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Mutual pulse injection-seeding scheme by the use of two Fabry–Pérot laser diodes for tunable dual-wavelength optical short-pulse generation

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Two Fabry–Pérot laser diodes, one being gain switched and the other dc biased, are used in a mutual pulse injection-seeding scheme for tunable dual-wavelength optical short-pulse generation. Wavelength selection and tuning are achieved by adjusting two fiber Bragg gratings and optical delay lines while a constant repetition frequency of 1.5053 GHz is maintained. An erbium-doped fiber amplifier is employed to enhance light intensity injected to the laser diode. The sidemode suppression ratio of the output pulses achieved is better than 25 dB over the wavelength-tuning range of 12.1 nm. The system is robust, flexible, and convenient for wavelength tuning. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1579846]

Multiwavelength optical short-pulse generation has been attractive for high-speed optical fiber communication systems and optical fiber sensor networks, as it supports a simultaneous wavelength-division-multiplexing and time-division-multiplexing operations. Among various kinds of techniques developed for multiwavelength optical short-pulse generation, injection seeding is simple and convenient. There are two types of injection-seeding schemes: Self-seeding and external injection seeding.[1–5] In self-seeding, a number of wavelength selective elements such as fiber Bragg gratings (FBGs) are incorporated into the laser external cavity to reflect part of the output back into the gain-switched Fabry–Pérot (F–P) laser diode cavity, and results in multiwavelength optical short pulse emission as long as the corresponding wavelength feedback arrives during the pulse build-up time. In order to enable a wavelength tunable operation, the repetition frequency of the electrical signal that drives the F–P laser diode and the optical path lengths corresponding to the selected wavelength elements need to be carefully adjusted, which may cause substantial inconvenience. On the contrary, in an external injection-seeding regime, the repetition frequency can essentially be selected arbitrarily and maintained as a constant, and the tunable multiwavelength operation is realized by simply adjusting the wavelength selective elements. An economic dc biased F–P laser diode can effectively be employed as the external injection-seeding source,[4] however, the sidemode suppression ratio (SMSR) achieved is still relatively low (<20 dB), or a number of continuous-wave tunable lasers have to be used, which in turn, substantially increase the system cost. As SMSR is one of the key factors to determine the usefulness of the optical short pulses in optical fiber communications, it is ultimately important to develop a more efficient system to produce tunable multiwavelength optical short pulses with a relatively high SMSR.[6]

In this letter, two F–P laser diodes, of which one is gain switched and the other is dc biased, are used to build up a mutual pulse injection-seeding system for dual-wavelength optical short-pulse generation. The multimode output from the gain-switched F–P laser diode is launched to the two FBGs connected in series and then directed to the dc biased F–P laser diode with enhanced power provided by an erbium-doped fiber amplifier (EDFA). The dual-wavelength optical pulses produced are then sent to the gain-switched F–P laser diode to establish a mutual pulse injection-seeding scheme. The system output has a SMSR of better than 25 dB over a wavelength-tuning range of 12.1 nm.

The experimental setup for dual-wavelength mutual pulse injection-seeding is shown in Fig. 1. Two economic 1.55 μm F–P laser diodes with mode spacing of about 1.1 nm are used. A constant high-frequency (1.5053 GHz) electrical signal with power of -18 dB m from a radio frequency signal generator (HP E4422B) is first amplified by a 28 dB m

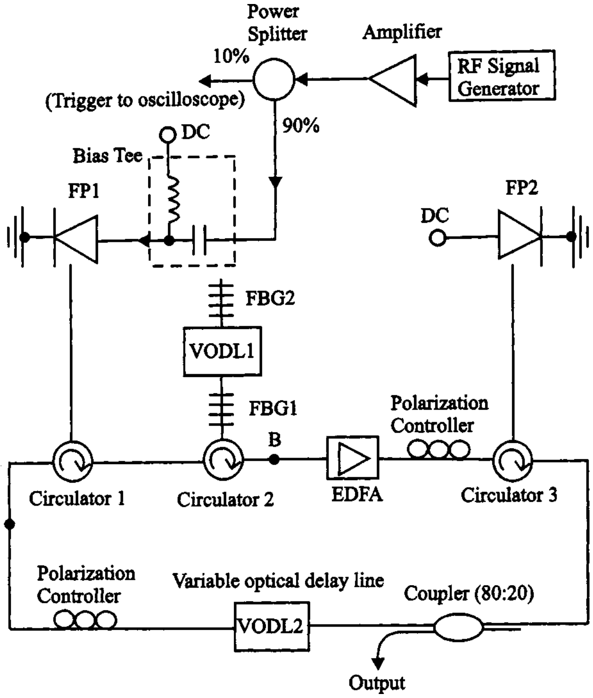

FIG. 1. Experimental setup for dual-wavelength mutual pulse injection-seeding scheme.

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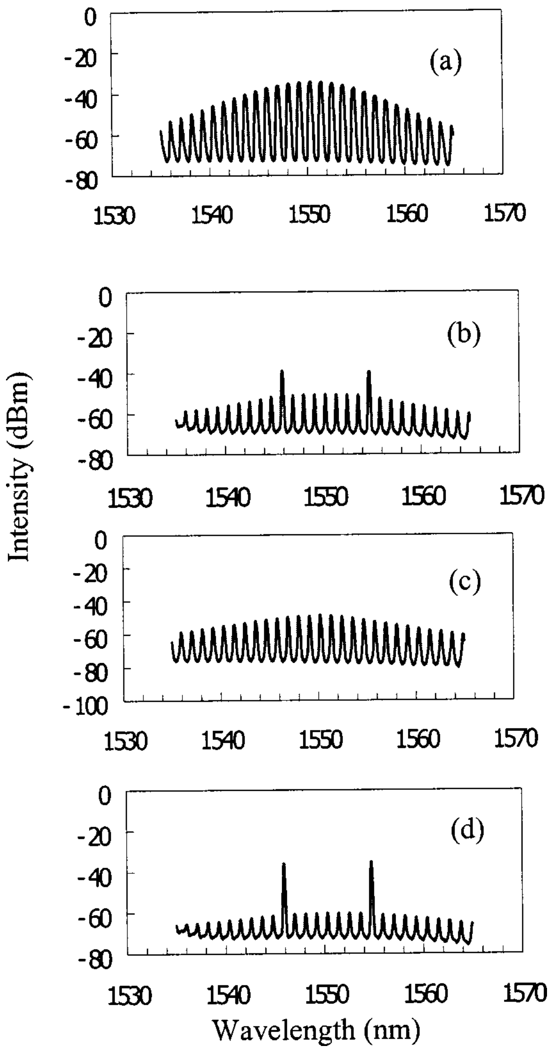

FIG. 2. (a) Output pulse spectrum of the gain-switched F–P laser diode, (b) dual-wavelength pulse spectrum reflected by the FBGs, (c) Output pulse spectrum of the dc biased F–P laser diode, and (d) Mutual pulse injection-seeded output spectrum.

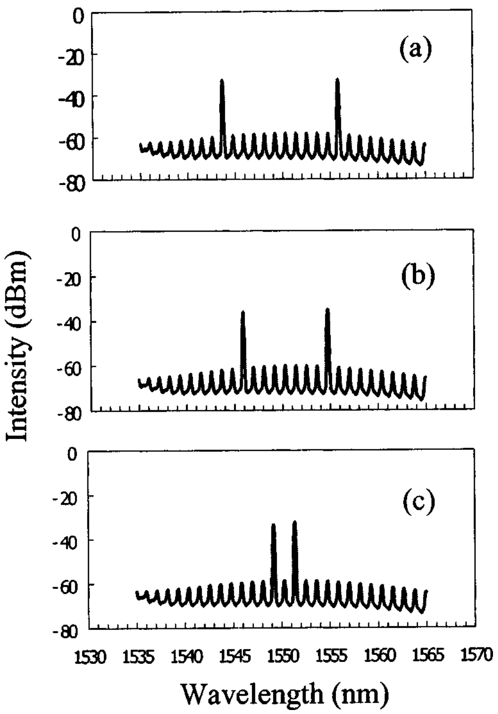

FIG. 3. Tunable dual-wavelength mutual pulse injection-seeded output spectrum: (a) At 1543.7 nm and 1555.8 nm, (b) at 1545.9 nm and 1554.8 nm, and (c) at 1549.2 nm and 1551.4 nm.

electrical power amplifier (Mini-Circuits ZHL-42W) and then divided into two parts, about 10% of the signal power is taken as the trigger to the digital sampling oscilloscope (Trektronics CAS 8003) and 90% of the signal power is used in conjunction with a dc bias current of 10 mA to drive the F–P laser diode, FP1, into a gain-switching operation via a bias-tee circuit. Initially, the multimode output from the gain–switched F–P laser diode is launched to the wavelength selection branch which consists of two FBGs connected in series via a variable optical delay line (VODL). The Bragg wavelengths of the two FBGs are 1555 nm and 1544 nm, respectively. The dual-wavelength optical pulses selected by the two FBGs, respectively, from the gain-switched F–P laser diode output are power intensified by the use of an EDFA and then directed to the 9 mA dc current biased F–P laser diode, FP2, through an optical circulator, resulting in a pulse injection-seeded dual-wavelength output. The mutual time delay of the dual-wavelength optical pulses is controlled by VODL1. The optical pulses produced at FP2 is subsequently sent to the gain-switched F–P laser diode, FP1, via VODL2. By carefully adjusting the two VODLs, the dual-wavelength optical pulses can be arranged to arrive at the gain-switched laser diode during the corresponding pulse emission time and, as a result, the gain-switched laser diode output also becomes dual-wavelength optical pulses. Thus, a mutual pulse injection-seeding scheme can be constructed for dual-wavelength optical short-pulse generation. Two polarization controllers are used in the system to control the polarization states of injection light into the laser diode in order to optimize the SMSR of the output pulses. An optical coupler (80:20) is used to branch out 20% of the system output for observing the wave forms and spectrums of the dual-wavelength optical pulse trains.

The process of establishing dual-wavelength optical short-pulses in the mutual pulse injection-seeding scheme can be investigated by initially disconnecting the optical loop at point A as shown in Fig. 1. The gain-switched laser diode output spectrum is demonstrated in Fig. 2(a), showing a multimode laser emission. After being reflected by the two FBGs, respectively, the dual-wavelength optical pulse spectrum obtained at point B is displayed in Fig. 2(b), where two relatively large intensity laser modes appear. The dc biased F–P laser diode spectrum is shown in Fig. 2(c). When the optical loop is connected, the stable output of the mutual pulse injection-seeding system is demonstrated in Fig. 2(d) where a dominant dual-wavelength pulse spectrum can be observed.

The dual wavelengths can be readily tuned by applying strains on two FBGs, respectively, in the mutual pulse injection-seeding scheme as shown in Fig. 3. The repetition frequency is maintained at 1.5053 GHz during the wavelength tuning. In Fig. 3(a), the dual wavelengths are located at 1543.7 nm and 1555.8 nm respectively, the wavelength separation is 12.1 nm. The wavelength separation becomes 7.7 nm in Fig. 3(b), where the two wavelengths are situated at 1545.9 nm and 1554.8 nm, respectively. In Fig. 3(c), the

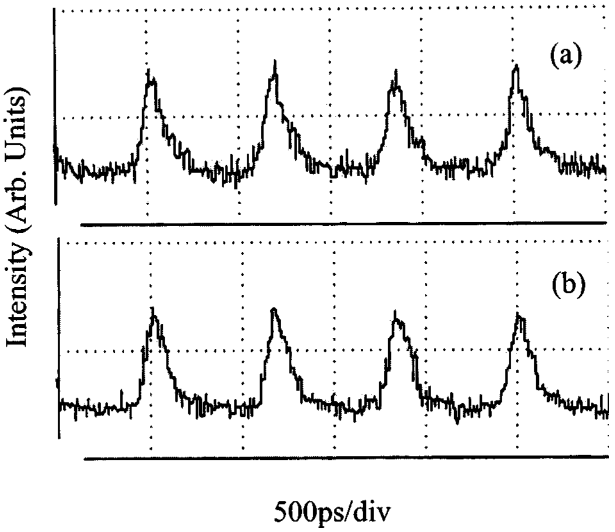

FIG. 4. Mutual pulse injection-seeded output pulse trains: (a) at wavelength 1545.9 nm and (b) at wavelength 1554.8 nm.

dual-wavelength separation is further reduced to 2.2 nm, around two laser mode spacing, and the peak wavelengths are situated at 1549.2 nm and 1551.4 nm, respectively.

The typical optical pulse wave forms corresponding to the two wavelengths displayed in Fig. 3(b) are shown in Fig. 4. The full width at half maximum value of the pulse width is around 150 ps. In order to optimize the SMSR of the system output, the VODLs may be slightly adjusted when tuning the wavelengths so that the output pulse from FP2 exactly coincides with the emission pulse at FP1.

Figure 5 shows the variation of SMSR with different wavelengths. The SMSR of higher than 22 dB is obtained within the wavelength range of 14.3 nm, corresponding to the two wavelengths of 1542.6 nm and 1556.9 nm. For the SMSR higher than 25 dB, the wavelength separation and tuning range that can be achieved is 12.1 nm, between the two wavelengths of 1543.7 nm and 1555.8 nm, respectively. The wavelength-tuning range is critically dependent on the gain spectrum of the F–P laser diodes and a broadband spectrum may lead to a wide tuning range. The value of SMSR depends on the overlap region between the two F–P laser diode spectrums, the gain width of the laser diodes and on the pulse propagation time between the two laser diodes, the polarization states of the pulse trains and the value of the EDFA gain. The fine adjustment of the wavelength overlap of the two F–P laser diodes can be performed by using temperature control of one of the laser diodes.

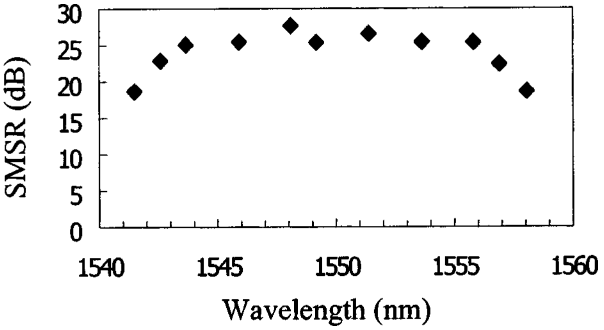

FIG. 5. SMSR of the output pulses obtained at individual wavelengths in the dual-wavelength operation.

EDFA plays an important role in establishing mutual pulse injection-seeded optical short-pulse trains as a large light intensity is required to induce optical short-pulse emission from a F–P laser diode at a selected wavelength and with a high SMSR. Although the cost and dimension of the system may also be increased, the use of EDFA can effectively support a large number of pulse wavelengths because of its wide gain bandwidth, which essentially represents a low cost alternative to tunable lasers in a multiwavelength optical short-pulse system.

In conclusion, tunable dual-wavelength optical short pulse generation has been achieved by the use of two F–P laser diodes of which one is gain switched and the other is dc biased in a mutual pulse injection-seeding system. A constant repetition frequency of 1.5053 GHz is maintained during the wavelength-tuning process. The SMSR of better than 25 dB over a wavelength-tuning range of 12.1 nm has been obtained. The system is robust, flexible, and convenient for wavelength tuning.

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