Chip-based compact squeezing experiment at a telecom wavelength

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ABSTRACT

We present a compact and easy-to-use set-up exploiting the association of commercial plug-and-play fibre components and integrated optics on lithium niobate for the generation and detection of squeezed light at a telecom wavelength. Light exhibits a reduced quantum noise of -2.00±0.05 dB below the shot-noise level in a single-pass configuration.

Keywords: Quantum communication; integrated optics; Squeezed states; Lithium Niobate; Homodyning.

1. INTRODUCTION

Squeezed states of light exhibit a reduce noise level with respect to the classical quantum limit represented by lasers' shot noise. In the last years, after having played a crucial role in fundamental research on light quantum properties, single- and multi-mode squeezed states have been identified as fundamental ingredients for a variety of quantum technologies ranging from quantum sensing to quantum computing and communication [1]. Nevertheless, squeezing generation and detection traditionally relies on free space systems, not scalable, requiring careful alignment and extremely sensitive to mechanical instability. Accordingly, we have been assisting in the last years to a growing interest towards the realization of compact, stable and versatile squeezing experiments compatible with practical and user-friendly realizations [2]. This effort has strongly benefitted from integrated optics on different substrates with the demonstration of on chip squeezing generation both in single pass [3] and in resonant systems [4] as well as on chip homodyne detection [5] or generation and detection [6]. These very nice results certify how the competition on the hot topic of squeezing miniaturization is increasing. At the same time, we stress that, in all these works, important building blocks of the squeezing experiment were still realized thanks to complex bulk optics systems.

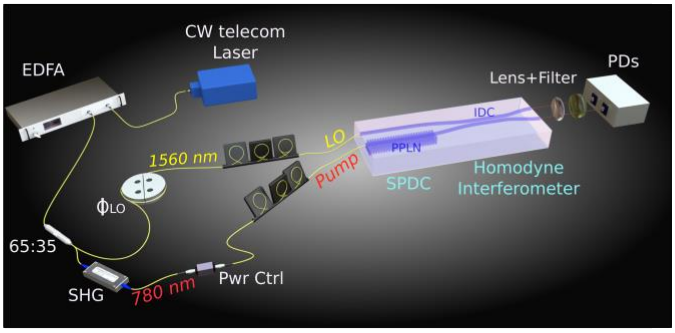

Figure 1. Experimental setup. It associates off-the-shelf fibre components with an original lithium niobate chip for the squeezing generation and detection.

In our work, we provide an original solution to the full miniaturization of continuous variable experiments by means of a hybrid approach associating integrated optics to mature classical technologies. This strategy allows gathering different tools to take advantages of compact and on-chip squeezing generation and detection as well as of the possibility of plug- and-play, versatile and stable systems based on commercial guided wave technology [7]. More in details, squeezing is generated in a single pass configuration via spontaneous parametric down conversion (SPDC) on lithium niobate and detected, directly on chip, thanks to a homodyne detector whose interferometric part relies on an integrated optical coupler. Lithium niobate is particularly suitable to develop photonic circuits, featuring high nonlinearity and the possibility of implementing quasi-phase-matching to engineer the nonlinear optical response [8]. Moreover, the high confinement of light in waveguides combined with non-linear properties allows obtaining compact and efficient generation of squeezing even in a single pass (cavity-free) configuration [3]. On the other hand, spatial mode matching issues at homodyne interferometers are greatly simplified with single-spatial-mode splitters and combiners [2], whose splitting ratio can be controlled, whenever required**,** thanks to electro-optical effect **[**6**]**. All the other building blocks of the experiment are realized thanks to off-the-shelf components coming from telecom and non-linear optics. The wedding between integrated optics and these technologies allows realizing and extremely compact and easy-to-assemble experiment, where stability and spatial mode matching issues affecting bulk experiments are completely removed.

2. EXPERIMENTAL SETUP

Our experimental setup is sketched in Fig.1. It associates an fully fibred injection system with our home-made lithium-niobate chip.
The setup relies on a master, fibre-coupled laser generating a CW optical beam at 1560.44 nm and amplified up to 0.95 W with an erbium-doped fibre amplifier (EDFA). At the output of the EDFA, the single mode laser light is split by a high-power 65:35 fibre coupler (f-BS). The less intense output is directed to a home-made fibre stretcher allowing to scan its phase, to be subsequently used as local oscillator (LO) for the homodyne interferometer. The brighter output is frequency doubled to 780.22 nm via second-harmonic generation periodically poled lithium-niobate ridge waveguide (SHG) in a commercial and used to pump the squeezer.

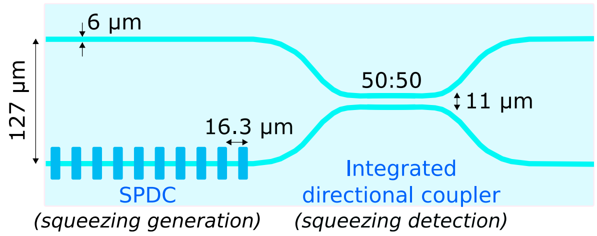

Figure 2. Photonic chip for the squeezing generation and detection.

The LO at 1560.44 nm and the pump at 780.22 nm are sent to a fibre array and coupled to the home-made photonic chip. A fibre polarisation controller (PC) on each arm is introduced to properly adjust the polarisation. The entire optical setup upstream the chip is made using by plug-and-play components guaranteeing a versatile and quick operation [2]. The chip is represented in Fig.2. Its total length is 5 cm. It includes a periodically poled waveguide for the generation of squeezing by SPDC at the telecommunication wavelength of 1540.44 nm, followed by an integrated beam-splitter, exploiting evanescent wave coupling and representing the core of the homodyne detection interferometric part. The SPDC occurs in one arm of the beam-splitter, while the other serves for the injection of the local oscillator (LO). All waveguides are obtained by soft proton exchange [8] and have a width of 6 µm. The 127 µm spacing between the input (output) waveguides is compatible with of-the-shelf fibre-arrays. The homodyne photodiodes are outside the chip and are bulk commercial components.

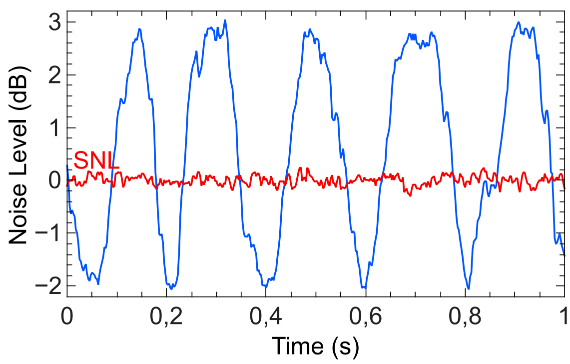

Figure 3. Normalised noise variances at 2 MHz as a function of the LO phase (proportional to the time). This measurement corresponds to the maximum coupled pump power (40 mW).

With our setup, for a CW pump power of 40 mW, we demonstrate a raw squeezing level of -2.00 ±0.05 dB, corresponding to - 3.00 ± 0.05 dB when corrected from avoidable losses (see Fig. 3) [7]. This value represents, to our knowledge, the highest reported squeezing level in single pass configuration pumped in CW regime and it demonstrates the validity of our approach.

The demonstrated approach is extremely versatile. Moreover, our solution provides squeezed light at a telecom wavelength so as to be compatible with quantum communication in existing optical fiber networks.

Finally, we would like to stress that the perspectives with such a photonic circuit lies in the on-chip generation and characterization of Schrödinger cat states as well as CV quantum qubits, thus making our chip a flexible tool for quantum metrology and computing.

3. CONCLUSIONS

In conclusion, we have demonstrated a compact, versatile, and easy-to-handle experiment combining integrated optics on lithium niobate and off-the-shelf telecom and nonlinear components. The realised photonic circuit integrates on-chip the squeezing generation and the optical coupler of the homodyne interferometer. The squeezed light generated at telecom wavelength exhibits a noise compression of -2.00 ± 0.05 dB for a pump power of 40 mW. Outside the chip, the setup employs only plug-and-play fibrered components requiring no alignment procedures and allowing for a quick system reconfiguration. These advantages guarantee an extreme reliability and make our approach a valuable candidate for real-world applications based on continuous variable quantum systems.

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