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Optics Communications 256 (2005) 73–77
OPTICS COMMUNICATIONS
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Utilizations of fiber Bragg gratings and Fabry–Perot lasers for fast wavelength switching technique

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Received 2 February 2005; received in revised form 15 June 2005; accepted 15 June 2005

Abstract

A novel tunable laser structure, based on Fabry–Perot lasers and fiber Bragg gratings with self-seeding operation, is proposed and experimentally investigated. The wavelength tuning can be obtained by properly adjusting the bias currents of FP lasers. The response time of wavelength switching of <6.8 ns, a 3.38 nm tuning range, and a side-mode suppression ratio of >23 dB have been achieved experimentally. This proposed tunable laser has the advantages of simple architecture, potentially low cost, data direct modulation and fast wavelength switching.

Keywords: Fabry–Perot; Optical switching; SMSR; WDM

1. Introduction

Wavelength-tunable lasers have been proposed to act as high-speed and wavelength selective light sources on wavelength division multiplexing (WDM) and optical switching systems. Especially, the fast tunable light sources can play a key role in the photonic switching networks. Recently, several researches for the fast tunable lasers have been reported, such as the rear sampled grating reflector (GCSR) laser with quasi-continuous grating assisted co-directional coupler [1,2], sample grating (SG) or super structure grating (SSG) distributed Bragg reflector (DBR) lasers [3–5]. All of these techniques employ the grating device to produce self-seeding for the wavelength tuning.

In this paper, we propose and demonstrate a new fast tunable technique based on the Fabry–Perot (FP) lasers and fiber Bragg gratings (FBGs) with optical self-seeding method. The performances of

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doi:10.1016/j.optcom.2005.06.035

side-mode suppression ratio (SMSR) and the response time for wavelength tuning have also been studied. Comparing with other wavelength switching techniques [1–5], this laser has the advantage of simple architecture, potentially low cost, data direct modulation and fast wavelength tuning, and is expected to benefit the applications of fast wavelength tuning.

2. Experiments

Fig. 1 shows the experimental setup of the proposed tunable laser. The FP lasers, LD-1 and LD-2, in the left side, which provide the multi-longitudinal-mode wavelength after passing through a 1 × 2 (3 dB) optical coupler (C) into the FBGs. Then, the FBGs will reflect a single-mode wavelength injecting into the LD-1 and LD-2. The reflected lightwave will inject into the FP laser to dominate the gain competition of a FP laser. The FP laser and FBG can be acted as the reflected mirrors of a laser. All the used FP lasers have the similar output spectra with 1.12 nm mode spacing and 20 dB bandwidth of 10 nm. Central wavelength of four FBGs is 1539.65, 1541.04, 1542.12, and 1542.94 nm, respectively. All FBGs have 3 dB bandwidth of 0.4 nm and ~ 98 % reflectivity. The optical spectrum of this tunable laser can be observed at position "a" in Fig. 1 by using an optical spectrum analyzer (OSA). To investigate wavelength tuning response time, the tunable laser output is converted into electrical domain by two O/E converters after passing through an erbium-doped fiber amplifier to compensate the device loss, a 1 × 2 optical coupler and two DWDM demultiplexers for wavelength filtering. By using a digital scope with 20-GHz bandwidth, the converted electrical signals can be measured and the response time for wavelength tuning can also be retrieved from the trace of the electrical signals. A function generator is used to provide the switching signal of LD-1 and the synchronous trigger signal into a digital scope.

3. Results and discussions

The wavelength of the proposed tunable laser can be tuned by controlling the bias currents of two FP lasers in Fig. 1. Different bias currents will produce various output spectra (gain medium) for FP lasers. Using the LD-1 and LD-2 and FBGs with self-seeding, different single-frequency spectra

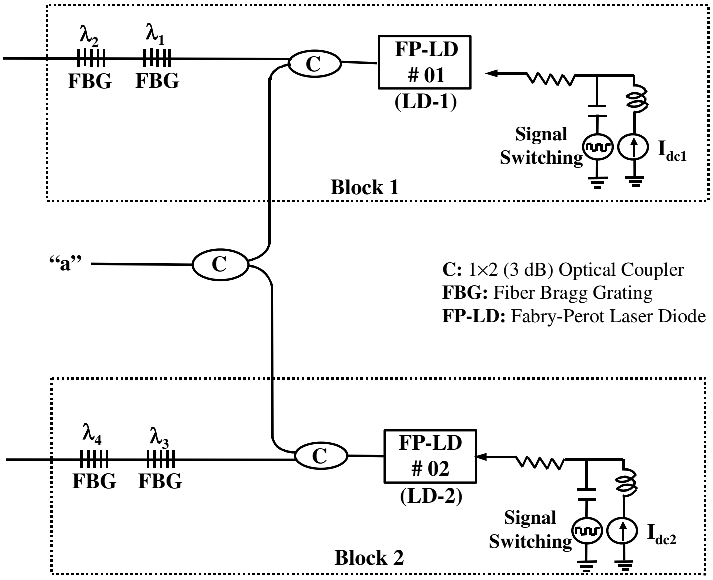

Fig. 1. Experimental setup of the proposed tunable laser for fast wavelength switching.

can be obtained. The operating current ranges of two LDs were all between 10 and 30 mA, respectively. Two LDs are all operated at 25 °C. Figs. 2(a) and (b) show the original wavelength spectra of LD-1 without self-seeding operation when $I_{\mathrm{dc1}} = 16$ and 25 mA, respectively. Figs. 3(a) and (b) also indicate the wavelength spectra of LD-2 without optical self-seeding operation when $I_{\mathrm{dc1}} = 18$ and 24 mA, respectively. When the proposed architecture is used, the wavelength can be selected at different operation conditions. Fig. 4 shows the optical spectra of the tunable laser for wavelengths operating from λ_1 to λ_4, which represents the optical wavelengths at 1539.78, 1540.92, 1542.04, and 1543.16 nm, respectively. The operation conditions of the FP lasers are $I_{\mathrm{dc1}} = 18$ mA and $I_{\mathrm{dc2}} = 0$ mA for λ_1; $I_{\mathrm{dc1}} = 24$ mA and $I_{\mathrm{dc2}} = 0$ mA for λ_2; $I_{\mathrm{dc1}} = 0$ mA and $I_{\mathrm{dc2}} = 16$ mA for λ_3; $I_{\mathrm{dc1}} = 0$ mA and $I_{\mathrm{dc2}} = 25$ mA for λ_4. The output powers for wavelengths from λ_1 to λ_4 are −8.2, −7.9, −8.9, and −8.1 dBm, and the power variation from λ_1 to λ_4 is less than 1 dB. From Fig. 4, the SMSR of >23 dB and the tunable range of 3.38 nm are achieved. The circuit model (or rate equations) for the Fabry–Perot laser has been reported [6,7]. When the bias current is increased, the output power increases and the central wavelength of FP laser shifts to the longer wavelength. Therefore, the single and tunable frequency output of this proposed laser depended on the photon competition to the FP laser with self-seeding. When only one longitudinal mode of the FP laser is supposed to fall on one of the pre-selected lasing wavelengths, the lasing spectrum of the FP laser requires external optical injection. When only one longitudinal mode of the FP laser is supposed to fall on one of the pre-selected lasing wavelengths,

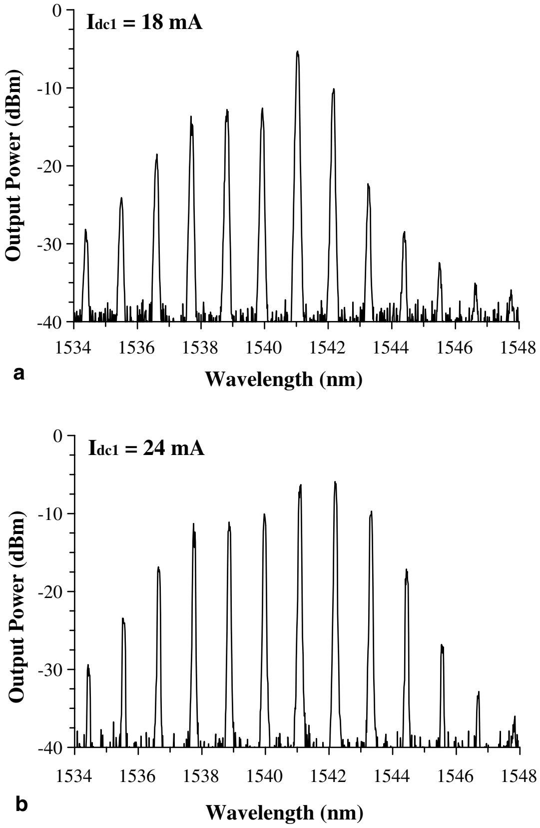

Fig. 2. The wavelength spectra of LD-1 without self-seeding operation when I_{dc1}: (a) 18 and (b) 24 mA.

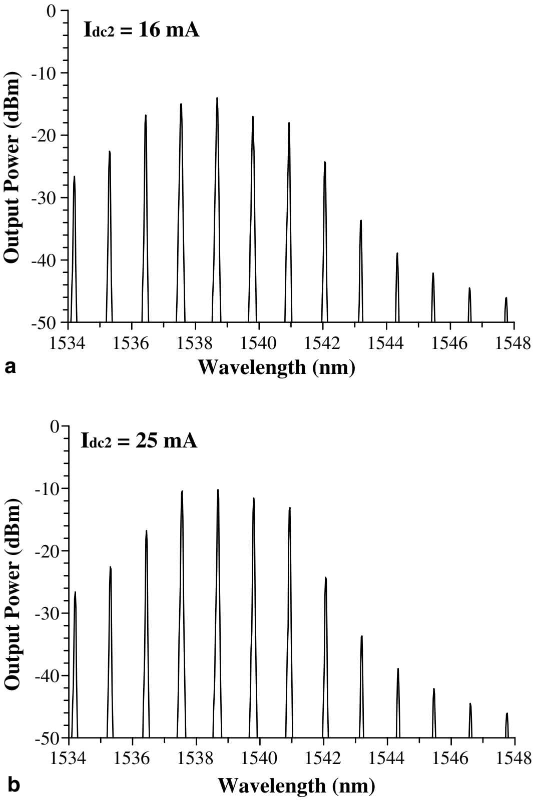

Fig. 3. The wavelength spectra of LD-2 without self-seeding operation when I_{dc1}: (a) 16 and (b) 25 mA.

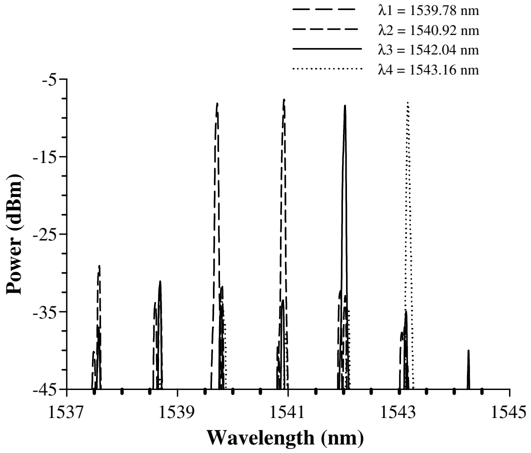

Fig. 4. Wavelength spectra of the tunable laser for wavelengths operating from λ_1 to λ_4, which represents the optical wavelengths at 1539.78, 1540.92, 1542.02, and 1543.16 nm, respectively.

the lasing spectrum of the FP laser requires external optical injection. For example, assume λ_1 and λ_2 are the designated wavelengths and the FBGs are manufactured accordingly. If the mode spacing Δv (or $m\Delta v$, m is an integer) of a FP laser accidentally equals $|\lambda_1 - \lambda_2|$, two modes will be injected back to the FP laser simultaneously and result in degraded SMSR or even emission at incorrect wavelength. If Δv (or $m\Delta v) = |\lambda_1 - \lambda_2|$, we need to adjust the mode spacing Δv by changing temperature. The central wavelength drift of the FP lasers used is nearly ±0.11 nm in our experiment when the temperature variation is adjusted at ±10 °C. To avoid the shortcoming, we can properly control the temperature of the two FP lasers for the accurate lasing wavelength selected.

The injection power needs to be large enough to dominate the optical amplification in the FP laser for single-frequency operation. Therefore, the lower power-level of injection lightwave will result in the SMSR degradation for this proposed tunable laser. However, too high injection light will not increase the SMSR due to the gain saturation of the FP lasers. The optical characteristic of FP laser and FBG, total cavity length and total losses of these components used will affect the SMSR and output power. However, the proposed laser has some drawbacks such as high cavity loss of 6 dB due to the two 3 dB couplers. The SMSR of the proposed laser is worse than that of commercial laser and fiber ring laser. Therefore, in the future we may need to reduce the cavity length and use the other properly component to replace the 3 dB coupler for enhancing the SMSR and output power of the proposed experimental setup.

The response time for wavelength tuning can be investigated by using the experimental setup shown in Fig. 1. To measure the response time for wavelength switching from λ_1 to λ_2, LD-1 is modulated by a negative pulse signal and operated at bias current of 18 and 24 mA for low and high levels. Due the bandwidth limitation of used signal generator, the applied pulse signal has a pulse width of 6.8 ns and a rising/falling time of 5 ns. As shown in Fig. 5, the effective response time of less than 6.8 ns is observed for wavelength switching from λ_1 to λ_2. In Fig. 5, it shows the switching time of <6.8 ns for the wavelength switching from λ_1 to λ_2 when the LD-1 turns on and the LD-2 off. While the LD-1 turns off and the LD-2 on, a response time of <6.8 ns for the wavelength switching from λ_3 to λ_4 is also observed in this experiment. When the control circuit of LD-1 and LD-2 is properly designed, the switching time of <6.8 ns for the wavelength switching from λ_1 to λ_3 or λ_4 can be retrieved in this experiment. As a result, the suitably gain competition of the FP laser by governing the bias current level will produce

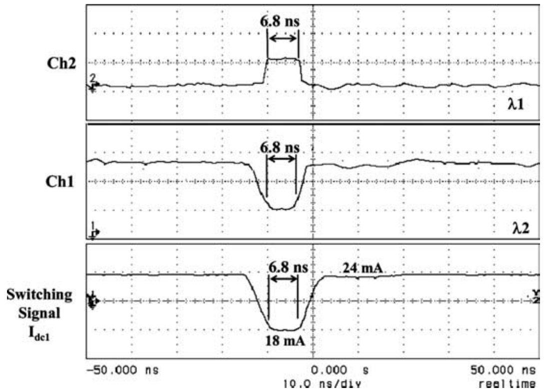

Fig. 5. Signal waveforms of channel 1 (λ_2) and channel 2 (λ_1) of the digital scope in Fig. 1 for wavelength tuning operation and the waveform of the wavelength switching signal.

the single-frequency operation with self-seeding. And the wavelength switching response time of <6.8 ns can be proofed by this proposed architecture. This proposed laser is manufactured by two Fabry–Perot lasers and accessories, four FBGs and three 1 × 2 couplers. Compared with the grating-based tunable laser techniques [1–5], our proposed configuration is simpler and cheaper than that of these methods.

4. Conclusion

In summary, a new tunable laser structure, which is based on FP lasers and FBGs with self-seeding technique, is proposed and experimentally demonstrated. The wavelength tuning can be obtained by adjusting the bias currents of FP lasers. The wavelength tuning time of <6.8 ns, 3.38 nm tuning range, and the SMSR of >23 dB have been achieved experimentally. This tunable laser has the advantages of simple architecture, potentially low cost, data direct modulation and fast wavelength tuning.

References

[1] Y. Fukashir., K. Shrikhande, M. Avenarius, M.S. Rogge, I.M. White, D. Wonglumsom, L.G. Kazovsky, in: Digest OFC'2000, vol. 2, pp. 338, 2000.

[2] Y. Gustafsson, S. Hammerfeldt, J. Hammersberg, M. Hassler, T. Horman, M. Isaksson, J. Karlsson, D.E. Larsson, O.D. Larsson, L. Lundqvist, T. Lundstrom, M. Rask, P.-J. Rigole, E. Runeland, A. Saavedra, G. Sarlet, R. Siljan, Electron. Lett. 39 (3) (2003) 292.

[3] I.A. Avrutsky, D.S. Ellis, A. Tager, H. Anis, J.M. Xu, IEEE J. Quantum Electron. 34 (4) (1998) 729.

[4] P.J. Rigole, S. Nilsson, L. Bäckbom, T. Klinga, J. Wallin, B. Stålnacke, E. Berglind, B. Stoltz, IEEE Photon. Technol. Lett. 7 (7) (1995) 697.

[5] V. Jayaraman, Z.-M. Chuang, L.A. Coldren, IEEE J. Quantum Electron. 29 (6) (1993) 1824.

[6] D.E. Dodds, M.J. Sieben, IEEE Photon. Technol. Lett. 7 (3) (1995) 254.

[7] P.J. Herre, U. Barabas, IEEE J. Quantum Electron. 25 (8) (1989) 1794.