Wavelength-tunable optical short-pulse generation by mutual pulse injection seeding of two gain-switched Fabry–Perot laser diodes

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A simple and robust system is presented to generate wavelength-tunable optical short pulses by use of two gain-switched Fabry–Perot laser diodes in a mutual pulse injection-seeding scheme. The operating wavelength of the optical pulses is flexibly selected by adjustment of a tunable filter, and its intensity is enhanced with an erbium-doped fiber amplifier. The side-mode suppression ratio achieved by the system is larger than 26 dB over a wavelength region of 25 nm and higher than 31 dB within an 18-nm wavelength. © 2003 Optical Society of America

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1. Introduction

Wavelength-tunable optical short-pulse generation has been an interesting research topic in recent years because of its applications in multiplexed optical fiber communication systems and optical fiber sensors. One can generate optical short pulses simply by gain switching a Fabry–Perot (FP) laser diode. To obtain single-wavelength optical pulse operation with wavelength tunability, self-seeding and external-injection seeding methods have been employed.[1–4] In a self-seeding system, part of the laser output is wavelength selected and then fed back into the laser internal cavity, resulting in a single-wavelength optical pulse emission provided that the reflected pulse arrives during the pulse build-up time. One can achieve wavelength tuning of self-seeding pulses by tilting diffraction gratings in the external cavity, by applying strain to the fiber Bragg gratings, or by using dispersive fibers while changing the repetition frequency. The repetition frequency and external cavity length can be kept constant in an external injection-seeding scheme where the wavelength element from a master laser source is injected into the gain-switched FP laser diode and leads to single-mode optical pulse emission provided that the injected wavelength coincides with one of the gain-switched FP laser modes. The price paid, however, is the relatively high cost of a master laser source, as a continuous-wave tunable laser is usually required. Although a dc-driven FP laser diode together with fiber Bragg gratings have recently been used as an external injection-seeding source,[5] the side-mode suppression ratio (SMSR) achieved in the system is still low (<20 dB). Another efficient means for tunable optical pulse generation is by mutual injection seeding of two gain-switched FP laser diodes,[6,7] in which the multimode laser output can be converted into stable single-mode pulse emission by use of dispersion-compensating fiber and careful control of the cavity length. Wavelength tuning is achieved by adjustment of the electrical pulse delay between the radio-frequency (rf) synthesizer and the pulse generator, and the tuning range is limited by the repetition frequency and the dispersion in the dispersion-compensating fiber.[7]

Here we present a simple and efficient means to generate wavelength-tunable optical pulses by mutual pulse injection seeding of two gain-switched FP laser diodes. The multimode output from the first gain-switched FP laser diode is mode selected when it passes through a tunable optical FP filter, and the single-wavelength output from the filter is intensified by use of an erbium-doped fiber amplifier (EDFA) before it is injected into the second gain-switched FP laser diode to produce single-wavelength optical

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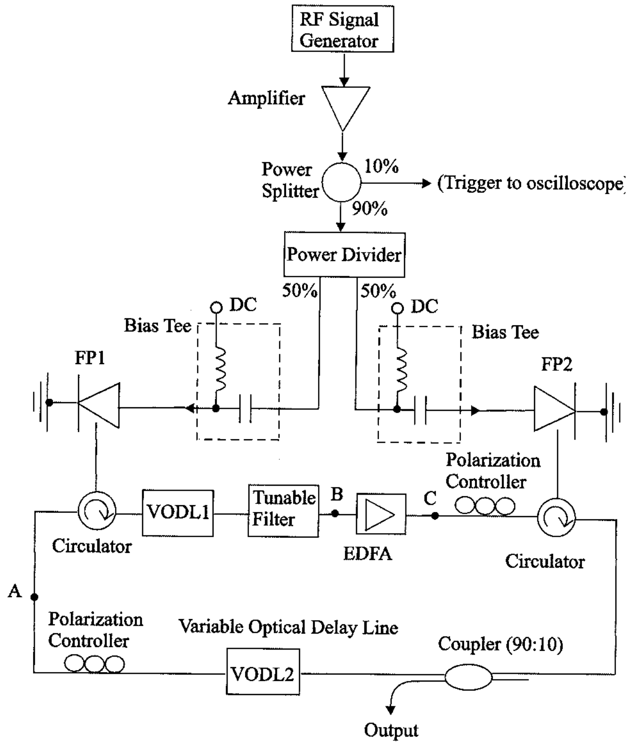

Fig. 1. Experimental configuration for mutual pulse injection seeding of two gain-switched FP laser diodes.

pulses. Such injection-seeded optical pulses are introduced back into the first gain-switched FP laser diode in a timely manner by use of two variable optical delay lines to form a mutual injection-seeding mechanism. When compared with the mutual injection-seeding approaches reported previously,[7] our system uses only a tunable optical filter for both single-mode selection and wavelength tuning, which leads to a more compact system configuration. In addition, the repetition frequency can be flexibly chosen and kept as a constant during system operation, without imposing any limit on the wavelength-tuning range. The SMSR achieved in the system is better than 31 dB across most of the 25-nm-wavelength region.

2. Experiment

The experimental setup is shown in Fig. 1. Two economic FP laser diodes with a peak wavelength close to 1.55 μm are gain switched by a rf sinusoidal signal, which is generated from a signal generator and amplified by a power amplifier with a gain of 30 dB. Approximately 10% of the amplified signal is used as the trigger for the oscilloscope; the rest of the signal power is equally divided into two parts and coupled with dc currents by means of two identical bias tee circuits before being used to drive the two FP laser diodes. Both FP laser diodes are gain switched at 530.55 MHz. The multimode optical pulse output from laser diode FP1 passes through a tunable FP filter with a bandwidth of 2.4 GHz by means of an optical circulator for wavelength selection and then amplified by an EDFA before being injected into laser diode FP2. By careful adjustment of the pulse travel time from FP1 to FP2 through a variable optical delay line, VODL1, single-wavelength optical pulse output from the tunable filter can be arranged to arrive at FP2 during the time period when an optical pulse emission starts. Pulse injection-seeded output from FP2 thus also becomes a single-wavelength pulse emission, which is then directed to FP1 by two optical circulators. A variable optical delay line, VODL2, is used to adjust the propagation time of the pulses from FP2 to FP1 so that the pulse arrival time coincides with the pulse emission time at FP1. As a result, the output from FP1 also becomes single-wavelength optical pulse trains. A stable mutual pulse injection-seeding output can thus be established at both FP laser diode outputs. Two polarization controllers are employed to adjust the polarization states of the injection pulses and to optimize the output SMSR. A 90:10 fiber coupler is used to branch out 10% of the system output to observe the pulse waveform and the corresponding spectrum. The optical spectrum analyzer used has a resolution of 0.1 nm.

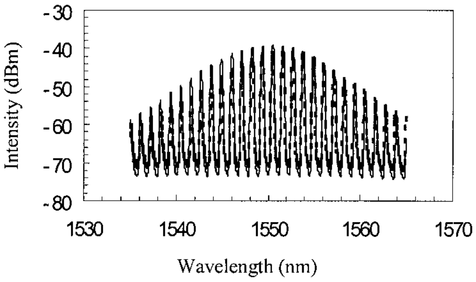

Fig. 2. Output spectra of two gain-switched FP laser diodes (solid curves, FP1; dashed curve, FP2).

3. Results and Discussion

The two gain-switched FP laser diode outputs are shown in Fig. 2. They are well-overlapped multimode spectra within the wavelength region between 1535 and 1565 nm. To observe the pulse injection-seeding process, the optical loop shown in Fig. 1 was first disconnected at point A, and the laser spectrum was recorded at point B, point C, and the fiber coupler output port, respectively. Figure 3(a) shows the tunable filter output at point B, where a dominant laser mode exists together with a few low-intensity side modes. Because of the small bandwidth (2.4 GHz) of the filter, a large power loss can be observed when Figs. 2 and 3(a) are compared. However, such a loss can be compensated and the power can be further enhanced by use of an EDFA. The amplified tunable filter output is demonstrated in Fig. 3(b), where a single laser mode appears above the EDFA amplified spontaneous emission curve. When the intensified single-mode pulses coincide with the pulses generated at FP2, the pulse injection-seeded spectrum can be observed in Fig. 3(c), and the SMSR obtained is approximately 18 dB. Because of the mode-partition effect in the laser source, the ampli-

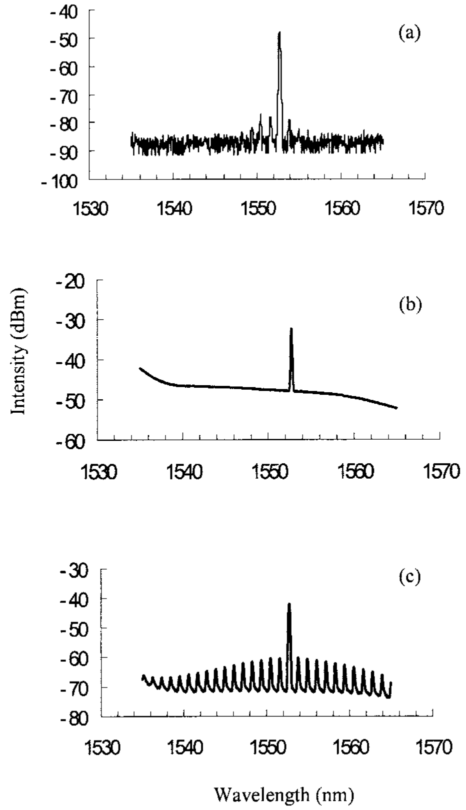

Fig. 3. Optical spectrum obtained at different stages of the pulse injection-seeding process: (a) at the tunable filter output, (b) at the EDFA output, (c) pulse injection-seeded output.

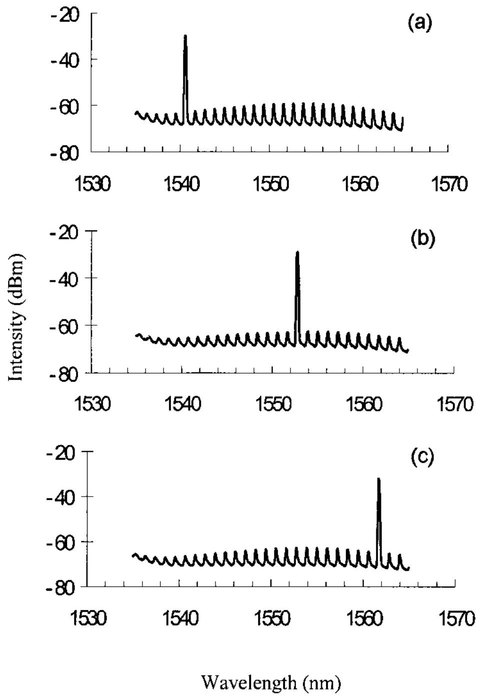

Fig. 4. Mutual pulse injection-seeded optical pulse spectra at wavelengths of (a) 1540.6 nm, (b) 1552.8 nm, (c) 1561.7 nm.

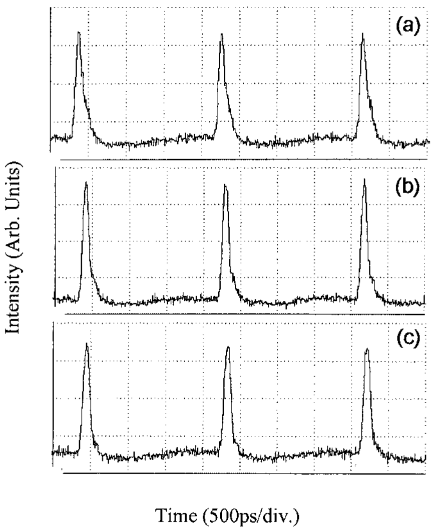

Fig. 5. Mutual pulse injection-seeded optical pulse trains at wavelengths of (a) 1540.6 nm, (b) 1552.8 nm, (c) 1561.7 nm.

tude noise on the optical pulses will be built up and result in a SMSR reduction. The SMSR plays an important role in the wavelength division multiplexed optical communication systems as a low value of SMSR (<25 dB) can cause substantial cross-channel interference and degrade overall system performance.[8]

The SMSR can be significantly improved by use of a mutual pulse injection-seeding scheme as shown in Fig. 1. In such a system, wavelength tuning can be achieved by simple adjustment of the tunable optical filter while maintaining a constant repetition frequency. The output spectra and the corresponding pulse trains are shown in Figs. 4 and 5. The peak wavelengths are located at 1540.6, 1552.8, and 1561.7 nm; the linewidth of the laser mode is approximately 0.2 nm. During the wavelength-tuning process, the optical delay lines could be slightly adjusted to maximize the SMSR. The full width at half-maximum value of the pulse width is approximately 120 ps.

The variation of the output SMSR at different peak wavelengths is demonstrated in Fig. 6. The wavelength range is between 1538 and 1563 nm. The SMSR is better than 26 dB within the whole 25-nm wavelength region and better than 31 dB between 1543.9 and 1561.7 nm, at approximately 18-nm wavelength range. The maximum value of the SMSR is

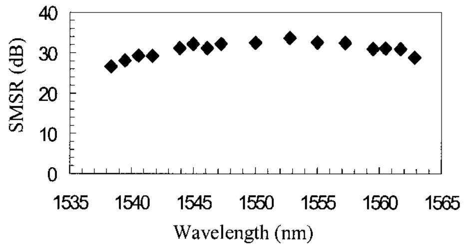

Fig. 6. Output SMSR at different peak wavelengths.

34 dB at a wavelength of 1552.8 nm. The SMSR is determined by the degree of overlap between the two gain-switched laser diode spectra and the gain width of the laser diodes and can be optimized by adjustment of the rf signal power, the pulse travel time between the two laser diodes, the polarization states of the pulse trains, and the EDFA gain.

4. Conclusion

In conclusion, a simple and efficient mutual pulse injection-seeding scheme for wavelength-tunable optical short-pulse generation has been demonstrated. We achieved wavelength tuning simply by adjusting the tunable optical filter while maintaining a constant repetition frequency. The SMSR of better than 31 dB over an 18-nm wavelength region and more than 26 dB within a 25-nm wavelength-tuning region has been achieved.

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References

1. L. P. Barry, R. F. O'Dowd, J. Debau, and R. Boittin, "Tunable transform-limited pulse generation using self-injection locking of an FP laser," IEEE Photon. Technol. Lett. **5,** 1132–1134 (1993).
2. D. Huhse, M. Schell, J. Kaessner, D. Bimberg, I. S. Tarasov, A. V. Gorbachov, and D. Z. Garbuzov, "Generation of electrically wavelength tunable ($\Delta\lambda = 40$ nm) singlemode laser pulses from a 1.3 μm Fabry–Perot laser by self-seeding in a fiber-optic configuration," Electron. Lett. **30,** 157–158 (1994).
3. D.-S. Seo, H.-F. Liu, D. Y. Kim, and D. D. Sampson, "Injection power and wavelength dependence of an external-seeded gain-switched Fabry–Perot laser," Appl. Phys. Lett. **67,** 1503–1505 (1995).
4. Y. Matsui, S. Kutsuzawa, S. Arahira, and Y. Ogawa, "Generation of wavelength tunable gain-switched pulses from FP MQW lasers with external injection seeding," IEEE Photon. Technol. Lett. **9,** 1087–1089 (1997).
5. M. Zhang, D. N. Wang, H. Li, W. Jin, and M. S. Demokan, "Tunable dual-wavelength picosecond pulse generation by the use of two Fabry–Perot laser diodes in an external injection seeding scheme," IEEE Photon. Technol. Lett. **14,** 92–94 (2002).
6. E. A. Chauchard, J. S. Wey, C. H. Lee, and G. Burdge, "Coherent pulsed injection seeding of two gain-switched semiconductor lasers," IEEE Photon. Technol. Lett. **3,** 1069–1071 (1991).
7. K. Chan and C. Shu, "Electrically wavelength-tunable pulses generated by synchronous two-way injection seeding," IEEE Photon. Technol. Lett. **11,** 170–172 (1999).
8. L. P. Barry and P. Anandarajah, "Cross-channel interference due to mode partition noise in WDM optical systems using self-seeded gain-switched pulse sources," IEEE Photon. Technol. Lett. **13,** 242–244 (2001).