Continuous wavelength-tunable optical short-pulse generation by use of two Fabry–Perot laser diodes in a mutual injection-seeding scheme

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A simple system for producing continuous and widely wavelength-tunable optical short pulses in a mutual injection-seeding scheme is presented. The system exhibits a good side-mode suppression ratio of greater than 32.7 dB over a large wavelength tuning range of 33.8 nm. The system is easy to operate and convenient for continuous wavelength tuning. © 2005 Optical Society of America

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Generation of wavelength-tunable optical short pulses is of great interest for high-speed optical fiber communication and time-division-multiplexed gas sensor networks.[1] A commonly used light source for short-pulse generation is a Fabry–Perot laser diode (FPLD), which has a larger wavelength-tuning range than a distributed feedback laser and is more stable than a fiber ring laser and more economic than an external-cavity diode laser.[2–5] However, wavelength tuning of a FPLD is usually carried out in a discrete manner, and the smallest tuning step is limited by the mode spacing of the FPLD used. This creates a difficulty in optical communication and gas sensor applications because the laser mode needs to be tuned exactly to the International Telecommunication Union grid wavelength and the gas absorption wavelength, respectively. The usefulness of a FPLD also depends on the side-mode suppression ratio (SMSR) of the output pulses; a small SMSR of <25 dB can lead to severe interference noise. An efficient technique for short-pulse generation is mutual injection seeding of FPLDs, which produces a stable output at a high repetition frequency and exhibits a good SMSR.[6,7] In this Letter we present a simple mutual injection-seeding system for continuous and widely wavelength-tunable optical short-pulse generation. The system consists of two gain-switched FPLDs, an erbium-doped fiber amplifier (EDFA), a tunable optical filter (TOF), a circulator, a variable optical delay line (VODL), and an optical coupler. The output pulses have a SMSR of 32.7 dB across a wide wavelength range of 33.8 nm. The system can be operated at a constant repetition frequency and is thus convenient for wavelength tuning.

Our experimental setup is shown in Fig. 1. A rf electrical sinusoidal signal was amplified and then divided into two parts; 10% was used as the trigger of the oscilloscope, and 90% was equally divided to drive the two laser diodes into gain-switching operation through two bias-tee circuits. The dc bias currents for FPLDs FP1 and FP2 were ~ 11 and ~ 14 mA, respectively, which is close to their corresponding thresholds. The ac signal power received by the two diodes was ~ 15 dBm. The output of FP1 was first introduced to an EDFA with a gain of ~ 20 dB through a coupler for power amplification and then sent to the TOF for wavelength selection. The TOF had a bandwidth of 2.4 GHz and a free spectral range of 8860 GHz and was tuned by varying the driving voltage. The optical pulses with selected wavelengths were injected into FP2 through a circulator. By choosing an appropriate repetition frequency, we ensured that the pulse arrived at FP2 when a new pulse started to burst, thus producing an injection-seeded single-wavelength pulse. The pulses generated passed through the VODL before being injected into FP1 to stimulate a single-wavelength pulse emission at FP1. The stabilized output was taken from one of the coupler ports. Two polarization controllers (PCs) were individually adjusted to optimize the SMSR of the pulses. Because the mutual injection-seeding system had good stability, no readjustment of the PCs was needed when the output stayed at a particular wavelength. However, if the wavelength were shifted up to ~ 0.3 nm, readjustment would be necessary. Two isolators were used to ensure the pulse propagation direction and eliminate the light reflected from the TOF.[8] The spectra of the output pulses were demonstrated by use of an optical spectrum analyzer with 0.1-nm resolution, and their corresponding waveforms were observed on a high-speed optical sampling oscilloscope (Trektronics, CAS 8003) connected to a 25-GHz photodetector (New Focus 1414). The repetition frequency of the rf signal was ~ 2518.46 MHz, which was kept constant during the system operation.

The output spectra of the gain-switched FPLDs are shown in Fig. 2. The central wavelengths of FP1 and

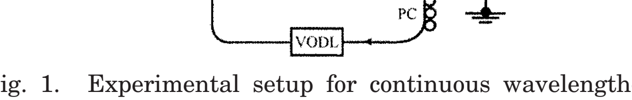

Fig. 1. Experimental setup for continuous wavelength-tunable optical short-pulse generation.

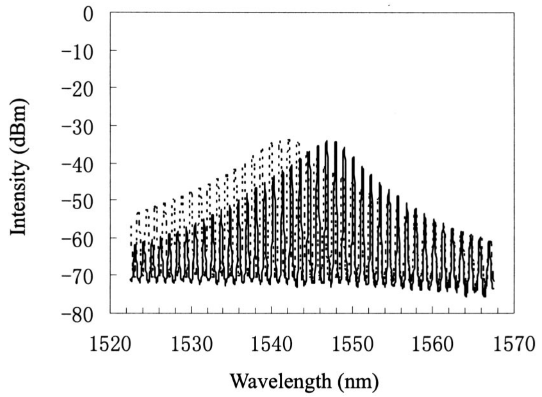

Fig. 2. Output spectra of two gain-switched FPLDs: solid curve, FP1; dashed curve, FP2.

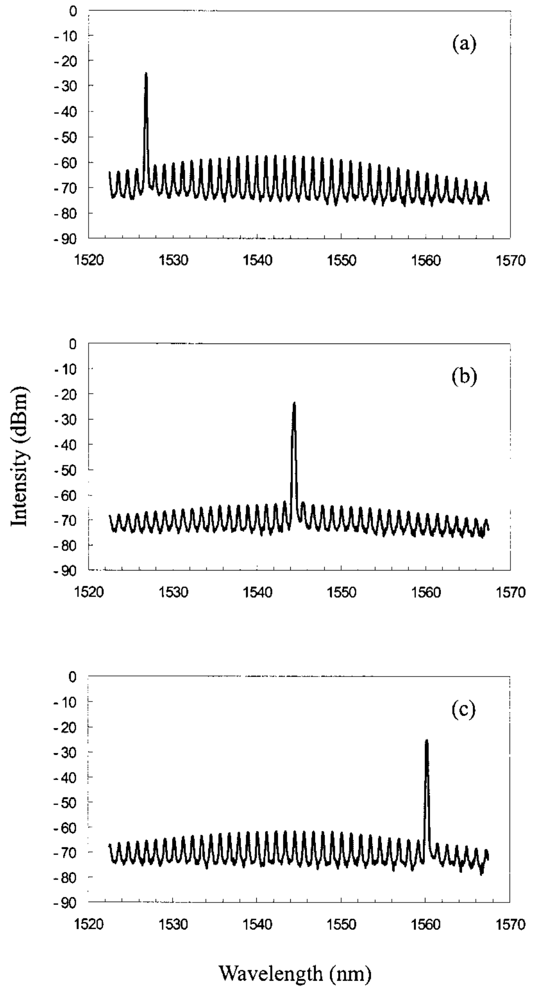

Fig. 3. Output pulse spectra for the laser modes at wavelengths of (a) 1526.8 nm, (b) 1544.4 nm, and (c) 1560.2 nm.

FP2 are ~1547 and ~1542 nm, respectively. The mode spacing is ~1.15 nm for both diodes. The output spectra corresponding to the laser modes, located at 1526.8, 1544.4, and 1560.2 nm, respectively, are displayed in Fig. 3. The SMSRs are ~36.0, 39.0, and 39.4 dB, respectively. When the wavelength is shifted away from the laser mode to 1527.2, 1544.9, and 1560.6 nm, respectively, a SMSR of 42.2, 33.4, and 39.9 dB, respectively, can be observed in Fig. 4. Good wavelength stability is maintained during system operation, which is due to the strong spectral seeding power obtained in the whole wavelength region as a result of using an EDFA.

The waveforms of the pulses corresponding to the spectra in Figs. 3(b) and 4(b) are displayed in Fig. 5. The FWHM values of the pulse widths are ~60 and ~45 ps. The observed waveforms are not detector limited since the rise time is 14 ps and the pulse width of the impulse response of the photodetector is 17 ps.

The continuous wavelength tuning capability of the system is demonstrated in Fig. 6. A tuning step of close to or less than 0.1 nm is used in a small wavelength range of ~0.9 nm, between 1543.6 and 1544.5 nm. The continuous wavelength tuning near the laser mode region is implemented by use of the

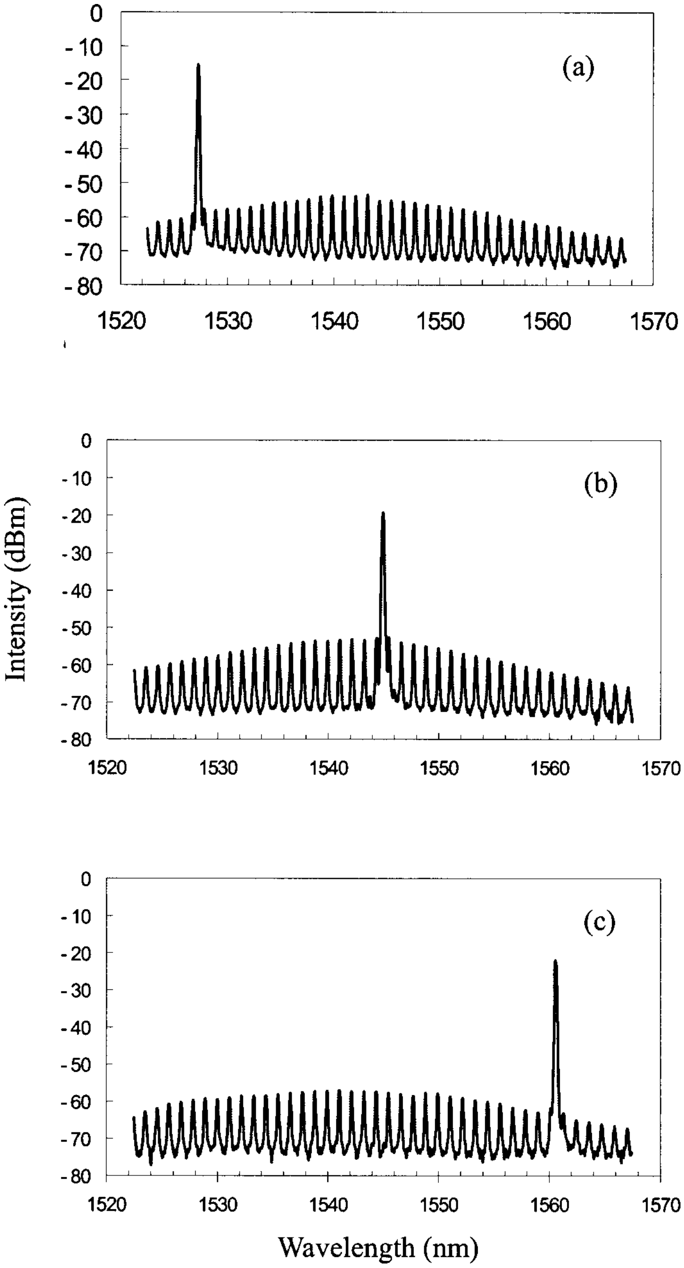

Fig. 4. Output pulse spectra for the wavelengths between two adjacent laser modes at wavelengths of (a) 1527.2 nm, (b) 1544.9 nm, and (c) 1560.6 nm.

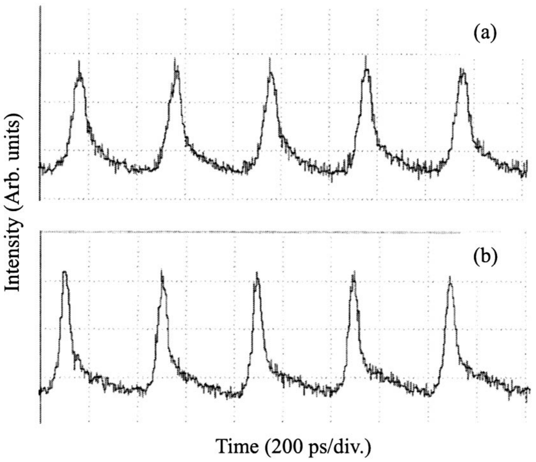

Fig. 5. Waveforms of the output optical pulse trains at wavelengths of (a) 1544.4 nm and (b) 1544.9 nm.

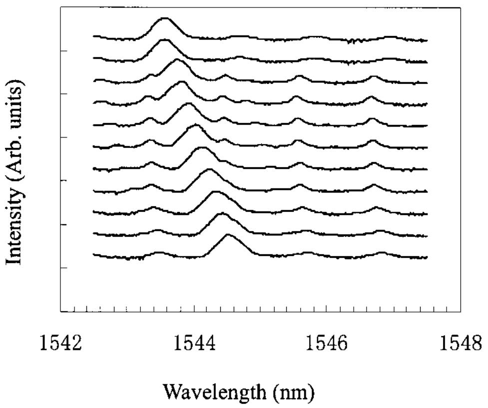

Fig. 6. Output spectra showing continuous wavelength tuning between 1548.9 and 1550.0 nm.

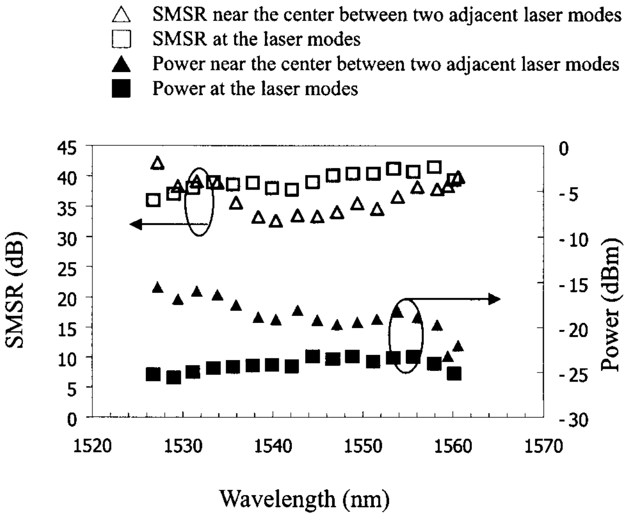

Fig. 7. SMSR and average power of optical pulses obtained at different wavelengths.

TOF only. For a wavelength shift of >0.2 nm a slight manual adjustment of the FP1 temperature is needed. The maximum wavelength shift induced by thermal control is approximately half a mode spacing.

The value of the SMSR and the average power of the output pulses obtained at different wavelengths are plotted in Fig. 7. At the laser modes the SMSR is slightly higher, but the average power is lower than that near the center of the two adjacent laser modes in most of the wavelength region. This is probably due to the phenomenon that the intensity of the reflected light from a Fabry–Perot etalon depends on the round-trip phase shift that the incident light experienced. At the mode wavelength the phase shift is a multiple of 2π, which corresponds to the minimum intensity of the reflected light.[9] Although the power level of a few microwatts obtained is adequate for gas sensor uses, it is not sufficient for applications in optical fiber communication that require at least several milliwatts. However, the output power can be readily enhanced to the milliwatt order by use of an EDFA at the system output branch.

When compared with the work reported in Ref. 7, the current system supports continuous wavelength tuning and has a simpler configuration with fewer VODLs and circulators used, which effectively minimizes the spectral loss at the selected wavelength. Moreover, the FPLDs are biased close to, instead of below, their threshold currents, which increases spectral power in a broad wavelength range. As a result, a slightly higher SMSR across a much wider wavelength region can be obtained. The FPLD-based mutual injection-seeding system also has a high potential for intracavity gas sensing by allowing a large number of passes through the gas cell before emitting stable output pulses, which may not be achieved by external-cavity laser diode operation.

We have demonstrated a simple mutual injection-seeding system for continuous and widely wavelength-tunable optical short-pulse generation. A SMSR of more than 32.7 dB was achieved across 33.8 nm, nearly twice the range obtained in Ref. 7, at a constant repetition frequency of 2518.46 MHz.

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