Measurement of fiber birefringence using Lyot-Sagnac interferometer

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Abstract: We propose and demonstrate a simple and accurate optical fiber modal birefringence measurement technique. The technique is based on discrete tuning of the periodic spectrum produced by the dual-segmented Lyot-Sagnac fiber interferometer.
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**Abstract:** We propose and demonstrate a simple and accurate optical fiber modal birefringence measurement technique. The technique is based on discrete tuning of the periodic spectrum produced by the dual-segmented Lyot-Sagnac fiber interferometer.

The modal birefringence of optical fiber is an important parameter for both the polarization-dependent optical devices using high birefringence fibers [1] and the optical fiber telecommunication systems using low birefringence fibers [2]. Various techniques have been proposed to measure the birefringence of optical fibers [2][3][4]. A polarization-sensitive analysis of the backscattered signal was proposed for measurement of low-birefringence fibers [3], which requires a length of fiber too long to be practical for some applications. For the measurement of fibers with less than one beat length, fiber twist adjustment in the fiber-optic loop mirror was suggested [2]. The fiber Sagnac loop interferometer can be also used to determine the birefringence of fiber, where the birefringence, or beat length, of optical fiber could be determined from the periodic transmission spectrum of the standard fiber Sagnac loop interferometer [4]. However, this measurement technique has not been practical for a short section of a low-birefringence fiber because its periodic transmission function is very broad. In this paper, we suggest a novel technique based on a Lyot-Sagnac fiber interferometer to measure a birefringence of low-birefringence fiber by decreasing the width of the periodic transmission function without using a very long fiber length.

A conventional fiber Sagnac loop interferometer has been demonstrated for applications in wavelength-division multiplexing (WDM) filters and in sensors because of its several advantages, such as temperature insensitivity, high extinction ratio, and independence of input polarization [4]. This device consists of a directional coupler with two output ports connected by a birefringence fiber loop. A phase difference between two counter-propagating beams results in transmission dependence on wavelength or fiber birefringence. The wavelength period, $\Delta \lambda$, is a function of the $\Delta \mu \cdot L$ product value, which is the intrinsic properties of the fiber. This is shown in Eq. (1), where $\lambda$ is the operation wavelength, $\Delta \mu$ is the fiber modal birefringence, $L$ is the effective length of the fiber.

$$\Delta \lambda = \frac{\lambda^2}{\Delta \mu \cdot L}$$  \hspace{1cm} (1)

Since the wavelength period depends on the $\Delta \mu \cdot L$ product of the fiber, $\Delta \lambda$ is a large value for the short length of a low-birefringence fiber. This requires an additional curve fitting process to deduce the value accurately. [4]. In order to reduce the width of the transmission function significantly, one can use a very long length of a low-birefringence fiber, but a long fiber length is a cumbersome to deal with and there is an additional uncertainties due to a possible tension and strain in the spool.

![Fig. 1. Fiber Lyot-Sagnac interferometer setup.](image-url)
Recently, we demonstrated a novel Lyot-Sagnac filter capable of discretely tuning the wavelength period, $\Delta \lambda_s$ by varying the effective value of the $\Delta n L$ product [5]. The fiber Lyot-Sagnac loop interferometer is composed with a 50:50 fiber coupler, two sections of fiber with a length $L_1$ and $L_2$, and all-fiber polarization controllers acting as half-wave plates, $\lambda/2$. This is schematically shown in Fig. 1. The arrows inside circle represent the relative angle directions of the fast axis of high birefringence fiber and the plane of Sagnac loop. By changing the fast axis direction angles of two fiber, such as each fast axis is either $+45^\circ$ or $-45^\circ$ relative to the plane of Sagnac loop, we can discretely vary the effective value of $\Delta n L$ and, thus, the wavelength period of the filter is discretely tuned. For the fixed angle polarization angles, $45^\circ$, $0^\circ$, $-45^\circ$ at the position of a, b, and c in Fig. 1, respectively, the effective value of $\Delta n L$ for the device becomes $\Delta n_1 L_1 + \Delta n_2 L_2$. In the other combination of relative angles, $\theta(a) = 45^\circ$, $\theta(b) = -90^\circ$, and $\theta(c) = 45^\circ$, the effective value of $\Delta n L$ product becomes $\Delta n_1 L_1 - \Delta n_2 L_2$. Therefore, the distinct values of $\Delta n L$ product result in two different wavelength periods, $\Delta \lambda_S$ and $\Delta \lambda_L$ as shown in Eq. (2), where $S$ denotes the summing case and the $L$ denotes the difference in that length;

$$\Delta \lambda_s = \frac{\lambda^2}{\Delta \omega S L_1 \pm \Delta \omega L_2}$$

(2)

In the fiber Lyot-Sagnac loop configuration of the Fig. 1, the section 1 is used as a reference section with a known high birefringence fiber and the section 2 becomes a measurement section having a low birefringence fiber to be measured. As compared with the conventional Sagnac loop, we could decrease the bandwidth of periodic transmission function of low-birefringence fiber easily and precisely since the denominator of Eq. (2) is increased as the larger value of $\Delta n_1 L_1$ is applied. Here, the small value of $\Delta n_2 L_2$ controls the discretely tuned two bandwidths of periodic transmission spectrum, $\Delta \omega S$ and $\Delta \omega_L$, as represented in the Eq. (2). Therefore, from measuring the two distinct wavelength periods $\Delta \lambda_S$ and $\Delta \lambda_L$, and the length of $L_2$, we could precisely determine the birefringence, $\Delta n_L$, of optical fiber. From the Eq. (2), the equation for the birefringence value of fiber 2 can be shown in Eq. (3);

$$\Delta n_2 = \frac{\lambda^2}{2L_2} \left( \frac{1}{\Delta \omega_S} - \frac{1}{\Delta \omega_L} \right)$$

(3)

Note that the values of $\Delta n_1$ and $L_1$ of the reference fiber 1 are not required in calculating the birefringence value of fiber 2. For the experimental demonstration of measuring the small value of the $\Delta n_2 L_2$ in the fiber Lyot-Sagnac loop configuration, we used a commercial high-birefringence fiber 1 (FS-PM-7811) with $\Delta n_1$ of $7.47 \times 10^{-4}$ and a low-birefringence fiber 2 with $\Delta n_2$, of $2.6 \times 10^{-5}$. The birefringence value of fiber 2, which is 30 times smaller than that of fiber 1, was designed to set up the fiber Lyot-Sagnac loop with a similar length for each fiber section. Fig 2 shows the calculated transmission spectrum of the conventional fiber Sagnac loop interferometer having the fiber 2 with the length, $L_2$, of 1.8m. It is impossible to measure the wavelength period value, $\Delta \lambda$, of 51.3 nm using the conventional C-band light source of 1530–1565 nm wavelength range because the wavelength period value is larger than wavelength width of light source. Though we could measure the wavelength period value using a broadband white light source, it is hard to couple into a single mode fiber for the measurement and is a low power per bandwidth. This also requires a following curve fitting process to estimate the birefringence of fiber from the measured value of $\Delta \lambda$ and the Eq. (1) as explained earlier.

Fig. 2. Typical calculated transmission spectra of the conventional fiber Sagnac loop interferometer with low birefringence fiber 2 only.
Fig. 3. Experimental measurement of two distinct bandwidths of periodic transmission of the fiber Lyot-Sagnac loop interferometer.

In the proposed fiber Lyot-Sagnac interferometer configuration, we could decrease the width of periodic transmission function using the reference section with 1.02 m of the fiber 1 (FS-PM-7811), which has a shorter length and a significantly higher birefringence than fiber 2. Fig. 3 (a) and (b) show the corresponding experimental result, respectively. The measured two different wavelength period values, $\Delta \lambda_5$ of 2.97 nm and $\Delta \lambda_4$ of 3.36 nm, can be directly obtained from the graph and the Eq. (3) can be used to determine the birefringence value as $2.61 \times 10^{-5}$. This method does not require the curve fitting because the wavelength period only vary insignificant amount within the spectral range needed to extract the period values. In general, $\Delta n_1 \cdot L_1$, of a reference fiber should be between 10 to 50 times the $\Delta n_2 \cdot L_2$, of a low birefringence fiber in question. In this experiment, the transmission spectra are measured using an Erbium-doped fiber laser source at the center wavelength of 1550 nm and an optical spectrum analyzer (Ando, AQ-6315) with a resolution of 0.05 nm.

In conclusion, we have proposed and demonstrated a simple and precise low-birefringence measurement technique for based on a Lyot-Sagnac interferometer configuration. Using the novel scheme, we discretely tuned the bandwidths of periodic transmission spectrum to induce the value of the $\Delta n \cdot L$ product.

References