Supercontinuum noise reduction with short normal dispersion fibers – a simple and general technique

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Abstract: We reduce the noise of soliton-based supercontinuum sources by adding a short normal dispersion fiber to force the spectrally distributed solitons to spectrally broaden through self-phase modulation and thereby overlap to average out the noise.

OCIS codes: (320.6629) Supercontinuum generation; (030.1640) Coherence.

1. Introduction

Broadband supercontinuum (SC) sources are used in a wide range of important applications, such as chemical sensing and imaging, confocal and two-photon microscopy, spectrally resolved photoacoustic imaging, stand-off detection, scanning near-field optical microscopy, and spectrometer based optical coherence tomography (OCT). Unfortunately, most commercial SC sources use long pump pulses (ps to ns) because of cost and the need for high average power, which means that they are based on modulational instability (MI), red-shifting solitons and soliton collisions, and the generation of optical rogue waves in the red edge of the spectrum [1]. As a consequence 99% of commercial sources suffer from high pulse-to-pulse relative intensity noise (RIN) due to the MI being generated from quantum noise and due to the highly phase and amplitude dependent soliton collisions. It is therefore important to develop simple and efficient ways of achieving noise reduction of MI-based SC sources. One way is to simply increase the repetition rate to average out the noise [2]. A few approaches have been suggested to reduce the RIN on a pulse-to-pulse level, such as spectral alignment of solitons at a 2nd zero dispersion wavelength (ZDW), either in the uniform fiber that generates the SC or introduced by fiber tapering [3], spectral alignment through gain-bands in active fibers [4], and seeding of MI, although seeding of MI is not efficient at high pump peak power [5].

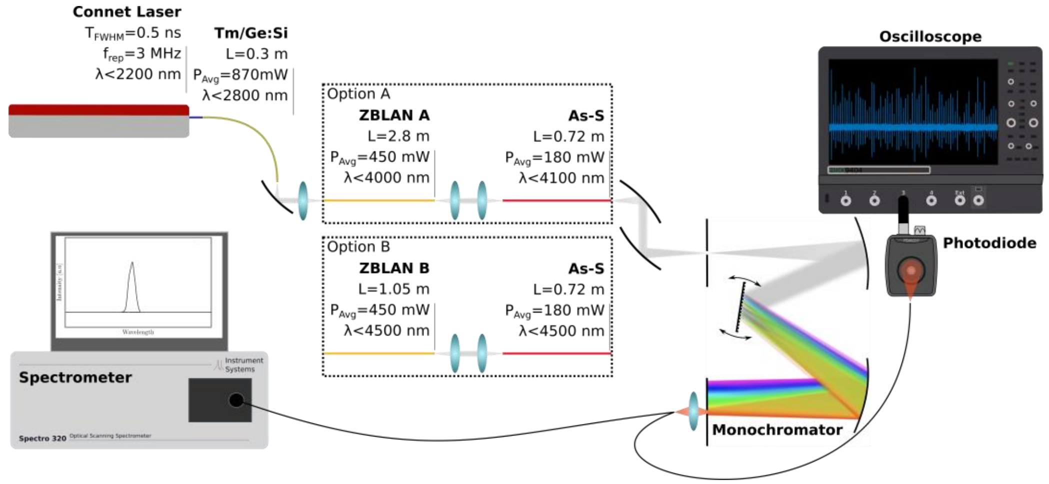

Fig. 1: Experimental setup. A 1550 nm pumped SC laser (Connect) is spliced to a Tm/Ge doped silica fiber. The output spectrum reaching 2.8µm pumps a ZBLAN fiber (A or B), followed by an As-S chalcogenide fiber. A monochromator (Czerny-Turner) spectrally filters the light before measuring either the spectrum or the RIN (with photodiode and oscilloscope).

In this paper we introduce a new and simple technique to reduce the noise of any MI-based SC source: Adding a short piece of normal dispersion fiber at the output to force the spectrally distributed solitons to spectrally broaden through self-phase modulation (SPM) and optical wave breaking (OWB) and thereby overlap to average out the noise. We demonstrate the method experimentally and numerically by adding a short piece of highly nonlinear arsenic-sulfide (As-S) fiber to a ZBLAN fiber based mid-IR SC source. We base the demonstration on a mid-IR SC because it is an emerging technology that can cover part of the molecular fingerprint region and therefore has enormous potential in broadband spectroscopy (e.g., pollution detection and food quality monitoring), stand-off detection, and non-destructive testing of highly scattering materials. To underline the efficiency of the technique we experimentally compare it to the noise reduction achieved by spectral alignment at a 2nd ZDW.

2. Experimental results and conclusion

The set-up is shown in Fig. 1 and the dispersion profiles of the fibers are shown in Fig. 2 (right), demonstrating that the As-S fiber has normal dispersion across the bandwidth of the ZBLAN SC, which ends at <4.4 µm. Here we give a summary of the experimental results. At the conference we will present all experimental details and supplement with the results of extensive modelling, which confirm the experiments and demonstrate the underlying physics.

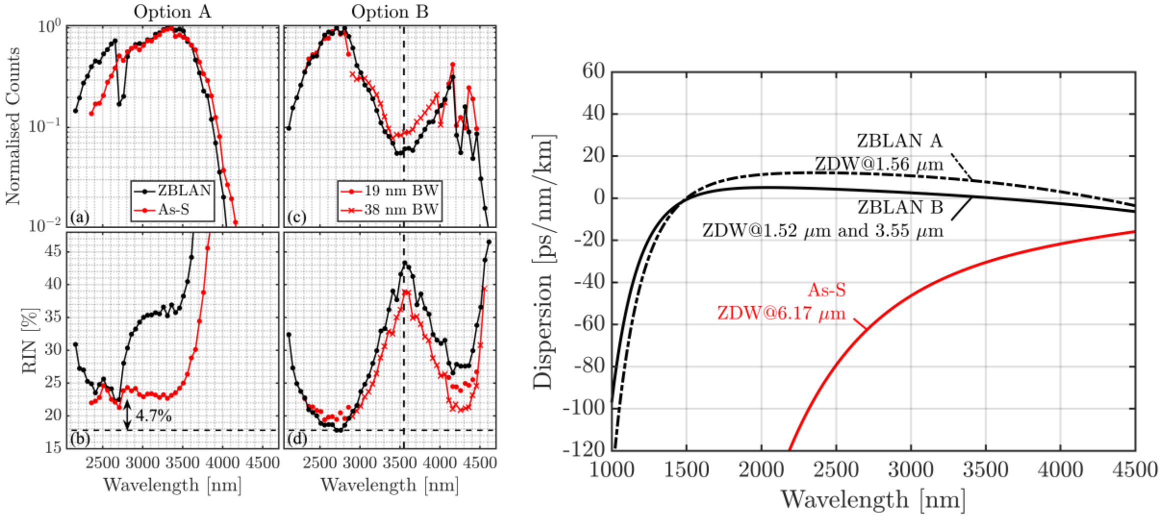

Fig. 2: *Left:* Measured PSD and RIN spectra using ZBLAN fiber A (left) and B (right). Black (red) curves show the ZBLAN (As-S) fiber output. The monochromator bandwidth was 38 nm (crosses) or 19 nm (dots). Vertical dashed line marks the second ZDW in ZBLAN fiber B and the horizontal dashed lines indicate the lowest RIN of 17.8 %. The double arrow shows the difference between the lowest RIN obtained with the two ZBLAN fibers. *Right:* Dispersion profiles of ZBLAN fiber A (dashed black), ZBLAN fiber B (solid black) and the As-S fiber (solid red). The dispersion of ZBLAN fiber B is a measurement. The dispersion of ZBLAN fiber A and the As-S fiber are calculated.

The experimentally recorded SC power spectral density (PSD) and RIN spectra, shown in Fig. 2 (left), demonstrate the concept: The spectrum out of ZBLAN fiber A extends to 4.2 µm and consist of solitons above at least 2.5 µm, since the dispersion is anomalous below 4.3 µm. Consequently, the RIN above 2.8 µm is very high. After only 72 cm of As-S normal dispersion fiber the RIN is strongly reduced by >10% across the whole SC bandwidth >2.8 µm. Simulations confirm this to be due to spectral averaging caused by the solitons undergoing very rapid SPM and OWB based spectral broadening, causing them to spectrally overlap. As demonstrated numerically in [3], the ZBLAN fiber B also provides soliton spectral alignment by stopping all solitons from red-shifting further than the 2nd ZDW at 3.5 µm and aligning them at around 2.8 µm, generating correspondingly aligned dispersive waves around 4.2 µm. This is seen to also lower the RIN to a similar low level as our technique, but only in narrow regions on each side of the 2nd ZDW at 3.5 µm, while the RIN around the 2nd ZDW is high, simply because there is no light. This underlines the benefit of our technique: The RIN is strongly reduced across a broad bandwidth.

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