Steady-state Performance Analysis of Brillouin Fiber Optic Gyroscope Ring Resonator

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ABSTRACT

Aiming at the requirement of Stimulated Brillouin fiber optic gyroscope, the characteristics of Stimulated Brillouin ring resonator are investigated, and obtain the steady-state performance when resonance. The relationship between the first stokes light power and input light is obtained after optimization, and also analyze the influence of resonator on the characteristics of the Stokes light power. Simulation results show that when the input pump power reaches the Stimulated Brillouin threshold, first Stokes light is obtained. And the power of stokes light increases with increasing fiber length.

INTRODUCTION

Since 1934 R. Y. Chiao and so on for the first time observed the phenomenon of stimulated Brillouin, after decades of research, the stimulated Brillouin scattering effect has been extensively studied in many fields of optics. Such as: stimulated Brillouin fiber lasers, stimulated Brillouin gyroscopes and nonlinear optics. Now, stimulated Brillouin scattering has become an important support for optical devices such as stimulated Brillouin fiber optic gyroscopes[1-5].

The research on Brillouin fiber optic gyroscope system shows that, the performance of the Brillouin ring resonator is the key to determining the performance of the gyro system. Brillouin ring resonator is mainly measured Stokes light, so it is important to ensure the stability of the Stokes light in the annular

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cavity. This paper analyzed the steady-state performance of the Brillouin ring resonator, and studied the stimulated Brillouin scattering in the resonant state. The influence of fiber length and resonant cavity performance parameters on the curve of Stokes light and pump light is obtained.

**THEORETICAL BASIS**

Figure 1. The diagram of Brillouin ring resonator.

The structure of the Brillouin ring resonator designed shown in Fig.1, mainly consists of a coupler (C), a directional coupler (C') and a fiber ring, the coupler couples the light into the fiber ring for transmission, the directional coupler outputs most of the light from one side, avoiding the resulting Brillouin light has an effect on the input light. We can see from Figure 1, light from the incident end transport through the coupler C into the fiber ring, when the power of the pump light satisfied Brillouin scattering conditions, will be generated at the end of the fiber after the stimulated Brillouin scattering, the reverse transmission was outputed via the directional coupler eventually. The length and intensity attenuation coefficients of the optical fiber are L and α, the insertion loss of the coupler C is γ, the intensity coupling coefficient is κ, the split coupler has a splitting ratio of 95:5. The normalized light intensity expression can be obtained by the following equation[6]:

\[
\frac{I_{p0}}{I_{in}} = \frac{E_{p0}^2}{E_{in}^2} = \frac{k(1-\gamma)}{(1-R)^2 + 4\sin(\beta L/2)}
\]

\[
\frac{I_{pout}}{I_{in}} = \frac{E_{pout}^2}{E_{in}^2} = \frac{1-\gamma(1-R)^2 + 4\sin(\beta L/2)}{1-k(1-R)^2 + 4\sin(\beta L/2)}
\]

(1)
In formula (1), \( \beta = n\omega / c \) is the propagation constant of light waves, \( n \) is the refractive index of the fiber, \( \omega \) is light wave angular frequency, \( C \) is the speed of light in the vacuum, \( R = \sqrt{1 - \gamma \sqrt{1 - \kappa e^{-\alpha z}}} \). When resonance occurs, the circular light intensity in the annular cavity reaches the maximum, the output of the light intensity is minimal, at this time \( \beta L = q \times 2\pi \) (\( q \) is any integer).

When resonance occurs, the optical signal will be limited the transmission in the annular cavity, at which point the pumping light signal is the weakest. When the pumped power in the annular cavity satisfies the stimulated Brillouin scattering condition, the backward stimulated Brillouin scattering occurs to produce Stokes light. The pump light and the Stokes light satisfy the following differential equations[7].

\[
\frac{dI_p}{dz} = -g_B I_p I_s - \alpha I_p
\]

\[
\frac{dI_s}{dz} = -g_B I_p I_s + \alpha I_s
\]

In formula (2), \( g_B = 5 \times 10^{-11} m / W \) is Brillouin gain factor, the differential equation shown in equation (2) is solved by setting the boundary condition:

\[
I_p(0) = \frac{P_p(0)}{A_{eff}} \\
I_s(L) = \frac{P_s(L)}{A_{eff}}
\]

\( A_{eff} \) is the effective cross-sectional area of the fiber used, \( P_p(0) \) and \( P_s(L) \) are respectively the pump power and Stokes light power, when \( z = 0 \) and \( z = L \). The differential equation of power form:

\[
P_p(z) = \frac{[P_p(0) - P_s(0)]P_p(0)\exp\left\{\frac{g_B}{A_{eff}}[P_p(0) - P_s(0)](1 - e^{-\alpha z})/\alpha\right\} e^{-\alpha z}}{P_p(0)\exp\left\{\frac{g_B}{A_{eff}}[P_p(0) - P_s(0)](1 - e^{-\alpha z})/\alpha\right\} - P_s(0)}
\]

\[
P_s(z) = \frac{[P_p(0) - P_s(0)]P_p(0)e^{-\alpha z}}{P_p(0)\exp\left\{\frac{g_B}{A_{eff}}[P_p(0) - P_s(0)](1 - e^{-\alpha z})/\alpha\right\} - P_s(0)}
\]

Equations (4) and (5) are analytical expressions of pump light and Stokes light with optical fiber loss items that can more accurately describe the power distribution of pump light and Stokes light in the fiber-optical.
NUMERICAL SIMULATION AND RESULT ANALYSIS

In this paper, analyzing the stimulated Brillouin scattering properties in resonant state, and analyze the relationship between the power of Stokes and the input pump power under different fiber lengths. The parameters used in the simulation are as follows: \( A_g = 80 \mu m^2 \) Fiber Brillouin gain \( g_B = 5 \times 10^{-11} m/W \), taking into account the optical fiber bending in the resonator and the insertion loss caused by the connector, select \( \alpha = 0.215 dB/km \) or \( \alpha = 0.0495 km^{-1} \). Stokes fiber at the end of the light is related to the type of fiber and the wavelength of the pump light, using the 1.55\( \mu m \) pump light and ordinary single-mode fiber selection \( P_{sl} = 0.05 nW \). This paper mainly analyzes the relationship between Stokes power at the output end and the length of the fiber ring cavity and the insertion loss of the coupler in the resonant state.

Figure 1. Power of output with different length of fiber \( (\gamma = 0.1) \).

Figure 2. Power of output with different length of fiber \( (\gamma = 0.15) \).

Figure 3. Power of output with different length of fiber \( (\gamma = 0.2) \).
This paper mainly analyzes the influence of the length of the cavity fiber on the relationship between the Stokes light at the output and the pump light at the input, and combined studied with the characteristics of coupler, the simulation results are shown in Fig. 1 to Fig. 3. It can be seen from Fig. 1 to Fig. 3 that when the input optical power is low, the output Stokes light power under different parameters is very low, which is approximately zero, when the Stokes light is in the annular cavity noise affects the performance of the system, and the stimulated Brillouin scattering will cause measurement errors to the system. And as the input power increases beyond the threshold power of the stimulated Brillouin, the Stokes light in the annular cavity increases sharply, and the stimulated Brillouin scattering will serve as a useful signal for use in, for example, Fiber optic gyroscope, stimulated Brillouin laser and other optical devices. It can be seen from the figure, with the input pump power increases, the need to choose high-power light source, the design of the light source also put forward higher requirements.

CONCLUSIONS

In this paper, Brillouin fiber ring resonator is designed for the application of stimulated Brillouin fiber optic devices. The resonant characteristics of the cavity and the excited Brillouin characteristics are analyzed in detail. The results show that the fiber produced by the fiber is very weak when the input pump power is low, which will affect the performance of the system as a noise signal. As the pump power increases to more than the first order Brillouin scattering of the threshold power, the Stokes light increases sharply, this phenomenon is the basis of the stimulated Brillouin fiber optic gyroscope and the stimulated Brillouin laser. At the same time, the simulation results also show that the insertion loss of the coupler and the fiber length affect the power of the Stokes light, which provides a reference for the study of the excited Brillouin fiber optic gyroscope and the stimulated Brillouin laser.

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REFERENCES