3M™ OnePol Reflective Absorbing Polarizer: dichroic dye dispersion in multilayer film simplifies system design, reduces power consumption and cuts system costs

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The Right Look Matters
3M™ OnePol Reflective Absorbing Polarizer allows large display manufacturers to simplify design, reduce system cost and achieve greater energy efficiency by improving brightness. Through a combination of dichroic dye dispersion and multilayer film technology, the new thin film provides the high degree of polarization found in conventional absorbing polarizers and the light recycling efficiencies found in reflective polarizers; as a result, reduced thickness is also possible. The improvement in energy efficiency could be particularly important under the new standards anticipated in ENERGY STAR Version 7.0 for televisions (scheduled to take effect in mid-2015).

Over the past six years, LCD televisions and monitors have made tremendous improvements in their performance. Resolution now approaches the limits of human perception; brightness, even at oblique viewing angles, is frequently as good as any viewer would want under normal conditions. Televisions are also more likely to have “smart” features like voice recognition and wi-fi connectivity. Monitors are more likely to have touch capability.

These performance advances are doubly remarkable because they occurred while televisions and monitors were making spectacular improvements in system design, system cost and energy efficiency. Today’s displays have fewer components in thinner profiles using more robust designs. Thanks to improved design, economies of scale and intense competition, they are less expensive. And, since the 2008 introduction of ENERGY STAR Version 3.0 (the first ENERGY STAR standard based on “power-on” rather than “stand-by” operation), the maximum power consumption allowed for televisions has been reduced by almost 75 percent. (Figure 1.)

The anticipated requirements under ENERGY STAR Version 7.0 (final version projected in Q3 2014, effective mid-2015) threaten to end this long run of simultaneous improvements in performance and energy efficiency while maintaining costs. More stringent power limitations could require manufacturers to apply the full array of energy saving tools at their disposal—and thereby accept more complex designs and modest increases in cost—or accept limits in performance.

The only other solution would be a technological breakthrough that would allow both a reduced system cost and an improvement in performance. 3M OnePol is such a breakthrough.
3M OnePol’s atypical structure

3M OnePol is a thin (approximately 75-85 microns depending on customer specifications) film that integrates the reflective properties of some multilayer films with the absorbing properties of dispersed dichroic dyes. It provides, in a single film, the functionality of the reflective polarizer used in many backlight units and the bottom absorbing polarizer in the liquid-crystal panel. As a result, it can help television and monitor manufacturers reduce energy consumption—consistent with ENERGY STAR Version 7—and material inputs with lower overall system costs and less thickness than designs using both these components.

These benefits are obtained with minimal tradeoffs in performance. 3M OnePol achieves a degree of polarization with approximately .01 percent blocked state leakage that is comparable to a conventional absorbing polarizer; it also reflects and recycles approximately 85 percent of blocked state light, comparable to common reflective polarizers.

A common representation of the optical effectiveness of a polarizer is PE Ratio, or polarization efficiency. PE ratio is defined as $\sqrt{(T_p-T_c)/(T_p+T_c)}$, where $T_p$ is parallel transmission of two polarizers and $T_c$ is crossed transmission of two polarizers. Figures 2 and 3 show a comparison of 3M OnePol and a conventional polarizer; in this test, the conventional polarizer measured 99.996 and 3M OnePol measured 99.991.

In the comparison, the transmission of the sample is normalized to the transmission containing the reference polarizer. (Figure 4.) For both the $T_p$ and $T_c$ tests, the Lambda reference polarizer is the first polarizer, and the polarizer under test is the second polarizer.

This performance is the result of 3M OnePol’s atypical structure as a single film with two distinct multilayer regions. (See Figure 5.)

The multiple layers in the bottom (backlight-side) region are structured to polarize and reflect light using the constructive interference principles embodied in multilayer films such as 3M DBEF (i.e., reflection occurs as light encounters the surfaces of layers with different refractive indices). At the same time, they collimate light by preferentially reflecting off-axis light back to the recycling cavity, while providing higher transmission for light closer to normal incidence. This mechanism was previously employed in 3M Collimating Multilayer Optical Film (CMOF). (See Figure 6.)

At intervals within the top (panel-side) region are layers in which dichroic dyes have been dispersed in modified polyester resin. While these dichroic dyes are effective as polarizers, they are typically less effective than the iodine that is used in conventional absorbing polarizers. Dichroic dyes are an attractive polarizing agent, however, because they are much less sensitive to humidity than the iodine, and the polyvinyl alcohol in which it is dispersed, and therefore more stable.

Dispersing these dyes through specific layers creates an internal recycling of undesirable light—that is, light with a polarization state that cannot be used by the LC panel—that amplifies the dyes’ polarizing function. Almost all of the unusable light that leaks through the dichroic dye on the first pass is reflected back by layers of film with varying indices of refraction. It passes back through the dichroic layer, where much of it is absorbed. Any light that is not absorbed is transmitted to layers of film beneath the dichroic dyes and, again, reflected back through the dichroic layer. Over the course of several ricochets through the dichroic layer, most of the light is absorbed. (See Figure 7.) This internal recycling allows 3M OnePol to match the transmission-blocking performance of conventional iodine absorbing polarizers while retaining the greater stability of the dichroic dyes.
Enabling both simplified and high-performance designs

Design flexibility across the supply chain is enabled by 3M OnePol. Manufacturers can configure 3M OnePol without any free floating films in a low cost, simplified, direct-lit design that also reduces material inputs and waste streams. Alternatively, 3M OnePol can be configured with multiple diffusers and prism films to create high-performance edge-lit or direct-lit designs with much greater brightness (and therefore energy efficiency). Because it gives panel makers the ability to differentiate their products, as either a conventional or a high-gain panel, 3M OnePol may redefine the LCD open cell market. Large display integrators will have the opportunity to source panels with built-in 3M OnePol value and a wide range of backlight designs to help simplify the supply chain. (See Figure 8.)

3M OnePol Enables Differentiation

When 3M OnePol replaces a conventional absorbing polarizer in a typical LCD television or monitor—that is, one equipped with a standard prism film but not a reflective polarizer—brightness increases by 21 percent; when 3M OnePol is paired with a high-gain prism film, the increase in brightness is 30 percent. In simplified, edge-lit systems with neither a prism film nor a reflective polarizer, replacing the conventional absorbing polarizer with 3M OnePol produces a 16 percent improvement in brightness. The gain in a simplified, direct-lit system is more modest—just 4 percent—but a gain nonetheless.

By enabling the elimination of backlight prism films which can warp and deform the image, 3M OnePol also allows simplified designs to be more robust.

As shown in Figure 5’s conoscopes, for each configuration, the viewing angle is also improved relative to the conventional design. A fall-off in the contrast ratio is observed, with the reduction ranging from 7 percent in the high-performance configuration with a high gain prism film to 25 percent in the simplified, direct-lit configuration. Given the extraordinarily high contrast ratios of many contemporary displays, a 7 percent reduction is virtually imperceptible and even a 25 percent reduction is unlikely to be meaningful for most viewers.

Because 3M OnePol’s absorption axis is at 90 degrees relative to conventional polarizers, it works best on panels that would otherwise not have a rear compensation film. This includes IPS (in-plane switching) panels, VA (vertically aligned) panels with one-sided compensation film, and TN (twisted nematic) panels without compensation film.

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Figure 8. 3M OnePol enables both high-performance and simplified designs. In both, brightness, and therefore energy efficiency, is improved compared to the conventional polarizer. (Data based on a 32” IPS TV panel.)
Durability

Based on 3M’s experience with multilayer film manufacturing and the stability of the dichroic dyes, 3M OnePol was expected to show good durability during environmental testing. Results confirm this expectation.

In one test of the film’s ability to withstand shipping conditions, three televisions equipped with 3M OnePol samples were placed in an oven at 60°C and 90 percent relative humidity with the backlight off for 240 hours. The devices were then removed. After two hours at room temperature, they were turned on and evaluated. After this evaluation, the televisions were returned to the oven under the same conditions for another 260 hours, after which they were removed. After two hours at room temperature, they were turned on and evaluated again.

The second evaluation of the 3M OnePol-equipped televisions revealed no sign of delamination from the panels, no significant panel warp, and no cosmetic yellowing or aging. Incidental curvature of the panel was observed, but only after it was removed from the TV for testing. In contrast, an off-the-shelf control TV showed some flexing in the corners.

In tests of stand-alone (i.e., not installed) 3M OnePol and conventional polarizers, polarization effectiveness was measured after protracted exposure (100, 500, and 1,000 hours) under dry and humid conditions. (See Figure 9.)

<table>
<thead>
<tr>
<th>Sample</th>
<th>85C</th>
<th>65/95% RH</th>
<th>Tshock</th>
<th>80C 90%RH</th>
<th>95C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Polarizer</td>
<td>-0.01%</td>
<td>-98.91%</td>
<td>0.01%</td>
<td>-91.35%</td>
<td>-0.07%</td>
</tr>
<tr>
<td>3M OnePol Lot A</td>
<td>-0.04%</td>
<td>-1.11%</td>
<td>0.01%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3M OnePol Lot B</td>
<td>0.01%</td>
<td>-0.01%</td>
<td>0.03%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3M OnePol Lot C</td>
<td>-0.03%</td>
<td>-0.03%</td>
<td>0.00%</td>
<td>-0.19%</td>
<td>-0.14%</td>
</tr>
</tbody>
</table>

In the dry test at 85°C, performance among all samples was comparable; the films were also comparable following 100 thermal shock cycles (−40°C x 1 hr / 85°C x 1 hr). In the humid test (65°C, 95 percent relative humidity), 3M OnePol’s performance was significantly better than the conventional polarizer. The conventional polarizer’s poor performance is attributed to the tendency of polyvinyl alcohol—an important component—to absorb moisture.

Cost impacts

The use of 3M OnePol could drive highly efficient, Version 7-compatible LCD system costs down significantly. Determining the precise cost benefit is difficult, but good-faith estimates suggest that the greatest impacts come from a reduction in system components: moving from three to two films in high-performance displays and from two to one or zero films in lower-performance displays. Quality and supply chain improvements also contribute to the cost benefits, as does the value of improved performance in higher end devices. (See Figure 10.)
Next steps

3M anticipates that 3M OnePol will be launched in 2015. As it moves toward commercialization, the company is working with television and monitor manufacturers to allow a smooth and rapid integration into their manufacturing processes in advance of the ENERGY STAR Version 7 effective date.

For additional information, please contact Adam Haag, Display Materials & Systems Division, 3M Company.

1 ENERGY STAR Program Requirements for TVs: Version 3.0. This requirement applies to TVs with 768 or 1080 resolution; maximum on mode power for 480 resolution is 210 watts. http://www.energystar.gov/products/specs/system/files/tv_vcr_prog_req_V3.0_0.pdf

2 ENERGY STAR Program Requirements for Televisions Partner Commitments Versions 4.0 and 5.0 http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/television/Final_Version%204.5_TV_Program_Requirements.pdf?Se75-1c67
