Squeezed vacuum 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 -2.94 dB, along with an anti-squeezing 5.487 dB, at the incident pump power of 500 mW. Degradation from the chip loss and phase noises is also performed, providing 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 that only have single photons and photon pairs. In this work, we use the periodically poled lithium niobate (PPLN) waveguide chip, acting as an optical parametric amplifier (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 is then 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 [3,4].

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 the pump and signal light. $\gamma = \sqrt{a P_{pump}}$ is the 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 level R_+ is the orthogonal term of amplification (anti-squeezing), and on the contrary, R_- is the orthogonal term of de-amplification (squeezing) [3,4].

3. Experimental results

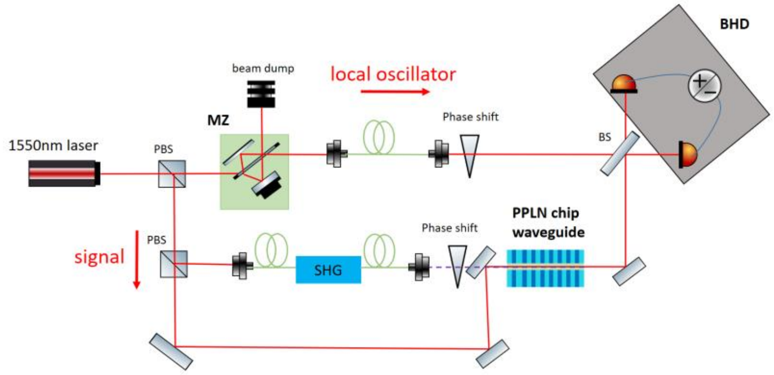

Fig. 1: Schematic of our experimental setup to perform quantum noise measurement [4]. Here, the 1550 nm light source is first divided into LO and signal light. Then, the SHG output drives the PPLN waveguide chip to generate squeezed states, characterized by our homemade BHD detectors.

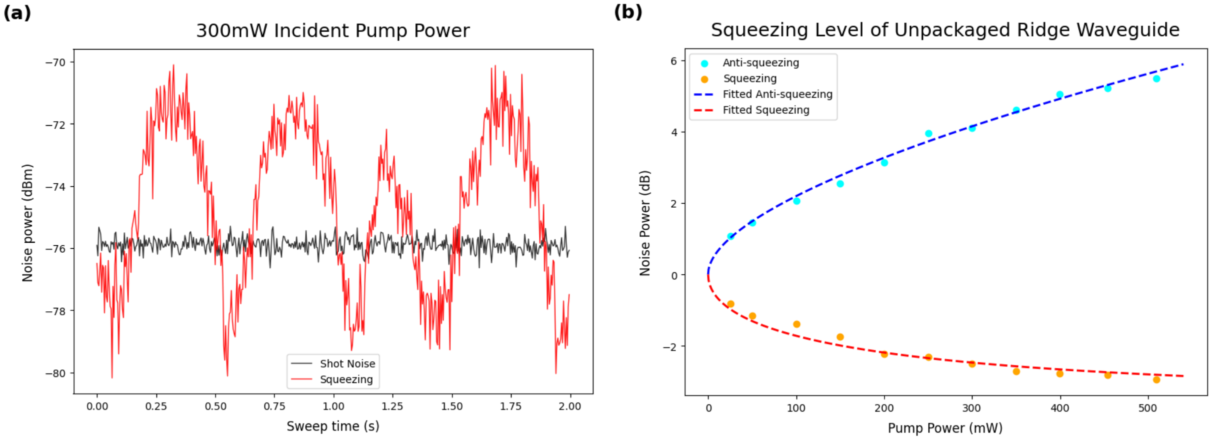

Fig. 2: Squeezed light measurement. (a) The noise of a squeezed vacuum with the shot noise when the incident pump power is 300mW, (b) the squeezing and anti-squeezing levels at different pump power.

In Fig. 2, we demonstrate the measured resulting quantum noise reduction, illustrated with squeezing and anti-squeezing levels. Figure 2(a) shows the noise power of the squeezed light generated within the PPLN waveguide with phase sweeping of LO light. As Figure 2(b) indicates, with the help of the OPA process, we can reach a maximum squeezing level up to -2.94 dB at about 500 mW pump power, while the anti-squeezing state is 5.487 dB.

In summary, we successfully fabricated and measured a quantum noise reduction up to -2.94, nearly -3.0 dB from the PPLN waveguide chip. Compared to the theoretical estimation, our experimental results agree 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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