Wideband digitally tunable lasers based on fiber Bragg grating external cavity array and 1×N optical switch

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A novel wideband digitally tunable laser based on fiber Bragg grating external cavities and $1 \times N$ optical switch provides 5 ms fast tuning time with output power more than 1 dBm over whole C-band that is only limited by the laser emission bandwidth. Less than 50 pm wavelength drift over -10 to 55°C temperature range make that the wavelength locker and monitor are not necessary in this tunable laser.

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Widely tunable semiconductor lasers are emerging as critical components for dense wavelength division multiplexing (DWDM). These devices are an increasingly important feature of new and proposed all-optical networks with the promise of supporting flexible wavelength-routing capabilities. Tunable lasers have been under developed for over a decade. There are many different approaches to make tunable lasers. The main basic structures are distributed feedback (DFB)[1], distributed Bragg reflector (DBR), sample-grating DBR (SG-DBR)[2], vertical cavity surface emitting laser (VCSEL)[3] and external cavity lasers (ECL)[4]. All those structures have their own advantages and disadvantages, such as wavelength stability, intricate fabrication process, complicate control and drive electronics in DFB, SG-DBR lasers, and the size and cost of assembly in ECLs. In this paper, a novel tunable laser with fiber Bragg grating (FBG) external cavity array and $1 \times N$ optical switches is proposed. This tunable laser can easily achieve tens of different wavelengths by tuning the $1 \times N$ optical switches and the wavelengths can be accurately preselected to fit ITU wavelength grids for WDM applications by choosing the Bragg wavelengths of FBGs.

The wavelength tunable laser mainly comprises of three parts (see Fig. 1). The first one is semiconductor laser chip with a collimator lens. The laser chip is a conventional Fabry-Perot laser with a broadband emission spectrum. The front facet of the laser chip is HR coated and the rear facet is AR coated. The front facet is coupled with a fiber for output. The second part is a $1 \times N$ optical switch, which tunes the laser wavelength by feed back light from different FBGs. The third part is a fiber Bragg grating array. The FBG is wavelength selective device, which will only reflect a specific wavelength light back to the laser chip to form a laser resonant cavity. Each FBG in the FBG array has different Bragg wavelength. While changing the state of the optical switch, the laser beam will be directed to different FBGs and the output light will have the exact same wavelength as the Bragg wavelength of the FBG.

An F-P chip with a gain peak around 1550 nm and 3 dB bandwidth of 50 nm (as shown in Fig. 2(b)) is used in the tunable laser. The rear facet is antireflection coated with ZrO_2 layers to yield a reflectivity below 10^{-4}, and the front facet of the laser chip is HR coated. The emission spectrum before AR and HR coating is shown in Fig. 2(a), and after AR and HR coating is shown in Fig. 2(b), and it can be seen that the intra-modes were suppressed greatly. The front facet is coupled with a fiber for output. The input port of a home made 1×8 fiber optical switch is coupled to the back facet through a collimator lens. The performance of the 1×8 fiber optical switch is shown in Table 1. Five home-made FBGs are located in the five output ports of

Table 1. Performance of 1×8 Optical Switch

Insert Loss	Return Loss	Switching Time
0.19/0.51 dB	< -55 dB	< 5 ms

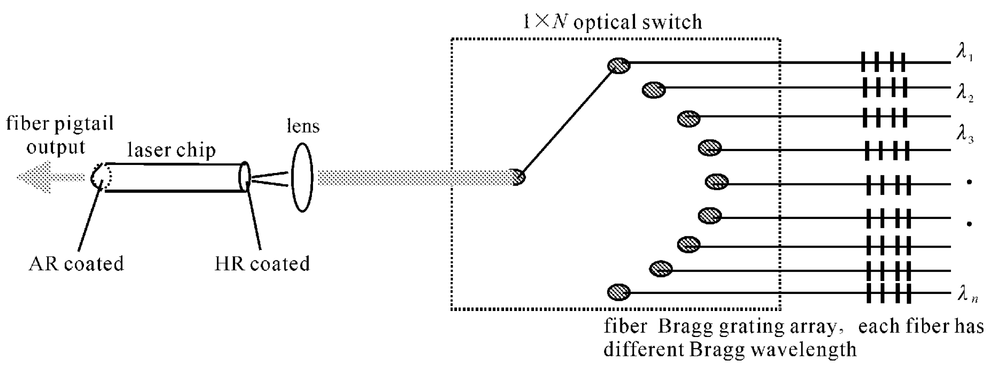

Fig. 1. Schematic of a wideband digitally tunable laser based on FBG array and $1 \times N$ optical switch.

Table 2. Performance of Digitally Tunable Laser

FBG#	Wavelength (nm)	ITU Standard Wavelength (nm)	Threshold Currents (mA)	SMSR (dB)
1	1531.84	1531.90	19	41.7
2	1549.30	1549.32	21	43.2
3	1550.80	1550.92	20	42
4	1552.64	1552.52	19	40.9
5	1554.12	1554.13	19	43

the 1 × 8 fiber optical switch. Bragg wavelengths are 1531.84, 1549.30, 1550.80, 1552.64 and 1554.12 nm cover the C-band, with a reflectivity of about 70% and a FWHM of 0.1 nm. Hence, the wavelength of the external cavity can be tuned by changing the state of the 1 × 8 fiber optical switch (see Fig. 1). The fiber gratings, located at a distance of 50 cm from the laser chip. A specific negative expansion ceramic substrate (NECS) was used to compensate the thermal variation of the FBG wavelength, NECS consists of polycrystalline β-quartz solid solution (Li_2-Al_2O_3-$n SiO_2$, $n > 2$), and has thermal expansion coefficient of about -65 to -85×10^{-7}/°C, which is sufficient large enough for total compensation of the Bragg wavelength shift[5].

The wavelength tunability of the digitally tunable laser is presented in Table 2, which shows a very stable and accurate wavelength tunability over C-band. Threshold currents below 21 mA are obtained over the full range. Figure 3 shows the spectrum of the tunable laser at 1549.3 nm, and it can be seen that more than 1 dBm output power was obtained in the fiber, with side mode suppression ratio (SMSR) larger than 40- and 3-dB bandwidth below 0.1 nm. Figure 4 is its *P*-*I* curve.

To measure the temperature characteristic of the tunable laser, first, F-P chip was mounted on a thermoelectronic cooler to stabilize its longitudinal modes. The injection current was kept constant during experiment. The FBG was temperature compensated by using NECS. A thermoelectronic cooler was used to tune its center wavelength. The temperature wavelength drift is presented in Fig. 5, only 0.05-nm variation is observed over -10 to 55°C temperature range, which make that the wavelength locker and monitor are not necessary in this tunable laser. The tuning time of laser is below 5 ms, which depends on the switching time of the 1 × 8 fiber optical switch.

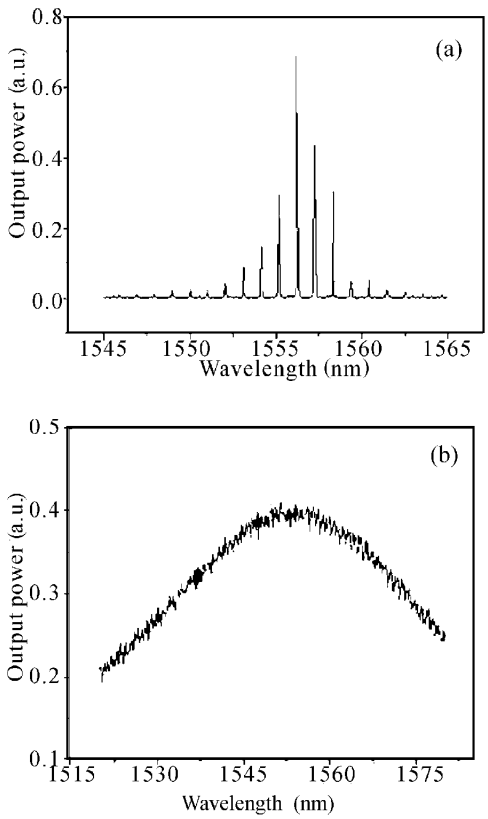

Fig. 2. The emission spectrum of the F-P chip. (a) Before AR and HR coated. (b) After AR and HR coated.

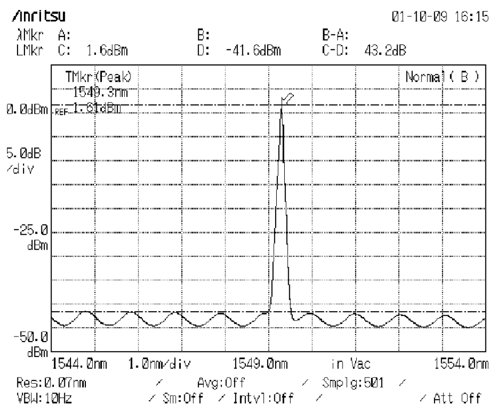

Fig. 3. Laser output spectrum of the digitally tunable laser at 1549.30 nm.

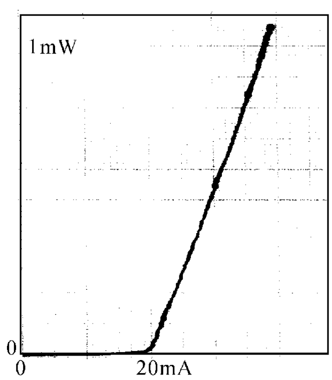

Fig. 4. *P*-*I* curve of the tunable laser at 1549.3 nm.

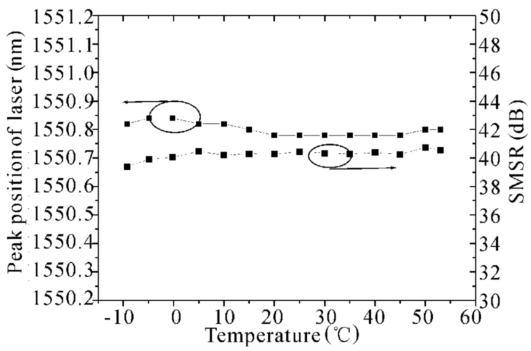

Fig. 5. Wavelength and SMSR drift versus temperature.

From the above, this wavelength tunable laser has following advantages:

1. The tuning is very simple and digital. The only adjustment for tuning wavelength is changing the state of the optical switch. It simplifies the controlling electronics.

2. The wavelength is very stable and accurate, and can match the ITU wavelength grids exactly. This is because the wavelength selected by FBGs and the FBG can be passively temperature compensated. Because of this, the wavelength locker and monitor are not necessary in this tunable laser.

3. The wavelength tuning range can be very broad and is only limited by the laser emission bandwidth. To get more wavelength channels, just adding more FBGs.

4. The linewidth is very narrow with the help of the external cavity structure.

In conclusion, we have demonstrated, for the first time to our knowledge, the operation of a novel wideband digitally tunable laser based on FBG external cavity array and $1 \times N$ optical switch, which provides 5-ms fast tuning time with output power more than 1 dBm over whole C-band that is only limited by the laser emission bandwidth. Less than 50 pm wavelength drift over -10 to 55 °C temperature range make that the wavelength locker and monitor are not necessary in this tunable laser.

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