Er-doped fiber ring laser gyroscopes operating in continuous waves

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A direction related polarizer was inserted into a ring laser cavity to eliminate one of the two eigen-modes as well as spatial hole burning of the gain medium in a bidirectional Er-doped fiber ring laser. Thus, a fiber ring laser gyroscope (FRLG) operating in continuous wave was demonstrated. A beat signal of over 30-dB noise was observed and a good linear relation between the beat frequency shift and cavity rotation rate was obtained.

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Over the past years a number of polarimetric fiber laser sensors were demonstrated[1−4] by using a simple electric signal processing scheme for frequency readout. Among these fiber sensors, Er-doped fiber ring laser gyroscope (FRLG) is a typical one. Because of advantages of high sensitivity and wide dynamic range of measured rotation rate, the effort to create this gyroscope was never discontinued. An ideal operation of a FRLG requires single longitudinal mode in both the clockwise (CW) and the counter-clockwise (CCW) directions with stable and equal intensities[5]. However, in practical bidirectional Er-doped fiber ring lasers, the effect of spatial hole burning in gain medium not only causes the multimode operation[6], but also a strong CW-CCW mode coupling due to the scattering from the gain grating formed in the gain medium. The CW-CCW mode coupling leads to a serious CW-CCW mode competition and mode lock-in phenomenon which makes the ring laser used for gyroscope impractical. Two main approaches to elimination of the spatial hole burning have been investigated, one is to use mode-locked lasers[7,8] where the counter propagating pulses do not overlap in the gain medium. However, instead of frequency readout, differences of durations between neighboring pulses are measured, which are sensitive to intensity variations of neighboring pulses. The other approach is to insert nonreciprocal elements[9,10] (such as Faraday rotators) into the laser cavities to result in frequency bias and keep the laser still in continuous wave operation. However, there are two eigen-modes (transverse modes) working for each direction of the ring laser, which makes the laser used for gyroscope operation invalid.

In this letter, a direction-related polarizer (DRP)[11] was utilized in the ring cavity to filter one of the two eigen-modes in each direction, thus to generate a pair of orthogonally polarized modes in counter-propagating directions (one for each direction). At the same time, the phenomenon of the spatial hole burning was also eliminated and thus a bidirectional fiber ring continuous wave laser used for gyroscope operation was achieved.

The experimental configuration of the bidirectional single mode fiber ring laser is shown in Fig. 1. There were two key devices in the ring cavity. One was the nonreciprocal device DRP which was composed of a polarizer and two 45° Faraday rotators. If a light beam passing through the device in one direction is x-polarized, then the light beam in opposite direction will be y-polarized, and thus this device is able to select two linearly orthogonally polarized modes in the two counter-propagating directions (one for each direction). The other was a compound filter which consisted of one tunable filter (the bandwidth was 0.3 nm) and one Mach-Zehnder comb filter (the arms difference was 39.6 cm and its 3-dB bandwidth was 378 MHz). It was used to suppress the mode hopping from one longitudinal mode to the others. Two polarization controllers (PC1 and PC2) in the ring were used to adjust fiber birefringence in laser cavity and thus to change the frequency bias. The output light beams in both directions (CW and CCW) were coupled out through a 90/10 coupler; then they went through an isolator (OI1 and OI2), respectively. PC3 installed in one of the output arms was used to adjust the polarization so that the two light beams mixed with matched polarization states. Then the mixed beam was detected by a photo-detector (PD) at the output port of coupler 2. The total length of the ring resonator was about 6 m corresponding to the free space range (FSR) of 33.8 MHz, and the whole ring was made of normal single mode fiber except the gain fiber, which was an Er-doped fiber of 1 m in length and was pumped by using a laser diode (LD) working at 976 nm wavelength. All free fiber ends were angled to eliminate the back reflection.

The threshold pumping power of the fiber ring laser was about 16 mW and its lasing wavelength was 1550 nm.

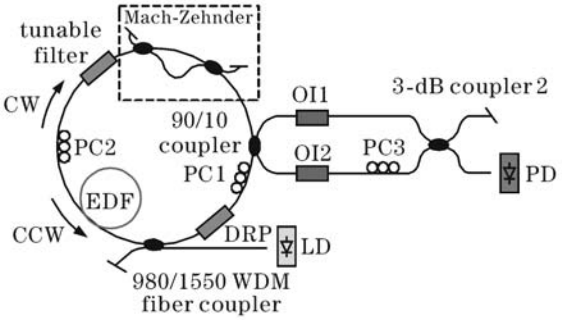

Fig. 1. Schematic of the experimental setup.

When the pumping power varied from 20 to 70 mW, the operation of single longitudinal mode in both CW and CCW directions was kept no change. The comparable intensities of the CW and CCW lasing modes were obtained by adjusting PC1 and PC2. Meanwhile, since the lasing modes in both directions were different due to using DRP, the phenomenon of spatial hole burning was suppressed, which ensures the operation of bidirectional single mode and avoids mode competition.

The light spectra for the CW, CCW, and CW-CCW combined outputs were measured by a scanning fiber ring resonator with FSR of 100 MHz, its scanning range was 73 MHz dependent on the applied voltage which was in sawtooth form. Figures 2(a) and (b) were taken when either of the output arms of the 90/10 coupler was bent to induce large bending loss so that only one of the CW and CCW outputs could reach the PD. Only one lasing spectrum was found in Fig. 2(a) or (b), while from Fig. 2(c) we had two lasing spectra for CW-CCW combined output. It implies that the operation of single longitudinal mode was achieved in both CW and CCW directions, which is just required for gyroscope usage.

Figure 3 shows the radio frequency (RF) spectrum of the CW-CCW beat signal. There was only one peak signal and its amplitude was of over 30-dB noise. Since the lasing modes in both directions were different, the frequency of the CW-CCW beat signal changed in the range of 100 kHz and 33 MHz depending on the adjustments of the PC1 and PC2 (i.e., adjustment of fiber birefringence).

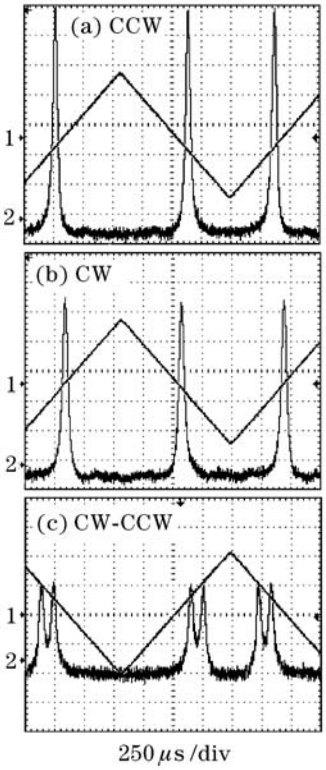

Fig. 2. Lasing light spectra for (a) CW, (b) CCW, (c) CW and CCW directions scanned by a fiber ring resonator.

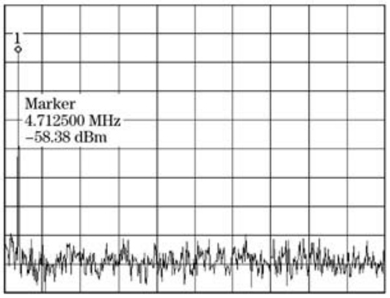

Fig. 3. RF spectrum of the CW-CCW beat signal.

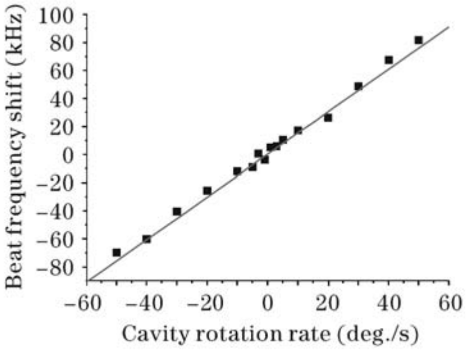

Fig. 4. Gyroscope beat frequency shift versus cavity rotation rate.

Before the fiber laser was used as a gyroscope, PC1 and PC2 were adjusted carefully to set a beat frequency as the frequency bias and at the same time to make the intensities of two lasing beams in opposite directions almost equal. Then the whole laser system was put on a controllable rotating platform to operate as a continuous wave gyroscope. Here, the frequency bias was selected to be 1.68 MHz.

Figure 4 shows a good linear relation between the beat frequency shift (from the frequency bias) against the cavity rotation rate, and the scale factor was measured to be 1.38 kHz/(deg.$\cdot$s^{-1}). However, because the fiber birefringence is temperature-sensitive, the null-drift from the frequency bias was as high as 5 deg.$\cdot$s^{-1}, which is able to be reduced if the whole laser system is packaged in a closed form.

Inserting a DRP into an Er-doped fiber ring laser, we have not only suppressed the phenomenon of spatial hole burning, but also obtained a real single lasing mode in each direction of both counter-propagating directions. Thus, a stable bidirectional fiber ring laser was achieved and a continuous wave fiber ring laser gyroscope was demonstrated. The CW-CCW beat signal was observed with signal-to-noise ratio of more than 30 dB, and a good linear relation between the beat frequency shift and the cavity rotation rate was obtained. This experiment is only a preliminary work, the null-drift should be reduced and the back-reflection needs to be suppressed.

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