High-performance Coatable Polarizer by Photoalignment

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Abstract

A coatable polarizer with high performance is a perpetual goal because of its numerous advantages. Here, we demonstrate a photo-induced coatable polarizer with a dichroic ratio of more than 50, a contrast ratio of more than 300, and a thickness less than 500 nm. This polarizer offers a simple and economical technique to realize advanced displays with low cost, ultra-thin profile, flexible style, and high performance.

Keywords

Coatable polarizer, dichroic ratio, photoalignment, azo dye.

1. Introduction

Thin film polarizers are indispensable elements in both liquid crystal (LC) and organic light emitting diode (OLED) displays. Polarizers are generally divided into two categories, absorptive and reflective. Absorptive polarizers, based on the anisotropic absorption of dichroic molecules, are widely used because of their good performance and low cost. The properties of an absorptive polarizer are characterized by the dichroic ratio (*N*), which is the ratio of the absorption coefficients along two orthogonal directions. The contrast ratio (CR) and optical efficiency (η) are contradictory at a fixed dichroic ratio. Their relationship can be derived from Beer's law and is expressed as

$$\mathrm{CR} = \eta^{1-\mathrm{N}} \qquad (1)$$

$$\mathrm{N} = \frac{\alpha_{//}}{\alpha_{\perp}}\ , \qquad (2)$$

where $\alpha_{//}$ and $\alpha_{\perp}$ are the absorption coefficients parallel and perpendicular to the absorption axis of the molecules respectively. High dichroic ratio is the key to achieve both large optical efficiency and contrast ratio at the same time.

Conventional polarizers are produced by mechanically stretched polyvinyl alcohol (PVA) doped with iodine [1]. Such PVA/iodine type polarizers possess a high dichroic ratio up to 60; however they still have some limitations. Firstly, they are very sensitive to heat and moisture, so additional protection layers, such as triacetate cellulose (TAC), are indispensable to improve the stability. This results in an increase of the fabrication cost and film thickness. Currently, PVA/iodine polarizers thinner than 5 μm cannot be manufactured because thin PVA is fragile during the stretching process and is difficult to deal with, which limits the further decrease of the film thickness. So far, the standard thickness of commercial PVA/iodine polarizers for practical use is still about 25 μm. Secondly, shrinkage force is generated after the stretching process, which is a serious concern as it may cause panel bending, display distortion, and dimensional variance [2]. The shrinkage problem becomes even more serious in thin flexible displays without the support of rigid substrates. Finally, with such polarizers, the absorption spectrum is not balanced in the whole visible region so the displays look greenish yellow [3].

Flat panel display technology is continuously evolving toward the next-generation of thinner and more flexible displays. Flexible displays are thin, lightweight, and possess the ability to be bent and folded for extreme portability and convenience [4-6]. Overcoming the limitations of conventional flat panel displays based on a glass substrate, flexible displays will open up new applications, such as e-paper, wearable displays, roll-up displays and so on. In fact, some wearable displays based on flexible e-paper and flexible OLEDs have already come onto the market, although they are small in size and only slightly bendable. Large-area rollable and foldable displays, which would enable us to use flexible displays with multimedia functions anywhere, at any time, are also expected in the near future.

Novel polarizers that are thin and free from shrinkage force are highly desired for next-generation displays. Coatable polarizers have the intrinsic advantages of low thickness, simple fabrication, low cost and compatibility with roll to roll manufacturing. Coatable polarizers show unique advantages, especially when applied as in-cell polarizers, which improve display performance and decrease the thickness.

One type of coatable polarizer is based on lyotropic liquid crystalline (LLC) molecules [7], which exhibit phase transitions as a function of the LC molecules' concentration in solvents. The absorption peaks of these LLC molecules are selected in the visible region, and they show anisotropic absorption after alignment. This type of LLC polarizer eliminates the shrinkage problem and can be thin and achromatic, but a critical defect is its relatively low dichroic ratio of about 20, which is unfavorable for practical applications.

Another type is a polarizer based on LC/dye mixtures. Dichroic dyes are mixed as a minority inside the LC host and follow the orientation of the LC molecules, which is known as the guest-host effect. In this case, the dichroic ratio of the polarizer is still limited by the ordering of the LC molecules. Generally, the order parameter of the nematic LC ranges from 0.3 to 0.7, which corresponds to a dichroic ratio below 8. To break this limitation, sematic B phase, a phase with a large order parameter, is suggested [8]. This phase can be obtained by carefully controlling the temperature of specific LC materials. To produce

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a dichroic polarizer, the ordering of both the LC and dye molecules is fixed in sematic B phase by in situ photopolymerization of the LC cells. The dichroic ratio of this polarizer is more than 50, which is adequate for display applications. The problems of this technique are the rarity of sematic B phase LC materials, fabrication complexity and the resulting high cost.

Photoalignment is a promising technique to realize a coatable polarizer in a simple manner. We have previously reported pioneering work on photo-induced coatable polarizers [9]. However, the dichroic ratio is around 20; not satisfactory for high performance applications.

In this work, we further improve the performance of the dichroic polarizer and achieve a high dichroic ratio and thinness, making a polarizer that is an excellent candidate for next-generation displays, especially flexible displays.

2. Method

The photoalignment method is a powerful approach to achieve anisotropic molecular ordering by either polarized light or oblique incidence. It is widely used in LC alignment, optical storage and the photonics field [10]. There are generally three types of mechanisms: photo-induced reorientation, photo-crosslinking, and photo-degradation. Among them, photo-induced reorientation has shown the highest order parameter.

Figure 1 shows the chemical structure of AD-1 molecules, a photo-reorientation material, which contain two azobenzenes in the core. Azobenzene derivatives have two geometric isomers, trans and cis. The isomerization can be activated by light with particular wavelengths. The trans to cis conversion corresponds to high-energy π-π* transition, while cis to trans conversion happens in low-energy n-π* transition. The cis isomers are less stable than the trans isomers, so the cis isomers will finally relax to trans isomers in random positions, even without stimulus. In the case of polarized irradiation, the absorbed energy is proportional to the square of cos θ, where θ is the angle between the direction of polarization and the absorption oscillator of the molecules (Figure 2). The repetition of photo isomerization won't stop until the absorption energy is minimized when the molecule's oscillator axis is perpendicular to the polarization direction. Therefore, the polarized irradiation will induce the anisotropic ordering of the azo materials and make it optically dichroic.

To fabricate the polarizer, 1% –5% AD-1 molecules are dissolved in chlorobenzene and form uniform thin films on 20 mm × 20mm glass substrates with a thickness less than 500 nm by spin coating. Afterwards, the thin films are soft baked at 70 °C for 5 mins. When they have cooled to room temperature, the photoalignment process is then started. The light source is a linear polarized laser whose central wavelength is at 442 nm. Its contrast ratio of two polarizations is 500. The fabrication process, which is simple, economical, and easily integrated to a wide variety of manufacturing processes, is exhibited in Figure 3. After the photoalignment, the optical performance of the polarizers is characterized by a UV/VIS Spectrophotometer Perkin Elmer (Lambda 20).

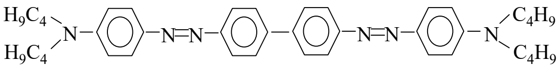

Figure 1: Chemical structure of AD-1 molecules.

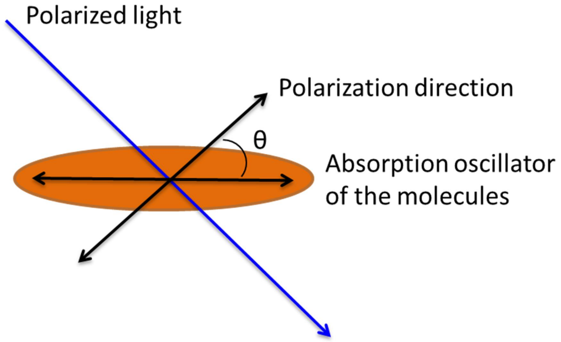

Figure 2: Under the irradiation of polarized light, the AD-1 molecules tend to reorient perpendicular to the polarization of the activated light. The absorption oscillator is parallel to the molecular axis.

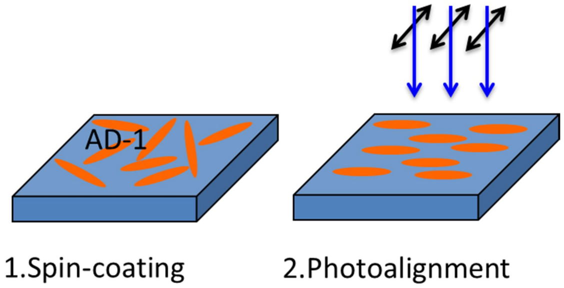

Figure 3: Fabrication process of a coatable photo-induced polarizer.

3. Results

The transmission spectra of an optimal polarizer are demonstrated in Figure 4. The transmission of the polarization parallel to the polarization of linear polarized light is around 88% from 400 nm to 550 nm, while the transmission of the polarization perpendicular to the polarization of linear polarized light is around 0.3% from 400 nm to 550 nm. The calculated dichroic ratio and contrast ratio are demonstrated in Figure 5 and Figure 6, respectively. The highest dichroic ratio is larger than 50, which is sufficient even for high-quality displays. The contrast ratio is around 300 from 425 nm to 525 nm, with a film thickness less than 500 nm, satisfying the demands of most displays. A higher contrast ratio can be obtained by increasing the film thickness.

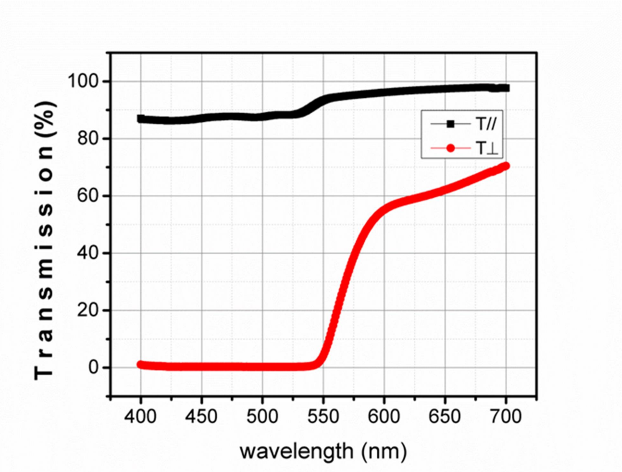

Figure 4: Transmission spectra of the polarization parallel and perpendicular to the polarization of linear polarized light, respectively.

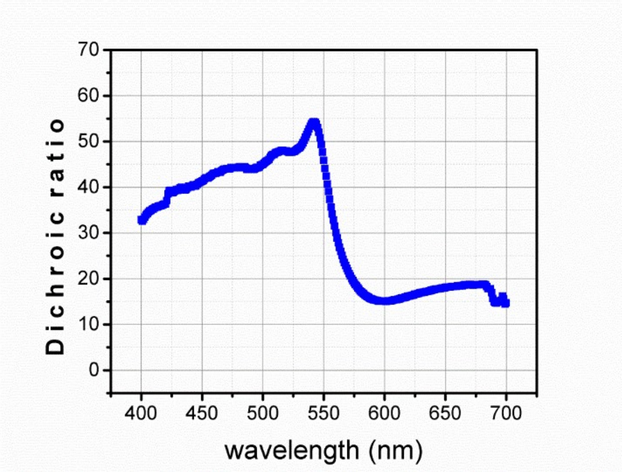

Figure 5: Calculated dichroic ratio of the coatable polarizer.

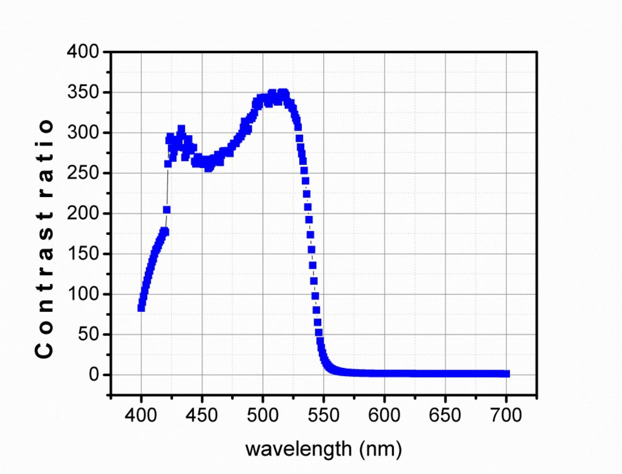

Figure 6: Calculated contrast ratio of the coatable polarizer.

4. Summary

Rapid development of flat panel displays drives the evolution of polarizers. Coatable polarizers have particular advantages, such as low cost, low thickness and high capability of integrating with a wide variety of manufacturing processes. We have successfully improved the performance of photo-induced coatable polarizers to an excellent standard, and demonstrated a coatable polarizer with a dichroic ratio of more than 50, a contrast ratio of more than 300, and a thickness less than 500 nm. This simple and economical technique has the potential to realize advanced displays with low cost, ultra-thin profile, flexible style, and high performance.

5. Acknowledgements

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