Combined mutual pulse injection-seeding and active mode locking system for wavelength tunable optical short pulse generation

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Abstract: A combined system to support simultaneous two way mutual pulse injection-seeding and active mode-locking schemes for wavelength tunable optical short pulse generation is presented. The system consists of two gain-switched Fabry-Pérot laser diodes, a bidirectional erbium-doped fiber amplifier, and a tunable optical filter and a coupler. The optical pulses generated exhibits a good stability, a high side-mode suppression ratio of more than 30 dB over a wide wavelength tuning range of 41 nm. The pulse width obtained is ~45 ps at the repetition frequency of around 2571.61 MHz.

OCIS code: (140. 3520) Lasers, injection-locked; (140. 4050) Mode-locked lasers; (140. 3600) Lasers, tunable; (320.5390) Picosecond phenomena;

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1. Introduction

Wavelength tunable optical short pulse generation has attracted a lot of research attention due to it's applications in optical communications and time division multiplexed optical fiber sensor networks. A simple way to generate wavelength tunable optical short pulses is by injection locking, including self-seeding [1-2] and external-injection seeding [3-4]. Recently, mutual pulse injection-seeding is developed as an alternative method to generate wavelength tunable optical short pulses [5-8], in which the output from a gain switched Fabry-Pérot (FP) laser diode is wavelength selected and then injected into another gain-switched or dc biased FP laser diode to excite a single wavelength optical pulse emission. The single wavelength optical pulses generated are subsequently directed into the first gain-switched FP laser diode during the pulse emission time, to stimulate also a single wavelength pulse output, thus establishing injection locking between the two FP laser diodes. As different injection paths have to be adopted for the two FP laser diodes, the system structure for mutual injection-seeding is relatively complex and more components need to be used. The wavelength tuning range achieved in mutual injection-seeding system is also limited as reported by now, about 19nm for the side-mode suppression ratio (SMSR) higher than 30dB. Moreover, gain switching of FP laser diode intrinsically induces strong frequency chirp [9]. Although the use of dispersion compensation fiber can effectively compress the optical pulses [10], a long fiber is needed which is more sensitive to environment changes. The use of linearly chirped fiber Bragg grating, however, is only suitable for a small wavelength tuning range [11].

In this paper, we present a system to generate wavelength tunable optical short pulses in a combined way of mutual pulse injection-seeding and active mode locking, which can effectively reduce the frequency chirp of the output pulses generated by injection locking of the gain-switched FP laser diode. The system consists of two gain-switched FP laser diodes, a bidirectional erbium-doped fiber amplifier (EDFA), a tunable optical filter and a coupler. Picosecond pulses with a good SMSR over a wide wavelength tuning range can be simultaneously obtained at both the output ends of the two FP laser diodes.

2. Experiment

The experiment configuration of our combined mutual pulse injection-seeding and active mode locking system is shown in Fig. 1. About -12 dBm microwave range electrical sinusoidal signal from a radio frequency (RF) signal generator (HP E4422B) is firstly amplified by a 28 dBm electrical power amplifier (ZHL-42W) and then split into two portions, about 10% of signal power is used as the trigger to the oscilloscope and the rest is further divided into two equal parts, then are coupled with dc currents via two identical Bias-Tee circuits before being used to drive two FP laser diodes into gain-switching operation. The peak wavelengths of the two gain-switched FP laser diodes are approximately 1542 and 1550nm respectively with mode spacing of 1.09 nm. The DC driving current of 11 mA is used for both the FP laser diodes, which is higher than their corresponding threshold current of 10mA.

In a mutual pulse injection-seeding operation, the multimode optical pulse output from laser diode FP1 is firstly amplified by a bidirectional EDFA and then passes through a tunable optical band pass filter (TB 1570 JDS filter) with bandwidth of ~1nm before being injected into laser diode FP2. By carefully adjusting the repetition frequency of signal generator, single wavelength optical pulse output from the tunable optical filter can be arranged to arrive at FP2 during the time period when an optical pulse emission starts. At the same time, the optical pulses from FP2 should also arrives at FP1 within the corresponding pulse emission time window after passing through the tunable optical filter and amplified by the EDFA, as the two FP laser diodes share the same external injection light path. As a result, a stable mutual pulse injection seeding output can thus be established at both the FP laser diode outputs. Two polarization controllers (PC) are employed to adjust the polarization states of the injection pulses and to optimize the output SMSR. Polarization will largely influence the waveform and SMSR of the pulses, but once it is set at an appropriate position, where the narrowest pulse

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and the highest SMSR can be obtained at a particular wavelength, then readjustment of PC is not needed. A 50:50 fiber coupler is used to branch out 50% of injection locking output of FP1 and FP2 respectively for the pulse waveform and spectrum observation.

Mutual pulse injection-seeding operation between the two FP laser diodes also satisfies the condition of active mode locking. In such an operation, two gain-switched FP laser diodes, an EDFA and an optical filter form a linear cavity fiber laser system in which the two laser diodes play the role as the mode lockers and the wavelength of the mode-locked optical pulses is selected by the tunable optical filter. The fundamental frequency of the laser linear cavity is 5.9666 MHz.

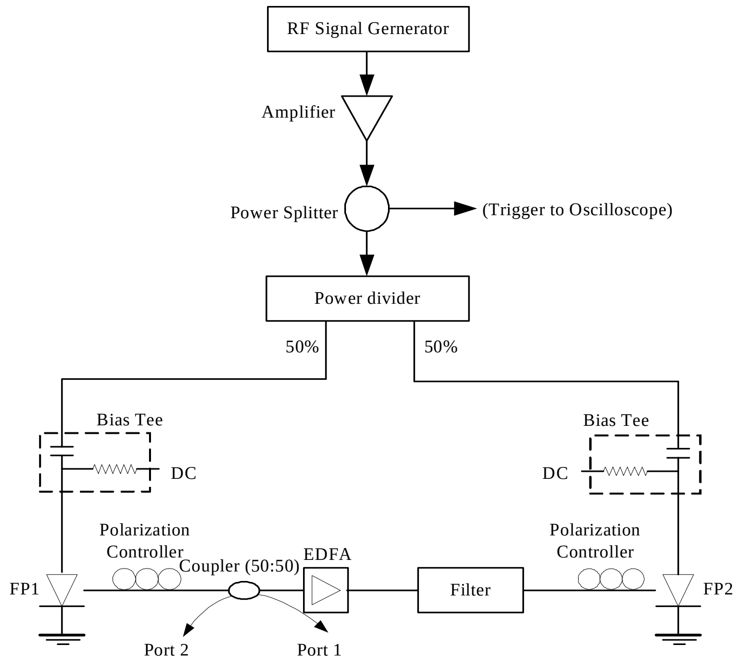

Fig. 1. Experimental arrangement for the combined mutual pulse injection-seeding and active mode-locking system

3. Results and discussion

Optical pulse spectra from gain switched FP1 and FP2 are shown in Fig. 2(a) and 2(b) respectively. Both the spectra exhibit multimode nature with mode spacing of 1.09nm. The spectral bandwidth of the laser mode is about 0.11nm. The center wavelength of FP1 is 1543.0 nm with peak intensity of -31.72 dBm and that of FP2 is 1550.4 nm with peak intensity of -32.60 dBm. After passing through the tunable filter, the output spectrum of FP1 is sharpened and centered at the selected wavelength as demonstrated in Fig. 3.

During the system operation, the mutual injection-seeded single wavelength optical short pulse emission can be easily achieved due to the tolerance in pulse arriving time (injection locking range is about 0.1nm in our experiment), but the full-width at half-maximum (FWHM) value of the pulse width is relatively wide. To enable an active mode locking operation, it is necessary to further tune the driving frequency carefully to a multiple of the fundamental frequency of linear cavity fiber laser, where the output pulse width becomes narrow.

Figures 4(a), 4(b), and 4(c) shows the spectra of the mutual injection-seeded and actively mode-locked optical pulses with EDFA amplification at output port 2. The repetition frequency used is 2571.61 MHz, corresponding to the 431th harmonic of the fundamental frequency. The wavelength-tuning is achieved by adjustment on the tunable optical filter. In Fig. 4(a), the peak wavelength is situated at 1528.05 nm. By adjusting the tunable filter, the wavelength can be shifted to 1546.58 nm as shown in Fig. 4(b). In Fig. 4(c), the wavelength is further moved to 1566.75 nm. The spectrum of injection-seeded combined actively mode-locked optical pulse output without EDFA amplification from FP1 (output port 1) is also shown in Fig. 5(d) with peak wavelength situated at 1544. 48nm. The optical pulse trains corresponding to the wavelengths demonstrated in Fig. 4 are shown in Fig. 5. The FWHM value of the pulse width is approximately 45 ps. Considering the 17 ps rise time of the photodetector used, the FWHM value of the pulse width should be modified to ~41.7 ps. As the corresponding spectral bandwidth is ~0.13 nm, a time bandwidth product (TBP) of 0.68 is achieved. Such a TBP value is better than that obtained in [7] and [8] respectively, which is larger than 1. A transform limited pulse can also be expected in our system by using an appropriate pulse compression.

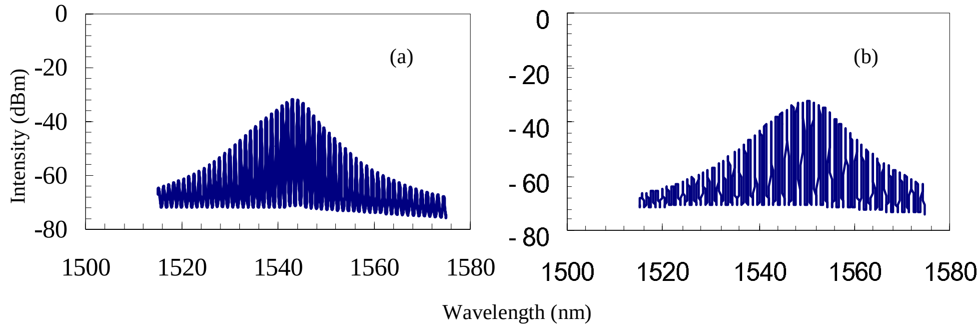

Fig. 2. Gain-switched FP laser diode spectra (a) FP1 output; (b) FP2 output

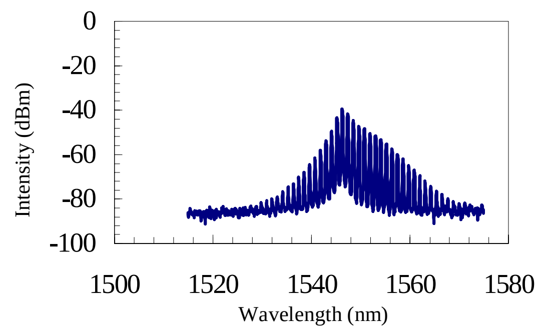

Fig. 3. Optical spectrum obtained at the output of tunable optical filter

Figure. 6 demonstrates the variation of pulse width with the change of repetition frequency. The results are obtained from the output port 2. It can be observed that when the repetition frequency is changed from 2572.31MHz to 2571.61MHz, the pulse width is decreased from ~ 80 to 45 ps. When repetition frequency is at 2571.61MHz, which is multiple of fundamental frequency of fiber laser, the pulses become the narrowest. The corresponding spectrum of the pulses in Fig. 6 is shown in Fig. 4(b), which is almost no change during the frequency tuning process.

The SMSR and the average power of the output pulses at both the output ends obtained at different wavelengths are shown in Fig. 7. It can be observed that optical pulse with the SMSR of larger than 30 dB, a wavelength-tuning range of about 41 nm can be obtained at output port 2, corresponding to the two wavelengths located at 1528.05 and 1569.00 nm. From output port 1, optical pulses with SMSR of large than 32dB over the same wavelength tuning range can be observed.

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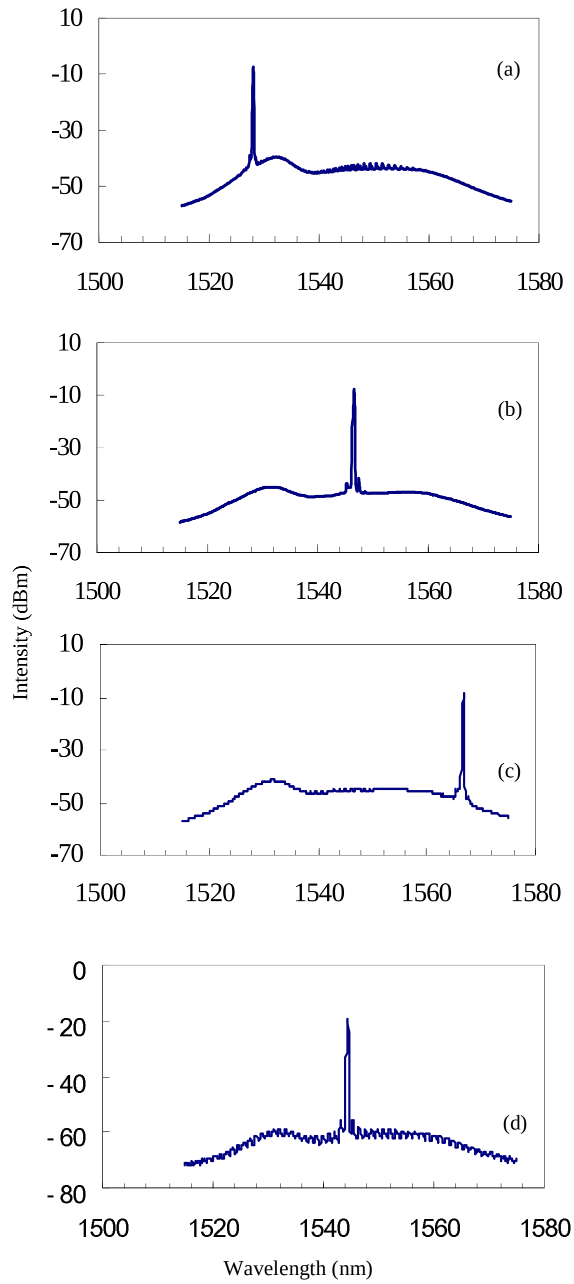

Fig. 4. Wavelength tunable optical short pulse spectra at output

(a) at 1528.05 nm at output port 2

(b) at 1546.58 nm at output port 2

(c) at 1566.75 nm at output port 2

(d) at 1544.48nm at output port 1

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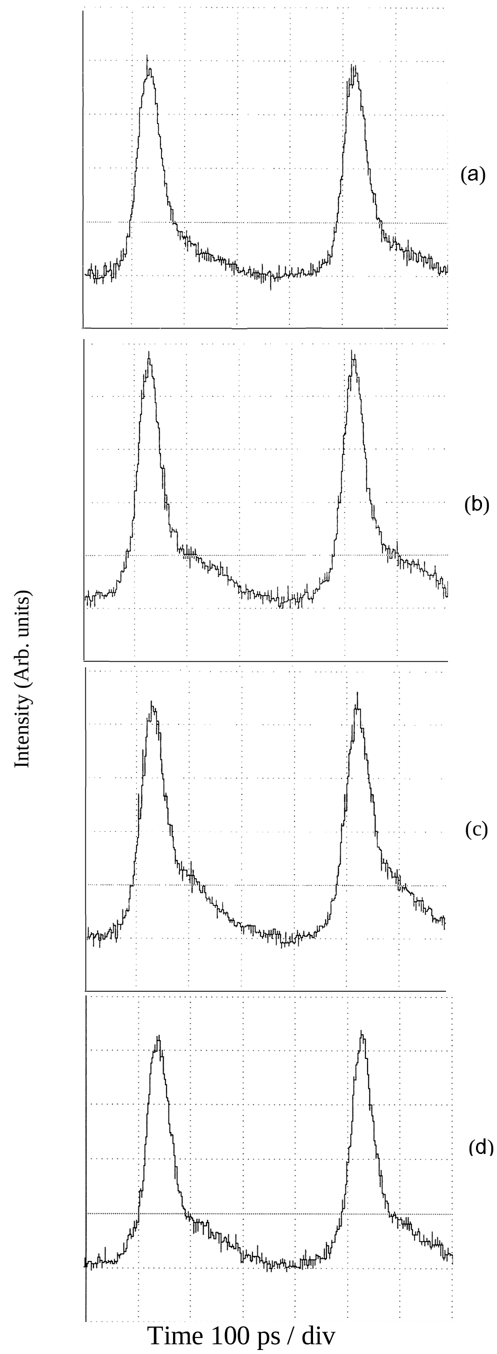

Fig. 5. Waveform of output optical pulse trains

(a) at wavelength 1528.05 nm at output 2

(b) at wavelength 1546.58 nm at output 2

(c) at wavelength 1566.75 nm at output 2

(d) at wavelength 1544. 48nm at output 1

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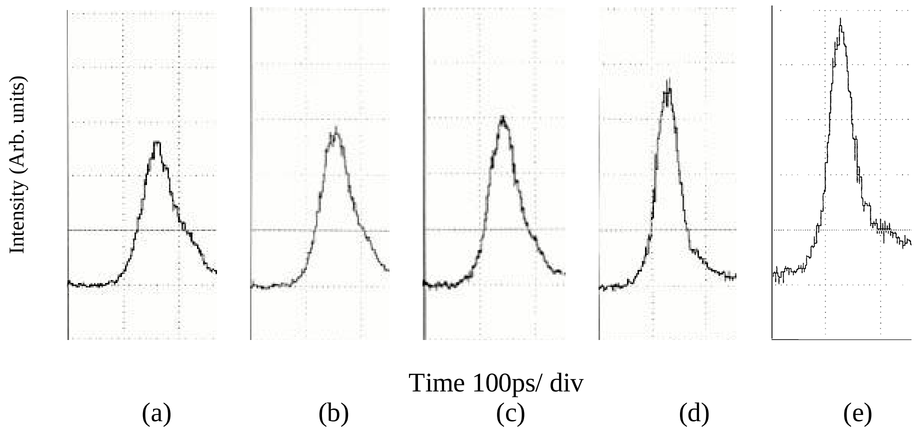

Fig. 6. process of pulse narrowing with repetition frequency changed

(a) with repetition frequency 1572.31MHz

(b) with repetition frequency 1572.11MHz

(c) with repetition frequency 1571.91MHz

(d) with repetition frequency 1571.71MHz

(e) with repetition frequency 1571.61MHz

The combined mutual injection seeding and mode-locking system in our experiment demonstrate its effectivity in frequency chirp reduction and high SMSR over a large wavelength range of output pulses. While in [11], linearly chirped fiber Bragg grating (LCFBG) is not only used as frequency chirp compensation, but also as elimination of other non Bragg reflection wavelength component of injection-seeding output pulses to increase SMSR (about 40 dBm over wavelength tuning range of 11.5nm at the output end of LCFBG), which will lead to frequency partition noise. Wavelength tuning range is limited by the tuning range of LCFBG.

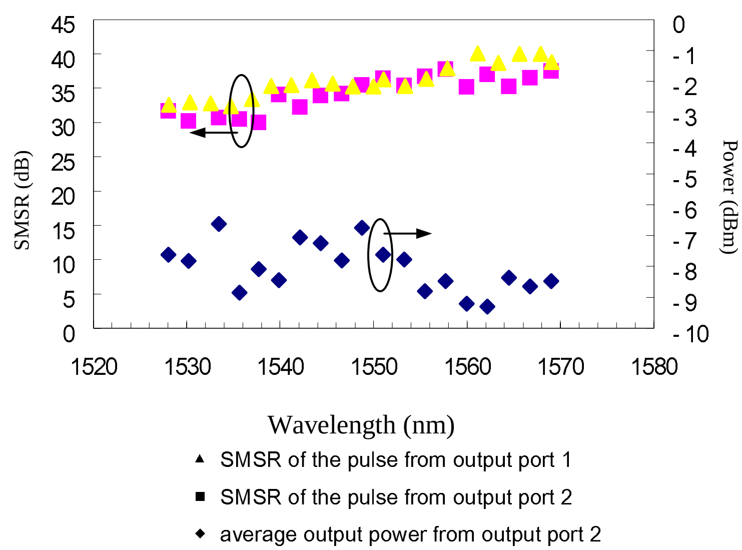

Fig. 7. Measured SMSR and average power of the output pulses at different wavelengths

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4. Conclusion

A combined mutual pulse injection-seeding and active mode-locking system has been developed to produce wavelength tunable optical short pulses. The mode-locked optical pulses exhibit a pulse width of 45 ps at the repetition frequency of around 2571.61 MHz. The wavelength-tuning range that can be achieved is 41 nm with a corresponding SMSR of better than 30 dB. The system is simple and robust and a stable optical short pulse operation can be obtained.

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