Simple self-seeding scheme for generation of wavelength-tunable optical short pulses

Dong Ning Wang

Department of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

Jiwu Chen

Department of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China, Department of Information and Electronics, Zhejiang University, Hangzhou, China, and China Institute of Metrology, Hangzhou, China

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A simple and efficient system for generating wavelength-tunable optical short pulses from a self-seeded, gain-switched Fabry–Perot laser diode is presented. The laser's external cavity consists only of a tunable optical filter. The side-mode suppression ratio is better than 30 dB over a relatively wide wavelength-tuning range of 26 nm. In addition, a constant repetition frequency of 534.65 MHz can be maintained during wavelength tuning. © 2003 Optical Society of America

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1. INTRODUCTION

Generation of optical short pulses has many applications in wavelength-division multiplexing (WDM) and in optical fiber sensor networks. One of the methods used successfully for generation of optical short pulses is active mode locking of a semiconductor laser diode that is specially designed with antireflection coatings on the laser's internal facets.[1,2] Another simple way to produce optical short pulses is by gain switching of a commercially available Fabry–Perot (F–P) laser diode with no antireflection coating on the laser internal facets; the output spectrum obtained will exhibit a multimode nature. If a wavelength-selective element is incorporated into the gain-switched F–P laser diode external cavity to reflect part of the wavelength output back into the laser diode, single-mode optical short pulse emission can occur, provided that the feedback arrives during the pulse's buildup time. Such an approach, known as self-seeding, has proved to be a simple and economical means to produce wavelength-tunable optical short pulses.[3–6] One can achieve wavelength tuning by adjusting a wavelength-selective element such as a fiber Bragg grating and tuning the repetition frequency of the laser driving signals or, alternatively, by adjusting the external cavity length. For single-mode wavelength-tunable optical short pulses, the key parameters that determine their usefulness in optical fiber communication include the side-mode suppression ratio (SMSR) and the wavelength-tuning range. A self-seeding system requires that the SMSR be >25 dB; otherwise the system may not be suitable for WDM applications because of the presence of mode partition noise.[7] Thus, achieving a high SMSR is of great importance. In most self-seeding schemes, however, the SMSR obtained is relatively low or the system exhibits only a small wavelength-tuning range (<19 nm).[5,6] Therefore a more-complicated system has to be adopted.

In this paper we present a simple self-seeding system that generates wavelength-tunable optical short pulses. The system consists only of a gain-switched F–P laser diode, a tunable F–P filter, a polarization controller, and two circulators. In this system, only the transmitted light pulses from the tunable F–P filter can reach the gain-switched F–P laser diode, unlike in the setup reported in Ref. 8, in which the feedback consists of both the transmitted and the reflected light pulses from the tunable filter that travel along different paths before they arrive at the gain-switched F–P laser diode and result in reduction in the SMSR owing to the broadened feedback pulses. The SMSR of our system is better than 30 dB over a relatively large wavelength-tuning range of 26 nm. The repetition frequency can be kept essentially constant during wavelength tuning. The system is simple, efficient, and robust.

2. EXPERIMENT

The experimental configuration for the self-seeding scheme is shown in Fig. 1. The light source used was a commercial F–P laser diode with a peak wavelength of 1.533 μm, a threshold current of 22 mA, and longitudinal mode spacing of ~1 nm. The laser diode was gain switched by use of a 534.65-MHz sinusoidal signal produced from a radio frequency signal generator (HP E4422B). The electrical signal power of -16 dBm was first enhanced by 30-dB by use of an electrical amplifier (Mini-Circuits ZHL-42W) and then divided by a power splitter. Part (10%) of the signal power was taken as the trigger of the oscilloscope, and the rest (90%) was passed

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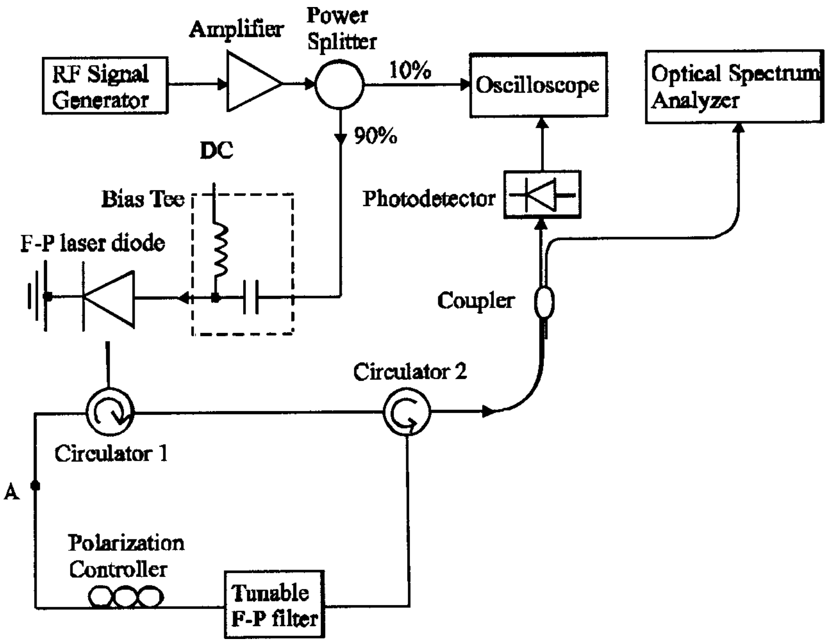

Fig. 1. Experimental configuration of the self-seeding system.

through a bias-tee circuit before it was employed to drive the laser diode in conjunction with a dc bias current of ~15 mA. The multimode optical pulse output from the gain-switched F–P laser diode was directed via two optical circulators to the tunable F–P filter, where one of the laser modes was selected and introduced back into the laser cavity. Single-mode optical short-pulse emission was thus established as long as the feedback wavelength element arrived at the moment when the pulse emission started to build up. A polarization controller was included in the laser's external cavity to optimize the polarization states of the pulses for improvement of the SMSR. The single-mode optical pulses generated were directed again to the tunable F–P filter with a bandwidth of 2.4 GHz and a free spectral range of 8860 GHz, where part of the light was reflected back and branched out from circulator 2's output port and collected through an optical coupler by an optical spectrum analyzer as well as by a 25-GHz photodetector (New Focus 1414), which was connected to a digital sampling oscilloscope (Trektronics CAS 8003C). Thus, both the spectral content and the waveforms of the output pulses could be observed.

To determine the percentage of transmitted and reflected power in the input to the tunable filter we used a distributed-feedback laser diode with a wavelength of 1.55 μm as the light source in the system. The input and the output (transmitted) powers of the tunable F–P filter were measured as -18.6 and -25.4 dBm, respectively, and the reflected power measured at the output port of circulator 2 was ~ -24.7 dBm, representing 25% of the input power to the tunable F–P filter.

3. RESULTS AND DISCUSSION

The multimode optical pulse spectrum obtained from the gain-switched F–P laser diode is shown in Fig. 2. The repetition frequency is set at 534.65 MHz during the system's operation. When the laser diode is self-seeded as shown in Fig. 1, single-mode light emission can be observed. The linewidth of the laser mode is ~0.1 nm; it is limited by the 0.1 nm resolution of the optical spectrum analyzer. We can readily switch from one single-mode operating wavelength to another by varying the voltage applied to the tunable optical filter; the tuning speed is of the order of milliseconds. The optical spectra that correspond to optical pulse trains of different wavelengths are displayed in Fig. 3. The peak wavelengths are located at 1523.6, 1534.4, and 1546.4 nm. Such wavelengths are not International Telecommunication Union (ITU) standard grid wavelengths. However, the peak wavelength can be fine tuned to fit the ITU grid wavelength by slight adjustment of the temperature controller of the F–P laser diode while the tunable filter's output is set to the ITU grid wavelength. The waveforms of the corresponding output pulse trains are illustrated in Fig. 4; the average powers of the optical pulses are 160.8, 212.4, and 169.8 μW. Such power levels are substantially lower than those of commercially available WDM sources, which are at least several milliwatts.[9] However, the output power in our self-seeding system can be readily enhanced to the

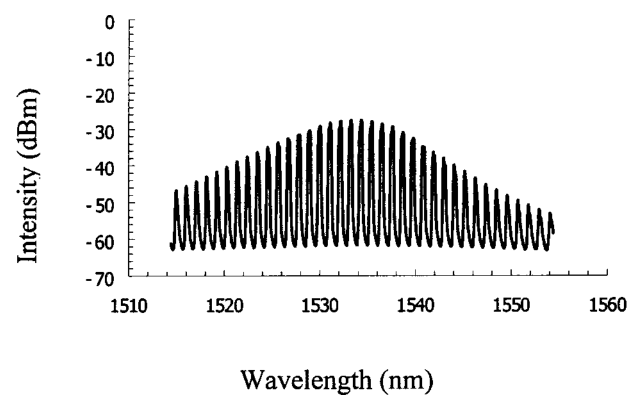

Fig. 2. Gain-switched F–P laser diode output spectrum.

milliwatt order to satisfy WDM applications by introduction of an erbium-doped fiber amplifier into the system's output branch. The FWHM value of the pulse width is ~250 ps. As the wavelength is tuned by adjustment of the tunable F–P filter in the laser's external cavity, a simple, robust, and convenient system for generation of tunable optical short pulses can be obtained.

The variation of SMSR with wavelength is shown in Fig. 5, where the wavelength-tuning range is ~33 nm, corresponding to a SMSR of >27 dB. The SMSR is better than 30 dB over a 26-nm wavelength range from 1521.4 to 1547.5 nm. The maximum value of SMSR that can be achieved is ~35 dB at 1531.2–1537.6 nm, in a wavelength range of ~6.4 nm.

As can be seen from Fig. 2, the spectrum of the F–P laser diode covers only parts of the *S* band (1490–1530 nm) and the *C* band (1530–1565 nm). However, it is possible to obtain a broad spectrum that covers the entire *C* band by selecting an appropriate F–P laser diode.

The tuning speed of the proposed system is higher than that of a distributed-feedback laser, similar to that of an external-cavity laser (~1 ms), but less than those of other commercially available systems (e.g., the tuning speed is <20 ns for multisegmented distributed Bragg reflector lasers and ~10 μs for microelectrical mechanical system vertical-cavity surface-emitting lasers.[9] The wavelength-tuning range and the SMSR of the proposed system are also smaller than those of multisegmented distributed Bragg reflectors (>35 nm and >35 dB), microelectrical mechanical system tunable lasers (>35 nm and >40 dB), or New Focus external-cavity lasers (>70 nm and >40 dB),[9–11] but the wavelength-tuning range is higher than that of cascaded distributed-feedback lasers (~15 nm).[12]

The output of the proposed self-seeding system consists of optical short-pulse trains, whereas commercially available tunable laser systems have a continuous-wave output. Overall, the proposed self-seeding system is simple

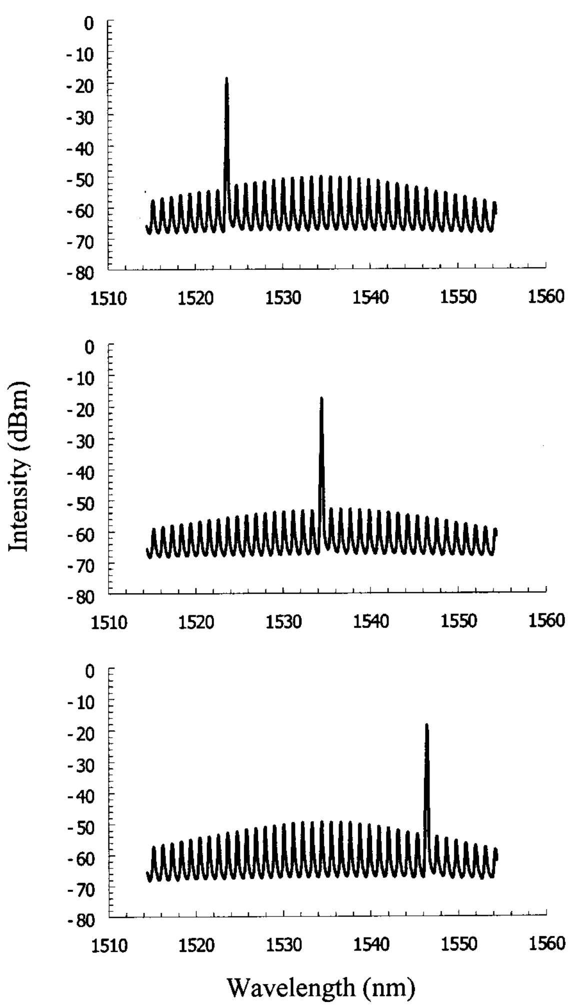

Fig. 3. Wavelength tunable optical short-pulse spectra at wavelengths of (a) 1523.6, (b) 1534.4, and (c) 1546.4 nm.

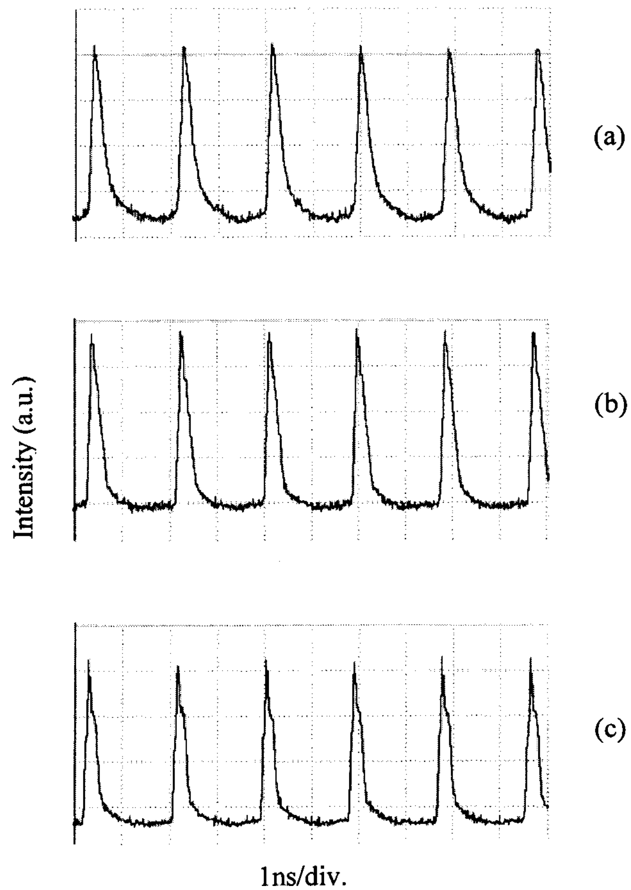

Fig. 4. Optical pulse trains at wavelengths of (a) 1523.6, (b) 1534.4, and (c) 1546.4 nm.

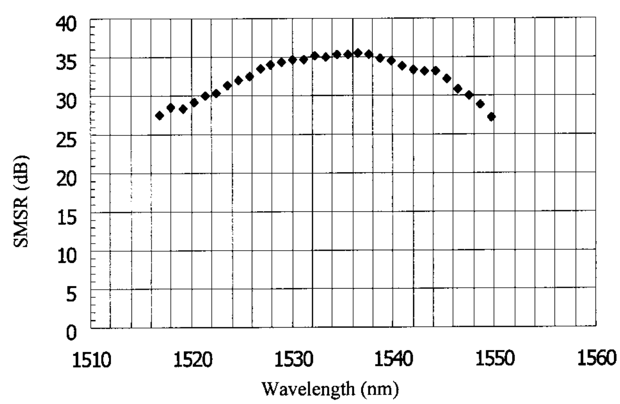

Fig. 5. SMSR values of the output pulses obtained at several wavelengths.

and of low cost and uses only commercially available F–P laser diodes without any antireflection coatings on the lasers' internal facets. Such a system represents an economical alternative to the current commercially available systems for generation of wavelength-tunable optical short pulses.

4. CONCLUSIONS

A simple, efficient, and robust self-seeding system has been demonstrated to produce wavelength-tunable optical short pulses. The wavelength tuning of the pulses can be conveniently achieved by adjustment of a tunable Fabry–Perot filter while a constant repetition frequency of 534.65 MHz is maintained. The side-mode suppression ratio obtained is better than 30 dB over a wavelength-tuning range of 26 nm.

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D. N. Wang's e-mail address is eednwang @polyu.edu.hk.

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