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High-Quality Ultrashort Pulse Generation Utilizing a Self-Phase Modulation-Based Reshaper*

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Abstract: An ultrashort 10-GHz pulse generation scheme was successfully demonstrated using a bulk material InGaAsP electroabsorption modulator to generate the seed pulse. A self-phase modulation-based reshaper was used after the adiabatic soliton compression in a comb-like dispersion profiled fiber. Experiments and simulations confirm that the reshaper effectively removes the pulse pedestal and improves the pulse extinction ratio. As a result, the 10-GHz pulse had no pedestal, a high extinction ratio, and a pulse width of only 1.4 ps.

Key words: ultrashort pulse generation; self-phase modulation; soliton compression; pulse pedestal

Introduction

Ultrashort high-quality pulse sources have extensive applications in terahertz generation，future ultra-high speed optical time-division multiplexing (OTDM)[1-3], and supercontinuum generation[4]. The actively mode-locked fiber/semiconductor laser is the most common method for generating high-quality short pulse trains. However, the pulse repetition rate in the semiconductor mode-locked laser can not be easily changed and the fiber mode-locked laser is not stable which limits practical applications. A more flexible and stable method is direct external intensity modulation of a continuous wave (CW) light directly. However, the pulse widths are always larger than 10 ps. A succeeding compression stage is necessary to achieve picosecond pulse width or less. Various compression schemes have been proposed using fiber nonlinearity, including the conventional soliton-effect compressor, the adiabatic soliton compressor using either a dispersion-decreasing fiber (DDF) or a comb-like dispersion profiled fiber (CDPF)[5-7], and supercontinuum (SC) compression using a normal group-velocity dispersion fiber[8]. All these compression schemes inevitably lead to pulse quality degradation, such as pulse pedestals and pulse extinction ratio reduction.

This paper discusses a high-quality ultrashort pulse generation scheme. In the scheme, a bulk material InGaAsP electroabsorption modulator (EAM) is used as an external modulator to generate a seed pulse train. The EAM is stable, polarization independent, and operates at high-speed. The EAM has been applied to pulse generation[5], wavelength conversion[9], demultiplexing, etc.

1 Ultrashort Pulse Generation Setup

A schematic of the pulse generation system is shown in Fig. 1. A 1544.57-nm continuous-wave light emitted from a tunable distributed-feedback laser diode is carved by a commercially available bulk material InGaAsP EAM driven by a 10-GHz sinusoidal signal. The dispersion compensating fiber (DCF) with −14

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ps/nm is used to compensate for the linear chirp in the original pulse after the EAM. Under the assumption of Gaussian pulse, the width of the compensated pulse is measured with a second harmonic generation autocorrelator to be around 18.0 ps. Then the pulse passes through the soliton compression stage, shown in the left dashed box in Fig. 1. In Fig. 1, HNLF means highly nonlinear fiber; DFB-LD means distributed-feedback laser diode; BPF means band-pass filter. The seed pulse after the DCF is boosted with an Erbium-doped optical fiber amplifer (EDFA) and injected into a 5-km dispersion shifted fiber (DSF) with a dispersion of 1.89 ps/(nm • km) and a zero dispersion wavelength at 1517 nm. The DSF acts as a soliton converter that reshapes and compresses the input pulse to a sech-like pulse. The pulse train is then amplified again and launched into a CDPF chain, which acts as an adiabatic soliton compressor. The soliton compression operates in the abnormal dispersive regime of the nonlinear fiber and need relatively little pump power compared with the SC method. The CDPF is made of 12 sections of alternatively arranged DSFs and standard single mode fibers and has a total length of 4.24 km[5].

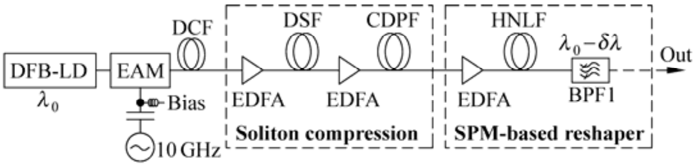

Fig. 1 High-quality ultrashort pulse generation system

The self-phase modulation (SPM)-based reshaping stage is shown in the right dashed box in Fig. 1. The pulse reshaper is based on SPM-induced spectral broadening in an HNLF followed by offset filtering[10]. The frequency chirp generated by the SPM effect has a much smaller effect on the pulse pedestal and background compared with the rising and trailing pulse edges; after the offset filtering the pedestal or background section is suppressed greatly. At the same time, the reshaper compresses the pulse by temporal carving of one of the pulse edges through spectral filtering the SPM-induced frequency chirp components on the corresponding edge[11]. This HNLF has a length of 1 km, a dispersion slope of 0.018 ps/(nm • km), a zero dispersion wavelength of 1555 nm, and a nonlinear coefficient of 8.4 W^{-1} • km^{-1}. The BPF has a 3-dB bandwidth of 2.5 nm. After amplification by the EDFA the pulse train is launched to the HNLF for spectral broadening. The center wavelength of the BPF has around 8 nm offset from the carrier in the short wavelength direction for slicing part of the SPM-broadened spectrum.

2 Numerical Simulations of the Seed Pulse Generation by EAM

The EAM shown in Fig. 1 is reverse biased at a fixed voltage and driven by a 10-GHz sinusoidal signal. The reverse voltage is V_b and the radio frequency (RF) signal has an amplitude of V_m and frequency of ω. When a CW light beam is injected into the EAM, the beam is modulated by the transmission and refractive index induced by the external RF signal. The optical field after the EAM can be expressed as

$$E(t)=E_0\sqrt{T_0\exp[-\Gamma\alpha(V)L]}\exp[-\mathrm{i}\frac{2\pi}{\lambda}\Gamma\Delta n(V)L] \tag{1}$$

where V is $V(t)=V_\mathrm{b}-V_\mathrm{m}\cos(\omega t)$ and the $\alpha(V)$ is the measured absorption coefficient as a function of the reverse voltage. $\Delta n(V)$ represents the refractive index variation as a function of reverse voltage and is calculated by the measured $\alpha(V,\lambda)$, α is the measured absorption coefficient as a function of reverse voltage V and the operating wavelength λ. T_0 is the intrinsic loss, L is the length, and Γ is the optical limiting factor of the EAM.

Equation (1) is used to calculate the resultant amplitude and chirp characteristics after the EAM. The chirp is defined as the difference between the instantaneous frequency and the carrier frequency with the following equation:

$$\Delta\omega=-\Gamma\frac{2\pi}{\lambda}L\frac{\mathrm{d}n}{\mathrm{d}t} \tag{2}$$

Figure 2 shows the amplitude and chirp characteristics of a pulse generated with a bias voltage of –3 V, 10 GHz RF signal with an amplitude of 2 V, and a 1545-nm CW light. Figure 2 shows that the generated pulse is very similar to a Gaussian pulse and has nearly linear negative chirp in the center section. Therefore,