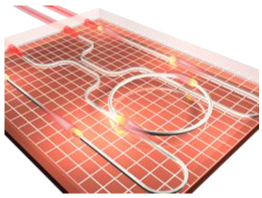
“CHRONOS”

Route to On-Chip Resonating Optical Clocks via Nonlinear Optics

This project aims to the definition of a novel operating principle for the control of mode phase locking in micro-cavity driven optical frequency combs (OFC). The perspective target of this proposal is the realization of integrated precision optical clocks with ultra-high repetition rates.

The work of this project is based on a novel mode-locking principle for high repetition rate (>200GHz) lasers previously developed by the MC fellow [1], embedding a nonlinear high-quality resonator in a fibre laser cavity. Although still limited to a reduced number of oscillating modes, her results demonstrate that such scheme delivers a stable, fully mode-locked pulse train, representing a simple and effective way to lock the phase of an OFC induced by four wave mixing in micro-resonators. Remarkably, the design consists of the simple fibre cavity: the fibre is the active element that provides the gain necessary to the lasing, while the micro-resonator is responsible for the wave mixing of the modes.

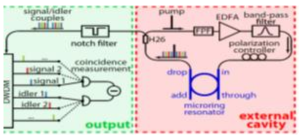


Representation of an integrated optical ultrafast clock based on a micro-ring resonator.

Starting from the investigation of the *phase relation* among the modes, this proposal targeted the definition of the control parameters for the generation of versatile OFC via double nested cavities, also thanks to the exact formalization of the underlining physics. As the final goal is to outline practical OFC sources, specifically identifying potential strategies towards their full integration, the verification of the theoretical modelling on an experimental test-bed is a core part of the project.

Project logo.

The main result, i.e. the study of the control parameters for the nested cavity laser has been achieved. Specifically, the experimental study of a self-locked optical parametric oscillator [2] design has been performed and has been instrumental in a number of interesting achievements in quantum optics. The laser scheme is at the basis of the recent generation of cross-correlated photon pairs, as published in Optics Express and Nature Communications [3-4].



Pumping scheme for the generation of integrated quantum sources, as in [3-4]

The experimental study of the laser targeted also a more general set of nonlinear filters, leading to the demonstration of a different mode-locking regime. Such results have been recently presented in top international conferences [5] and are now being prepared for publication.

In addition, the detailed study of the four-wave-mixing dynamic developed at this stage allowed also for the development of a work on the stability of optical beams, recently published in the top physics journal Physical Review Letters [6], with interesting fallouts in for optical waveguides direct laser writing [7]. An innovative approach for the noise characterization of the laser has been developed and published during the research activities for developing the experimental setup [8].

Impact

The rush towards the integration of ultrafast, high precision optical clocks is witnessed by the huge number of high impact works on the topic of the last few years. This interest is indeed catalysed by the impact that high precision OFCs had in the last decade on metrology and spectroscopy; furthermore, the technology for the fabrication of high quality micro-cavities has matured only in the very last years, boosting the scientific investigation toward this exciting direction. In this framework, the demonstration of planar high quality resonators compatible with the silicon technology opened up the unique perspective to use such devices as light sources in microchips. These considerations triggered the preliminary studies that the MC fellow carried out in her previous research activities, leading to the

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definition of the system presented in Fig. 1, at the basis of this proposal. The development of an in-depth understanding of the mode mixing in this structure as proposed in the CHRONOS programme appeared, then, timely and fundamental for the further development of such design.

As the aim of the proposal was the development of a new technology, the constant experimental verification of the theoretical predictions had the double value of bursting the research endeavour towards the definition of prototypes readily usable in different scientific environments (as in outcome [4-5]) while guaranteeing the knowledge transfer from the previous institution of the MC fellow (the Canadian INRS-EMT-*Third Country*) to the University of Sussex, *host institution*.

The investigation carried out here, not only had the intrinsic scientific-technological value discussed above, but represents the possibility to develop an exceptional simple test-bench –easy to manage and highly versatile- for a general class of optical technologies.


Recently refurbished laboratories at the University of Sussex.

This optical design is indeed at the core of the involvement of the MC fellow in the Birmingham led research action (EPSRC Q-Hub for Sensor and Metrology), where the MC fellow will start leading the Microcomb work package from September 2015, while the scientist in charge is coordinating the general research activities of the Sussex Unit. Notably, the institution of the third country is a partner in this research action. Then, this proposal fulfilled the aim of the MC call, in producing state of the art research, integrating the MC fellow in the EU academic scenario and fulfilling a transfer of knowledge to the hosting country (the UK). As planned, this proposal contributed to the growing up of synergies between the British Physics Department and the *Third Country* institution well beyond the finality of the MC project.

Summarizing, this proposal contributed i) to maintain and promote the leadership of the fundamental research in Europe. This project was theoretically and experimentally challenging: it aimed to the definition of a novel class of optical clocks enabled by the use of advanced approaches in nonlinear science creating new, fundamental and interdisciplinary knowledge; ii) to improve the competitiveness of the European photonics industry at the international level through the development of cost-effective photonics ultrafast sources for a wide range of applications.

References

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