Broadband Squeezed State Generated in Ring-shaped Optical Parametric Oscillator

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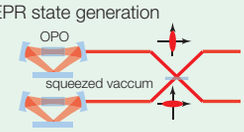
1. Introduction

Squeezed vaccum state is widely used in quantum optics experiments.

ex.) EPR state generation



To **accelarate** the processing speed, Optical Parametric Oscillator (squeezed state source) needs to be **broadband**.

squeezing / anti-squeezing level is:

$$R_{\pm}(\omega) \sim 1 \pm \frac{T}{T+L}\frac{4x}{(1\mp x)^2+\left(f/f_{\mathrm{HWHM}}\right)^2}$$

Small cavity is broadband:

$$f_{\mathrm{HWHM}} \sim \frac{cT}{2\pi L}$$

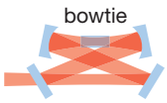
f_{HWHM} : line-width of OPO
T : transmittance of coupling mirror
L : optical path length of OPO

For complex experiment (ex. teleportation), **ring cavities** have advantage, because we can use phase reference beam in opposite direction.

Fabry-Perot

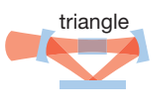
✓ simple and small, especially in monolithic cavity [1].
! optical path is degenerate.
= reference beam suffers from parametric amplificaiton.

bowtie



✓ two directional optical paths.
✓ output beam is collimated.
! complex layout, hard to miniturize.

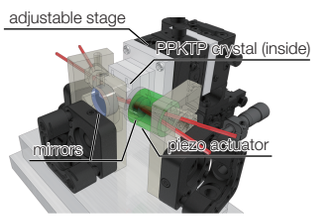
triangle

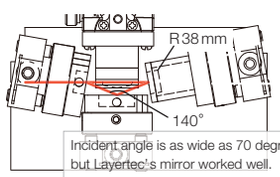


✓ possible to shrink.
✓ two directional optical paths.

adopted!

2. Design of OPO

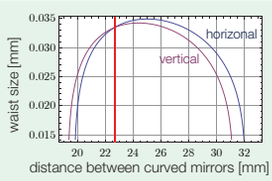




Incident angle is as wide as 70 degrees, but Layertec's mirror worked well.

Line-width is 78 MHz (HWHM), where the round-trip length is 48 mm, coupler mirror transmittivity is 13.6%.

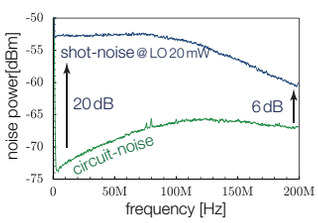
A disadvantage of ring cavities is that their transverse mode is elliptic. However, vertical / horizonal modes match at a specific path length.



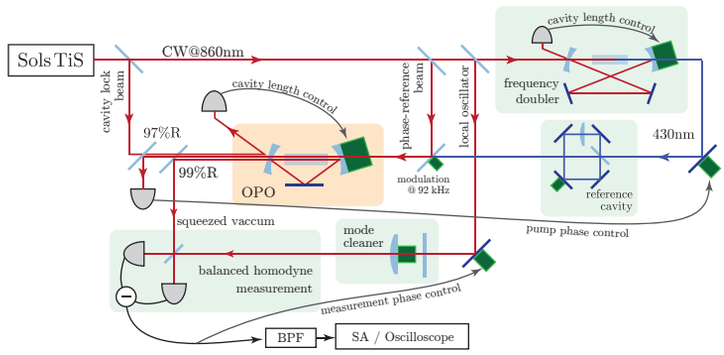
3. New Homodyne Detector

A broadband homodyne-detector was developed in [2], and improved in our lab.

Quantum efficiency is near **99**%.

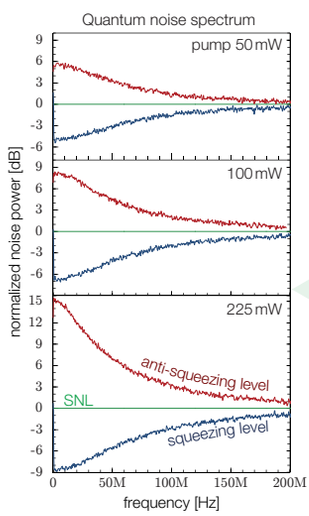


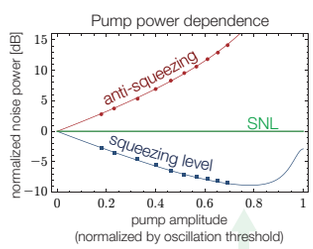
4. Measurement Setup



✓ all cavities were controled by modulation-free method (tilt lock)
• interference effiency @homodyne is 98%
• transfer efficieny from the OPO to the detector is 95%

5. Result





FFT of waveform
RBW: 300 kHz
Average: 1333

Frequency: 3 MHz
RBW: 300 kHz
Average: 4500
phase fractuation: 0.8°

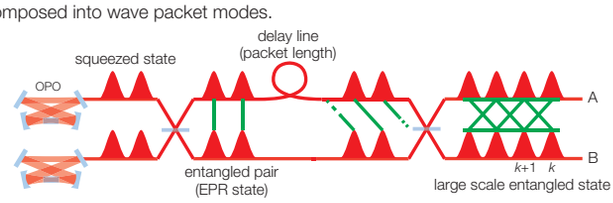
✓ broadband homodyne detection without noise/loss compensation
✓ maximum −8.4±0.2 dB of squeezing

6. Summary

We have succeeded in generating broadband squeezed state with **triangle OPO**, and −3 dB squeeze was measured up to 90 MHz.

7. Application example: time-domain cluster state generation

In our lab, time-domain multiplexed cluster state was generated [3], using CW beam decomposed into wave packet modes.



In previous experiment, delay line was 30 meters long [3], which makes the system weak in vibration.

Our OPO can generate 4 times broader bandwidth squeezed state = 1/4 length wavepacket. It will shorten the delayline to 7 m.

References

[1] Moritz Mehmet, et al. *Squeezed light at 1550nm with a quantum noise reduction of 12.3 dB*, Optics Express 19, 25. (2011)
[2] Kumar, et al. *Versatile wideband balanced detector for quantum optical homodyne tomography,* Optics Communications 285, 24. (2012)
[3] Yokoyama, et al. *Ultra-large-scale continuous-variable cluster states multiplexed in the time domain,* Nature Photonics 7, 982. (2013)