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Large quadratic electro-optic properties of ferroelectric base $0.92Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.08PbTiO_3$ single crystal

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ABSTRACT

Large Kerr effect in $0.92Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.08PbTiO_3$ (PMN–0.08PT) single crystal has been observed. The effective quadric electro-optical coefficient $(R_{11} - R_{12})$ of PMN–0.08PT single crystal is measured by a Senarmont compensator method. The refractive indices and extinction coefficient of PMN–0.08PT single crystal ranging from 300 to 1700 nm have been measured by variable angle spectroscopic ellipsometry (VASE). The transmission character of PMN–0.08PT single crystal in the range of 300–2200 nm has been investigated by UV–visible–NIR spectrometer. The transmission ratio is 65% in the range of 600–2100 nm and the calculated reflection loss is about 20%. The effective quadric electro-optical coefficient $(R_{11} - R_{12})$ is calculated to be $8.19 \times 10^{-16}\ m^2\ V^{-2}$ and the $n^3(R_{11} - R_{12})$ is $141.8 \times 10^{-16}\ m^2\ V^{-2}$ at 514.5 nm, respectively. The V_π of the sample is 632 V.

1. Introduction

Optical materials with large electro-optic (EO) coefficients are highly desirable for uses in optical communications, optical signal processing, and other commercial applications. In many EO applications, the modulation of light is usually based on the Pockels effect (first-order EO effect) or on the Kerr effect (second-order EO effect). The relaxor ferroelectric crystals $(1-x)$PMN–xPT are very well known for its high electromechanical coupling factor, piezoelectric coefficients and field induced strain response [1,2]. Large linear EO coefficients in $(1-x)$PMN–xPT ($x = 0.24$–0.40) single crystals near the morphotropic phase boundary (MPB) have been reported in recent years [3,4]. Remarkable quadratic electro-optic coefficient of PMN–xPT ($0.15 \le x \le 0.4$) thin films also have been found by Lu et al. [5]. These optical properties have been attributed to a phase transition between the tetragonal and the rhombohedral phases due to the electric field, which is associated with large changes in the crystal lattice constants and the refractive index [6–9]. However, the quadric EO coefficients of cubic phase $(1-x)$PMN–xPT ($x < 0.1$) single crystals have not been reported. For there is a phase transition between the cubic and the rhombohedral phases in $(1-x)$PMN–xPT ($x < 0.1$) single crystals near room temperature, electric-field may induce large change in refractive index of the cubic $(1-x)$PMN–xPT ($x < 0.1$) single crystals. In this letter, the Kerr effect of PMN–0.08PT single crystal was investigated by a modified Senarmont compensator method. The effective quadric electro-optical coefficient and half-wave voltage are calculated. The refractive indices and transmission character of the single crystal were studied and the reflection loss was also discussed.

2. Experimental procedure

Large size and high quality PMN–0.08PT single crystal was grown by modified Bridgman method [10,11]. The single crystal was oriented using X-ray diffractometer. For VASE measurement, the sample was cut along ⟨0 0 1⟩ direction. The surface for light reflection was optically polished. The VASE measurement was carried out in the wavelength range of 300–1700 nm with 5 nm steps at incidence angle of 65° by a W-VASE32 TM Ellipsometer with synchronously rotating polarizer and analyzer at room temperature. For transmission measurement, the incident light was perpendicular to the (0 0 1) faces. Transmission spectrum was measured by a JASCO's V-570 UV–visible–NIR spectrometer in the wavelength range from 300 to 2200 nm at room temperature. EO measurement was performed by a modified Senarmont setup as shown in Fig. 1. The sample was cut into cube with 3 mm × 3 mm × 6 mm. The E

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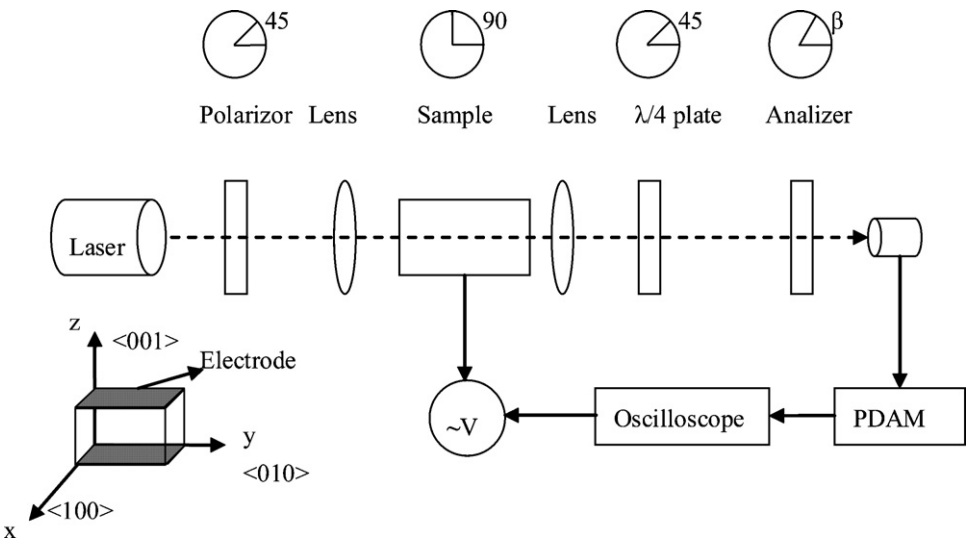

Fig. 1. Experiment arrangement of the optical and electronic components in the modified Senarmont system.

field was applied across the ⟨0 0 1⟩ direction (3 mm thickness) and the incident light propagated along the ⟨1 0 0⟩ direction (6 mm thickness). The polarization direction of polarizer was set at 45° to the principal c axis of the crystal. Thus the quadric EO coefficient is defined by, $(R_{11} - R_{12}) = \Delta n/(1/2)n^3E^2$, where Δn is the induced birefringence, n is the refractive index of the undistorted indicatrix $(R_{11} - R_{12})$ is the effective quadratic electro-optic coefficient, and E is the applied field.

3. Results and discussion

3.1. Refractive indices and dispersion equation

The refractive indices at different wavelength of PMN–0.08PT single crystal were investigated by the spectroscopic ellipsometry. The theory for ellipsometric analysis is based on the Fresnel reflection or transmission equations for polarized light encountering boundaries in planar multi-layered materials. These come from solutions to Maxwell's equations. The ellipsometry measurements are normally expressed in terms of Psi (Ψ) and Delta (Δ):

$$\rho = \tan(\Psi) \cdot e^{i\Delta} = \frac{r_p}{r_s} \tag{1}$$

where r_p and r_s are the complex Fresnel reflection coefficients for p^- (in the plane of incidence) and s^- (perpendicular to the plane of incidence) polarized light, respectively. Spectroscopic ellipsometry (SE) measures the complex ratio as a function of wavelength. For bulk isotropic sample investigated here, its complex refractive index ($\tilde{n} = n + ik$) can be revealed automatically by comparing the computer modeling data with the experimental data [10–12]. Fig. 2 shows the wavelength dependence of the refractive indices and extinction coefficients at room temperature for PMN–0.08PT single crystal, respectively. The result shows that PMN–0.08PT single crystal has lager refractive indices at different wavelength and the refractive indices and extinction coefficients strongly depend on the wavelength especially in the UV region. This is similar to other ABO_3-type perovskite structure compounds [13,14]. The extinction coefficients decrease and become small when the wavelength is above 500 nm. This indicates that PMN–0.08PT single crystal is transparent in the visible light region. Because of the similar BO_6 octahedron unit structure, they have analogous energy band structure determining the refractive indices [13,14].

From the well known simple dispersion theory, the refractive index can be given by typical Sellmeier dispersion equation:

$$n^2 = A + \frac{B}{\lambda^2 - C} - D\lambda^2 \tag{2}$$

where A, B, C and D are all constants and λ is wavelength in microns. These constants can be obtained by the least squares fitting of the equation with the refractive indices measured by VASE. Thus the Sellmeier dispersion equation of n for PMN–0.08PT is

$$n^2 = 5.8255 + \frac{0.191154}{\lambda^2 - 0.042151} + 0.022096\lambda^2 \tag{3}$$

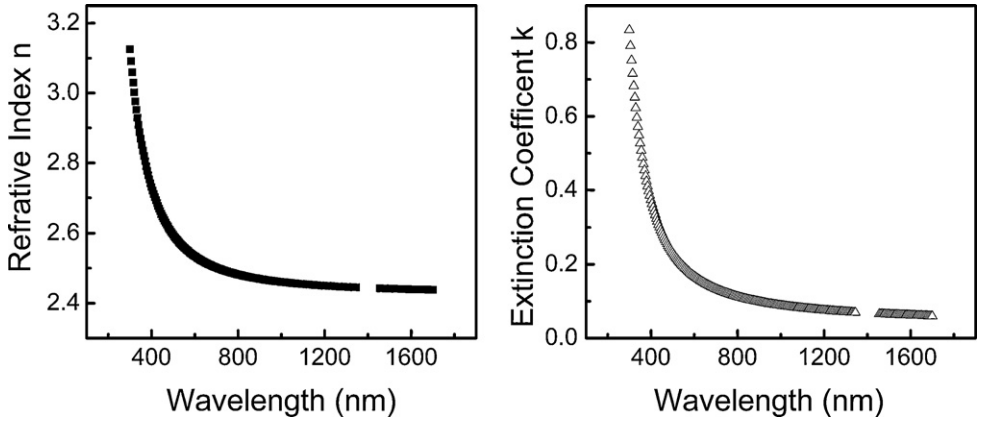

Fig. 2. The refractive indices and extinction coefficients of PMN–0.08PT single crystal measured at different wavelengths.