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Technical hands-on courses (TC) – TC2

Hands-on Fimmwave, PICWave and Harold Training

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Abstract
In addition to the scientific-based training, EDIFY offers to all ESR specific short-term hand-on training which can provide the ESRs with skills in highly experienced organizations, receiving cutting-edge technological knowledge and skills. These hands-on training will be provided at the same time the ESRs are seconded to Partner Organizations providing the courses, i.e. PBV, PDesign and BP, and are aimed to explore knowledge in circuit simulation and packaging.

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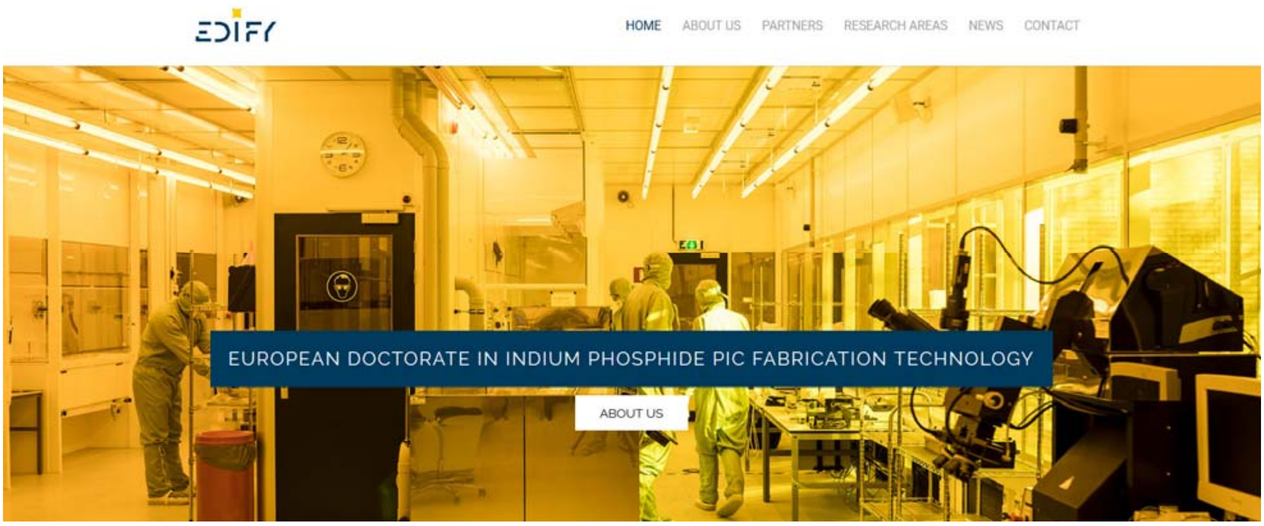
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1. INTRODUCTION

The aim of this report is to provide a brief overview of the second **Technical Hands-On-Course (TC2**) **– Hands-on Fimmwave, PICWave and Harold training**, organized in the framework of the project EDIFY. As a general introduction, the challenge for the EDIFY Training Network is to develop new fundamental skills on simulation, design, measurement automation, fabrication and validation, and organization in an integrated photonics foundry. These skills will help to develop a new generation of technology advances in material and semiconductor properties aimed for low loss waveguides, more efficient passive devices as well as aluminium containing quantum wells for active devices like semiconductor optical amplifiers, saturable absorbers, modulators and lasers. To achieve this, EDIFY 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 integrated photonics InP design, fabrication, characterization and modeling. To provide the opportunity for the fellows to be involved in the creation of a new line of industrial automation and organization of tasks in the InP foundry.
- TO2: To provide academic and industrial sector employers with researchers skilled in a wide range of techniques and methods, and direct experience of interaction across disciplines and sectors.
- 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 active/passive devices and enhance/optimize the process of automated integrated photonics fabrication to enable the future of photonics industry in Europe in the next years.
- TO5: To cascade expertise and spread good practice throughout Europe by personnel exchange, and delivering European researchers able to become leaders in the fields of integrated photonics design, fabrication and characterization and industrial organization and automation in photonics industry in the near and mid-term future.

The four ESRs have been enrolled 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, a group of Scientific-based courses (SC) offered to each ESR will allow them to obtain ten ECTS (60 lecturing hours and 40 hours of homework).

In addition to the scientific-based training, EDIFY offers to all ESR specific short-term hand-on training which can provide the ESRs with skills in highly experienced organizations, receiving cutting-edge technological knowledge and skills. These hands-on training will be provided at the same time the ESRs are seconded to Partner Organizations providing the courses, i.e. PBV, PDesign and BP, and are aimed to explore knowledge in circuit simulation and packaging. This group of Technical-based courses (TC) offered to each ESR, will allow them to obtain six ECTS (30 lecturing hours and 10 hours of homework).

1.1 TECHNICAL HANDS-ON COURSES (TC)

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

Title	*Hands-on Optodesigner training (TC1)*	Month: 22	Duration: 1 Week
Lead	PBV		
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 today and the importance of considering test and packaging in an early stage. The unique combination of lectures and hands- on training exercises will teach how to perform circuit simulations, including fabrication tolerances, how to use and develop a design library (PDK) and how to set-up libraries in a structured way. PhoeniX Software tools will be used for this purpose.			
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.			
Title	*Hands-on Fimmwave, PICWave and Harold (TC2)*	Month: 23	Duration: 2 Weeks
Lead	PDesign		
Contents: To learn a suite of robust and fully vectorial mode solvers for 2D+Z waveguide structures. It supports a large number of complementary algorithms which allows it to solve a large variety of waveguides which may be made of any material and of almost any geometry.			
Skills for ESRs: to learn how to model InP related waveguides; buried, etched (rib, ridge) and geometries commonly used in opto-electronics; , slanted-wall and graded structures; and waveguides; simulation of gain and absorption spectra of active material.			
Title	*Bright Photonics (TC3)*	Month: 22	Duration: 1 Week
Lead	BP		
Contents: PIC design flow and design training; How to develop a PIC from user specification to packaging. This reaches across PIC technologies (SOI, InP, SiN, glass) and across multiple packages. The training will be hands-on on the newly in-house developed open source Nazcad design flow tool, covering mode solving, foundry and technology definition, layout design and verification, and data processing.			
Skills for ESRs: An introduction towards becoming an all-round PIC engineer and exposure to the latest software developments in the open source Python language to empower the engineer to customize a design flow to evolving needs.			

1.2 TC 2 – HANDS-ON FIMMWAVE, PICWAVE AND HAROLD TRAINING

The second of these **Technical courses, TC2 – Hands-on Fimmwave, PICWave and Harold Training**, has been held between 19-23 Oct 2020 in a virtual mode (10:00-14:00). This course should have been developed in a secondment in one of the partners, Photon Design Ltd. However, all secondments, due to the current pandemia, has been postponed and we had to reorganize it 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 complementary training included in the TC courses is fundamentally oriented to software and programming (circuit design, simulation and layout), this type of course is the most suitable to be taught online.

Fimmwave is a vectorial 3D mode solver including a variety of calculation engines each optimized for different geometries. Suitable for all types of waveguides including multi-mode waveguides & fibers, high index structures (E.g SOI), metals, Graded Index, photonic crystal fibers and more.

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.

Technical Hands-on Course TC2: Hands-on Fimmwave, PICWave and Harold Training (Dr. Nathan Soper)

1. **Fimmwave:**
    a. **The FMM Solver:** This solver, based on the Film Mode Matching method, is optimized for rectangular waveguide structures commonly seen in integrated optics. It is fully vectorial capable of solving structures with complex refractive index such as metallic components, or even radius of curvature.
    b. **The FDM Solver:** The FDM Solver brings the Finite Difference method to FIMMWAVE. It can model both real and lossy materials, supports PML absorbing boundary conditions, and anisotropic dielectric tensors (diagonal tensor).

c. **Effective Index Solver:** This well known approximate method is both a fast and reliable way of finding estimates for 3D modes for near 2D waveguides (many ridge structures fit into this category). This home grown solver is extremely robust; in particular it can deal with structures with completely decoupled cores.
d. **The FEM Solver:** The FEM Solver brings the Finite Element method to FIMMWAVE and is offered as an optional add-on to the base module. Ideal for structures with curved interfaces or unusual shapes such as holey fibers.
e. **Vectorial Fibre Solver:** This option houses two vectorial engines for solving generic circular waveguides with arbitrary refractive index. The first is based on a rigorous solution to the vectorial wave equation in cylindrical co-ordinates. It will find all the modes of such structures using metallic or transparent boundaries. Although it is a fully vectorial solver it exploits the circular symmetry, thus making it an almost instant calculation.
f. **Stress Solver:** The Stress Solver for FIMMWAVE allows the user to calculate the stress fields in a waveguide and the consequential perturbation of the waveguide modes. This Finite Element method based solver supports thermally induced stress fields – typically generated during cooling of a device constructed from materials with different thermal expansion coefficients.
g. **Thermal Profiler and EO module:** This option allows the user to study the thermal or electro-optic response of the waveguides. The change in refractive index profile of the structure is calculated by a 2D Poisson Solver before the subsequent modes are calculated.
h. Design utilities and optimization.

2. 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.

3. **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.

1.3 SKILLS, OUTCOMES AND METHODOLOGY

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

- 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.

The **methodology** applied was based in:

Lectures: The lecturer introduced 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 the Fimmwave, PICWave or Harold manuals. It is also expected that the ESRs reviewed the concepts introduced in the webinars 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.