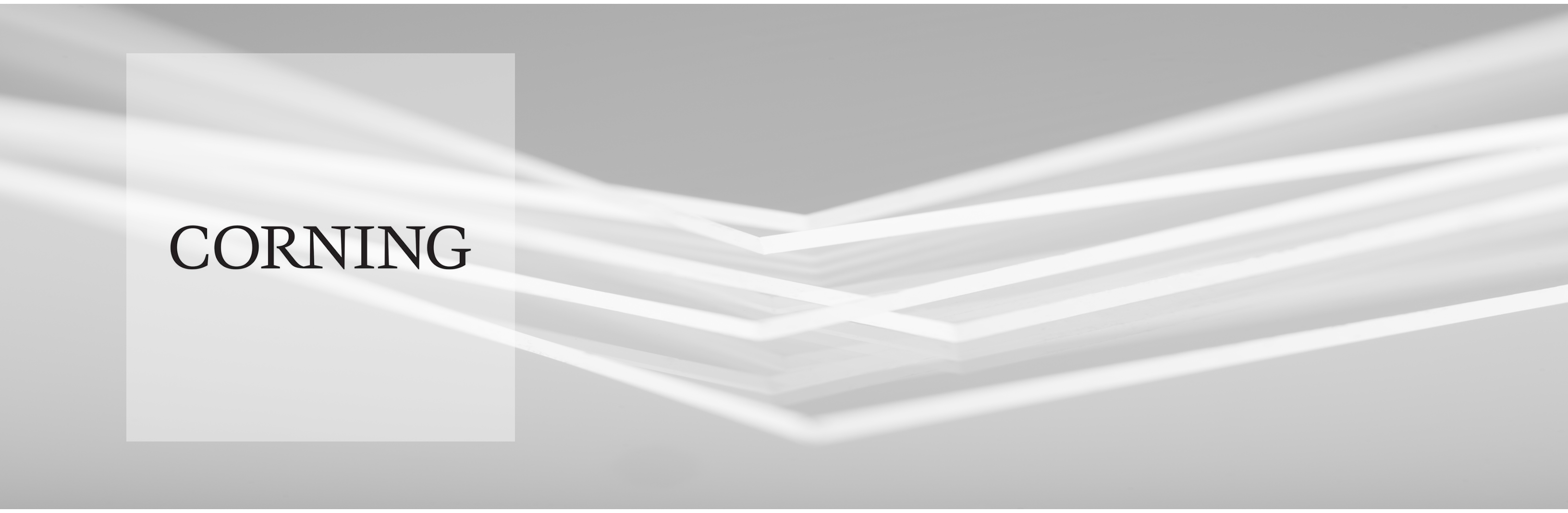
Panel Stress State Determines Light Leakage in Curved LCD



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Abstract

Substrate stress state determines the light leakage (LL) from dark state VA and IPS liquid crystal (LC) curved panels. Membrane stress creates VA but not IPS LL. Shear and bending stress create IPS but not VA LL. This result enables mitigation, design, and possibly new processes/components to enable non-traditional form factor LCDs.

1. Glass retardance magnitude and light leakage

Liquid crystal displays (LCDs) are ubiquitous from smartphones to TVs and are an essential part of the modern world. A key attribute that glass provides is to be "stress free" (i.e. not contribute significant retardance vs. the liquid crystal (LC) retardance used to electro-optically modulate the light between the crossed polarizers). The equivalent retardance magnitude of an LCD in the dark state is approximately the inverse of the square root of the contrast. The LCD intrinsic substrate retardance magnitude requirement is to be a fraction of the equivalent dark state retardance magnitude as modulated by the human eye contrast sensitivity function.

The stress-optic law:

$$\Gamma = \Delta\sigma \cdot C \cdot t = C \cdot t \cdot \sqrt{(\sigma_{xx} - \sigma_{yy})^2 + - \cdot \sigma_{xy}^2} \quad (1)$$

gives the magnitude of the retardance produced for a given in-plane state of stress and glass thickness. Γ is the retardance in nm, $\Delta\sigma$ is the difference of the first two principal stresses or twice the shear stress in MPa, C is the stress-optic coefficient in MPa^{-1} and t is the glass thickness in nm. C, the stress-optic coefficient of the glass is, to a good approximation, the weighted average of the C's of the component oxides of that glass[1]. Display glasses, to be cost effective to manufacture and environmentally conscious, are ~70% SiO_2. It turns out that the range of C for display glasses is ~15% (i.e. very limited ability to control LL from externalthermo-mechanical generated stress in glass with C).

Reducing retardance magnitude reduces LL. In practice, this requires reducing the external thermal and/or load gradients, or, using thinner glass. This has been presented in our previous work[2,3]. For the analysis of LL from stress intrinsic to the glass, the magnitude and orientation of the retardance of the two glasses is un-correlated.

Curved LCDs made with stress free flat glasses are not stress free when curved. Measurements, simulations and analysis of this special case were introduced in our previous work with emphasis on the relationships of glass retardance to curvature and thickness[4]. In this work, we present a simple conceptual model for understanding and managing the LL for curved LCDs with supporting measurements and simulations. This is also applicable to the case of flat LCDs that get out of plane deflections or loads (for example an IPS display pushed or bent out of plane near the edge of the view area).

2. Glass retardance orientation and light leakage

The retardance and light leakage concepts and results presented in this paper are readily understood, verified and applied by the methods of: the Mueller calculus, the Jones calculus, or the Poincare sphere[5]. We concentrate on explaining the model and presenting validating measurements and simulations. The reader is free to perform the manipulations with whatever method he or she is most familiar with.

Retardance has both a magnitude and orientation. The orientation of the fast axis, θ_{fast}, in terms of the in-plane stress components is given by:

$$\theta_{fast} = \frac{\pi}{2} + \frac{1}{2} tan^{-1}\left(\frac{2 \cdot \sigma_{xy}}{\sigma_{xx} - \sigma_{yy}}\right) \quad (2).$$

Another approach to manage LL is to try and have the phase change of the light from retardance going through the backlight side glass canceled by an opposite phase change from light going through the viewer side glass. The LC between the glasses may or may not contribute its own phase change. Let us assume that the retardance magnitude of both pieces of glass is the same and it is only the orientation that is variable. This is a very reasonable assumption for a curved LCD.

Non-canceling phase change from glass, LC, glass stack is a necessary but not sufficient condition for LL. There will not be any LL if the retardance orientation is aligned with the polarizers, typically 0°/90°. The LL will be max if the retardance orientation is 45° for the 0°/90° polarizers. For the 0°/90° polarizer case the LL goes as $\sin(2\theta_{fast})$.

For the case of dark state VA LC, we assume the LC contributes no significant retardance on the scale of LL. So if the retardance (magnitude and phase) of both pieces of glass is the same then the resultant phase change is additive (i.e. the same as one thick piece of glass with the total phase change equal to the sum of the two individual phase changes). On the other hand, if one piece of glass advances (or delays) the phase by, say, δ° and the other piece of glass delays (or advances) the phase by -δ° then the light exits the glass, LC, glass stack with no phase change.

However, for the case of dark state IPS the LC is approximately one half-wave of retardance. The result of passing a beam of light through a half-wave retarder is to "reverse" the polarization state[5]. Now, if the phase change of the two pieces of glass is the same/opposite, the half-wave retarder flips the phase after the backlight side glass and now the result after the viewer side glass is to cancel/sum the phase changes of the individual glasses. This is the opposite of the VA case.

3. LL vs. glass stress states in curved LCD panel

We consider bending, membrane and shear stress. The case of bending stress has the viewer side (smaller radius of curvature) surface of the glass in compression and the back light side (larger radius of curvature) in tension. The neutral axis is between the two glasses and the tension and compression through the glasses cancel. Optically, this is the case of opposite phase changes from the two glasses. For VA LC between the glasses, there will be no LL, as described above. For IPS, there will be LL depending on fast as described above.

The case of membrane stress has the stress equal on the two pieces of glass. Optically, this is equivalent to the same phase change for both pieces of glass. For VA LC between the glasses, there will be LL depending on fast as described above. An example of laboratory observed LL on a curved VA panel and a finite element method (FEM) simulation of curved panel VA LL are shown in Figure 1. To force a state of membrane stress for the simulation, a single piece of glass was curved and used for both TFT and CF (i.e. the stress at each location of the panel for the CF and TFT glass is the same). The agreement is quite good. For IPS, there will not be LL.

The case of equal and opposite shear stress (i.e. twist or rotation), between the two glasses is readily understood from equation 2. The optical result is the same as the bending stress case: for VA LC between the glasses, there will be no LL, as described above; for IPS, there will be LL depending on fast as described above. Figure 2 shows a CCD image of the dark state LL of a lab curved IPS panel and the measured circular retardance of the same when the exit polarizer (analyzer) is removed. Again, the agreement is quite good. The LL for the various conditions is summarized in Table 1.

The case of shear stress between the two pieces of glass in the curved LCD panel is the most interesting case. It is easy to imagine the natural bending and membrane stresses that may occur when curving a flat LCD panel, but what is the source of the shear? When a flat panel is curved the two inner surfaces on opposite sides of the LC that start at the same length end up different lengths. If the geometry of the glasses, seal and panel were ideal, there would be a uniform stress in the x direction (panel curved about y axis). However, in the real world case there are stresses in both x and y directions that do not cause LL because aligned with the polarizer directions and also a component of twist between the glasses. This is the fundamental cause of the strong (i.e. much more than VA, LL in curved IPS).

Understanding the source of IPS twist type LL in curved panel also suggests that removing twist will eliminate this LL. We have done this in our lab by removing the short/long side seals of curved IPS panel and observing the characteristic IPS LL/no-LL. Figure 3 shows the configurations and the measured circular retardance and LL. This is quite compelling. We also believe that annealing the seal of the curved IPS panel will also relieve the twist component. There are likely other methods to accomplish the same result.

Table 1. LL vs. LC mode, stress type, and stress direction.

curved panel stress type	LC	glass θ_{fast}°		circular Stokes S_3, no analyzer	LL Stokes S_0
		θ_{TFT}	θ_{CF}		
membrane	IPS	±45	±45	0	
twist, bend	IPS	±45	∓45	$\mp\sin(2\Gamma)$	$2\sin^2(\Gamma)$
membrane	VA	±45	±45	$\mp\sin(2\Gamma)$	$2\sin^2(\Gamma)$
twist, bend	VA	±45	∓45	0	0

4. Discussion

We have shown that the LL of curved VA and IPS panels can be managed by controlling the type of panel stress used to curve the panel. This technology has other applications beyond conventional curved LCD-TVs.

The first application is to LL situations from out of plane deflections and loads in conventional flat LCDs. A second area of application is in non-traditional form factor LCDs. For example, one could imagine a small radius of curvature thin glass VA panel bonded to a curved cover glass. This configuration would have almost entirely bending stress in the panel and would be expected to have minimal LL.

5. Acknowledgments

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6. References

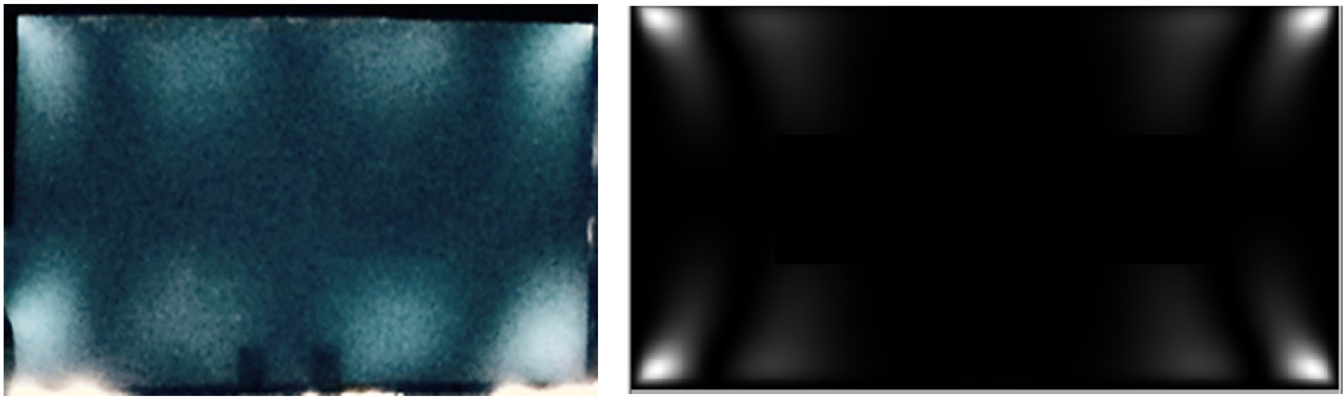
[1] M. Guignard, L. Albrecht, J. W. Zwanziger, “Zero-Stress Optic Glass without Lead,” Chemistry of Materials **19(2)**, 286-290 (2007).

[2] J. M. Cohen, R. G. Greene, D. Strope, A. Kaplan, “Impact of Birefringence on Large LCDs,” SID Symposium Digest of Technical Papers **33(**1), 329–331 (2002).

[3] R. G. Greene, C. C. Contreras, C. Gierbolini, R. S. Schweiger and T. M. Proulx, "Thin LCD Substrates Reduce Edge-Light Mura," SID Symposium Digest of Technical Papers **42(**1), 655–658 (2011).

[4] K. Hemanth Vepakomma, T. Ishikawa, R. G. Greene, "Stress Induced Substrate Mura in Curved LCD,” SID Symposium Digest of Technical Papers **46(**1), 634–636 (2015).

[5] *Polarized Light* (2nd ed.), Dennis Goldstein, CRC Press, 2003.



(a) LL from curvedVA panel in dark state (b) LL from FEM simulation of curved VA panel in dark state

Figure 1. CCD pictures of LL from curved VA and IPS panels in dark state.

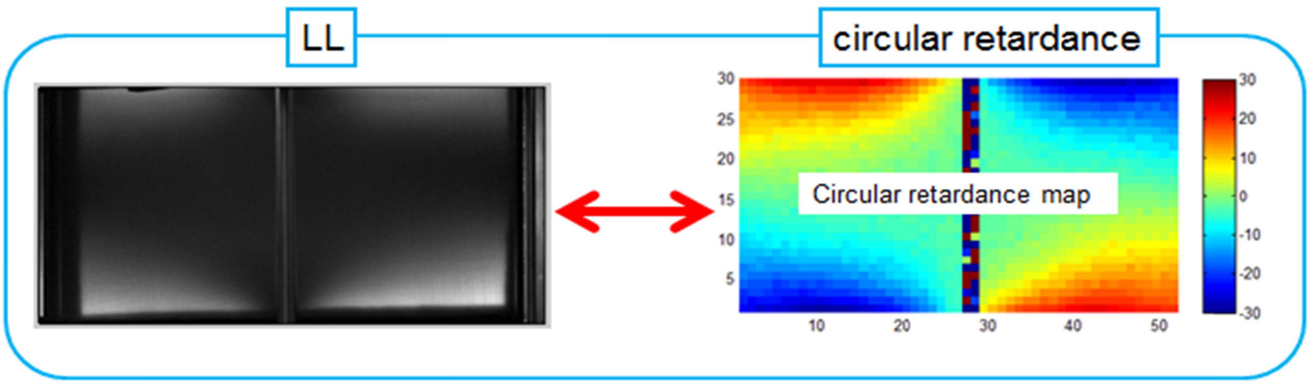


Figure 2. CCD image of curved IPS panel LL in dark state (left) and measured circular retardance with analyzer removed.

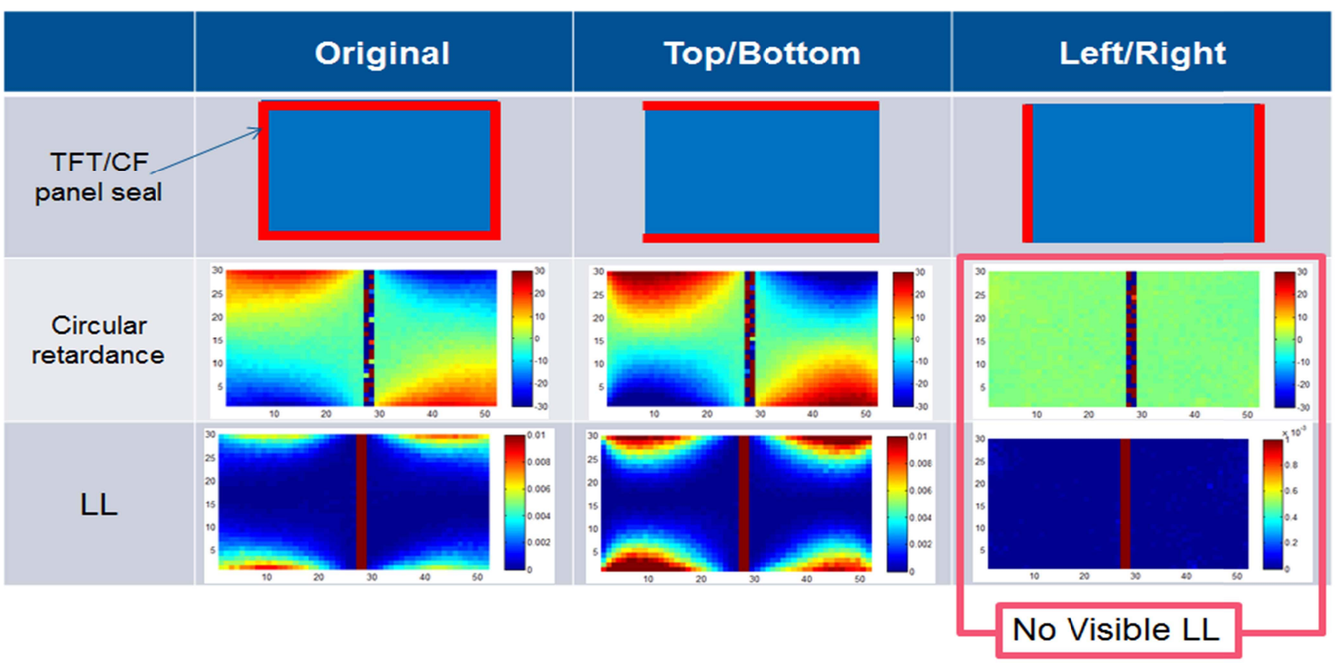


Figure 3. Curved IPS panel with original seal, left/right and top/bottom seal removed vs. measured circular retardance and LL. The vertical band in the center of the figures in the lower two rows is an artifact from the fixture holding the panel.