Fast Wavelength-Tunable Laser Technique Based on a Fabry–Pérot Laser Pair With Optical Interinjection

Chien-Hung Yeh, Chien-Chung Lee, Yaw-Wen Hsu, and Sien Chi

***Abstract*—A new fast tunable laser technique, which is based on a Fabry–Pérot (FP) laser pair with optical interinjection, has been proposed and experimentally demonstrated. By adjusting different bias currents of FP lasers, the wavelength tuning can be realized. In the experimental demonstration, a 2.3-nm tuning range with three different wavelengths, the sidemode suppression ratio (SMSR) of >20 dB, and the wavelength switching time of <6.8 ns have been reached. In addition, the SMSR performance versus injection power level has also been investigated. This tunable laser has the advantage of simple architecture, data direct modulation, and fast wavelength tuning.**

***Index Terms*—Fabry–Pérot (FP) laser, optical switching, wavelength-tunable.**

I. INTRODUCTION

WAVELENGTH-TUNABLE lasers are important devices for 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 new tunable lasers have been demonstrated, such as the rear-sampled grating reflector (GCSR) laser with a grating-assisted codirectional coupler [1], [2], sample grating or super structure grating (SSG) distributed Bragg reflector (DBR) lasers [3]–[5], and high-speed electroabsorption SSG-DBR lasers [6]. All of these studies use the grating technique to produce self-seeding for tuning the lasing wavelength. In this letter, we have proposed and demonstrated a new configuration, which is based on a Fabry–Pérot (FP) laser pair with an optical interinjection technique, to obtain fast wavelength tuning for single-frequency output. The characteristics of sidemode suppression ratio (SMSR) and response time for wavelength switching have also been investigated. Compared with other wavelength-tuning techniques [1]–[7], this proposed laser has the advantage of simple architecture, data direct modulation ability, and fast wavelength tuning.

II. EXPERIMENT

The proposed and experimental setup for the fast tunable laser is shown in Fig. 1. The FP laser (LD-1) at the left-hand side, which can provide different spectral tilt and power by controlling bias currents, and the FP laser (LD-2) at the right-hand side both act as the interinjection light sources. A multiband filter,

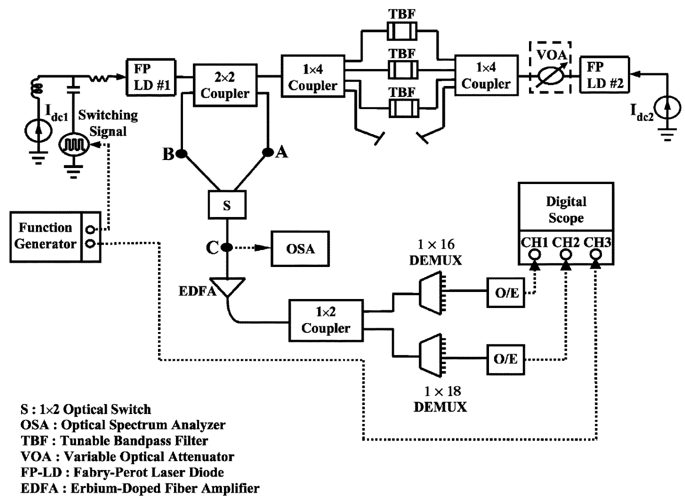

Fig. 1. Proposed and experimental setup for the fast tunable laser.

which is composed of a 2 × 2 coupler, two 1 × 4 couplers, and three tunable bandpass filters (TBFs), is placed between LD-1 and LD-2, and can increase wavelength selectivity. Both LD-1 and LD-2 have similar characteristics, such as longitudinal mode wavelengths located at 1541.21 (λ_1), 1542.34 (λ_2), and 1543.50 nm (λ_3), mode spacing of 1.12 nm, and 20-dB bandwidth of 10 nm. The TBFs, which have a 3-dB bandwidth of 0.8 nm and central wavelengths located from λ_1 to λ_3, are used to enhance the wavelength selectivity and reject unwanted light. When keeping LD-2 at a constant current and increasing the spectral tilt of LD-1 by adding bias current, lasing wavelength of this tunable laser can be switched from short wavelength to long wavelength. Optical output of this proposed fast laser can be selected at the "A" or "B" port by using a 1 × 2 optical switch, and the optical spectra can be observed at the "C" position by employing an optical spectrum analyzer, as seen in Fig. 1. To measure the performance of SMSR, a variable optical attenuator is placed in front of LD-2 to adjust the power-level injected into LD-1. To investigate response time for wavelength switching, the tunable laser output is converted into the electrical domain by two optical-to-electrical converters after passing through an erbium-doped fiber amplifier for compensating the losses of devices, a 1 × 2 optical coupler, and two dense WDM demultiplexers for λ_1 to λ_3 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.

Manuscript received July 17, 2003; revised October 24, 2003.
The authors are with the Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan 30050, R.O.C. (e-mail: depew.eo89g@nctu.edu.tw).
Digital Object Identifier 10.1109/LPT.2004.823770

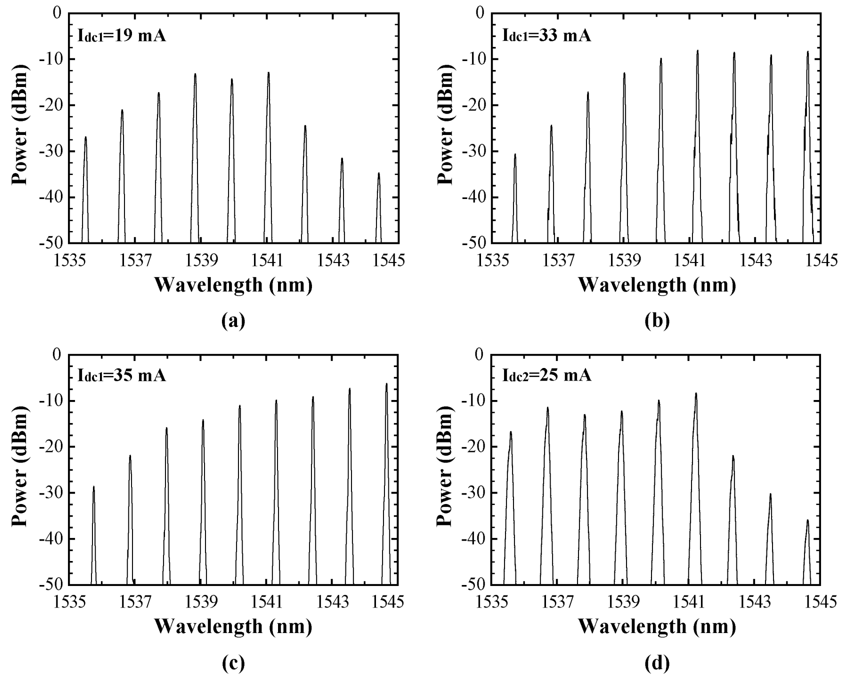

Fig. 2. Optical spectra of two FP lasers at different bias current operations without optical interinjection. (a), (b), and (c) are LD-1, (d) is LD-2.

III. Result and Discussion

Fig. 2 shows the output spectra of LD-1 and LD-2 at different bias currents without optical interinjection. Due to all the products from the same manufacturer, thereby, the similarly matched spectra of two FP lasers can be simply achieved. When bias current of LD-1 is increased from 19 to 35 mA, the spectral tilt from 1541 to 1545 nm will be increased as shown in Fig. 2(a)–(c). Fig. 2(d) indicates the output spectrum of LD-2 with bias current of 25 mA. The circuit model (or rate equations) [8], [9] for the FP laser has been reported. It is realizable that when the bias current added and then the output power increased simultaneously, the behavior is easily observed by the theoretical analysis. Identically, when the bias current added, the central wavelength of FP laser would shift to a longer wavelength. Therefore, the spectral tilt could be increased by the behaviors. After putting LD-1 and LD-2 into the configuration in Fig. 1, a single-frequency output with wavelengths ranging from λ_1 to λ_3 can be achieved, as shown in Fig. 3. The outputs at "A" and "B" ports have the same optical spectra. The operating conditions of two FP lasers are $I_{\mathrm{dc1}} = 19$ mA and $I_{\mathrm{dc2}} = 25$ mA for λ_1, $I_{\mathrm{dc1}} = 33$ mA and $I_{\mathrm{dc2}} = 25$ mA for λ_2, and $I_{\mathrm{dc1}} = 35$ mA and $I_{\mathrm{dc2}} = 25$ mA for λ_3. The output power levels from λ_1 to λ_3 are -8.68, -7.85, and -8.21 dBm, and the power variation from λ_1 to λ_3 is less than 0.9 dB. Two FP lasers are kept at 23 °C for our configuration. When the temperature increases, the wavelength would slightly shift to a longer wavelength. However, the wavelength variation is less than 0.2 nm while the temperature variation is less than 5 °C for the experimental FP lasers. Therefore, when the different bias currents of two FP lasers are used, the SMSR of this proposed laser would be still maintained by adjusting the temperature properly.

To investigate the SMSR performance, the SMSR versus the different injecting power from LD-2 are measured at the "A" port, as indicated in Fig. 4. The injecting power needs to be large enough to dominate the optical amplification inside LD-1 for single-frequency operation. The lower power-level of injection light from LD-2 will lead to the SMSR degradation for this tunable laser. However, too high injecting power will not increase the SMSR due to the gain saturation of the FP laser. Besides, it is noted that the minimal injection power should keep larger than -8 dBm to maintain the SMSR better than 20 dB for lasing wavelength from λ_1 to λ_3.

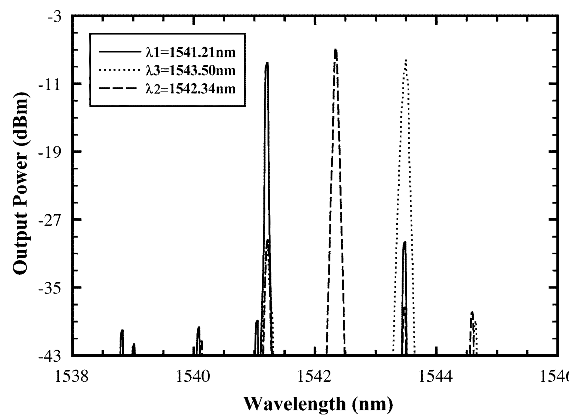

Fig. 3. Optical spectra of the tunable laser for lasing wavelengths λ_1, λ_2, and λ_3, where $\lambda_1 = 1541.21$ nm, $\lambda_2 = 1542.34$ nm, and $\lambda_3 = 1543.50$ nm, respectively.

To measure the response time for lasing wavelength switching from λ_1 to λ_3, the LD-1 is operated at a bias current of 19 mA and modulated by a pulse signal. As a result, LD-1 will be operated at driving currents of 19 and 35 mA for low and high levels. The definition of switching time was according to the 90% interval of rising–falling time for the electrical domain. Due to the bandwidth limitation of the signal generator used, the applied pulse signal has a minimal pulsewidth of 6.8 ns and rising–falling time of 2.5 ns. As shown in Fig. 5(a),

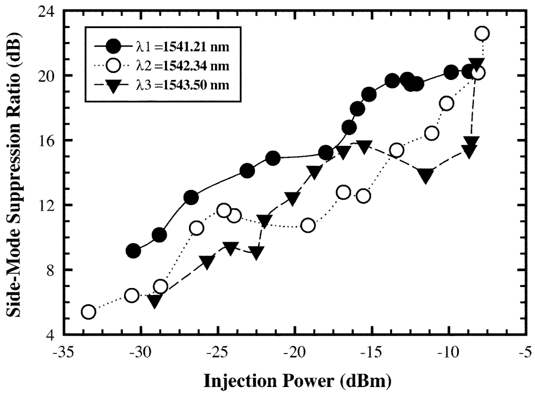

Fig. 4. SMSR versus the different power level of optical interinjection.

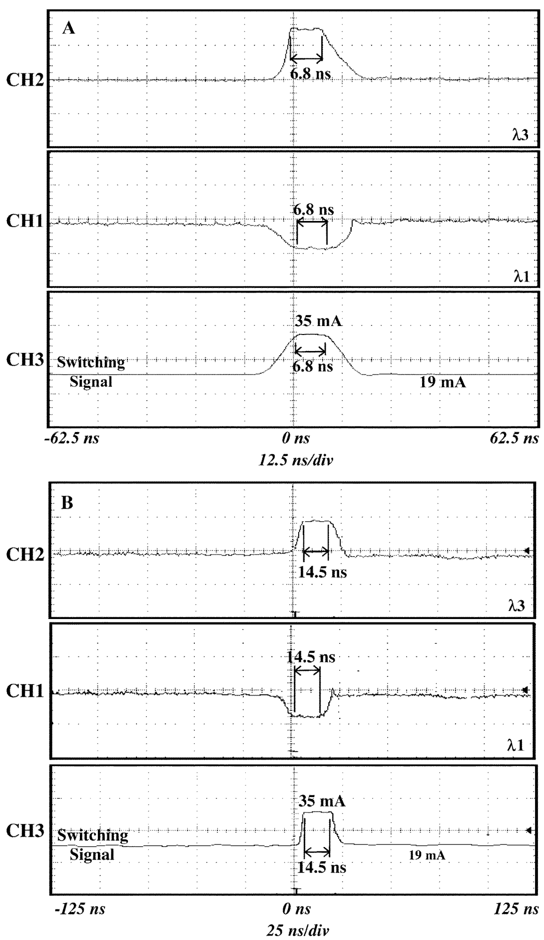

Fig. 5. Signal waveforms of Channel 1 (λ_1) and Channel 2 (λ_3) of the digital scope for wavelength switching operation and the waveform of the wavelength switching signal at the (a) "A" and (b) "B" ports in Fig. 1, respectively.

the wavelength switching interval of 6.8 ns is observed for wavelength switching from λ_1 to λ_3 at the "A" port. However, for the "B" port output, the lasing wavelength switching cannot be observed under the same applied pulse signal. This is because the response time for the "B" port was greater than that of the "A" port. Furthermore, the properly applied pulsewidth is extended to 14.5 ns (the rising–falling time of 2.5 ns) in order to retrieve wavelength switching for the "B" port, as indicated in Fig. 5(b). The applied pulsewidth is extended to 14.5 ns in order to retrieve wavelength switching for the "B" port, as indicated in Fig. 5(b). The outputs from the "A" port and "B" port indicate the light from LD-1 and LD-2, respectively. The cavity length possibly causes the different response times at the "A" and "B" ports.

For an industrial application, this proposed laser configuration would be integrated. The integrated device, which provides TBF preliminary suppression, could reduce the cavity length and insertion loss, and increase the output power. Therefore, the wavelength switching of this device could reach subnanoseconds. For the larger tuning capability, to use FP lasers with slightly different free spectral ranges, and tuning with the Vernier effect is very possible. This can be achieved by using temperature control for each of FP lasers.

IV. Conclusion

We have proposed and experimentally demonstrated a new fast tunable laser technique, which is based on FP lasers with optical interinjection. By adjusting different bias currents of FP lasers, the wavelength tuning can be realized. In the experimental demonstration, a 2.3-nm tuning range with three different wavelengths, the SMSR of >20 dB and the wavelength switching time of <6.8 ns have been reached. In addition, the SMSR performance versus injection power level has also been investigated. This tunable laser has the advantage of simple architecture, potentially low cost, data direct modulation, and fast wavelength tuning, and it is expected to benefit the applications of fast wavelength tuning.

Acknowledgment

The authors would like to thank H. Y. Sung for help with the experiments.

References

[1] P. J. Rigole, S. Nilson, L. Backbom, B. Stalnacke, T. Klinga, E. Berling, B. Stoltz, D. J. Blumenthal, and M. Shell, "Wavelength converage over 67 nm with GCSR laser. Tuning characteristics and switching speed," in *Int. Semiconductor Laser Conf. (ISLC'96)*, 1996, pp. 125–126.

[2] 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 *Dig. Optical Fiber Communications (OFC 2000)*, vol. 2, 2000, pp. 338–348.

[3] 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.*, vol. 29, pp. 1824–1834, June 1993.

[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 Photon. Technol. Lett.*, vol. 7, pp. 697–699, July 1995.

[5] H. Ishii, H. Tanobe, F. Kano, Y. Tohmori, Y. Kondo, and Y. Yoshikuni, "Broad-range wavelength converage (62.4 nm) with superstructure-grating DBR laser," *Electron. Lett.*, vol. 32, pp. 454–455, 1996.

[6] G. Alibert, F. Delorme, P. Boulet, J. Landreau, and H. Nakajima, "Subnanosecond tunable laser using a single electroabsorption tuning super structure grating," *IEEE Photon. Technol. Lett.*, vol. 9, pp. 895–897, July 1997.

[7] A. Mooradian, J. P. Donnelly, C. S. Harder, and K. Iga, "Introduction to the issue on semiconductor laser," *IEEE J. Select. Topics Quantum Electron.*, vol. 7, pp. 93–95, Mar./Apr. 2001.

[8] D. E. Dodds and M. J. Sieben, "Fabry–Pérot laser diode modeling," *IEEE Photon. Technol. Lett.*, vol. 7, pp. 254–256, Mar. 1995.

[9] P. J. Herre and U. Barabas, "Mode switching of Fabry–Pérot laser diode," *IEEE J. Quantum Electron.*, vol. 25, pp. 1794–1799, Aug. 1989.