Fast tunable laser based on Fabry-Perot lasers with optical injection

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Abstract. We have proposed and experimentally demonstrated a new tunable laser structure, which is based on Fabry-Perot (FP) lasers with external lightwave injection. The wavelength tuning can be obtained by adjusting the bias currents of FP lasers. The wavelength tuning time of <2 ns, 3.3-nm tuning range, and the side-mode suppression ratio (SMSR) of >19 dB have been achieved experimentally. In addition, the SMSR performance has also been investigated. This tunable 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. [DOI: 10.1117/1.1668281]

Subject terms: Fabry-Perot lasers; wavelength-tunable; optical switching.

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1 Introduction

Tunable lasers have been proposed to act as high-speed and wavelength selective light sources on wavelength division multiplexing (WDM) and optical switching systems. Fast tunable light sources can play a key role in photonic switching networks. Recently, several research findings for 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] and sample grating (SG) or super structure grating (SSG) distributed Bragg reflector (DBR) lasers.[3–5] In this paper, we have proposed and demonstrated a new fast tunable technique based on Fabry-Perot (FP) lasers with optical injection. The performances of side-mode suppression ratio (SMSR) and the response time for wavelength tuning have also been studied. Compared with other wavelength-tuning techniques,[1–5] this tunable 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

Figure 1 shows the experimental setup of the proposed tunable laser. The FP laser, LD-1, in the left side provides the optical injection to the FP lasers LD-2 and LD-3 in the right side. The lightwave from LD-1 passes through an optical circulator (OC) and is injected into LD-2 and LD-3 by a 1×2 optical coupler. All the FP lasers used have similar output spectra with 1.12-nm mode spacing and 20-dB bandwidth of 10 nm. The optical spectrum of this tunable laser can be observed at position "a" in Fig. 1 by using an optical spectrum analyzer (OSA). To measure the performance of the SMSR of this proposed laser, a variable optical attenuator (VOA) is placed in front of LD-1 to adjust various power levels of injection light. To investigate wavelength tuning response, the tunable laser output is converted into the electrical domain by two optic-to-electric (O/E) converters after passing through an erbium-doped fiber amplifier to compensate the device loss, and a 1×2 optical coupler and two dense wavelength-division multiplexing demultiplexers for wavelength filtering. The electrical signals are measured by a digital scope with 20-GHz bandwidth and the response time for wavelength tuning can also be observed.

3 Results and Disscussions

The wavelength of the proposed tunable laser can be tuned by controlling the bias currents of the FP lasers in Fig. 1. Different bias currents will produce various output spectra for FP lasers. By properly selecting bias current settings for the optical injection source (LD-1) and host sources (LD-2 and LD-3), different single-frequency spectra can be obtained. The operating current ranges of these LDs were all between 10 mA to 30 mA, respectively. The central wavelengths of these LDs were different and the tuning ranges were near 5 nm. Figures 2(a) and 2(b) show the original spectra of LD-1 without optical injection when $I_{dc1}=17$ and 23 mA, respectively. Figure 3(a) shows the optical spectra of the proposed tunable laser without optical injection. The operation condition of the FP lasers in Fig. 3(a) are $I_{dc1}=0$ mA, $I_{dc2}=17$ mA, and $I_{dc3}=0$ mA and $I_{dc1}=0$ mA, $I_{dc2}=0$ mA, and $I_{dc3}=14$ mA. The multi-mode spectra are observed when no external light is injected. When optical injection is added, this tunable laser can be operated in single-frequency mode. Figure 3(b) shows the optical spectra of the tunable laser for wavelengths operating from λ_1 to λ_4, which represents the optical wavelengths at 1537.64, 1538.63, 1539.74, and 1540.93 nm, respectively. The operation conditions of the FP lasers are $I_{dc1}=17$ mA, $I_{dc2}=0$ mA, and $I_{dc3}=14$ mA, for λ_1; $I_{dc1}=17$ mA, $I_{dc2}=17$ mA, and $I_{dc3}=0$ mA for λ_2; $I_{dc1}=23$ mA, $I_{dc2}=0$ mA, and $I_{dc3}=14$ mA for λ_3; $I_{dc1}=23$ mA, $I_{dc2}=17$ mA, and $I_{dc3}=0$ mA for λ_4. The output

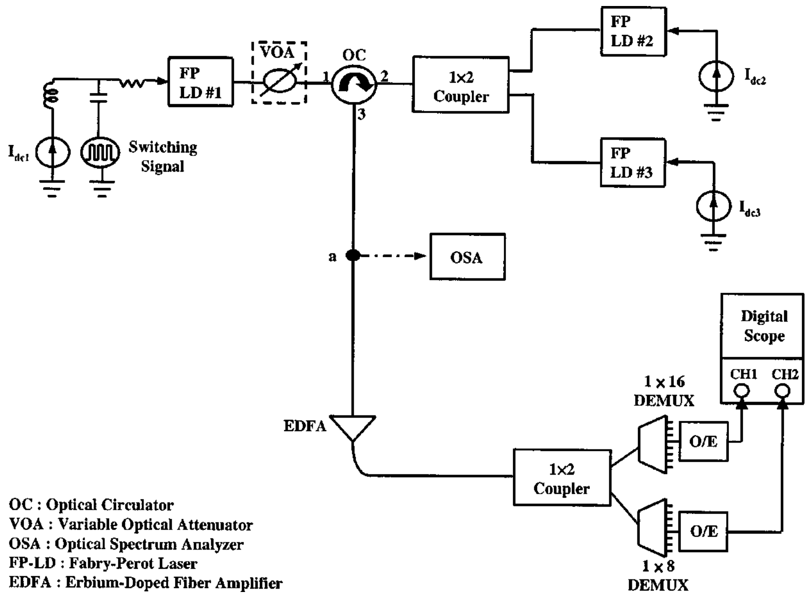


Fig. 1 Experimental setup of the proposed tunable laser.

powers for wavelengths from λ_1 to λ_4 are -11.9, -12.3, -12.8, and -12.4 dBm, and the power variation from λ_1 to λ_4 is less than 0.9 dB. From Fig. 3(b), the SMSR of >19 dB and the tunable range of 3.3 nm are achieved. The circuit model (or rate equations)[6,7] for the Fabry-Perot laser has been reported. When the bias current is increased, the output power increases and the central wavelength of the 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 optical injection.

To investigate the SMSR performance, the SMSR versus different power level of optical injection are measured as shown in Fig. 4. The injected power needs to be large enough to dominate the optical amplification in the host FP laser for single-frequency operation. Therefore, the lower power level of injection lightwave will result in SMSR degradation for this proposed tunable laser. However, too high a level of injection light will not increase the SMSR due to the gain saturation of host FP lasers. Besides, it should be noted that the minimal injection powers of -13.5 dBm are needed to keep the SMSR$>$19 dB from Fig. 4. During three hours of observation, the variation of output light was less than 0.1 dB for this proposed laser.

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_2 to λ_4, LD-1 is modulated by a negative pulse signal and operated at bias current of 17 mA and 23 mA for low and high levels. Due to the bandwidth limitation of the signal generator used, the applied pulse signal has pulse width of 6.8 ns and rising/falling time of 5 ns. As shown in Fig. 5, the effective response time of less than 2 ns is observed for wavelength switching from λ_2 to λ_4.

4 Conculsion

In summary, a new tunable laser structure, which is based on FP lasers with external lightwave injection, has been

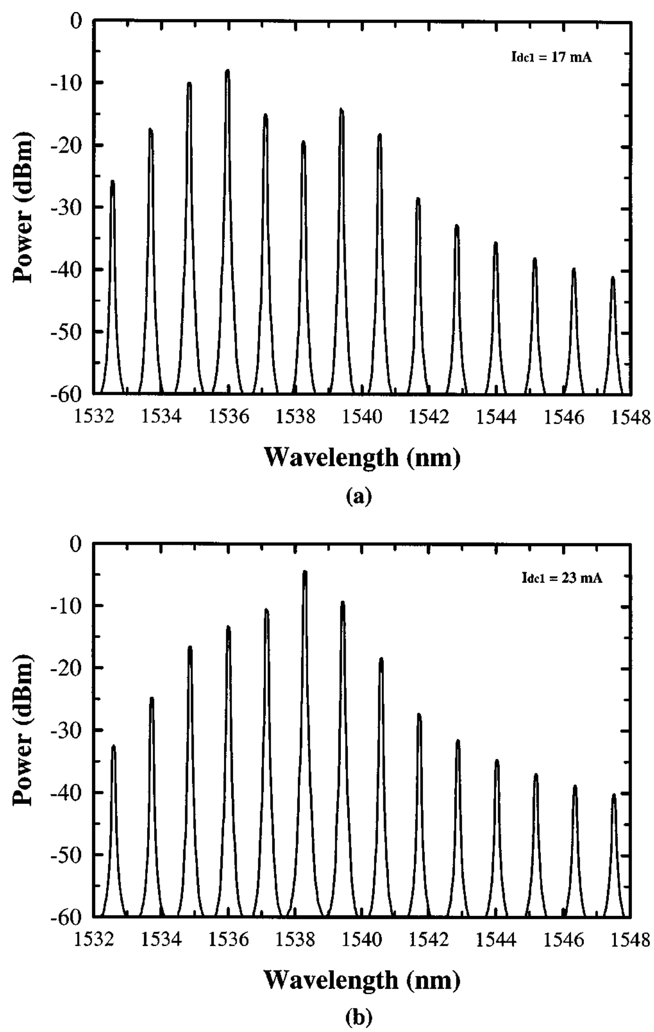
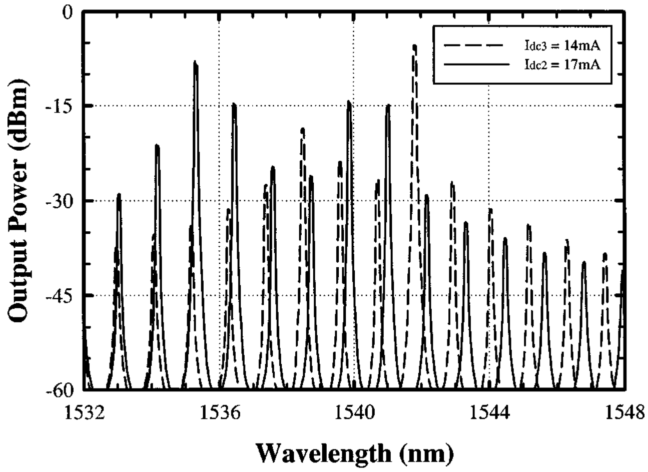
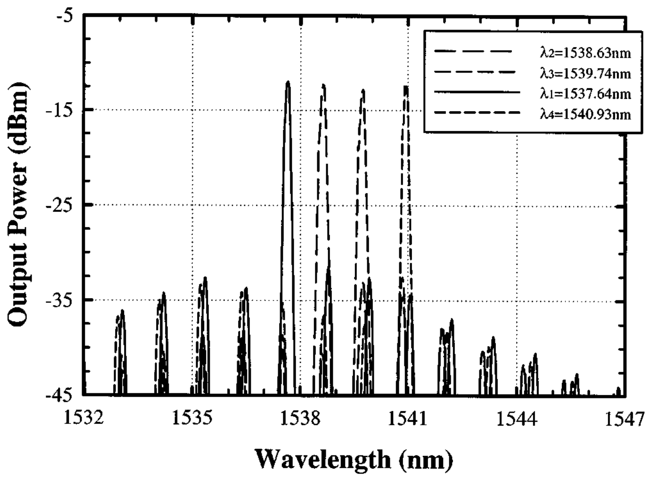


Fig. 2 Original spectra of LD-1 without optical injection when $I_{dc1}=17$ and 23 mA, respectively.



(a)



(b)

Fig. 3 (a) The optical spectra of the proposed tunable laser without optical injection, while the operation condition of the FP lasers are $I_{dc1}=0$ mA, $I_{dc2}=17$ mA, and $I_{dc3}=0$ mA and $I_{dc1}=0$ mA, $I_{dc2}=0$ mA, and $I_{dc3}=14$ mA. (b) The optical spectra of the tunable laser for wavelengths operating from λ_1 to λ_4, which represents the optical wavelengths at 1537.64, 1538.63, 1539.74, and 1540.93 nm, respectively.

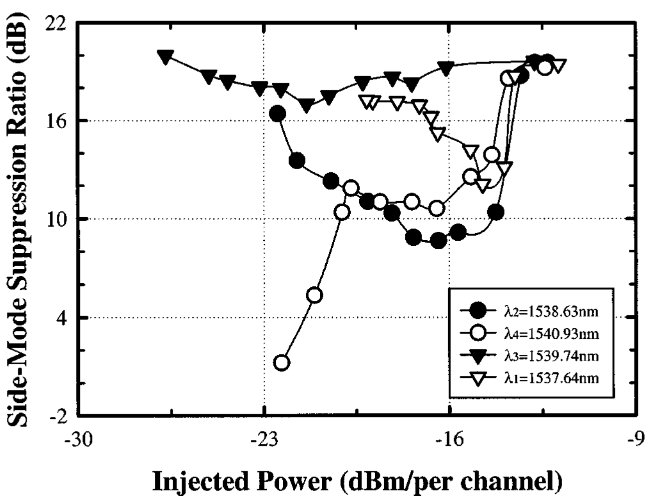


Fig. 4 SMSR versus different power level of optical injection of the proposed laser.

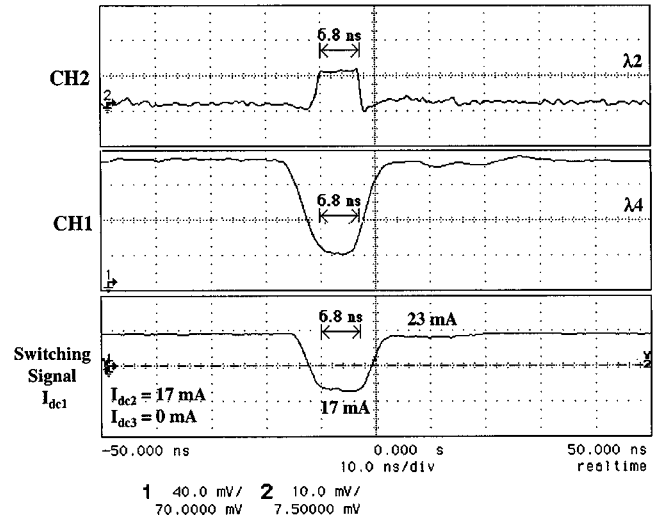


Fig. 5 The signal waveforms of channel 1 (λ_2) and channel 2 (λ_4) of the digital scope in Fig. 1 for wavelength tuning operation and the waveform of the wavelength switching signal.

proposed and experimentally demonstrated. The wavelength tuning can be obtained by adjusting the bias currents of FP lasers. The wavelength tuning time of <2 ns, the 3.3-nm tuning range, and the SMSR of >19 dB have been achieved experimentally. In addition, the SMSR performance has also been investigated. This tunable laser has the advantages of simple architecture, potentially low cost, data direct modulation, and fast wavelength tuning, and is expected to benefit the applications of fast wavelength tuning.

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References

1. Y. Fukashir, K. Shrikhande, M. Avenarius, M. S. Rogge, I. M. White, D. Wonglumsom, and L. G. Kazovsky, ‘‘Fast and fine wavelength tuning of a GCSR laser using a digitally controlled driver,’’ in *Digest OFC 2000* **2**, 338–348 (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, ‘‘Record output power (25 mW) across C-band from widely tunable GCSR lasers without additional SOA,’’ *Electron. Lett.* **39**(3), 292–293 (2003).
3. I. A. Avrutsky, D. S. Ellis, A. Tager, H. Anis, and J. M. Xu, ‘‘Design of widely tunable semiconductor lasers and the concept of binary superimposed gratings (BSGs),’’ *IEEE J. Quantum Electron.* **34**(4), 729–741 (1998).
4. P. J. Rigole, S. Nilsson, L. Bäckbom, T. Klinga, J. Wallin, B. Stålnacke, E. Berglind, and B. Stoltz, ‘‘114-nm wavelength tuning range of a vertical grating assisted codirectional coupler laser with a super structure grating distributed Bragg reflector,’’ *IEEE Photonics Technol. Lett.* **7**(7), 697–699 (1995).
5. V. Jayaraman, Z.-M. Chuang, and L. A. Coldren, ‘‘Theory, design, and performance of extended tuning range semiconductor lasers with sampled gratings,’’ *IEEE J. Quantum Electron.* **29**(6), 1824–1834 (1993).
6. D. E. Dodds and M. J. Sieben, ‘‘Fabry-Perot laser diode modeling,’’ *IEEE Photonics Technol. Lett.* **7**(3), 254–256 (1995).
7. P. J. Herre and U. Barabas, ‘‘Mode switching of Fabry-Perot laser diode,’’ *IEEE J. Quantum Electron.* **25**(8), 1794–1799 (1989).

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