High-order soliton generation in dispersion flattened fiber

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By using the amplified 10-GHz, 5.5-ps sech^2 pulses with high quality and chirp-free from regeneratively mode-locked fiber laser (RMLFL) as the soliton source, 2—5 order optical soliton phenomena are observed successfully in a 4.28-km dispersion flattened fiber. The experimental results agree well with the theoretical calculation.

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Currently a pulse source with high repetition and small duty cycle is essential for ultra-high speed optical communication, especially in the application of optical time division multiplexing (OTDM) and soliton transmission. This could be realized by externally modulating a continuous wave from distributed feedback Bragg (DFB) laser using an electroabsorption modulator (EAM)[1] or by exploiting a mode-locked laser diode (MLLD)[2]. However, pulses from such an EAM are with intrinsic chirp and the output is seriously limited when proper bias voltage is set to achieve small duty cycle. The output of MLLD, though stable and nearly transform limited, is not wavelength tunable and also power limited. In contrast, an actively and harmonically mode-locked fiber laser is favored for its tunable wavelength, short duration, high repetition, and high output power. Unfortunately, a normal harmonically mode-locked fiber laser is suffered from unstability for lack of cavity length control and super modes suppression. We have demonstrated a stable 10-GHz regeneratively mode-locked fiber laser (RMLFL) applying electrical phase locking technology[3,4]. Such a tunable soliton source with small duty cycle (between 4%—8%) meets the requirement of OTDM up to 80 Gb/s, and by increasing pump power the duty cycle may be decreased further and support 160-Gb/s OTDM. Moreover, this soliton source with chirp-free property is preferable in ultra-long haul soliton transmission. In this paper, we set focus on its application in high order soliton generation, because high order soliton has important applications in optical pulse compression and spectral broadening[5,6].

This experiment is based on fiber nonlinear effects and the setup is shown in Fig. 1. Pulse width and spectrum are measured by second harmonic generation (SHG) autocorrelator and optical spectrum analyzer (OSA), respectively.

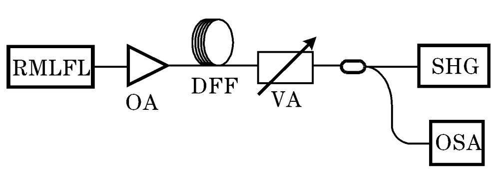

Fig. 1. Experimental setup of high order soliton generation. OA: optical amplifier; DFF: dispersion-flattened fiber; VA: variable attenuator.

Adjusting the filter inside the cavity of RMLFL, the soliton wavelength is set to 1551.25 nm. The measured pulse-width and spectrum-width are 5.5 ps and 0.46 nm respectively by adjusting pump power. Figure 2 shows the autocorrelation trace and spectrum, it is obvious that the autocorrelation trace (solid line) fits with a sech^2 profile (dashed line) than a Gaussian one (dotted line). The time bandwidth product (TBP) is calculated to be 0.32, which indicates that this is a chirp-free pulse of soliton style.

For high order soliton generation, 4.28-km dispersion flattened fiber (DFF) is used. The dispersion, dispersion slope, nonlinear coefficient, and attenuation parameters of DFF are 1.55 ps/(nm·km), 0.015 ps/nm^2·km, 2.35 (W·km)$^{-1}$, and 0.275 dB/km at 1550 nm, respectively. Since there is no or little chirp in the pulse, no dispersion compensation method is needed and the characteristics of the output pulse could be determined by initial width, average power of the lunched pulse, and fiber parameters. As a result the 4.28-km DFF corresponds to a

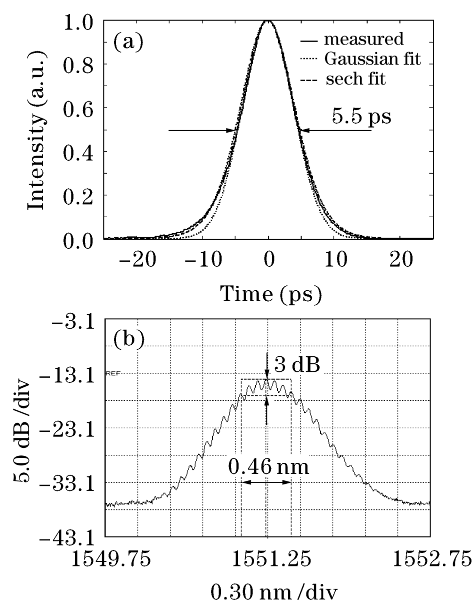

Fig. 2. Autocorrelation trace (a) and spectrum (b) of input pulse.

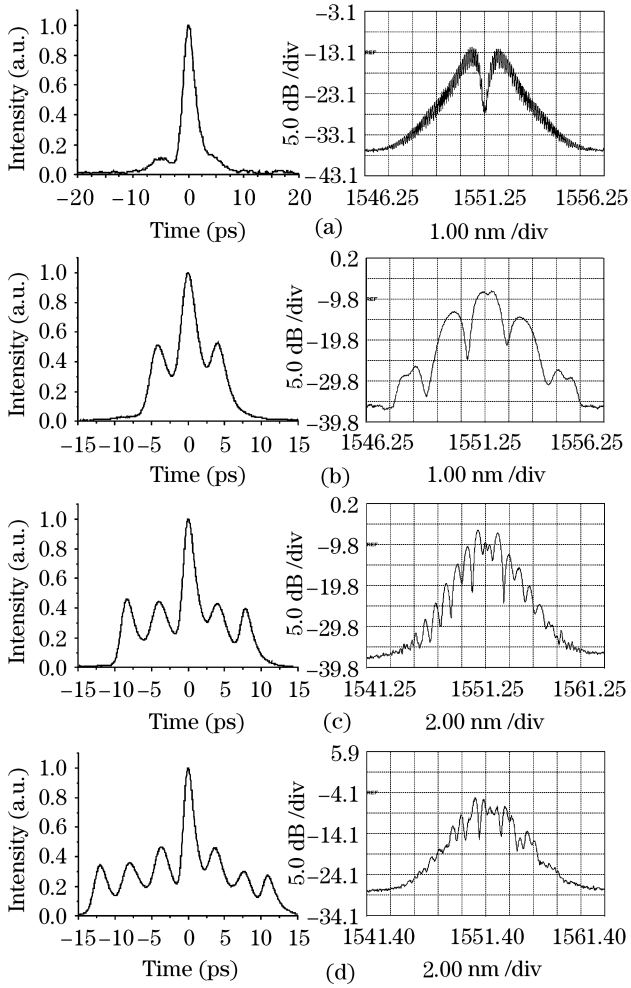

Fig. 3. Autocorrelation traces and spectra for high order soliton. (a)—(d) are for 2—5 order solitons respectively.

length of about 0.55 soliton period. Changing average power of soliton stream, 2—5 order solitons are achieved. Figure 3 shows the acquired autocorrelation traces and spectra of different order solitons. In Fig. 3(a) the spectral resolution is set to 0.05 nm and others 0.1 nm, the soliton is compressed to 1.57 ps corresponding to a compression factor of 3.5. Here all the temporal traces and spectra are in good agreement with following numerical results, which reflects the ideal soliton properties of the output from RMLFL.

To verify our experimental results, numerical simulation is carried out according to actual pulse and fiber parameters. The peak powers of 2—5 order solitons are 0.346, 0.778, 1.384, and 2.162 W, respectively. Figure 4 gives autocorrelation traces and spectra of 2—5 order solitons by solving nonlinear Schroedinger equation using split-step Fourier method. Each line from left to right corresponds to 2—5 order solitons respectively. Compared with Fig. 3, the calculated autocorrelation traces and spectra agree well with the experimental results for 2 and 3 order solitons. As for 4 and 5 order solitons, higher order nonlinear effects and higher order dispersion may be induced due to higher power and serious spectral broadening. This causes difference between spectra and asymmetry behavior in Fig. 3. However, judging by the autocorrelation traces, the experimental results agree with the simulative results.

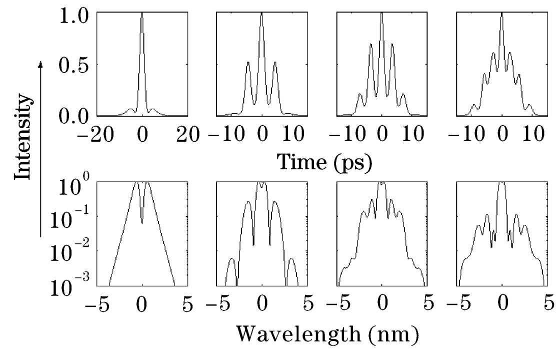

Fig. 4. Calculated autocorrelation traces and spectra for 2—5 order solitons in DFF. The wavelength centers at 1551.25 nm.

In conclusion, a stable RMLFL and its applications in higher-order soliton generation have been demonstrated. 2—5 order optical soliton phenomena are achieved successfully in a 4.28-km DFF. The experimental results agree well with the theoretical calculation, which confirms this soliton source is chirp-free.

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