Repetition rate tunable ultra-short optical pulse generation based on electrical pattern generator

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An actively mode-locked laser with tunable repetition rate is proposed and experimentally demonstrated based on a programmable electrical pattern generator. By changing the repetition rate of the electrical patterns applied on the in-cavity modulator, the repetition rate of the output optical pulse sequences changes accordingly while the pulse width of the optical pulse train remains almost constant. In other words, the output ultra-short pulse train has a tunable duty cycle. In a proof-of-principle experiment, optical pulses with repetition rates of 10, 5, 2.5 and 1.25 GHz are obtained by adjusting the electrical pattern applied on the in-cavity modulator while their pulse widths remain almost unchanged.

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Optical code division multiple access (OCDMA) is a promising technique, which has been intensively researched in the last decade for its security and the capability of enabling multiple users to share the bandwidth and communicate simultaneously[1−4]. OCDMA is also considered as a promising solution to the next-generation all-optical access network[5], confidential optical communication[6−7], and all-optical packet switching[8]. In OCDMA systems, ultra-short optical pulse source with low repetition is an important issue. Possible solutions of this problem include a passively mode-locked laser[9,10], compression of the chirped low-repetition-rate optical pulse using dispersive media[11,12], and direct selection using high-speed optical switching. However, the repetition rate of the output of all-fiber passively mode-locked laser is normally around several tens of mega herts[9,10], and it is not feasible to be used in modern optical communication networks. Besides, the output of a passively mode-locked laser is hard to be externally synchronized. Using dispersive media to compress the output of actively mode-locked laser with relatively low repetition rate is not an ideal choice, because normally dispersive media will introduce unintended loss and therefore more optical power is needed. Direct selection of high-repetition-rate ultra-short optical pulse is a simple and competitive method, but the extinction ratio is not infinite, which will introduce unintended noise.

In this letter, a novel method is proposed and demonstrated, which can be used to generate ultra-short optical pulse with tunable repetition rate (that is, tunable duty cycle). Therefore, this method is applicable to areas requiring ultra-short optical pulses with low repetition rate, such as OCDMA, multi-wavelength pulse generation[13], photonic analog-to-digital conversion[14], etc. In this method, a 10-Gb/s programmable electrical pattern generator (EPG) with a code length of 16 bits is applied on the in-cavity modulator of an actively mode-locked laser. By changing the pattern of the EPG, ultra-short optical pulses with almost unchanged pulse widths and repetition rates of 10, 5, 2.5, and 1.25 GHz are generated.

As shown in Fig. 1(a), external selection of the mode-locked laser outputs is a simple method to generate ultra-short and low-repetition-rate pulse train. However, this method is disadvantageous in two folds. Firstly, the extinction ratio of a practical modulator is never infinite, so unintended noise is introduced; secondly, synchronization is needed when an external modulation setup is used, which requires microwave phase shifter or optical delay line, either way will introduce system complexity. In order to obtain low-duty-cycle laser pulse train, a straightforward idea is to maintain the short duration of the time "window" introduced by applying electrical signal on $LiNbO_3$ modulator and to lower the repetition rate of the applied electrical signal. Therefore, instead of sinusoidal microwave signal, a pattern signal is used. In the setup shown in Fig. 1(b), which is different from regular actively mode-locked lasers where sinusoidal electrical signal is used, a short duration electrical pattern is applied on the in-cavity modulator. This forms a time "window" with its duration comparable to that of the applied electrical pattern signal (which is normally much shorter than one half of the period of the sinusoidal signal with the same repetition rate), and therefore low-repetition-rate ultra-short optical pulses are expected.

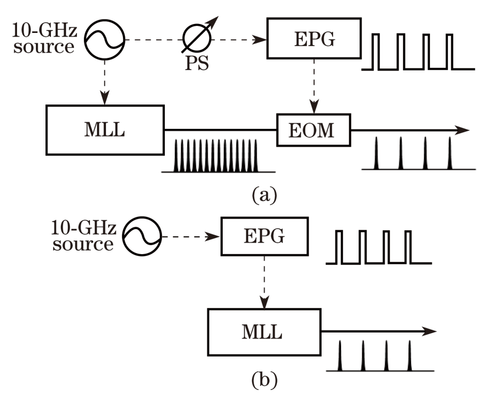

Fig. 1. (a) External selection of high-repetition-rate ultra-short pulse train; (b) low-repetition-rate ultra-short optical pulse generation by using an EPG. PS: phase shifter; MLL: mode-locked laser; EOM: electro-optic modulator.

In order to demonstrate the feasibility of this method, a proof-of-principle experiment was carried out, in which the output of the EPG was applied on the in-cavity modulator of an actively mode-locked laser. The experimental setup is shown in Fig. 2. In Fig. 2, the electro-optic modulator (EOM) is a 10-GHz $LiNbO_3$ intensity modulator, the dispersion shifted fiber (DSF) is a section (∼200 m) of ITU-T G.653 fiber, the optical band-pass filter (OBF) is with 3-dB full width at half maximum (FWHM) bandwidth of 0.8 nm, the output coupler (OC) is a 90:10 one, and the saturation power of the erbium-doped fiber amplifier (EDFA) is 17.1 dBm. The EPG generates a 10-Gb/s data stream with a period of 16 bits. The EPG is triggered by a microwave source, which outputs 10-GHz sinusoidal signal. By adjusting the pattern of the EPG output (1010 1010 1010 1010, 1000 1000 1000 1000, and 1000 0000 1000 0000 correspond to repetition rates of 5, 2.5, and 1.25 GHz, respectively), electrical patterns with repetition rates of 5, 2.5, and 1.25 GHz are obtained, as shown in Fig. 3.

The laser output is shown in Fig. 4(a) when 10-GHz sinusoidal signal is applied on the in-cavity modulator. When pattern signals with repetition rates of 5, 2.5, and 1.25 GHz are applied, the pulse width of the laser outputs remains constant, but the repetition rate decreases accordingly, as shown in Figs. 4(b)–(d). In other words, by tuning the pattern of the EPG, ultra-short optical pulse trains with different repetition rates are achieved. The output optical pulses shown in Fig. 4 are more Gaussian-like. This is because that the laser output is affected by all in-cavity components, including the modulator, the EDFA, the OBF, the DSF, and so on. The combination of all in-cavity components results in the more Gaussian-like optical pulse train.

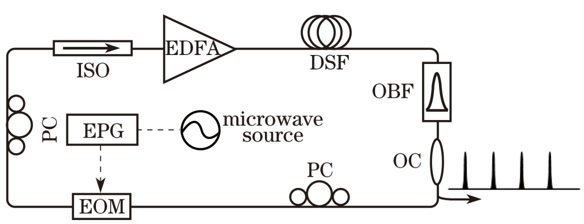

Fig. 2. Experimental setup. ISO: isolator; PC: polarization controller.

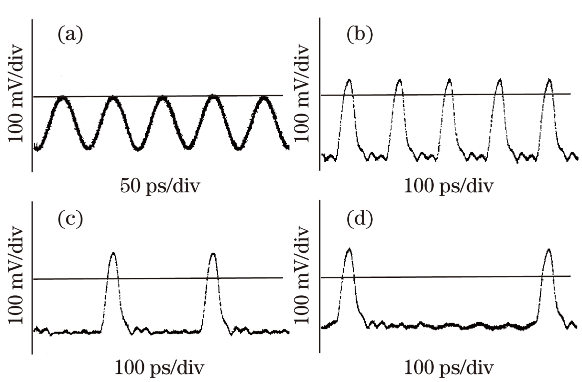

Fig. 3. (a) 10-GHz sinusoidal wave (input of EPG); (b)–(d) pulse sequences (outputs) with repetition rates of (b) 5, (c) 2.5, and (d) 1.25 GHz.

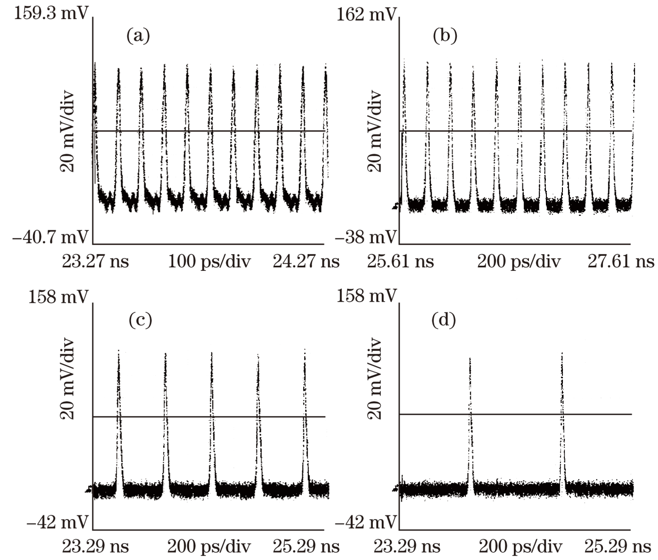

Fig. 4. Outputs of the mode-locked laser when (a) 10-GHz sinusoidal signal, (b) 5-GHz pattern, (c) 2.5-GHz pattern, and (d) 1.25-GHz pattern are applied on the in-cavity modulator.

In conclusion, an actively mode-locked laser with tunable repetition rate is proposed and demonstrated. This method has potential applications in OCDMA, photonic analog-to-digital conversion, and other areas requiring low-repetition-rate ultra-short optical pulses.

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