Using a wavelength tunable diode laser to measure the beat length of a birefringent fiber

Fang-Wen Sheu and Shu-Chun Yang

Department of Applied Physics, National Chiayi University, Chiayi 60004, Taiwan

Tel: +886-5-2717993; Fax: +886-5-2717909; E-mail: fwsheu@mail.ncyu.edu.tw

Abstract: In this report we demonstrated a method for measuring the beat length of a birefringent fiber. In this method the beat length is determined from the wavelength dependence of the phase difference between two orthogonally polarized modes at the output end of a sample fiber. In addition to the mode hopping of the laser diode's optical wavelength due to the temperature variation, we have also observed the phase hopping of the output light polarization at the end face of the birefringent fiber. It is a simple and precise method to determine the birefringence magnitude of anisotropic materials in an optics laboratory course.

OCIS codes: (140.2020) Diode lasers; (260.1440) Birefringence; (060.2420) Fibers, polarization-maintaining

1. Introduction

In heterodyne-type optical communications or some kinds of fiber-optic measurement, the polarization state of the received signal must be kept constant. To meet this requirement, various birefringent fibers have been developed in which the propagation constants of two orthogonally polarized modes (HE_x and HE_y) are different. The degree of such modal birefringence is often expressed by the beat length between these two modes. There are many methods to measure the beat length. In this report, the beat length is determined from the wavelength dependence of the phase difference between the two modes at the output end of a sample fiber [1].

2. Experimental Setup and Principle of Measurement

Figs. 1(a) and 1(b) show the schematic diagram and photograph of the experiment setup. An AlGaInP diode laser (THORLABS DL3147-060 Sanyo) is used as the light source. As shown in Fig. 2, the optical wavelength is tunable by controlling the laser diode's temperature, and the laser spectrum is measured by an optical spectrum analyzer (ADVANTEST Q8384). The linearly polarized laser light, having a polarization angle of 45° with respect to the principal axes of the birefringent sample fiber [Figs. 1(c) and 1(d), 3M FS-PM-7811, $\Delta n = 7.718\times10^{-4}$], is launched at the fiber input end via a microscopic objective lens [2]. The phase difference between the HE_x and HE_y modes at the fiber output end is given as $\phi = \ell\,\Delta\beta$, where $\Delta\beta = \frac{2\pi}{\lambda}\cdot\Delta n$ denotes the difference in the propagation constants of the two modes and ℓ is the fiber length. The phase difference ϕ can be determined from the maximum and minimum transmitted light intensities I_a and I_b, respectively, of the elliptical polarization as $\sin\phi = \pm\frac{2\sqrt{I_a I_b}}{I_a + I_b}$, when we rotate an analyzer behind the fiber and measure the transmitted optical power. Because of the variation of the device temperature, the optical wavelength λ of the laser light source is swept by a small amount of $\Delta\lambda$, where $|\Delta\lambda| << \lambda$. Then the change in ϕ induced by $\Delta\lambda$ is given as $\Delta\phi = \ell\,\Delta\lambda\frac{d(\Delta\beta)}{d\lambda} = \ell\,\Delta\lambda(-\frac{2\pi}{\lambda^2}\Delta n) = \ell\,\Delta\lambda(-\frac{\Delta\beta}{\lambda}) = -\frac{\Delta\lambda}{\lambda}\ell\Delta\beta$. Using the definition of beat length $L_B = \frac{2\pi}{\Delta\beta}$, it can be rewritten as $\frac{\Delta\phi}{\Delta\lambda} = -\frac{1}{\lambda}\frac{2\pi\ell}{L_B}$. Thus, by measuring the phase difference ϕ as a function of the wavelength λ, we can calculate the $\phi-\lambda$ relationship and hence obtain the value of beat length L_B.

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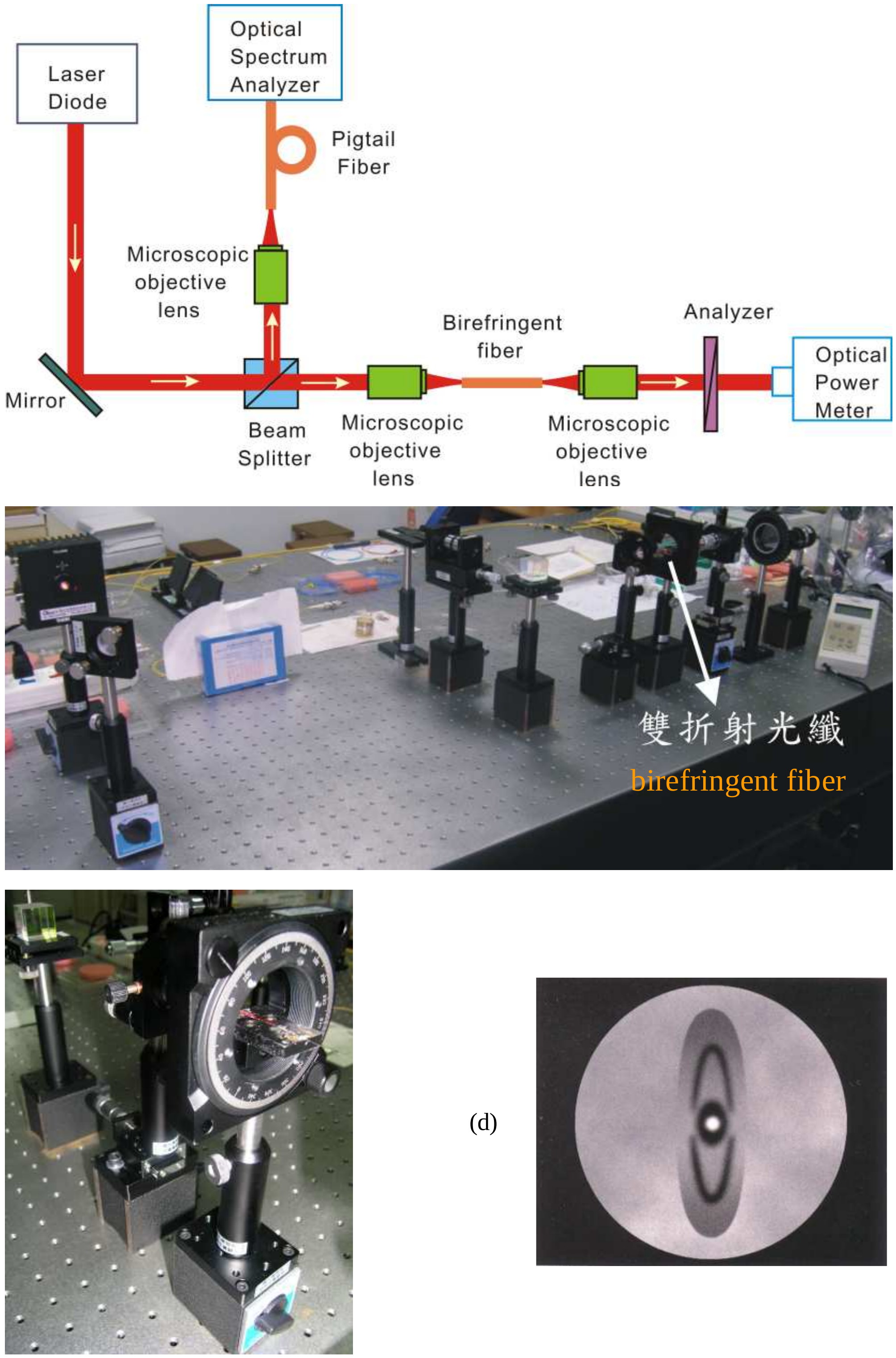


Fig. 1. The (a) schematic diagram amd (b) photograph of the experimental setup. (c) The birefringent fiber under test in a rotary mount. (d) The cross-section picture of the birefringent fiber (3M Single Mode Polarization Maintaining Fiber, FS-PM-7811, THORLABS INC. Catalog 2004).

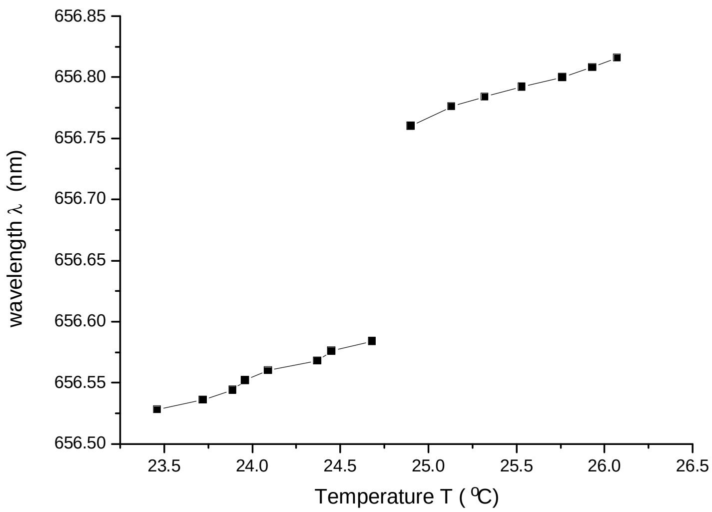
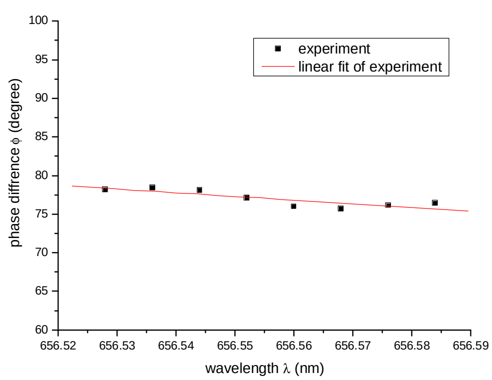


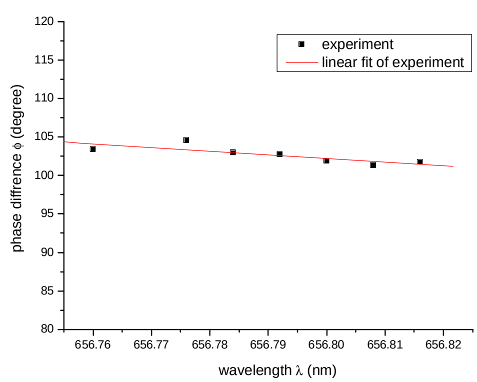
Fig. 2. The laser optical wavelength versus the laser diode's temperature.

3. Experimental Results

The wavelength dependence on the device temperature reveals a discontinuous change because of the mode hopping of the laser diode. As shown in Fig. 2, there are two kinds of longitudinal modes, one of which has a center wavelength λ_c = 656.556 nm and the other has λ_c = 656.79 nm. The corresponding measured $\phi - \lambda$ diagrams also exhibit a hopping phenomenon and are shown in Figs. 3(a) and 3(b). The slopes of their linear fitting curves are $\frac{\Delta\phi}{\Delta\lambda} = -47.19^\circ$/nm and $\frac{\Delta\phi}{\Delta\lambda} = -47.71^\circ$/nm, respectively. The predicted beat lengths $L_B = \lambda_c / \Delta n$ are 0.8507 mm and 0.8509 mm, respectively. The sample fiber has a length ℓ = 7.2 cm. Using the relationship $\frac{\Delta\phi}{\Delta\lambda} = -\frac{1}{\lambda_c}\frac{2\pi\ell}{L_B}$, we can calculate the measured beat length L_B to be 0.8366 mm and 0.8272 mm for the two kinds of longitudinal modes, and the error percents are 1.657 % and 2.785 %, respectively. The errors may be due to the device thermal fluctuation in tuning the temperature of the laser diode.



(a)



(b)

Fig. 3. The measured results and linear fits of the phase difference ϕ as a function of the wavelength λ for (a) the longitudinal mode with center wavelength λ_c = 656.556 nm, and (b) another longitudinal mode with center wavelength λ_c = 656.79 nm.

4. Conclusion

We have successfully achieved measuring the beat length of a birefringent fiber by a wavelength tunable diode laser. In this method the beat length is determined from the wavelength dependence of the phase difference between two orthogonally polarized modes at the output end of a sample fiber. In addition to the mode hopping of the laser diode's optical wavelength due to the temperature variation, we have also observed the phase hopping of the output light polarization at the end face of the birefringent fiber, because the fiber length is far larger than that of the birefringent retardation wave plates. In an optics laboratory course, this simple method can be used to determine the value of beat length, or the magnitude of birefringence, of any anisotropic materials precisely.

Acknowledgements

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