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Characteristics analysis of fiber optic ring resonator based on photonic crystal fiber

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ABSTRACT

Aiming at the requirement of high-powered in optical sensing systems based on resonator, photonic crystal fiber is proposed to optimize the performance of fiber optic ring resonator (FORR). In this paper, the model of FORR is obtained after derivation, and the characteristics of FORR based on TIR-PCF, Air-core PBF and conventional fiber are analyzed, respectively. Results show that the finesse of FORR is almost the same as that of conventional fiber when the intensity loss of coupler is less than 0.1. In addition, when the fiber length is less than 20m, the sensitivity of all the three fibers is the same, and with the further increases of fiber length, the sensitivity of FORR based on Air-core PBF decreases quickly than the others.

1. Introduction

As the essential component in Resonator fiber optic gyroscope (RFOG) [1–5], the characteristics of resonator is important for the veracity and real-time of navigation. So the optimization of fiber and coupler has been a hotspot and investigated by many researchers in colleges and graduate schools [6–9].

Investigation show that the characteristics of fiber exhibits large fluctuation when suffer from large temperature change rate which will influence the resonance curve of resonator. And photonic crystal fiber (PCF) and photonic band-gap fiber (PBF)exhibit better performance than conventional fiber due to its high birefringence, high nonlinearity and low confinement lossetc recently [10–12]. So its performance can be optimized and used in the designing of resonator to obtain favorable properties.

For example, Yang et al. analyzes the characteristics of resonator in series and parallel connection in theory, respectively. Results show that the spectrum of both structure accord well with experimentation [13]. He Zhou et al. analyzes the polarization model of resonator used in Brillouin fiber optic gyroscope (BFOG), and they also investigate the characteristics of polarization error due to the fluctuation of environment. Analysis shows that the polarization error can be depressed by 90°-rotation splicing which is also been approved by experiment [14]. Li. et al. analyzes the relationship between error and spectrum width of laser by formulating the output-electric-field in resonator used in BFOG. And after analysis, it is found that the spectrum width of laser is playing an important role in improving the performance of BFOG [15].

However, there are little reports about PCF used in optimization of RFOG or BFOG. So in this paper, the characteristics of resonator with conventional fiber, TIR-PCF and Air-core PBF are analyzed, and the resonance curves, finesse and sensitivity are also obtained.

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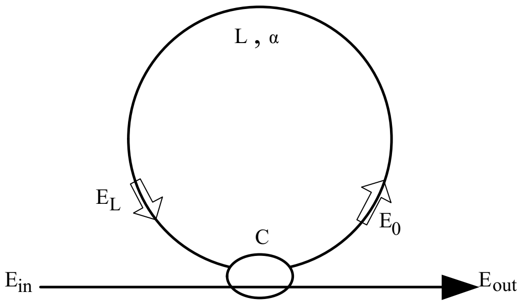

Fig. 1. Structure of fiber optic ring resonator.

2. Theory

The structure of fiber optic ring resonator is shown in Fig. 1, which consists of one bus waveguide, one coupler and one fiber loop. In this paper, both the bus waveguide and fiber loop are made of polarization maintaining fiber. Let L and α denote the length and power transmission coefficient of the fiber, γ and k denote the insert loss and coupling coefficient of coupler.

The intensity of electric field of output can be obtained as follows:

$$E_0 = \sqrt{1-\gamma}(i\sqrt{\kappa}E_{in} + \sqrt{1-\kappa}E_L)$$

$$E_{out} = \sqrt{1-\gamma}(\sqrt{1-\kappa}E_{in} + i\sqrt{\kappa}E_L)$$

$$E_L = E_0 e^{-\alpha L/2} e^{-i\beta L}$$

Then the normalized output can be obtained as

$$\frac{I_0}{I_{in}} = |\frac{E_0}{E_{in}}|^2 = \frac{k(1-\gamma)}{(1-R)^2 + 4\sin(\beta L/2)}$$

$$\frac{I_{out}}{I_{in}} = |\frac{E_{out}}{E_{in}}|^2 = \frac{1-\gamma}{1-k}\frac{(1-\gamma-R)^2 + 4\sin(\beta L/2)}{(1-R)^2 + 4\sin(\beta L/2)}$$

Where $\beta = n\omega/c$, n is the effective refractive index, $R = \sqrt{1-\gamma}\sqrt{1-\kappa}e^{-\alpha/2}$.

The spectrum width of resonator can be obtained as:

$$\Delta f_c = \frac{c}{nL}\cdot\frac{2}{\pi}\sin^{-1}\left(\frac{\kappa_r}{2\sqrt{1-\kappa_r}}\right)$$

Where $\kappa_r = 1-(1-\gamma)\exp(-\alpha L)$.

The sensitivity of resonator

$$\delta\Omega \cong \frac{\lambda P}{4A}\frac{\sqrt{2}\Gamma}{SNR}$$

Where

$$FSR = \frac{c}{nL} = \frac{1}{\tau}$$

$$F = \frac{FSR}{\Delta f_c} = \frac{\pi}{\frac{2}{\pi}\sin^{-1}\left(\frac{\kappa_r}{2\sqrt{1-\kappa_r}}\right)}$$

$$SNR = \sqrt{\frac{\eta t_0 I_0}{2hf_0}}\frac{T_{FRR\_\max} - T_{FRR\_\min}}{\sqrt{T_{FRR\_\max}}}$$

3. Results and analysis

In this paper, characteristics of the normalized output, finesse and sensitivity are analyzed with conventional fiber, TIR-PCF and Air-core PBF, respectively. And some parameters are as follows: $\lambda = 1.55\mu m$, $t_0 = 1s$, $I_0 = 1mW$, $\eta = 0.8$