12th Optoelectronics and Communications Conference/16th International Conference on Integrated Optics and Optical Fiber Communication (OECC/IOOC2007)
Technical Digest, July 2007, Pacifico Yokohama

12C2-5

High birefringence ring filter with a reflector: application in single-frequency fiber lasers

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Abstract

A high birefringence fiber ring filter with an inline reflector is newly proposed. Narrowband reflection peaks with large effective free spectral range are achieved by the intrinsic vernier effect between the traveling orthogonally polarized lights along the fast and slow axes in the high birefringence fiber. The special properties facilitate its application in single frequency fiber lasers.

1 Introduction

Single frequency fiber lasers [1-2] are of considerable interest for various applications in medical surgery, communication systems, and sensors. There are a number of methods to achieve stable single frequency operation in fiber lasers. For example, the single frequency erbium-doped fiber lasers have been obtained in both linear and ring configurations. However, it is necessary to shorten the length of the gain medium to increase the free spectral range (FSR) in linear cavities, which limits the attainable output power [3]. On the other hand, complex rings [4] are usually used as frequency selectors for lasing single frequency in ring-cavity fiber lasers. However, the complex rings are sensitive to environment fluctuations although they increase the FSR to alleviate the cavity-length problem through the vernier effect. Recently, a feedback Mach-Zehnder resonator with a reflector was proposed to increase the FSR [5], but it may not be sufficiently stable just like the common Mach-Zehnder comb filter for the optical field circulating in two different resonant cavities. A common problem with most of the coupled-cavity approaches is the stringent environmental stability required.

In this paper, characteristics of a high birefringence fiber (HBF) ring structure with an inline reflector are described. Distinct from the common fiber ring resonator, the single mode fiber is replaced with a piece of HBF. By employing the special setup, we can resolve the problems encountered by the ring resonators used as narrowband filters in single frequency fiber lasers as mentioned above. The proposed setup provides improved performance while possessing a simple structure, which dramatically facilitates its application in single frequency fiber lasers.

2 Principle of operation

Figure 1 shows the setup of our proposed HBF ring resonator. The simple configuration consists of one fiber coupler (OC) with intensity coupling ratio k, an inline reflector with intensity reflectivity R and a piece of HBF with length L ($=L_1+L_2$). The refractive indexes of the fast and slow axes in the HBF are n_f and n_s, respectively.

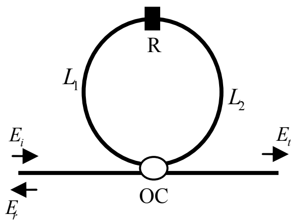

Fig. 1 The schematic setup of our proposed HBF ring resonator.

When the optical field with amplitude E_i is input from the left port, it will be decomposed along the slow and fast axes in the HBF according to the formula (1). Through calculation, we obtain the amplitude ratios:

$$E_i = A_s E_i^s + A_f E_i^f \tag{1}$$

$$\frac{E_r^s}{E_i^s} = \frac{-ik\sqrt{R}e^{i2\pi/\lambda(n_s L_2)}}{(1-k)e^{i2\pi/\lambda(n_s L)} - 2\sqrt{(1-k)(1-R)} + e^{-i2\pi/\lambda(n_s L)}} \tag{2}$$

$$\frac{E_r^f}{E_i^f} = \frac{-ik\sqrt{R}e^{i2\pi/\lambda(n_f L_2)}}{(1-k)e^{i2\pi/\lambda(n_f L)} - 2\sqrt{(1-k)(1-R)} + e^{-i2\pi/\lambda(n_f L)}} \tag{3}$$

It can be seen from the Eqs. (2) and (3) that the two terms are both periodic in $1/\lambda$ with slightly different periods. Only when the circulating fields along the fast and slow axes in the HBF ring are both resonating, the reflectivity is maximal. It follows that the effective FSR is enhanced by the vernier effect between the fast and slow axes. Namely, the FSR is $n_f/(n_s-n_f)$ times that of the circulating light along the fast axis, *i.e.*:

$$FSR = \frac{c}{(n_s - n_f)L} = \frac{n_f}{(n_s - n_f)} FSR_f = \frac{n_s}{(n_s - n_f)} FSR_s$$

3 Calculation and discussion

In our calculation, all losses are ignored since they have little impact on the performance. The input signal is assumed to be adjusted by a polarization controller such that $|A_s|^2=|A_f|^2=0.5$.

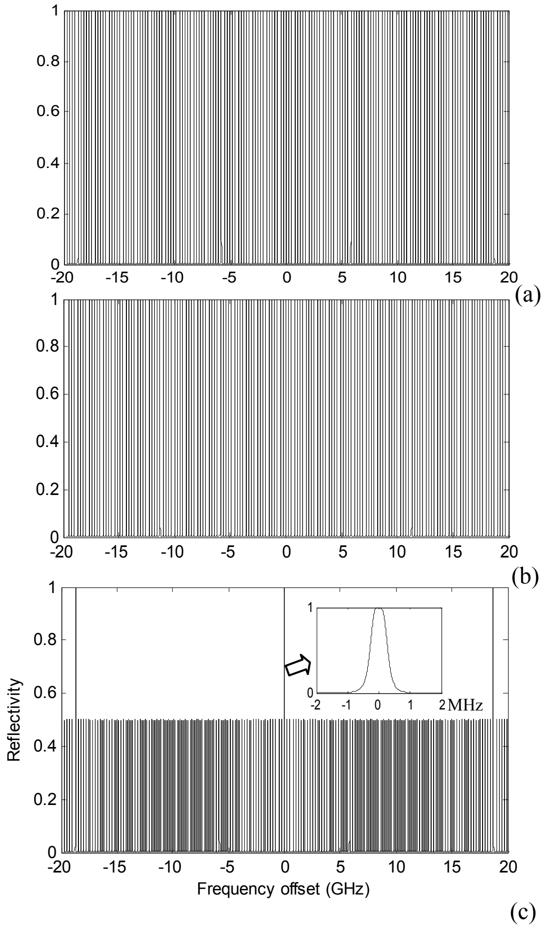

Fig. 2 Reflection spectra of the proposed HBF ring resonator: (a) along the slow axis; (b) along the fast axis; (c) of the input signal.

Figure 2 shows the reflection spectra with k=1% and the corresponding critical R value [5]. The values of other parameters involved are: L=0.8m, n_s=1.48, n_f=1.46. Therefore, the ratio of FSR_s to FSR_f is 73/74. As a result, the effective FSR is enhanced by 73 times, which can be seen from Fig. 2(c). The inset shows one reflective peak with full width at half maximum as narrow as about 280 kHz. The maximal reflectivity occurs at frequencies where the circulating light along the fast and slow axes are both resonating. At frequencies where only one of the fast and slow components resonates, the reflectivity drops by 3 dB. There is no power reflected from the input port at frequencies that neither circulating light is resonating. The effective FSR is thus dramatically increased by the vernier effect without shortening the fiber length. The side reflectivity suppression ratio is 3 dB, which is enough to obtain the lasing field only at the reflection peak when used in single frequency fiber lasers. The smaller the difference between the fast- and slow-axis indexes, the more the effective FSR is enhanced.

4 Conclusion

A HBF ring resonator with an inline reflector is newly proposed. Owing to the difference between the refractive indexes of the fast and slow axes in the HBF, the effective FSR of the HBF ring can be dramatically increased by the vernier effect. Since there is no need for compound resonators for generating the vernier effect, the proposed structure is simple but still provides with enhanced performance. All special properties improve the feasibility of making single frequency fiber lasers by employing the HBF ring resonator as a filter.

Acknowledgements

This work was partially supported by KOSEF through Grant No. R01-2006-000-11088-0 from the Basic Program Project and by the Second Phase of the Brain Korea 21 Project.

5 References

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