9.1: Intrinsic Polarizers — Ultra Durable Dichroic Polarizers for LCD Projection

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Abstract

High temperature polysilicon (HTPS) projection engines provide a challenging environment for film-based optical components, especially the absorbing polarizers that are critical for image formation. Intrinsic polarizers do not contain unstable dichromophores and have been shown to be well suited for this application.

1. Introduction

The class of film-based synthetic polarizers now ubiquitously used in display applications falls into the category of dichroic polarizers, where dichroism is the property of absorbing light preferentially depending upon the polarization characteristics of the incident rays [1]. Several types of dichroic polarizers were invented and developed in the early 1900s. These included the polyvinyl alcohol-iodine type which has become the multi-million square meter mainstay of the LCD industry; the polyvinyl alcohol-dye type which incorporates aligned organic dye molecules and is known for its enhanced durability; the now discontinued microcrystalline type which incorporated aligned micro-crystals in an oriented matrix and the polyvinylene type which is an intrinsic polarizer. The intrinsic type is an especially durable dichroic polarizer that does not necessarily require the protection afforded by cladding layers and was originally targeted for use in the challenging application of mounting on automobile headlamps.

As distinct from the commercially available iodine and dye types, an intrinsic polarizer polarizes light due to the inherent chemical structure of the base material that is also used to form the polarizing film. For example, the K-type polarizer is manufactured by a linear orientation and acid catalyzed dehydration of polyvinyl alcohol (PVA) [2]. The final chemical structure is depicted in Fig. 1(a) where it can be seen that the conjugated alkene dichromophore forms an integral part of the oriented PVA substrate. Stretched PVA is a common material for other kinds of film-based polarizers; however, the dichroic light absorbing, or dichromophoric, properties come from dye additives or other suspended materials that become associated with the oriented PVA as illustrated in Fig. 1(b).

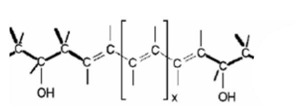

Fig. 1(a).

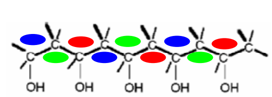

Fig. 1(b).

A well described example of an intrinsic polarizer is the K-type polarizer originally developed by Polaroid Corporation. K-type polarizers have long been known for their superior stability in hostile environments [3] and the invention of a high polarizing efficiency version, known as KE, in the 1990s opened the doors for potential wide-spread application [4]. However, despite earnest efforts to commercialize KE polarizers in the late 1990s it was recognized that a successful introduction would require both a simplified and cost competitive manufacturing process as well as a large-scale and well suited application [5].

2. LCD projection systems

The development of the polarized light illumination system by Seiko Epson Corporation [6] in the 1990s has strongly contributed to the rapid growth of HTPS based liquid crystal projectors with ever increasing brightness levels. The basic design considerations for these projectors and the associated polarizers have been reviewed in detail [7] and it is recognized that along with the advantages of brightness, color saturation and lack of image-related artifacts, the LCD projector design also faces challenges associated with the durability of the liquid crystal alignment layers and the polarizing components, that may be subject to bleaching or darkening under the associated high temperature and flux conditions [8].

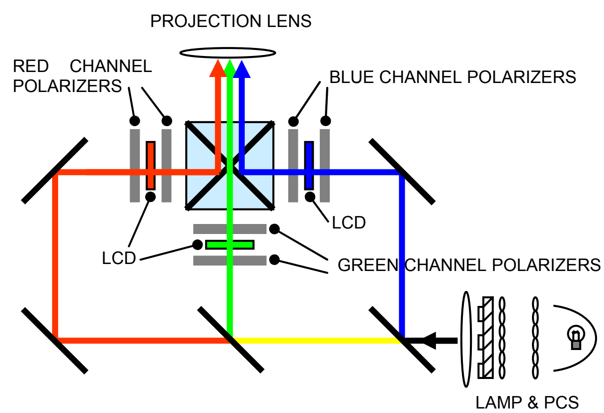

Fig. 2. Diagram of a typical HTPS light engine.

A typical and simplified design for a LCD projection system is illustrated in Fig. 2. The combined lamp, spatial integration system and polarization conversion unit deliver a linearly polarized homogeneous output that is diverted into the red, green and blue channels by angled dichroic mirrors. Fundamentally, each color channel has a similar design where the light passes through an entrance polarizer that imparts a high degree of linear polarization, subsequently the polarization state is modulated by the liquid crystal cell and finally the exit polarizer serves to block or transmit the modulated light. The absorptive polarizing films situated after the imagers are expected to block approximately 99.99% of the light in order to provide a high contrast image. The dichroic x-cube serves to recombine the red, green and blue signals. Typically, the transmissive twisted nematic (TN) imager panel is surrounded by at

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least one pair of absorbing polarizers that are themselves laminated to free-standing substrates. During operation there is a constant airflow around the polarizing plates and the imagers as any light absorbing materials in the illumination path will generate heat that, if not rapidly dissipated, will cause catastrophic failure. Depending on the application, the air temperature may be maintained in the range of 70-80°C. However, even with these cooling schemes, high lumen projectors currently use multi-stage absorptive polarizers so that the heat load is not all absorbed by a single component. For example, rather than the minimum of a single entrance and single exit polarizer per channel a high lumen light engine may incorporate two or more polarizers in each position. Design modifications to enhance the lifetime of these systems also include use of heat conductive substrates such as crystalline quartz or sapphire [9] as well as specially designed cooling schemes.

The operational conditions that the polarizers have to endure are different depending on whether they are used in the entrance or exit positions. The entrance polarizers are primarily "cleaning-up" pre-polarized light from the polarization conversion system (PCS) and heat generation due to absorption will be relatively low. However, in the blue entrance channel there is a significant, and damaging, low wavelength component, even though the ultra-violet wavelengths below 430nm are usually blocked with highly efficient cut-off filters. The exit polarizers may have to totally block light for an extended period; an extreme example being the projection of a black image. In this case the heat generated by light absorption is very high and also localized in an area equivalent to the active size of the imager. Current trends in projection engine design call for more compact and lower cost systems resulting in the adoption of smaller imagers with correspondingly higher flux densities impinging on the polarizing components.

This high heat load coupled with the bleaching effects of high intensity light is known to cause failure in the commonly used dye polarizers. Wire-grid polarizers have found utility as blue channel entrance polarizers where their added durability and high blue transmittance are a particular benefit [10].

The use of intrinsic polarizers in LCD projection systems has been explored at 3M and it has been found that they offer significant performance advantages over the currently utilized materials. Intrinsic polarizers do not contain organic dye-based dichromophores and they have been shown to be totally resistant to the flux-induced blocked state fading that can result in degradation of both polarizer and projected image contrast. In addition, owing to the inherent durability of the intrinsic polarizer it is possible to construct polarizing components that eliminate other optically non-functional layers that are subject to darkening under high temperature and high flux conditions.

2.1 Polarizer design considerations

The optical and mechanical design of HTPS projection engines is complex and outside of the scope of this paper. However, in order to provide polarizing elements that have the potential to be drop-in replacements for currently used materials there are three fundamental considerations:

1). the optical properties of the polarizer with respect to wavelength;

2). the structure of the polarizing unit including substrates, carrier films and coatings; and

3). the durability of the polarizer to heat and flux.

3. Results

3.1 Polarizer optics

The KE polarizer is a broad-bandwidth dichroic polarizer and as such has good polarizing capability over the visible range. In this respect it is similar to an iodine polarizer and well-suited for use in full color LCD applications. This property is illustrated in Fig. 3 which shows a typical pass and block transmittance curve for KE polarizer in the 400-650nm wavelength range. Dye polarizers can also be made broad-bandwidth by blending of red, green and blue dichroic dyes; however, for the projection application it is often advantageous to make dye polarizers that are specifically tuned for each color band. For example a dye polarizer for use in the blue channel will usually exhibit very poor dichroism in the green and red wavelengths.

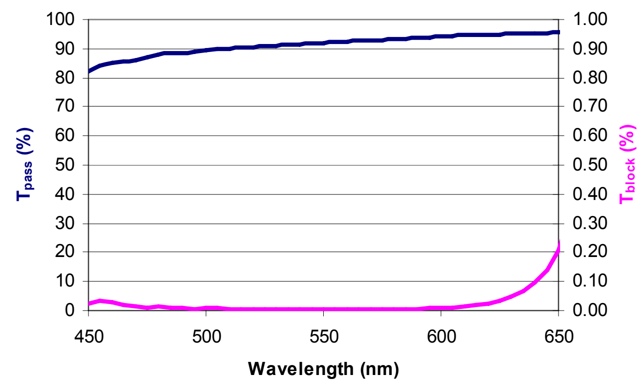


Fig. 3.Typical KE T_{pass} and T_{block} performance by wavelength (with anti-reflection coating).

Typical optical performance characteristics of KE polarizers for projection applications are tabulated below (Table 1). For characterization purposes the red, green and blue wavelength ranges are typically split into spectral ranges of 430-500nm (B), 500-590nm (G) and 600-680nm (R) and the pass state transmittance (T_{pass}) and blocked state transmittance (T_{block}) are reported as average values over the respective ranges. T_{pass} is the percentage measure of how much linearly polarized light is transmitted and T_{block} is the measure of how much linearly polarized light is blocked. Although there are numerous factors involved in the optical design of the projection engine it is generally advantageous for each channel to have polarizers that have high contrast (T_{pass} / T_{block}) coupled with high T_{pass}.

Table 1.

Channel	Blue	Green	Red
λ range (nm)	430-500	500-590	600-680
T_{pass}	85%	91%	91%
T_{block}	0.03%	0.01%	0.03%

Typical value for KE components with anti-reflection coatings on exposed surfaces. These values do not necessarily reflect capability or projection polarizer specifications.

3.2 Polarizer structure

In considering the structure of components within the illumination path it is important to consider that many organic materials will be subject to some form of degradation when exposed to continuous high levels of flux and heat. The common form of degradation for polymeric materials is yellowing and it is recognized that high temperatures and low wavelength irradiation are particularly damaging in this respect. When components in the blue channel turn yellow it is immediately noticeable as the blue wavelengths are absorbed and the whites in the projected image will start to look yellow. Therefore, in designing polarizing films it is desirable to eliminate as many non-optically functional layers as possible. This is not a simple task as film-based materials usually require carrier substrates and adhesive layers in order to process them through continuous manufacturing schemes.

Iodine and dye synthetic polarizers are usually thought of as monolithic structures with thicknesses in the range of 0.15-0.2mm. In reality the dichroic layer is a layer of oriented polyvinyl alcohol (PVA) with a thickness of only about 0.03mm. The bulk of the structure is usually made up of cellulose triacetate (TAC) films that are symmetrically bonded to the PVA layer and serve the dual purpose of protecting the dichroic layer from degradation and acting as an isotropic support to enable roll to roll manufacturing processes. Depending upon the final application these structures may also contain layers of adhesive, protective films and other surface modifications as illustrated in Fig. 4.

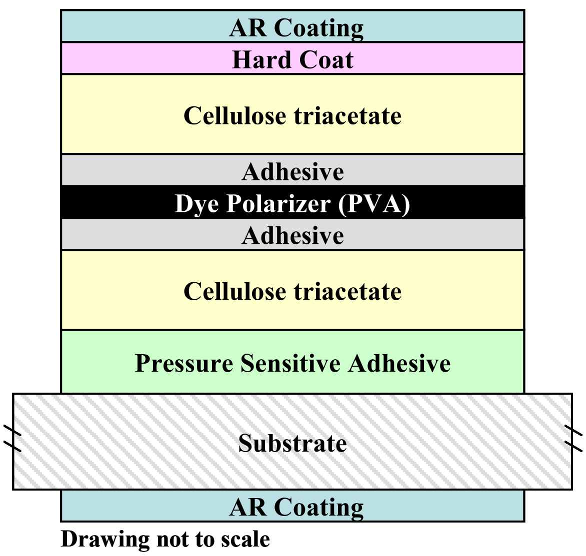


Fig. 4. Typical dye polarizer based projection component.

Due to the inherent durability of the KE polarizer it is possible to manufacture simplified structures. For example, the structure illustrated in Fig. 5 is a 3M Vikuiti™ KE polarizer manufactured specifically for projection applications and does not have a substrate layer between the PVA and the pressure sensitive adhesive. This structure is unusual for an absorbing polarizer as it incorporates only a single layer of TAC. The advantage of this simplified structure is that one of the non-functional TAC layers that is prone to long term heat and light induced degradation can be eliminated.

Current development efforts are directed at producing polarizing elements that take full advantage of the intrinsic polarizer's durability. One such structure is illustrated in Figure 6. In this case the KE polarizing layer is suspended in a matrix of a non-yellowing optically clear polymer.

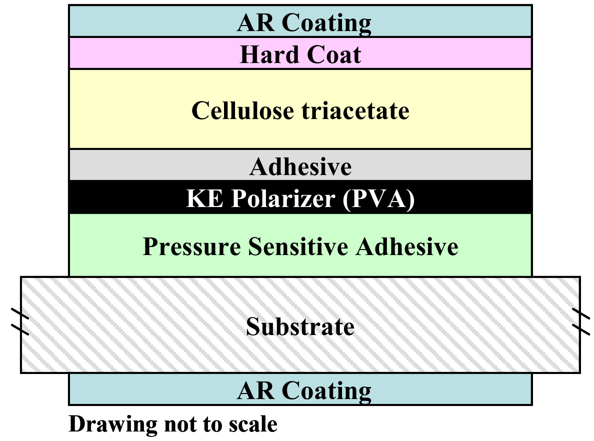


Fig. 5. Typical KE polarizer based projection component.

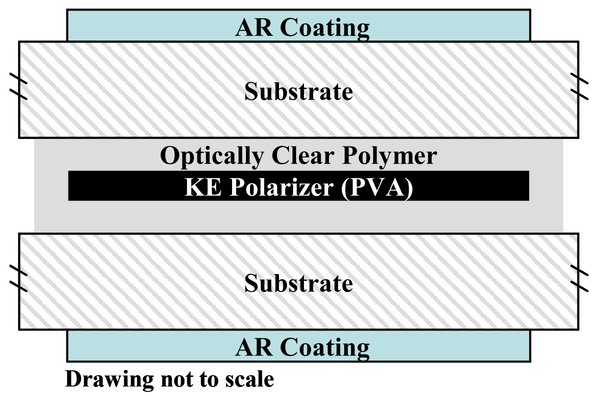


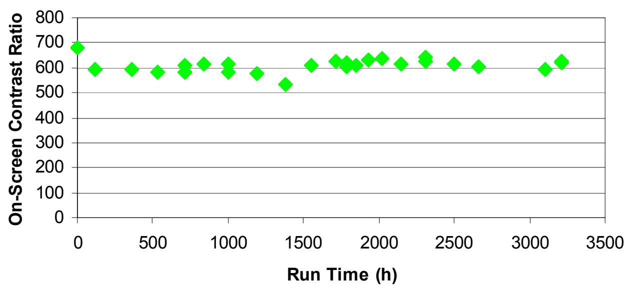
Fig. 6. KE polarizer projection component without TAC.

3.3 Polarizer durability

3M Vikuiti™ KE polarizer structures of similar construct to those illustrated in Fig. 5 have been tested for extended periods of time in commercially available LCD projectors.

In one such test a 3500 ANSI lumen projector having 1.0 inch imagers and illuminated by a 250W UHE lamp was carefully dismantled and the existing dye polarizers in the green and blue entrance and exit channels were replaced with KE polarizing components of virtually equivalent optical properties.

The test projector was then run for several thousand hours in a full brightness constant-on mode with a projected black image: the exit polarizers are therefore fully absorbing the signal. In addition, the lamp was routinely replaced at approximately 1000h intervals. The sequential on-screen contrast and the red, green, blue, black and white chromaticity coordinates were measured at regular intervals and the 3M Vikuiti™ KE polarizer structures were removed periodically for optical evaluation. It was found that there was no degradation to the color or contrast of the projected image during this test period. For example, there was no degradation in on-screen contrast ratio during the >3200h run time. Examination of the KE polarizer green exit component, which is the major contributor to on-screen contrast, both during and after the test, indicated that there was no change to the T_{pass} and T_{block} values. The results for the sequential contrast ratio measurement and green exit polarizer T_{pass} and T_{block} performance are illustrated graphically in Fig. 7.



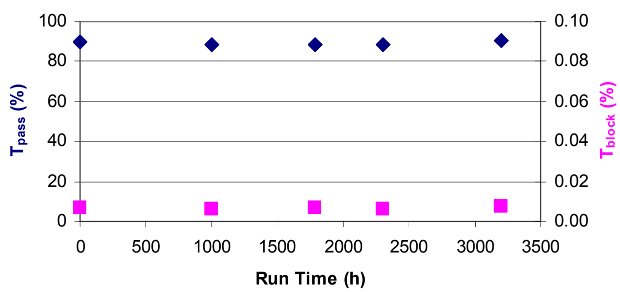


Fig. 7. Upper:– On-screen sequential contrast ratio change with run time. Lower:– Green exit polarizer T_{pass} and T_{block} change with run time.

4. Conclusion

By incorporation of intrinsic polarizing components into the challenging environment inside an LCD projection light engine it is possible to produce LCD projection engines with absorbing polarizing components that do not darken or lose contrast over many thousands of hours of continuous operation.

5. Acknowledgements

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