RELAZIONE FINALE PROGRAMMA DI RICERCA STM

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Istituto di afferenza: Istituto Nazionale di Ottica – CNR

con qualifica Ricercatore **livello** III

Descrizione dettagliata dell'Istituzione ospitante: Laboratoire de Physique de la Matière Condensée (LPMC) - Université de Nice-Sophia Antipolis – Nice (France). For details see the institutiion web site http://lpmc.unice.fr/

Dipartimento di afferenza (tendina): Scienze Fisiche e Tecnologie della Materia

Titolo del programma: Non-classical light in fully guided-wave optical devices for quantum communications.

Relazione finale

Thanks to the STM project it has been possible to reinforce the already established collaboration between the "Quantum information with light and matter" (QILM) research group at LPMC and the "Quantum optics" group of INO-CNR. This project was focused on the generation and characterization of *squeezed* light, namely light with a purely quantum behavior, on an optical chip. The development of compact and miniaturized non-classical sources of light is at the basis of the future quantum communication technologies.

Squeezed light is characterized by reduced quantum noise with respect to vacuum fluctuations. For instance, the noise of a light field in a coherent state (which describes light from a laser source) is governed by quantum uncertainty principle and is represented by a circular uncertainty region, where the two axis are represented by the amplitude and phase quadratures. By using nonlinear effects one can achieve lower noise in amplitude or phase and the circular uncertainty region is "squeezed" into an ellipse, thus the uncertainty is reduced along one filed component and increased in the other satisfying the Heisenberg principle.

The opportunity of using squeezed light to reduce quantum noise can have wide applications in a variety of measurement systems, both in quantum communications and elsewhere. For instance, it has been suggested as a way to boost the sensitivity of the gravitational-wave detectors [1,2].

In the last years, several papers have been published on the generation and manipulation of squeezed states of light. Most of experiments, however, employ free-space non-linear crystals inserted in an optical cavity and they are not developed at telecom wavelengths. Compared to previous realizations, we aim at realizing a miniaturized optical setup that, besides being more stable and compact, will be fully compatible with existing telecom fiber networks. These efforts are in line with the interest for real-world implementation of squeezing experiments: the possibility of miniaturizing quantum technologies is at the center of recent investigations, in particular with the demonstration of a photonic chip for in situ operations on squeezing.

The reconfigurable optical chip on Lithium Niobate (LN) designed at QILM is aiming at integrating an optical scheme for the quantum teleportation of single photon quantum states. The very same chip, however, can be conveniently exploited as a stage for the integrated production and manipulation of different non-classical states generated at a telecom wavelength such as squeezed states (states of the electromagnetic field characterized by fluctuations along one quadrature of the light field lower than those of the vacuum).

The chip consists in an optical circuit realized with wavegiudes in a LN substrate (obtained by soft proton exchange method). This optical circuit has two inputs and four output waveguides connected together by three beam splitters, the reflection and transmission coefficients of these beam-splitters can be controlled by an external electrical field thus enabling a large degree of freedom on the circuit configuration. At one input of the first beam-splitter, a periodically poled region (13mm long) is realized in order to enable nonlinear interaction to generate squeezed light. The quantum light can be routed inside to the optical circuit to be mixed with a reference beam, which is injected in along the unused input port, to perform homodyne detection on chip.
Unfortunately, during my visit at QILM, the chip was still under construction and, at the end of my STM period, only the waveguide construction and the periodically poled structure were accomplished. The accomplishment of the final construction tasks is scheduled for the end of September 2016.

In order to optimize the time schedule, we have focused our attention on the theoretical model and design of the future experiment, that it will be presumably start before the end of November. In particular, I have succeeded in the following tasks:

1) Analysis of the losses inside the chip;
2) Theoretical estimation and analysis of the efficiency of the SPCD sources in the chip;
3) Study and design for an efficient optical apparatus to couple light from the chip's output to the homodyne detector;
4) Some considerations concerning the use of continuous wave or pulsed lasers sources to pump the chip have been drawn.

In order to estimate the expected amount of detected squeezing, we have realized a theoretical model for the chip that includes the brightness of the SPDC sources, the propagation losses inside the chip, and the optical collection system to couple the chip's output light to the homodyne detector.
The estimated parameters have been compared with the squeezing source recently realized using a fully-guided approach by the collaboration between QILM and INO-CNR and recently published [3]. In conclusion, we have estimated, in the worst scenario, a detectable squeezing value of -0.5dB. As soon as the chip under construction at QILM will be ready, we will proceed with the characterization, setup realization and final measurements.

References

[1] J. Aasi et al., *Nat. Phot.* **7**, 613–619 (2013).

[2] E. Oelker, L. Barsotti, S. Dwyer, D. Sigg, and N. Mavalvala, *Opt. Expr.* **22**, 21106 (2014).

[3] F. Kaiser, B. Fedrici, A. Zavatta, V. D'Auria, and S. Tanzilli, *Optica* **3**, 362 (2016).