Two Novel Schemes for Photon-Number Squeezed Pulse Generation in Ultrafast Nonlinear Fiber Optics

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Abstract: We experimentally prove two novel techniques which solve issues in photon-number squeezed pulse generation with ultrafast nonlinear fiber optics: one is with Er-doped fiber laser source, and the other is with a normal dispersion fiber at 800 nm. We successfully obtaine photon number squeezing for each case.
OCIS codes: (270.6570) Squeezed state; (320.7110) Ultrafast nonlinear effect; (320.7130) Ultrafast processes in fibers.

1. Introduction

Current studies in the generation of squeezed laser pulses are motivated by the possibility of using highly squeezed pulses to create and distribute continuous-variable entanglement for quantum communication applications. Squeezed light pulses at the telecommunication wavelength is an important resource in optical fiber based quantum information and communication technology. However, erbium-doped fiber amplifiers (EDFA) used in classical communication systems contain substantially high intensity noise which is much higher than the shot noise level (SNL) due to beat noise of amplified spontaneous emission. Therefore, alternatively, optical parametric oscillators or Cr:YAG lasers have been employed in squeezed pulse experiments. In this work, we applied a collinear balanced detection (CBD) technique [1] for generating squeezed light and achieved photon number squeezing at 1.55 μm using a noisy EDFA laser as a light source.

On the other hands, more experiments have been carried out at ~800 nm with a parametric down-conversion scheme to generate entangled photon pairs since quantum information can be stored or exchanged with alkali atom systems at this wavelength range. But it is difficult to generate squeezed pulses in the normal dispersion regime of optical fibers since pulses increase their pulse width by the chromatic dispersion and thus effective optical nonlinearity cannot take place, which is a large difference from soliton pulse propagation in the anomalous dispersion regime. In this work, we utilized spectral narrowing caused upon negatively chirped ultrashort pulses in the normal dispersion regime and achieved photon number squeezing at 800 nm.

2. Photon number squeezing by noise reduced1.5-μm EDFA with the CBD technique

This technique compensates intensity noise at a specific radio-frequency by means of pulse splitting and recombination with a relative time delay τ [1]. Fig. 1 (a) shows the experimental setup. We used a femtosecond fiber laser (Femtolite, IMRA) as a light source. The center wavelength was 1560 nm, the pulse width was ~160 fs (full width at half maximum, FWHM), and the repetition rate was 47.5 MHz. The intensity noise of a pulse train generated from the light source is already higher than the SNL by 10 dB at an average optical power of 3 mW. Therefore, it is impossible to obtain squeezing without removing this additional noise. In our experiment, we used a nonlinear optical polarization interferometer (NOPI) [2] to generate photon-number squeezing. To overlap orthogonally polarized intense and week pulses at the fiber output, we added a proper time delay by a first interferometer. Next, both orthogonally polarized pulses were divided into two pulse trains for the CBD technique. Because of a slight difference in the length between the two separate fibers, we needed another interferometer. After the fibers, the intense pulses of each pulse train were divided at PBS3 and 4 with a branching ratio of 95:5 because in the NOPI scheme we must generate linearly polarized pulses to measure the photon-number squeezing. Then, finally we combined two pulse trains at PBS5 and detected them by one photodiode. As a result, a maximum photon-number squeezing of 2.6 dB was obtained when average power was 4 mW (see Fig. 1 (b)) with the CBD technic at 1.5 μm.

3. Photon number squeezing by 800 nm pulses with spectral narrowing

In Fig. 2(a) a schematic view of the experimental setup for photon number squeezed pulse generation at 800 nm is shown. We also employed an NOPI using a conventional 40-cm long fiber. Through a normal dispersion fiber, both the pulse width and spectrum are broadened when a Fourier transform limited (FTL)pulse is launched. Thus, sufficient self-phase modulation did not take place, and no squeezing was observed.

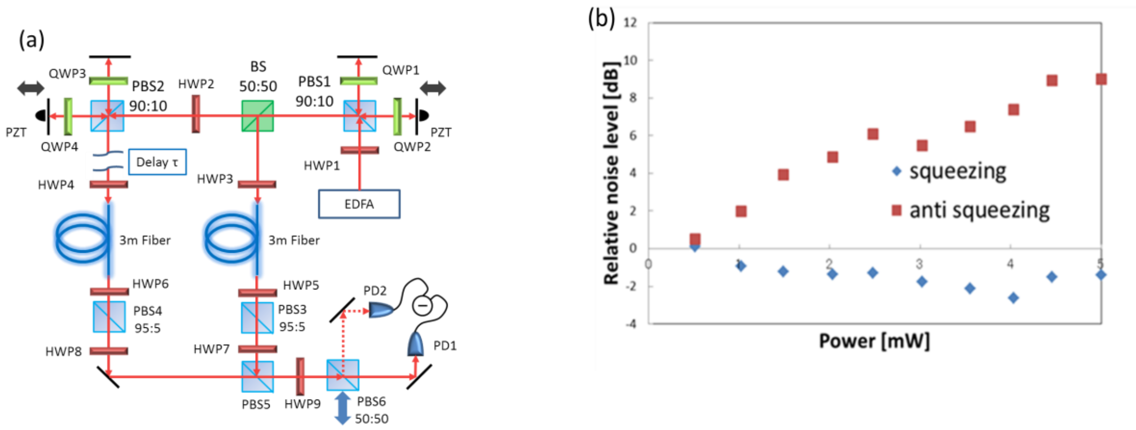

Fig. 1 (a)Experimental setup of CBD-photon number squeezing with EDFA laser using the nonlinear polarization interferometer. HWP: half wave plate, PBS: polarization beam splitter, QWP: quarter wave plate, BS: 50:50 beam splitter, PZT: piezoelectric transducer. (b)Plots of intensity noise relative to the SNL as a function of laser power coupled in to the fiber.

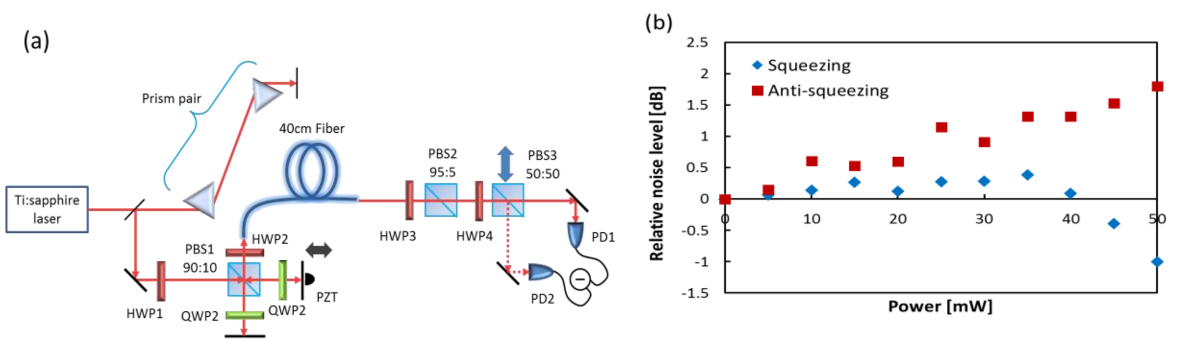

Fig. 2 (a)Experimental setup for generation of photon-number squeezed state by Ti:sapphire laser. HWP: half wave plate, PBS: polarization beam splitter, QWP: quarter wave plate, BS: 50:50 beam splitter, PZT: piezoelectric transducer. (b) Plots of intensity noise relative to the SNL as a function of laser power coupled in to the fiber.

By adding negative dispersion to the initial pulse so that an FTL pulse can be formed at the middle of the fiber, we obtained slight squeezing at lower incident powers, since at higher powers we could not obtain spectral matching between the intense and the week laser pulses at the end of the fiber. When we added more negative dispersion so that an FTL pulse can be formed at the end of the fiber, significant spectral narrowing took place upon the intense laser pulse. Then, even with strong self-modulation, a better spectrum matching was obtained. Consequently, we obtained a maximum photon-number squeezing of 1.0dB at an incident laser power of 50 mW (see Fig. 2(b)).

4. Conclusion

We achieved photon number squeezing at 1.55 μm using a noisy EDFA laser as a light source by use of the CBD technique. This experimental evidence indicates that our scheme makes it possible to observe phase-modulated vacuum noise entered at a beam splitter which separates two pulse trains by electrically cancelling substantial intensity noise of a light source at a specific RF frequency. We also achieved photon number squeezing at 800 μm using spectral narrowing of negatively chirped pulses through a normal dispersion fiber.

References

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