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Effect of local-action on electro-birefringence in bilayer composite and micro-displacement sensing

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ABSTRACT

A bilayer composite with electro-birefringence effect was fabricated using ferroelectric and stress-birefringence medium. Its electro-optical response was studied. The transmission light intensity was found to change with displacement of the incident beam to the elastic-optical layer in two dimensions perpendicular to the beam. The effects of local-action and interfacial elastic coupling on the stress distribution in the elastic-optical material were analyzed. Starting from the basic equations of elasticity, a physical model of electro-stress birefringence for the bilayer composite was derived. It was found that the theoretical calculations in general accord with the experimental results without considering ferroelectric relaxation. And the micro-displacement sensing of two-dimension was realized with the bilayer composite of electro-stress birefringence.

1. Introduction

Layered electro-optical composites made by electostriction and stress-birefringence materials, can display electro-birefringence effects. It attracted continues interest due to its potential applications in electro-optical sensing technology.

The electro-birefringence effect in the layered composite originates from the product effect of electro-strictive and elasto-optical effects. Under an applied electric field, the mechanical deformation of the electro-strictive phase is transferred to the elasto-optical one through interfacial elastic coupling, thereby changing the refractive index of elasto-optical phase.

Many of the multilayer films or laminate composites, such as metal multilayers (or superlattice materials) [1–3], layered composites of magnetoelectric effect or magnetooptical effects etc. [4–7], take effects based on interlayer elastic coupling. In those composites, the stress-inducing layer usually subjects to a body force, such as the stress caused by magnetostriction or electrostriction. Then the adjoining elastic layer(s) will bear a surface force due the body force in the stress-inducing layer. So far, it tends to think that the stress induced by the surface force are uniformly distributed in the elastic layer when discussing the effect of interlayer elastic coupling [8–11]. However, this assumption often gives rise to theories that do not match experimental results. For example, it was found that the theoretical value of the magnetoelectric effect of laminated composites is often three times of experimental results [12,13]; In the study of the magneto-optic effect in bilayer composites, according to the supposition, it is believed that the magneto-optical retardation should be invariant with increasing the distance from the incident point of the beam to the interfacial, but the magneto-optical retardation observed decreases with increasing the distance to the interface [14]. Obviously, these phenomena are not consistent with the assumption that the stress uniformly distributed in the layer stressed. In fact, according to the principle of local action, namely, Saint-Venant's principle, under a surface force parallel to the interface, the stresses distribute non-uniformly along both thick and length directions in an elastic medium [15,16].

In this work, a bilayer composite containing electrostriction and elasto-optical materials is fabricated. Its electro-optical response was investigated. And the influence of the local-action on the electro-optic effect was discussed according to the experimental results.

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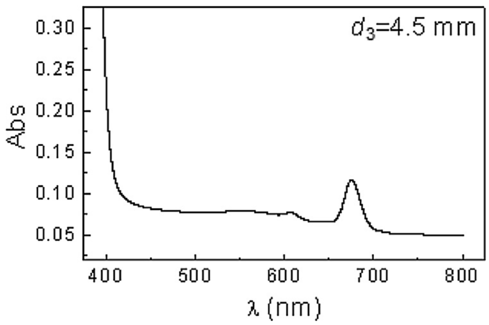

Fig. 1. Wavelength dependent absorption for a PC plate with a thickness of 4.5 mm.

2. Sample characterization

The samples under investigated were bilayers fabricated by combining flakes of polycarbonate (PC) and lead zirconate titanate $PbZr_xTi_{1-x}O_3$ (PZT). Both PC and PZT were taken as the elasto-optical (EO) and electro-strictive (FE) materials, respectively.

PC is a thermoplastic polymer and has a high transparency, optical isotropy, no natural birefringence and few mechanical creeps at room temperature. [17–19]. It is often used in the study of photo-elasticity due to its good performance in stress-birefringence. For a birefringence material, the phase difference between the ordinary (o) and extraordinary (e) light beams is known as retardation δ, which is given as

$$\delta = 2\pi c d\sigma/\lambda, \tag{1}$$

where σ is the difference between principal stresses, d is the distance that the beam passed through the PC, and c is the stress-optical constant, which can indicate the stress-optical sensitivity of an elasto-optical material [17].

Commercial PC bulk was cut into flakes with the size desired. All the PC flakes were annealed prior to use to relieve the possible residual stress induced in the primary manufacturing process. For Annealing, the PC samples were heating to 158 °, and maintaining the temperature for 2 h, then cooling down to 140 ° at a rate of 5 °/h, and finally furnace cooled down to the ambient temperature.

Test of light absorption was firstly performed. The result was shown in Fig. 1. It is found that its absorbance (Abs) decreases slowly with increasing wave length λ. A sharp peak of absorption appears at about λ =676nm. For a PC sample of 4.5 mm in thickness, the Abs decreases from 0.084 at λ =440nm to about 0.050 at λ =780nm. The peak value of Abs is about 0.117. The result shows that the PC is almost transparent throughout the region of visible light but blocks all ultraviolet lights.

A series elasto-optical tests using PC samples with different width d_3 was performed. The results were given in Fig. 2. The geometrical arrangement for the test was shown in the inset of Fig. 2. The applied stress σ was perpendicular to the beam, and measured with a spring scale, which was calibrated before hand. A laser (He-Ne) beam with λ=632.8 nm was employed in the tests. Taking the normalized transmission light intensity NTLI=$I/I_{\max}$ to characterize the electro-optical effect, where $I_{\max}$ was the maximum intensity of the transmission light, it was found that NTLI varied periodically. And the varied period was also changed with changing the distance of the optical path, namely, the width of the PC samples, d_3.

Stress that induces a retardation of π is often called half-wave stress and noted as σ_π. From Fig. 2, we can work out σ_π of the PC as a function of the width, as shown in Fig. 3. It was found that the data (the solid points) can be fitted by a curve of exponential decay.

$$\sigma_\pi = a_1 + a_2 \exp(a_3 d_3 + a_4), \tag{2}$$

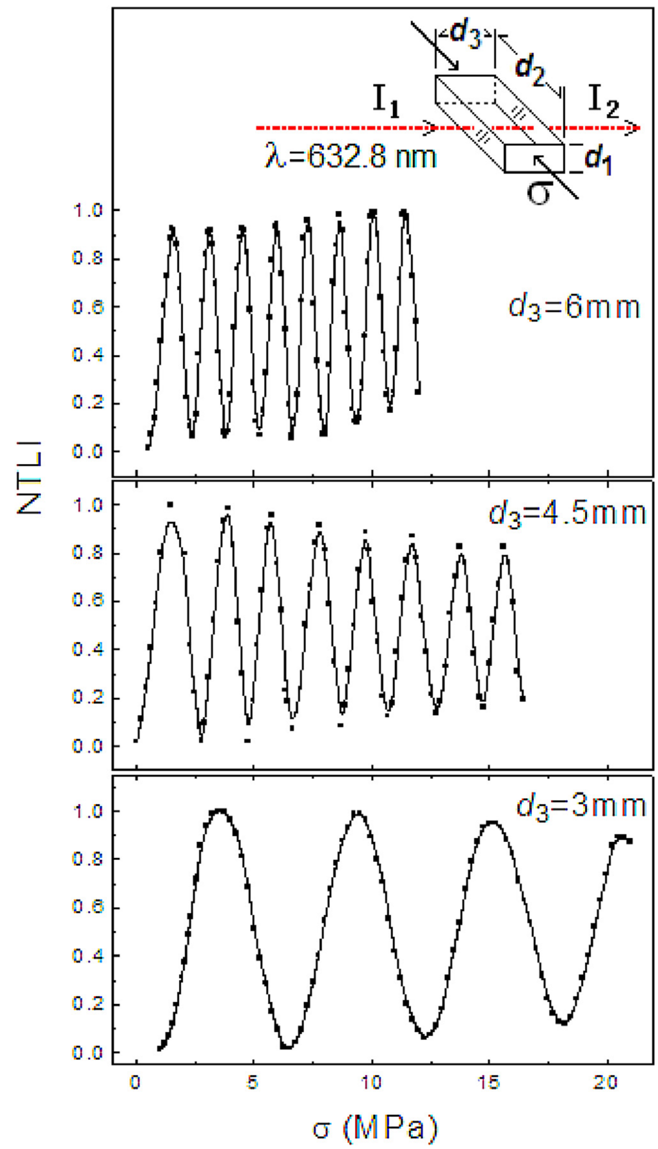

Fig. 2. Normalized transmitted light intensity (NTLI) as a function of stress for the PC strips with same length and thickness but different width; Inset: Schematic draft of the stress-optical test on a strip of PC. The points are values measured and the lines ate fitted using to guide the view.

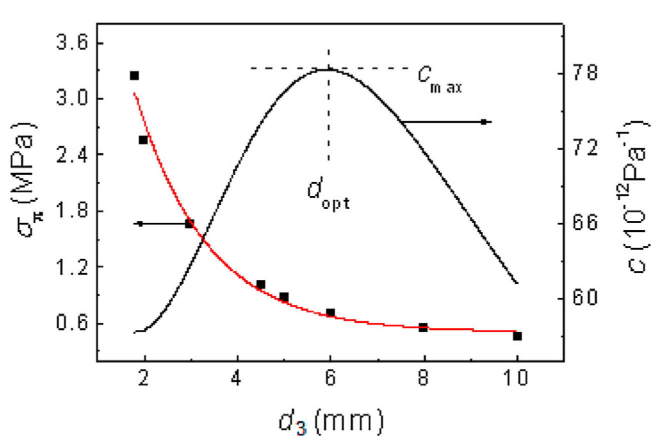

Fig. 3. The half-wave stress (Left axis) and stress-optical constant (Right axis) as a functions of the width (the distance of the beam passing through) for the PC used.