High Performance Ring-Cavity Tunable Lasers Based on Fiber Bragg Gratings

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Abstract

We report the development of ring-cavity tunable fiber laser based on tunable fiber Bragg gratings integrated optical circulator. The tunable laser, operates in the C band, has laser linewidth, power variation and tuning range of 0.015 nm, ±0.5 dB and 31.0 nm, respectively. As 40 mW of pump power is used, the ring-cavity tunable laser has a side mode suppression ratio of 60 dB and power conversion efficiency of 25%. These characteristics insure a high quality operation of such tunable laser.

Keywords: Tunable laser, optical switch, fiber Bragg gratings, fiber laser, optical communication.

1. Introduction

In recent years, lasers sources have various applications in sensing, instrument testing, optical signal processing, optical communications, and in photon analog-to-digital converters (ADCs) [1-2]. Moreover, tunable lasers are flexible for usage in wavelength routing, wavelength protection and optical measurement. Several methods have been proposed to investigate tunable lasers, for example, by using photonic crystal mirrors [3] and a multiple quantum-well waveguide. Among them, erbium-doped fiber ring laser (EDFRL) is a potential candidate, partially because the feature of low temperature sensitivity of wavelength. The selection of their operation wavelengths has been achieved by using different optical filtering devices, like Mach–Zehnder filters or in-fiber comb filters. However, the tuning range is narrow [4] or the linewidth is wide due to large filter bandwidth. Another approach is the dual wavelength tunable fiber laser. Lasing occurred at two different wavelengths alternatively by using a cavity consists of two overlapping cavities with a common gain medium [5].

The paper addresses an important optical device of widely tunable laser. We propose and demonstrate tunable fiber-Bragg-gratings (TFBGs) based tunable lasers covering the C-band, also constructed by a 1×2 optical switch (OSW) and optical circulator (OC). Our results show that the tuning ability could be realized by appropriately switching the OSW and compressing/straining the TFBGs.

2. Operation Mechanism of Tunable FBG (TFBG)

From the theory of solid mechanics [6], the transverse displacement (ν) is related to longitudinal strain (ε) and which was applied to the FBG for tuning purpose.

$$E\varepsilon = \frac{My}{I} \tag{1}$$

And

$$\nu = \frac{-PL^3}{48EI} \tag{2}$$

Where ***E*** is elastic modulus, ***I*** is the moment of inertia, ***P*** is load, ***L*** is the span of the 3-pinot bending support, ***y*** is the distance to the point at which the bending strain is desired, and which is measured from the neutral axis. Thus, from Eqn (1) and Eqn (2), we get the relation equations between ν and ε:

$$\varepsilon = \frac{48\nu y}{-2L^2} \tag{3}$$

The wavelength shift is linear proportion to strain [7] as:

$$\Delta\lambda_B = \lambda_B(K_\varepsilon \varepsilon + K_T \Delta T) \tag{4}$$

Where λ_B is the peak wavelength of FBG, K_ε is strain constant and K_T is thermal constant, respectively. If the temperature is kept constant, the tuning wavelength $(\Delta\lambda_B)$ is

$$\Delta\lambda_B = \lambda_B \frac{48K_\varepsilon \nu y}{-2L^2} \qquad (5)$$

From Eqn. (5) the tuning wavelength is proportional to transverse displacement (ν). By changing ν, we can tune the TFBG for fiber laser application. Firstly, we embedded the FBG in the outer laminar as shown in Fig. 1. The composite with TFBG embedded inside is attached on a 3-point tuning device by using instant adhesive glue. By strained or compressed tuning the precise screw of 3-piont bending device, we can apply both directions in the transverse displacement for increasing the tunable range up to ±10 nm easily. No other complicated and bulky components are needed to perform the tuning function. Fig. 2 shows superposed tuning spectra of two home-made TFBGs. The tuning range of each FBG is about 15 nm with reflectivity of over 99.9%. Without tuning, the FBG_1 has central reflective wavelength of 1540.5 nm while that of FBG_2 is 1552.7 nm. We demonstrate the FBG_1 to be tuned from 1535- to 1545 nm, while FBG_2 to be tuned from 1547- to 1561 nm. Fine tuning resolution as precise as 0.1 nm for FBG is possible.

3. Schematic Description of TFBG laser

Fig. 3 shows proposed scheme of the wavelength tunable laser. This ring cavity includes 10 meters of erbium-doped fiber (EDF), a wavelength division multiplexer (WDM) coupler and a 980 nm pumping laser. The 3-port OC has benefit to form the loop back cavity as a reflective mirror by integrated fiber Bragg gratings. At the right hand side, there are one 1x2 OSW and two TFBGs ($TFBG_1$, $TFBG_2$) connected to each port of the OSW. By compressing or straining these TFBGs, their overlapping spectra could cover the C band. The decided tuning wavelength, either in the shorter C band (1530-1545 nm) or the longer C band (1546-1560 nm), is dependent on the witching status of OSW. This switching speed is 10 ms for this OSW. The transmission spectrum (or reflection) is not degraded when the FBG be tuned to the boundary points (1530-, 1545, or 1560 nm). Note that the maximum tuning ability of TFBG of our sample is up to 20 nm.

4. Results and Discussion

Fig. 4 shows superposed optical spectra of the ring-cavity tunable laser. It could cover the C-band window. The output power is increased as the reflectivity is increased. The average output power is 0.0 dBm (i.e., 1 mW) for each channel and power variation is less than ± 0.5 dB over the whole tuning range. Thus, no VOA is necessary for power equalization. The coupler ratio is 10/90, with 90% of lasing power be loop back to the ring cavity and 10% of lasing power be detected by optical spectrum analyzer (OSA) and/or power meter. The pumping power of the 980 nm laser diode is 40 mW. So, the ring cavity tunable laser has pumping efficiency of 25%, side mode suppression ration (SMSR) of 60 dB and narrow linewidth of 0.015 nm, limited by resolution of the OAS.

The tunable laser proposed here is in a unidirectional ring cavity design. It is well suited for obtaining nearly single longitudinal mode operation due to the cancellation of spatial hole-burning effect in the case of a traveling wave field in a ring cavity. Laser linewidth can be reduced by means of inserting one sub-cavity in the ring cavity [8]. The sub-ring cavity is composed of a PC and two 50:50 couplers. The main ring integrated sub-ring serves as a mode filter. The laser mode oscillates only at a frequency that satisfies the resonant conditions of the main cavity and the sub-ring cavity simultaneously. The PC in sub-ring cavity must be tuned to the same states of polarization as that of the main cavity. No polarization mode competition effect is observed.

A versatile and cost-effective laser source should have tunable ability to allow someone to choose which wavelength is needed, or to scan over a range of bandwidth. Our proposal TFBG lasers may fulfill such requirements. In theory, the proposed method could apply to the whole C+L band by parallel connection of several TFGBs with a 1xN OSW pair. Of course, TFBGs with appropriate originally central reflective wavelengths are necessary.

5. Conclusion

We report the investigation of ring cavity tunable laser, which is based on FBG technology. The laser linewidth, power variation and tuning range are 0.015 nm, 0.5 dB and 31.0 nm, respectively. The ring-cavity tunable laser also has 60 dB of SMSR to insure high-quality operation. With the features mentioned above, the tunable laser is possible for high-speed modulation in either digital or analog system. It may also find vast applications in optical communication and optical measurement.

Acknowledgments

The work is partially supported by NSC under projects No. 94-2219-E-011-007 and

94-2622-E-011-021-CC3, Taiwan, ROC. We thank Y.C. Lai, S.C Chen and J.R. Wang for their kindness help.

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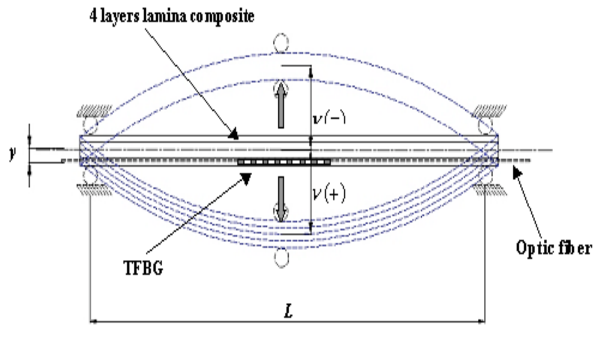

Fig 1. Schematic diagram shows a 3-point bending device used for fiber Bragg grating tuning purpose.

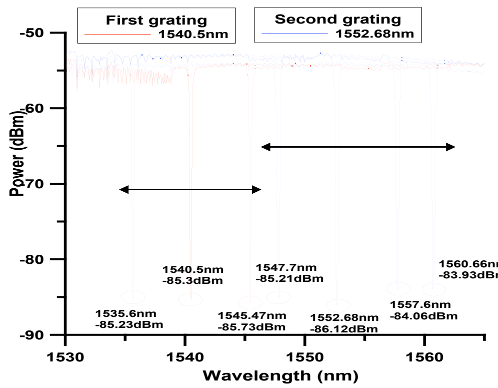

Fig. 2 Superposed transmission spectra of two C band TFBGs. The joint TFBGs have precisely tuning resolution.

Fig. 3 TFBG based ring-cavity tunable laser; PC: polarization controller; OSW: optical switch; OC: optical circulator; TFBG: tunable fiber Bragg grating; ISO: optical isolator; EDF: erbium-doped fiber; OSA: optical spectrum analyzer.

Fig. 4 Superposed optical spectra of the ring-cavity tunable laser. The whole C band is covered by using two TFBGs.