Characteristics of a PLZT electro-optical deflector

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A beam deflector was designed and fabricated by using a lead lanthanum zirconate titanate (PLZT) ceramic with high quadratic electro-optic (EO) effect, based on refraction at an interface between areas with and without applied voltage. Its EO coefficients of $R_{33} = 2.1 \times 10^{-16}$ V^2/m^2 and $R_{13} = -0.37 \times 10^{-16}$ V^2/m^2 were obtained. Moreover, the hysteresis characteristics of the EO deflection were observed, and the effects of temperature on the characteristics of beam deflector were also investigated in detail.

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High speed beam steering devices have important applications in variety of areas, such as radar, optical switch and cross-connectors, acquisition-pointing-tracking systems. Mechanical rotator type deflectors have been widely used; while a deflector without moving component is more attractive for higher speed and higher reliability. There are several kinds of optical deflectors to be developed. Among them optical phase arrays (OPA) and acoustic-optic deflectors were paid attention mostly; nevertheless an elector-optic (EO) deflector is another good candidate. With the development of materials with large EO coefficients, EO deflectors may provide a larger deflection angle, and they have also received more attention, including lead lanthanum zirconate titanate (PLZT)[1−3], lithium niobate ($LiNbO_3$)[4,5], lithium tantalate ($LiTaO_3$)[6], EO polymeric material[7], and so on. Compared with other EO materials, PLZT has some distinct advantages, such as higher EO coefficients, availability of larger volume materials, and low cost.

In this letter, an EO beam deflector with a triangular electrode was designed and fabricated on a PLZT ceramic slab. The deflection angle varying with the applied voltage was measured; the quadratic hysteretic characteristics resulting from the EO effect were observed; and the effects of temperature on the characteristics of PLZT beam deflector were also investigated. Experimental results indicate that PLZT is a promising material for EO beam deflector.

The PLZT ceramics used in this study is a quadratic EO material, its La/$PbZrO_3$/$PbTiO_3$ proportion is 9/65/35, which is supposed with the largest EO coefficient in the PLZT family. To the 9/65/35 PLZT ceramic, only quadratic terms are considered since unpoled quadratic PLZT ceramics have a symmetric random structure and exhibit little linear EO effect. If an external electric field is applied to the material in y-direction, and the incident optical beam is in the z-direction ($E_x = E_z = 0$; $E_y = E$), the refractive index changes for y- and x-polarized beams can be written as

$$n_y = n + \Delta n_{/\!/} = n - \frac{1}{2} n^3 R_{33} |E|^2, \tag{1a}$$

$$n_x = n + \Delta n_{\perp} = n - \frac{1}{2} n^3 R_{13} |E|^2, \tag{1b}$$

where R_{13} and R_{33} are the corresponding quadratic EO coefficients for light polarized perpendicular and parallel to E, respectively; n is the refractive index of the ceramic without applied field.

The studied deflector in this letter is a rectangular parallelepiped with a triangular electrode, as shown in Fig. 1. When an electrical field is applied to the PLZT ceramic, the refractive index of the material under the triangular electrode will change due to the EO effect, and form an index interface between two triangular areas, which causes the incident beam to deflect. The deflection angle can be deduced simply by geometrical optics, and described as

$$\begin{cases} n' \sin(\frac{\pi}{2} - \alpha) = n \sin\theta \\ n \sin(\frac{\pi}{2} - \alpha - \theta) = \sin\beta \end{cases}, \tag{2}$$

where α is the angle of triangular electrode and β is the deflection angle, as shown in Fig. 1. Since the EO induced index change is quite small, the deflection angle can be obtained as

$$\beta = \sin^{-1}[\cos\alpha(\sqrt{n^2 - n'^2 \cos^2\alpha} - n' \sin\alpha)]. \tag{3}$$

Figure 2 shows the deflection angle varying with the inclination angle α of the electrode. From this figure, it is very easy to know that the deflection angle β will increase with the angle α reducing. Moreover, the beam deflects to positive x-direction in the case of negative EO coefficient, and *vice versa*.

In order to test the above theory, we carried out the experiment using the setup shown in Fig. 3. A 633-nm He-Ne laser beam is incident upon the polished facet of a PLZT ceramic perpendicularly, and an optical attenuator (OA) and a polarization controller (PC) were used to control its intensity and polarization. The size of PLZT sample is 20 × 4 × 0.5 (mm). A Ti:Pt:Au triangular

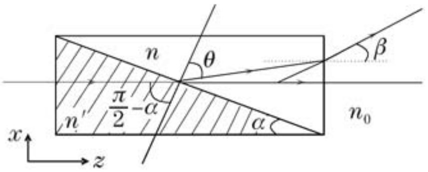

Fig. 1. Principle of the EO effective prism on PLZT ceramic (the dashed part is poled area).

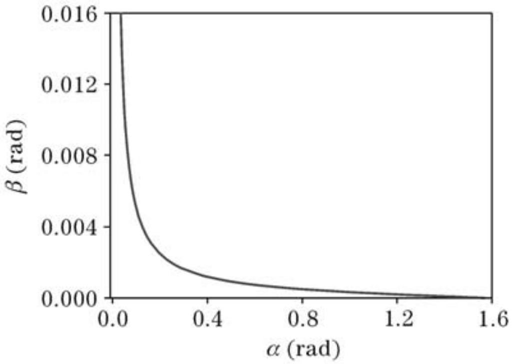

Fig. 2. Deflection angle β varies with the inclination angle α of the electrode. $n = 2.5$ and $n' = 2.5 - 0.0005$.

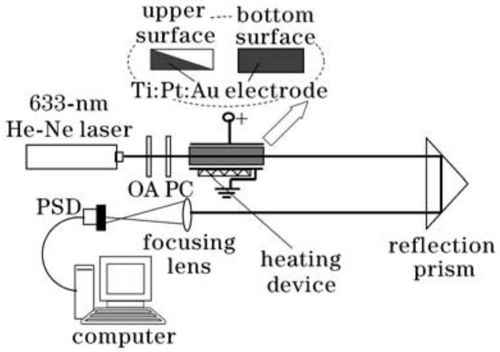

Fig. 3. Experiment setup for PLZT EO deflector.

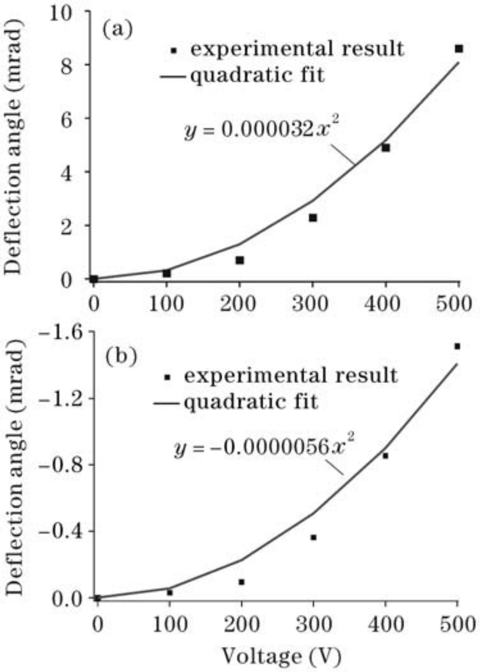

Fig. 4. Deflection angle varies with the applied voltage for (a) y- and (b) x-polarized beams.

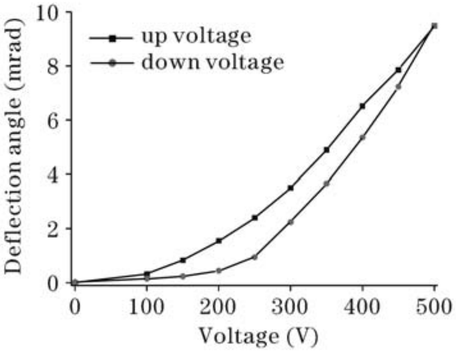

Fig. 5. Hysteresis characteristic of the PLZT deflector.

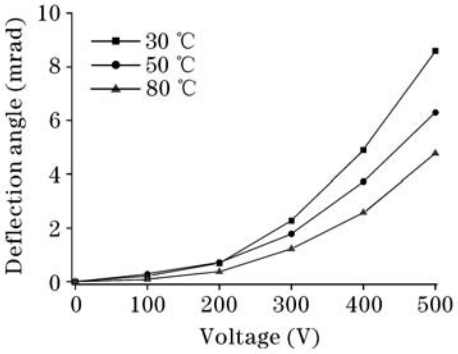

Fig. 6. Effect of temperature on PLZT EO deflection.

electrode was deposited on the upper surface with an inclination angle of $\alpha = \tan^{-1} 0.2$. The bottom electrode covered the whole rectangular surface of the sample. The deflection angle was measured by spot displacement on the position sensitive detector (PSD), which was placed in a distance of 3.5 m after the sample; and the relation between the displacement and deflection angle was calibrated. Moreover, a heating device was also fixed on the bottom surface of the PLZT sample in order to investigate the effect of temperature on the performance of the EO deflector.

Figure 4 shows the deflection angle varying with the applied voltage for the x- and y-polarized beams, respectively. The fitting curves indicate good quadratic EO effects of the PLZT ceramic material. It is worth noticing that the deflections of the x- and y-polarized beams were different not only in amount, but also in deflection direction. Under the applied voltage of 500 V, the deflection angles were 8.6 and −1.5 mrad for the y- and x-polarized beams, respectively. Consequently the corresponding EO coefficients can be calculated by using Eqs. (1) and (3) to be $R_{33} = 2.1 \times 10^{-16}$ V^2/m^2 and $R_{13} = -0.37 \times 10^{-16}$ V^2/m^2, which are coincident with the reported results in Ref. [8]. Moreover, a hysteresis characteristic between the deflection angle and the applied voltage was also observed, as shown in Fig. 5.

Temperature effect of the EO deflector was also studied in detail. Figure 6 shows the beam deflection of the y-polarized beam for different temperatures. It is shown that the deflection angle decreases with the temperature increasing. For instance, the deflection angles of the y-polarized beam under 500-V voltage were measured to be 8.6, 6.3, and 4.8 mrad for 30, 50, and 80 °C, respectively. It means that the EO coefficient of the PLZT ceramics will reduce with the temperature increasing. The main cause is that the temperature dependence can be attributed to more vigorous molecular movement at higher temperature, which will weaken the EO polarization. So it is a very important characteristic for PLZT ceramics in practical application.

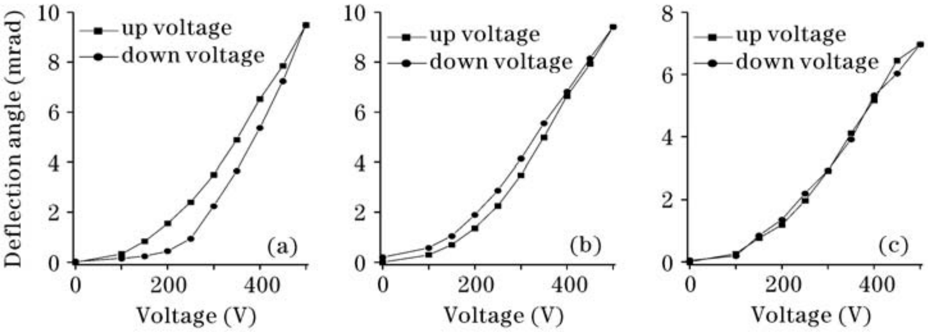

Fig. 7. Effect of temperature on the hysteresis characteristic of PLZT ceramics. (a) 30 °C; (b) 50 °C; and (c) 80 °C.

The hysteresis characteristic was also investigated for different temperatures of 30, 50, and 80 °C, respectively, as shown in Fig. 7. It is shown that the hysteresis characteristic is weakened with the temperature increasing. For the case of 80 °C, the hysteresis characteristic becomes inconspicuous. It implies that spontaneous polarization of the electric domain becomes weak at high temperature.

The study on temperature and hysteresis effects for PLZT EO deflector not only makes us know the PLZT EO material's characteristics adequately, but also suggests some measures or methods to eliminate their effects in practical applications, and ultimately to obtain exact beam scan. For example, to temperature effect, some temperature compensations will be necessary; to hysteresis characteristic, single-direction applied voltage scanning may eliminate hysteresis characteristic to induce scanning error, such as sawtooth-wave voltage scan scheme. Moreover, it must also be noticed that a shortcoming for the EO deflector is a high working voltage applied for practical operations due to a thick PLZT plate used in this work. However, the voltage can surely be reduced by using a thinner material, especially using thin films. Further work is being undertaken.

In conclusion, an EO deflector of PLZT ceramic with triangular electrode was demonstrated experimentally. The quadratic EO coefficients were deduced from the deflection data, and hysteresis characteristics were observed. The temperature effects on the characteristics of PLZT were also investigated in detail. The experimental results indicate that PLZT ceramic with high EO coefficient is a good candidate for beam deflection and other applications.

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References

1. K. Nashimoto, S. Nakamura, T. Morikawa, H. Moriyama, M. Watanabe, and E. Osakabe, Appl. Phys. Lett. **74,** 2761 (1999).
2. T. Utsunomiya, K. Nagata, and K. Okazaki, Jpn. J. Appl. Phys. **24,** (Suppl. 24-2) 281 (1985).
3. T. Utsunomiya, Jpn. J. Appl. Phys. **28,** (Suppl. 28-2) 164 (1989).
4. S. J. Barrington, A. J. Boyland, and R. W. Eason, Appl. Opt. **43,** 1038 (2004).
5. D. Djukic, R. Roth, J. Yardley, R. Osgood, S. Bakhru, and H. Bakhru, Opt. Express **12,** 6159 (2004).
6. J. Li, H. C. Cheng, M. J. Kawas, D. N. Lambeth, T. E. Schlesinger, and D. D. Stancil, IEEE Photon. Technol. Lett. **8,** 1486 (1996).
7. L. Sun, J.-H. Kim, C.-H. Jang, D. An, X. Lu, Q. Zhou, J. M. Taboada, R. T. Chen, J. J. Maki, S. Tang, H. Zhang, W. H. Steier, C. Zhang, and L. R. Dalton, Opt. Eng. **40,** 1217 (2001).
8. J. A. Thomas, "Optical phased array beam deflection using lead lanthanum zirconate titanate" PhD Dissertation (University of California, San Diego, 1998) p.64.