Ultra-high contrast OLCD: Thin and light dual cell LCDs on TAC film

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ABSTRACT

Dual Cell LCD TVs on glass are a new industry trend that allows LCD displays to compete on contrast with OLED TVs, but with a lower manufacturing cost. However, glass-based dual cells have some drawbacks in transmission, cost, and lack true pixel-level dimming control, all because of the large inter-cell separation.

We report on a breakthrough approach for creating dual cell LCDs on ultra-thin plastic films that can significantly reduce inter-cell separation to less than the pixel pitch, resulting in a simpler construction that avoids the need for compensation films and other trade-offs. The resulting structure is particularly suited to TVs, monitors and automotive displays.

1. INTRODUCTION

LCD technology has reinvented itself many times over the past few decades. One recent example of this is the introduction of dual cell LCDs, which employ two LC cells in the light path of each pixel, rather than one [1]. This significantly improves the black level of the display to a level similar to OLED TVs, resulting in an increase of CR from >1000:1 to >1,000,000:1. Whilst the dual cell architecture is not new, its application to mainstream TVs is now bringing it to mass market applications where it can compete with OLED TV on performance, at a lower cost.

Today's dual cell TVs consist of two separately fabricated cells, each comprising two glass substrates of 400µm or more each (4 substrates in total). This results in a large inter-cell separation causing undesirable moiré fringes [2] between the two displays that vary with viewing angle. These fringes are removed by introducing an optical compensation film diffusion layer between the cells. In the case where a diffusion film is used, then the light is depolarized and therefore the overall dual cell structure requires 4 polarizers, 2 per cell, since the two cells are acting as independent optical switches. The addition of the diffusion film and the polarizer directly increases BOM, and indirectly increases BOM through losses in transmission that require a brighter backlight. Variants of this approach have been reported, such as those using other polarization-selective films in place of the diffusion layer in order to maintain the polarization, but these films introduce a trade-off between transmission and moiré reduction [2]. It is worth emphasizing that the origin of moiré fringes is the large separation between the two cells, compared to the pixel pitch, as a result of the relatively thick glass substrates in LCDs. Figure 1 shows a schematic diagram of a typical dual cell structure on glass, showing approximately to scale the separation of the two cells of a 4K 55" TV built on 400µm glass substrates. In this case the pixel pitch is around 317um, whereas the inter-cell separation is around 1mm or more, making true 1:1 pixel coupling unviable.

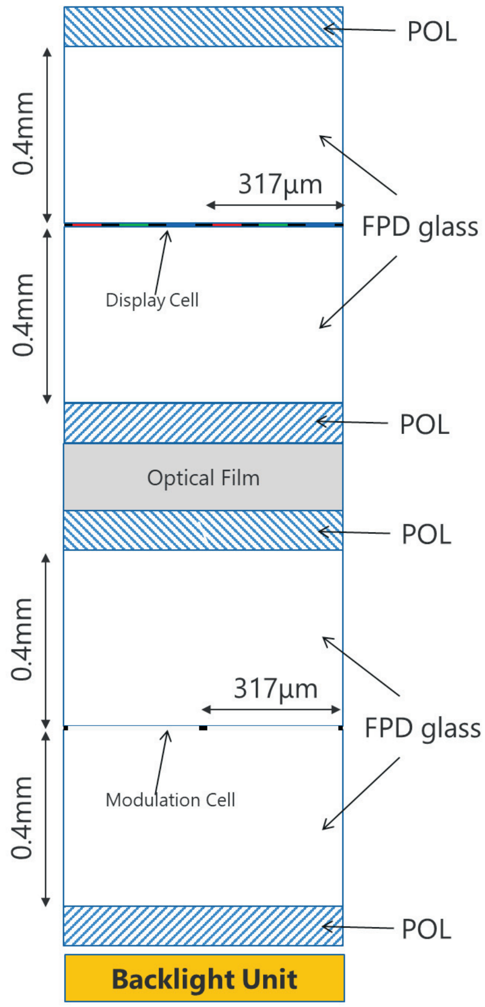

Fig. 1 Schematic glass Dual Cell structure drawn to scale for a 4K 55" TV, to illustrate the large inter-cell separation relative to pixel pitch

As a result of the large inter-cell separation in glass dual cell displays, combined with the trade-off of introducing the optical compensation film, then true pixel level dimming is not possible. Instead, the modulation cell can be considered as providing several thousand zones of local dimming. Whilst this can be utilized with image processing algorithms [3], it does not achieve true pixel-level dimming as seen in OLED TVs.

In summary, current dual cell approaches on glass overcome the moiré problem by adding in cost, rather than preventing the moiré in the first place, as would be possible by using ultrathin substrates. FlexEnable has developed a process for manufacturing LCDs directly onto ultra-thin plastic TAC films, which can be used to produce dual cell structures with much smaller cell separation. If the inter-cell separation can be reduced to less than the pixel pitch, then little or no compensation should be needed.

2. OLCD PROCESS AND STACK

The process that FlexEnable has developed for manufacturing LCD displays directly onto thin TAC films uses organic TFTs instead of Si. All of the process steps for these organic LCDs (OLCD), including the array and cell assembly, are performed at low temperature (< 100°C), and can be implemented on existing a:Si TFTLCD production line equipment sets. The complete low temperature process allows displays to be built onto TAC for the first time, enabling conformable LCDs on ultra-thin substrates that have the same optical performance as glass [4,5], and with a similar cost structure to glass LCD [6].

Figure 2 shows a schematic cross section of a typical OLCD single cell structure. The OTFT array is built directly onto a 40µm TAC film substrate which is itself mounted onto a glass carrier during fabrication [7]. The stack consists of a top-gate OTFT structure connected to a pixel electrode for a conventional IPS pixel structure.

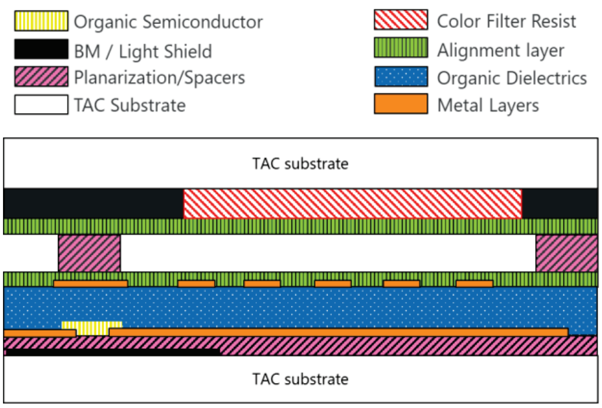

Fig. 2 Schematic OLCD stack using TAC substrate

The TAC film on which the display is built is a commonly used substrate for polarizers, and as such has ideal optical properties for use in the cell, including zero birefringence [8]. TAC film can be employed as a substrate because all manufacturing process steps for OLCD are performed at less than 100°C, including not only the OTFT and array, but also the colour filter, photoalignment and spacer layers.

The resulting OTFTs have both mobility (1.5cm^2/Vs), and stability (BTS) that are better than a:Si [9]. The overall cell structure has around 130µm thickness.

3. OLCD DUAL CELL STRUCTURE

3.1 OLCD Dual Cell Structure

A dual cell structure was assembled using two monochrome IPS OLCD cells with monochrome pixels at a pitch of 195µm. The final stack uses off the shelf polarizers, and has inter-cell separation of approximately 300µm (this can be further reduced in future versions). No optical compensation films such as strong diffusion layers were included in the stack. Figure 3 shows a schematic diagram, approximately to scale, of the overall OLCD stack.

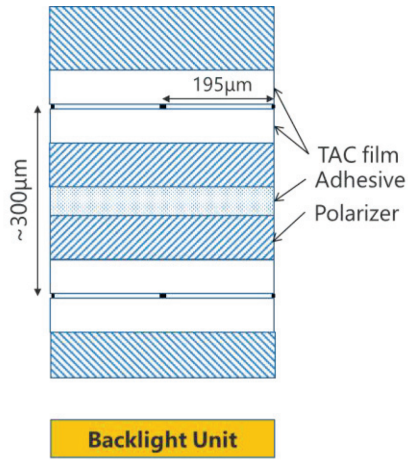

Fig. 3 OLCD dual cell test structure comprising two monochrome dual cells of the same design

Both of the monochrome cells used in this test structure are of the same design. With the stack shown in Fig. 3, the inter-cell separation is slightly larger than the pixel pitch of this particular cell, but is already less than the pixel pitch for a 55” 4K TV (317µm), even when off the shelf polarizers are used. With further stack optimization the inter-cell separation can be reduced to a fraction of the pixel pitch, thereby resulting in true pixel level dimming for dual cell. It is worth also noting that the entire dual cell structure (without BLU) shown above has approximately the same thickness as a single sheet of FPD glass.

3.2 Measurement Results

The assembled cell was combined with a high brightness backlight (with no local dimming). The display was then driven with various test images and the brightness of different regions was measured using a Konica Minolta CS-100A. Before the dual cell stack was assembled the contrast of one of the single OLCD cells was also measured using temporarily applied polarizers.

Figure 5 shows the measured contrast of the OLCD single cell and OLCD dual cell structures. The measured single cell contrast (with loose polarizers) was around 500:1. In order to then measure the contrast of the combined dual cell structure, the BLU brightness was deliberately set very high in order to facilitate measurement of the black state. The same BLU brightness was used for contrast measurements of the single cell and dual cell. We were able to measure an overall contrast of 266,000:1 from this dual cell structure. With a design optimized for dual cell use we believe this contrast can be significantly increased.

	Single Cell	*Dual Cell*
Black State / cd/m^2	18	0.015
White State / cd/m^2	9580	3987
Contrast Ratio	532:1	266,000:1

Fig. 5 Measured contrast of a single cell and dual cell OLCD test structures. The same high brightness backlight was used for all measurements.

Figure 4 shows an optical micrograph of the dual cell HDR display pixels. Individual pixels can be seen driven to full white (a) and full black (b,c). Interestingly, if one cell is driven white whilst the other cell is driven white, the conventional single cell LCD black is seen, which manifests only as a dark grey in this image (d).

In practice, the threshold for ideal HDR displays reach a black level of 0.01cd/m^2, next to a white of >1000 cd/m^2. This is a contrast of 100,000:1, a figure which is easily met on a per pixel basis by this dual cell LCD approach.

The recently introduced VESA HDR1400 specification [10] requires a black level of 0.02cd/m^2 or better and a white of >1400cd/m^2 (flash test), and to the best of the author's knowledge there are no displays on the market that can reach this level of contrast on a per pixel level at the time of writing. For example, whilst OLED TVs can achieve the required black level, they cannot reach the brightness requirements. Conversely, single cell LCDs can reach the white level but not the black level without BLU, which introduces small levels of blooming and cannot achieve pixel-level dimming.

Dual cell LCDs on glass therefore provide a route to meet the black level and the white level (without true pixel level dimming), but a significantly brighter BLU must be used to overcome the lower transmission as a result of additional polarizers ad compensation layers and second cell. Dual Cell OLCD therefore offers a route to higher transmission stack because of the reduced need for compensation, as well as pixel-level dimming, both of which are a result of the significantly reduced cell separation compared to glass dual cell LCDs.

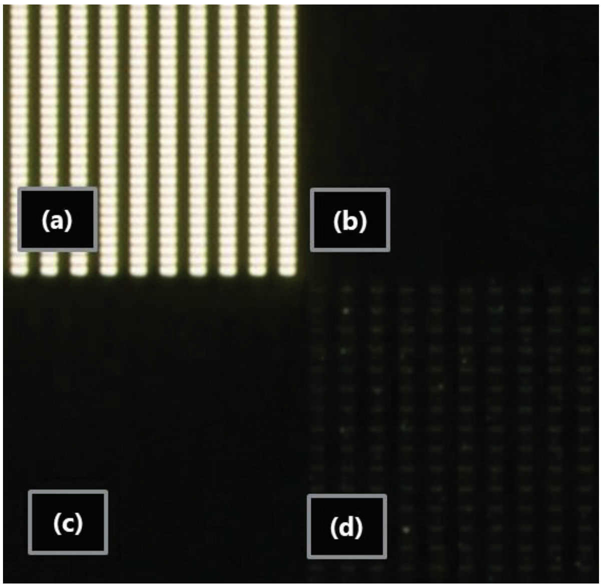

Fig. 4 Optical micrograph of neighbouring pixel areas on the dual cell display driven in different states (a) – both cells fully open, (b, c) – both cells fully closed; (d) – display cell closed, modulation cell open.

4. SUMMARY

OLCD's low temperature process means it can be manufactured directly onto ultra-thin zero-retardation TAC film substrates which allow dual cell structures to enter a new close-coupled regime where optical performance is enhanced to pixel level dimming and stack complexity and cost is reduced. Whilst these initial results were obtained on single cells unoptimised for this purpose, the overall approach can be applied to any LC type, and there's significant scope to further improve the overall performance and cell separation.

The attributes of dual cell OLCD are strongly desirable for TVs, monitors and automotive displays in particular, where black level is key. Dual Cell OLCD is also the only dual cell approach that brings high contrast whilst retaining the ability to conform the display to surfaces, allowing greater design freedom for large displays.

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