Widely tunable dual-wavelength optical short pulse generation in a self-seeding scheme

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Two gain-switched Fabry–Pérot laser diodes have been used in a self-seeding scheme for widely tunable dual-wavelength optical short pulse generation. The wavelengths and their spacing can be tuned in a flexible manner by adjustment of the wavelength-selective elements that consist of a fiber Bragg grating and a tunable optical filter. The side-mode suppression ratio of the output pulses achieved is better than 26 dB over a wavelength-tuning area of approximately 30 nm. © 2004 Optical Society of America

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1. INTRODUCTION

There has been increased research interest in multiwavelength optical short pulse generation as it provides an efficient means to achieve wavelength-division multiplexing and time-division multiplexing simultaneously and hence is advantageous for many optical fiber communication and optical fiber sensor applications. Optical short pulses can be generated by mode locking laser diodes[1,2] that are compact and reliable. In addition, narrow optical pulses with low timing jitter can be obtained.[3–6] Multiwavelength optical short pulses can also be produced by use of laser diode arrays and multichannel grating cavity lasers.[7,8] However, the laser diodes used in mode locking require a specially designed structure or antireflection coating on the laser internal facet. In contrast, only commercially available Fabry–Pérot (FP) laser diodes are used in the self-seeding system, which is simple and economic.[9,10] To stimulate a multiwavelength operation, one or more wavelength-selective devices such as diffraction gratings and fiber Bragg gratings (FBGs) must be used in the laser external cavity. The selected wavelength elements are required to be fed back into the gain-switched FP laser diode. Provided that each of the feedback wavelengths arrives during the pulse build-up time, a simultaneous multiwavelength optical short pulse emission can be obtained. To enable a tunable multiwavelength operation, the repetition frequency of the driving electrical signal to the laser diode and the optical path lengths corresponding to the selected wavelength elements have to be adjusted in a combined manner as both the variation of driving frequency and of optical path length could lead to a wavelength shift or a change in the number of operating wavelengths. The adjustment can be performed either by fixing the repetition frequency first and then changing the external cavity length or initially keeping the cavity length unchanged and then start to vary the repetition frequency before fine tuning the repetition frequency and the cavity length again. Flexible tuning of the wavelengths and their spacing over a large wavelength region is essential for a wide range of system applications. However, the wavelength-tuning range in self-seeding is limited by the spectral width of the FP laser diode used and the tuning capability of the wavelength-selective elements. The wavelength-tuning range or the largest wavelength spacing that can be achieved in a multiwavelength self-seeding system is typically less than 20 nm.[9,10]

We present a self-seeding system that uses two gain-switched FP laser diodes for generation of dual-wavelength optical short pulses with large and flexibly tuned wavelength spacing. The wavelength selection branch of the system consists of a FBG and a tunable optical filter. A side-mode suppression ratio (SMSR) of better than 26 dB across a wavelength-tuning range of approximately 30 nm can be obtained. The system effectively extends the research reported in Ref. 11 by supporting a flexible and convenient dual-wavelength tuning.

2. EXPERIMENT

The experimental configuration for the tunable dual-wavelength self-seeding scheme is shown in Fig. 1. Two commercial FP laser diodes with peak wavelengths of 1.53 and 1.55 μm were gain switched by use of a radio-frequency (rf) electrical sinusoidal signal together with dc bias currents. The threshold currents of the two laser diodes were 14 and 10 mA. The power of the electrical signal used to drive each of the FP laser diodes was ~12 dBm. The output from the two gain-switched FP laser diodes had a multimode nature and was power enhanced by use of an erbium-doped fiber amplifier (EDFA) and then directed to the wavelength selection branch that consists of a FBG and a tunable optical FP filter (TF00SC, Micron Optics, Inc.) with a bandwidth of 2.4 GHz and a free spectral range of 8860 GHz. We tuned the wavelength by varying the driving voltage of the optical filter. The Bragg wavelength and the tuning range of the FBG were 1531 and 14 nm, respectively. One of the wavelength elements was reflected from the FBG and subsequently sent to the gain-switched FP laser diode through a circulator and a coupler. The other wavelength compo-

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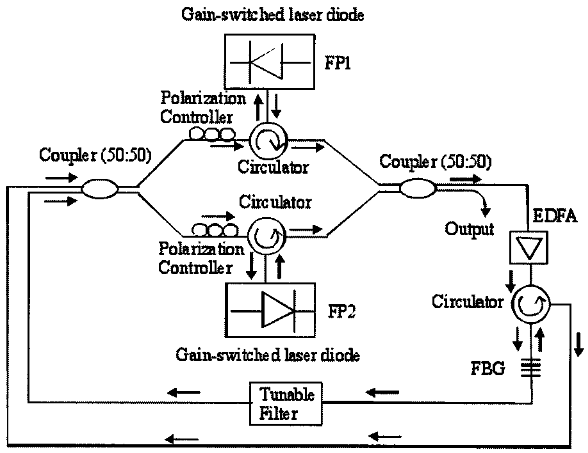

Fig. 1. Experimental configuration for the tunable dual-wavelength self-seeding scheme.

nent was transmitted directly through the FBG and the tunable optical filter before being introduced to the laser diodes by a coupler. By adjusting the repetition frequency of the driving signal, we could arrange for the optical pulses reflected by the FBG and those transmitted through the tunable optical filter to arrive at the gain-switched laser diodes during the corresponding pulse emission period, thus creating a simultaneous dual-wavelength optical short pulse emission. Two polarization controllers were added to the system to control the polarization states of light injected into the laser diode to optimize the SMSR of the output pulses. An optical coupler was used to branch out part of the system output to observe the waveforms and the spectra of the dual-wavelength optical pulse trains.

Our current system had further developed the experimental setup reported in Ref. 11 by incorporating a second laser diode and a second wavelength-selective element (FBG) into the system, and employing an EDFA to intensify the power of the optical pulses.

3. RESULTS AND DISCUSSION

The output spectra from the two gain-switched FP laser diodes are shown in Fig. 2. The two spectra partially overlap and are centered at 1531 and 1550 nm. The whole spectral range covered is larger than what appears in Fig. 2 in Ref. 11, thus exhibiting the potential to increase the wavelength-tuning range. The two wavelengths can be tuned independently by adjustment of the FBG and the tunable optical FP filter. The output spectra with different wavelength separations are shown in Fig. 3. Figure 3(a) shows a relatively small wavelength spacing of 1.7 nm, which represents the separation of the two adjacent FP laser modes situated at 1528.4 and 1530.1 nm. The SMSR obtained in this case is better than 28.5 dB. By tuning the FBG and the optical filter, the dual-wavelength locations can be shifted flexibly and their spacing can be increased. In Fig. 3(b) the dual-wavelength separation is increased to ~27.4 nm, and the peak wavelengths are situated at 1526.8 and 1554.2 nm. The repetition frequency of the driving electrical signal can be maintained at approximately 545.2 MHz during the whole dual-wavelength tuning process. The SMSRs obtained are greater than 26 dB for all the wavelengths within the region. The smallest and the largest spacing of dual-wavelength emission peaks achieved in the experiment that correspond to the SMSR of greater than 25 dB are ~1.7 and ~29.3 nm, respectively. Such values are essentially limited by the separation of the adjacent laser modes and the spectral region covered by the two laser diodes employed. However, for a given output SMSR, the smallest wavelength spacing can be reduced and the largest wavelength spacing can be increased if a relatively large spectral power at the corresponding wavelengths becomes available by use of more optical amplifiers in the system.

The dual wavelengths can also be tuned in a flexible manner, i.e., keeping the wavelength spacing essentially unchanged. Figure 4 illustrates such an operation: the wavelengths are shifted to different locations and their separation is maintained at ~4.8 nm in Figs. 4(a) and

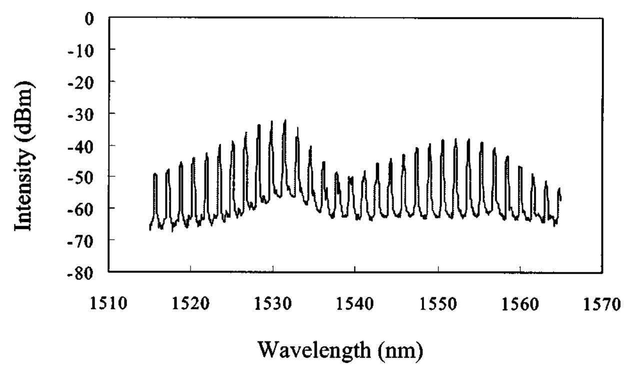

Fig. 2. Output spectra of the two gain-switched FP laser diodes.

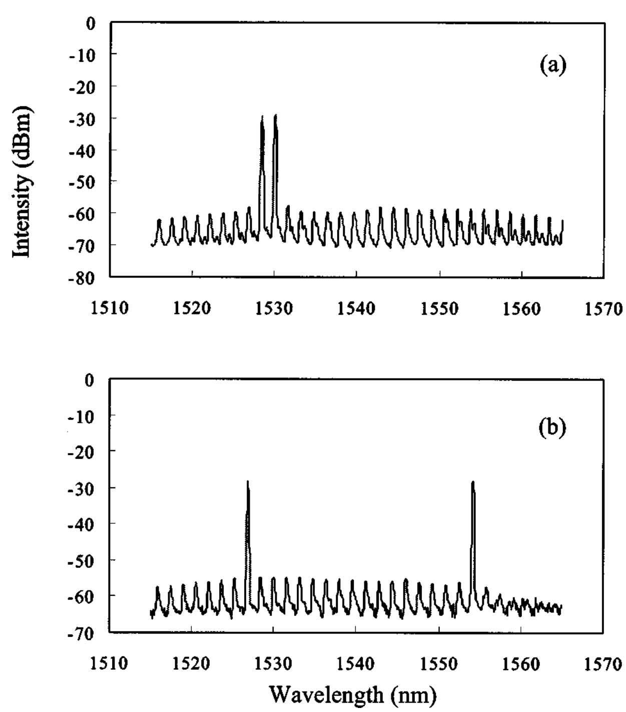

Fig. 3. Tunable dual-wavelength self-seeded output spectra at (a) 1528.4 and 1530.1 nm and (b) 1526.8 and 1554.2 nm.

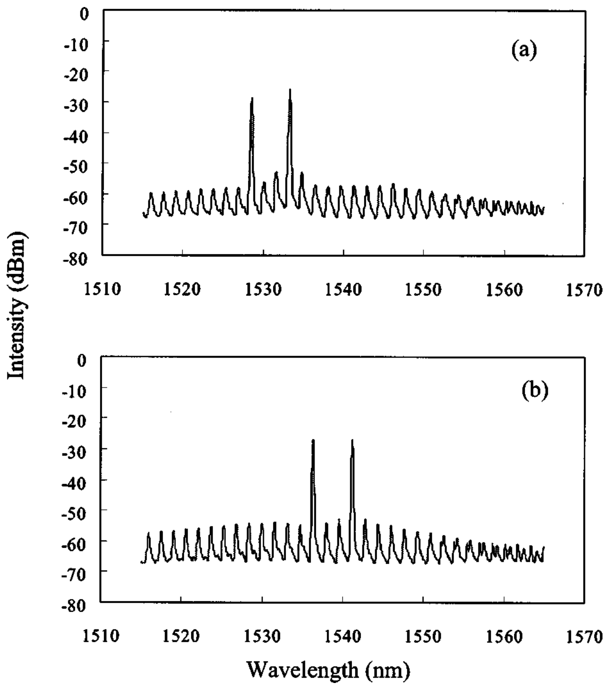

Fig. 4. Tunable dual-wavelength self-seeded output spectra with fixed wavelength spacing at (a) 1528.6 and 1533.4 nm and (b) 1536.3 and 1541.1 nm.

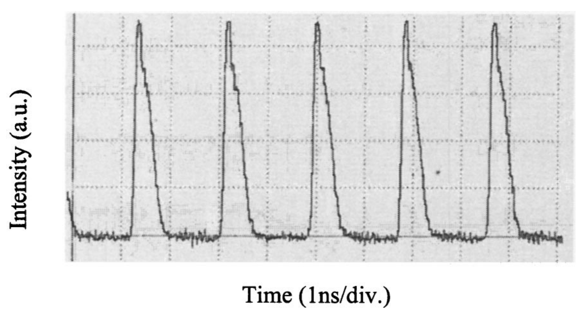

Fig. 5. Self-seeded output pulse trains at 1528.4-nm wavelength.

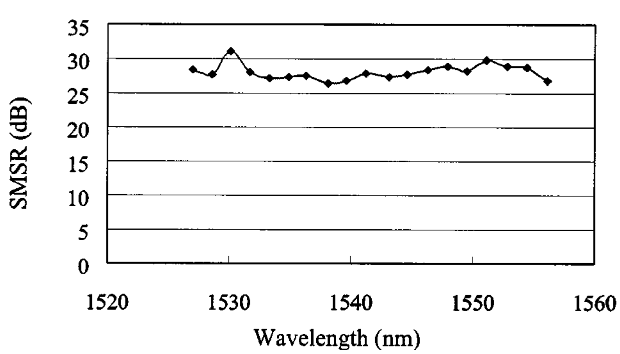

Fig. 6. Measured values of the SMSR obtained at different wavelengths in the dual-wavelength operation.

4(b). The SMSR of greater than 26 dB can also be maintained during the wavelength-tuning process while the repetition frequency remains at 545.2 MHz.

The typical optical pulse waveform that corresponds to one of the two wavelengths displayed in Fig. 3(a) is demonstrated in Fig. 5. The single wavelength pulses are obtained by use of a tunable optical FP filter at the system output. The full width at half-maximum (FWHM) values of the pulse width are approximately 280 ps.

The dependence of the SMSR of the output pulses on the wavelength is shown in Fig. 6. The SMSR of higher than 26 dB is obtained within the wavelength range close to 30 nm, corresponding to the dual wavelengths located at 1526.8 and 1556.1 nm. The SMSR and the corresponding wavelength-tuning range obtained are comparable with that reported in Ref. 11, where the SMSR is greater than 27 dB for the wavelength-tuning range of ~33 nm and greater than 30 dB across a 26-nm wavelength-tuning region, although a dual-wavelength instead of a single-wavelength operation was obtained. The introduction of a second laser diode and a second wavelength control element in the system leads to a SMSR reduction as either the available spectral power has to be shared between the two wavelengths in the same laser diode or the feedback wavelength power in each of the laser diodes becomes less than that in the single-wavelength operation. To stabilize the SMSR in the system output, the external cavity length and the repetition frequency need to be maintained and a fluctuation in temperature and a change in environment should be avoided.

The wavelength-tuning range of the system depends on the gain spectra of the two FP laser diodes and the overlap region. The value of the SMSR depends on the polarization states of the pulse trains and the number and the spectral power of the operating wavelengths. There should be no essential difference in the SMSR between the wavelength located in the overlapped spectral region and that situated at the edge of the laser spectrum where there is no overlap, as long as the same spectral power level remains. The number of the wavelength output can be readily increased if the number of the cascaded FBGs is increased in the system. To improve the SMSR of the multiwavelength output, the feedback wavelength power in the corresponding laser diode should be increased and an optical delay line also needs to be inserted between the two FBGs in the cascaded FBG array to control the mutual pulse propagation delay accurately.

The current system also exhibits good scalability: the number of the operating wavelengths and the wavelength-tuning range can be increased if three or more laser diodes are used, which, however, increases the system complexity.

4. CONCLUSION

Tunable dual-wavelength optical short pulse generation has been achieved in a self-seeding scheme. The light source used is a combination of two gain-switched FP laser diodes. The wavelength selection branch of the system consists of a FBG and a tunable optical filter. The SMSR of better than 26 dB over a wavelength-tuning range of approximately 30 nm was obtained. The system is flexible and convenient for dual-wavelength tuning.

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