DRIVE In

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

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Comprehensive Education Programme Report

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Abstract

Through the Doc-TIC PhD Programme a number of course modules in canonical areas related to photonics (active and passive devices), quantum mechanics, solid-state physics and integrated photonics are given to the ESRs. Moreover, other collateral as transferable skills training courses were given to the students. Besides, some other extra training was accesible to students. In this report, the overall collection of these trainings and final comments are exposed.

Keywords: Open Access, Media, Events, Training, Education

Change Record

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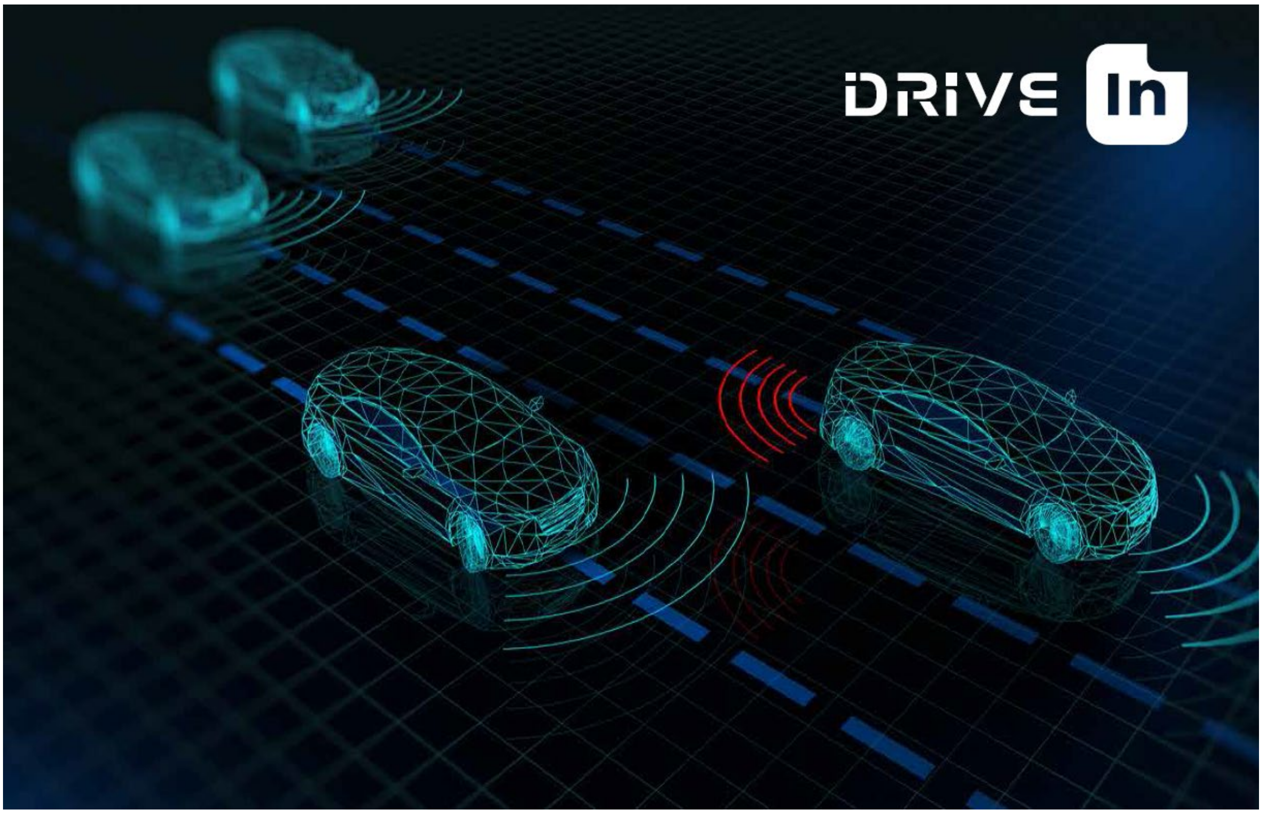
DRIVE In

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1. INTRODUCTION

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**.

In the next sections we describe the contents of the Education Programme provided in DRIVE-In, the number of attendants, main topics covered by each Course or training and relevant aspects of each of them.

1.1 SCIENTIFIC COURSES

The first group of courses were those related to technology and science:

Title	Fundamentals on Microelectronics, Photonics and Quantum Mechanics (SC1)	Month: 9	Duration: 3 Weeks
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 basis for the design and behaviour of materials and devices.			
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 to interfaces with semiconductor materials.			
Title	Integrated Photonics' Devices (SC2)	Month: 10	Duration: 1 Month
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 that can be designed and fabricated will be studied.			

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 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		
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, the course ends with a broad view on building block and compact models´ generation, PDK design and characterization process.			
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 Weeks
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 spectral analysis) and photodetection (responsivity and dynamics). Proper interpretation of the results is included.			
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 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		
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 circuits for the different WPs.			
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 ESRs.			

The outline of the first group of scientific courses, ***SC1***, focused ***on basic physics and photonics*** is described below.

Photonics, quantum mechanics, solid-state physics (SC1a) Prof. Francisco Javier Fraile-Pelaez

1. Basic Concepts of Photonics and Optical Communications
2. Electromagnetic Formalism of the Propagation and Amplification of Light
3. Laser Oscillation
4. Basic Nonlinear Optics
5. Direct and Coherent Optical Detection. Noise
6. Fundamentals of Quantum Mechanics

7. Fundamentals of Semiconductor Physics
8. Semiconductor Optical Sources and Amplifiers

Classical and Modern Physics (SC1b) Prof. Angel Paredes Galan

1. Introduction: from electromagnetism to optics
2. Laser physics
    - Laser oscillation: basic concepts.
    - Interaction of radiation with matter and line broadening.
    - Passive optical resonators.
    - Pumping.
    - Rate equations.
    - Pulsed lasers.
    - Types of lasers.
3. Nonlinear optics
    - The nonlinear wave equation.
    - Frequency mixing.
    - The Kerr effect and nonlinear effects on beam propagation. Numerical simulation.
4. Quantum optics
    - Photon statistics.
    - Coherent states and squeezed light.
    - Cold atoms.
    - Quantum information processing.

APPENDIX: Extra topics
- Relativistic / ultrafast optics
- Optical tweezers
- Optical clocks
- Topological photonics

Prof. Francisco Javier Fraile Pelaez has more than 25 years of experience in research areas like optoelectronic devices, optical communications, nonlinear optics and quantum optics. He has supervised more than 10 PhD. students and 3 postdocs. He is national evaluator from the Spanish

Ministry of Education and ANEP auditor. He has more than 50 articles and has written two internationally recognized books on optical communications.

Prof. Angel Paredes Galán is Ph. D. in Particle Physics from the University of Santiago de Compostela in 2004. Postdoctoral stays at École Polytechnique (France) - as a Marie Curie fellow - , University of Utrecht (the Netherlands) and University of Barcelona (Spain). His current research interests lie at the intersection of particle physics, many body quantum physics and laser-driven optical technologies.

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.

A different scientific intensive course was given, ***SC2, related to optoelectronic devices design***. In the following paragraph we describe the syllabus and topics covered.

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

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 nonlinaear 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 researches on the fields of photonic crystals, nonlinear optics and quantum optics.

A new set of skills and competencies were acquired by the ESRs in a new course, ***SC3, in this case devoted to software modeling.***

The outline of this course is described below. The training included in SC3 is fundamentally oriented to software and programming (design flow and simulation software tools) and for that reason this type of course is the most suitable to be taught online.
Topics covered in the course: 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.

Scientific Course SC3: Software tools and design flow intensive training (Dr. Katarzyna Lawniczuk)

1. **Introduction**: PIC requirements and specifications depending on the specific application. Technology selection.
2. **PIC technologies (SOI, InP, SiN, glass).** PIC design constraints related to technology and across multiple packages. How the PIC specifications and technology selection influence the circuit design. How to carefully design your PIC to accommodate the circuit into the mask layout.
3. To learn to use **PIC design with Nazca Design in Python**:
    a. To **get started and directions** into the more advanted features of circuit integrity validation, GDS manipulation and PDK development.
    b. **The role of Nazca** in the PIC development chain and how an open source design tool with community and commercial support provide long term security, flexibility and innovation.
4. **Hands-on through an example: A PIC transceiver**. Design flow tool. Foundry and technology definition. Layout design and verification. Mode solving. Data processing.

Dr. Katarzyna Ławniczuk was awarded a joint Ph.D. degree from Eindhoven University of Technology, the Netherlands, and Warsaw University of Technology, Poland, in 2014. Her research focused on Indium Phosphide-based multiwavelength lasers and photonic integrated transmitters. She was the coordinator of JePPIX at Eindhoven University of Technology from 2013 to 2016

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.

Another scientific course***, SC4, devoted to fabrication***, was taught in DRIVE-In. The outline of this course is described below. SC4 has been taught in a virtual mode by Dr. Francisco Soares, former Senior Scientist in HHI Fraunhofer.

Topics covered in the course were: crystal properties of semiconductors, substrate manufacturing, vacuum technology, epitaxy, lithography, wet and dry etching, plasma deposition, metallization.

Scientific Course SC4: Technology, fabrication and characterization (Dr. Francisco Soares)

Basics of this course: 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.

Syllabus

1. Technologies, materials and properties.
2. Foundry platforms and fabrication technologies: Group IV and III-V.
3. Applications depending on the technologies.
4. Introduction to characterization: the characterization part explains how the basic parameters of a realized device can be determined.
5. Electrical properties: diode characteristics, contact and sheet resistances based on IV measurements have been explained, including the interpretation of the results.
6. Optical characterization:
    a. Waveguide propagation loss (Fabry-Perot measurement).
    b. Electrooptic phase shifting (interferometric measurement).
    c. Gain measurement (Thomson method).
    d. Laser emission (LI curves and spectral analysis) .
    e. Photodetection (responsivity and dynamics). Proper interpretation of the results is included.

Dr. Francisco Soares has more than 20 years experience in the design, fabrication, and characterization of photonic integrated circuits (PICs). His main expertise is in PICs based on Indium-Phosphide technology, but he is also experienced in several other technologies as well, such as silica waveguide technology, Silicon-On-Insulator technology, and the polymer technology. He has worked in four different cleanrooms (in Europe and the US) developing fabrication processes for realizing PICs. He was one of the first researchers to implement the generic foundry model in the InP technology for realizing highly-integrated PICs containing DFB lasers, optical amplifiers, high-speed Mach-Zehnder modulators, high-bandwidth photodetectors, and all kinds of passive devices. He has supervised one PhD Student, and around five MSc Students. He has authored and co-authored more than 50 publications, and co-authored one chapter in a book.

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.

Finally, a ***course on PIC design and layout structure, SC5***, was given in DRIVE-In. 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.

In addition to the scientific-based training, DRIVE-In offered to all ESR specific short-term hand-on training which provided the ESRs with skills in highly experienced organizations, receiving cutting-edge technological knowledge and skills. These hands-on training have been provided at the same time the ESRs are seconded to Partner Organizations providing the courses, i.e. BP, and were aimed to explore knowledge in circuit simulation and packaging.

In the following Table we describe the fundamentals of these technical hands-on courses and corresponding skills acquired by the ESRs.

Title	Hands-on JeppiX training (TC1)	Month: 13	Duration: 2 Weeks
Lead	UVigo		
Contents: To get an overview of the latest status of the integrated photonics eco-system for the three major photonics technologies: InP, silicon photonics and TriPleX (SiN). This overview will include the available design tools and the importance of considering test and packaging in an early stage. The unique combination of lectures and hands-on training will teach how to perform circuit simulations, including fabrication tolerances, how to use and develop a PDK and how to set-up libraries in a structured way. Several Software tools will be used for this purpose (Synopsys Optodesigner, VPI, Lumerical).			
Skills for ESRs: Get introduced to Integrated Photonics Design Flow Automation. Learn the use of photonic integrated circuit simulation tools. Obtain in-depth knowledge of integrated design from mask to photonic and process flow simulations. Exchange experiences and ideas with other participants. Learn different technologies for integrated devices, other software tools, cleanroom processing and testing mechanisms.			
Title	Hands-on VPI Photonics (TC2)	Month: 13	Duration: 2 Weeks
Lead	VPIP		
Contents: To learn a suite of robust circuit solvers for integrated photonics structures, using HHIF PDKs. It supports time and frequency domain solvers, and large number of complementary algorithms which allows it to solve a large variety of photonics and electronics problems which may be made of any material and of almost any geometry. VPI Photonics allows product modelling, design and optimization of heterogeneous PICs, linear electric circuits, and multisection optoelectronic devices and can show how the current co-simulation with electronic software (Keysight ADS) works and highlight the current limitations. Designed optoelectronic devices cover applications such as widely tuneable and mode-locked lasers, gain-clamped SOAs, electro-absorption modulators, wavelength converters and 2R/3R optical regenerators, etc. Designed PICs cover applications such as coherent transmitters and receivers for advanced modulation formats, optical interconnects, recirculating optical buffers and reconfigurable delay lines, multi-ring filters and arrayed waveguide gratings, and practically any other monolithically integrated or hybrid PICs based on silicon (Si), indium phosphide (InP) or gallium arsenide (GaAs) substrates. VPIPhotonics optical design and configuration products come with an extensive library of over 700 demonstration applications.			
Skills for ESRs: to learn how to model InP related devices, subsystems and circuits; how to optimize their performance, perform the layout and mask simulation, optimize structures according to specifications sweeping parameters and gain knowledge on programming and scripting aspects. Design topics include: Graphical User Interface features, Overview of signal models and simulation technique, Parameter sweeps and optimizations, Visualization and post-processing of simulation results, Scripted simulations and automated system design			
Title	Automotive ADAS devices and specifications (TC3)	Month: 14	Duration: 1 Week
Lead	CTAG		
Contents: A full course on ADASs. It will give an overview about sensor types, topologies, and system setups today. It will show later on examples based on camera sensors, radar sensors, lidar, free space optics communication systems inside and outside the car, types of Advanced Driver Assist Systems. It will introduce driver assist systems associated with the windshield and their related concerns. This module provides an overview of some of these systems and how they assist the driver. These include: Lane departure warning and lane keep assist systems; Collision mitigation systems; Pre-collision systems; Automatic high-beam assist systems; Night vision systems; Head-up displays; Automatic Windshield Wipers.			
Skills for ESRs: An introduction and overview towards ADASs, algorithms devices and electronics technologies to develop ADASs; specifications and guidelines to produce devices with enhanced performance; interdisciplinary knowledge in photonics and electronics applied to automotive disciplines.			

Since the training included in TC1 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 specifications, PIC technologies and design, cells and layer, interconnect, building block and PDK creation, GDS introduction and advanced manipulation, connection DRC, circuit level path-tracing and compact models.

Technical Hands-on Course TC1: Jeppix Training (Dr. Katarzyna Lawniczuk)

5. **Introduction**: PIC requirements and specifications depending on the specific application. Technology selection.
6. **PIC technologies (SOI, InP, SiN, glass).** PIC design constraints related to technology and across multiple packages. How the PIC specifications and technology selection influence the circuit design. How to carefully design your PIC to accommodate the circuit into the mask layout.
7. To learn to use **PIC design with Lumerical and Nazca Design in Python**:
    a. To **get started and directions** into the more advanted features of circuit integrity validation, GDS manipulation and PDK development.
    b. **The role of Nazca** in the PIC development chain and how an open source design tool with community and commercial support provide long term security, flexibility and innovation.
8. **Hands-on through an example: A PIC transceiver**. Design flow tool. Foundry and technology definition. Layout design and verification. Mode solving. Data processing.

A second TC, number 2, was related to VPI Photonics software. The outline of this course is described below. Topics covered in the course: design waveguides and fibers, automate the design of photonic integrated circuits, design fiber-based devices such as doped-fiber amplifiers, and ultimately simulate high-speed optical transmission systems. Each day includes software access and an 8-hour virtual session of lectures, guided labs, and independent work with 1-on-1 support.

Technical Hands-on Course TC2: Hands-on VPI Photonics (Dr. Eugene Sokolov)

Section 1.

Cross-section design (waveguide-based example)

- Predefined and custom materials
- Nonuniform meshing

- Various layout shapes
- Best solvers for desired applications
- Mode visualization
- Extraction of circuit-level parameters

BPM for 3D photonic integrated devices

- Expanding the cross-section into 3D structures
- Simulation of basic integrated components such as Waveguides, Bends, S-bends, etc.

Section 2.

- Photonic design environment & getting started
- Passive photonic components: waveguides, ring resonators, AWGs
- Active photonic elements: lasers, amplifiers, tunable optoelectronic components
- Heterogeneous PICs combining active and passive photonics
- Hybrid PICs combining different technologies
- Application cases, your own designs

Section 3.

- Simulation of Erbium- and Thulium-doped fiber amplifiers
- Design multi-pump Raman amplifiers
- Optimization of fiber amplifier design
- Characterization of fiber amplifiers

Section 4.

- High-speed access networks
- Optical interconnects for datacenter applications
- Performance assessment of PAM-4 signals
- Fundamental automation techniques
- DSP demodulation for high-order coherent M-QAM systems
- Mitigation of transmission-induced impairments using DSP
- Performance comparison of different modulation formats
- Exploring benefits of probabilistically-shaped QAM constellations and FEC coding
- Investigation of nonlinear interference noise in WDM systems

Section 5.

- GPU and Parallel Simulation
- Simulation scripts and Macros
- API (Cosimulation and Simulation Engine Driver)
- Design your own schematics

Finally TC3 has been held between 8-12 March 2021 as online seminar (10:00-13:00). Topics covered in the course: Understanding the Advanced Driver Assistance Systems (ADAS) in general; the role of ADAS towards Autonomous Driving; sensors used in ADAS; how various ADAS systems are tested in Industry; ADAS systems explained with animations and industrial examples; role of Machine Learning and Deep Learning in latest ADAS development

Technical Hands-on Course TC3: Automotive ADAS devices and specifications (Mr. Diego López – Technical team leader)

1. **Introduction to Automated, Connected, and Intelligent Vehicles**
   • Introduction to the Concept of Automotive Electronics
   • Automotive Electronics Overview
   • History & Evolution
   • Infotainment, Body, Chassis, and Powertrain Electronics
   • Advanced Driver Assistance Electronic Systems

2. **Connected and Autonomous Vehicle Technology**
   • Basic Control System Theory applied to Automobiles
   • Overview of the Operation of ECUs
   • Basic Cyber-Physical System Theory and Autonomous Vehicles
   • Role of Surroundings Sensing Systems and Autonomy
   • Role of Wireless Data Networks and Autonomy

3. **Sensor Technology for Advanced Driver Assistance Systems**
   • Basics of Radar Technology and Systems
   • Ultrasonic Sonar Systems
   • Lidar Sensor Technology and Systems
   • Camera Technology
   • Night Vision Technology
   • Other Sensors
   • Use of Sensor Data Fusion
   • Integration of Sensor Data to On-Board Control Systems

4. **Connected Car Technology**
   • Connectivity Fundamentals
   • Navigation and Other Applications
   • Vehicle-to-Vehicle Technology and Applications
   • Vehicle-to-Roadside and Vehicle-to-Infrastructure Applications
   • Wireless Security Overview

5. **Advanced Driver Assistance System Technology**
   • Basics of Theory of Operation

- Applications – Legacy
- Applications – New
- Applications - Future
- Integration of ADAS Technology into Vehicle Electronics
- System Examples
- Role of Sensor Data Fusion

6. Impaired Driver Technology
- Driver Impairment Sensor Technology
- Sensor Technology for Driver Impairment Detection
- Transfer of Control Technology
- Advanced Driver Assistance System Sensor Alignment and Calibration

1.2 TRANSFERABLE SKILLS TRAINING

Sometimes it's difficult for PhD students to identify what skills they have since the academic experience is not necessarily focused on articulating skill sets. We also often find that PhD students struggle, understandably, to present the transferability of their academic experiences to non-academic contexts. In the DRIVE-In project we provided the ESRs with a set of Transferable Skill Courses that help them solve some of these problems. Specifically, we have designed some courses on these areas:

Entrepreneurship Skills

- Facilitate group discussions or conduct meetings
- Motivate others to complete projects (group or individual)
- Respond appropriately to positive or negative feedback
- Effectively mentor subordinates and/or peers
- Collaborate on projects
- Teach skills or concepts to others
- Navigate complex bureaucratic environments

Project Management & Organization

- Manage a project or projects from beginning to end
- Identify goals and/or tasks to be accomplished and a realistic timeline for completion
- Prioritize tasks while anticipating potential problems
- Maintain flexibility in the face of changing circumstances

Written & Oral Communication

- Prepare concise and logically-written materials
- Organize and communicate ideas effectively in oral presentations to small and large groups
- Write at all levels — brief abstract to book-length manuscript
- Debate issues in a collegial manner and participate in group discussions
- Use logical argument to persuade others
- Explain complex or difficult concepts in basic terms and language
- Write effective grant proposals

1.2 TRANSFERABLE SKILL COURSES

The Transferable Skill Courses included in the DRIVE-In program were:

Title	***Project management (TSC1)***	**Month: 40**	**Duration: 1 Week**
Lead	UVigo		
Contents: This course will give an introduction into the basics of project management in particular to the notions of project life cycle, milestones, deliverables, special requirements of complex R&D projects, work breakdown structure and work packages, cost projection and risk assessment, communication, etc. Exercises will be provided from the many years of experiences with coordinating projects funded by the European Commission.			
Skills for ESRs: The ESRs learn to properly set-up and plan a project with new approaches to time management.			
Title	***Scientific writing and dissemination (TSC2)***	**Month: 40**	**Duration: 2 Weeks**
Lead	UVigo		
Contents: The purpose of this seminar is the improvement of written English skills specifically e vocabulary and styles required for scientific writing. Resource materials and strategies for verifying the specificity and correctness of specialty vocabulary for scientific papers and publications will be made available to the participants and discussed. These materials can be used by the participants to continue improvement of writing skills after the seminar.			
Skills for ESRs: The ESRs learn how to use written language effectively to present scientific data for scientific publishing. To learn how to deal and manage innovation processes in company, to understand the workflow of innovation and research in a company department, to learn how to manage the ESR´s scientific career, to evaluate and develop a proposal for an European project.			
Title	***Entrepreneurship (TSC3)***	**Month: 42**	**Duration: 1 Week**
Lead	UVigo		
Contents: The course covers the essentials on:- ***Day 1*** - Business Models and Business plan construction; Business mission statement, vision, products & services; Definition of the target markets using the Value Proposition Canvas; Understanding the target industry;- ***Day 2 -*** The basics of marketing and marketing for different Products or Service types: The internet side of marketing; Developing a market communications plan including how to communicate benefits and competitive advantages; Promotional components to help reach target customers including estimated costs - ***Day 3*** **-** Legal and Operations Understanding the different legal entities and pros and cons of each; Basics of employment law, workers' compensation & unemployment compensation - the difference between independent contractors and employees; Basics of patents, copyright, trademarks & trade secrets - Buying a business or franchise - An overview of business operations (Technology needs, Location, Risk Management); Human Resource Management and Operations - Management/personnel regulations and job descriptions - Hiring the first employee, including recruiting & interviewing - Operations Continued; Accounting and Record Keeping; Financing- crowdfunding, angel and venture capital - Importance factors including credit for bank financing - Steps for applying for a loan - Different reasons for borrowing money (start-up, cash flow, capital equipment, expansion, etc.			
Skills for ESRs: Analyse customer value creation; Conduct an initial novelty screening and draft a patent application; Draft a business plan on a selected subject; Analyse team member skills, competencies and experience Identify business opportunities in industrial challenges.			

TSC2- SCIENTIFIC WRITING AND DISSEMINATION (40 HOURS)

Scientific writing and publishing

- Develop writing skills and confidence writing for journals
- Understand editorial processes and what editors look for
- Learn best practices for submitting a paper and peer review

Effective collaboration in research

- Understand the different forms, benefits, and challenges of collaborative research
- Develop key collaborative skills such as communication and teamwork
- Learn how to initiate and run a successful collaboration
- Learn how to maximize the value of, and conclude, a collaborative project

Data Management & Narrative Tools for Researchers

- Understand the benefits of managing research data effectively
- Learn the steps required to create and maintain a data management plan
- Learn how to apply best practices to organise, store, archive and check the quality of your data
- Evaluate the different options for sharing research data
- The importance of conducting effective data analysis
- The best tools for exploring various datasets
- The range of analytic methods available and understand which is most suited to your data
- Strategies for obtaining feedback, troubleshooting and expressing the limitations of your analysis

Grant Writing, Networking, Communications and Experimental Design

- Understand how narrative tools can improve the quality of your grant applications
- Learn to align your grant proposal with the requirements and objectives of your chosen funder
- Learn how to apply narrative tools when writing their grant proposal to make it more informative, persuasive and engaging

- Identify techniques that can help to overcome the challenges that researchers commonly experience when delivering oral presentations
- Learn how to build compelling research stories to use as the foundation for your presentations
- Learn how to create professional slide decks that effectively communicate research findings to your audience
- Learn how to apply strategies to help you deliver your presentation effectively on the day, in both virtual and face-to-face environments

- Understand the theory behind and the importance of networking, and how to use your research and career goals to guide you to find appropriate networking opportunities
- Learn how to research and prepare key resources to help you build an effective network
- Learn strategies to approach and connect with potential contacts, and how to follow up – both in person and online
- Learn strategies for nurturing your networking contacts, and how to leverage them to advance your research and career

TSC1- PROJECT MANAGEMENT (150 HOURS)

Upon completion of the Nature Masterclass Course, ESRs are able to:

- Understand project management design, development, and deployment
- Use project management tools, techniques, and skills
- Employ strategies to address the ubiquitous issue of resistance to change
- Align critical resources for effective project implementation
- Understand the implications, challenges, and opportunities of organizational dynamics in project management
- Identify and use key performance metrics for project success
- Understand how to manage project cost, quality, and delivery
- Engage and lead effective project management teams in your organization
- Impart project management knowledge, tools, and processes to your colleagues
- Recognize and mitigate the early seeds of failure in the project life cycle

The syllabus of the course is:

The Right Start: Preparing people and organizations for the challenge of change: Identify and link the three essential elements of true innovation

- Examine insights into the antecedents and consequences of project failure
- Summarize the characteristics of a change-adverse workforce
- Identify the driving force in establishing individual readiness for change
- Define three domains required to create organizational readiness for change
- Discuss, interpret, and ascribe meaning to a typology for change initiatives
- Examine seven critical success factors for launching change initiatives
- Understand the structure and expectations of MGMT 5030 Project Management

Strategic Excellence in Project Management: Project Activation Management System (PAMS) Process for Project Management

- Consider the definition and common attributes of a project
- Understand stakeholders' key to the early development of a project

Phase II: The Start-Up Process. Introduction to Green-Lighted Projects PAMS Process for Project Management

- Review the steps in the Start-Up process
- Understand how to build a strong project foundation
- Discuss the challenges and opportunities of working in a team
- Discuss the team expectations document that teams created
- Consider strategies to influence without authority

Phase III: "Develop" – Preparing Projects for Launch PAMS Process for Project Management

- Explore elements of key project management tools including WBS, schedule, budget
- Understand risk mitigation strategies
- Consider key performance metrics
- Discuss scope and scope statements

Phase IV: "Implement" PAMS Process for Project Management

- Construct the final project implementation plan
- Manage plan revisions and change control

- Conduct problem solving and stakeholder management
- Discuss strategies for monitoring the project implementation plan

Phase V: "Close" PAMS Process for Project Management

- Explore the process for closing out the project
- Capture Lessons Learned
- Highlight the importance of project team recognition

Tales and tips from the Field: Enable East Case Studies

Project Presentations, assignments

TSC 3 – ENTREPRENEURSHIP (120 HOURS)

The ESRS received an additional online training on Entrepreneurship in a seven modules training:

Strategic Innovation: Building and Sustaining Innovative Organizations

- Understand key ideas about innovation and product strategy
- Strategize for value capture in a business model
- Critically examine the roles of various players in a business ecosystem

Strategic Innovation: Managing Innovation Initiatives

- Analyze innovations and their impact on organizations
- Articulate a research-informed perspective on innovation
- Utilize frameworks, tools, and concepts to address challenges that arise in innovation

Creativity Toolkit I: Changing Perspectives

Design pitches for innovative ideas to build excitement and clarity
-Evaluate the pitches of others to identify great new ideas
-Lead groups to foster effective collaboration for innovation

Entrepreneurship I: Laying the Foundation

- Develop a foundational understanding of the entrepreneurial process
- Consider the relationship between growth and error
- Understand how particular opportunities influence entrepreneurial phenomena

Entrepreneurship II: Preparing for Launch

- Develop an understanding of what is required in a new venture
- Create a plan to identify and approach your first customers
- Build financial projections for the new venture
- Understand how to raise equity capital for the new venture
- Monitor the health and scalability of a new venture

Innovation: From Creativity to Entrepreneurship Capstone

- A venture of one's own or within a larger organization
- To develop the current business model and compare against alternative business models so as to identify potential opportunities and challenges.

1.3 OTHER COURSES

Finally, other courses were offered as part of the education program of the ESRs:

- Winter School training:
  The four ESRs have been enrolled in a Winter School (26th of October - 06th of November 2020) taking advantage of the annual JePPIX Design Course. JePPIX (http://www.jeppix.eu/) is the joint European platform for photonic integrated components and circuits, established in 2006, and committed to driving the industrialisation and use of high performance indium phosphide, silicon nitride and hybrid photonic integration. JePPIX Partners representing all Photonics Supply chain work together to stimulate the evolution of integrated Photonics by defining standards, and optimising work flow to ensure the best insight into the technology. JePPIX also shares insights on the evolution of technology, emerging markets and applications, and future customer demands in the JePPIX Roadmap.

Our ESRs have been enrolled in this training, that is designed for students/researchers/professionals who have a good background in photonics and who wish to understand how to get the best out of design tools and the PIC technology. Experts from the Institute of Photonic Integration (formerly known as the COBRA Institute) are joined by specialist trainers from the Photonic CAD community, professional designers and experts from foundries to share insights and knowhow.
Participants gain first hand clean room experience and a detailed insight into the steps in designing and creating PICs. The Winter School covers the theory and practice of integrated photonic component and circuit design using the powerful JePPIX building blocks. Hands on training with lab tools and design tools are complemented with clean room tours to develop insights into design rules. Layout and simulation methods are developed with JePPIX CAD tool developers and professional designers.

In the first week of the Winter School, our ESRs have developed insights into mode analysis to better understand the design space for waveguide based integrated optics, how best to construct interferometers and filters. Active building blocks including semiconductor optical amplifiers, modulators and detectors have been introduced in terms of physical principles and practical implementation as components and circuit elements. Methods for laying out circuits have been developed. Hybrid and monolithic integration schemes have been described.

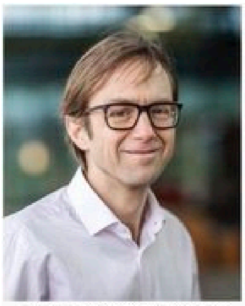
In the second week, the emphasis turned to practical skills, with the opportunity to trial commercial CAD tools, process design kits (PDKs) and develop insights with expert designers and leading academic instructors. Representatives from the foundries have also been available to talk through the latest platform capabilities. Visits to clean room facilities and measurements laboratories were included to provide insights into the role of fabrication tolerances and testing methods on design methods. Packaging have also been reviewed to ensure package, test and manufacture aware design.

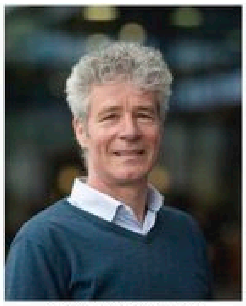
The technical program of this Winter School was:

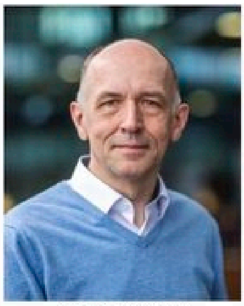
JePPIX Deep-Dive PIC Design Course 2020 – Week 1					
Time	Monday (26.10)	Tuesday (27.10)	Wednesday (28.10)	Thursday (29.10)	Friday (30.10)
09:00-10:00	Welcome & JePPIX Ecosystem *Sylwester Latkowski*	MMI couplers *Xaveer Leijtens*	Active components: SOA, lasers (Part 1) *Erwin Bente*	Processing introduction: Lithography, epitaxy, COBRA flow *Yuqing Jiao*	Active components: SOA, lasers (Part 2) *Erwin Bente*
10:15-11:15	Dielectric waveguide basics *Xaveer Leijtens*	Arrayed Waveguide Gratings *Xaveer Leijtens*	Simulation methods: mode, BPM, FDTD *Victor Calzadilla*		Standardization and packaging *Sylwester Latkowski*
11:30-12:30		Mode analysis *Xaveer Leijtens*	What is a mask? GDS, cell, PDK, DRC *Katarzyna Ławniczuk*		
Lunch break					
			Parallel sessions	Parallel sessions	Parallel sessions
13:30-14:30	2D confinement, propagation *Xaveer Leijtens*	Overview of software tools *Aura Higuera*	Software Hands-on NAZCA or PhotonDesign or Luceda*	Software Hands-on Nazca or PhotonDesign or Luce	Software Hands-on NAZCA or PhotonDesign or Luceda*
14:45-15:45	Curved waveguides, junctions *Xaveer Leijtens*	Participants' presentations			
16:00-17:00	Couplers and splitters *Xaveer Leijtens*	Mode analysis *Xaveer Leijtens*			

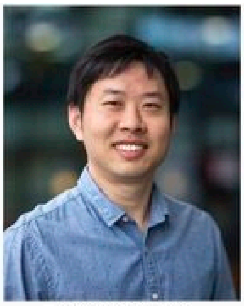
JePPIX Deep-Dive PIC Design Course 2020 – Week 2					
Time	Monday (2.11)	Tuesday (3.11)	Wednesday (4.11)	Thursday (5.11)	Friday (6.11)
09:00-10:00	Process tolerances and device design *Victor Calzadilla*	Workshop on the PHIsim PIC simulator *Erwin Bente*	Fraunhofer HHI *Moritz Baier*	KLayout *Dzmitry Pustakhod*	Evaluation 9:00-9:30
10:15-11:15	SMART Photonics *Nazanin Shafiee*	Lasers in InP technology *Erwin Bente*	LioniX International *Douwe Geuzebroek*	Characterization of optical chips *Marija Trajkovic*	Design with Experts 9:30-12:30
11:30-12:30	Why InP? Application examples *Anna Nikiel*	Practical hands-on worked example *Rastko Pajkovic*	From system specs to PIC design *Iñigo Artundo*	JePPIX MPW workflow and DRC *Xaveer Leijtens*	
Lunch break					
		Parallel sessions	Parallel sessions	Parallel sessions	
13:30-14:30	RF Components: MZI, EAM, Detectors *Weiming Yao*	Software Hands-on Ansys/Lumerical or Synopsys or VPIphotonics	Software Hands-on Ansys/Lumerical or Synopsys or VPIphotonics	Software Hands-on Ansys/Lumerical or VPIphotonics* or Synopsys*	
14:45-15:45					
16:00-17:00	Hybrid integration *Kevin Williams*				

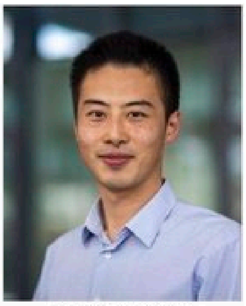
And the lecturers have been:

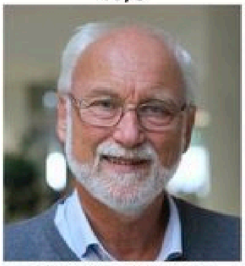

Prof. Dr. Kevin Williams
Full Professor and Chair of the Photonic Integration research group,
TU/e

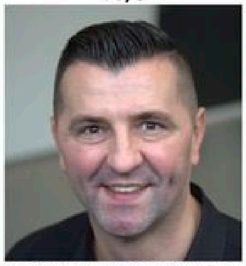

Dr. Xaveer Leijtens
Associate Professor in the Photonic Integration research group,
TU/e


Dr. Erwin Bente
Associate Professor in the Photonic Integration research group,
TU/e


Dr. Yuqing Jiao
Assistant Professor in the Photonic Integration research group,
TU/e


Dr. Weiming Yao
Scientist in the Photonic Integration research group,
TU/e


Prof. Dr. Meint Smit
Full Professor in the Department of Electrical Engineering,
TU/e

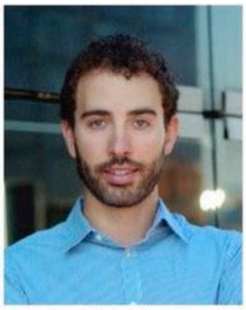

Dr. Sylwester Latkowski
Senior Researcher in the Photonic Integration research group,
TU/e


Dr. Victor Calzadilla
Scientist in the Photonic Integration research group,
TU/e


Dr. Luc Augustin
CTO,
SMART Photonics


Dr. Moritz Baier
Head of the Photonic InP Foundry group,
Fraunhofer HHI

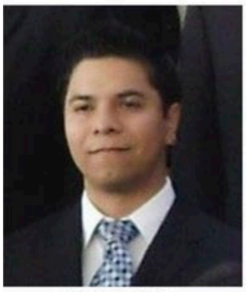

Dr. Douwe Geuzebroek
VP Marketing and Sales,
LioniX International


Dr. Iñigo Artundo
CEO,
VLC Photonics


Dr. Dominic Gallagher
CEO,
Photon Design


Dr. Ronald Broeke
General manager,
BRIGHT Photonics and Nazca Design


Dr. Pieter Dumon
Co-founder, CTO,
Luceda Photonics


Dr. Luis Orbe
Customer Support Coordinator,
Synopsys


MSc. Greg Baethge,
Senior Support Engineer,
Lumerical Inc.


MSc. Andrzej Polatynski,
Photonics Application Engineer,
VPIphotonics


Dr. Huub Ambrosius
Managing Director,
Nanolab TU/e


Dr. Dzmitry Pustakhod,
Scientist in the Photonic Integration research group,
TU/e

- Additional complementary skills training not included in the original proposal (all ESRs attended in virtual mode):
    - Nanophotonics and nanoelectronics. May 2020 – webinar
    - VLC Photonics Webinars - Photonic Integration Technology – Sep/Dec 2021
    - UVigo - How to manage a research project. Mar 2021
    - Synopsys workshop – How to simulate LiDAR systems. Mar 2021
    - From Waveguides to Optical Transmission Systems VPI training-Oct 2021