ANNEX 4: FINAL REPORT

INDIVIDUAL FELLOWSHIPS

Project n°: 275703
Project Acronym: IFOCS
Project Full Name: IN-FIBER OPTICAL CAVITIES STRUCTURES

Marie Curie Actions

IEF-IOF-IIF- IIFR -Final Report

Period covered: from 1/SEPTEMBER/2011 **to** 31/AUGUST/2013

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Project beneficiary name: MIGUEL A. PRECIADO

Project beneficiary organisation name: ASTON UNIVERSITY

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1. FINAL PUBLISHABLE SUMMARY REPORT

This project was focused on the study and development of photonics processors for optical signal processing applications, focusing on in-fiber optical cavities structures (IFOCS), which are the “in-fiber” implementation of coupled multi-cavity structures. “In-fiber” optical devices are embedded in an optical fiber, and they are highly desirable because of their easy integration, high power handling, tolerance of harsh environments, flexible form factor, variable wavelength accommodation, low cost and scalable manufacturing. The main aim of the proposed research consists in the study and research of the potential applications of IFOCS, focusing on the options for designing and fabricating tuneable and the combination of complementary structures. Multi-cavity optical structures are resonant structures composed of the combination of several optical cavities. The resulting composite device provides high order spectral responses, and enables the design of devices than act as significantly more complex signal processors than the corresponding to a single cavity. In the case of a coupled cavities configuration, these structures can be implemented with a sequence of reflectors, as is schematically represented in Fig. 1(a). IFOCS constitutes an “in-fiber” implementation of an optical cavity structure, in a coupled configuration, the properties of which will be exploited in the proposed research. They are based on a specially designed chirped fiber Bragg grating where the reflectors are spatially distributed along the whole length of the device (see Fig. 1(b)).

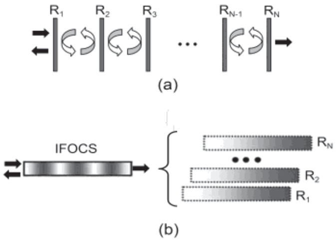

Fig.1. Plot (a) shows an ideal reflectors implementation of coupled multi-cavities. Plot (b) show an IFOCS implementation, where the reflectors are spatially distributed and overlapped in a chirped fiber Bragg grating (b).

We have first study and developed an analytical method showed in Fig. 2 to design very high order optical cavities structures implementable with IFOCS [**1**] (see fig. 3). Arbitrary group delay responses synthesis, including stepped group delay profiles, second and third order dispersion or sinusoidal phase modulation. Designs implementable by plenty of different technologies, including linear resonators, ring resonators, or 1D grating structures (FBGs, thin-film,...). All-pass optical cavities structures, also known as Gires-Tournois etalon-based structures, are highly suitable in WDM multichannel systems, since their response is spectrally periodic, and can be implemented in a number of technological options. Concretely, Fiber Bragg grating (FBG) implementation offers an in-fiber and inexpensive solution.

We have also developed a design technique [2-4] showed in Fig. 4, which generalize previously developed methods to a broader range of structures for amplitude and phase spectral filtering, which enable in-fiber processors using **novel practical designs for feasible implementations based on IFOCS** as a readily feasible approach for complex linear photonic processors with applications in optical communications, fiber sensing or microwave photonics. A novel approach to very high-order linear filtering photonic processors a phase-modulated fiber Bragg grating (FBG) in transmission is proposed, designed and fabricated [2-4]. We show that phase-modulated FBGs can provide transmission responses suitable for pulse shaping applications, offering important technological feasibility benefits, since the coupling strength remains basically uniform in the grating. Moreover, this approach retains the substantial advantages of FBGs in transmission, such as optimum energy efficiency, no requirement for an optical circulator, and robustness against fabrication errors. The previous design technique enables the introduction of a novel kind of photonics processors, namely distributed interferometers, which allows the implementation of robust Mach-Zehnder interferometers, a basic optical device used in countless optical applications from optical communications, fiber sensing, or photonics signal processing in general (see Fig. 5). The experimental results has successfully validate the proof of concept of transmissive phase-modulated FBGs (see Fig. 6 and 7).

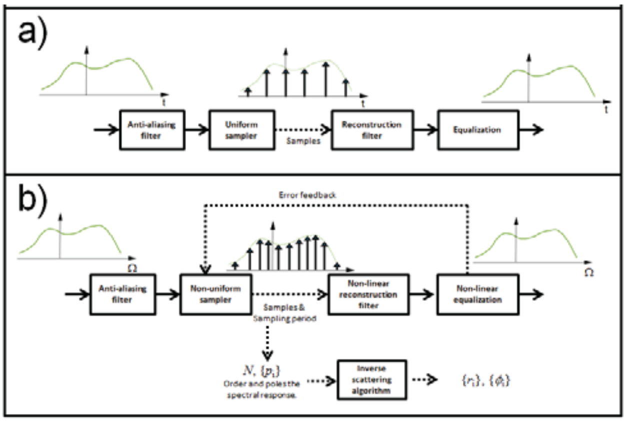

Fig. 2. (a). Classic signal sampling and reconstruction process (b). Proposed method schematic based on classic signal sampling and reconstruction process

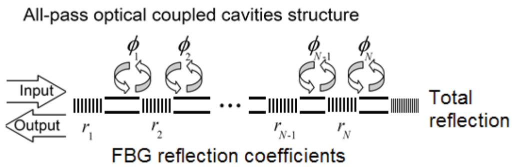

Fig. 3 Typical IFOCS structure resulting from previous method.

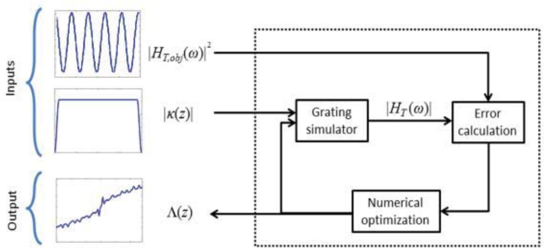

Figure 4. Proposed design method based on numerical optimization for the originally proposed transmissive phase-modulated FBGs based on IFOCS structres of very high order.

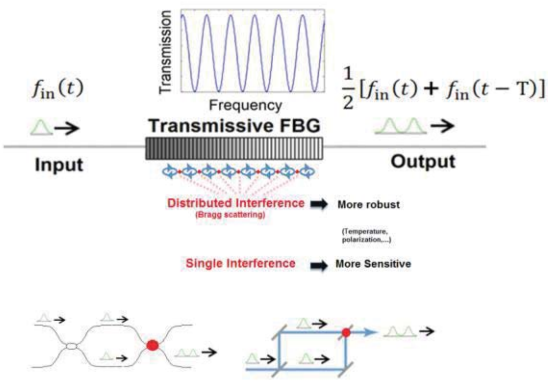

Figure 5. Originally proposed “distributed interferometer” implemented on a FBG.

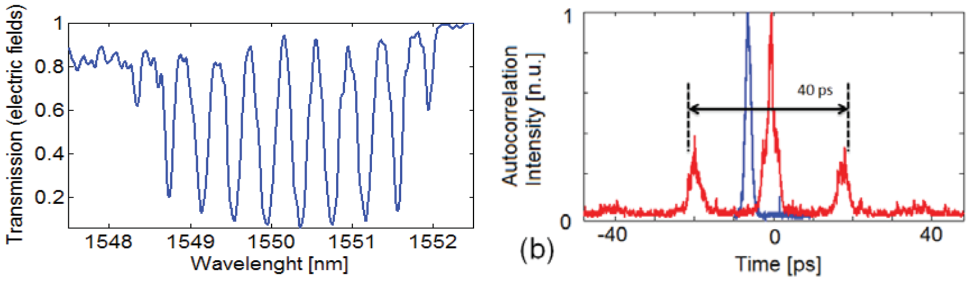

Figure 6. Distributed interferometer spectral (a) and temporal (b) results for fabricated photonic device using the proposed approach for transmissive phase-modulated FBGs based on IFOCS structures of very high order.

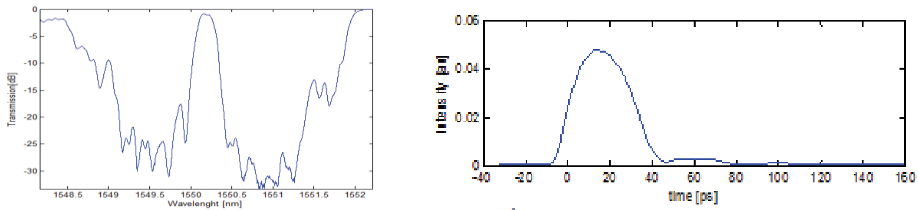

Figure 7. Spectral (a) and temporal (b) results for fabricated photonic device using the proposed approach for transmissive phase-modulated FBGs based on IFOCS structures of very high order. Example for parabolic pulse shaping from an input Gaussian pulse with FWHM of 5 ps.

Additionally to the main aim of this project, in the concrete application pulse shaping, we have study the unique propagation properties of Airy-based pulse shapes, and we have proposed novel Airy-based wavepackets with unique propagation properties such as attenuation invariance or pre-defined peak amplitude modulation [5-7]. Also, the first experimental demonstration of a first-order optical differentiator based on a transmissive FBG has been reported [8,9].

From the point of view of the potential impact of the project, it is expected that the findings of the project, namely the development of novel techniques and approaches in the field of optical cavities structures and transmissive IFOCS, novel Airy-based pulses by linear pulse shaping, and first experimental demonstration of first-order optical differentiator on a transmissive FBG .

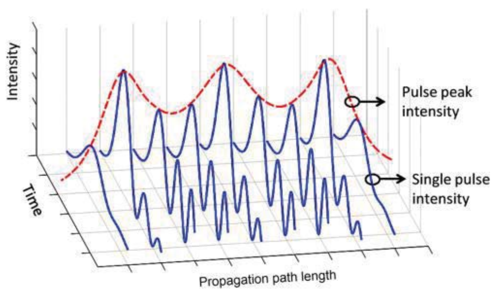

Fig. 8. Illustrative representation of the linear dispersive PAM of the Airy-based pulse (example of oscillatory pre-defined PAM). Arbitrary pre-defined PAM can be used.

As an immediate exploitable result in industry it is important to highlight the development of a novel family of optical processors based on transmissive IFOCS implemented on FBGs, in particular the introduction of a patent pending approach [10] based novel concept of distributed Mach-Zehnder interferometer, where the interference is distributedly performed all along the grating length, with potential applications in fields ranging from fiber sensing, optical communications, or photonic signal processing in general.

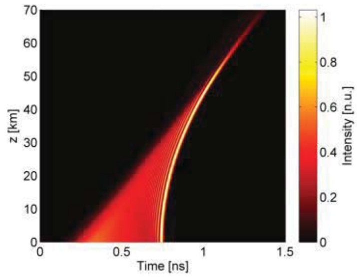

Fig. 9. (Color online) Color map representation of the evolution of the temporal intensity of the propagated pulse, partially invariant to attenuation during its propagation.

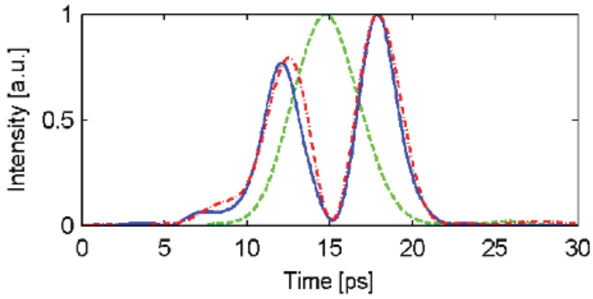

Fig. 10. First proof of concept of a first-order temporal differentiator by a transmissive FBG. FROG recovered temporal intensity of the input pulse (dashed green), output pulse (solid blue), and numerically calculated temporal differentiation (dash-dotted red)

For more information check https://sites.google.com/site/miguelpreciadoresearch/

REFERENCES

[1] M. A. Preciado, X. Shu, K. Sugden, and M. A. Muriel, "Synthesis of Arbitrary Group Delay Responses with All-Pass Optical Cavities Structures". BGPP 2012.
[2] M. A. Preciado, X. Shu, and K. Sugden, "Proposal and design of phase-modulated fiber gratings in transmission for pulse shaping," Opt. Lett. 38, 70-72 (2013)
[3] M. A. Preciado, X. Shu and K. Sugden, "Pulse shaping by phase-modulated fiber gratings in transmission". OFC/NFOEC´13.
[4] M. A. Preciado, X. Shu, A. El-Taher and K. Sugden, "Virtual delay line interferometer by a transmissive phase-modulated fiber Bragg grating". ECOC 2013.
[5] Miguel A. Preciado, "Linear dispersive pre-defined peak amplitude modulation of spectrally modulated Airy-based pulses," Opt. Express 21, 13394-13401 (2013)
[6] M. A. Preciado and K. Sugden, "Proposal and design of Airy-based rocket pulses for invariant propagation in lossy dispersive media," Opt. Lett. 37, 4970-4972 (2012)
[7] M. A. Preciado and M. A. Muriel, "Bandlimited Airy Pulses for Invariant Propagation in Single-Mode Fibers," Journal of Lightwave Technology 30, 3660 - 3666 (2012)
[8] M. A. Preciado, X. Shu, P. Harper, and K. Sugden, "Experimental demonstration of an optical differentiator based on an FBG in transmission," Opt. Lett. 38, 917-919 (2013).
[9] M. A. Preciado, X. Shu, P. Harper and K. Sugden, "First order optical differentiator based on an FBG in transmission" CLEO'13 Munich
[10] M. A. Preciado, X. Shu, GB Patent Application 1307388.7 (2013)
[11] J. Skaar, "Synthesis of fiber Bragg gratings for use in transmission" J. Opt. Soc. Am. A 18, 557-564 (2001).