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A wavelength converting and switching method based on Fabry–Perot laser diodes

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Abstract

We propose and experimentally demonstrate a new wavelength converting and switching technique, which is based on a Fabry–Perot laser diode (FP-LD) pair with optical external injection method. Therefore, adjusting properly bias current levels of FP-LDs can be realized the optical conversion and tuning. For the experimental demonstration, three different wavelengths [side-mode suppression ratios (SMSRs) are above 20 dB] are converted and the wavelength switching response time is less than 6.8 ns.

Keywords: Wavelength converting; Fabry–Perot laser; Optical switching

1. Introduction

Wavelength converting and switching techniques are necessary optical devices for wavelength-division-multiplexing (WDM) systems and optical switching applications. Especially, wavelength converters may be important components in future WDM networks because they improve network management and internetworking between networks [1,2]. Wavelength converters with reconfigurable functionality may enable WDM networks to have improved operation flexibility over WDM networks employing wavelength converters without such functionality. Amongst several wavelength conversion techniques, all optical wavelength conversion based on semiconductor optical amplifiers (SOAs) are promising because they can be operated at high speed with high-conversion range [1,3,4]. Moreover, various

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methods for all-optical wavelength conversion have been investigated up to now, including nonlinear optical gating based on fiber loop, cross-gain modulation, cross-phase modulation, four-wave mixing techniques using semiconductor optical amplifiers [5,6], using absorption modulation of an injection-locked Fabry–Perot laser diode [7], and difference frequency generation in quasi-phase-matched waveguides [8]. One of the major goals of the current research is to develop simpler cost-effective wavelength converters that can operate at submilliwatt input powers and, thus, avoid the need of an additional amplifier stage [7,9].

Recently, several fast wavelength tuning studies have also been reported, such as the sample grating (SG) or super structure grating (SSG) distributed Bragg reflector (DBR) lasers, grating assisted co-directional coupler with rear sampled grating reflector (GCSR) laser, and high speed electro-absorption-SSG-DBR lasers [10–13]. All of these techniques employ the fiber grating device to produce self-seeding for the wavelength tuning. In this paper, we have proposed and demonstrated a new technique for wavelength converting and fast wavelength tuning simultaneously. This proposed technique, based on optical external-injection method, is constructed by two Fabry–Perot laser diodes (FP-LDs), which act as host and optical injection sources, respectively. Then, we can obtain the wavelength converting by controlling the bias current levels of FP-LD. The behaviors of the response time for wavelength switching have also been investigated. Compared with other wavelength converting and tuning techniques [3–13], this proposed configuration has the advantages of simple architecture, potential low cost, wavelength conversion, direct modulation ability, wavelength conversion, and fast wavelength tuning. In future, this experimental architecture would be integrated on a package to reduce the cavity length and enhance the stability of optical output.

2. Operation principles and experimental setup

Fig. 1 shows the proposed and experimental setup for the wavelength converting and switching. The Fabry–Perot laser, LD-1, which can provide different spectral tilt and power by controlling bias currents, acts as injection light source. The output of LD-1 is transmitted through an optical circulator (OC), a multi-band filter that is composed by two 1×4 couplers and three tunable bandpass filters (TBFs), and is launched into LD-2. Both LD-1 and LD-2 have similar longitudinal multimode wavelengths with mode spacing of around 1.12 nm and 20 dB bandwidth of 10 nm. The LDs can be directly modulated at 1 GHz. The TBFs have 3-dB bandwidth of 0.8 nm and central wavelengths located at 1540.90, 1542.04 and 1543.20 nm, respectively. However, these filters are used to enhance the wavelength selectivity and reject unwanted light wave for tuning or converting wavelength. The optical spectrum of this

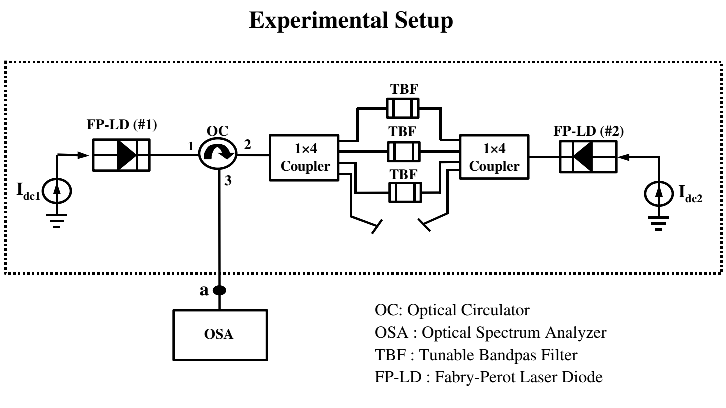

Fig. 1. The proposed and experimental setup for wavelength converting and tuning.

tunable laser can be observed at the "a" point by using an optical spectrum analyzer (OAS), as shown in Fig. 1. Simultaneously, to investigate wavelength tuning response time, the wavelength output of the proposed configuration is converted into electrical domain by two O/E (optical-to-electrical) converters after passing through an erbium-doped fiber amplifier for compensating the losses of devices, a 1×2 and 50:50 optical coupler and two DWDM demultiplexers for wavelength filtering. Two DWDM demultiplexers have 3 dB bandwidth of 0.4 nm. The electrical signals are measured by a digital scope with 20 GHz bandwidth and the response time for wavelength switching can also be retrieved from the traces of the electrical signals.

3. Results and discussions

The output spectra of LD-1 for different bias currents ($I_{dc1} = 20, 22$, and 25 mA) are shown in Fig. 2. When the bias current of LD-1 are increased from 20 to 25 mA, the spectral spectra will be increased across the wavelength range from 1539.78 to 1542.08 nm. To demonstrate the feasibility of the proposed structure for wavelength converting (or tuning), the spectra of the proposed tunable laser for different operation conditions of LD-1 and LD-2 are observed by OSA. The multi-mode spectrum in Fig. 3 is observed when no externally light is injected (operation conduction: $I_{dc1} = 0$ mA and $I_{dc2} = 25$ mA). Both Fabry–Perot resonance wavelengths and the mode separation are strongly dependent on cavity length, injection current, material refractive indices, and external injection lightwave. In general, the controllability for getting the specific wavelength is low. However, we can obtain the signal-frequency output by the proposed structure employing the optical external injection method with a Fabry–Perot laser pair. When external lightwave (from LD-1) injected is added, this output wavelength can be converted and tuned in single-frequency operation at different current levels. By this proposed method, we can easily to obtain a single-frequency (λ_1) output while the bias currents of two FP-LDs operated at $I_{dc1} = 20$ mA and $I_{dc2} = 25$ mA, as seen in Fig. 4. And Fig. 4 shows

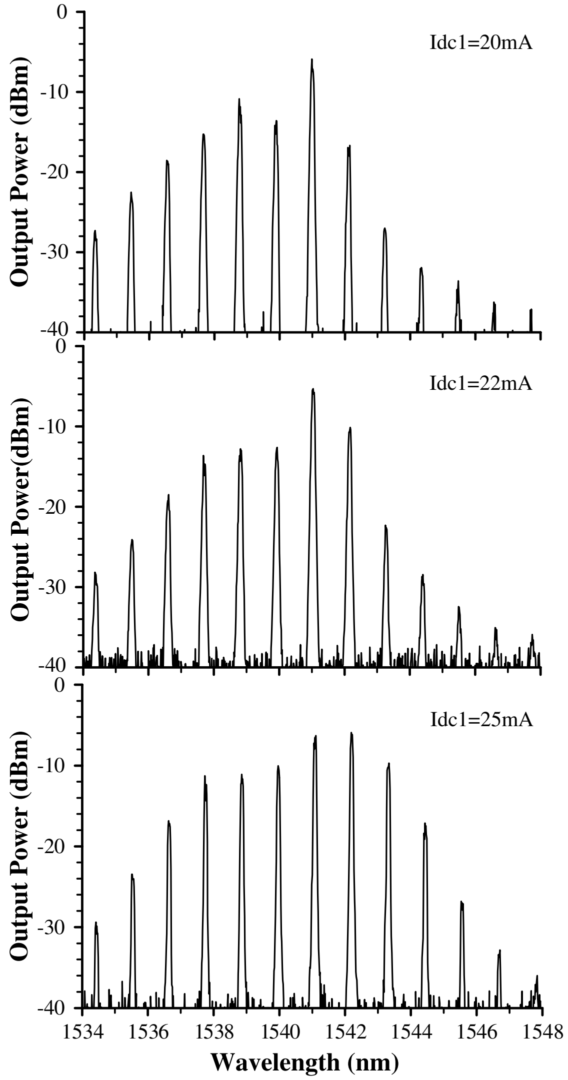

Fig. 2. The output spectra of LD-1 for different bias currents when bias current of LD-1 are 20, 22 and 25 mA, then the spectral spectra will be increased from 1539.78 to 1542.08 nm.

the optical spectra of the proposed scheme for the wavelength converting and tuning from λ_1 to λ_2 or λ_1 to λ_3, respectively.

The circuit model (or rate equations) for the FP-LD has been reported [14,15]. 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

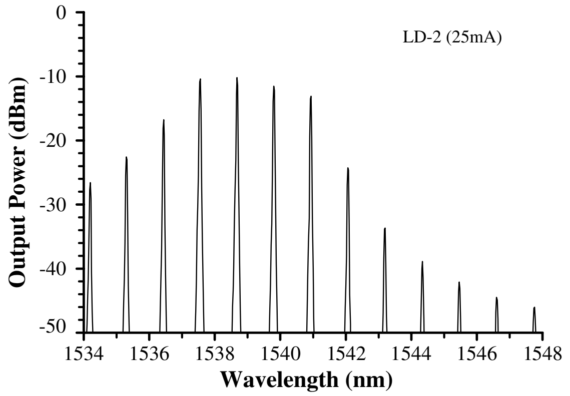

Fig. 3. The multi-mode spectrum of the proposed laser when no externally light is injected ($I_{dc1} = 0$ mA and $I_{dc2} = 23$ mA).

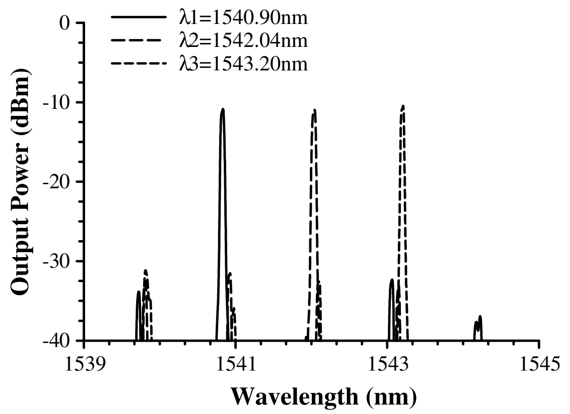

Fig. 4. The output wavelength spectra of the proposed structure at 1539.78, 1540.92 and 1542.08 nm, respectively.

wavelength of FP-LD would shift to a longer wavelength. In this proposed configuration, we use external injection method to retrieve the single-frequency output by properly adjusting bias current level of two LDs. When various operated current level of two LDs applied, the output wavelength could be converted and tuned. The wavelengths λ_1, λ_2 and λ_3 represent 1540.90, 1542.04 and 1543.20 nm, respectively. The operation conditions of the FP lasers are $I_{dc1} = 20$ mA and $I_{dc2} = 25$ mA for λ_1; $I_{dc1} = 22$ mA and $I_{dc2} = 25$ mA for λ_2; $I_{dc1} = 25$ mA and $I_{dc2} = 25$ mA for λ_3. In other words, the output wavelength also can be converted or tuned from λ_2 to λ_1 or λ_2 to λ_3, and λ_3 to λ_1 or λ_3 to λ_2, respectively. If we do not use these TBFs, the proposed structure is not easy to obtain the single-frequency output with three-wavelength switching. When these TBFs are not used in the proposed configuration, we just retrieve two-wavelength tuning. Therefore, these filters are used to enhance the wavelength selectivity and reject unwanted light wave for tuning or converting wavelength.

Wavelength conversion and tuning is achieved by controlling the various bias current level of LD-1. The output powers from λ_1 to λ_3 are -10.9, -10.5 and -10.6 dBm, respectively, and the power variation from λ_1 to λ_3 is less than 0.3 dB. From experimental result (in Fig. 4), the side-mode suppression ratio (SMSR) of output wavelengths is larger than 20 dB. The injected power (external injection lightwave from LD-1) needs to be large enough to dominate the optical amplification in the host FP-LD (LD-2) 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. As a result, three different wavelengths can be converted in the proposed configuration by adjusting properly bias current levels of two FP-LDs.

The proposed technique also can regard as fast wavelength switching technique. Therefore, the response time for wavelength switching can be observed by using the experimental setup shown in Fig. 1. To measure the response time for wavelength switching from λ_1 to λ_3, the LD-1 is modulated by a negative pulse signal and operated at bias current of 20 and 25 mA for low and high levels. The definition of switching time was based on the 90% interval of rising/falling time for the electrical domain. Due to the bandwidth limitation of used signal generator, 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 6.8 ns is observed for wavelength switching from λ_1 to λ_3.

Comparisons of the references mentioned [7,9], the post-related reports use a DFB laser as an external injection light and an external modulator

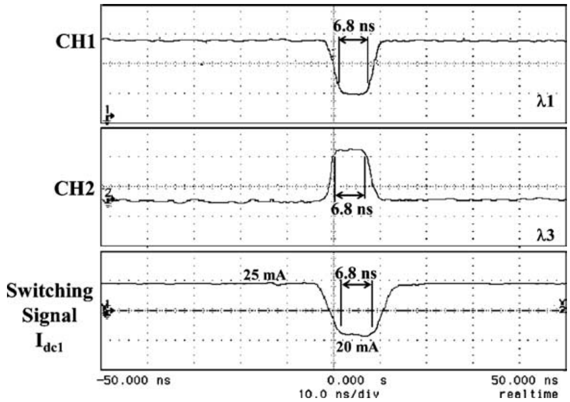

Fig. 5. The signal waveforms of channel 1 (λ_1) and channel 2 (λ_3) of the digital scope in Fig. 1 for wavelength tuning operation, and the waveform of the wavelength switching signal. The LD-1 is modulated by a negative pulse signal and operated at bias current of 20 and 25 mA for low and high levels.

for the lightwave modulation. In our experiment, we employ a FP-LD as the external injection and directly modulate the FP-LD (without any external modulator). Therefore, the proposed experiment has simply architecture, direct modulation ability, and lower cost for the wavelength converting and switching.

This experimental setup also can remove the optical circulator, and the output port (observation point) is placed at the right or left coupler. This reconstructive structure would become an inter-injection method. This setup also can obtain three wavelength converting or tuning and the switching time is as the same as above experiments results when the observed output at the right or left coupler. If the cavity length can be reduced, the switching time would be less than nanosecond due to the modulation characteristics of FP-LD.

4. Conclusion

A new wavelength conversion technique, based on two FP-LDs with optical external-injection, has been experimentally demonstrated. By adjusting properly bias current levels of two FP-LDs, the wavelength converting and tuning can be realized. In the experimental demonstration, three different wavelengths selecting, the SMSR of 20 dB and the wavelength switching time of <6.8 ns have been reached. This proposed technique has the advantage of simple architecture, potentially low cost, wavelength conversion, data direct modulation and fast wavelength tuning. Therefore, it is expected to benefit the applications of wavelength converting and fast wavelength tuning in WDM systems.

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