaluation of demonstrators, just started recently. Deriving from the system and component specifications, first packaging concepts and a preliminary general roadmap for component and system measurements have been established. For each of the three demonstrators a test board with the embedded opto-electronic chips will be designed. Wire bonding capabilities are evaluated to achieve best HF and bias coupling. The several opto-electronic devices will be first measured on chip by using electrical and optical probing. For the demonstration the chips will be packaged on the test board and connected to electrical interface and optical fiber.

In WP6 - Dissemination, Standardization and Exploitation, many activities have been achieved in the first period of the project. These involve: press releases, project introduction at several workshops and conferences, project webpage, dissemination kit and first scientific publications. To secure the rights to DIMENSION's key findings five patents have been filed by the consortium partners. Different standardization bodies have been identified and are taken into account for actively supporting their efforts. These contain IEEE 802.3bs (400G Ethernet) for the first and Consortium for On-Board Optics (COBO) as well as OIF 'IC-TROSA' (Integrated Coherent Transmitter Receiver Optical Subassembly) for the second demonstrator.

3 Progress beyond the state of the art, expected results until the end of the project and potential impacts (including the socio-economic impact and the wider societal implications of the project so far)

The cost-effective integration of high-quality III-Vs on large-area silicon substrates remains one of the most challenging issues that must be solved to build a competitive III-V/Si photonics technology. So far, three major routes have been identified:

- Thick buffers can be grown between Si and InGaAs to gradually accommodate for the lattice mismatch and minimize the density of crystalline defects. Although some optically-active device demonstrations exist based on this approach, the defect density is typically too high to enable ultra-low power lasers with a long life-time.
- Direct wafer bonding can be used to integrate III-V materials on top of Si photonics components. This method typically allows a quick turn-around for the demonstration of new III-V/Si photonic technology concepts, but the cost is prohibitive for large scale production.
- The third approach aims to filter defects by growing InGaAs into high aspect-ratio trenches (ART). Yet, this method is the most cost-efficient solution to date due to its selective epitaxy nature: only the required amount of material is grown where required. However, this method is a non-versatile technology for the design of hybrid III-V/Si photonic components.

In DIMENSION, a direct wafer bonding technology will first be used to reach an early demonstration of the III-V/Si photonic technology for further optimize the optical component performance. In parallel a radically new technique to integrate high-quality III-V materials on Si photonics component in a cost-efficient way is developed. This breakthrough technique is a selective epitaxy based method named Confined Epitaxial Lateral Overgrowth (CELO). It has the same cost-efficiency as the ART technique thanks to the use of selective epitaxy, while providing higher material quality and higher design versatility thanks to a unique defect filtering technique in multiple directions. This method has already been applied for the integration of InGaAs channel material for CMOS technology, and will be extended to photonic components in this project.

4 Outlook

In the second project period, the first electrical design will be fabricated and characterized. Based on the insights they will be further optimized and co-integrated with the silicon photonics devices and active optics on the same EPIC technology platform. After fabrication the devices will be measured intensively. In the second project period 10 deliverables and three milestones are scheduled.