Vacuum squeezed states from PPLN waveguide chips

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Abstract:
We report the experimental generation and measurement of quantum squeezed light source from a PPMgO:LN Ridge waveguide chip at 1550 nm. The measured squeezing level reaches a quantum noise reduction up to -2.7 dB, along with and anti-squeezing 4.6 dB, at the pump power of 350 mW. Degradation from the chip loss and phase noises is also performed, which provides an important platform for the development of quantum integrated optical circuits.

Key Word— *squeezed light, optical parametric amplifier (OPA), balanced homodyne detection (BHD)*

1. Introduction

The development of efficient quantum photon sources as well as powerful quantum devices and circuits has been in great demand. On-chip solution for quantum light sources provides the critical step toward integration with optical circuits. As classical counterparts utilizing both digit and analog information processing, we will also provide quantum qubits in continuous variables (CV), which is a complementary family to the fragile discrete variables only with single photons and photon pairs. In this work, we utilize the periodically poled lithium niobate (PPLN) waveguide chip, acting as an optical parametric amplification (OPA), to generate squeezed states with a quantum noise reduction [1,2].

As illustrated in Fig. 1, our PPLN waveguide chip consists of multiple waveguide networks on a monolithic PPMgO:LN Ridge waveguide chip. A CW light from a main fiber laser at a wavelength of 1550 nm is injected into the first periodically poled waveguide "SHG" to perform a frequency up-conversion for generating a 775 nm pump beam. The OPA generates squeezed light according to the optical parametric process. The squeezed light then is separated from the beam, and interferences with a local oscillator (LO) beam (split from the main laser) by a directional coupler (DC). Electrodes patterned on top of the waveguides are used to control the splitting ratio of the directional coupler and the phase of the LO. The output interference signals were detected by a balanced homodyne detector (BHD) to obtain the squeezing level [3].

2. Estimation on Squeezing levels

Theoretically, we estimate the squeezing level from the chip, by measuring the nonlinear gain of the chip. With known input and output pump power, we have the model of nonlinear gain as

$$P_{out} = \eta_o \exp(\pm 2\gamma)\, P_{in} + (1-\eta_o) P_{in}, \tag{1}$$

where η_o is the overlap coefficient between pump and signal light. $\gamma = \sqrt{aP_{pump}}$ is squeezed parameter, a is the conversion efficiency of SHG, and then, $G_\pm = \exp(\pm 2\gamma)$ is called intrinsic parametric gain.

With the parameters of intrinsic parametric gain, we can roughly estimate the squeezing level that the experimental structure and the chip can produce,

$$R_\pm = \eta \exp(\pm 2\gamma) + (1-\eta), \tag{2}$$

where η is the effective detection efficiency. During the OPA process, amplification and de-amplification phenomena occur relative to the phase change. The squeezing energy level R_+ is the orthogonal term of amplification (anti-squeezing), and on the contrary, R_- is the orthogonal term of de-amplification (squeezing) [4].

3. Experimental results

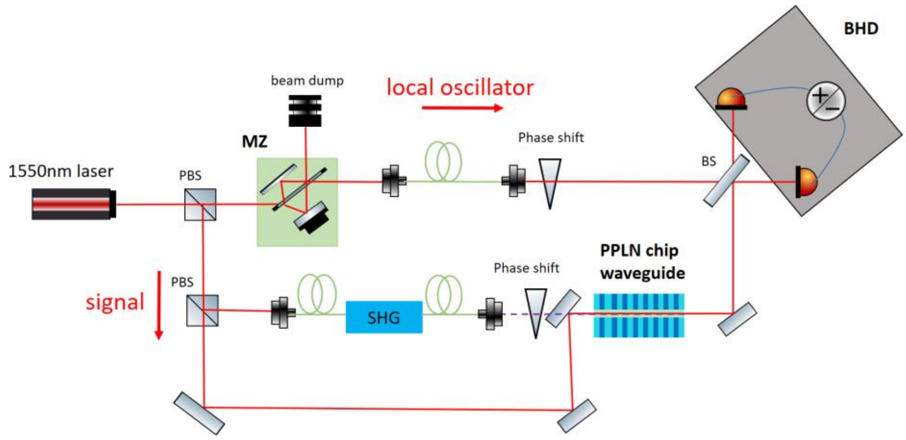

Fig. 1: Schematic of our experimental setup to perform quantum noise measurement [3]. Here, the 1550 nm light source is firstly divided into LO light and the signal light. Then, the SHG output drives the PPLN waveguide chip to generate squeezed states, characterized by our home-made BHD detectors.

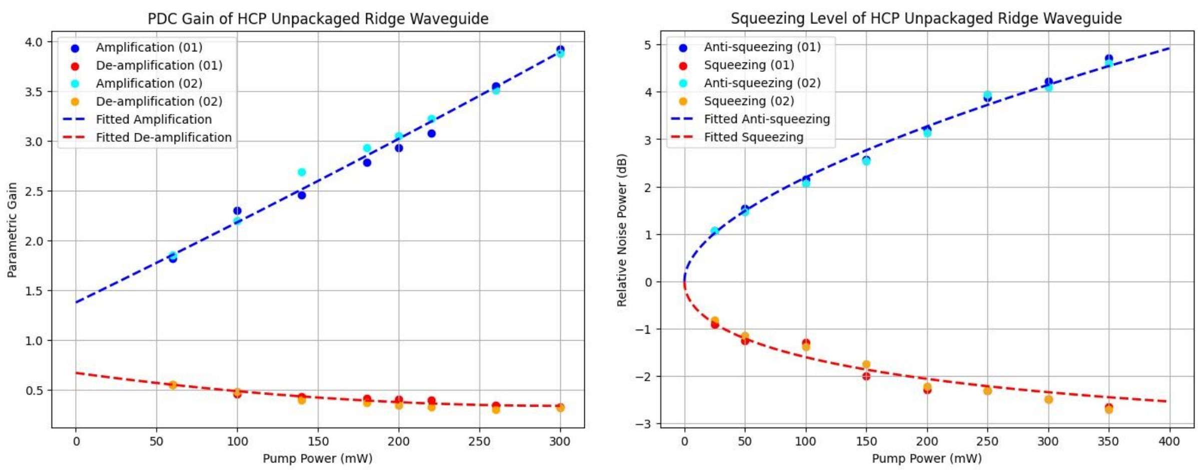

Fig. 2: (a) The measured nonlinear gain, (b) the squeezing and anti-squeezing levels at different pump power [4].

In Fig. 2(a) and 2(b), we demonstrate the measured nonlinear gain of our OPA, and the resulting quantum noise reduction, illustrated with squeezing and anti-squeezing levels, respectively. Our PPLN waveguide chip provides a nonlinear gain of 3.87 amplification and 0.347 de-amplification at a pump power of 300 mW. With help of OPA process, we can reach a maximum squeezing level up to -2.65 dB, while the anti-squeezing state is 4.70 dB [3,4].

In summary, we successfully fabricate and measure a quantum noise reduction up to nearly -2.7 dB from PPLN waveguide chips. Compared to the theoretical estimation, our experimental results give good agreement with the parameters measured. To enhance the squeezing level, in the measurement setup we may shorten the distance of the experimental optical path and/or improve the stability of the holder stage.

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