A New Fast-Response VA-FFS LC Device Using Three-Electrode Design with Improved Transmission for VR Applications

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Abstract

We propose a new design to enhance the transmission of a fast-response VA-FFS LC device by using a new three-electrode design while maintaining the fast response speed of these devices. These devices are very attractive for fast-response LC applications and have been actively developed and employed for VR/AR applications in recent years.

Keywords

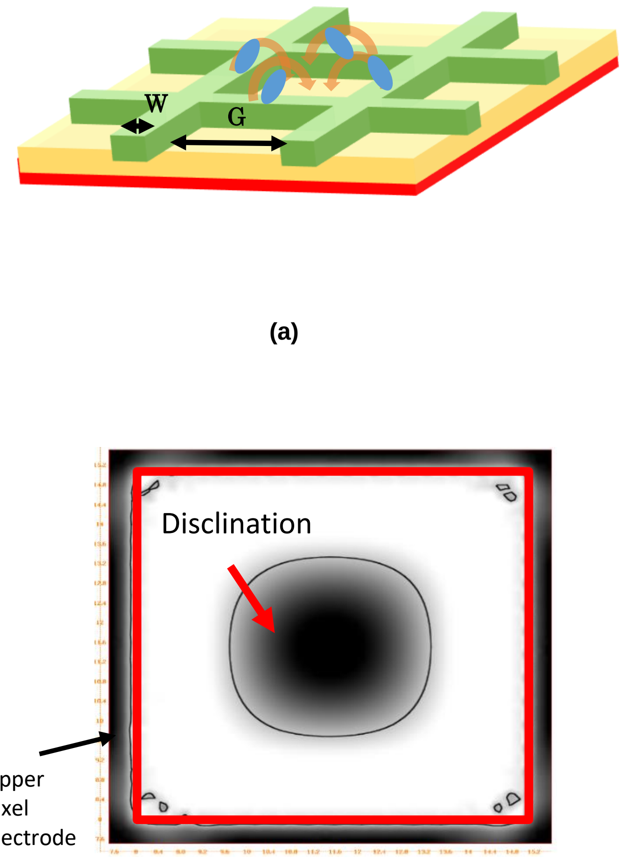
Fringing-Field Switching(FFS); three-electrode; fast-response time; Virtual Reality (VR)

1. Introduction

We have previously proposed to use VA-FFS (Vertical-Alignment Fringing-Field Switching) LC mode to generate very fast response time (sub-millisecond) in a VA cell with FFS electrode [1-2]. The fast response mechanism is based on self-imposed boundaries or standing walls (as we first proposed) [1-2]. This concept has also been employed and developed for Parallel Alignment (PA) LC devices and are called Short-pitch Lurch Control(SLC) [3], Virtual Walls [4-5] or other names. These devices are very attractive for applications that require very fast response time of LC, such as those in VR/AR applications and have been actively developed and employed for these applications in recent years [3-5,7].

We have recently also further proposed to use 3D structure [6-7] to enhance the switching speed as smaller domains of LC are generated as shown in Fig.1a. However, the transmission of these devices are often limited by the disclinations (or virtual walls) of the molecules in e.g. the center of the pixel unit, which appears as a dark state at the switched-state as shown in Fig.1b .

In this paper, we propose a new electrode design that can potentially enhance the transmission of these devices. The principle is by employing a three-electrode design such that the LC molecules in the center of a pixel unit also switch and hence transmission becomes brighter (or higher) at the switched-state. The structure of this three-voltage design is shown in Fig. 2a where the bottom common electrode in Fig.1 is now with a hole in the center of each square pixel unit (or period) and another pixel electrode (pixel_2) with opposite polarity of upper pixel electrode (green) is placed at the bottom of the whole pixel. The cross-section and details of this new design is further illustrated in Fig 2.b. The radius of the hole in the center of common electrode is r.



(a)

(b)

Figure 1. (a) Structure of a 3D VA-FFS LC device where W is width and G is gap of the upper pixel electrode (green) and bottom is a continuous common electrode (red), (b): Top view transmission profile showing there is a large area of disclination in the center of a pixel unit (e.g. middle square part in Figure 1a), which appears as a dark state.

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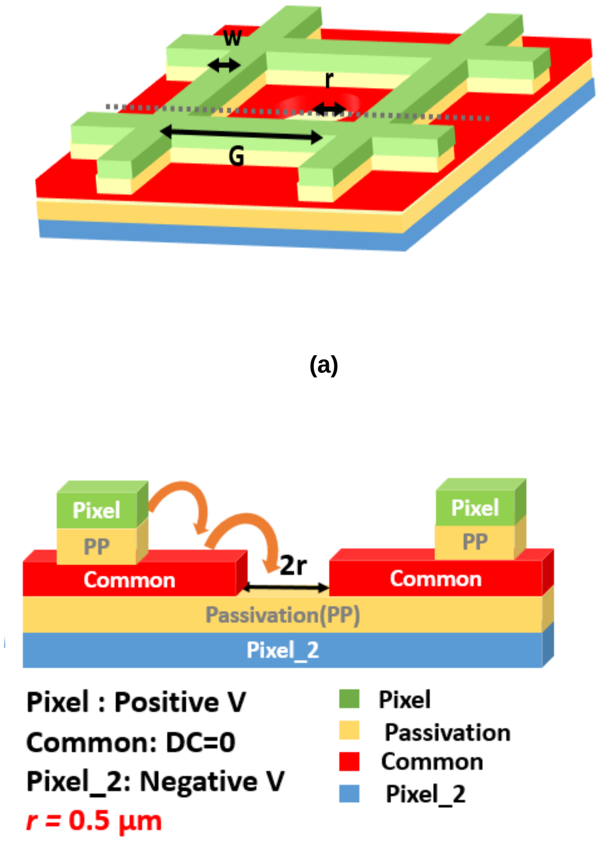


(a)

(b)

Figure 2. (a) Structure of our new design with a three-electrode for a 3D VA-FFS where the common electrode(red) is now with a hole in center and another pixel electrode Pixel_2 (blue) is placed under the whole structure which has opposite voltage polarity of the upper pixel electrode(green), (b) Cross-sectional view of our new design. Radius of the hole in the common electrode is r. Note the new Pixel_2 (blue) has opposite voltage polarity of the upper pixel electrode(green).

2. Experimental Results and Discussion

From our simulation results (using 3D LCD Techwiz from Korea), we found that we could now indeed also switch the LC molecules around the center of a pixel unit by using this new design as shown in Figure 3 and thus increased the transmission of this fast-response LC device by reducing the area of disclinations (dark state) in the center of a pixel unit as shown in the figure on the right hand side (bottom). The reason why we could now also switch the LC molecules around the center of the pixel unit is due to the fact that new electric field (fringing) is generated and spread over the central region by introducing the new negative pixel 2 (i.e. opposite polarity of positive upper green pixel). Thus, instead of having only electric field between upper pixel electrode (green) and common electrode in the original design, we now also have electric field between common electrode and bottom pixel 2 (blue) in this new design as shown in Fig. 2b.

From our results, we found that we could now increase the transmission of these devices by about 8% to about 15% depending on the electrode dimension (G=3 µm to 7µm) as shown in Table 1, while maintaining the fast response speed (both fall and rise times as shown in Table 2). The electrode width w and the width of central hole (2r) were both kept at 1µm. In this experiment, we used E7 as the LC material ($\Delta n = 0.2$, $\Delta\varepsilon = 14.4$, $\gamma = 150$mPa, $K_{11} = 11.7$pN, $K_{22} = 8.8$pN, $K_{33} = 19.5$pN) with cell gap *d* of 5um. Faster response time is possible by using faster LC materials.

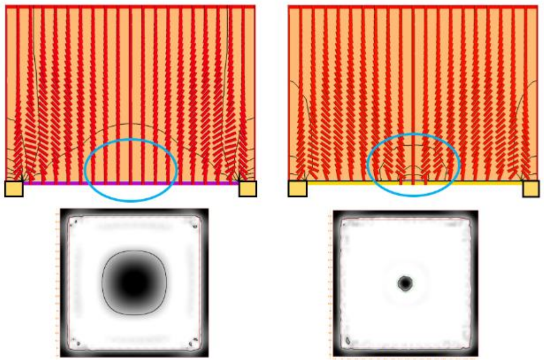
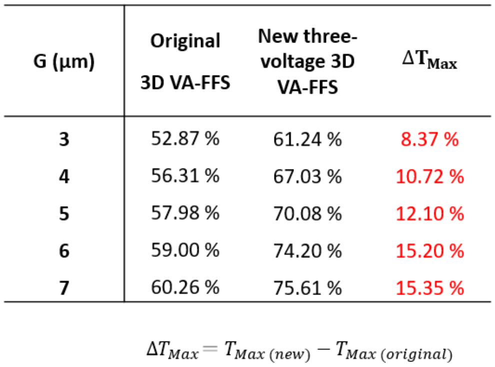


Figure 3. Cross-sectional view of the switched LC molecular arrangement of original 3D VA-FFS (top-left) and our new three-voltage 3D VA-FFS (top-right). The corresponding top-view transmission profiles are shown in bottom-left and bottom-right of the figure. The area of disclination (dark state in center) is much reduced in our new three-voltage design and hence helps boost the transmission of this device.

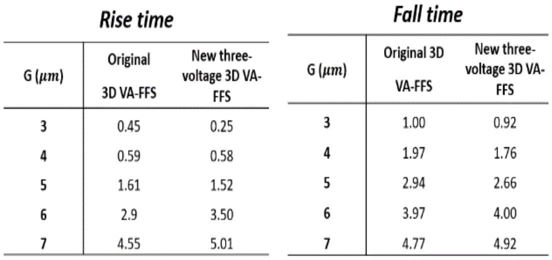
Table 1: Transmission of original 3D VA-FFS and new three-voltage 3D VA-FFS with different electrode gap G (electrode width W maintains at 1μm). ΔTmax is the increase in transmission of our new three-electrode design compared to the original design.



G (μm)	Original 3D VA-FFS	New three-voltage 3D VA-FFS	ΔT_{Max}
3	52.87 %	61.24 %	8.37 %
4	56.31 %	67.03 %	10.72 %
5	57.98 %	70.08 %	12.10 %
6	59.00 %	74.20 %	15.20 %
7	60.26 %	75.61 %	15.35 %

$$\Delta T_{Max} = T_{Max\,(new)} - T_{Max\,(original)}$$

Table 2: Response time (rise and fall) of original 3D VA-FFS and new three-voltage 3D VA-FFS with different electrode gap G (electrode width W maintains at 1μm). Results show that both rise and fall times are not affected much by the new three-electrode design, thus it can maintain fast-response time characteristics of the original 3D VA-FFS



Rise time

G (μm)	Original 3D VA-FFS	New three-voltage 3D VA-FFS
3	0.45	0.25
4	0.59	0.58
5	1.61	1.52
6	2.9	3.50
7	4.55	5.01

Fall time

G (μm)	Original 3D VA-FFS	New three-voltage 3D VA-FFS
3	1.00	0.92
4	1.97	1.76
5	2.94	2.66
6	3.97	4.00
7	4.77	4.92

3. Conclusion

We have proposed a new design to enhance the transmission of a fast-response VA-FFS LC device by using a new three-electrode design while maintaining the fast response speed of these devices. These devices are attractive for fast-response LC applications such as VR/AR where high speed of LC is required. The concept and technique of using standing walls, SLC or virtual walls has been actively developed and employed for fast-response LC applications such as VR/AR in recent years.

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