Polarized-light backlights for liquid-crystal displays

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A novel backlight system improves energy efficiency and reduces optical polarization losses.

The optical efficiency of color LCDs is notoriously low. Of every lumen of light generated in the backlight, only 2–8% is used owing to light losses in polarizers, color filters, and other optical layers. The luminance is therefore usually enhanced in the viewing direction, at the expense of light emitted at large angles. This is done using micro-optical foils that select and transmit light emitted in certain angular ranges and recycle the rest (see Figure 1). A second enhancement that is sometimes used recycles the polarization. Light with the desired polarization state is transmitted, but orthogonally polarized light is reflected toward the backlight. The latter must be depolarized and re-emitted by the backlight system.

We aim to apply the angular and polarization selection more efficiently. In this context, both polarization-dependent light scattering\(^1,2\) and the polarization dependence of the so-called Brewster angle\(^3\) have been demonstrated. Use has also been made of oriented poly(ethylene terephthalate) (PET) foils\(^4\) and liquid-crystalline polymers.\(^5\) These approaches suffer from several drawbacks, however, including the nonuniform extraction of light and the need to inject collimated light, with the associated efficiency losses. It has also been proposed to integrate a wire-grid reflective polarizer into the light guide.\(^6,7\) The additional challenge associated with the latter approach, apart from manufacturing issues, relates to how one can eliminate large absorption losses in the metal film.

In our polarized-light backlight system (illustrated in Figure 2) light is extracted from a light guide to result in highly polarized, high-luminance emission near normal angles while the orthogonal polarization is recycled within the light guide. Key in our approach is the use of microstructured birefringent polymeric layers integrated into the light guide. The microgrooves are filled with an isotropic polymer that is index-matched for p-polarized light (see Figure 2). Hence this light propagates unimpeded through the light guide. However, a large index mismatch affects s-polarized light. This light is effectively extracted from the light guide by total internal reflection. The exact shape of the microgrooves allows control over the angular distribution of the emitted light.

Two types of polarized-light backlights have been developed. The first\(^8,9\) uses uniaxially oriented poly(ethylene naphthalate) (PEN) and PET foils. Through stretching,\(^10,11\) the index of re-

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Figure 3. Stretched birefringent poly(ethylene naphthalate) (PEN) and poly(ethylene terephthalate) (PET) foils microstructured using (left) diamond-tool machining and (right) hot embossing. PMMA: Poly(methyl methacrylate).

Figure 4. 6.4in-diameter demonstrator backlight compared with a conventional backlight, both partially covered with an s-oriented polarizer. The fraction in the stretch direction typically increases to 1.70 and 1.85 for PET and PEN, respectively. Perpendicular to the stretch direction typical values are 1.54 for PET and 1.56 for PEN. Microstructuring is done by diamond-tool machining or hot embossing. Microscope pictures in Figure 3 illustrate good shape reproduction. The birefringence of the foils is maintained surprisingly well in the hot-embossing process so that this seems a promising route for mass fabrication. A demonstrator backlight is shown in Figure 4 next to a conventional backlight. It can be seen that a polarizer absorbs half of the light of the conventional but not of the new backlight.

The second type of polarized-light backlight uses a uniaxially aligned liquid-crystalline polymeric (LCP) film from Dejima Optical Films. This is a somewhat elastomeric material with a thickness of about 8 µm that can be laminated mechanically onto a microstructured light guide. Figure 5 shows a microscopic cross-section. The ordinary and extraordinary refractive indices of the birefringent film, $n_o$ and $n_e$, are 1.51 and 1.66, respectively. Although the LCP layer is heavily deformed in the lamination process (see Figure 5), its birefringence is maintained. Figure 6 shows a mobile-phone demonstrator. For this application, reduction of the module’s thickness through elimination of some light-management foils is of paramount importance.

S-polarized light is preferentially extracted from all light guides. The measured total lumen efficiency for both types is 1.6–1.7 times higher than for a conventional backlight that does not use polarization recycling. We expect to get even closer to

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the theoretical gain factor of 2.0 by reducing the residual nonpolarization selective scattering and by developing a further optimized design of the extraction structures. The angular emission pattern can be designed such that neither brightness enhancements nor reflective polarizer films are needed, leading to reduction of complexity, thickness, and costs.

Part of this work was done in collaboration with the Dutch Polymer Institute at Eindhoven University of Technology.

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References