Supercontinuum generation from dispersion-flattened photonic crystal fiber using picosecond pulses

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We present the all-fiber system for supercontiuum (SC) generation with picosecond pulses. By launching 1.6-ps pulses from pulsed erbium-doped fiber laser (EDFL) into a section of photonic crystal fiber (PCF), the spectral broadening is observed. The bandwidth of 237 nm (at 20 dB level) is achieved.

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Supercontinuum (SC) generation has attracted considerable attention in recent years because it is suitable for application in dense wavelength-division-multiplexing optical networks[1], optical coherence tomography[2], and frequency metrology[3].

Various methods have been developed in SC generation using different ultrashort pulses and nonlinear-optic media. To date, nanosecond, picosecond, and femtosecond pulse trains have been used as pumping sources to generate SC[4−6]. At the same time, SC generation is realized by using dispersion-shifted fibers, tapered fibers, and photonic crystal fibers (PCFs)[7−9]. Especially for PCFs, it is the attractive candidate for SC generation due to its high nonlinear coefficient and designable dispersion properties. This can largely reduce the pump power and fiber length. Here, we report on SC generation in 40-m dispersion-flatted PCF using 1.6-ps pulse trains. The bandwidth of 237 nm (at 20 dB level) is achieved.

The schematic diagram for SC generation in dispersion-flattened PCF is shown in Fig. 1. The output pulse trains are amplified successively by two erbium-doped fiber amplifiers (EDFAs) which are all pumped by 980-nm laser diode (LD). The performance parameters of EDFA 1 are: the output saturated power is 12 dBm, small signal gain is more than 30 dB, noise figure is 6.7 dB, optical bandwidth is 1531—1565 nm. While the performance parameters of EDFA 2 are: the output saturated power is 14 dBm, small signal gain is more than 35 dB, noise figure is 6.9 dB. Spectral characteristics of the output pulses are measured by using an optical spectrum analyzer (OSA) with 0.1-nm resolution.

The PCF with small normal dispersion was manufactured by crystal fiber A/S. Diameters of the outer silica cladding and the coating are 128 and 250 μm, respectively. The core diameter (average) is 2.1 μm. The fiber gives a quite unique opportunity of dispersion control. This is possible because the penetration of the electromagnetic field into the fiber cladding depends on the wavelength of radiation inside the fiber. As the result, the refractive index of the cladding at different wavelengths can be controlled by arranging capillaries in a certain way at the time of pulling. This technique was used to create fibers with flat dispersion profile which allows generations of flat and SC spectra. The fiber has a dispersion parameter of more than −1.7 ps/(nm·km) from 1510 to 1620 nm as shown in Fig. 2. The nonlinear coefficient and loss coefficient are 11 $W^{-1}\cdot$ km^{-1} and 9 dB/km (at 1510—1620 nm), respectively. Both ends of the PCF were fusion-spliced to standard single mode fiber, which yielded a loss of about 0.5 dB at 1550 nm.

In experiment, the fiber laser operates under passive mode-locking and generates optical pulses at the repetition rate of 50 MHz. The mode-locking spectrum has a 20-dB width of 5.76 nm at central wavelength of 1550 nm, as shown in Fig. 3. The generated pulses are then amplified by two EDFAs. The pulse width is 1.6 ps and the average power of the input pulse is 0.047 mW, the corresponding single pulse energy and peak power are 0.98×10^{-12} J and 0.61 W, respectively. Figure 4 shows

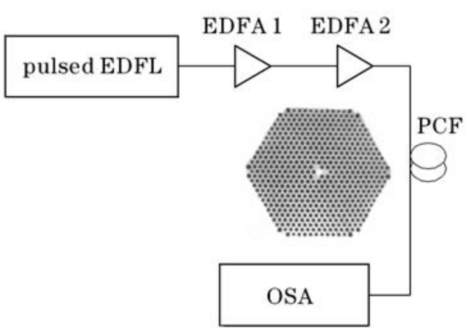

Fig. 1. Experimental setup of SC generation in dispersion-flattened PCF.

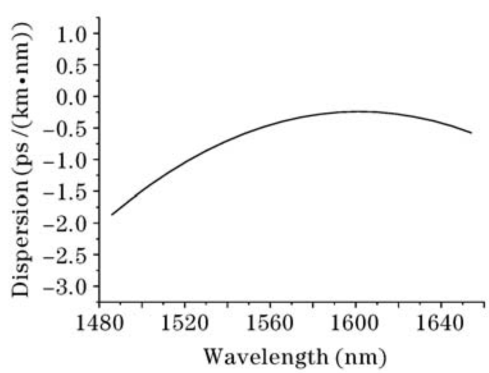

Fig. 2. Measured dispersion of the PCF.

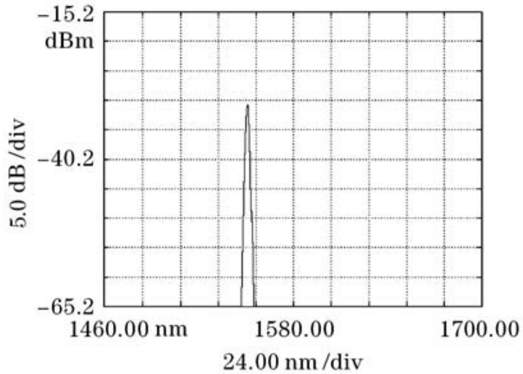

Fig. 3. Spectrum from the passive mode-locked fiber laser.

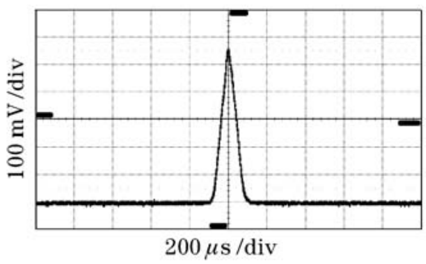

Fig. 4. Autocorrelation trace of input pulse.

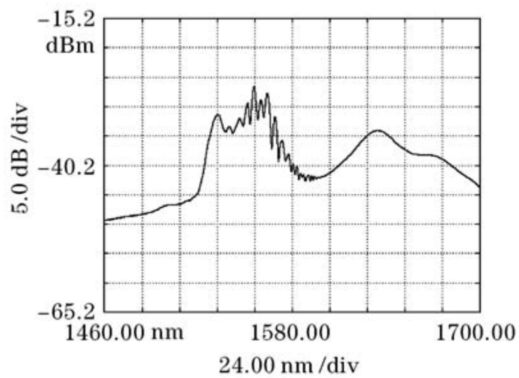

Fig. 5. SC spectrum for average power of 11.64 mW launched into the PCF.

the second harmonic generation (SHG) autocorrelation trace of the input pulse. Then the amplified pulses are launched into a segment of 40-m PCF, which is used as the nonlinear medium for the SC generation. The output spectrum is analyzed by an OSA with the resolution of 0.01 nm.

As the pulses amplified by EDFA 1 only are launched into the dispersion-flattened PCF, SC generation occurs as shown in Fig. 5. It is observed that the original spectrum from the fiber laser is broadened to a SC spectrum. The results show that when the average power of the input pulse increases to 11.64 mW, the SC has 20-dB width of over 197 nm from 1503 to 1700 nm at central wavelength of 1555 nm. Note that the cutoff wavelength of the spectrum analyzer is 1700 nm, and therefore the actual SC spectrum should be broader than 197 nm. When there is one EDFA in the experiment, there are more peaks from 1532 to 1604 nm in the SC spectrum.

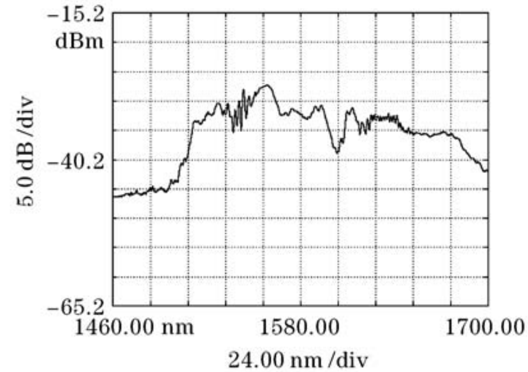

Fig. 6. SC spectrum for average power of 26.12 mW launched into PCF.

As the pulse trains are amplified by two EDFAs, with increasing the average power, the spectrum broadening is larger than in the previous case. Figure 6 shows the plot of SC spectrum in the PCF with central wavelength of 1558 nm. It is shown that when the average power of the input pulse amounts to 26.12 mW, the 20-dB spectrum broadens to more than 237 nm from 1463 to 1700 nm. However, as the input power increases, other nonlinear effects besides self-phase modulation (SPM) such as four-wave mixing and Raman amplification will also contribute to the SC generation, and the different amplitudes of the generated spectral components will affect the flatness of the SC.

When the power launched into PCF is increased, two main effects take place. From Figs. 4 and 5, we can see that with the increasing of pump power, the bandwidth of the SC increases and the spectrum becomes much flatter. For the SC generation process, it is explained that when pumping with pulses around 1550 nm in the normal dispersion region of the PCF, the initial broadening of the pulse is caused by SPM. And the magnitude of the SPM-induced broadening is dominantly determined by the peak power of the pump pulse. Then the linear frequency chirp induced by SPM interacts with the small normal dispersion, making the pulse waveform nearly parabolic before the pulse width becomes much broader. Such pulses can broaden the spectrum greatly[10]. Besides SPM and dispersion, other nonlinear processes, such as Raman amplification, and four-wave mixing, are regarded as factors for SC generation.

In the paper, SP generation in a section of dispersion-flattened PCF using 1.6-ps pulse trains is reported. The emission spectrum ranges from 1463 to 1700 nm, the corresponding bandwidth is 240 nm (at 20 dB level). The original input signal is provided by a 50-GHz repetition rate picosecond laser with the pulse energy of 0.61 nJ. The SC configuration is all fiber, compact, and reliable, which is easy to make them practical and easily accessible for uses in optical communication system.

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