

Piezoelectric strain coefficient measurement based on elasto-optic effect of fiber

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Based on elasto-optic effect theory, we present a simplified model for the fiber squeezer assisted with a piezoceramic actuator (PZT), and it is experimentally demonstrated with reasonable approximation. Results show that there is a quadratic polynomial relationship between the arccosine reciprocal value of light intensity outputted from polarization analyzer and the reciprocal value of applied voltage for the PZT. Using this formula, the key parameters of the PZT such as the piezoelectric strain coefficient are further obtained. Our conclusions are significant for accurate measurement and polarization control.

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Squeezing the fiber is an important method to adjust and control the polarization state in optical fiber communication^[1,2]. Its principle is based on the elasto-optic effect of the fiber under squeezing. Due to the unique squeezing performance of piezoceramic actuator (PZT)^[1-3], it is widely used in the fiber squeezer to produce elasto-optic effect. In order to properly adjust the polarization state, especially to realize the automatic control of polarization state, it is important to reveal the elasto-optic effect and the relationship between PZT squeezing and polarization state. Here we made a fiber squeezer by using a PZT (PTBS200), while investigating in detail the fiber elasto-optic effect, and obtaining the polynomial relationship between the light intensity and the PZT driving voltage, which allows us to further achieve key parameters of the PZT.

Figure 1 shows the schematic diagram of the fiber squeezer. We denote the stress of the fiber by σ . According to the elasto-optic effect^[3], the phase differences of two polarized lights along the squeezing and its orthogonal direction can be expressed as

$$\delta = \frac{\pi n^3}{\lambda E} (1 + \rho)(p_{12} - p_{11})\sigma. \quad (1)$$

For fused silica fiber, the elasticity modulus $E = 7.0 \times 10^{10}$ N/m², Poisson's ratio $\rho = 0.17$, photoelastic coefficients $p_{11} = 0.121$, $p_{12} = 0.270$, and refractive index $n = 1.545$. When $\lambda = 1550$ nm, we get

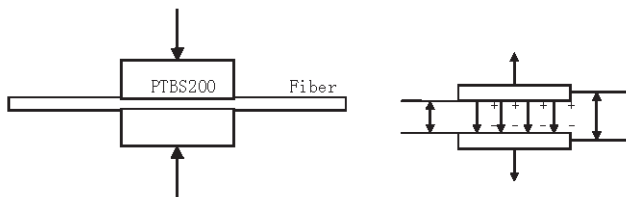


Fig. 1. Schematic diagram of the fiber squeezer.

$$\delta = 1.862 \times 10^{-5} \sigma. \quad (2)$$

Assume the included angle is α between the axis of the polarization analyzer and the x -axis. The output light intensity after the polarization analyzer will be

$$P_a = P_x \cos^2 a + P_y \sin^2 a + \sqrt{P_x P_y} \sin(2a) \cos \delta, \quad (3)$$

where P_x and P_y are the light intensities along the x -axis and the y -axis.

In our experiment, we keep α and the incident light with its polarization (namely, P_x and P_y are fixed). Ignore the loss of extrusion, then Eq. (3) can be simplified as $P_a = A + B \cos \delta$, where $A = P_x \cos^2 a + P_y \sin^2 a$ and $B = \sqrt{P_x P_y} \sin(2a)$. Then when the detected light intensity reaches the maximum, we get $\delta = 0^\circ$, and when it reaches the minimum, $\delta = 180^\circ$. Thus, we have

$$\sigma = 5.37 \times 10^4 \arccos[(P_a - A)/B]. \quad (4)$$

On the other hand, considering the capacitance characteristics of the PZT, we established the equivalence principle diagram as shown in Fig. 1. Assume C as the equivalent capacitance of PZT, d is the separation distance, S_0 is the effective area of capacitance electrode, and U is the applied voltage. The extrusion force generated by PZT can be expressed as $F = qE = CU^2/d = \varepsilon S_0 U^2/d^2$. Denoting the squeezing area by S and $S_0/S = k$, then the squeezing stress σ in optical fiber is

$$\sigma = F/S = \varepsilon U^2 S_0 / d^2 S = k \varepsilon U^2 / d^2. \quad (5)$$

As $d = d_0 + \Delta l$, where d_0 is the original distance when $U = 0$, Δl is the micro-displacement produced by the driving voltage U . Under the condition of loading, Δl is

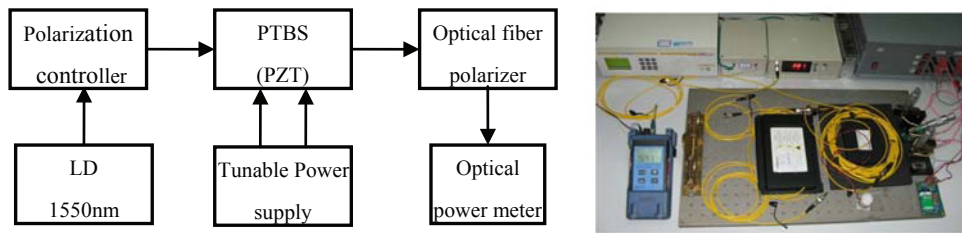


Fig. 2. Left: experimental scheme, right: picture of the set-up.

determined by the following formula:

$$\Delta l = \chi_1 E + \chi_2 E^2 \approx \chi_1 U/d_0 + \chi_2 U^2/d_0^2, \quad \Delta l \ll d_0, \quad (6)$$

so $S(p) = 1.261 \times 10^{-6} + 9.133 \times 10^{-4} U^{-1} - 3.390 \times 10^{-3} U^{-2}$

$$S(p) = 4.109 \times 10^{-7} + 1.027 \times 10^{-3} U^{-1} - 5.761 \times 10^{-3} U^{-2}. \quad (7)$$

Thus,

$$\sigma^{-1} = a_0 + a_1 U^{-1} + a_2 U^{-2} \quad (a_0 = 2\chi_2/k\epsilon d_0; a_1 = 2\chi_1/k\epsilon; a_2 = d_0^2/k\epsilon). \quad (8)$$

Therefore, the relationship between σ^{-1} and U^{-1} is quadratic polynomial. Recall Eq. (4), and note $S(P) = \{5.37 \times 10^4 \arccos[(P_a - A)/B]\}^{-1}$, we get

$$S(P) = a_0 + a_1 U^{-1} + a_2 U^{-2}. \quad (9)$$

The experimental scheme and its set-up are presented in Fig. 2.

The PZT used in the experiment is the PTBS200/8×8/10 model (Boshi Precision Measure & Control Co., Ltd). Its nominal displacement is 10 μm (maximum: 13 μm) and static capacity is 1.1 μF . We record the driving voltage (U) and corresponding optical power (P) and by plotting the experimental data and fitting it we get the quadratic polynomial fitting curve, which is shown in Fig. 3.

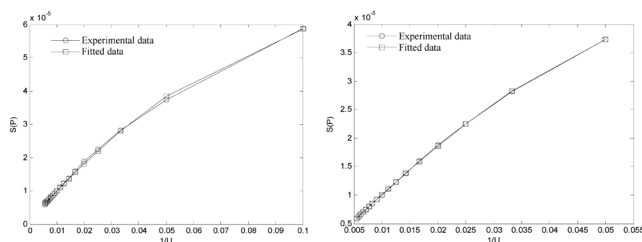


Fig. 3. Experimental data and its fitting under different starting voltages, left: 10 V and right: 20 V.

From Fig. 3 we can find that the experimental data match well with the quadratic curve, which have the same format as Eq. (9). But the polynomial coefficients differ a bit for different starting voltages. The reason is that there is a plastic coating layer outside the fiber, though we have added a stress in advance, it does not fully squeeze it. Therefore, under low starting voltage (10 V), the plastic coating layer reduces the deformation of the silica fiber, so the coefficients are a bit smaller than higher starting voltage (20 V).

Comparing the results in Fig. 3 (right) with Eq. (9), we get $a_1 = 1.027 \times 10^{-3}$. Moreover, we know that $\epsilon = 6.106 \times 10^{-8}$ while $\epsilon_r = 6900$ ^[4], $S_0 = 8 \times 8 = 6.4 \times 10^{-5} \text{ m}^2$, $S = 8 \times 0.25 = 2 \times 10^{-6} \text{ m}^2$, we get $k = S_0/S = 32$. Then we obtain the key parameter of the PZT: $\chi_1 = 1.003 \times 10^{-9} \text{ (m}^2/\text{V)}$.

In conclusion, we investigate the elasto-optic effect in the optical fiber in detail, and present a simplified model for the fiber squeezer assisted with the PZT. Theoretical analysis shows that there is a quadratic polynomial relationship between the arccosine reciprocal value of light intensity outputted from polarization analyzer and the reciprocal value of applied voltage for the PZT, which is demonstrated by the experiment. More important, based on the experimental results, we obtain the piezoelectric strain coefficient of the PZT which is close to the value provided by the company. Our conclusions are significant for polarization control and accurate measurement of PZT parameters.

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