

Title: Efficiency Enhancement of Liquid Crystal Projection Displays using Light Recycle
Technology

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ABSTRACT

A new technology, developed at Jet Propulsion Laboratory (JPL), using low-absorption color filters with polarization and color recycle system, is able to enhance efficiency of a single panel liquid crystal display (LCD) projector to the same efficiency of a three panel LCD projector.

Keywords: LCD, color filter, color recycling, display, projector.

Technical summary

A single panel liquid crystal display (LCD) projector has a simple optical system, and cost much less than a three panel LCD projector. But a conventional single panel LCD projector has a very low efficiency, because it has to throw away two third of the incident light due to the color filters. In addition, the current polarization conversion, which uses micro-lens array with polarization beam splitter and half wave retarder, increase the beam divergence angle, also leads to lower efficiency.

The new technologies of reflective color filter and color recycling system^{1,2}, invented by Dr. Yu Wang at JPL, will enable a single panel LCD projector to reach brightness as brighter as a three panel LCD projector.

The technology for color filtering in a liquid-crystal or other flat-panel display device will make it possible to brighten the display without increasing the amount of light supplied from behind the panel. The need for technology arises as follows: At present, each pixel in a typical single panel LCD panel contains three dye filters: red, green, and blue. Each filter transmits its single primary color and absorbs the other colors, so that less than one-third of the available light is used for viewing.

In the proposed technique, one would replace the dye filters with reflective color filters, for example: thin metal film filter^{3,4}, surface-plasmon filter^{5,6} or interference filters, which are more reflective than absorptive. In addition, the filters and illumination optics will be arranged so that much of the light reflected from the filters would be reused as illumination. The overall effect should be an increase in brightness and efficiency.

Figure 1 illustrates this concept as applied to a liquid-crystal panel back-lit by a lamp with a collimating reflector. After the polarization beam splitter (not shown), polarized light shines on the color filter arrays of a reflective LCD panel. These in-pixel color filters are reflective color filters with a little absorption, each color filter transmits one color, and reflects the rest of the two colors. Light reflected from a color filter on the panel returns to the collimating reflector, where it will be reflected twice and sent to a different location on the panel. Of course, neither the original

light from the lamp nor the light reflected from the panel will be collimated perfectly as shown in simplified form in the figure; all incident and reflected beams of light will have some angular spread. This spread would be beneficial in that it would make the illumination more nearly uniform across the panel. Therefore this panel can generate an image three times brighter than a same panel using the conventional dye color in-pixel color filters.

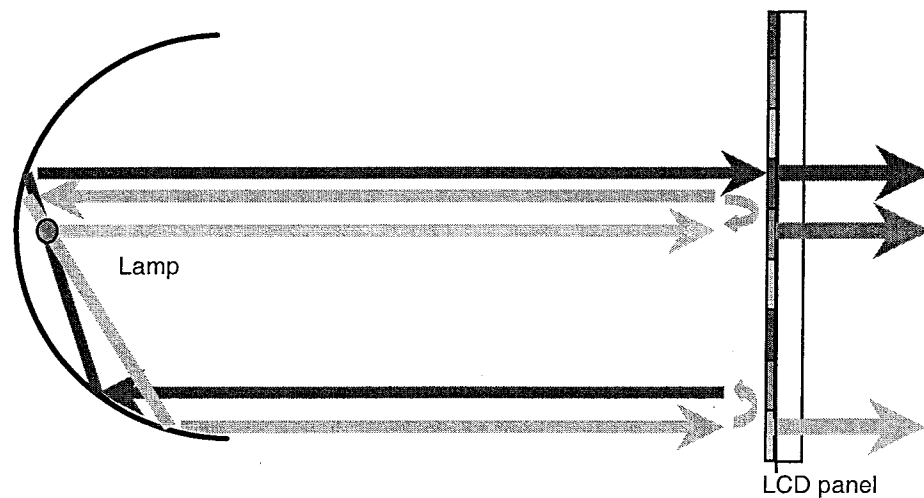


Fig. 1 Color recycle using reflective color filters.

For example, if white light from the lamp shines on a red in-pixel color filter, red color will pass through and modulated by the LCD to generate an image, while green and blue color will be reflected back to the light collector, get reflected twice, and shines on the LCD panel again. If this returned light (which only have green and blue colors left) hits another red color filter, it will be reflected again; if it hits a green color, then green color will pass through and only blue color will be reflected back. And finally, the blue color will be reflected twice by the light collector, and shines upon the LCD panel again. Therefore, each color will bounce back and forth between the light collector and the LCD panel until each color finds the corresponding color filter. In this case, almost all the light from the lamp can be used, and this single panel LCD can have an efficiency as high as a three panel LCD. Though Fig. 1 is an example of using this technology for projector, it can be easily converted to be used for a direct view panel.

I have reported using surface plasmon tunable color filters for flat panel displays^{7,8}. Surface plasmon color filters can generate a very good color spectrum, and can be fabricated as in-pixel color filters to replace the dye color filters. Thin metal film filter, another technology developed at JPL, would be more suitable for projectors.

The physics of thin metal film filter is simple, it works upon the same principle as the dielectric interference filter, only now the high index material of the dielectric interference is replaced by metal. Because metal can reflect much more light than high index dielectric materials, the thin metal film filter can reach good color with much less layers. For example, a five layer (Ag/MgF₂/Ag/MgF₂/Ag) can achieve performance better than typical dye color filter filters.

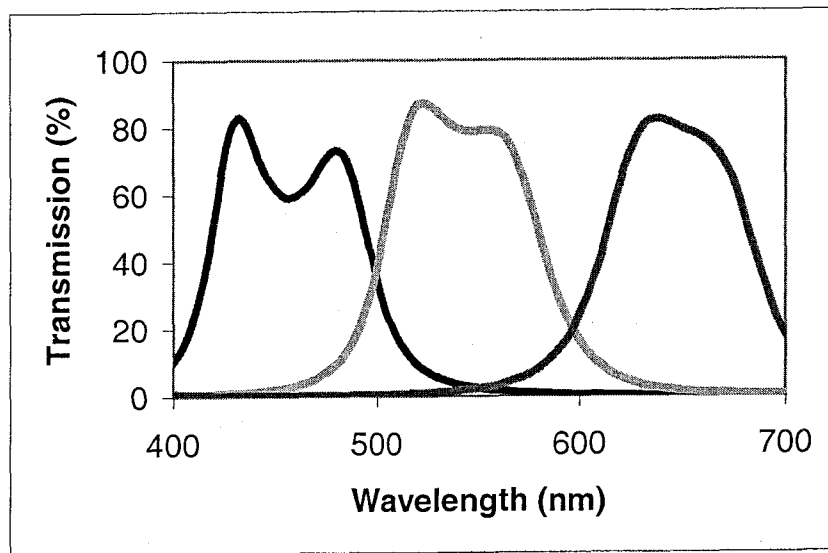


Fig. 2 Performance of thin metal film filter.

By inserting a quarter wave retarder in front of the polarization beam splitter and place a mirror behind the beam splitter, we can also have a polarization recycle without increase either the beam diameter or the angle divergence. As shown in Fig. 3, unpolarized light from the lamp, reflected by light collector, pass a quarter wave retarder, the light is still unpolarized. When incident on a polarizing prism, s-polarized light is reflected down toward a LCD panel; and p-polarized light passes the prism, reflected by a mirror, and goes backward to the lamp and light collector. This backward light passes the quarter wave retarder, becomes circular polarized, gets reflected twice by the light collector, and passes the quarter wave retarder again. When a linear

polarized light passes a quarter wave retarder twice, it changes its polarization, therefore the p-polarized light now becomes s-polarized, and reflected by the prism goes to the LCD panel.

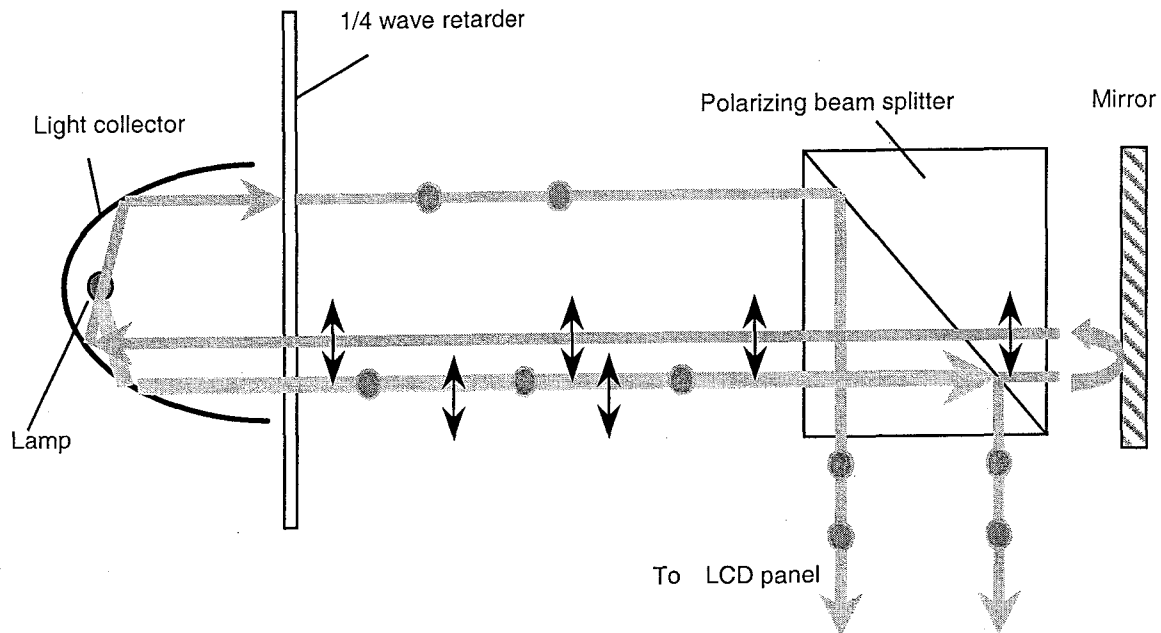


Fig. 3 Polarization recycle without increase either beam diameter or beam divergence.

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