Distributed Birefringence Measurement of Polarization Maintaining Fiber Using Transient Brillouin Grating

Yongkang Dong, Liang Chen, and Xiaoyi Bao*
Department of Physics, University of Ottawa, Ottawa, ON, K1N 6N5, Canada
*xbao@uottawa.ca

Abstract: We propose a true distributed birefringence measurement of polarization-maintaining fiber based on transient Brillouin grating. A birefringence variation of 2.5×10^{-6} along 8 m Bow-tie fiber is measured with 20 cm spatial resolution.

OCIS codes: (060.2420) Fibers, polarization maintaining; (290.5900) Scattering, stimulated Brillouin

1. Introduction and principle

Polarization-maintaining fibers (PMFs) have attracted considerable interest in telecommunication and optical sensing community. The phase modal birefringence of PMF is an important parameter for its applications. Many methods have been proposed to measure the birefringence of PMF [1-4]. During the fabrication of the PMF, due to the non-uniformity of the material and environmental condition in fiber drawing process, it is inevitable to introduce birefringence variation along the fiber. However, the reported methods can only give the average birefringence of the test fiber, and can not characterize the birefringence variation along the fiber. In this paper, to the best of our knowledge, we propose a true distributed birefringence measurement of PMF based on transient Brillouin grating (TBG) for the first.

In this method, two short counter-propagating pump1 and pump2 pulses, where the frequency of pump1 is larger than that of pump2 by a Brillouin frequency shift ν_B, are launched into one axis of the PMF to excite a TBG through stimulated Brillouin scattering. Following pump2 pulse, a long probe pulse is launched into another axis, and energy from the probe pulse could be partly reflected at the expense of TBG. A maximum reflected probe signal could be obtained when the frequency difference $\Delta\nu$ between the pump2 and probe satisfies the following equation $\Delta\nu = \Delta n \cdot \nu / n$ [5-7], where Δn is the local phase modal birefringence, n is the average group refractive index and ν is the optical frequency of probe pulse. The spatial resolution is the length of the local TBG determined by the pump pulse width, so that a high spatial resolution can be obtained by using short pump pulses. When $\Delta\nu$ is swept, $\Delta n(z)$ will be calculated from recovered information of the reflected probe pulse.

There are two schemes to perform the birefringence measurement: the TBG is excited in the fast axis and probed in the slow axis and the TBG is excited in the slow axis and probed in the fast axis, shown as Fig. 1 (a) and (b), respectively. For both cases, the frequency differences (birefringence frequency shift) between the pump2 and probe are the same, which is proportional to the local birefringence. As can be seen in the following context, the birefringence frequency shift is about 43 GHz for Bow-tie, which is difficulty to be measured directly. In order to precisely measure the birefringence frequency shift and thus accurately calculate the birefringence, we choose the second scheme. In this scheme, the frequency difference between the pump1 and probe is smaller than the birefringence frequency shift by a Brillouin frequency shift, and can be measured by a high-speed photo-detector and an electrical spectrum analyzer. So the birefringence frequency shift equals to the measured frequency difference between pump1 and probe plus a Brillouin frequency shift.

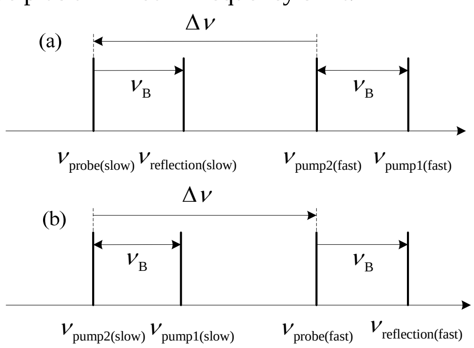

Fig. 1 Frequency relationship of pump1, pump2, probe and reflection: (a) the TBG is excited in the fast axis and probed in the slow axis and (b) the TBG is excited in the slow axis and probed in the fast axis.

2. Experimental setup and results

The experimental setup of distributed birefringence measurement of PMF based on TBG is shown in Fig. 2. Two narrow linewidth (3 kHz) fiber lasers operating at 1550 nm are used to provide the pump1 and pump2, respectively, and their frequency difference is locked by a phase locking loop in a frequency counter. A tunable laser with a wavelength resolution of 0.1 pm is used as probe light. The frequency difference between pump1 and probe is monitored and recorded by a high-speed detector with a bandwidth of 45 GHz (Model 1044, New Focus) and an electrical spectrum analyzer (44 GHz, E4446A, Agilent). The EOM1 is used to generate a 2 ns square-shaped pulse. Two high extinction ratio EOM2 and EOM3 are used to generate the square-shaped 2 ns pump2 pulse and 8 ns probe pulse with the extinction ratio larger than 45 dB, which are then combined with a 3-dB coupler. The power of pump1 pulse, pump2 pulse and probe pulse in the PMF are about 200 mW, 30 W and 30 W, respectively. The two pump pulses are launched into the slow axis and the delay between them is well controlled to create a TBG at a specific location. Following the pump2 pulse with a time delay of 2 ns, the probe pulse is launched into the fast axis and its reflection by the local TBG is detected by a 1-GHz detector. A tunable fiber Bragg grating with a bandwidth of 0.2 nm is used to filter out the transmitted pump1 pulse. A 8 m Bow-tie PM fiber is used as fiber under test. The measured ν_B of the Bow-tie fiber at room temperature is 10.815 GHz and the Brillouin spectrum width is 61 MHz.

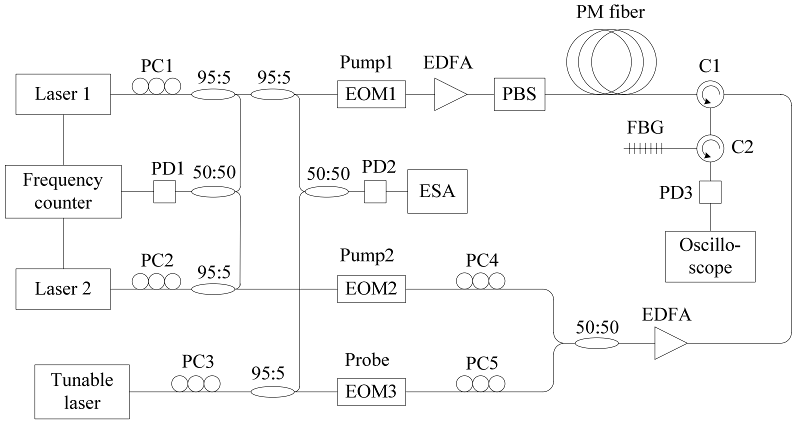

Fig. 2 Experimental setup. PC: polarization controller, EOM: electro-optic modulator, PBS: polarization beam splitter, C: circulator, PD: photo-detector, EDFA: Erbium-doped fiber amplifier, ESA: electrical spectrum analyzer.

The measured transient Brillouin grating spectrum (TBGS) is the convolution of the probe pulse spectrum and the intrinsic TBGS, therefore a long probe pulse is preferable to get a narrow TBGS [6]. However, the probe pulse width is limited by the TBG lifetime of ~10 ns in optical fibers. Moreover, reflected light from the front part of the probe pulse could be depleted by the back part of the probe pulse, which decreases the signal intensity and is also a limitation to the probe pulse width. All the following TBGS are measured with 8 ns probe pulse width. In our experiment, the effective length of the TBG, i.e., spatial resolution is ~ 20 cm for the 2 ns pump pulses.

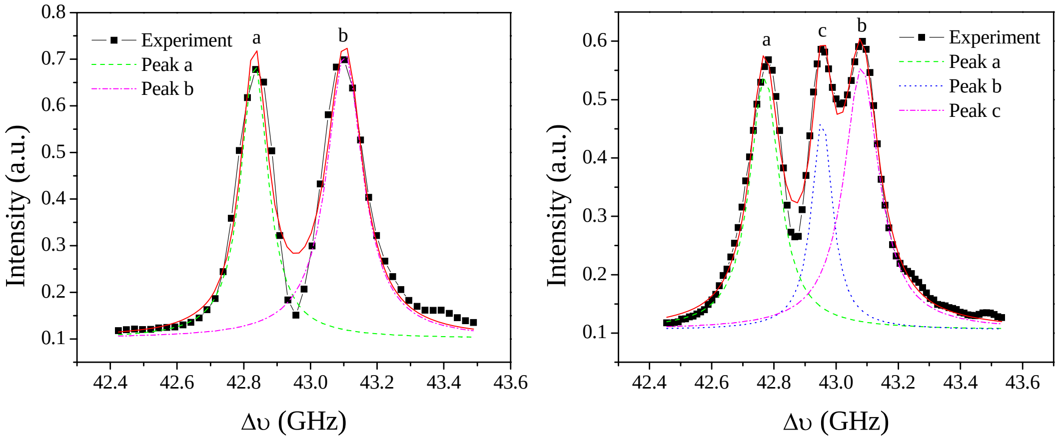

Fig. 3 Typical TBGSs in Bow-tie fiber (a) TBGS with 2 peaks and (b) TBGS with 3 peaks.

Fixing the frequency difference of pump1 and pump 2 at 10.815 GHz for the strongest TBG, its response is measured by tuning the tunable laser. The measured typical TBGSs of Bow-tie fiber are shown in Fig. 3, where most part of the fiber exhibit a two-peak spectrum shown as Fig. 3 (a) except at 0.5 m~0.7 m with three-peak spectrum shown as Fig. 3 (b). Multi-peak spectrum means that there are multiple waveguide modes existing in the core, and thus the birefringence should be replaced by multi-mode propagation refractive indices for this fiber since it characterizes the refractive index difference between different polarization modes; each peak corresponds to a phase refractive index difference between two axes of PMF.

Because peak a and peak b exist along the whole fiber shown as Fig. 3, we choose peaks a and b to characterize the birefringence of Bow-tie fiber with the average group refractive index of silica core to be 1.463. The calculated birefringence is plotted in Fig. 4. It can be seen that the birefringence has a characteristic periodic variation with a period of ~3.5m, and exhibits an increasing tendency along the fiber, which indicate that there could be another large period. Different periods could correspond to different disturbance factors during the fiber drawing process. The two peaks exhibit the same variation tendency with the frequency difference between them kept as a constant. The average frequency difference between the two peaks is 286 MHz, which corresponds to a refractive index difference of 2.1×10^{-6}. For individual peak, the birefringence variation is $\sim2.5\times10^{-6}$ along the 8 m fiber.

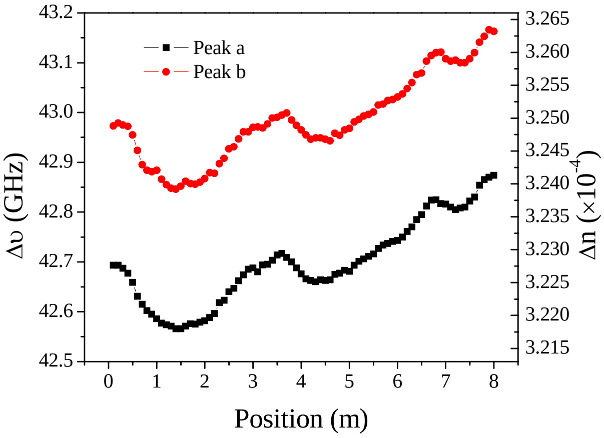

Fig. 4 Measured distributed birefringence of 8 m Bow-tie fiber using peak a and peak b.

3. Conclusion

In summary, we have proposed and demonstrated a true distributed birefringence measurement of polarization maintaining fiber based on TBG, where two short pump pulses was used to create a local TBG and a long probe pulse was used to map the TBGS associated with birefringence. The distributed birefringence of a 8 m Bow-tie fiber was measured with 20 cm spatial resolution. The results show that there are multiple waveguide modes existing in the core, and the birefringence changes at 3.5 m period in the tested Bow-tie fiber.

The authors acknowledge the research supports from Natural Science and Engineering Research council of Canada and Canada Research Chair Program.

4. Reference

[1] B. E. Olsson, M. Karlsson, and P. A. Andrekson, "Polarization mode dispersion measurement using a Sagnac interferometer and a comparison with the fixed analyzer method," IEEE Photo. Technol. Lett. **10**, 997-999 (1998).

[2] C. S. Kim, Y. G. Han, R. M. Sova, U. C. Paek, Y. Chung, and J. U. Kang, "Optical fiber modal birefringence measurement based on Lyot-Sagnac interferometer," IEEE Photo. Technol. Lett. **15**, 269-272 (2003).

[3] D. A. Flavin, R. McBride, and J. D. C. Jones, "Dispersion of birefringence and differential group delay in polarization-maintaining fiber," Opt. Lett. **27**, 1010-1012 (2002).

[4] P. Hlubina and D. Ciprian, "Spectral-domain measurement of phase modal birefringence in polarization-maintaining fiber," Opt. Express **15**, 17019-17024 (2007).

[5] V. P. Kalosha, W. Li, F. Wang, L. Chen, and X. Bao, "Frequency-shifted light storage via stimulated Brillouin scattering in optical fibers", Opt. Lett. **33**, 2848-2850 (2008).

[6] Y. Dong, X. Bao, and L. Chen, "Distributed temperature sensing based on birefringence effect on transient Brillouin grating in a polarization-maintaining photonic crystal fiber," Opt. Lett, **34**, 2590-2592 (2009).

[7] K. Y. Song, W. Zou, Z. He, and K. Hotate, "Optical time-domain measurement of Brillouin dynamic grating spectrum in a polarization-maintaining fiber," Opt. Lett. **34**, 1381-1383 (2009).