UV curable colour filters for plastic substrates

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HPL-2008-146

Keyword(s):
UV curable, colour filter

Abstract:
Liquid crystal displays have been on the market for decades, starting out with small portable appliances, like watches in the 80's, growing up to laptop and computer displays, and now conquering the home entertainment sector with high definition television sets. Nevertheless this mature technology is under permanent pressure to beat all other emerging technology by price, reliability and quality. The most costly component of the display is the multi-layer substrates. Standard commercially available displays are glass based but there is a growing interest in plastic displays. Plastic as a substrate would not only offer the consumer a more robust appliance but could also reduce production cost by allowing roll to roll processing on top of printing processes already established for glass substrates.

External Posting Date: October 21, 2008 [Fulltext] Approved for External Publication
Internal Posting Date: October 21, 2008 [Fulltext]

Submitted to RadTech, Cincinnati, OH, USA

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Introduction

Liquid crystal displays have been on the market for decades, starting out with small portable appliances, like watches in the 80's, growing up to laptop and computer displays, and now conquering the home entertainment sector with high definition television sets. Nevertheless this mature technology is under permanent pressure to beat all other emerging technology by price, reliability and quality. The most costly component of the display is the multi-layer substrates. Standard commercially available displays are glass based but there is a growing interest in plastic displays. Plastic as a substrate would not only offer the consumer a more robust appliance but could also reduce production cost by allowing roll to roll processing on top of printing processes already established for glass substrates.

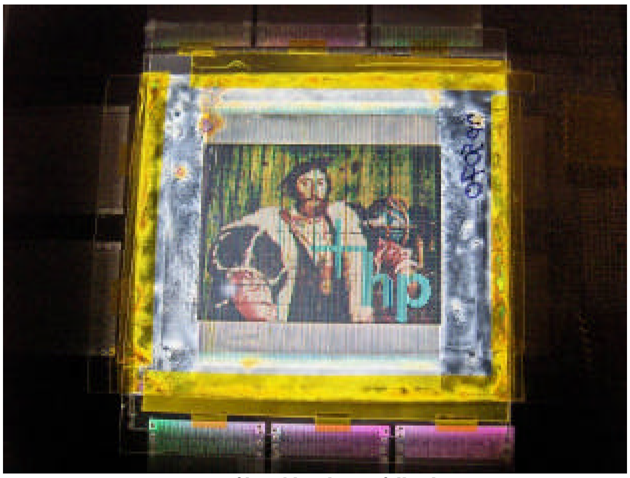


Figure 1: Picture of bistable, plastic, full colour prototype

HP Labs Bristol has developed a prototype of a bistable, plastic, full colour display. This display is a transmissive backlit display like the majority of lc displays but new in its embodiment: all layers, except the polarisers are printed on plastic substrates. The colour filters resins were jetted and cured by UV irradiation.

Requirements

These colour filters have to fulfil requirements which can be divided roughly into optical, rheological and mechanical.

Optical performance
In this prototype, as in most of the lc displays on the market, the combination of the liquid crystal and the polarisers forms a light valve. In one orientation the liquid crystal molecules change the light polarization in such a way that it can pass through two crossed polarisers, in another orientation the polarization of the light generated by the first polariser stays untouched and cannot pass the second polarizer. All light is absorbed. This is possible because liquid crystals are birefringent, that is polarisation changing, materials which modify the light wave and can be switched by an electric field from polarization modifying to non-modifying.
Since the colour filters are between the polarisers they themselves should not change the polarization of the light, otherwise light leakage would occur and a high contrast full colour image would not be possible. For a pigment based formulations it means that the pigment size should not be bigger than 250nm to suppress scattering, the host resin should not be birefringent after curing, and no flocculation or aggregation should occur during curing.

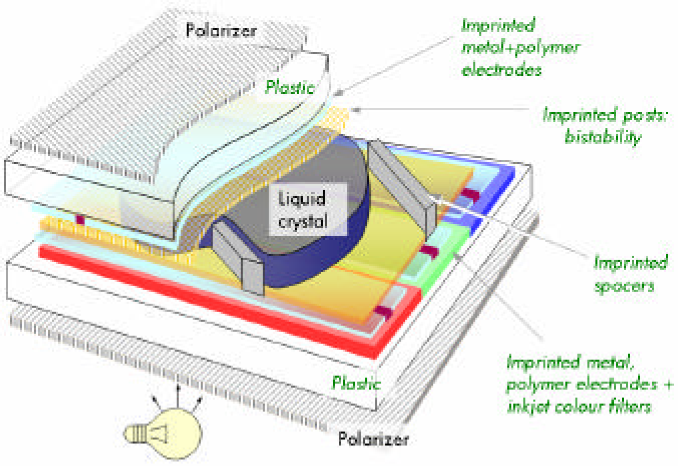


Figure 2: Layout of the HP prototype of a bistable plastic display

To reach a high enough colour saturation the pigment load in the cured film (thickness: 2 – 4 micron) should guarantee absorption of 80% of the incident light at the absorption band of the pigment.
The resin and then film should not bleach during processing and its transmission should not increase by more than 10% when illuminated by 3000 cd/m^2 for 10 000 hours.

Rheological requirements

The rheological requirements are dependent on the print head. Here a Spectra SE-128 by Fujifilm Dimatix was the print head of choice. It can handle fluids with a viscosity in a range of 8 – 20 cP and it can be heated up to 90°C. The decision was made not to go beyond 45°C. In addition the pigment suspension should survive the shear necessary to generate a drop velocity of 10m/s without phase separation.

Mechanical requirements

The printed and cured pigment film has to endure several further processing steps including the lamination of the layered substrates. The cured film needs to withstand 160°C for 1h without bleeding or blooming and without softening.

Because the colour filters are jetted directly onto the plastic substrates the mechanical characteristics of the cured material should match those of the substrates as closely as possible to avoid stress at the interface. The shrinkage during curing should be minimized to allow maximal control over film thickness and again minimal stress at the interface.

To keep the number of processing steps low the cured films should have a high surface energy to allow the next layer to adhere to it without further treatment. The uncured resin should wet acrylate surfaces without the need to modify these surfaces either.

We felt that all these requirements were best satisfied by UV curable pigmented acrylate resins. Vinyl resins would be flexible enough for the plastic substrates but are not sufficiently robust to survive further processing steps undamaged.

Pigments

For a transmissive display the choice of pigment is very much a function of the light source. With the advent of LED as backlights attention has to be paid to their spectrum. Even for an LED lamp which appears white to the observer the spectrum can be very peaky and can have gaps in the emission in the frequency range of the visible spectrum.

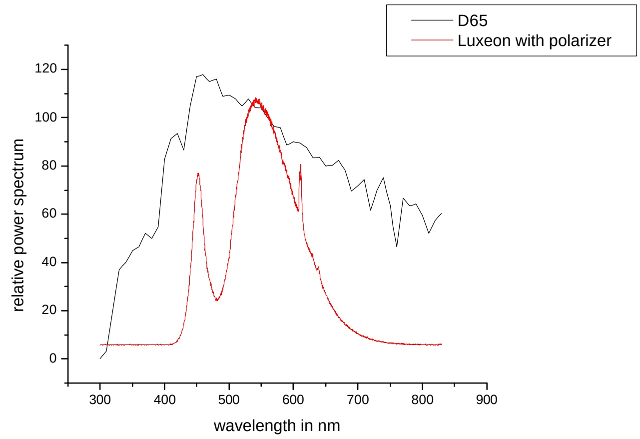


Figure 3: D65 spectrum and spectrum of a Luxeon backlight in combination with a polarizer.

Figure 3 shows the spectrum for a LED backlight called Luxeon and the CIE D65 spectrum which represents daylight and is used for the calculation of chromaticity coordinates. Especially for blue this spectrum is problematic. With a very narrow transmission peak at 450nm it is a mismatch to many blue absorbers. For example pigment blue 15:6 has its transmittance peak at 475nm, almost exactly where the Luxeon light has its emission minimum at the blue end of the spectrum. The result is a quite substantial shift of the chromaticity co-ordinate, see figure 4.
Other pigments benefit from lacking wavelengths in the Luxeon spectrum. C.I. pigment violet 23, usually used as a co-grind, could be used with this backlight as a blue since the lack of emission in violet shifts it near to the NTSC blue point (figure 4). The NTSC red point is hit by C.I. pigment red 149 and for green there is not much choice anyway, either C.I. pigment green 7 or pigment green 36 can be used. These green pigments are relatively weak absorbers and the final matrix has to contain 9w/w% to reach the absorption target whereas for all other pigments 4-5 w/w% are enough.

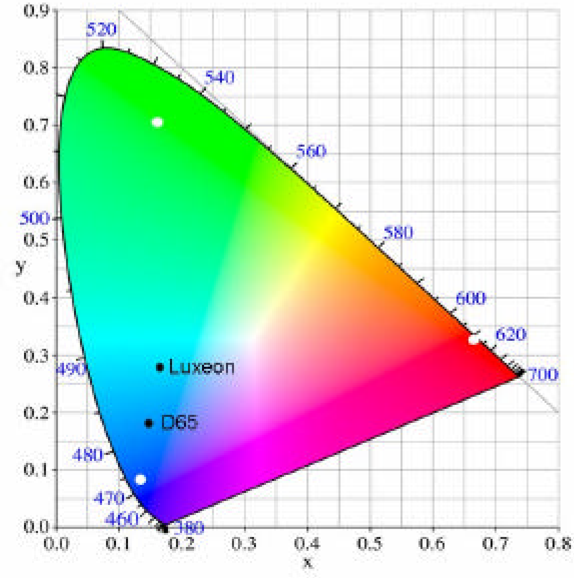
Resin preparation

20 to 30w/w% of pigment with the appropriate amount of dispersant (we found that 8 – 15w/w% of dispersant gave the most stable suspensions) were milled into a commercially available solvent free grinding vehicle using a planetary mill (Fritsch Pulverisette 7 Premium Line). The milling times were dependent on the miller's patience and the bead size. They varied between 15min at 1100 rpm and 2h at 500 rpm. The advantage of a planetary mill is that even a paste like premix can still be successfully milled. The beads were then separated form the product by adding to the product/bead paste a mixture of commercially available monomers with photo-initiators and filtering the final matrix through a porous sintered glass plate under vacuum. The final matrix was then mixed with a high shear mixer at 95000 rpm for 10min and filtered again through a paper filter with 2.5 micron retention.

Mill base
20 to 30 w/w% (green) pigment
8 to 15 w/w% (green) dispersant
55 (green) to 72w/w% solvent free grinding vehicle

Final matrix
20 to 30 w/w% (green) mill base
4w/w% Photo-initiator mix
66 (green) to 76% blend of acrylate mono- and oligiomers

Tests
The resins were then spun onto glass and cured under nitrogen. Even though some samples looked completely clear when observed with the unaided eye, inspection under the polarization microscope showed that flocculation had occurred and light leakage between crossed polarisers made the resin unsuitable for colour filters. Figure 5 shows a cured film which would be acceptable for general printing but generates too much light leakage between crossed polarisers to be suitable as a colour filter film. Viscosity measurements with a Brookfield DV-I+ Viscometer showed whether a stable suspension in the right viscosity range was achieved. Highly thixotropic



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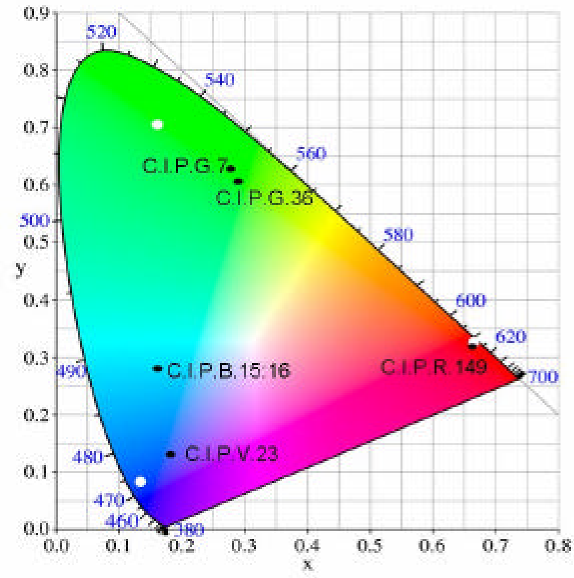

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Figure 4:The white dots represent the chromaticity coordinates of the NTSC standard. a) chromaticity shift caused by different spectra of light source. b) chromaticity coordinates for different pigments calculated with the spectrum of the LED Luxeon instead of a D65 spectrum.

behaviour was always a sign that the dispersant was not ideal and the suspension would phase separate under shear. The samples were baked for 1h at 160C and then tested for softening.
The resin was jetted through a single nozzle (PicPIP from GeSiM) to check phase separation under shear.

Figure 5: Flocculation during curing, 200x magnification. No polarisers.

Summary

We showed that UV curable acrylate based pigmented resins are suitable to jet colour filters onto plastic substrates. The choice of pigments is strongly coupled to the spectrum of the backlight and cannot be generalized. Low shrinkage during curing allows good control over film thickness and minimizes stress between film and substrate. The cured acrylate films are tough enough to withstand further processing steps but stay flexible enough to follow the substrate when bent during roll to roll processing. The blend used for the prototypes will need modification when mill, light source or substrate material are change.

Acknowledgments

The authors would like to thank Nabowia Sali and Neil Poole from HP TechInk, SA for technical and moral support and Molly Hladik from HP San Diego, USA for useful discussions.