Integrated Photonics for the Next Generation of Autonomous Vehicles using InP Technologies

Deliverable D6.5 (D24)

Scientific Courses – SC5

Lead Beneficiary	UNIVERSITY OF VIGO
Delivery date	2020-11-20
Dissemination	Public
Status	Approved
Version	1.0
Keywords	Photonics, Physics, Solid-state physics, Robotics, Training, Automation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 860763

Document Information

Grant Agreement Number	860763
Project Acronym	DRIVE-In
Work Package	WP 6
Deliverable	D6.5
Title	Scientific Courses
Author(s)	Francisco Javier Diaz Otero
File Name	DRIVE-In_D6.5_Scientific Courses_UVIGO_20201120_v1.0.docx

Abstract

Through the Doc-TIC PhD Programme a number of course modules in areas related to photonics (active and passive devices), quantum mechanics, solid-state physics and integrated photonics are given to the ESRs.

This Scientific-based course (SC5) offered to each ESR is already tailored to present the students with the design trajectory to simulate single devices, subsystems and circuits and how to implement Systems on a Chip.

.

Keywords: Photonics, Physics, Solid-state physics, Robotics, Training, Automation

Change Record

Revision	Date	Description	Reviewer
0.1	01-09-2020	Outline proposal	Francisco J. Diaz Otero
0.5	01-11-2020	Partial contents developed	WP1 partners
0.7	01-11-2020	Version for peer review	Anxo Moreira (UVIGO)
0.9	05-11-2020	Reviewed	Braulio Gómez Saavedra (VPI)
1.0	20-11-2020	Final deliverable for the EC	EC


DRIVE In
HOME
ABOUT US
PARTNERS
THE TEAM
RESEARCH AREAS
CONTACT US
PUBLICATIONS
NEWS
Applied optoelectronics
RESEARCH AREAS

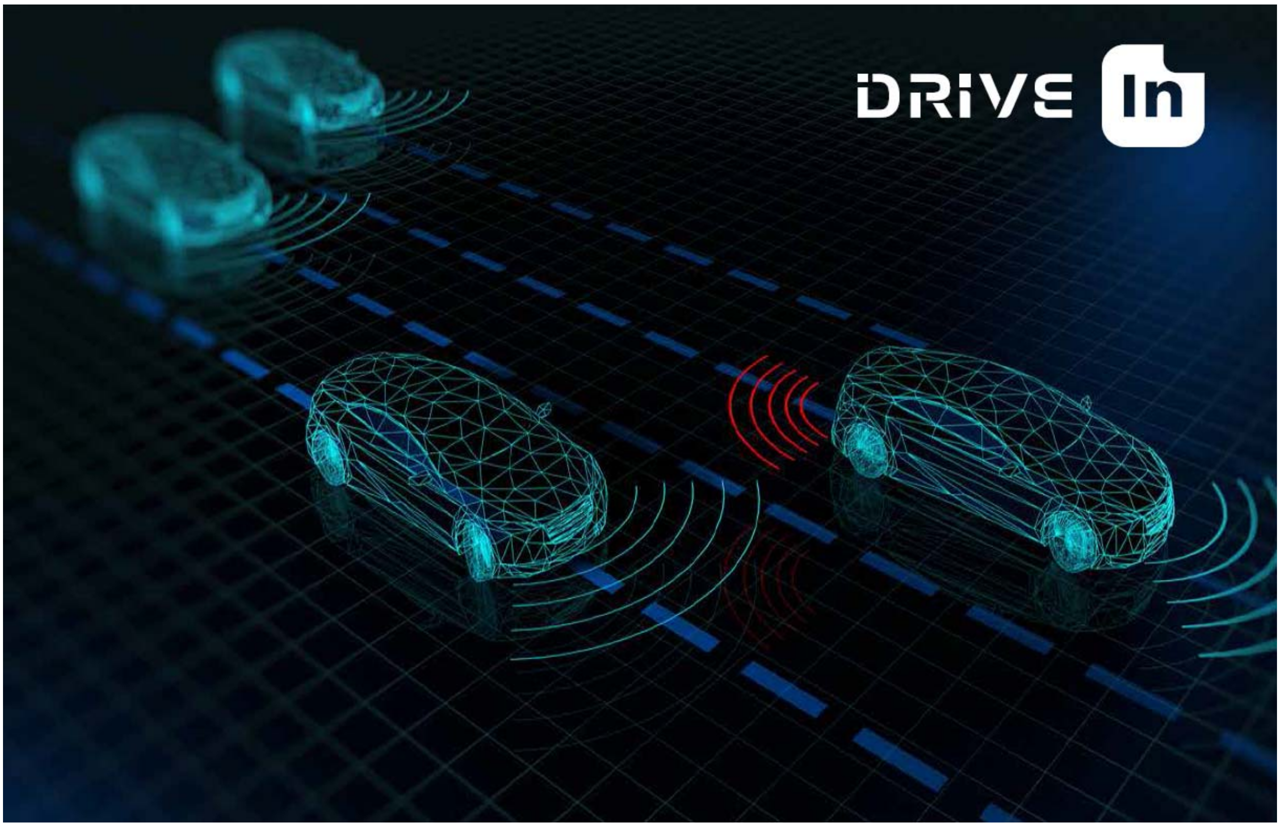
DRIVE In

TABLE OF CONTENTS

1. INTRODUCTION

The aim of this report is to provide a brief overview of the **Scientific Course 5** organized in the framework of the project DRIVE-In. As a general introduction, the challenge for the DRIVE-In Training Network is to develop new fundamental skills on simulation, design, measurement automation, fabrication and validation, and organization in an integrated photonics foundry. These are intended to develop PDK specifically for LiDAR and FSO applications and new hybrid photonics and electronics modelling and simulation software for the next generation of ITSs and ADASs enabling integrated InP technologies. As collateral goals, the ESRs will contribute to the development of new test structures, advanced PIC designs and new optoelectronic hybrid software tools. To achieve this, DRIVE-In training strategy aims to combine scientific advanced training (Scientific Courses 1-5), technical hands-on courses (TC1-3), Winter School and regular EID meetings and networking events. Furthermore, all ESRs will be equipped with a range of transferable skills, as defined in the proposal.

The following specific training objectives (TOs) are defined to fulfill these goals:

- TO1: To enhance the attractiveness of a career in the front-line area of research in photonics' software circuital and physical simulation, design and modelling tools and in the creation of building blocks, test structures and models for generic InP integration platforms. This will provide the opportunity for the ESRs to be involved in the creation of a new and major research area in hybrid photonics and electronics simulation and modelling, joining two major different technologies like microelectronics and integrated photonics; by applying consolidated knowledge coming from integrated circuits to develop integrated photonics-electronics software with enhanced performance.
- TO2: To provide future employers (both academic and industrial) with the next generation of researchers that: i) are skilled in a wide range of techniques and methods, stemming from software to design, fabrication and characterization of InP integrated circuits; ii) have direct experience of interaction across disciplines and sectors with different background in electronics/photonics towards the development of a completely new area of research, producing new devices suitable for, but not limited to, the next generation of ITSs and hereby ADASs.
- TO3: To produce researchers with excellent transferable skills and the ability to transform abstract and challenging ideas into influential and practical outcomes.
- TO4: To create an active, long-term network of young researchers whose personal contacts, support and expertise will help Europe shape the future of research in ITSs and ADASs for active/passive sensoring and optical communication devices; and to enhance/optimize the software simulation tools by integrating electronics in the optical design process.

- TO5: To cascade expertise and spread good practice throughout Europe by personnel exchange and delivering European researchers able to – in the near and mid-term future – become leaders in the fields of integrated hybrid photonics and electronics software simulation and design, PIC designs, ADAS applications and automation in photonics industry.

The four ESRs **have been enrolled (07/10/2020) in the PhD program from the UVigo (Doc-TIC)**. Doc-TIC is the PhD Program promoted by the School of Telecommunications Engineering and atlanTTic. Its mission is to train the best professionals and researchers to generate quality research with international impact and to provide the industry with professionals with advanced knowledge to improve its competitiveness at global level. Doc-TIC involves the merging and expansion of the previous PhD Programmes in Signal Theory and Communications (TSC) and Telematics Engineering, both with Mention of Excellence awarded by the Spanish Ministry of Education. Each ESR will be required to accumulate at least 30 ECTS (European Credit Transfer and Accumulation System) credits, among the pool of scientific- and transferable skills-based courses at UVigo and TUe **to obtain their PhD title**.

Through the Doc-TIC PhD Programme the UVigo offers a number of **course modules in areas related to photonics (active and passive devices), quantum mechanics, solid-state physics**, all of which are given in English. Between them, **this Scientific-based course (SC5) offered to each ESR, will allow them to obtain five ECTS** (15 lecturing hours and 15 hours of homework).

1.1 SCIENTIFIC COURSE SC5: PHOTONIC INTEGRATION - DEVICE AND CIRCUIT SIMULATION

In the following Table we describe the fundamentals of these scientific-based training group of courses and corresponding skills to be acquired by the ESRs.

Title	Fundamentals on Microelectronics, Photonics and Quantum Mechanics (SC1)	Month: 9	Duration: 3
Lead	UVigo		
Contents: This group of courses covers the latest research of optical communications and optical devices, semiconductors, microelectronics and quantum mechanics. Concepts on physical foundations of the optical transmission systems and optical information processes, in particular, those that deviate most from the classical technics such as the optical generation and photonic detection; Basic theory of CMOS systems, electronic design and simulation, optical devices and optical subsystems like LEDs and lasers, photodetectors, modulators, fibre/RF amplifiers and optical/RF filters. SC1 will provide fundamental concepts from classical and modern physics as well as form the			
Skills for ESRs: To calculate the main parameters of the electromagnetic waves: frequency, wavelength, propagation constant, polarization, Poynting vector, phase constant, attenuation constant; Analyze the propagation of waves in media with and without losses; To understand the origin and reasons for the use of optical transmission systems. To be able to specify the type of optical fibres and other necessary opto-electronical components that are needed for a certain optical link. Also, to understand their physical and technological limitations; To understand the physical concepts underlying semiconductor physics, band gaps, electrical and optical properties and their application to physical devices like optical Lasers and LEDs; To apply deep concepts related to quantum mechanics			
Title	Integrated Photonics' Devices (SC2)	Month: 10	Duration: 1
Lead	UVigo		
Contents: Covered is the theory of optical waveguiding: propagation in free space, reflection and refraction, three layer waveguides. Guided optical modes and modal fields are treated. Three-dimensional wave guides and curved waveguides are described. Waveguiding devices such as splitters/combiners arrayed waveguide gratings. Optoelectronic devices such as lasers (FP, DBR, DFB, VCSEL), semiconductor optical amplifiers and photodiodes will be explained. The steady state and dynamic behaviour of lasers is discussed using rate equation models. Within this course a deep theoretical knowledge and applications on active and passive integrated devices			

Skills for ESRs: To understand the basic concepts of photonic integration design; to understand the physics and behaviour of semiconductor optoelectronic devices such as waveguiding devices, (de)multiplexers, diode lasers, detectors and their applications. These will be key to understand main parameters and variables needed to design BBs, focusing on dynamics and elements needed on			
Title	Photonic integration: software tools and design flow intensive training (SC3)	Month: 11	Duration: 2
Lead	UVigo		
Contents: Intensive training that wraps-up knowledge from the previous on integrated photonics´devices, combining them for circuit simulation software. Training seminars and hands on sessions on Photonic Design for different applications: telecom and datacom systems, optical access networks, medical and sensoring systems; as well as different devices such as lasers, photodetectors, splitters, waveguides, MZIs. In these seminars experts from BP in the field of photonic modelling lead guided tours, provide lectures on various application topics, and are available for questions and support during individual lab exercises. Design topics include: Overview of signal models and simulation techniques; Parameter sweeps and optimizations; Visualization and post- processing of simulation results; Scripted simulations and automated system design; layout and mask design. Moreover, the course covers the flow design process, from the rough designers´ idea to an optical circuit design, physical and circuital simulation, mask generation, fabrication process and packaging. Finally,			
Skills for ESRs: Active/Passive photonic integrated circuits; Semiconductor lasers and other active photonic devices; Integrated photonic waveguides; Doped-fiber lasers and amplifiers; Hybrid (EDF/Raman) amplification and Raman pump optimization; Co-simulation (integration of third-party code), flow design and compact model/building block generation.			
Title	Photonic integration: technology, fabrication and characterization (SC4)	Month: 11	Duration: 2
Lead	HHIF		
Contents: In this intensive training the process of fabrication and measurement is covered, e.g. the following subjects: Crystal properties of semiconductors, Substrate manufacturing, Vacuum technology, Epitaxy, Lithography, wet and dry etching, Plasma deposition, Metallization. The characterization part will explain how the basic parameters of a realized device can be determined. For electrical properties diode characteristics, contact and sheet resistances based on IV measurements will be explained, including the interpretation of the results. Optical characterization focusses on waveguide propagation loss (Fabry-Perot measurement), electrooptic phase shifting (interferometric measurement), gain measurement (Thomson method), laser emission (LI curves and			
Skills for ESRs: To understand the process steps needed for fabrication of devices and photonic integrated circuits. To learn which process steps and technologies are needed to fabricate a device or photonic integrated circuit. To understand how devices and			
and tested including electrical and optical characterization.			
Title	Photonic Integration: device and circuit simulation (SC5)	Month: 12	Duration: 3
Lead	BP		
Contents: This course presents the student with the design trajectory to simulate single devices, subsystems and circuits and how to implement Systems on a Chip. Emphasis lies on design approaches to improve the overall system performance in terms of robustness, power-delay product, and hands-on experience to design an integrated circuit using commercial EDA tools provided by one of the beneficiaries. At the end of the course, the student will understand the various trade-offs between area, time, power, cost, and design effort, and also have the basic knowledge and hands on experience to carry out both the front and back end stages needed to implement			
Skills for ESRs: To understand SoC design complexity and performance/power trade-offs as well as manufacturing costs. To learn Physical design using EDA tools, logic simulation and synthesis and to learn technology trends in nanometre technologies. Different tools for modelling devices (Lumerical, Photon Design), circuit simulation (VPI), layout and mask generation (Nazca Design) are presented to the			

1.2 SYLLABUS

The outline of this course is described below. SC5 has been held between 9-13 Nov 2020 in a virtual mode (10:00-13:00). This course should have been developed in a face-to-face mode. However and due to the current pandemia, the lecturer Dr. Ronald Broeke couldn´t travel and the course was moved to an online version. However, this unfortunate circumstance did not imply a considerable change in the contents or in the extension of the training. Since the training included in SC5 is fundamentally oriented to software and programming (circuit design, simulation and layout), this type of course is the most suitable to be taught online.

Topics covered in the course: PIC layout design, cells and layer, interconnect, building block and PDK creation, GDS introduction and advanced manipulation, connection DRC, circuit level path-tracing and compact models.

Scientific Course SC5: Photonic integration – Device and circuit simulation (Dr. Ronald Broeke)

PICWave is a bidirectional time-domain modeling of photonic ICs capable of modeling the interaction between both passive and active components using the TWTD (Travelling Wave Time Domain) method. Suitable for studying the interaction of optical components in a larger circuit as well as the design of individual active components such as Laser Diodes, SOAs, TWAs, DFB & DBR lasers. PICWave can model gain switching, mode-locking, time resolved spectra and more.

Harold is a detailed hetero-structure laser diode modeling. Including bandgap narrowing, quantum wells - capture/escape, recombination, strain, drift-diffusion, power dissipation effects. Can be used as a stand-alone product or complementary to PICWave.

1. **PICWave:**

   a. **Active module:** Lorentzian optical phase and intensity noise model; Electrical noise model; Travelling wave electrode model; Longitudinal hole burning; Lateral hole burning; Carrier diffusion; Non-linear gain; Auger processes; Thermal effects.
   b. **Features:** PI and PV curves; MQWs; Quantum efficiency; Chirp simulation; RIN spectra; Material database system; Import gain tables; Electro-absorb modulator model.
   c. **Applications:** Photonic integrated circuits (PICs); Tunable laser diodes; Large ring resonators; Mach-Zehnder modulators; Travelling wave SOAs; Electro-absorption modulators.

EXAMPLES

Large ring resonator.

Mode hopping in a Fabry-Perot laser.

2. **Harold:**

   a. **Electrical model**: Self consistent solution of Poisson Equation, drift-diffusion, and capture/escape for both holes and electrons.
   b. **Thermal model**: Full vertical-longitudinal solution of the heat flow equation, including the substrate, the metal contacts and the heat sinks.
   c. **Optical model**: Photon distribution according to the optical mode of the laser cavity. The total photon density is determined considering the gain/loss balance in the full cavity.

d. **Capture/escape**: In QW regions, thermal equilibrium between confined and unconfined carriers is not assumed, but described by means of appropriate capture/escape balance equations.
e. **Quaternary alloys**: Utilization of quaternary alloys is fully supported through the material database.
f. **Gain model**: Material gain for quantum well lasers is computed as a function of the wavelength and carrier concentration, using a parabolic band approximation.
g. **Recombination:** Shockley-Read-Hall, Auger, stimulated and spontaneous recombination processes are included.
h. **Surface recombination:** Recombination at the facets is included via deep trap levels at the mirror.
i. **Quantum well:** The program will determine the energy levels by solving Schrödinger's equation; this data is then used in the gain computations.

Dr. Ronald Broeke, founder of BP, received his Ph.D. degree in electrical engineering from the Delft University of Technology in the Netherlands, on the design, fabrication and characterization of photonics integrated circuits (PIC) for WDM networks. Researcher at the University of California at Davis on applications like optical cdma and arbitrary waveform generation, followed by several years at ASML (world leader in wafer-steppers) engaging in hands-on project management and business intelligence systems of the R&D department.

1.3 SKILLS, OUTCOMES AND METHODOLOGY

With these contents, the students have acquired a set of **competences**:

- Ability to project, calculate and design products, processes and facilities in photonics areas.
- Capacity for mathematical modeling, calculation and simulation in engineering companies, particularly in research, development and innovation tasks in areas related to photonics and associated multidisciplinary fields.
- Ability to apply acquired knowledge and to solve problems in new or unfamiliar environments within broader and multidiscipline contexts, being able to integrate knowledge.
- Ability to apply advanced knowledge of photonics, optoelectronics and high-frequency electronics.

As well as proposed **learning outcomes**:

1. Functional knowledge of the essential photonic devices for optical communications: LEDs and lasers, photodetectors, optical modulators, couplers, circulators, AWG, fibre amplifiers, semiconductor optical amplifiers, optical filters, single-mode fibres, multi-mode fibres and multicore fibres.

2. Knowledge of the noise models used to characterise the optical transmitter subsystems, optical amplifiers and receivers, and capacity to calculate its impact in terms of the signal to noise ratio and error probability.
3. Knowledge of the physical concepts underlying semiconductor physics, band gaps, electrical and optical properties and their application to physical devices.
4. Understanding and mastering of the basic concepts on the general laws of Mechanics and Thermodynamics; Ability to use the basic instrumentation to measure physical quantities.

The **methodology** applied was based in:
Lectures: The professor introduces the main contents of each chapter to the students. These lectures did not cover all the contents of each subject. For that reason, the students had to review the supplementary notes provided in class. It is also expected that the students reviewed the concepts introduced in the classroom and expand on their contents using the guide of each chapter, together with the recommended bibliography, as a reference.
Laboratory: The lectures included some exercises in the lab involving different optical devices and optical communication systems.
Case studies: It consisted on activities that complement the master sessions and allow a better understanding of the theoretical concepts.