Scratch-Resistant UV-Curable Coating for Advanced Display Films

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I. Introduction

Advanced Display Films (ADF) used in liquid crystal displays, such as computer monitors and TVs, to increase the brightness of LCD through improved management of the existing light provided by the backlight. The function of the ADF is to direct light coming from the light guide toward the viewer. The escape criterion for light rays to be passed through the ADF is determined by the geometry of the prismatic (coated) surface of the film and the refractive index of the material. As illustrated by Figure 1b, light rays impinging on the polymer-air interface at an angle above the critical angle are directed toward the viewer (dashed ray) while rays impinging at an angle below the critical angle (solid ray) are recycled and redirected.

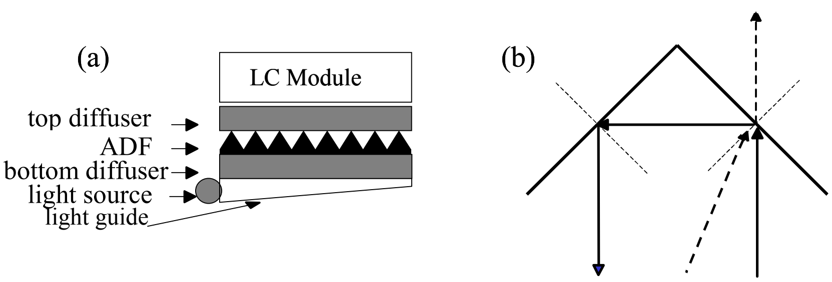


Figure 1. (a) Schematic of an LCD. (b) Schematic of light rays impinging on the polymer-air interface at angles above (dashed ray) and below (solid ray) the critical angle.

Prismatic films used in LCD are subject to stringent visual requirements. The cosmetic defects (scratches, smudges, indents) could occur on both coated and uncoated sides of the film. The unique prismatic geometry of ADF makes the films particularly prone to visible damage during manufacturing process and final product assembly. The goal of this study was to develop an advanced UV-curable coating that provides scratch-resistance and a method for measuring scratch visibility of prismatic films.

II. Experimental

ADF Coating

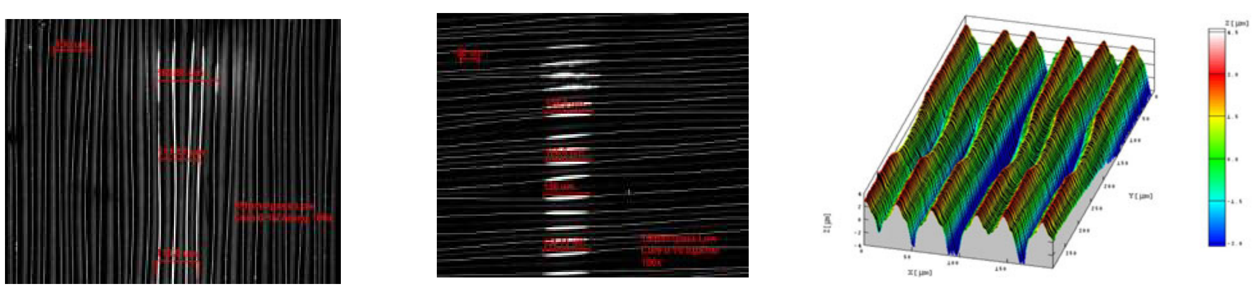
Illuminex™ ADF is a micro-replicated prismatic film that uses a patented, proprietary coating[1] applied to a high-quality polycarbonate (PC) optical film. The coating has a number of requirements including the following:

1. Polymerization induced by UV-light to achieve rapid cure;
2. Good adhesion to PC to prevent delamination;
3. High refractive index (>1.56) to achieve higher brightness;
4. Good dimensional stability to prevent deformation of prisms;
5. Low shrinkage to minimize internal stress;
6. High ductility to minimize cracking of the coating.
7. Good abrasion and scratch resistance to minimize damage to the prisms.

The ADF coating consists of a UV-curable acrylate monomer, brominated aromatic acrylate monomer, photoinitiator and additives as described previously by Chisholm et al.[1] The coating was shown to provide good adhesion to PC ("5B" rating based on ASTM D3359), high refractive index (RI > 1.58), good dimensional stability, low shrinkage and high ductility.

Vibrating Testing of ADF

The coated films were evaluated for scratch and abrasion resistance using a vibration testing that was performed at different frequencies (1-200 Hz). The visual inspection was conducted before and after the testing. There were several scratches found to be on the coated (prismatic) side of ADF along and across the prisms (Figure 2a and 2b). The dimensions of scratches were measured using microscopy (Zeiss Axioplan Microscope with AxioCam MRc5 digital camera) and profilometry (Surfcoder ET4000A -- Kosaka Laboratory Ltd.) (see Figure 2c). The results of measurements were used to develop a new method for scratch visibility of prismatic films.

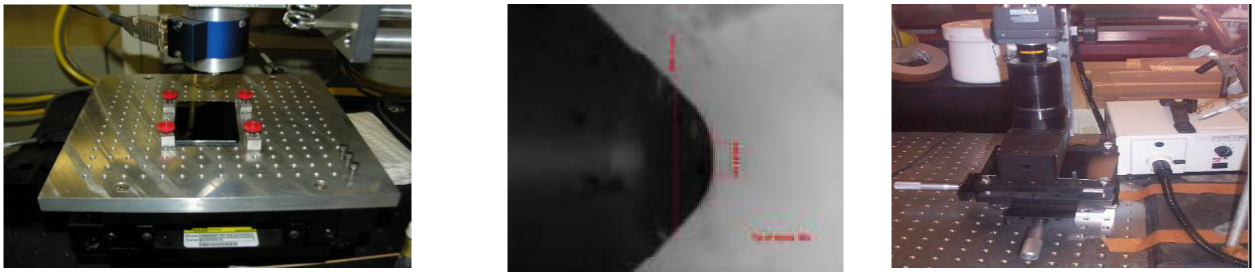


(a) (b) (c)

Figure 2. (a) Microscopic image of scratch along the prisms; (b) Microscopic image of scratch across the prisms; (c) Profilometry image of scratch across the prisms.

Scratch Testing

MVP Gen III Scratch tester[2] was used to create single scratches of ADF using controllable force and speed (Figure 3a). Scratches were made using an indenter under a specified load (0.1-0.7 N) and speed (0.1-1 mm/sec). The indenter was mounted on a 3-axis force transducer, which provides feedback to actively produce small vertical motions that compensate for sample tilt or curvature to maintain constant force. The stylus consists of a diamond cone indenter with a 40º cone angle and tip radius of 400µm (Figure 3b). Scratches were made perpendicular to the prismatic structure (across the prisms).



(a) (b) (c)

Figure 3. (a) MVP Gen III Scratch Tester; (b) Stylus; (c) Scratch Imaging System.

Scratch Visibility

Scratch visibility methodology was developed to evaluate different coating formulations for ADF. Assessment of scratches was performed using a SLX Scratch Imaging System[3] that was modified to be able to measure the amount of reflected light from the prismatic film's background and from the damaged area. The scratched films were evaluated using a reflected light polarizing microscope (Hitachi; lens: Melles Griot Invarion) and a tungsten-halogen light source (Fostec, DCR II). The camera objective lens was positioned at an angle of 90° from the scratch. The light source was positioned at approximately 45°angle (Figure 3c). The objective lens registers a scratch of about 10mm long, and the electron signal for each scratch line is then integrated and recorded.

The optical mass of an object, M, is the sum of the gray level values, GL, of all pixels in the object. The individual gray level values are assigned by the imaging system program in unit steps in the range of 0-255, where 0 = black and 255 = white. The optical mass, M, can be calculated as follows:

$$M = \sum_{i=1}^{n} GL_i \qquad (1)$$

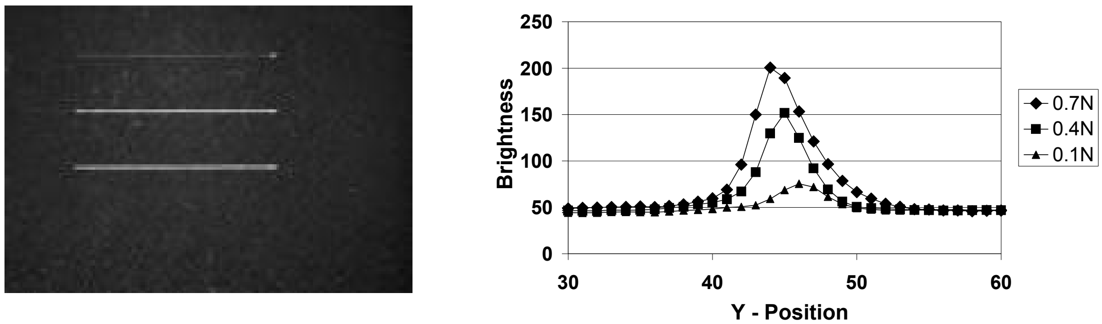
where n is the number of pixels. The brightness of the object, B, is

$$B = \frac{M}{A} \qquad (2)$$

where A represents the area of the object. The percentage change in the brightness between the scratch and the background in the scratch visibility, ΔB, given by Chu et al.[4]:

$$\Delta B = \frac{B_{scratch} - B_{background}}{B_{background}} \times 100\% \qquad (3)$$

An example of three scratches at different forces and measurements of brightness are shown in Figure 5a and 5b. The visibility was calculated from the brightness of scratches ($B_{scratch}$ = 75, 150 and 200) and background ($B_{background}$ = 50) and approximately equal to ΔB = 50%, 200% and 300% at 0.1N, 0.4N and 0.7N, correspondingly.



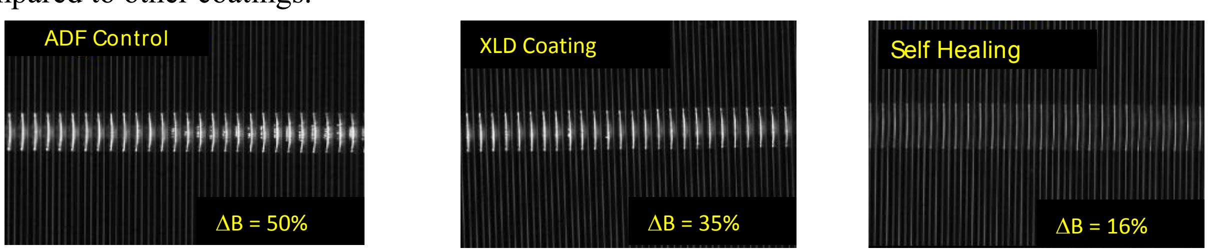
(a) (b)

Figure 5. (a) Image of scratches at 0.1N (top), 0.4N (middle), 0.7N (bottom); (b) Brightness measurements at different load.

III. Results

The combination of scratch and visibility test results with mechanical properties of polymeric materials has been used to formulate a new scratch-resistance coating for ADF. Marring is reported[5] to result from two types of scratches, fracture scratches and plastic scratches. A third type of elastic response does not produce any scratches at all. Polymeric coatings can undergo three types of recovery: “elastic” (immediate and complete recovery), “plastic” (no recovery, permanent deformation), “viscoelastic” (time dependent recovery, sometimes incomplete). High crosslink density (XLD) coatings potentially allow for elastic response, however, if XLD and temperature of glass transition (T_g) are too high, fracture scratches are observed.[5] In contrast, coatings with lower T_g are reported[6,7] to provide good scratch-resistance and elastic recovery from deformations caused by abrasion and scratch. The present study compares the existing ADF coating with the higher crosslink density coating (XLD) and “self-healing” coating (SH) formulated based on elastic recovery.

Figure 6 shows results of scratch visibility results for existing and new coatings at the scratch load of 0.4N. It can be seen that the self-healing coating has significantly lower scratch visibility compared to other coatings.



(a) (b) (c)

Figure 6. Image of scratches at 0.4N for ADF Control coating (a), high crosskicking density coating (b) and self-healing coating (c).

In conclusion, the new self-healing coating provides improved scratch-resistance for Advanced Display Films. The coating was optimized for additional requirements including adhesion, refractive index, viscosity, dimensional stability and shrinkage.

IV. References

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