

Thermo-optically tunable fiber ring laser without any mechanical moving parts

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Abstract. A thermo-optically tunable fiber ring laser has been constructed. The laser is based on a polymer-spaced Fabry-Pérot (F-P) étalon with a cavity length of 470- μm and an ultra-low polarization-dependent loss (PDL) of <0.1 dB. A wavelength tuning range of ~ 1.4 nm and a high wavelength stability of ~ 0.02 nm have been demonstrated without involving any moving mechanical parts. Such a nonmechanical tunable fiber laser structure leads to a reduced device size and allows easy device packaging due to the ultra-low PDL of the wavelength tuning element. © 2006 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.2219737]

Subject terms: tunable fiber laser; wavelength division multiplexing; thermo-optic; polymer-spaced Fabry-Pérot étalon; polarization insensitive wavelength tuning; nonmechanical moving wavelength tuning.

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Wavelength-tunable lasers are highly desired to achieve dynamically reconfigurable optical networks and significantly reduce the number of redundant lasers required in optical communication inventories.¹⁻⁴ Tunable fiber lasers are among the most promising sources due to their high energy conversion efficiency (>20%), large gain bandwidth across C and L bands, and inherent compatibility with optical fibers, which leads to extremely low insertion loss and reduced packing cost.³ However, most of the existing tunable laser technologies involve moving mechanical parts,⁴⁻⁹ which not only requires precise mechanical moving control elements, but also increases device size and weight and generates reliability issues. In this paper, we present a thermo-optically tunable fiber ring laser without involving any moving mechanical parts. The laser is based on a polymer-spaced Fabry-Pérot (F-P) étalon with a short cavity length of 470 μm and an ultra-low polarization-dependent loss (PDL) of <0.1 dB. A wavelength tuning range of ~ 1.4 nm and a wavelength stability of ~ 0.02 nm have been demonstrated. Such a fiber laser provides a compact device structure and allows easy device packaging due to the ultra-low PDL of the wavelength tuning element.

The schematic diagram of the thermo-optically tunable fiber laser is shown in Fig. 1. It consists of a wavelength division multiplexing coupler (WDM 980/1550 nm),

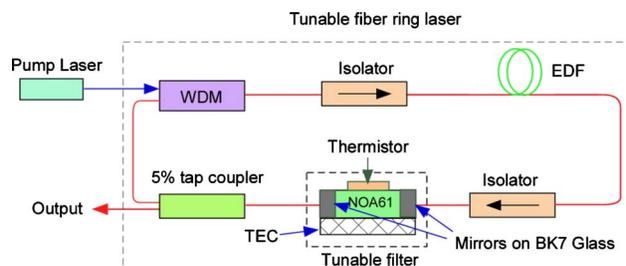


Fig. 1 Schematic structure of the thermo-optically tunable fiber ring laser.

a 3-m-long erbium doped fiber (EDF; OFS HG980), two isolators, a polymer-filled F-P étalon and a 5% output tap coupler. The total length of the fiber ring cavity is 5 meters, which gives a longitudinal mode separation of ~ 20 MHz. The polymer-filled F-P étalon functions as a thermo-optically tunable optical filter, which selects the lasing wavelength of the fiber laser. It was constructed by filling polymers into an air-spaced F-P étalon. The cross section and the cavity length of the air-spaced F-P étalon are 3 mm \times 3 mm and 470 μm , respectively. The polymer fill inside the F-P étalon is Norland optical adhesive 61 (NOA61), which has a refractive index of 1.541 at the wavelength of 1560 nm at room temperature (25 $^{\circ}\text{C}$). The finesse of the polymer-filled F-P cavity was measured to be approximately 100. The F-P étalon has a free-spectral range (FSR) of 1.66 nm and a 3-dB bandwidth of 0.02 nm, which indicates that there are approximately 100 longitudinal modes in each pass band of the F-P filter. The polymer-spaced F-P étalon was packaged with polarization maintenance (PM)-fiber pigtailed collimators on both the input and the output sides. The focal length and the aperture of the PM-fiber pigtailed collimators are 0.8 mm and 2 mm, respectively. Due to this ultra-low PDL, no special attention was paid to aligning the polarization orientation of the FP filter to the fiber laser. The insertion loss (IL) and PDL of the F-P filter were measured to be 1.1 dB and 0.1 dB, respectively.

The resonant wavelength of the F-P étalon is given by:

$$m\lambda_m = 2nL = 2S, \quad (1)$$

where n is the refractive index (1.541 at room temperature at the wavelength of 1.56 μm), L is the cavity length, m is an integer, and S is the optical path length $S=nL$. The temperature dependence of the optical path length¹⁰ is given by:

$$dS = \left(\frac{dn}{dT} + n\alpha_{CTE} \right) LdT, \quad (2)$$

where α_{CTE} is the coefficient of thermal expansion (CTE), $\alpha_{CTE}=220 \times 10^{-6}/^{\circ}\text{C}$ for NOA61, and dn/dT is the thermo-optic coefficient, which is $1.85 \times 10^{-4}/^{\circ}\text{C}$ for NOA61.¹¹ The resonant wavelength λ_m can thus be tuned by changing the refractive index n or the cavity length L , or both. The wavelength tuning range $\Delta\lambda$ (the shift of the resonant wavelength λ_m) can be written as:

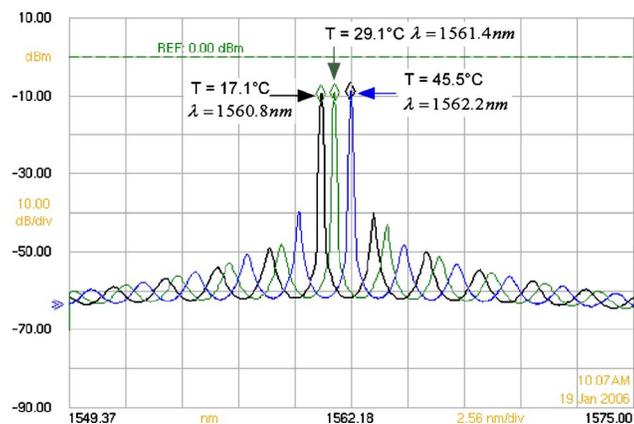


Fig. 2 Wavelength tuning spectrum of the thermo-optically tunable fiber ring laser.

$$\Delta\lambda/\lambda = \Delta(S)/S = \left(\frac{1}{n} \frac{dn}{dT} + \alpha_{CTE} \right) \Delta T. \quad (3)$$

As indicated in Eq. (3), by controlling the temperature, a thermo-optically tunable optical filter can be achieved. This tunable optical fiber functions as a wavelength selection element for the fiber laser.

The wavelength tuning spectrums of the fiber ring laser at different temperatures were characterized using an optical spectrum analyzer (Agilent 86140B), as shown in Fig. 2. As indicated in Fig. 2, the wavelength of the fiber ring laser can be continuously tuned from 1560.8 nm to 1561.4 nm when the temperature of the F-P étalon was increased from 17.1°C to 45.5°C. A side-mode suppression ratio (SMSR) over 30 dB was obtained. Figure 3 shows the measured wavelength tuning ranges $\Delta\lambda$ at different temperatures. The solid trace is the calculated wavelength tuning range $\Delta\lambda$ as a function of temperature. Note that the measured wavelength tuning ranges $\Delta\lambda$ are smaller than calculation results. One possible reason for this is because the F-P cavity is mounted on a thermal-electric cooler (TEC), which has a much smaller coefficient of thermal expansion. This would limit the expansion of the polymer materials and result in smaller wavelength tuning ranges $\Delta\lambda$ than expected values.

To obtain high wavelength stability, the temperature of the thermo-optic filter was controlled by a temperature controller. The close-loop gain and time constant were optimized to achieve an excellent temperature stability of $\sim 0.02^\circ\text{C}$. The wavelength tuning speed was approximately 500 ms. By reducing the thermal capacitance of the polymer-filled F-P étalon, e.g., decreasing the size and increasing the thermal conductivity of the F-P étalon, faster wavelength-tuning speed (tens of ms) can be expected. The power consumption of the polymer-spaced F-P filter at 45.5°C was measured to be ~ 0.1 W. The wavelength stability at each temperature was measured to be ~ 0.02 nm. The wavelength instability is not due to the temperature fluctuation (0.02°C). We believe that it is the result of the mode-hopping and competing of multilongitudinal modes within the passband of the F-P étalon as well as volume relaxation of polymer materials.¹² By increasing the finesse of the F-P étalon, the number of the longitudinal modes

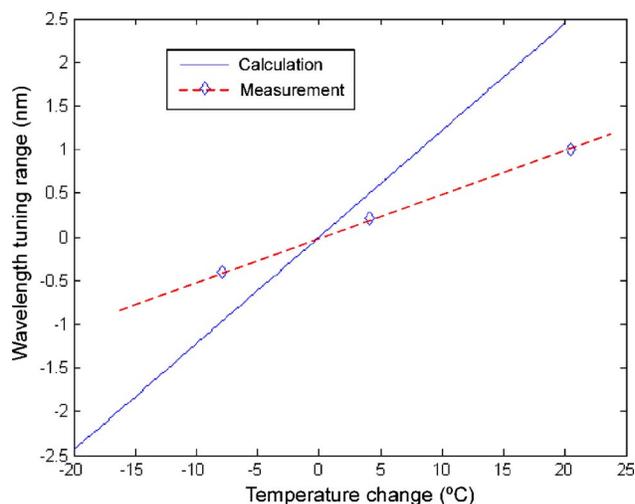


Fig. 3 Measured wavelength tuning ranges $\Delta\lambda$ at different temperatures as compared with calculation.

within the passband of the F-P cavity can be reduced, and a higher wavelength stability can be expected.

In summary, we present a thermo-optically tunable fiber ring laser with high wavelength stability. The laser yields a wavelength tuning range of ~ 1.4 nm without any moving mechanical parts. A wavelength stability of ~ 0.02 nm and a SMSR of over 30 dB were obtained. By increasing the finesse of the F-P cavity, a higher wavelength stability can be expected. Such a fiber laser provides a compact structure by eliminating the mechanical moving parts. In addition, the ultra-low PDL of the wavelength tuning element allows easy device alignment and packaging.

References

1. J. P. Rayn, WDM North American development trends, *IEEE Commun. Mag.* **36**(2), 40–44 (1998).
2. C. Vazquez, S. Vargas, J. M. S. Pena, and P. Corredera, "Tunable optical filters using compound ring resonators for DWDM," *IEEE Photonics Technol. Lett.* **15**, 1085–1087 (2003).
3. X. Dong, P. Shum, N. Q. Ngo, H.-Y. Tam, and X. Dong, "Output power characteristics of tunable erbium-doped fiber ring lasers," *J. Lightwave Technol.* **23**, 1334–1341 (2005).
4. Y. Hibino, "Recent advances in high-density and large-scale AWG multi/demultiplexers with higher index-contrast silica-based PLCs," *IEEE J. Sel. Top. Quantum Electron.* **8**, 1090 (2002).
5. J. Stone and L. W. Stulz, "Pigttailed high finesse tunable FP interferometer with large, medium, and small FSR," *Electron. Lett.* **23**, 781–783 (1987).
6. J. L. Jackel, J. E. Baran, A. d' Alessandro, and D. A. Smith, "A passband-flattened acousto-optic filter," *IEEE Photonics Technol. Lett.* **7**, 318 (1999).
7. J. Y. Liu and K. M. Johnson, "Analog smectic ferroelectric liquid crystal Fabry Perot optical tunable filter," *IEEE Photonics Technol. Lett.* **7**, 1309 (1995).
8. E. L. Wooten, R. L. Stone, E. W. Miles, and E. M. Bradley, "Rapidly tunable narrowband wavelength filter using LiNbO₃ unbalanced Mach-Zehnder interferometers," *J. Lightwave Technol.* **14**, 2530–2536 (1996).
9. A. Locco, H. G. Limberger, and R. P. Salathe, "Bragg grating fast tunable filter" *Electron. Lett.* **33**, 2147–2148 (1997).
10. Y. Kokubua, N. Funato, and M. Takizawa, "Athermal waveguide for temperature-independent lightwave devices," *IEEE Photonics Technol. Lett.* **5**, 1297–1300 (1993).
11. Norland product data, <https://www.norlandprod.com/adhesives/noa61pg2.html>.
12. X. Wang, B. Howley, M. Y. Chen, and R. Chen, "Crosstalk-minimized polymeric 2×2 thermo-optic switch," *IEEE Photonics Technol. Lett.* **18**, 16–18 (2006).