Photonics Research Labs (PRL)

HEAD OF THE GROUP RESEARCH REPORT

The Photonics Research Labs (PRL) brings together research lines or Labs focused on different technologies and fields of application within the area of photonics and optical communications. Currently formed by more than 40 researchers, PRL mission is to produce high-quality scientific knowledge in the field of optics, quantum optics and photonics, through research projects, R&D contracts, and collaboration agreements with the private sector. Our research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems, space-division multiplexing fibers, photonic integrated circuits, programmable photonics and fiber optic sensing and industrial scenarios.

PRL is nowadays involved in different H2020 EU funded projects: "NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor" (NEoteRIC), "Applications and Fundamentals of Microresonator Frequency Combs" (MICROCOMB) and "European Network on Future Generation Optical Wireless Communication Technologies" (NEWFOCUS). Of particular interest regarding excellence are the two projects granted by the European Research Council (ERC): Consolidator Grant "Revolutionizing fibre-wireless communications through space-division multiplexed photonics" (InnoSpace) and Advanced Grant "Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems" (UMWP-Chip).

Continuous work to transfer research results to the market has led to the foundation of 4 successful spin-off companies: VLC-Photonics (acquired by Hitachi High-Tech Corporation in November 2020), Calsens, Ephoox engineering and iPronics programmable photonics (awarded with a EIC Transition grant by the European Innovation Council in January 2022).

A complete list of research activities can be found at https://www.iteam.upv.es/group/photonics-research-labs-prl and http://www.prl.upv.es

Also, follow us in:

- Twitter: @PRL_UPV
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1.- Project activities

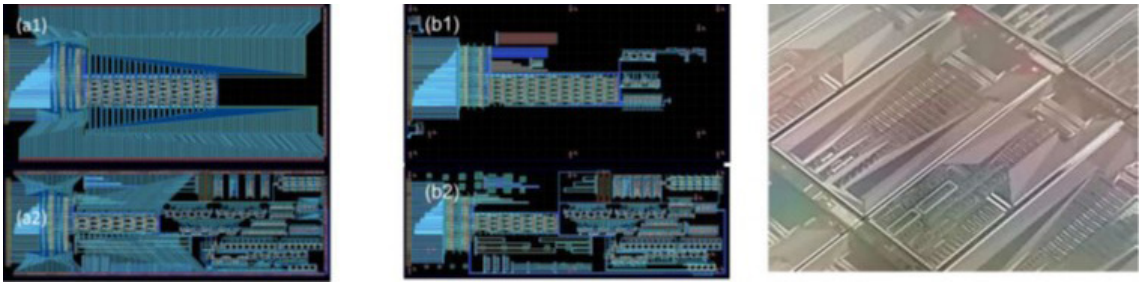
1.1.- Ongoing projects

Name of the project: *Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems (UMWP-Chip).*

Webpage of the project: *https://cordis.europa.eu/project/id/741415*

Funding entity and duration: *European Research Council (ERC), 66 months*

Summary of the project: *Information and communication technology (ICT) systems are expanding at an awesome pace in terms of capacity demand, number of connected end-users and required infrastructure. To cope with these rapidly increasing growth rates there is a need for a flexible, scalable, and future-proof solution for seamlessly interfacing the wireless and photonic segments of communication networks. RF or Microwave photonics (MWP) is the best positioned technology to provide the required flexible, adaptive, and future-proof physical layer with unrivalled characteristics. Its widespread use is however limited by the high-cost, non-compact and heavy nature of its systems. Integrated Microwave Photonics (IMWP) targets the incorporation of MWP functionalities in photonic chips to obtain cost-effective and reduced space, weight, and power consumption systems. IMWP has demonstrated some functionalities in through application specific photonic circuits (ASPICs), yielding almost as many technologies as applications and preventing cost-effective industrial manufacturing processes. A radically different approach is based on a universal or general-purpose programmable photonic integrated circuit (PIC) capable of performing with the same hardware architecture the main required functionalities. The aim of this project is the design, implementation and validation of such processor based on the novel concept of photonic waveguide mesh optical core and its integration in a Silicon Photonics chip. Its three specific objectives are: (1) The architecture design*



(a) (b) (c)

Generated layouts/designs of silicon programmable photonic processors chip incorporating the programmable mesh and external high-performance building blocks (a). 2 Chips to be wire-bonded (b). 2 Chips to be flip-chipped (c) fabricated from (a).

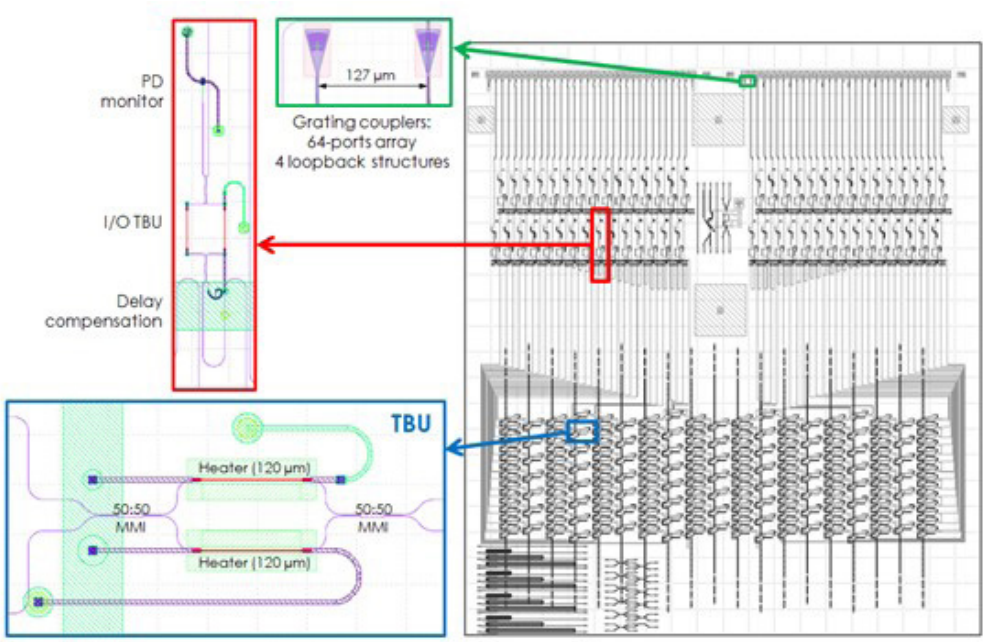
and optimization of a technology agnostic universal MWP programmable signal processor; (2) The chip mask design, fabrication, and testing of the processor; and (3) The experimental demonstration and validation of the processor. Targeting record values in bandwidth and footprint its potential impact will be very large by unlocking bandwidth bottlenecks and providing seamless interfacing of the fiber and wireless segments in future ICT systems.

Name of the project: *NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor (NEoteRIC)*

Webpage of the project*: https://neoterich2020.eu/*

Funding entity and duration*: European Union's Horizon 2020, 48 months*

Summary of the project*: The technological proposition of NEoteRIC aims to merge cutting edge photonic technologies like reconfigurable silicon integrated structures and planar ferroelectric schemes so as to spawn a disruptive generation of general purpose neuromorphic photonic chips, having hundreds of nodes, exhibiting supreme processing speed and consuming negligible power. Low-power & high-speed chip reconfiguration will unleash the true potentials of NEoteRIC's arsenal providing for the first-time photonic implementation of cutting-edge neuromorphic paradigms, multi-task capabilities and on-chip. NEoteRIC's pave a clear technological roadmap to revolutionize high speed imaging applications through careful escalating steps that start from the realization of innovative reconfigurable integrated photonic building blocks, moving to their encapsulation to low-power high-bandwidth machine learning subsystems and finally reaching to application-bound integrated systems able to deliver unparalleled performance in terms of frame rate and marginal power. Through NEoteRIC's photonic-FPGA neuromorphic platform*



2nd Generation of the Photonic Processor (high node density with TO phase-shifters).

cytometric data analysis will be performed in the analogue-optical domain, alleviating the need for high-speed electronics, offering unparalleled speed, eliminating offline data storage and minimizing power consumption due to photonic passive processing. NEoteRIC's devices can be directly implemented in a vast pallet of applications ranging from laser manufacturing to cyber security applications.

Name of the project: *Revolutionizing fibre-wireless communications through space-division multiplexed photonics (InnoSpace)*

Webpage of the project: *https://cordis.europa.eu/project/id/724663*

Funding entity and duration: *European Research Council (ERC), 72 months*

Summary of the project: *Space-Division multiplexing (SDM) has been touted as a solution for the capacity bottleneck in digital communications by establishing independent light paths in a single fibre via multicore fibres (MCF) or few-mode fibres (FMF). This project envisions an unprecedented revolution in fibre-wireless communications through the powerful concept of SDM that lead to reconfigurable multifunctional architectures that will allow resource and functionality sharing by suitable software definition. The key challenge that is being faced in the project is to design, implement and demonstrate the feasibility of this new optical technology that offers the required parallelism for the implementation of a compact broadband tunable true time delay line (TTDL) using a single optical fibre, without the need to resort to bulky, heavy, power-consuming and expensive replication architectures, enabling important functionalities such as controlled signal distribution, signal filtering, antenna beam-steering, arbitrary waveform generation and multi-gigabit-per-second analogue-to-digital conversion. These functionalities, in turn, are required in a variety of Information Technology applications, such as broadband wireless and satellite communications, distributed antenna systems, signal processing, sensing, medical imaging and optical coherence tomography. This approach not only goes beyond the state-of-the-art properties of TTDLs, but it also leads to the novel concept of distributed signal processing than can be implemented in the link connecting a central office and a remote base station. The project outcomes will hence constitute a groundbreaking achievement in the next generation of fibre-wireless communications with dramatic scientific, technical, and economic impacts.*

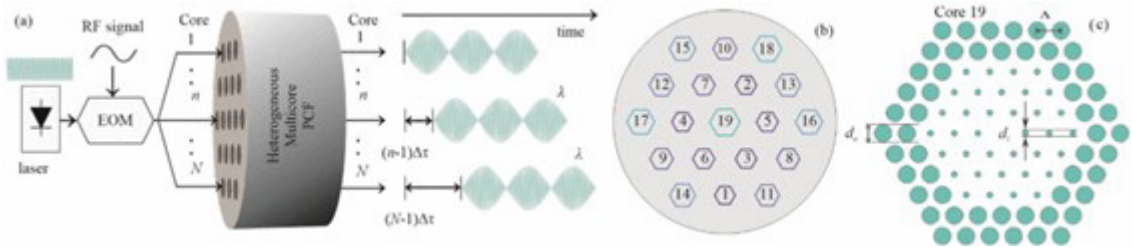
Name of the project: *European Network on Future Generation Optical Wireless Communication Technologies (NEWFOCUS)*

Webpage of the project: *https://www.cost.eu/actions/CA19111/#tabs|Name:overview*

Funding entity and duration: *European Union's Horizon 2020, 48 months*

Summary of the project: *The design of future wireless communication networks that cope with the ever-growing mobile data traffic as well as support varied and sophisticated services and applications in vertical sectors with a low environmental impact is recognized as a major technical challenge that European engineers face today. The COST Action NEWFOCUS propose truly radical solutions with the potential to impact the design of future wireless networks. Particularly, NEWFOCUS aims to establish optical wireless communications (OWC) as an efficient technology that can satisfy the demanding requirements of backhaul and access network levels in beyond 5G networks. This also includes the use of hybrid links that associate OWC with radiofrequency or wired/fiber-based technologies.*

Towards this vision, NEWFOCUS is carrying out a comprehensive research programme under two major pillars. The first pillar is on the development of OWC-based solutions capable of delivering ubiquitous, ultra-high-speed, low-power consumption, highly secure, and low-cost



Schematic of (a) a sampled TTDL based on a heterogeneous multicore PCF exploiting the fiber spatial diversity; (b) cross-section of a heterogeneous 19-core PCF, individual cores represented by numbered hexagons with Λcore=36 μm, (c) core 19 in close-up for which di=0.87 μm, do=2.42 μm and Λ=3.08 μm.

wireless access in diverse application scenarios. The developed solutions will in particular support Internet-of-Things (IoT) for smart environments with applications in vertical sectors. The second pillar concerns the development of flexible and efficient backhaul/fronthaul OWC links with low latency and compatible with access traffic growth.

In addition to scientific and technological advances, NEWFOCUS serves as a global networking platform through capacity building of all relevant stakeholders including universities, research institutions, major industry players, small medium enterprises, governmental bodies, and non-governmental organisations. Within this rich consortium, NEWFOCUS is training experts to accompany related European industries for the standardisation and commercialization of the OWC technology.

Name of the project: *Applications and Fundamentals of Microresonator Frequency Combs (MICROCOMB)*

Webpage of the project: *https://www.microcomb-eu.org/*

Funding entity and duration: *European Union's Horizon 2020, 48 months*

Summary of the project: *This network establishes and supports cross-sectorial training and research programme bringing together leading European academic and industrial centers working in the area of optical frequency combs in microresonators (microcombs). The programme allows to combine and share some of the world leading experience and expertise in the microcombs and train a new generation of scientists in this actively developing area bordering physics and photonic engineering and having pronounced applied and fundamental dimensions. The frequency comb research itself is the Nobel prize winning area (T. Hänsch and J. Hall, 2005), while the microcombs can qualify as an emerging disruptive technology. Europe lacked before the start of this project a structured and comprehensive training programme in this area, while facing a growing competition with its global rivals. This programme will have a lasting impact increasing European innovation capacity through expanding knowledge base, new IP, trained personnel, better equipped laboratories, and future collaborations leading to product development. The project addresses research and technology problems with interdisciplinary importance from the areas of precision frequency metrology, ultrafast data processing, optical to RF signal conversion, astronomical measurements, and soliton physics.*

Name of the project: *Specialty fibers exploiting spatial multiplexing for signal processing, sensing and beyond (SYNERGY)*

Webpage of the project:

Funding entity and duration: *Ministerio de Ciencia e Innovación, 36 months*

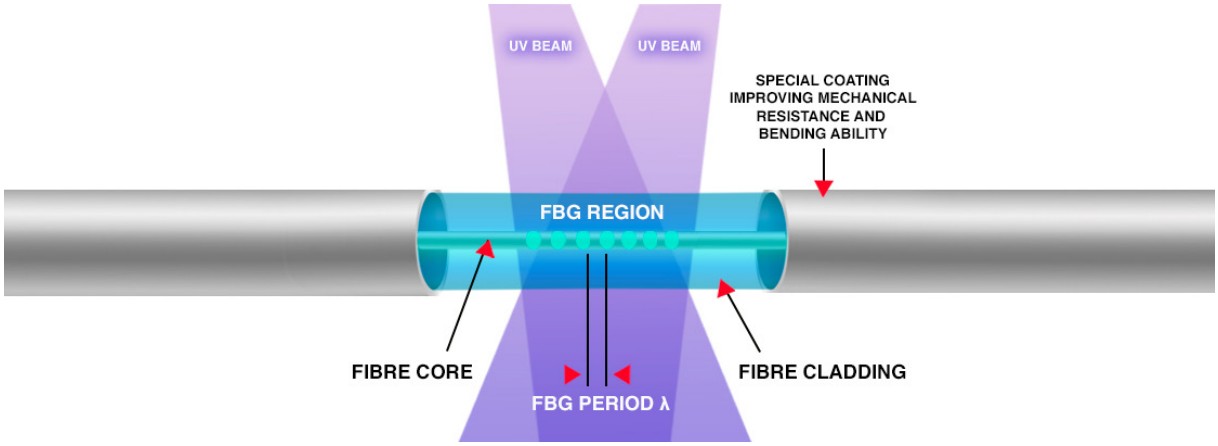
Summary of the project: *Firstly, SYNERGY seeks a novel Spatial Division Multiplexing (SDM) fiber solution for a better optical True-Time Delay Lines (TTDL) performance for microwave signal processing in terms of RF bandwidth, chromatic dispersion range, number of signal samples and robustness against fabrication errors, going beyond our preliminary demonstrations in the field. Furthermore, it will explore the implementation of different optical signal processing functionalities, such as optical sampling or parallel chromatic dispersion compensation.*

Secondly, SYNERGY project aims at pioneering and developing innovative optical technologies based on specialty SDM fibers to revolutionize the future display of broadband fibers-wireless communication scenarios. More specifically, the general goal is to exploit the inherent parallelism of multicore fibers, few-mode fibers and combination of both to implement a variety of signal processing and multiparameter sensing applications featuring unique properties beyond the state of the art in terms of compactness, lightness, system stability, power efficiency, versatility and record bandwidth.

Finally, SYNERGY will bring the chance to develop sensors not only with commercially available fibers but also with specialty ones, improving the sensor sensibility and providing novel techniques of interrogation for better requirement benchmarking. We want to explore the incorporation of specially designed cavities not only to use the reflected light, but also to exploit the benefits of retrieving the phase of the signal, while providing a robust design against external interferences. We plan as well to develop structures that will enhance the interaction with the external medium and postprocess the fibers with different coatings and terminations.

Name of the project: *Interrogación de Temperaturas Extremas con Sensores Ópticos (INTENSO)*

Webpage of the project: *https://intenso.itq.webs.upv.es/*



Fiber Bragg Grating.

Funding entity and duration: *Agencia Valenciana de la Innovación, 30 months*

Summary of the project: *The use of a new type of sensors based on optical fibers for the measurement of high temperatures in very hostile conditions is gaining a huge interest at industrial level. This application has been greatly favored by recent innovations in optoelectronics and in the different manufacturing technologies of both passive components and optical cables, and recent improvements in assembly and connectorization techniques. These sensors have proven, without any doubt, to possess high accuracy and reliability of measurements and are positioning themselves as a relevant technology due to the inherent properties of optical fibers. However, the optical fiber by itself is fragile and the sensors currently available on the market are usually coated by a layer of thermoplastic/metallic composite materials to give them mechanical strength while retaining the inherent flexibility of the fiber. Such coatings are not suitable and greatly limit the practical applicability of this technology at an industrial level in processes that operate in very extreme conditions. To overcome this limitation we propose to develop new coatings prepared for very high temperatures environments while preserving the inherent flexibility of the fiber, even under chemically aggressive conditions.*

Name of the project: *Energy efficient hybrid Optical networks for indoor Communications and Lighting (FOCAL)*

Webpage of the project:

Funding entity and duration: *Ministerio de Ciencia e Innovación, 36 months*

Summary of the project: *The Project consists in the definition of the architecture of an indoor hybrid wired and wireless optical network based on VLC communications (Fi2VLC) to provide coverage and 5G services in residences and offices. Full characterization of hybrid POF and VLC links with improved capacity and flexibility, also including different multiplexing techniques will be addressed. Electro-optical transceivers based on low cost commercially available LEDs will be designed to transmit digital modulation formats such as OFDM, QPSK, CAP, 16QAM, etc. and adaptive modulations to adjust the transmission capacity to the actual demand in a multiuser scenario. The Project also includes the experimental characterization of the networks (QoS, BER, SNR) using the developed technologies (multiplexing, adaptive modulations and multiuser access) for service transmission and the implementation of software-defined Fi2VLC networks for energy efficient operation. Finally, the techno-economical evaluation of the implemented solutions will assess their viability in short term 5G networks.*

Name of the project: *Broadband HYbrid Silicon Nitride Photonic Integrated CircuitS (BHYSINPICS)*

Webpage of the project:

Funding entity and duration: *Ministerio de Ciencia e Innovación, 36 months*

Summary of the project: *Integrated photonics has experienced exponential growth in the last 10 years, thanks to the research, development, and commercial exploitation of generic technologies, which allow complex photonic systems into a single micro-chip. These technologies cover different parts of the spectrum, depending on the properties of the materials used in manufacturing, for different applications, in the visible (VIS), near (NIR) and mid infrared (MIR) wavelength ranges. However, there is no broadband technology platform, that allows light guiding over VIS, NIR and MIR. Even if it existed, the problem of hybridization with other active technologies, to enable the*

incorporation of sources and light detectors, would not be solved either. Together with the two previous aspects, the increasing complexity of photonic integrated circuits (PICs) requires advanced characterization methods, beyond those traditionally used. This project aims at researching and developing technologies, manufacturing, and design processes, alongside the associated characterization methods, to address these three challenges: i) a passive photonic integration platform covering VIS, NIR and MIR, ii) advanced characterization methods and iii) micro-fabrication processes for hybridization with active technologies.

Name of the project: *Embedded optical fiber sensors in composites for 3D structural Health monitoring in real time (EOS-3D)*

Webpage of the project:

Funding entity and duration: *Ministerio de Ciencia e Innovación, 24 months*

Summary of the project: *The EOS-3D project will deal with the development of a 3D Shape Sensing system in composite materials for transport applications. The main objective is the real-time structural health monitoring based on optical fiber sensors using SDM technologies, mainly MCF fibers and validate proof of concept by embedding the sensors in composites parts, similar to the ones used in aerospace applications, through an experimental setup in certified measurement equipment.*

Name of the project: *Inter-core crosstalk for future space division multiplexing networks and optical sensor devices (INSTILL)*

Webpage of the project:

Funding entity and duration: *Ministerio de Ciencia e Innovación, 36 months*

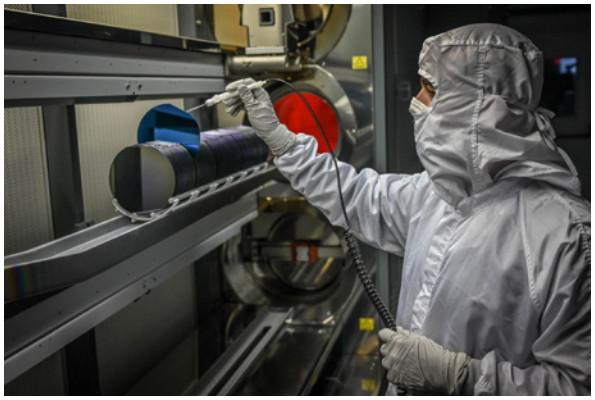
Summary of the project: *In this project we intend to develop new and disruptive devices based on inter-core crosstalk produced by the inscription of fiber diffraction gratings in the cores of a Multicore Optical Fiber (MCF) to improve the performance of Space Division Multiplexing (SDM) amplifiers, Reconfigurable Add-Drop Optical Multiplexers and optical sensors. Tilted Fibre Bragg Gratings (TFBG) and Long Period Grating (LPG) in MCFs have shown that it is possible to deliberately and locally increase inter-core crosstalk in MCFs to transfer light from one core to another in a specific wavelength range. This project will study the optimization of the properties of these gratings and the modification of the fiber structure to increase this effect and proposes novel schemes to use this phenomenon in the design of optical devices for SDM networks and optical sensors. In particular, we propose to use inter-core crosstalk to implement a new injection scheme of the pumping signal in a distributed way. This scheme can contribute to improve the performance of SDM amplifiers, avoid current limitations, and increase the maximum detection range of the distributed optical sensors. Another application of this technology that will be explored in this project is the use of inter-core crosstalk as a mechanism to implement distributed optical sensors that can simplify the current interrogation schemes.*

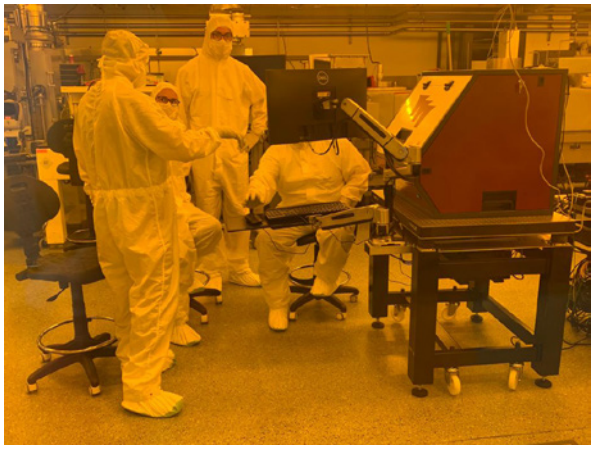
Name of the project: *Multi-level Microfabrication Technologies (IDIFEDER/2021/046)*

Webpage of the project: *https://www.fab.upv.es/*

Funding entity and duration: *Generalitat Valenciana and the European Regional Development Fund (ERDF), 24 months*

Summary of the project: *The project addresses the acquisition and retrofit of capital*





UPVFAB Technopole facilities.

semiconductor manufacturing equipment at UPVfab (www.fab.upv.es). This includes: a) retrofit of ther Tempress LPCVD Si3N4 tube for low stress silicon nitride process, b) incorporation of a sputter process module and a PECVD SiO2 module to the Nordiko 5000 cluster tool, c) acquisition of a chemical-mechanical polishing tool and d) direct laser writing lithography tool. All the equipment can process up to 8-inch wafers (currently configure for 6 inch).

Name of the project: *Advanced Instrumentation for world class microwave and programmable photonics Research (IDIFEDER/2021/050)*

Webpage of the project: *https://www.prl.upv.es/advanced-instrumentation-for-world-class-microwave-and-programmable-photonics-research-2-2/*

Funding entity and duration: *Generalitat Valenciana and the European Regional Development Fund (ERDF), 24 months*

Summary of the project: *The Photonics Research Labs (PRL) has thoroughly enlarged and improved through this project the equipment and instrumentation available in its facilities due to the procurement of a last generation infrastructure for the acquisition of i) photonic chip encapsulation capabilities through the incorporation of a multifunctional, modular and expandable machine designed for an R&D laboratory environment, capable of automatically carrying out the different tasks required for the assembly, preparation and optical, electrical, thermal and mechanical encapsulation of integrated photonic circuits of low and intermediate complexity; ii) the ability to write periodic and aperiodic variations in all types of circular guides (optical fibers) and flat guides by incorporating a femtosecond laser of high pulse energy that generates a two-photon process and allows the variation of the guide structure in nanometer sizes. For this, it was necessary to accompany the laser with an ultra-precision alignment system in the three axes with nanometer resolution, which has the flexibility to generate complex structures in the guides and to allow possible future extensions when necessary; iii) measurement and spectral characterization capabilities of optical networks using multiple channels in new and promising optical windows spanning from 350 to 2400 nm, either in terms of energy efficiency (visible) or low latency and high capacity (2-micron band).*

Láser de femtosegundos de estado sólido y elevada energía de pulso

Name of the project: *Microwave Photonics IC Systemization and Development*

Webpage of the project:

Funding entity and duration: *HUAWEI TECHNOLOGIES CO., LTD., 36 months*

Summary of the project: *The goal of this project is to research and develop some of the key microwave-photonic technologies required for microwave-photonic radio base station architecture – more specifically these key technologies are modulator, true-time delay, and tunable filter with supporting required technologies such as semiconductor optical amplifier, photodetector, etc. The scope of the project includes systemization of the end-to-end microwave-photonic architecture to assess system performance, proposal of novel concepts/techniques, assessment of key technologies feasibility, maturity, performance, and limitation, and research/development of the key technologies*

Name of the project: *H2 safety – Fibre optics development for LH2 Gauging*

Webpage of the project:

Funding entity and duration: *Airbus Operations, S.L., 18 months*

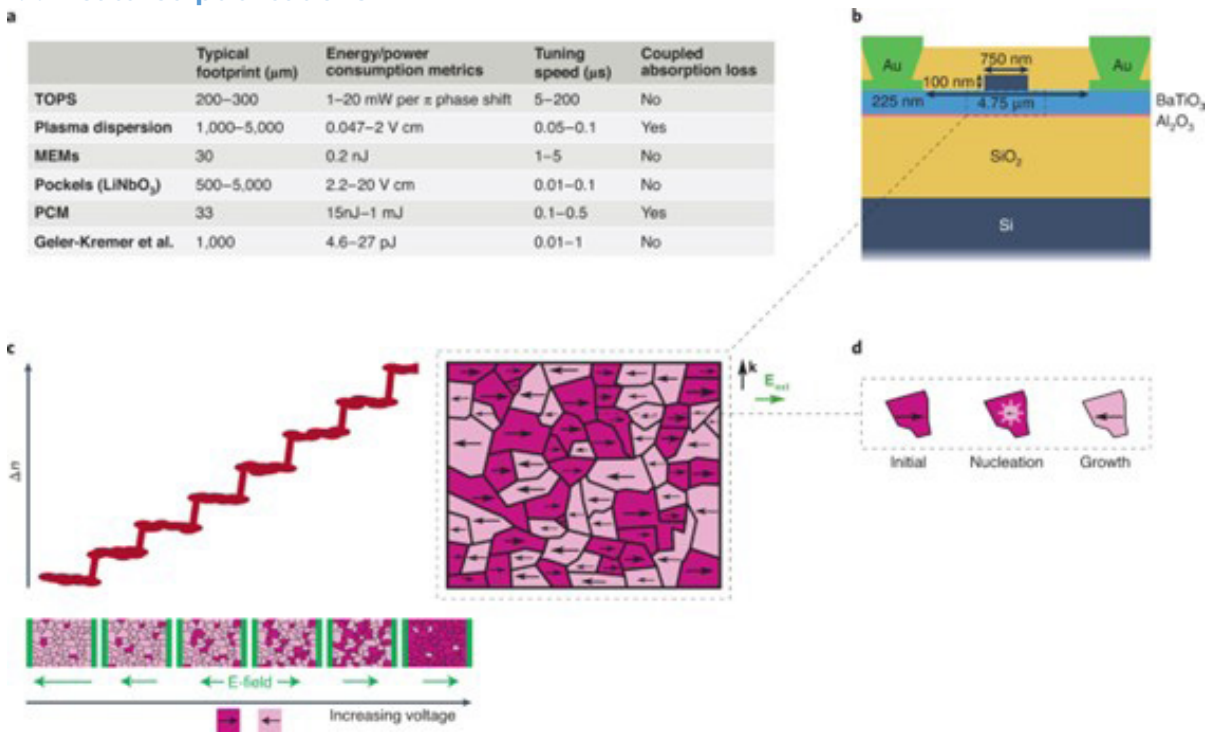
Summary of the project: *Within the ZeroE program, we will perform research in the field of liquid hydrogen (LH2) characterization by developing and testing optical fibre sensors designed to operate as part of the equipment of the LH2 optical gauging system.*

2.- Research results

2.1.- Featured publications

a

	Typical footprint (μm)	Energy/power consumption metrics	Tuning speed (μs)	Coupled absorption loss
TOPS	200–300	1–20 mW per π phase shift	5–200	No
Plasma dispersion	1,000–5,000	0.047–2 V cm	0.05–0.1	Yes
MEMs	30	0.2 nJ	1–5	No
Pockels ($LiNbO_3$)	500–5,000	2.2–20 V cm	0.01–0.1	No
PCM	33	15nJ–1 mJ	0.1–0.5	Yes
Geler-Kremer et al.	1,000	4.6–27 pJ	0.01–1	No



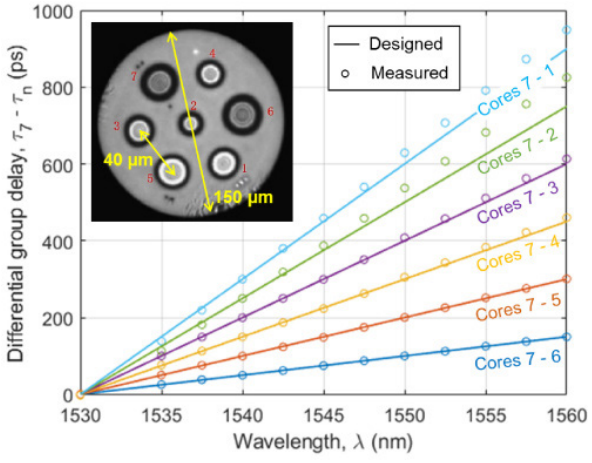
a, Comparison between different technologies for the implementation of OPS. b, BaTiO3 on silicon OPS structure reported by Geler-Kremer and colleagues10. c, Refractive index change by domain switching. d. Illustration of the internal process of a domain switching.

Title, Authors, Name of the publication, pages, year: *"A new change of phase", J. Capmany, D. Pérez-López, Nature Photonics 16, pp 479-480, 2022*

Brief summary of the paper*: Ferroelectric domain switching controlled by electrical pulses provides a controllable means to tune the refractive index of BaTiO3 thin films. Now, a device based on this material is presented that is capable of implementing low-power, high-speed and CMOS-compatible programmable phase shifters in silicon photonic chips.*

Title, Authors, Name of the publication, pages, year: *"Heterogeneous multicore fiber-based microwave frequency measurement", E. Nazemosadat, S. García, I. Gasulla, Optics Express 30, pp 26886-26895, 2022*

Brief summary of the paper*: A novel microwave frequency measurement scheme using a heterogeneous multicore fiber (MCF) is experimentally demonstrated. The inherently different relative group delays among the cores of a heterogeneous 7-core MCF are used to realize two individual 2-tap microwave filters with different free spectral ranges (FSRs). The ratio of the frequency response traces of these two filters is used to establish an amplitude comparison function (ACF). Furthermore, by varying the operational wavelength, the relative group delays between the cores and consequently the FSRs of the filters are tuned and different ACF curves are obtained. The complementary information provided by these different ACFs allows us to estimate the unknown frequency with an improved accuracy, over a broad measurement range. In our experiments, a measurement error of ±71 MHz is achieved over a frequency range of 0.5-40 GHz. The proposed scheme offers flexibility and compactness, thanks to the parallelism provided by MCF.*



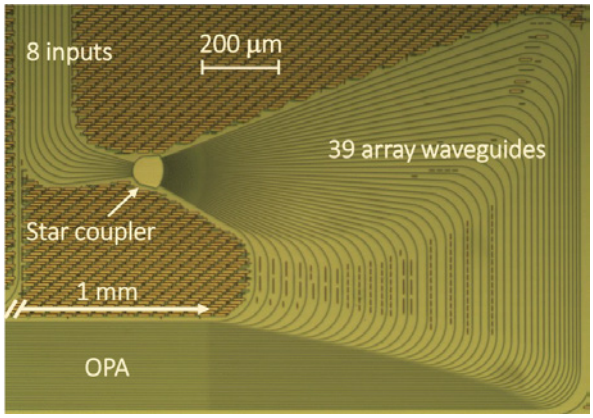
Differential group delays of the MCF cores with respect to core 7. The inset shows the SEM image of the fabricated MCF.

Title, Authors, Name of the publication, pages, year: *"Harmonic and Intermodulation Distortion Analysis in Directly Modulated Lasers over Local and Remote Photonically Generated Millimeter-Wave Signals", L. Vallejo, J. Mora, B. Ortega, Journal of Lightwave Technology, 2022*

Brief summary of the paper*: This paper presents a comprehensive analytical derivation and experimental evaluation of the impact of harmonic and intermodulation distortion on data transmission over local and remote photonically generated millimeter wave (mmW) signals over an optical fronthaul based on a directly modulated laser (DML) and carrier-suppressed (CS) external modulation for frequency up-conversion. Frequency response of different harmonic distortion (HD) and intermodulation (IMD) terms are measured for a 40 GHz signal under back-to-back, local and remote scenarios for the sake of comparison. Furthermore, measurements of error vector magnitude (EVM) of single and multiband QPSK signals are presented in good agreement with the frequency measurements for (2wk), (wk-w1) and (wk+w1)-type distortion terms. Wideband signals with in-band distortion and multiband signals with out-of-band distortion are examples that need to be transmitted over local generation mmW approach in cloud-radio access networks (C-RAN), in spite of the high performance achieved by remote generation approach due to the combined effect of fiber dispersion and laser chirp. Results will serve as valuable guidelines for 6G networks deployment in concrete application scenarios.*

Title, Authors, Name of the publication, pages, year: *"Scalable switched slab coupler based optical phased array on silicon nitride", P. Muñoz, D. Pastor, LA. Bru, GM. Cabanes, J. Benítez, D. Goodwill, E. Bernier, IEEE Journal of Selected Topics in Quantum Electronics 28, pp 1-16, 2022*

Brief summary of the paper*. Two-dimensional optical-phased array is demonstrated by using a multiple-input star coupler, compatible with FMCW LiDAR. Previous approach using a single-input design achieves two-dimensional beam-steering by relying on a tunable laser source, taking advantage of grating coupler radiation angle wavelength dependance and variation of the waveguide refractive index. While implementing a convenient way to distribute power in a single step, star coupler architecture is inefficient in terms of employed waveguide length and thus, optical loss and footprint. Multi-input approach partially alleviates this by condensing several single-input devices into one, permitting to reduce the footprint proportionally to the employed number of inputs. We fabricated in silicon nitride technology a proof-of-concept steerer with beam waist 0.36 ×0.175° addressing a field of view of 15° ×2.8°. A new design iteration is also reported with and 0.24° ×0.16° beam waist and 15° ×11.2° field of view. Implications of this optical-phased array chips from a LiDAR system perspective are also presented.*



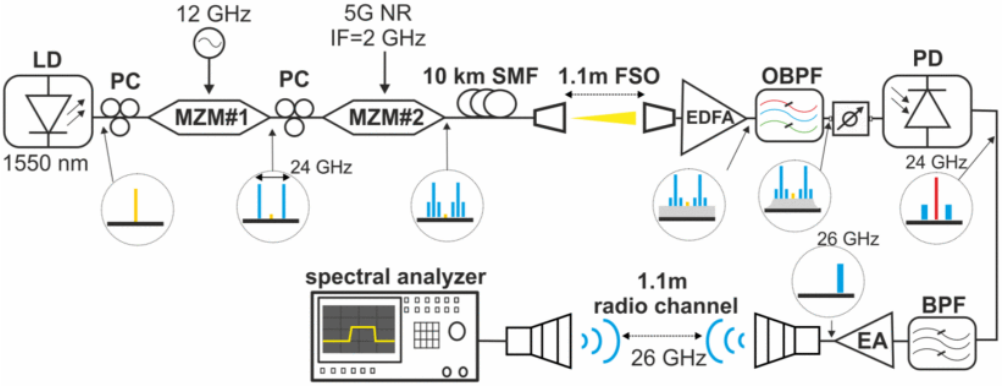
Multi-input star coupler fabricated device microscope picture.

Title, Authors, Name of the publication, pages, year: *"Modeling amplified arbitrary filtered heterodyne microwave photonic links", E. Sánchez, D. Pérez-López, D. Pérez-Galacho, D. Wessel, J. Capmany, Optics Express 30, pp 6519-6530, 2022*

Brief summary of the paper*: We report an end-to-end analytic model for the computation of the figures of merit (FOMs) of arbitrarily filtered and amplified heterodyne coherent microwave photonics (MWP) links. It is useful for evaluating the performance of complex systems where the final stage is employed for up/down converting the radio frequency (RF) signal. We apply the model to a specific case of complex system representing the front-haul segment in a 5G link between the central office and the base station. The model can be however applied to a wider range of cases combining fiber and photonic chip elements and thus is expected to provide a useful and fast tool to analyze them in the design stage.*

Title, Authors, Name of the publication, pages, year: *"Optical CS-DSB Schemes for 5G mmW Fronthaul Seamless Transmission", J. Bohata, L. Vallejo, B. Ortega, S. Zvánovec, IEEE Photonics Journal 15, pp 1-7, 2022.*

Brief summary of the paper*: This paper describes the experimental demonstration of the hybrid optical/millimeter wave signal generation and transmission over combined optical fiber and free space optics fronthaul network with a seamless antenna link. An electrical bandpass filter is used to filter out the spectrum after*



EM setup for optical mmW generation at 26 GHz with the seamless transmission, insets illustrate spectra at given points.

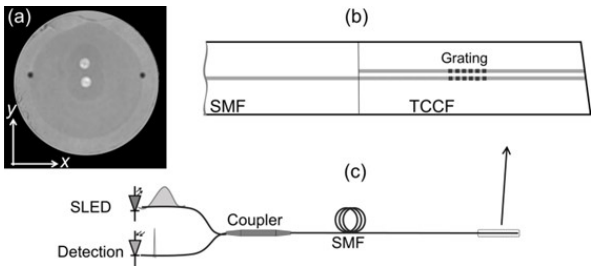
photodetection to realize the seamless antenna transmission. The successful transmission of 64/256-quadrature amplitude modulation (QAM) 5G signal with up to 200 MHz bandwidth is presented by using two different setups: one is based on two Mach-Zehnder modulators (MZM) and the other employs a directly modulated laser (DML) to provide more cost efficient fronthaul solution. The DML based approach reveals mildly better performance in comparison to the MZMs in terms of higher achieved signal-to-noise ratio and lower error vector magnitude (EVM). More specifically, the best signal-to-noise ratio and EVM achieved with the DML based setup has been 31.5 dB and 3. 3%, respectively, compared to 30.3 dB and 3.8% with the MZMs based setup while transmitting 256-QAM signal with 100 MHz bandwidth. However, both setups kept the EVM well below the given 9% and 4.5% limit for 64- and 256-QAM, respectively.

Title, Authors, Name of the publication, pages, year: *"Sensing with coupled-core optical fiber Bragg gratings", JA. Flores-Bravo, J. Madrigal, J. Zubia, W. Margulis, S. Sales, J. Villatoro, Frontiers in Optics, FM2C. 2, 2021*

Brief summary of the paper*: Sensitive bending and vibration sensors based on a coupled-core optical fiber with Bragg gratings are proposed and demonstrated. The interrogation of such sensors is cost effective without comprising the sensors performance.*

Title, Authors, Name of the publication, pages, year: *"Coupled-core fiber Bragg gratings for low-cost sensing", JA. Flores-Bravo, J. Madrigal, J. Zubia, S. Sales, J. Villatoro, Scientific Reports 12, pp 1-9, 2021*

Brief summary of the paper*: overcome this issue, in this work, it is proposed and demonstrated the use of coupled-core optical fiber Bragg gratings. It was found that the relative reflectivity from such gratings changed when the coupled-core fiber was subjected to point or periodic bending. This feature makes the interrogation of such gratings simple, fast, and cost-effective. The reflectivity changes of the gratings are attributed to the properties of the supermodes supported by the coupled-core fiber. As potential applications of the referred gratings, intensity-modulated vector bending, and vibration sensing are demonstrated. We believe that the results reported here can pave the way to the development of many inexpensive sensors. Besides, coupled-core fiber Bragg gratings may expand the use of grating technology in other areas.*



(a) Cross section of the twin coupled-core optical fiber (TCCF) used in the experiments. The coordinate system to orient the cores is indicated. (b) Schematic representation of a single mode fiber (SMF) spliced to the TCCF. (c) Sketch of the device interrogation; SLED is superluminescent light emitting diode. The input and reflected light are illustrated with a broad and narrow 'spectrum', respectively.

Title, Authors, Name of the publication, pages, year: *"Photonic crystal fibers for microwave signal processing, S. Shaheen, I. Gris-Sánchez, I. Gasulla, IEEE Photonics Conference (IPC), 2021*

Brief summary of the paper: *We present a novel design of an optical True Time Delay Line based on a 19-core Photonic Crystal Fiber that operates in a broad radiofrequency signal processing range from 1 to 67 GHz on a 10-km link, thus enabling simultaneous microwave signal distribution and processing.*

Title, Authors, Name of the publication, pages, year: *"Advanced and versatile interferometric technique for the characterization of photonic integrated devices", LA Bru, D Pastor, P Muñoz, Optics Express 29, pp 36503-36515, 2021*

Brief summary of the paper*: Adaptable and complex optical characterization of photonic integrated devices, permitting to unearth possible design and fabrication errors in the different workflow steps are highly desired in the community. In this article, a technique was proposed capable of resolving full optical amplitude and phase response, in both frequency and time domains, of a photonic integrated device. It relies on optical frequency domain interferometry and makes use of a novel integrated architecture; a 3-way interferometer enabling single input and single output detection. We derive the test structure design rules and provide extensive experimental validation in silicon nitride and silicon on insulator technologies, by testing relevant devices such as arrayed waveguide grating, Mach-Zehnder interferometers, and ring resonators. Horizontal and vertical chip coupling, different external setup arrangements, and the optical dispersion de-embedding inherent to the technique are demonstrated. Finally, we discuss why this characterization approach might lay the groundwork of a standard testing tool for photonic integrated devices.*

2.2.- Awards.

Sergi García awarded with the COIT/AEIT prize for best doctoral thesis.

On October 8, 2021, Dr. Sergi García Cortijo, Postdoctoral Researcher at the Photonic Research Labs, has been awarded by COIT (the Spanish official association of telecommunication engineers) the prize to the best 2020 Spanish Doctoral thesis on Technologies and Applications of Telecommunication Engineering.

The Jury of the XLI call for the Best Doctoral Thesis, Master's Thesis and Academic Trajectories in Telecommunications Engineering Awards, has awarded this distinction to Sergi García for his work "Distributed radiofrequency signal processing based on space-division multiplexing fibers", supervised by Dr. José Capmany and Dr. Ivana Gasulla.

This PhD thesis represents an important milestone to exploit the inherent parallelism of multicore and few-mode fibers to implement sampled discrete true time delay lines, providing in a single optical fiber a compact and efficient approach for both Microwave Photonics signal distribution and processing, which is the main goal of my ERC Consolidator Grant project InnoSpace.

Furthermore, the true time delay lines that have been developed during his thesis can be applied to a wide range of Information and Communication Technology paradigms besides fiber-wireless communications, such as broadband satellite communications, distributed sensing, medical imaging, optical coherence tomography and quantum communications.

Award Sergi Garcia