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Signal to Noise Ratio Analysis of a Chirped Pulsed Four-Wave Mixing by the Dispersive Fourier Transform Method

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Abstract: Four wave mixing is investigated when chirped pump and signal pulses are injected in a photonic crystal fiber. The shot-to-shot stability of the amplified coherent signal was measured by using the dispersive Fourier transform method.

1. Introduction

Four-wave mixing (FWM) has been extensively investigated in optical fibers since it provides a high gain value and a large gain-bandwidth with an adjustable central wavelength. For these reasons, FWM based parametric amplification is currently a promising technology to deliver ultra-short pulses when a photonic crystal fiber (PCF) is injected by pump and signal pulses [1]. However, as any phase insensitive optical amplifier, FWM is also subject to amplified spontaneous emission, often called parametric fluorescence PF, i.e., parametric amplification of the quantum noise due to a two-photon emission from two pump photons. For ultra-fast amplifiers, the PCF is injected with a pump and a coherent signal pulse with a high linear chirp. At the output, the signal is recompressed to the Fourier transform limit. The instantaneous frequencies of the PF are generated with temporal and spectral distributions according to the phase-matched FWM relation and the pump chirp [2] while the amplified signal has a distribution that mostly follows the initial chirp. At the amplifier output, the signal is selected but the spontaneous emission of the incoherent PF degrades the amplification quality and the shot-to-shot stability. In this work, we investigated the role of each contribution by measuring the gain value and the signal to noise ratio by recording an ensemble of single shot FWM spectra.

2. Experiment and method

The pump pulse is generated from a mode-locked oscillator (Flint, Light Conversion) delivering a train of pulses at 76 MHz with a duration of 80 fs and a spectrum centered at 1030 nm. A part of the oscillator output is injected in a volume Bragg grating (VBG) that stretches the pulses to a duration of ~50 ps and an acousto-optic modulator to decrease the repetition rate to 1 MHz. Then the pulses seed several ytterbium doped fiber amplifiers to increase the average power to a maximum of 1 W. The pump pulse is then injected in a 5-meter-long PCF with a zero-dispersion wavelength at 1028 nm. Two FWM lobes are observed with an optical spectrum analyzer (OSA) and they are located around 1000 and 1077 nm for an average power of 15 mW (Fig. 1.a, black curve) [3]. Another part of the oscillator is used to generate a continuum in an all normal dispersion fiber [4] and a second chirped VBG selects a spectrum part (Fig.1.a, blue curve) centered at 1077 nm with a bandwidth of 13 nm at full width at half maximum. Depending on the VBG orientation, the signal chirp has the same or opposite sign as the pump chirp (named case I or II, respectively). In the two cases, the pulse duration is ~150 ps. When this chirped signal pulse is injected in the PCF with a power of 20 μ W together with the chirped pump pulse, the signal is amplified (Fig. 1.a, red and green curves) with a spectrally integrated gain of 35 dB. This value is identical in the two cases although the shape of the amplified signal is quite different. The gain bandwidth is much narrower in case II with a bandwidth of ~3 nm because the relative pump/signal chirp does not match for maximum amplification [1]. At the PCF output, single shot spectra are recorded by a dispersive Fourier transform set-up with a 4.6 km long fiber (SMF28), a fast photodiode and an oscilloscope with a maximum bandwidth of 8 GHz. As an example, Figure 1.b shows a superposition of 500 single shot spectra (grey curves) and the averaged curve (blue curve) recorded with the DFT method for case I.

3. Results and discussion

From the ensemble of single shot spectra, the signal to noise ratio (SNR) is measured from the average value and its standard deviation (Fig.1.b). The SNR at the pump wavelength is higher than 20 and is spectrally modulated

due to the saturation of the FWM process; i.e the pump depletion. The maximum SNR at the signal wavelength is ~ 22 (case I) after amplification in the FWM process while we measured this value at ~ 23 without any amplification. Therefore, we can conclude that the amplification does not significantly degrade the shot-to-shot stability of the signal pulse even at high gain when the chirp is optimum. We also measured the gain and integrated SNR (Fig. 1.c) as the function of the injected signal power in order to understand the origin of this stability. The parametric amplifier strongly saturates since the gain decreases from ~ 43 dB to 35 dB when the signal power increases. This saturation provides stability of the amplified signal such that, the signal output power increases when the input decreases acting as a negative feedback [5,6]. This intensity fluctuation limitation allows getting a high SNR value, similar to the input one (Fig. 1.c). For case II, the gain evolution is similar (Fig. 1.c) but the SNR is smaller by a factor 10. In fact, the amplifier saturates only at the signal spectrum center and therefore the spectral edge fluctuation deteriorates the SNR.

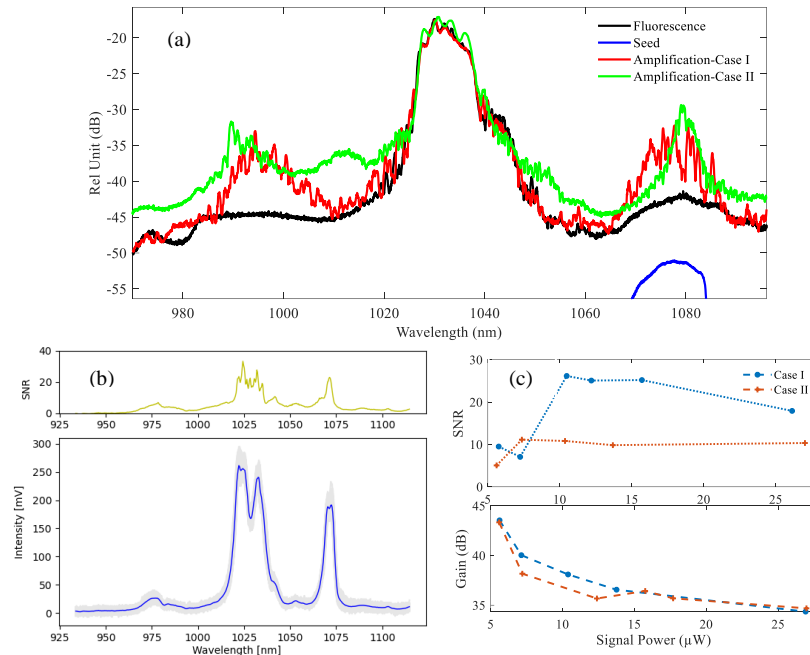


Fig. 1. a) Fluorescence spectrum (black line) and seeded FWM bands for case I (red line) and II (green line) recorded with an OSA. The seed spectrum is displayed in blue b). Measurement of the spectrum and SNR with the DFT method for case I. c) SNR and Gain values as the function of the signal power.

4. Conclusion

The shot-to-shot stability of seeded FWM has been investigated when chirped pump and signal pulses are injected in a photonic crystal fiber. By using the DFT method, we highlighted that the SNR value of the amplified signal can be similar to the injected one due to the saturation regime.

5. Acknowledgments

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