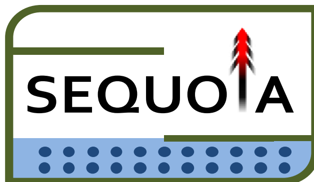

FP7 – 619626

SEQUOIA

energy efficient Silicon Emitter using heterogeneous integration of III-V QUantum dOt and quantum dash materIAls

PROJECT PERIODIC REPORT

Grant Agreement number: FP7-619626

Project acronym: SEQUOIA

Project title: energy efficient Silicon Emitter using heterogeneous integration of III-V QUantum dOt and quantum dash materIAls

Funding Scheme: STREP

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

Periodic report: **2nd**

Period covered: **from** **April 1st 2015** **to September 30, 2016**

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.

3.1 Publishable summary

3.1.1 Summary description of project context and objectives,

The SEQUOIA project intends to make significant advances in silicon photonic integrated circuits (PICs) by heterogeneously integrating novel III-V materials, namely quantum dot (Qdot)- and quantum dash (Qdash)-based materials on silicon wafers, through wafer bonding, and also by exploiting novel device concepts through hybrid III-V/silicon integration. These new complex hybrid PICs will offer better performance and enhanced functionality through the use of new materials and novel integration processes. For the second period of the project, the main objectives are focused on the Qdot/Qdash material elaboration for wafer bonding on Si, on the bonding of Qdot/Qdash wafers on Si and on the building blocks for future complex PICs.

The second objective of the SEQUOIA project in the second period is to develop a wafer bonding technique allowing in particular a high-yield heterogeneous integration of Qdot/Qdash wafers on SOI wafers for the fabrication of hybrid III-V/Si PICs. The wafer-scale integration of the innovative Qdot/Qdash materials on silicon will ensure the potential for cost-effective volume production of highly sophisticated devices and PICs, as well as very high integration density combined with enhanced functionality.

The third objective of SEQUOIA project in the second period is to develop silicon building blocks such as modulators, filters, and grating couplers for the fabrication of hybrid III-V/Si PICs.

The fourth objective is the design, fabrication and characterization of the transmitter (Tx) PICs. Two types of Tx PICs are studied inside this project: Qdot/Qdash-based directly modulated lasers (DMLs) and silicon ring resonator filters, and QDot/Qdash based comb lasers and silicon ring resonator modulators. WDM operation is targeted, with the final objective of achieving 400 Gb/s with 16 channels. The application fields will be the transceivers with short (less than 10 km) and medium (from 10 to 40 km) reaches to interconnect core routers and high performance computers in data centers or telecommunication network centers.

The final objective is to disseminate the research results achieved by the project and to elaborate an industrial exploitation plan.

3.1.2 Summary of work progress and the main results

The project is structured in 5 technical work packages (WP). WP1, led by III-V Lab, is devoted to specifications and exploitation. WP2, led by UKAS, is focused on the material development for Qdot/Qdash-based lasers on Si. WP3, led by CEA, works on important building blocks such as silicon modulators, wavelength multiplexers and output grating couplers. Then there are two WPs on WDM PICs: WP4 on 400 Gbit/s Tx PICs based on chirp-managed-lasers (CMLs), and WP5 on 400 Gbit/s Tx PICs integrating Qdot/Qdash-based lasers to generate WDM combs and silicon-based modulators.

In WP1 an updated version of D1.01 for hybrid lasers was provided. In particular the power consumption of the two types of demonstrator was estimated and compared to other solution.

In WP2, the performance of the QDot lasers operating at 1.5 µm has been improved at UKAS. However the surface quality of the QDot wafers on InP substrate (UKAS) and on GaAs substrate (INNO) is still to be improved for the wafer bonding. At III-V Lab two Qdash wafers with good surface quality have been delivered to CEA for the wafer bonding, and one wafer has been

successfully bonded on a SOI wafer. For WP2 the next 3 months will be the most critical period, in which high surface quality QDot/Qadsh wafers on InP substrate and on GaAs substrate are expected to be delivered and to be bonded on SOI wafers.

In WP3, all Tasks have been completed with very interesting results. The design of silicon ring modulators (Task 3.1) for both operating wavelengths is now complete, and the fabrication is in progress. The parametric cells developed for these components allowed a quick integration with the hybrid lasers onto the mask **SEQ3**. Tasks 3.2 (multiplexers), 3.3 (grating couplers) and 3.4 (CML ring resonators) shared the same mask **SEQ2**, and the fabrication was completed. The Echelle grating based wavelength multiplexer showed insertion losses below **2.5 dB** for all the channels with crosstalk below **13 dB** in the C-band, whereas the O-band design exhibits a slightly higher non uniformity, with nevertheless a higher crosstalk ≥ **15 dB**. In both cases, the absolute wavelength registration was perfectly respected with **100.08±2.03 GHz** for the C-band. For the Task 3.3, the fiber coupling losses of grating couplers were measured to be down to -1.6 dB (-3 dB) for the O-band (for the C-band). Ring resonators for CML have also been optimized through simulations and fabricated.

In WP4, hybrid III-V/Si quantum-well (QW) DFB lasers and silicon micro-ring-resonators (MRRs) have been used for CML applications. 25 Gb/s operation has been successfully demonstrated by using a discrete DF laser and a discrete MRR through a collaboration between DTU, UR1 and III-V Lab, while 10 G operation has been achieved on integrated DFB laser and MRR by III-V LAB/CEA. For the final demonstrator dealing with the integration of DFB laser array and MRR together with AWG, the design has been made on the masks SQ3A and SQ3B, and the fabrication is in progress.

In WP5, an important part of the works has been devoted to propose a new way to handle the mode-partition noise in mode-locked-lasers (MLLs). In parallel, the chirp in MRR based modulators has been carefully studied. Final mask design of the Tx PIC composed of the comb laser and MRR modulators has also been on the masks SQ3A and SQ3B, and the fabrication is in progress.

Regarding the dissemination activities in WP6, a number of conference contributions (an important part of them were invited talks) and several journal paper submission took place. In addition the visibility of the SEQUOIA consortium and the project goals were significantly increased by organizing an international workshop on "Next Generation Ultra-Broadband Silicon Photonics Based Integrated Circuits " at the ECOC 2016 conference in Dusseldorf. This workshop got a large interest with more than 100 participants and a very prominent list of distinguished speakers who contributed also on the two panel discussions included in the workshop.

As a basis element for dissemination a public WEB site (http://www.uni-kassel.de/projekte/SEQUOIA/home.htm) was established since the third project month.

In terms of project management, the coordinator organizes the monthly phone meetings, bi-annually face-to-face project meetings and also some dedicated phone meetings. There is a good communication and coordination inside the consortium.

3.1.3 Conclusion

In the last period, Sequoia project has made significant progress. One QDash wafer has been successfully bonded onto a SOI wafer, other Qdot/Qdash wafers are going to be delivered in the next 3 months. All building blocks have been designed, fabricated and characterized. Results on CML type demonstrator is making the state of the art in this filed. For the final demonstrators, all the designs have been made on the masks SQ3A and SQ3B, and the fabrication is in progress.