Amplified spontaneous emission pulses for high-power supercontinuum generation

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Abstract: The authors demonstrate an incoherent light source based on a reflective semiconductor optical amplifier as pump for high-power supercontinuum generation for the first time. The obtained power level is about 160 mW and 20 dB spectral bandwidth is around 170 nm.

1 Introduction

Supercontinuum (SC) generation has attracted much attention due to a broad range of applications including optical communication, optical coherent tomography, and optical frequency metrology [1]. The common method for SC generation is achieved by a piece of highly non-linear medium pumped by ultra-short pulses [2, 3]. However, it is not straightforward to increase the output power because non-linear effects and dispersion in high-power amplifiers oppose severe obstacles obtaining clean ultra-short pulses at relatively high average power level. Additionally, the generated SC spectrum tends to have significant ripples due to pulse distortion. An alternative approach to achieve high-power and smooth SC spectrum is using continuous-wave light source or amplified spontaneous emission (ASE) source as pump, in which the pump incoherence can aid SC generation and spectral flatness [4, 5]. Previous reports have demonstrated a flat SC spectrum of 956 nm with high spectral density over −10 dBm/nm by using ASE noise source together with an erbium-doped fibre amplifier [6]. The noise source is composed of a 1.55 μm ASE source, an electro-absorption modulator and an external electrical pulsed source, which inevitably increase the complexity and cost of the whole system. In this paper, for the first time to our knowledge, a simple and low-cost ASE noise source based on an electrical-driven reflective semiconductor optical amplifier (RSOA) is applied for SC generation. The generated SC spectrum has achieved power level of 160 mW and 20 dB spectral bandwidth of 170 nm.

2 Experimental setup and results

Fig. 1 shows the experimental setup for SC generation. The used RSOA is housed in a pigtailed coaxial package based on a TO-56 can together with an FC/APC fibre connector, which is compatible to the following fibre links. Such RSOA utilises InP-based buried heterostructure design with a ∼1.2 μm wide InGaAsP tensile bulk active region. It has high reflectively coating for the rear facet while low reflectivity of $<10^{-5}$ in the front facet. The electrical bandwidth of RSOA is around 1.1 GHz and the saturated output power is about 5 dBm. To obtain optical pulses, the RSOA is directly modulated by an electrical pulsed source which is arbitrary waveform generator (AWG: Agilent 33250A). The AWG can generate nearly-square electrical pulses with maximum repetition rate of 80 MHz and shortest pulse duration of 5 ns. To boost up the optical power produced from the RSOA, two-stage amplification is applied. The preamplifier and the second-stage amplifier can enhance the optical power level up to 10 and 23 dBm, respectively. A bandpass filter with centre wavelength of 1547 nm and 3 dB bandwidth of 40 nm is used to suppress the ASE noise due to the preamplifier. Two optical isolators are used to protect the RSOA and the second-stage amplifier from the optical reflection-induced damage. Subsequently, the amplified pulsed beam is launched into 1 km long highly non-linear fibre (HNLF) for spectral broadening. The HNLF has mode field diameter of 3.7 μm and non-linear coefficient of 15 $(\mathrm{W\ km})^{-1}$ at 1550 nm. The group velocity dispersion coefficient of the HNLF is −0.23 ps/nm/km and the dispersion slope is about +0.030 ps/km/nm^2 at 1550 nm. The loss of the HNLF is <0.7 dB/km. The optical spectrum and the optical pulse trains are recorded by an optical spectral analyser (Ando AQ6317B) with a resolution of 0.01 nm and a 1.2 GHz photodetector followed by an oscilloscope (Agilent Infiniium 54832B), respectively.

The threshold voltage for RSOA to emit light is about 1.5 V. The output optical power is 8 μW, and the centre wavelength of spectrum locates at 1573 nm. When the applied voltage is increased, the centre wavelength of spectrum shifts toward shorter wavelength with a slope of ∼30.4 nm/V. To obtain the centre wavelength of spectrum at C-band, the applied voltage is set to be ∼2 V with an output power of 44 μW. The generated optical spectrum shows centre wavelength of 1540.692 nm and 20 dB spectral bandwidth of ∼150 nm. Fig. 2 depicts the optical pulse generated from RSOA which has pulse duration of 5.3 ns with repetition rate of 50 MHz. The optical power is further boosted up to 160 mW by the two-stage amplification. By launching the amplified optical pulses into the HNLF, the optical spectrum is gradually broadened. Fig. 3 shows optical spectra at different power levels. When the input power level is increased from 1 to 160 mW, the 20 dB bandwidth is increased from 18 to 170 nm; meanwhile, the spectral density is raised from −48 to −20 dBm/nm. Compared with the method using an ultra-short pulse train for SC generation, the SC spectrum here has good spectral smoothness [2, 3]. To understand why the optical spectrum can be broadened by using ASE light as pump, the simulation is further conducted.

3 Simulation analysis and discussion

Considering propagation of ASE light along optical fibre with nanosecond time slot, the starting point is how to describe the pulse mathematically. Previous reports show that an ASE light propagating along optical fibre can be treated as a bunch of noise burst [6]. The behind physical mechanism is that the continuous wave in the presence of perturbation tends to break up into pulses due to noise enhancement through modulation instability gain [6]. Moreover, the pulse-to-pulse coherence of the noise burst does not exist unlike the conventional ultra-short pulses. In this calculation, the ASE light has a fine temporal structure with envelope duration of around 5.3 ns. It contains thousands of short pulses with duration of around 300 fs associated with random amplitude and random phase. The incoherence of such bunch of pulses is presented by adding the amplitude of their optical spectra instead of an interference-induced spectral fringe. An SC generation by such

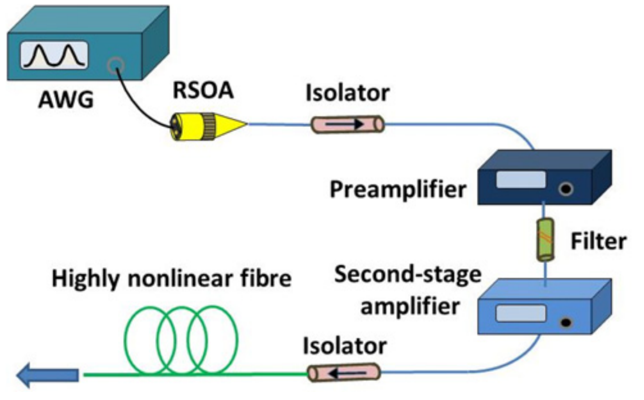

Fig. 1 *Experimental setup for SC generation*
AWG: arbitrary waveform generator and RSOA: reflective semiconductor optical amplifier

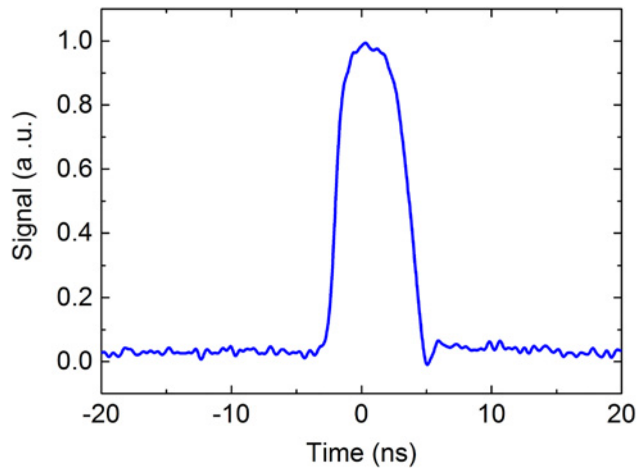

Fig. 2 *Optical pulse generation from RSOA*

noise burst along optical fibre can be modelled by non-linear Schrodinger equation [7]. The parameter used in the simulation for HNLF is given as follows: fibre non-linearity of $\gamma = 15$ (W km)$^{-1}$, group velocity dispersion coefficient of $\beta_2 = 0.23$ ps/nm/km, fibre length of $L = 1000$ m, the fractional contribution of the delayed Raman-gain spectrum of $f_R = 0.18$, and coefficients of Raman-gain spectrum of $\tau_1 = 12.2$ fs and $\tau_2 = 32$ fs.

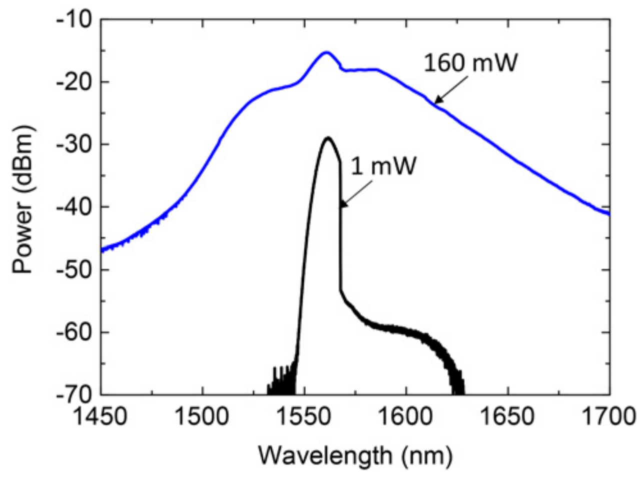

Fig. 3 *Spectral broadening in HNLF at various input power levels*

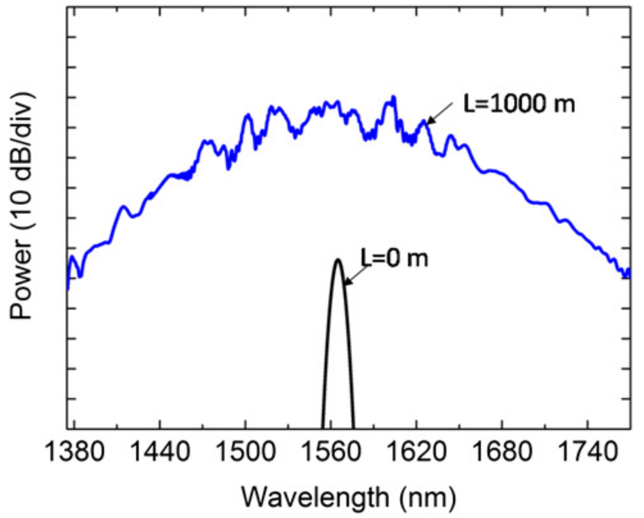

Fig. 4 *Simulation results on spectral profiles of bunch of noise burst at different locations of HNLF. All spectra are offset vertically for clarification*

The simulation results show that a bunch of noise burst still has a fine temporal structure along 1 km long HNLF. Fig. 4 plots the spectral profiles of a bunch of noise burst at different locations of HNLF. The 20 dB spectral bandwidth is broadened from 17 to 170 nm after propagation along 1 km HNLF. In terms of 20 dB spectral bandwidth and spectral shape, the simulation results are consistent with the experimental results. However, the spectral fluctuation can be observed in simulation but not observed in the experiment. This happens because in the experiment the fluctuation of spectrum is averaged out when repetitive noise bursts are launched out and detected by a slow detector [6]. The simulation results here confirm that the ASE light propagating along HNLF can be treated as a bunch of noise burst and the SC generation is originated from the interplay among fibre dispersion, non-linearity, and Raman effect.

4 Conclusion

In this paper, we demonstrate an incoherent light source based on RSOAs as pump for high-power SC generation. The obtained results have relatively high spectral density. The power level is about 160 mW and 20 dB spectral bandwidth is about 170 nm. The simulation results show that pulses generated from RSOA can be treated as a bunch of noise burst and the SC generation along the HNLF is originated from the interplay among fibre dispersion, non-linearity, and Raman effect.

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6 References

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