



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

### **Deliverable D6.2 (D21)**

#### Scientific Courses – SC2

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## Abstract

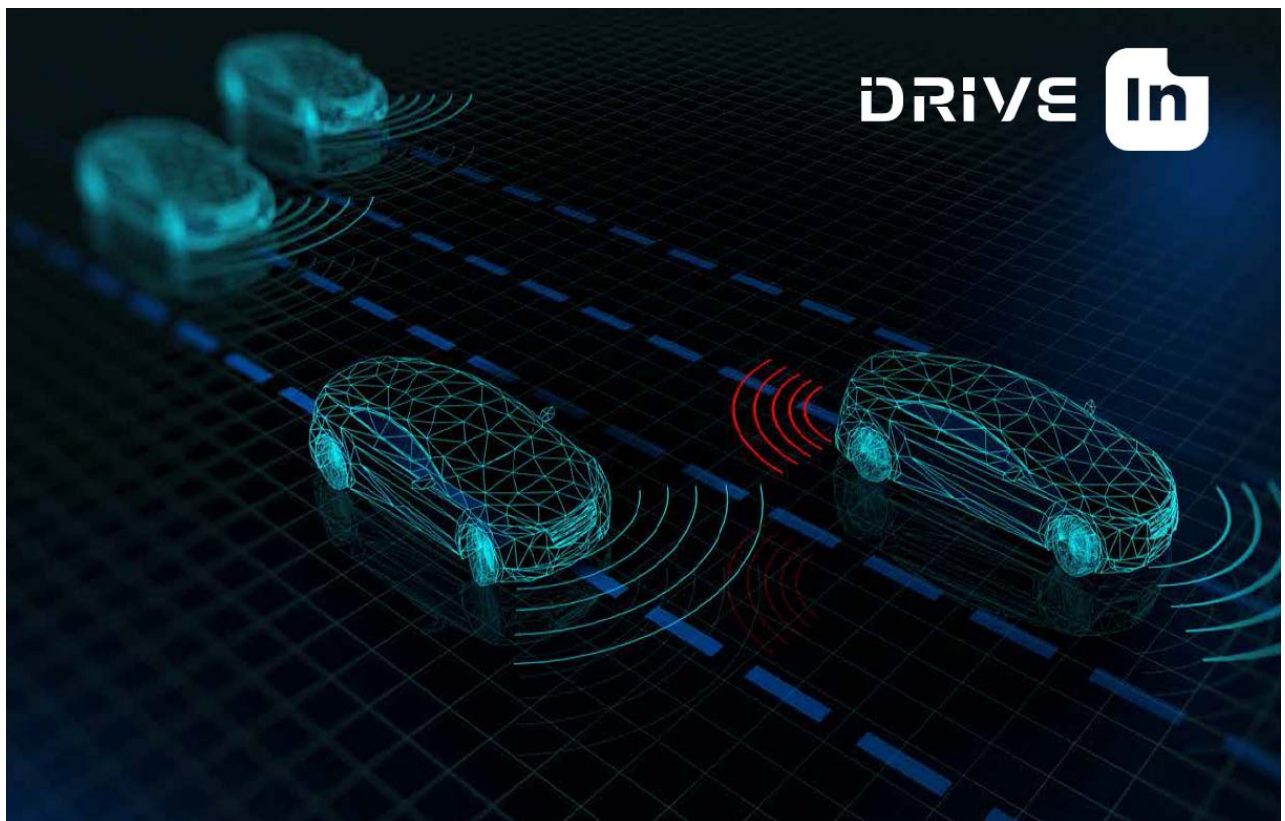
Through the Doc-TIC PhD Programme a number of course modules in areas related to photonics (active and passive devices), quantum mechanics, solid-state physics and integrated photonics are given to the ESRs. This second of group of Scientific-based courses (SC2) offered to each ESR is already tailored to refresh previous concepts and as an introduction to modern physics concepts and photonics.

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

## Change Record

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## 1. INTRODUCTION

The aim of this report is to provide a brief overview of the second **Scientific Course** 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 circuitual 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 sensing 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 group of Scientific-based courses (SC2) offered to each ESR, will allow them to obtain ten ECTS** (60 lecturing hours and 40 hours of homework).

## 1.1 SCIENTIFIC COURSE 2

In the following Table we describe the fundamentals of these first 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 Weeks
Lead	UVigo		
<b>Contents:</b> 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 basis for the design and behaviour of materials and devices.			
<b>Skills for ESRs:</b> 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 to interfaces with semiconductor materials.			
Title	Integrated Photonics' Devices (SC2)	Month: 10	Duration: 1 Month
Lead	UVigo		
<b>Contents:</b> 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 that can be designed and fabricated will be studied.			



<b>Skills for ESRs:</b> 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 active/passive devices and circuit simulation structures.			
Title	Photonic integration: software tools and design flow intensive training (SC3)	Month: 11	Duration: 2 weeks
Lead	UVigo		
<b>Contents:</b> 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 sensing 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, the course ends with a broad view on building block and compact models' generation, PDK design and characterization process.			
<b>Skills for ESRs:</b> 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 Weeks
Lead	HHIF		
<b>Contents:</b> 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 spectral analysis) and photodetection (responsivity and dynamics). Proper interpretation of the results is included.			
<b>Skills for ESRs:</b> 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 photonic integrated circuits are measured and tested including electrical and optical characterization.			
Title	Photonic Integration: device and circuit simulation (SC5)	Month: 12	Duration: 3 Weeks
Lead	BP		
<b>Contents:</b> 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 circuits for the different WPs.			
<b>Skills for ESRs:</b> 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 ESRs.			

## 1.2 SYLLABUS

The outline of this course is described below.

### Photonic Integrated Devices Design (SC2) Prof. Jose Ramon Salgueiro

#### 1. Introduction

Optics for communications. Integrated optics. Waveguides. Types of waveguides. Fabrication technologies.

#### 2. The step-index planar waveguide

Geometrical analysis. Propagation and radiation modes. TE and TM modes. Electromagnetic analysis. Energy carried by the modes. Mode excitation and coupling. Experimental techniques.



### 3. Graded-index planar waveguides

Parabolic profile. Variational method. WKB method.

### 4. Channel waveguides

Introduction and examples. Modal equations. Scalar approximation. Marcatilli's method. Effective index method.

### 5. Modal coupling theory

Coupled modal equations. Parallel waveguides. Symmetric waveguides. Proximity couplers. Y-junctions.

### 6. Numerical methods

Modal analysis in the frequency domain. Beam propagation methods. Time-domain simulation methods.

### 7. Optical fibers

Types of fibers. Propagation modes. Step-index fibers. Weak-guiding approximation. LP modes. Dispersion phenomena in optical fibers. Attenuation in optical fibers.

### 8. Photonic crystals and metamaterials

Miscellaneous topics

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**Prof. Jose Ramon Salgueiro**, PhD in Physics from University of Santiago de Compostela (Spain) in 2001 working with the Group of Integrated Optics and Optical Fibers. After his PhD he became assistant professor at the University of Vigo in Ourense (Spain) working in nonlinear optics with the Physical Optics Group. In 2002, he joined for two years the Nonlinear Physics Group at the The Australian National University in Canberra (Australia). Then, he had a tenure track contract of the Ramón y Cajal program in 2005 at the University of Vigo, where he is currently Professor and researchs on the fields of photonic crystals, nonlinear optics and quantum optics.





### 1.3 SKILLS, OUTCOMES AND METHODOLOGY

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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.



## 1.4 AGENDA

The agenda for SC2 can be found below. With this schedule the students fulfilled the ten ECTS intended for these scientific courses with an intensive training scheme. There was an introductory session with ESRs and lecturers to provide a first basis to develop the learning plan, meeting in person with all the ESRs and answering doubts or questions. Despite the situation due to the pandemia, lectures have been held in a face-to-face mode.

**SC1a: Photonics, quantum mechanics, solid-state physics**  
**SC1b: Laser physics, nonlinear optics, quantum optics**  
**SC2: Photonic integrated devices design**  
**SC3: Photonic integration: software tools and design flow intensive training**  
**SC4: Photonic integration: technology, fabrication and characterization**

Week 1	Mon sep 21	Tue sep 22	Wed sep 23	Thu sep 24	Fri sep 25	Sat sep 26	Sun sep 27		
9:00									
10:00			DRIVE-IN KICK OFF MEETING						
11:00									
12:00									
13:00									
14:00									
15:00									
Week 2	Mon sep 28	Tue sep 29	Wed sep 30	Thu oct 1	Fri oct 2	Sat oct 3	Sun oct 4		
9:00									
10:00		SC1a	SC1b	SC2					
11:00									
12:00									
13:00									
14:00									
15:00									
16:00									
17:00									
18:00									
19:00									



Week 3	Mon oct 5	Tue oct 6	Wed oct 7	Thu oct 8	Fri oct 9	Sat oct 10	Sun oct 11
9:00							
10:00	SC1a	SC1a	SC1b	SC2	SC2		
11:00							
12:00							
13:00							
14:00							
15:00			SC1b	SC1b			
16:00							
17:00							
18:00							
19:00							
Week 4	Mon oct 12	Tue oct 13	Wed oct 14	Thu oct 15	Fri oct 16	Sat oct 17	Sun oct 18
9:00							
10:00	SC1a	SC1a	SC1b	SC2	SC2		
11:00							
12:00							
13:00							
14:00							
15:00			SC1b	SC1b			
16:00							
17:00							
18:00							
19:00							
Week 5	Mon oct 19	Tue oct 20	Wed oct 21	Thu oct 22	Fri oct 23	Sat oct 24	Sun oct 25
9:00							
10:00	SC1a	SC1a	SC1b	SC2	SC2		
11:00							
12:00							
13:00							
14:00							
15:00			SC1b	SC1b			
16:00							
17:00							
18:00							
19:00							



Week 6	Mon oct 26	Tue oct 27	Wed oct 28	Thu oct 29	Fri oct 30	Sat oct 31	Sun nov 1
9:00							
10:00	SC4	SC4	SC4	SC4			
11:00							
12:00							
13:00							
14:00							
15:00			SC1b	Sc1b			
16:00							
17:00							
18:00							
19:00							

