

# Photostable Composite Thin-Film Polarizer with Multi-Layered Dichroic Structure Using Photoaligned Azo Dyes

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## Abstract

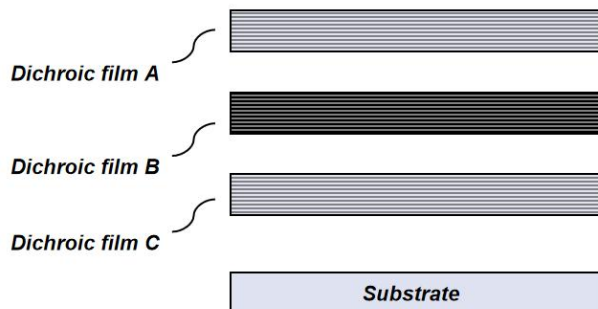
*In this work, we introduce a multi-layer composite thin-film polarizer engineered to improve the photostability of azo dye-based absorptive polarizers. By integrating light-stable LCP-M10 layers with photo-aligned azo dye films, the structure effectively mitigates photodegradation, maintaining high dichroic performance over extended exposure. Optical measurements demonstrate superior long-term stability and consistent absorbance, highlighting the potential of this design for durable, high-performance display systems.*

## 1. Introduction

Polarizers are indispensable in modern optoelectronic systems, particularly in liquid crystal displays (LCDs), where they modulate the polarization state of incident light to enable image formation<sup>1</sup>. A typical LCD stack includes two polarizers—analyzer and polarizer—placed orthogonally to control light transmission. The optical performance of these polarizers directly influences brightness, contrast ratio, and color accuracy.

Among various types, absorptive polarizers based on dichroic dyes are favored for their high contrast and ease of integration into thin-film form factors<sup>2</sup>. Azo dyes, in particular, are widely used due to their strong anisotropic absorption and tunable molecular structure, which enable high dichroic ratios through alignment techniques such as photo-alignment<sup>3</sup>. However, a critical limitation is their sensitivity to high-energy light, especially blue and UV wavelengths, which leads to photodegradation—manifested as reduced molecular alignment, chromophore bleaching, and ultimately performance decline<sup>4,5</sup>.

In this study, we introduce a multi-dichroic-layer composite thin-film polarizer that leverages the synergy between photo-aligned azo dye films and photostable liquid crystal polymer (LCP) layers, the schematic is shown in Figure 1. This design not only preserves the optical performance of the azo dye but also acts as a functional barrier that filters incident radiation. The proposed architecture is especially suited for thin, in-cell LCD configurations and other compact display systems where long-term optical stability is required.



**Fig. 1.** Schematic of the multi-dichroic-layer composite thin-film polarizer.

## 2. Experiments

### 2.1 Film Fabrication

The core functional layer in our composite structure consists of photo-aligned azo dye films using AD1 or AD12 molecules. These dyes were spin-coated onto glass substrates pre-treated with alignment layers, followed by polarized light irradiation to induce molecular orientation. The degree of alignment was verified through polarized absorbance spectroscopy.

To form the protective composite, we introduced LCP-M10 as outer layers. LCP-M10 is a photo-crosslinkable liquid crystal polymer with strong molecular orientation stability and low photoreactivity under blue/UV light. Two concentrations (1% and 3% w/w) of LCP-M10 solution were prepared in anisotropic solvents and spin-coated to achieve uniform coverage. After coating, films were cured under UV light to ensure mechanical and chemical stability.

### 2.2 Optical Characterization

Spectroscopic measurements were performed using a UV-Vis-NIR spectrophotometer equipped with a polarization filter to evaluate absorbance in P- and S-polarized light conditions. The Dichroic Ratio (DR), defined as  $DR = A_p / A_s$ , was used as a primary metric for polarization selectivity.

### 2.3 Structural Design and Optimization

Three configurations were fabricated: Structure 1: AD1 only, structure 2: M10 (3%) + AD1 + M10 (1%), structure 3: M10 (3%) + AD12 + M10 (3%).

Each structure was tested for total transmittance,

absorbance, and angular dependence of polarization efficiency. Figure 2 illustrates the DR for each configuration. Structure 2 demonstrated the best trade-off between optical performance and structural simplicity, leading to its selection as the reference architecture.

(a)

Structure 1	$A_p$	$A_s$	DR
1% M10	0.2	0.04	5
AD1	3.6	0.02	180
3% M10	0.7	0.1	7

(b)

Structure 2	$A_p$	$A_s$	DR
1% M10	0.2	0.04	5
AD1	3.6	0.02	180
3% M10	0.7	0.1	7
3% M10	0.7	0.1	7

(c)

Structure 3	$A_p$	$A_s$	DR
1% M10	0.2	0.04	5
AD1	3.6	0.02	180
3% M10	0.7	0.1	7
3% M10	0.7	0.1	7
3% M10	0.7	0.1	7

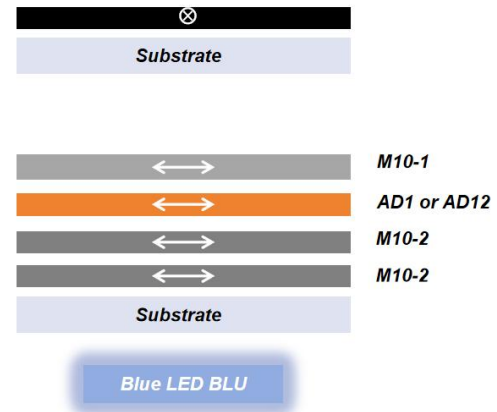
**Fig. 2.** Measured optical parameter of multi-layer structure 1-3.

### 2.4 Accelerated Aging Test

In our study, we compared the performance of our designed structures with that of a commercial polarizer. We made this comparison based on how well each structure balanced high absorbance with low loss of transmitted light.

The optimal design we selected is Structure 2, which consists of two LCP-M10 layers and one AD layer. The final structure is shown in Figure 3. In this composite film, the first LCP-M10 layer (referred to as M10-1) is placed directly above the AD1 layer. Its main role is to act as a shield, protecting the AD1 layer from ambient light. The second LCP-M10 layer (referred to as M10-2) has a higher Dichroic Ratio and is positioned so that it faces the incoming light from the source. When the light

source is turned on, the light first passes through the M10-2 layer. This layer absorbs part of the light and reduces the intensity that reaches the AD1 layer. By doing so, the M10-2 layer helps maintain the alignment and stability of the AD1 layer, ensuring that the overall optical properties of the polarizer remain strong.



**Fig. 3.** Final design of multi-layer structure.

To test the photostability of the composite polarizer, we carried out an accelerated aging test. We exposed the composite polarizer to a polarized blue light source with an intensity of 0.24 mW/cm<sup>2</sup>, which is double the usual required intensity. The test ran continuously for 1,800 hours. We measured the absorbance of the composite film in both the P state and the S state at the beginning of the test and again after 1,800 hours. We also measured the optical density at both times to check for any significant changes.

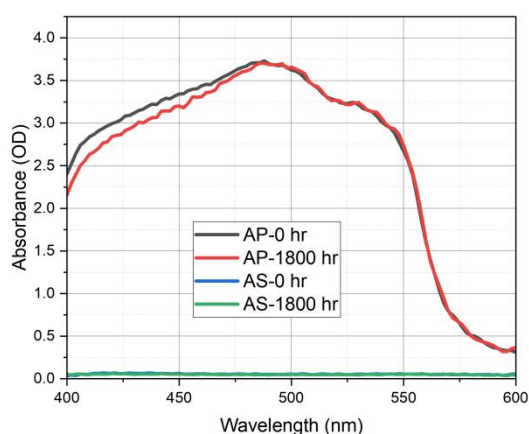
### 3. Results

Figure 4 presents the absorbance spectra of the composite polarizer before and after the aging process. Over 1,800 hours of exposure, the absorbance in both the P-state and S-state showed less than 3% variation. The Dichroic Ratio remained nearly constant, indicating excellent resistance to photo-induced molecular disorder.

Comparatively, the commercial polarizer exhibited a 12% decrease in P-state absorbance and a ~20% drop in DR, validating the superior photostability of our design.

Additional tests were conducted to assess the angle dependence of polarization. At incident angles up to 45°, Structure 2 retained over 85% of its DR, demonstrating robustness against off-axis light — a critical feature for modern wide-viewing-angle displays.

The high optical density and low loss of Structure 2 also ensure that it can be integrated into systems where both light efficiency and contrast are critical. No significant cracking, delamination, or yellowing was observed, confirming its mechanical integrity under accelerated aging.



**Fig. 4.** Photostability test of multi-dichroic-layer composite polarizer.

#### 4. Discussion

The experimental results comprehensively demonstrate that the incorporation of LCP-M10 layers in the multi-dichroic composite structure significantly enhances the photostability of azo dye-based polarizers. This improvement can be attributed to two interrelated mechanisms. First, the outer LCP-M10 layers act as spectral filters that absorb and attenuate incoming blue and ultraviolet photons. By doing so, they effectively reduce the photon flux reaching the underlying azo dye layer, thereby mitigating light-induced degradation. Second, these layers also serve as structural shields: once photo-cured, the crosslinked LCP network forms a dense barrier that minimizes the diffusion of oxygen and moisture. This barrier reduces surface photo-oxidation and other environmental stressors, which are major contributors to dye molecule deterioration over time.

Unlike many conventional stabilization approaches that require altering the dye's chemical composition—often at the cost of optical performance—this multilayer design preserves the dichroic properties of the azo film. It maintains high absorbance and polarization selectivity while achieving long-term operational stability. The thinness and processability of the LCP layers further ensure compatibility with large-area fabrication and flexible integration into modern display assemblies.

Importantly, the proposed structure retains a compact profile and demonstrates strong mechanical integrity under prolonged exposure conditions. It shows no signs of delamination, yellowing, or cracking after 1,800 hours of continuous illumination.

#### 5. Conclusion

In summary, the multi-dichroic-layer composite thin-film polarizer offers a structurally simple yet highly effective strategy for extending the operational lifetime of azo dye-based polarizers. Its good photostability, robust optical performance, and manufacturing compatibility

make it a promising solution for advanced display systems requiring both high efficiency and reliability.

#### 5. Acknowledgments

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