Group photo of PRL staff

PHOTONICS RESEARCH LABS

PROF. DR. DR. JOSÉ CAPMANY – GROUP LEADER – PHOTONICS RESEARCH LABS

The Photonics Research Labs (PRL) are currently formed by more than 40 telecom engineers and physicists. The 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. The PRL research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems and photonic integrated circuits. Part of the research is also performed in the field of fiber optic sensor and industrial photonics. Among others, PRL has been granted two Excellent Projects by the European Research Council (ERC).

Web site: www.prl.upv.es

Twitter: @PRL_UPV

LinkedIn: www.linkedin.com/in/photonicsresearchlabs

MAIN ACTIVITIES

Microwave Photonics

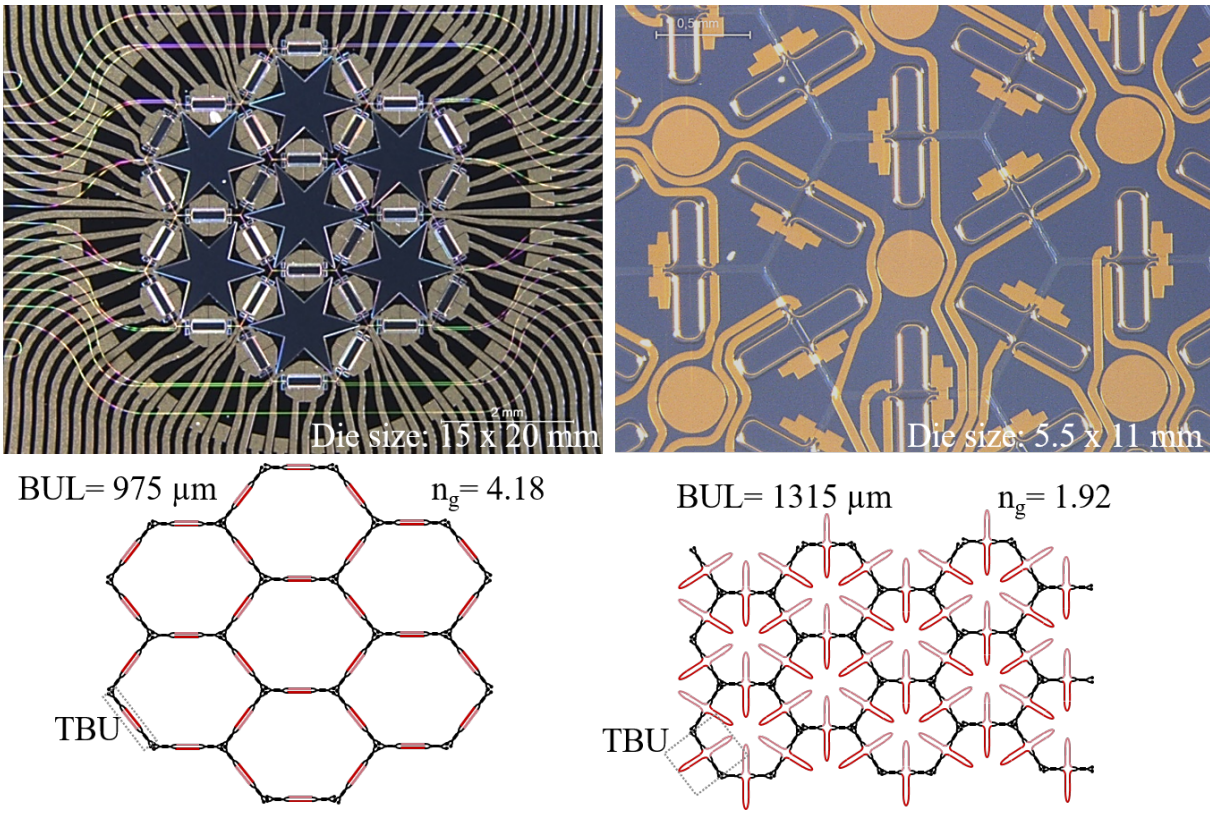
Among the most productive research lines, PRL is considered a world-leading group in Microwave Photonics (MWP), principally due to its contributions to the field of microwave photonic signal processing, a fundamental technology for the convergence of fixed and wireless telecommunication networks. The research is focused in tunable and reconfigurable microwave filters based in fibre gratings and delay lines for the processing of radiofrequency, microwave and milimetric signals, directly in the optical domain, Remote antenna array feeders by means of optical delay lines (beamforming and beam stearing), Signal processing and distribution over space-division multiplexing (SDM) optical fibers, Slow and Fast Light (SFL) Effects applied to Microwave Photonics. Implementation of tunable broadband microwave phase shifting and true time delay functionalities by means of different SFL technologies as Coherent Population Oscillations in Semiconductor Optical Amplifiers and stimulated Brillouin scattering in optical fibers, RADAR and Ultra Wide Band (UWB) applications and Optical Frequency Division Multiplexing (OFDM) techniques.

Photonic integrated circuits

Design of integrated photonic devices for multiple applications (optical telecom, optical signal processing, sensing, biophotonics): Silica or PLC (SiO_2), Silicon-on-Insulator (SOI), Silicon Nitride (Si_3N_4), active devices in InP.

Cryptography and quantum information

The research line is focused on the applications of Quantum Mechanic principles to information processing in optical telecommunication systems (Entanglement, Quantum state teleportation and Encryption).



Reconfigurable photonic integrated processor

Fibre Bragg Gratings

Design and fabrication of Fibre Bragg Gratings for communication networks (Dispersion compensation and optical filters) and Sensing applications (high temperature, stress, pressure, chemical, bio).

Optical Networks

Optical links conform a large part of the current global communication network, and the trend is growing with the latest deployments of Fiber-to-the-Home networks and fiber backhauling of mobile and radio networks. PRL currently develops an active line on the development of novel architectures and technologies as well as providing reasonable cost solutions for access networks with high capacity and upgraded reconfigurable features towards the convergence with 5G upcoming standards.

Photonic Instrumentation and Advanced Techniques for Metrology

Research and development of innovative photonic instrumentation focuses on photons or optical fields and the light-matter interaction for a wide range of scientific and industrial applications. Our main target is to design, implement and demonstrate the feasibility of photonic instruments with advanced functionalities featuring unique properties beyond the current state of the art.

FLAGSHIP PROJECTS

ERC Advanced Grant awarded to Prof. José Capmany – UMWP-Chip: Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems.

ERC Consolidator Grant awarded to Dr. Ivana Gasulla InnoSpace: Revolutionizing fibre-wireless communications through space-division multiplexed photonics.

RESEARCH HIGHLIGHTS

1. J. Capmany, J. Yao, W. Li and S. Pan, "Editorial for focus issue on microwave photonics", **Chinese Optics Letters**, 15, 010001, 2017.
2. M. Rius, M. Bolea, J. Mora and J. Capmany, "Incoherent Photonic Processing for Chirped Microwave Pulse Generation," in **IEEE Photonics Technology Letters**, vol. 29, no. 1, pp. 7-10, Jan.1, 1 2017.
3. J. Hervas, A.L. Ricchiuti, W. Li, N.H. Zhu, C.R. Fernandez-Pousa, S. Sales, M. Li, and J. Capmany, "Microwave Photonics for Optical Sensors," in **IEEE Journal of Selected Topics in Quantum Electronics**, doi: 10.1109/JSTQE.2017.2651117.
4. J. Hervás, D. Tosi, H. García-Miquel, D. Barrera, C. R. Fernández-Pousa, and S. Sales, "KLT-Based Interrogation technique for FBG multiplexed sensor tracking," **Journal of Lightwave Technology**, vol. 35, no. 16, pp. 3387–3392, 2017.

5. J. Benítez, M. Bolea, and J. Mora, "High-performance low coherence interferometry using SSB modulation," **IEEE Photon. Technol. Lett**., vol. 29, no. 1, pp. 90–93, 2017.

6. J. Capmany, "Single-shot incoherent optical processing of microwave signals: opening the path to low cost high performance analog photonics," **Science Bulletin**, vol. 62, no. 9, pp. 652–653, 2017.

7. J. Benítez, J. Mora, and M. Bolea, "SCM Adaptation to Improve Scanning Rate in RF Interferometry Applications," **IEEE Photonics Technology Letters**, vol. 29, no. 12, pp. 999–1002, 2017.

8. D. Pérez, I. Gasulla, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Multipurpose silicon photonics signal processor core," **Nature communications**, vol. 8, p. 636, 2017.

9. D. Zheng, J. Madrigal, D. Barrera, S. Sales, and J. Capmany, "Microwave Photonic Filtering for Interrogating FBG-Based Multicore Fiber Curvature Sensor," **IEEE Photonics Technology Letters**, vol. 29, no. 20, pp. 1707–1710, 2017.

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11. P. Muñoz et al., "Silicon Nitride Photonic Integration Platforms for Visible, Near-Infrared and Mid-Infrared Applications," **Sensors**, vol. 17, no. 9, p. 2088, 2017.

12. D. Zheng, J. Madrigal, H. Chen, D. Barrera, and S. Sales, "Multicore fiber-Bragg-grating-based directional curvature sensor interrogated by a broadband source with a sinusoidal spectrum," **Optics letters**, vol. 42, no. 18, pp. 3710–3713, 2017.

13. D. Barrera, J. Madrigal, and S. Sales, "Tilted fiber Bragg gratings in multicore optical fibers for optical sensing," **Opt. Lett**, vol. 42, pp. 1460-146, 2017.

14. J. Madrigal, F. J. Fraile-Peláez, D. Zheng, D. Barrera, and S. Sales, "Characterization of a FBG sensor interrogation system based on a mode-locked laser scheme," **Optics express**, vol. 25, no. 20, pp. 24650–24657, 2017.

15. A. Triana, D. Pastor, and M. Varón, "A Code Division Design Strategy for Multiplexing Fiber Bragg Grating Sensing Networks," **Sensors**, vol. 17, no. 11, pp. 2508, 2017.

16. D. Perez, I. Gasulla, F. J. Fraile, L. Crudgington, D. J. Thomson, A. Z. Khokhar, Ke Li, Wei Cao, Goran Z. Mashanovich, Jose Capmany, "Silicon photonics rectangular universal interferometer," **Laser & Photonics Reviews**, vol. 11, no. 6, 2017.

17. S. García, D. Barrera, J. Hervás, S. Sales and I. Gasulla, "Microwave Signal Processing over Multicore Fiber," **Photonics,** vol. 4, no. 4, pp. 4, 2017.

18. D. Sartiano and S. Sales, "Low Cost Plastic Optical Fiber Pressure Sensor Embedded in Mattress for Vital Signal Monitoring", **Sensors,** vol. 17, no. 12, 2017

19. J. Tang, T. Hao, W.Li, D. Domenech, R.Baños, P. Muñoz, N. Zhu, J. Capmany, and M. Li, "Integrated optoelectronic oscillator," **Opt. Express** 26, 12257-12265, 2018.

20. D. Pérez, I. Gasulla and J. Capmany "Towards Programmable Microwave Photonics Processors," **Journal of Lightwave Technology,** vol. 36, no. 2, pp. 519 – 532, 2018.

21. D. Barrera, J. Madrigal, S. Sales, "Long period gratings in multicore optical fibers for directional curvature sensor implementation", **Journal of Lightwave Technology,** vol. 36, no. 4, 1063-1068, 2018

22. J. Hervás, D. Barrera, J. Madrigal, S. Sales, "Microwave Photonics filtering interrogation technique under coherent regime for hot spot detection on a weak FBGs array", **Journal of Lightwave Technology**, vol. 36, no. 4, 1039 – 1045, 2018

23. J. C. Bellido et. al., "Fast Incoherent OFDR Interrogation of FBG Arrays Using Sparse Radio-Frequency Responses", **Journal of Lightwave Technology**, 2018, 10.1109/JLT.2018.2821199.

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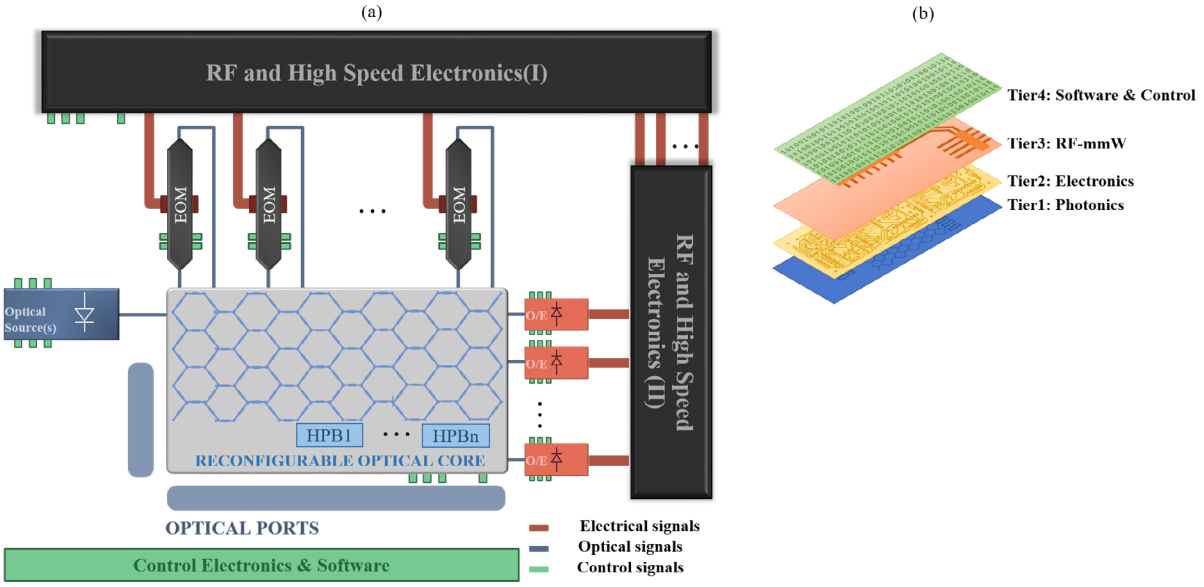
28. L.P. Pereira, R. Min, Xuehao Hu, B. Ortega, C. Marques, C. Caucheteur, P. A. Joao Pinto, "Polymer optical fiber Bragg grating inscription with a single Nd:YAG laser pulse," **Optics Express**, vol. 26, no. 10, 2018.



ERC Advanced Grant – UMWP-Chip
Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems

SPIN-OFF COMPANIES

VLC Photonics (2011)

VLC Photonics' mission is to provide engineering solutions that allow our customers to harness the benefits of photonic integration, as well as to build up on our providers technologies. The mission spans from the initial work of drafting high-level optical system architectures to the final part of specifying its deepest technical details, all the while under a customized approach to the specific application domain at hand.

CalSENS (2013)

Cálculo y Estructuras Sensadas, CALSENS S.L., offers services of monitoring of processes and structures, of advice in the evaluation of its security and of decision making to guarantee its correct operation. It was born from the union of telecommunications engineering professionals and of roads, channels and ports that collaborate since 2004 in photonic technology research projects applied to the monitoring of processes and structures. This allows us to offer the customer an optimal solution adapted to their needs in the fields of civil engineering, aerospace, transportation and energy.

ePHOOX Engineering (2016)

EPHOOX Technology S.L. (founded in 2016) continues its activities towards the development of novel solutions based on Microwave Photonics technology for specific environments such as 5G. The module OVNA-P100X has been designed and manufactured as an advanced instrumentation for characterization and monitorization of photonic devices and hybrid RoF systems. Ongoing activities will provide soon an upgraded version with improved performance and new functionalities.

1.- PROJECT ACTIVITIES

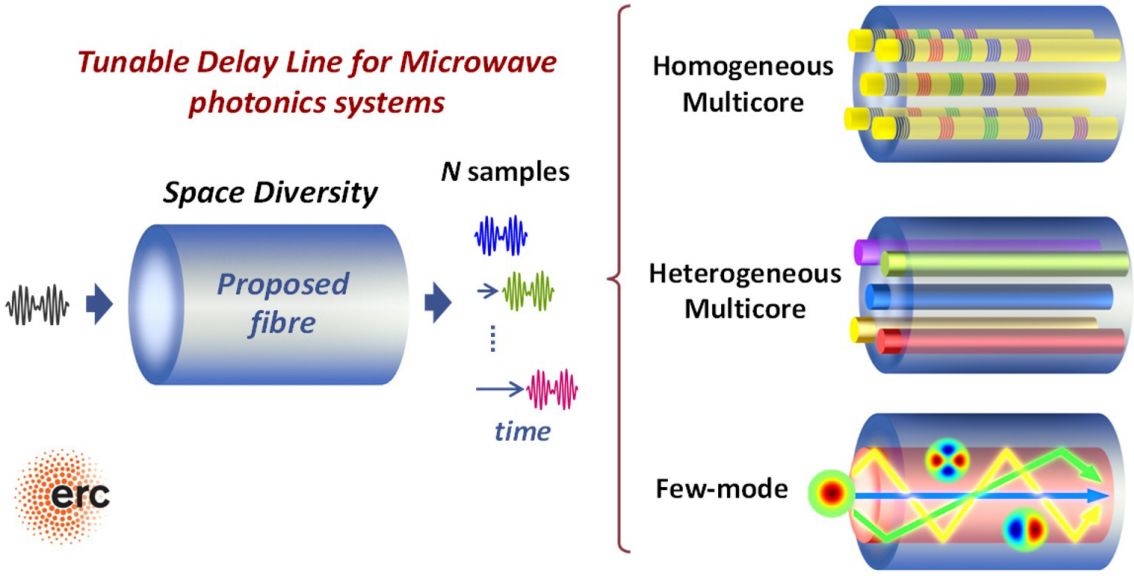
1.1.- ONGOING PROJECTS

ERC Advanced Grant: Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems (UMWP-Chip)

IP: *José Capmany Francoy*

2017 - 2022. European Funding - European Research Council (ERC)

Summary: *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*



ERC Consolidator Grant: INNOSPACE
Revolutionizing fibre-wireless communications through space-division multiplexed photonics

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 a processor based on the novel concept of photonic waveguide mesh optical core and its integration in a Silicon Photonics chip.

ERC Consolidator Grant: Revolutionizing fibre-wireless communications through space-division multiplexed photonics (InnoSpace)

IP: Ivana Gasulla Mestre

2017 - 2022. European Funding - European Research Council (ERC)

Summary: *InnoSpace aims to revolutionize next generation fibre-wireless communication paradigms, such as 5G systems and Internet of Things, by pioneering the use of the photonic Space dimension. The present fiber-wireless landscape is characterized by radio-over-fiber distribution architectures that are static and inefficient, (with a replication of bundles of optical fibers) as well as by radiofrequency signal processing systems, such as antenna beamsteering or signal generation, which are nowadays bulky, heavy and power consuming. To overcome these limitations, we propose the application of Space-Division multiplexing to fiber-wireless scenarios where we provide "simultaneously" in a single optical fiber, a compact approach for both distribution and processing functionalities. This leads to the novel concept of "fiber distributed signal processing".*

H2020 BlueSPACE: Building on the Use of Spatial Multiplexing 5G Networks Infrastructures and Showcasing Advanced technologies and Networking Capabilities

IP: Salvador Sales Maicas

2017 - 2020. European Funding – H2020

Summary: *The core concept of BLUESPACE is to exploit the added value of Spatial Division Multiplexing (SDM) in the Radio Access Network (RAN) with efficient optical beamforming interface for the pragmatic Ka-band wireless transmission band. Both being seamlessly integrable in next generation optical access networks infrastructures with massive beam steering capabilities and with flexible network management control. The main objectives targeted by the BLUESPACE project are BlueSpace are: to develop a truly viable and efficient path for 5G wireless communications with a 1000-fold increase in capacity, connectivity for over 1 billion users, strict latency control, and network software programming. BlueSPACE targets a disruptive yet pragmatic approach for the deployment of scalable, reconfigurable and future-proof fronthaul solutions for 5G communications, offering unrivalled characteristics that include: a) increased bandwidth provision by naturally enabling and supporting massive multiple Input Multiple Output (MIMO) transmission starting/ending in the fiber medium by enabling space diversity in the RF domain by supporting RF beam steering in the photonic domain, b) compact infrastructure that is reconfigurable by means of Software Defined (SDN) and Network Function Virtualization (NFV) paradigms and c) the possibility of providing full integration with other existing approaches for the implementation of access networks, such as Passive Optical Networks (PONs). This approach relies on the core concept of this project, which is the introduction of Spatial Division Multiplexing (SDM) in the fronthaul of the mobile access*

network.

COST Action EUIMWP: European Network for High Performance Integrated Microwave Photonics

IP: José Capmany Francoy

2017 - 2020. European Funding – H2020

Summary: *This Action aims to shape and bring the relevant integrated Microwave Photonics community, supporting coordination and networking actions to consolidate this new ecosystem. EUIMWP is providing exchange of knowledge, ideas and, equally important, delivering a portfolio of technological benchmarkings to establish performance indicators and define future technological requirements in high-performance scenarios, mainly radar, 5G, Internet of Things, automotive and aerospace technologies. Over 40 partners from academia, industry and public organizations are founding members of the Action.*

Fibre Nervous Sensing Systems (MSCA-ITN-2016-ETN)

IP: Salvador Sales Maicas

2016 - 2020. European Funding - European Commission

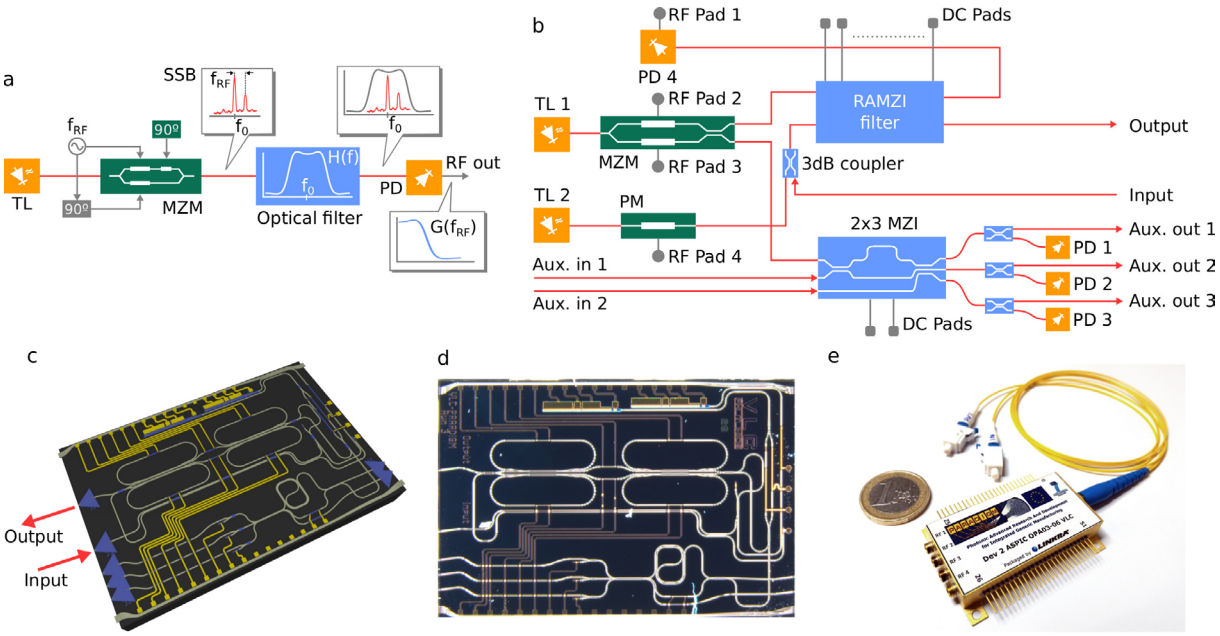
Summary: *FINESSE (FIbre NErvous Sensing SystEms) is a collaborative research and training network, gathering together 26 European universities, research centers and industrial partners with complementary expertise with the ultimate vision of a widespread implementation of distributed optical fibre sensor systems for a safer society. The objective behind FINESSE (FIbre NErvous Sensing SystEms) is to mimic the nervous system of living bodies by turning man-made and natural structures into objects that are sensitive to external stimuli owing to advanced distributed fibre-optic sensor technology, with the objective to either give early warning in case of possible danger or occurrence of damage, or to optimise the operation of the structure to allow for a sustainable use of natural resources and assets. Enabling such functionalities will greatly contribute to realizing a safe, secure and energy efficient Europe, which is an identified societal concern. Website: http://itn-finesse.eu/*

Photonic integrated circuits accessible to everyone

IP: Pascual Muñoz Muñoz

2016 - 2019. Public Funding - European Commission

Summary: *The aim of the PICs4All CSA is to establish a European network of Application Support Centres (ASC's) in the field of Photonic Integrated Circuits (PICs) technology. The main task of these ASC's is to lower the barrier to Researchers and SMEs for applying advanced Photonic IC technology, in particular InP and TriPleX based, and thus to increase the awareness of the existence of this worldwide unique facility. Website: http://pics4all.jeppix.eu/*



Monolithic Integrated Microwave Photonics Filter

Desarrollo de sistemas de caracterizacion y monitorizacion basados en fotonica de microondas de aplicacion en el mercado emergente de redes 5G (CARACTER) (RTC-2016-5343-7)

IP: José Mora Almerich

2017 - 2019. Public Funding - Ministerio de Economía y Competitividad

Summary: *The main objective of the project is to develop a family of characterization systems based on the advanced control of high performance microwave photonic components and a competitive price determinant for the implementation of new generation networks. The interest of the consortium in the present project is to analyze the feasibility of the Microwave Photonic technology for the development and implementation of an advanced performance analyzer for the characterization of devices and monitoring of hybrid radio-fiber systems that is capable of operating until the 70 GHz.*

Silicon Nitride Spectrometers (TEC2016-80385-P)

IPs: *Pascual Muñoz Muñoz, Daniel Pastor Abellán*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad

Summary: *Spectrometric devices are employed in multitude of disciplines, as information technologies, analytical chemistry, bio/life sciences and safety & security. The wavelength range spanning the upper part of the Near Infra-Red (NIR), wavelengths in the range of 1.5-4.0 μm, has recently raised considerable interest both for telecom due to the fiber capacity crunch, and non-telecom applications, since inorganic and organic molecules of fluids, and gases, exhibit fingerprint vibrations in this part of the spectrum. Compact integrated optics spectrometers on photonic integrated circuits (PICs) are comparatively smaller, but to the date they have not achieved the reconfiguration capabilities of the conventional bulk instruments. Among the different PIC technologies, Silicon Nitride on Silicon Oxide waveguiding platforms have received considerable interest in the recent years, due to their broad wavelength range of operation, from visible to the lower part of the mid infrared (400-4000 nm), serving to photonic applications in multiple disciplines (physics, engineering, bio/life sciences, safety & security, to name a few).*

Multicore fibers for next-generation fiber-wireless applications (TEC2016-80150-R)

IP: *Ivana Gasulla Mestre*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad

Summary: *The pioneering idea of FITNESS is to develop a novel area of application for Space-Division Multiplexing by exploiting, for the first time, the inherent parallelism of multicore fibres to implement broadband delay lines for radiofrequency signals, which is the basis of multiple Microwave Photonics functionalities. More specifically, this project works on designing and fabricating group index variable delay line built upon the heterogeneous multicore fibres, where each one of the different cores that comprise it will feature an independent group delay.*

Desarrollo de láseres de pulsos ultracortos con prestaciones avanzadas y bajo coste para su aplicación en la nueva industria (ULTRALASER) RTC-2015-3631-5

IP: *José Mora Almerich*

2016 - 2018. Public Funding - Ministerio de Economía y Competitividad

Summary: *This project is focused on the development of high-efficiency pulses and femtoseconds based on modular technology with a competitive price adapted to the advanced applications of the small industry. The family of lasers obtained in the project will be composed of an ultra-short pulse laser of moderate energy, essentially in the range of the picoseconds whose compression to the range of the hundreds of femtoseconds will be studied throughout the project. A solid-state ultra-short pulse laser (up to 50 fs) and a laser system (laser plus modules for pulse processing) combining fiber technology and compression and amplification technology by free space propagation for very high performance.*

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

D. Pérez, I. Gasulla, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Multipurpose silicon photonics signal processor core," **Nature communications**, vol. 8, p. 636, 2017.

This paper is a joint collaboration between ITEAM-PRL and ORC University of Southampton and reports the design, fabrication and experimental demonstration of a silicon photonics multipurpose processor core based on an integrated hexagonal waveguide mesh. The mesh is composed of 7 hexagonal MZI waveguide cells. We demonstrated the implementation of over 20 different configurations of photonic circuits ranging from simple single-input/single-output FIR filters, optical ring resonators (ORRs), coupled resonator waveguides (CROWs), side-coupled integrated spaced sequences of optical

resonators (SCISSORs) and ring loaded MZIs to multiple-input/multiple-output linear optic 2×2, 3×3 and 4×4 transformations including Pauli Matrices and a C-NOT gate. The experimental demonstration of this multifunctional integrated waveguide mesh photonic processor core included both classical FIR and IIR signal processing functions as well as multiport linear optics operations.

D. Perez, I. Gasulla, F. J. Fraile, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Silicon photonics rectangular universal interferometer," **Laser & Photonics Reviews**, vol. 11, no. 6, 2017.

This paper is a joint collaboration between ITEAM-PRL, the University of Vigo and ORC University of Southampton and reports the implementation of a fixed rectangular universal interferometer using a reconfigurable hexagonal waveguide mesh circuit. A suitable adaptation synthesis algorithm tailored to this mesh configuration was provided and the experimental demonstration of a rectangular multiport interferometer by means of a fabricated silicon photonics chip was reported. The 7-hexagonal cell chip can implement 2×2, 3×3 and 4×4 arbitrary unitary transformations. The proposed hexagonal waveguide mesh operates in a similar way as a Field Programmable Gate Array (FPGA) in electronics. This work represents an important step-forward towards fully programmable and integrable multiport interferometers

2.2.- PATENTS

J. Capmany, I. Gasulla, D. Pérez and S. Sales, "Compact broadband tunable photonic dispersive delay line," Application no. P201730990. Publication date: July 28, 2017.

Priority country: Spain.

2.3.- AWARDS.

1. **Daniel Pérez López,** Postdoctoral Researcher at the PRL has been awarded by COIT (the Spanish official association of telecommunication engineers) the prize to the best Spanish PhD thesis on Information and Communication Fundamentals and Basic Technologies, and their Applications.

Title: "Integrated Microwave Photonic Processors using Waveguide Mesh Cores"

Supervisors: Prof. Dr. Dr. José Capmany Francoy and Dr. Ivana Gasulla Mestre.

3.- SPECIAL EVENTS

20th European Conference on Integrated Optics – Valencia – 2018

Co-chairs: Pascual Muñoz and Pablo Sanchis

The 2018 European Conference on Integrated Optics (ECIO 2018, www.ecio-2018.org) celebrated its 20th anniversary in Valencia from the 30th May to the 1st June 2018. The conference focused on leading edge research on integrated optics, optoelectronics and nano-photonics and gathers experts from academia and industry to show their latest technical results, and showcase their products and services. The application scope was broad and it ranged from tele/datacom communications, optical interconnects, and (bio) optical sensing applications to more disruptive areas as quantum computing and mid-IR photonics. The conference featured more than two hundred attendees, and the 2019 edition will take place in Ghent University, Belgium. Conference topics covered waveguide technology and platforms, devices and materials, integrated circuits and applications of photonics integrated circuits (PICs). The most recent advances in photonic integration technologies, such as silicon photonics and III-V optoelectronics, was one of the main features of the conference. Assembly, packaging and hybrid integration techniques was also present, as well as novel concepts on materials, 2D materials or phase change materials.

Special events
20th European Conference on Integrated Optics – Valencia - 2018