Multi-wavelength pulse generation using flattop optical frequency comb and arrayed waveguide grating

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A scheme of multi-wavelength pulse generator using optical frequency comb and arrayed waveguide grating (AWG) is proposed and experimentally demonstrated. A flattop optical frequency comb is shaped into multiple narrowband Gaussian spectra by using an AWG which contains a number of Gaussian channels, and then multi-wavelength optical pulses are achieved. In the experiment, six wavelength pulses with full width at half-maximum (FWHM) of 14.6 ps at 10 GHz are obtained, and two wavelength-interleaved pulse trains at 20 GHz and four wavelength-interleaved pulse trains at 40 GHz are demonstrated by using the multi-wavelength optical pulses. This scheme has flexibility because the pulse width, the repetition rate, and time-interval can be readily controlled.

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Multi-wavelength optical pulse is very useful in optical communication and optical signal processing[1,2], which has attracted the interest of researchers for many years. Several configurations have been proposed for multi-wavelength optical pulse generation, such as using an actively mode-locked erbium-doped fiber ring laser[3], time-lens compression[4], and sampled fiber grating[5]. In this letter, a scheme of multi-wavelength optical pulse generation using flattop optical frequency comb (OFC) and arrayed waveguide grating (AWG) was proposed and demonstrated experimentally. Six wavelength pulses with full-width at half-maximum (FWHM) of 14.6 ps at repetition rate of 10 GHz were obtained, where the power variation of the six wavelength pulses was less than 1 dB. When the obtained multi-wavelength pulses delay a definite time with adjacent wavelengths and couple together, the wavelength-interleaved pulse train can be achieved. In this letter, two wavelength-interleaved pulse train at 20 GHz and four wavelength-interleaved pulse train at 40 GHz were demonstrated.

The scheme of multi-wavelength optical pulses generation contains three parts, as shown in Fig. 1. The first part is flattop OFC generator, the second one is multi-wavelength optical pulse generation, and the third one is wavelength-interleaved pulse train construction.

The OFC is generated by strong modulation of a continuous-wave laser (CWL) with cascaded intensity modulator (IM) and phase modulators (PMs) driven by sinusoidal waveform[6]. By using nonlinear effect of IM to improve flatness of OFC, 15 comb lines with spectral power variation less than 1 dB were obtained[7]. Using this method, the number of comb lines is in direct proportion to phase modulation index (as shown in Fig. 2(a)). If the half-wave voltage of PM is fixed, more comb lines can be achieved by increasing the amplitude of sinusoidal waveform applied on PM. However, one PM cannot be applied with too large amplitude of sinusoidal waveform. In this letter, we use one IM and two cascaded PMs (Fig. 1(a)) to obtain more comb lines. The half-wave voltage of IM is 6.5 V, the half-wave voltages of two PMs are 3 V, and the bandwidths are 10 GHz. The powers of 28 dBm are applied on two PMs corresponding to phase modulation indices of 8.3, so the sum of phase modulation index is 16.6. By using phase shifters (PSs, adjustable range 0-4π) to adjust the phases between IM and two PMs, 29 comb lines with spectral power variation less than 1.5 dB are obtained, as shown in Fig. 2(b). It can be seen from Fig. 2(a), 29 comb lines can be achieved when phase modulation index is 16 (the small difference

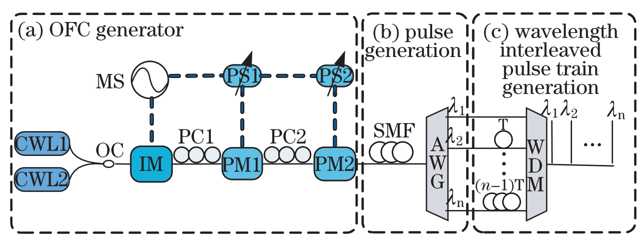

Fig. 1. Scheme of multi-wavelength optical pulse generated with OFC and AWG. (a) OFC generator (OC: optical coupler, MS: microwave source); (b) multi-wavelength optical pulse generation; (c) wavelength-interleaved pulse train generation (WDM: wavelength division multiplexing).

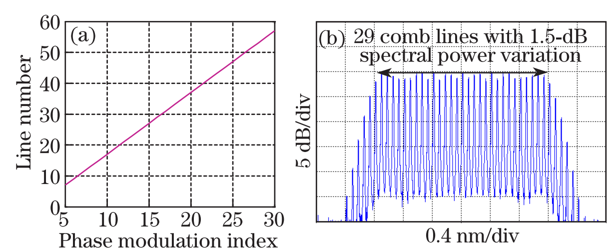

Fig. 2. (a) Relation between the number of comb lines and phase modulation index; (b) generated OFC using cascaded IM and PMs.

of phase modulation index is caused by loss). So the experimental result agrees well with theoretical analysis.

In principle, Gaussian optical pulse can be obtained by filtering a flattop OFC using a Gaussian filter. This is because Gaussian shape pulse in time domain has a Gaussian spectrum and the phase of spectrum is zero. The optical pulse width is related to the bandwidth of filter used in this scheme, so we can obtain adjustable pulse width by using different bandwidth of filters. The repetition rate of optical pulse varies with frequency spacing of OFC which depends on the microwave frequency applied on modulators, so the repetition rate of pulse can be readily controlled.

As shown in Fig. 1, the generated OFC from Fig. 1(a) propagates through a 1.1-km spool of single mode fiber (SMF) to reduce the chirp introduced by modulation and is filtered by an AWG which has a number of Gaussian channels, and multi-wavelength optical pulses can be achieved. In order to increase the number of multi-wavelength pulses, two CW distributed feed back (DFB) lasers (1 548.79 and 1 552.13 nm) were used, and their output power and linewidth were 13 dBm and 1 MHz, respectively. Two OFCs were obtained. The bandwidth of the central 29 comb lines is $\Delta\lambda = (29-1)\times 0.08\,\text{nm} = 2.24$ nm, and 0.08 nm is spectral line spacing . The central 29 comb lines of first OFC begins at 1 547.67 nm and ends at 1 549.91 nm, and the second one begins at 1 551.01 nm and ends at 1 553.25 nm. Each OFC can be shaped into three wavelength pulses, so six optical pulses at central wavelengths of 1 548.08, 1 548.78, 1 549.58, 1 551.20, 1 551.98, and 1 552.78 nm were obtained after filtering by AWG. The pulses were converted in to electrical signal by a detector with 50-GHz bandwidth and were measured by a digital sampling oscilloscope (Tektronix 11801C). The single wavelength optical pulse is shown in Fig. 3(a) (red dotted line is experimental data, blue soild line is fitting curve). The FWHM of which is 14.6 ps, and repetition rate is 10 GHz. Since the increased bandwidth can potentially support a shorter optical pulse, narrower optical pulse can be obtained by using filter with greater bandwidth. The radio-frequency (RF) spectra of the obtained pulses were measured utilizing a RF spectrum analyzer (Agilent N9020A), as shown in Fig. 3(b). For all wavelengths, the spurious-free dynamics are greater than 65 dB. Figure 3(c) shows the optical spectra of the six wavelength pulses whose central wavelengths equal the central wavelengths of channels of AWG, and the spectral power variation of these spectra was less than 1 dB.

The obtained multi-wavelength pulses delays a definite time with adjacent wavelengths and couple together by a WDM, then wavelength-interleaved pulse train can be achieved, as shown in Fig. 1(c). And according to the number of wavelengths we used, various wavelength-interleaved pulse trains can be obtained, such as two wavelength-interleaved and four wavelength-interleaved pulse trains. In the experiment, two wavelength-interleaved pulse train at 20 GHz and four wavelength-interleaved pulse train at 40 GHz are obtained as shown in Figs. 4(a) and (b). The repetition rate for each wavelength is 10 GHz. Time intervals between adjacent wavelengths are 50 and 25 ps for two and four wavelength-interleaved pulse train, respectively.

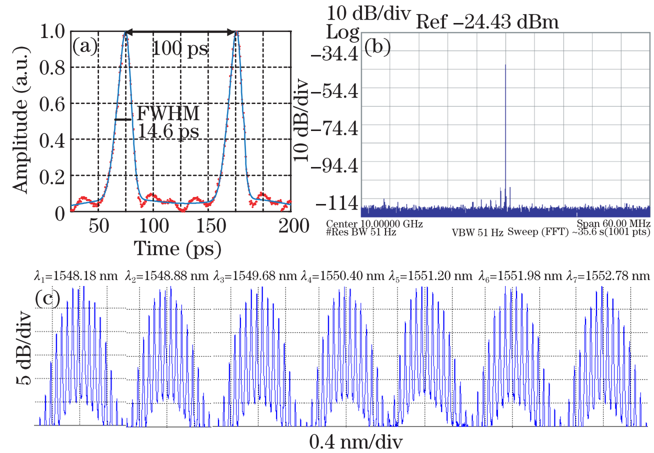

Fig. 3. (a) (Color online) Single wavelength optical pulse with FWHM of 14.67 ps and repetition rate of 10 GHz; (b) RF spectrum of optical pulse; (c) optical spectra of six wavelength pulses after AWG.

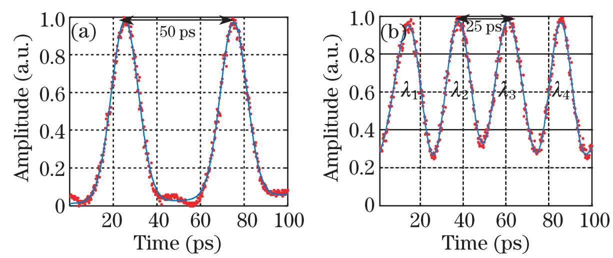

Fig. 4. (a) Two and (b) four wavelength interleaved pulses.

In conclusions, a scheme of multi-wavelength pulse generator using flattop OFC, SMF and AWG is proposed and demonstrated experimentally. In the experiment, six wavelengths with FWHM of 14.6 ps and repetition rate of 10 GHz are obtained, where the power variation of the six wavelength pulses is less than 1 dB. Two wavelength-interleaved pulse trains at 20 GHz and four wavelength-interleaved pulse trains at 40 GHz are achieved by using the multi-wavelength optical pulses. This scheme has flexibility where the pulse width, repetition rate, and the time-interval can be readily controlled.

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