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RESEARCH ARTICLE

Tunable and programmable fiber ring laser based on digital-controlled chirped fiber Bragg grating

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Abstract This paper proposed and experimentally demonstrated an all-fiber tunable and programmable bandpass filter using a linearly chirped fiber Bragg grating (CFBG). The center wavelength and spacing of the transmission peaks could be independently tuned via computer. The tunable range is about 18 nm. With this filter we demonstrated a tunable fiber ring laser which has an output power of about −7 dBm, full-width at half-maximum linewidth of ~0.017 nm which is limited by the resolution of the optical spectrum analyzer (OSA). Furthermore, a spacing tunable dual-wavelength fiber laser was achieved with the same setup. This all-fiber laser features advantages like simple structure, low cost, flexible and digital tuning capability.

Keywords chirped fiber Bragg grating (CFBG), tunable filter, fiber ring laser, phase shift

1 Introduction

With the rapid development of optical communications systems, there is a growing need for tunable fiber ring laser. It has promising applications in wavelength-division-multiplexing (WDM) networks. In general, the wavelength of a fiber ring laser can be varied by tuning an intracavity filter. Several tunable fiber ring lasers have been reported to use various types of optical filters, such as a fiber Fabry-Perot filter [1], a widely tunable fiber Bragg grating [2], a tunable phase-shifted chirped fiber grating [3] and a 2D filter based on a phase liquid crystal on silicon (LCoS) modulator [4–6]. In this paper, we propose and demonstrate a programmable all-fiber bandpass filter by the combination of digital controlled heating array and a linearly-chirped fiber Bragg grating (LCFBG). Thermo-optical effect is used to change the temperature arbitrarily along the LCFBG to introduce bandpass peak.

Theoretically, a 100% transmission peak within the stop band can be obtained with a π phase shift introduced by temperature change at the center of a uniform FBG [7]. For a LCFBG, the Bragg wavelength changes linearly with the position along it. Therefore the wavelength of the transmission peak is determined by the position of the phase-shifted point [8–12].

We used a thermal head (digital controlled heating array) which was originally used in the thermal dot matrix printer to control the position of the phase-shifted point. The thermal head consists of an array of tantalum thin-film resistors as heating elements. There are 384 heating elements distributed along the 48 mm long heating array, which means the length of each heating element is 0.125 mm. Each heating element can be controlled independently by computer. With this computer-controlled thermal head, we demonstrated tunable and programmable all-fiber filter based on LCFBG. The tunable range has been achieved to about 18 nm and the rejection ratio is ~8 dB. Furthermore, we demonstrated tunable and programmable fiber ring laser with this filter and semiconductor optical amplifier (SOA). The laser exhibits a very narrow bandwidth of ~0.017 nm, a wavelength tuning range of ~18 nm, and an output power of ~−7 dBm, respectively. We also achieved a spacing tunable dual-wavelength lasing with the same structure. This all-fiber laser features advantages like simple structure, low cost, flexible and digital tuning capability.

2 Programmable optical filter setup and experimental results

Figure 1 shows the schematic diagram of our proposed tunable and programmable filter. The LCFBG is placed

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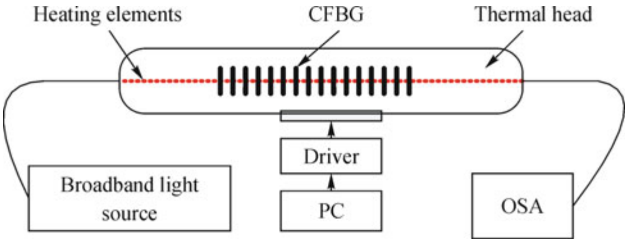

Fig. 1 Schematic diagram of proposed tunable and programmable filter

along the heating array of the thermal head. We design the driver of the thermal head and its interface to PC for a fully digital control of the individual thermal element. The heating position and heating width of the thermal head are determined by the signal sent from the control computer. As a result, the position of the phase-shift point in the LCFBG is therefore programmable and switchable with fast speed (less than 1 ms).

Once the heating position of the thermal head has been configured by the computer program, a small contact point on the LCFBG will be heated to raise the temperature, thus a temporary thermally induced phase shift will be introduced into the LCFBG. Hence a narrow passband transmission peak will be caused within the transmission stopband of LCFBG.

Figure 2 shows an obvious transmission peak around 1550 nm rising up within the transmission stop-band when one position is heated by the thermal head. As we shift the heating position along the LCFBG, the wavelength of the transmission peak can be adjusted continuously and the tunable range is ~18 nm, with the sideband rejection ratio about ~10 dB. From Fig. 3, we can see that the transmission peak (measured wavelength and linear fit) in the stopband of the LCFBG changes linearly with the position of the heating element.

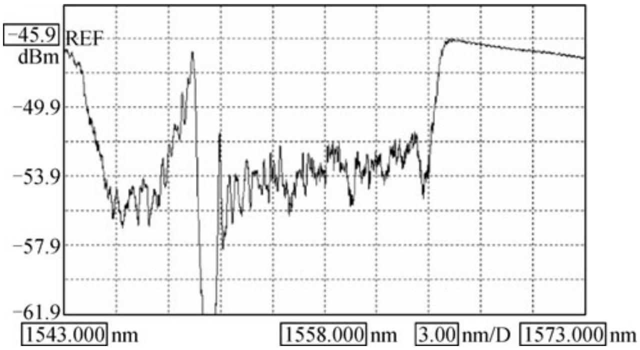

Fig. 2 Transmission peak of filter induced by heating position

By heating 3 separated points simultaneously, Fig. 4 shows an example of multi-wavelength transmission peaks obtained with our proposed scheme. In fact, more transmission peaks can be introduced by heating more contact points on the LCFBG. It's easy to accomplish this by reconfiguring control signal sent from computer without changing the hardware. In Fig. 4, the spacing of the heating points is 2.5 mm and the length of the CFBG is about 11.25 mm. So the limited number of transmission peaks is 4. The number of the transmission peaks can be increased by using longer LCFBG. The spacing of the wavelength of the transmission peaks could be turned. Thus a tunable and programmable all-fiber bandpass filter can be achieved.

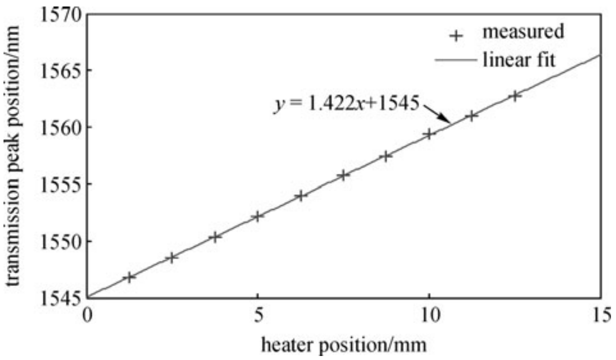

Fig. 3 Relationship between wavelength of transmission peak and heating position along LCFBG

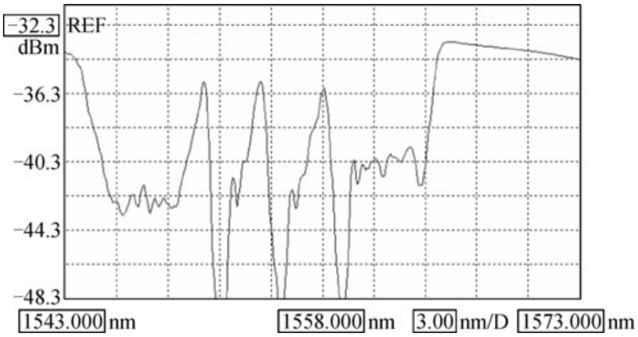

Fig. 4 Multiple transmission peaks of filter

3 Programmable optical fiber ring laser

As a consequence, we demonstrated a tunable and programmable fiber ring laser using above mentioned all-fiber filter. Figure 5 shows the schematic diagram of our proposed tunable fiber ring laser. The laser consists of a SOA as the wideband gain medium, an isolator to ensure unidirectional propagation of lightwave in the ring cavity, a tunable and programmable CFBG-1 based optical filter, a circulator, a CFBG-2 (which is identical to the CFBG-1), 10/90 fiber coupler and two polarization controllers (PCs), respectively. The reflective CFBG-2 suppresses the transmission outside the stopband of the CFBG-1, hence eliminates the unwanted laser oscillation outside the stopband of the transmission of CFBG-1 to achieve stable

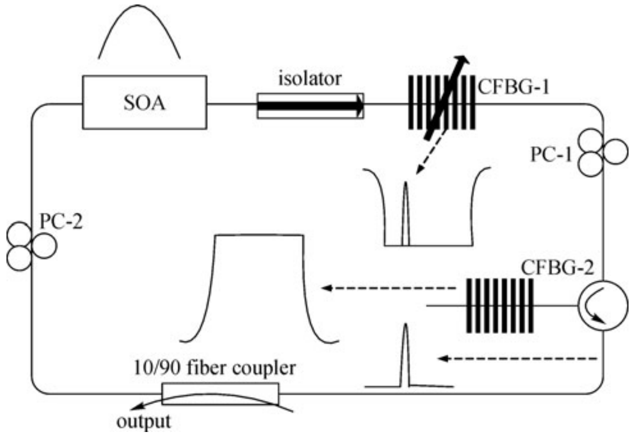

Fig. 5 Schematic setup of tunable fiber ring laser

laser operation.

Figure 6(a) shows single wavelength laser spectrum around 1562 nm when heating one contract point. The full-width at half-maximum of the laser is ~0.017 nm, which is limited by the resolution of the optical spectrum analyzer (OSA). The output power is ~−7 dBm. When we heat several different contact points (the length of each contact point is 0.625 mm) simultaneously, there will be corresponding multiwavelength laser oscillation as shown in Fig. 6(b), in which a dual-wavelength lasing is achieved.

One advantage of this dual-wavelength laser is that the wavelength spacing between two lasing lines can be continuously adjusted without missing band. Figure 7 shows the relationship between the spacing of the lasing wavelengths and the spacing of two heating points. The wavelength separation can be adjusted from 3.60 to 16.12 nm seamlessly. The minimum lasing wavelength spacing is limited by the CFBG chirp rate, spacing of the heating point, the thermal flow and the phase error [13], respectively.

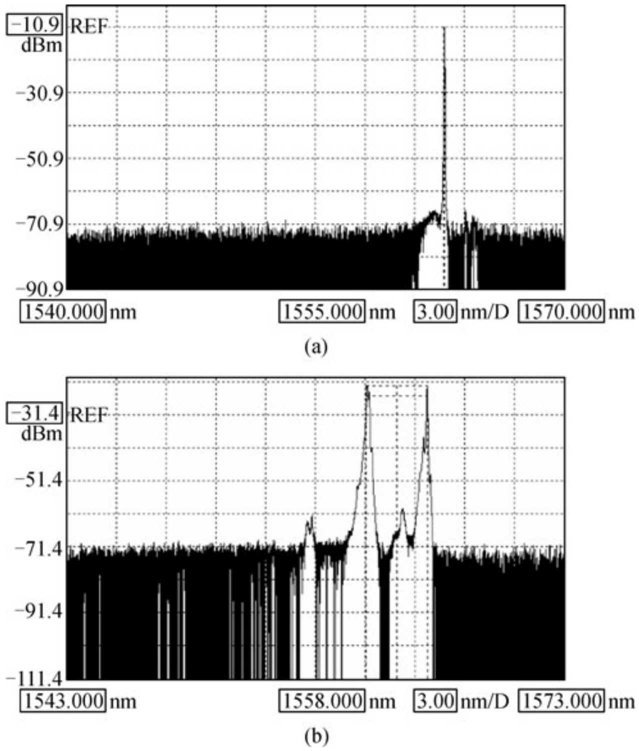

Fig. 6 Output laser spectrum. (a) Single wavelength lasing operation; (b) dual-wavelength lasing operation

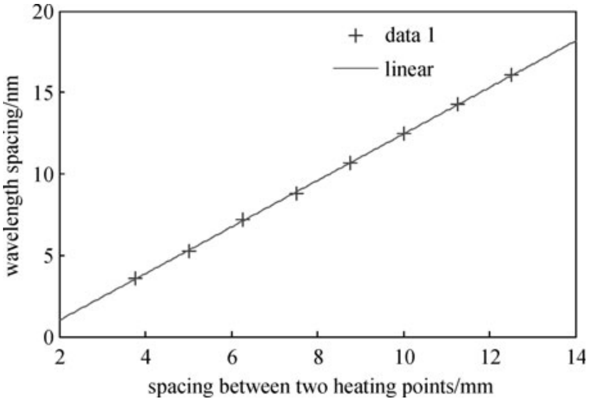

Fig. 7 Relationship between wavelength separation and spacing of two heating points

4 Conclusions

A fully programmable and tunable fiber ring laser has been experimentally demonstrated using our proposed digitally controlled all-fiber bandpass filter without any moving part. Under the single wavelength lasing operation condition, a tunable range of ~18 nm was achieved by thermally tuning a LCFBG. The laser has an output power of ~−7 dBm in this case. With dual-wavelength lasing operation, spacing between the two lasing wavelengths could be tuned from 3.60 to 16.12 nm. The laser shows significant advantages like simple all-fiber structure, compact size without moving part, low cost, flexible and digital tuning capability. Such laser has potential applications in fiber sensing, fiber communication, and optical instruments, etc.

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