Novel discretely tunable narrow linewidth fiber laser with uniform wavelength spacing

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Received October 26, 2006

A novel configuration of the tunable fiber laser with uniform wavelength spacing in dense wavelength division multiplexing (DWDM) application is proposed. The ring type tunable fiber laser consists of an all-fiber comb filter which determines the wavelength spacing, and a piece of adjustable fiber grating to select the discrete lasing wavelength for DWDM application. The proposed all-fiber ring type tunable laser has potential application in the DWDM and other optical systems due to its advantages such as narrow linewidth, easy tuning, uniform wavelength interval, etc..

OCIS codes: 140.3510, 140.3560, 140.3600.

The high speed and high capacity dense wavelength division multiplex (DWDM) optical communication system needs multi-wavelength optical sources/channels with sufficiently narrow linewidth and uniform wavelength spacing. Various types of multi-wavelength sources at the ITU-T wavelength have been proposed[1−4]. The fiber lasers, consisting of various types of doped fibers, owing to their flexibility in tuning range and method, and lasing wavelength, become more and more attractive for the communication and non communication applications. In this paper, we report a novel tunable fiber laser implemented by the combination of Sagnac loop with the highly birefringent (HiBi) fiber and adjustable fiber gratings in the ring laser loop. Compared with other type of tunable lasers, this all-fiber type laser shows advantages of narrow linewidth, uniform wavelength spacing, and possibly large tuning range.

The novel configuration of the tunable fiber laser designed for the DWDM application is illustrated in Fig. 1. The Er-doped fiber is pumped by a 980- or 1480-nm high power laser diode (LD) through the wavelength division multiplexing (WDM) coupler. The isolator following the Er-doped fiber ensures the optical wave circling only in one direction in the ring loop. A Sagnac interference filter, which constructed by a standard 50:50 single-mode fiber coupler at 1550-nm wavelength and a piece of HiBi fiber with both ends spliced to the coupler output[5], is partly composed of the ring path of the fiber laser. To achieve optimal visibility in the transmission spectrum of this Sagnac interferometer, the birefringence axes on both ends of the HiBi fiber spliced to the output of the coupler are set orthogonally[5]. In Fig. 1, a tunable fiber grating connected to one branch of the output coupler is used to select the lasing wavelengths. The Bragg wavelength of the fiber grating can be tuned to match the maximum of the transmission spectrum of the Sagnac interferometer which can result in lasing at the fixed wavelength.

The principle of the Sagnac interferometer can be described briefly as follows. Since the propagation constants of the orthogonal polarization states are dependent on wavelength, the phase difference between the two reentering waves in the Sagnac loop varies with wavelength of the input light. Therefore the transmission spectrum of the Sagnac filter varies uniformly or periodically with wavelength in a relative small wavelength range. The output power of the Sagnac filter can be derived by the Jones' Matrix as[6]

$$P_{\text{output}}(\lambda) = \frac{1}{2}[1 + \cos \Delta\beta(\lambda)L] \sin^2 \theta, \tag{1}$$

where λ is the optical wavelength of the source, $\Delta\beta$ the linear birefringence of the HiBi fiber, L the fiber length, and θ the misalignment angle between the birefringent axes of the HiBi fiber on the both ends. It is clear that when the angle of θ was set to 90° the output spectrum has maximum contrast.

In Fig. 1, a 980-nm LD with maximum output power of 120 mW is used to pump the Er-doped fiber. The Sagnac interferometer comb filter consists of a 50:50 single-mode fiber coupler at 1550 nm and a piece of 8-m length HiBi fiber. The transmission spectrum of the comb filter measured with a broadband source and the optical spectrum analyzer (AQ6317B) is shown in Fig. 2, where the wavelength spacing was obtained to be 0.51 nm at 1550 nm. Without losing the generality which determines the

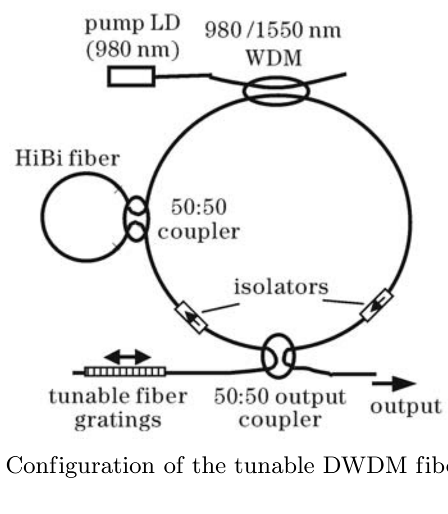

Fig. 1. Configuration of the tunable DWDM fiber laser.

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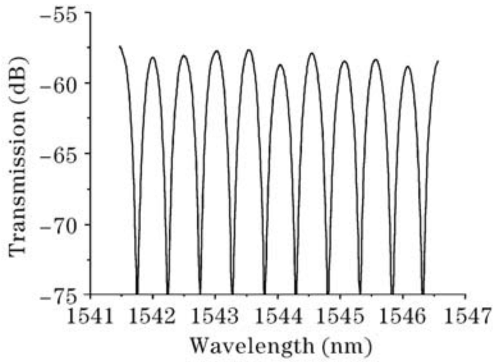

Fig. 2. Transmisssion spectrum of the Sagnac filter with HiBi fiber in the loop.

interval of the lasing wavelength when tuning the fiber grating. The two isolators connected in the ring loop can prevent the optical wave circling in opposite directions which may cause unstable in the output power. The fiber grating connected in one branch of the 50:50 output coupler operating at 1550 nm has center wavelength of 1544.32 nm and full-width at half-maximum (FWHM) of 0.18 nm. The fiber grating is glued to an elastic plastic rule which can be adjusted and bent into different status. In this way the center wavelength of the grating can be adjusted from 1541 to 1546 nm without significant change in the shape of the reflection spectrum. Figure 2 is the transmission spectrum of the Sagnac filter. The lasing of the system can be observed when the pump power has increased to a certain level. It should be pointed out that the power of the pump laser should not increase too much since in this case non-discrete lasing of the laser may happen when tuning the fiber grating. In the experiment, the 10-m Er-doped fiber (from Fibercore Co.) and 50:50 output coupler are employed, the discrete lasing with about 20-mW pump power at the pre-fixed wavelength determined by Sagnac filter is achieved.

Figure 3 shows the tuning of the output laser when the fiber grating is adjusted by bending. It is observed that the lasing wavelengths were located exactly at the maximum of the transmission spectrum of the Sagnac filter, with a wavelength spacing of 0.51 nm. This wavelength spacing or interval can be adjusted easily by changing the length of the spliced HiBi fiber, so the DWDM system with the required 0.8 or 0.4-nm wavelength spacing can be achieved in this way. The transmission wavelength of

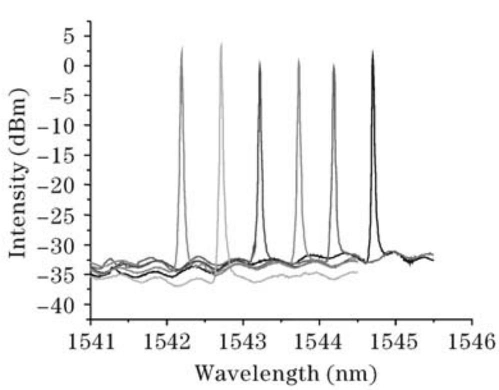

Fig. 3. Tuning of the DWDM laser wavelength via the FBG.

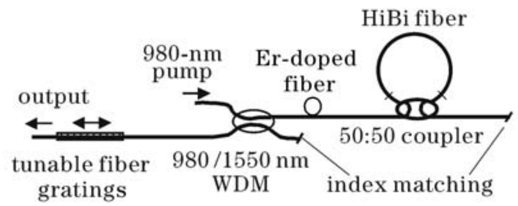

Fig. 4. Configuration of tunable DWDM proposed in Ref. [7].

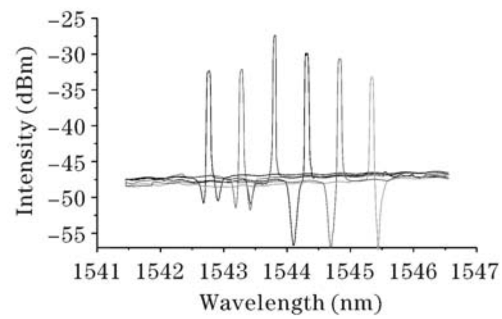

Fig. 5. Output spectrum of the tunable laser illustrated in Fig. 4.

the Sagnac filter may be shifted by varying the temperature of the HiBi fiber or optical phase in the Sagnac loop, and the Sagnac loop is kept carefully in a temperature controllable box. From Fig. 3 one can see that the extinction is larger than 35 dB, and the measured linewidth of the output laser is smaller than 0.01 nm, which is limited by the resolution of the optical spectrum analyzer.

The DWDM tunable laser was also realized by Fig. 4[7,8]. In this configuration the fiber loop with HiBi fiber serves as one of the reflectors of the linear cavity of the fiber laser. To compare better the output property between this linear cavity version (Fig. 4) and our ring cavity version (Fig. 1), the output spectrum was also measured from Fig. 4 as shown in Fig. 5, with the same Sagnac filter and Er-doped fiber. It is clear that lasing at the discrete wavelength defined by the maximum transmission of the Sagnac filter is more difficult compared with that in Fig. 1. The measured linewidth of the output laser is around 0.05 nm, which is much broader than that obtained by Fig. 1. The 15-dB extinction in Fig. 5 is also lower than that in Fig. 3. Obviously, owing to the traveling wave behavior of the ring type tunable DWDM fiber laser proposed, it should have better performance than that in Fig. 4.

It should be pointed out that since the birefringence of the conventional stress induced HiBi fiber employed in the Sagnac loop of Fig. 4 may vary significantly with the temperature, the ambient temperature of the Sagnac loop should be kept almost no change in the application. To reduce the difficulty of almost constant temperature required for the stress induced HiBi fiber, less even neglectable temperature dependant on HiBi fiber, such as the reported photonic crystal fibers with geometrically formed large birefringence[9], could be employed in the loop.

In conclusion, the new type of tunable DWDM fiber laser has advantages of narrow linewidth, uniform wavelength spacing, easy tuning, all-fiber, and better performance in comparison with other versions. Therefore, this new approach to realize the tunable laser operating at discrete DWDM wavelengths should have potential practical application in the optical communication and other systems.

The work was supported by the Foundation of the Backbone Teachers of the Ministry of Education of China, and the Natural Science Foundation of Fujian Province (No. A0010004). X. Dong's e-mail address is xpd@xmu.edu.cn.

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