# Full-Color Video e-Paper Based on Oxide TFT

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## Abstract

***In order to break the bottleneck of traditional e-paper in playing color video information content. A new full color video e-paper based on electrowetting display (EWD) technology and driven by oxide TFT is proposed. By optimizing the panel design and process conditions, the 10.3 inch prototype with 186PPI resolution was successfully developed, which combines the advantages of oxide backplate with electrowetting display (EWD ) technology . We successfully drives the stacked EWD panels by the top gate IGZO backplate processed with 12 masks . By adopting this structure, the device mobility is 17.2 cm2/Vs with aperture ratio of pixel 90.3%, reflectivity of single color mod is 38.5%, reflectivity of full color mod is 12%, and refresh rate up to 60HZ, which supports the playing of regular video contents.***

## Author Keywords

Oxide TFT; Top gate; Electrowetting display (EWD);Video

## 1. Introduction

With the popularization of electronic screens and the increase in frequency of use, visual health problems such as visual fatigue and myopia are increasingly prominent, especially the increase in myopia rates of adolescents, which has attracted widespread attention from the whole society. Current traditional display products and emerging display technology coexist in the market environment In the following, the innovation and development of eye protection technology has become the core competitiveness of the industry. It can be seen that mainstream display technologies such as LCD, OLED, laser display, and electronic paper are actively conducting continuous technological innovation for eye protection functions to meet increasingly growing visual health needs.

The LED/LCD/OLED display has direct stimulation of human eyes, high energy consumption, and low outdoor viewing contrast. The reflection characteristics of an analog paper of the electronic paper display are displayed by reflecting environmental light to display the pattern, which has a paper printing effect. Compared with the traditional transmitted LCD display, the electronic paper display does not require backlight and easy to read. Even under the sun, the electronic paper display is still clearly visible. Reduce the stimulation of the eyes, reduce glare and blue light radiation. It helps to read and watch for a long time without causing eye fatigue. Because of its eye protection characteristics, it is suitable for products such as learning machines, electronic textbooks and other education fields, which will help reduce blue light radiation and the formation of healthy eye habits. Electronic paper has a dual stability characteristics. In the state of completely removing the power supply, the screen on the display can continue to be displayed and will not disappear. Its low power consumption and high visibility are also suitable for digital signs, mibes boards, shelf labels, orientation systems and so on.

The electrical display based on the particle system and the fluid - based wetting display based on the fluid system is currently the main principle of electronic paper display. Traditional electronic paper refreshes slowly, low color brightness, and cannot be played by mainstream color video information. Electrowetting display (EWD) has the advantages of fast response speed, low power consumption, high brightness, wide color gamut potential, which can break through the key technical bottlenecks of color and videoization of electronic paper. It is expected to become one of the new display technologies for the future of mainstream display markets. The electronic paper market is in a rapid development stage, the market size is continuously expanded, and technological innovation and application scenarios are continuously expanding. In the future, the electronic paper market is expected to achieve breakthroughs in large size, colorful, flexible and other directions, and further promote market growth. Oxide TFT have high on state current and low leakage characteristics. Based on the urgent demand for color video electronic paper in the current market, we have conducted some research in EPD by combining the advantages of oxide backplates and electrowetting display technology, and finally got some good results.

## 2. Design and Fabrication

### 2.1 Pixel and panel design

Pixels are the core unit of the display. The design of the pixels is reasonable or not directly affects the display effect of the display. The EPD display is a reflective display. Pixel design needs to consider issues such as reflectivity, charging ratio, and low power consumption at the same time. This article EPD is a full-color display through the vertical stack of three layers of cell, which contains a reflection cell and two transmitted cells. This article needs to design two pixels, one is used to reflect cell, and the other is used in transmitted cell. Reflect pixel and transmitted pixel need to consider the charging ratio and voltage maintenance ability. This article is a video EPD, which is relatively high refresh rate. Therefore, the TFT charging capacity is high. At the same time, in order to save power, TFT is required to have a low leakage. For reflective pixel, the electrode reflectivity needs to be considered. Hope that the reflectivity is as high as possible, that is, the reflector should be as large as possible; for the transmission of Pixel, the transmission ratio needs to be considered, that is, the


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opening area is as large as possible，so we use the Transparent storage capacitors. In order to meet the above needs at the same time, this article uses 12 Masks TG IGZO TFT backplate combined with the Cu line process. TG IGZO TFT has a stronger charging capacity and smaller size, which can save space. The Cu line process can further reduce the width of the line and save space. The schematic diagrams of pixel is shown in Figure 1.

Panel design is also a very critical part. Panel design needs to consider many details, such as RC loading, layout, display effects, etc. In this article, a 10.3 inch EPD panel is designed. Two source ICs are selected to send data signals. In order to save costs and reduce panel border width, gate driver is replaced by GOA circuit.

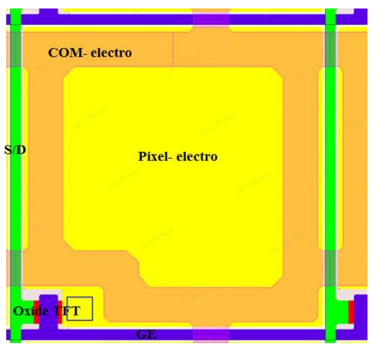


**Figure 1.** The schematic diagram of pixel

### 2.2 Backplate Fabrication

Top-gate self-aligned structure has merits of lower parasitic capacitance and higher driving stability by no overlap between metals and no back-channel damage during source-drain patterning. This article has a high requirements for the stability of the TFT device for electrowetting display EPD, because there are not only oil but also water in the electrowetting display cell. Oil and Water are also packaged in the cell of the electrowetting display EPD. Water vapor can easily spread to the TFT device, it affects the stability of the TFT device. In order to meet the needs of a high -stabilizer TFT device, 12 masks TG IGZO TFTs were conducted on a Gen 4.5 glass substrate. The fabrication process is as follows. Firstly, light shielding metal and bottom gate was deposited by sputtering and patterned on substrate. Then, a-IGZO as the semiconductor layer was sputtered via DC power and defined by photolithography and wet etching. SiOx as the top gate insulator (GI) layer was deposited by PECVD and followed by depositing MoTi/Cu top gate (GE) via DC sputtering. Top Gate and GI layer were continuously defined to form top-gate self-aligned structure. Inter-layer dielectric (ILD) was deposited and contact hole was patterned. Source/drain layer was deposited by sputtering and patterned on the ILD layer. And the semi-conductive layer is connected with source/drain layer by the negative doping area of the semi-conductive layer via the open hole of ILD. The Passivation(PV-1) layer was deposited by PECVD and followed by coating a planarization layer to cover the TFT and circuit, the planarization layer with a contact hole. And then commom ITO was sputtered and patterned, The Passivation(PV-2) layer was deposited by PECVD and contact hole was patterned. The next step is the production of pixels. Pixel electrode is divided into two types. The reflective backplane corresponds to the reflect electrode, and the transmitted backplane corresponds to the transmission electrode. The reflector uses high reflectivity metal, and the transmitted electrode is made of transparent ITO. The pixel electrode was deposited by sputtering and patterned by photolithography and wet etching. Passivation (PV3) layer was formed, which is used as a protection layer to prevent the diffusion of H2O and O2 molecules to active layer. Finally, BM was coating and patterned on the PV3 for Reduce the metal reflection， Based on this, 12 masks TG IGZO TFTs backplate has been conducted, which the schematic diagrams are shown in Figure 2.

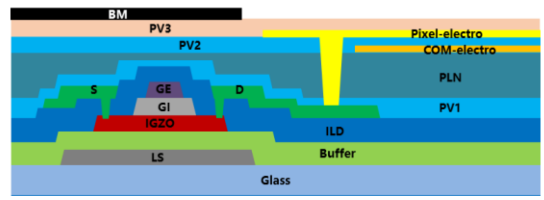


**Figure 2.** The schematic diagram of a-IGZO TFTs with TG self-aligned structure

### 2.3 Electrowetting cell Fabrication

As shown in Figure 3a, the TFT substrate glass with ITO layer was cleaned. Then amorphous fluoropolymer was spin-coated on the surface of the ITO layer of the TFT glass substrate (Figure 3b) with a thickness of around 850 nm and baked on a hotplate for 3 min at 100℃ . A further curing process by heating in an oven at 180℃ for 30 min was conducted for completely removal of the solvent. Photoresist layer was spin-coated on the surface after a hydrophilic treatment of the fluoropolymer layer by a reactive ion etching process (Figure 3c). Then, a standard lithography process was carried on to fabricate the pixel wall and pinning structures (Figure 3d) with five different designed lithography masks with (central EPS as an example, Figure 3j) or without EPS design. The prepared pixels with central EPS design were illustrated in Figure 3i. After the lithography process, a thermal reflow process (Figure 3e) at 200℃ for 2h was applied to restore the hydrophobic fluoropolymer layer . The thickness of the pixel wall after the reflow process was around 5.6 μm, while the thickness of the pinning structure was 5.8 μm. The periodic length of each pixel was 136.5 μm, and the width of the pixel wall was 13 μm, while the diameter of the pinning structure was 15 μm. Then, along with the oil filling into pixel (Figure 3f), water and oil was sealed between the substrate and the cover by the pressure sensitive adhesive (Figure 3g)

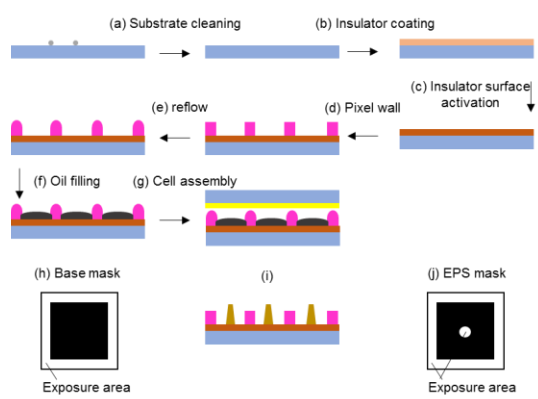


**Figure 3.** (a-g): Schematic diagram of the fabrication process of electrowetting EPD; (h,j) are the top view images of the lithography masks of one pixel with (j) or without (h) extra pinning structure (EPS) design; (i): illustration of the pixels with central EPS design.

## 3. Results and Discussion

### 3.1 Characteristics of Reflective backplate and Transmissive backplate

In this article, the TG IGZO TFT backplate which is suitable for electrowetting display is manufactured. By optimizing the channel layer IGZO film, the uniformity of 9 points of the G4.5 mother glass threshold voltage from 3.2V to 0.8V. Vth is about 0.98V, and the mobility reach 17.2 cm2/Vs. As shown in Figure 4.

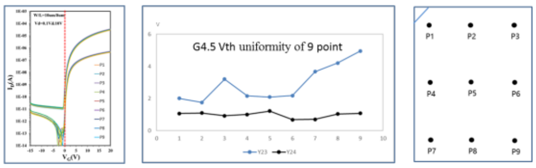


**Figure 4.** Vth uniformity of 9 points of the G4.5 mother glass

For the reflective backplate, the electrode reflectance rate was 80.6%; For the transmissive backplate, the aperture ratio is 90.3%, and the transmission rate is 79.1%. As shown in Table 1.

**Table 1.** Characteristics of Reflective backplate and Transmissive backplate

| item | category | measure | point | result |
|---|---|---|---|---|
| Transmissive backplate | aperture ratio |  |  | 90.3% |
| | transmission |  | | 79.1% |
| Reflective backplate | reflectance |  | | 80.6% |

### 3.2 The 186PPI 10.3 inch prototype

As shown in the figure 5, We have prepared a 10.3 inch full color electrowetting display EPD, and the resolution is 1536(gate) * 1152 (source), pixel size is 136.5um. Combine the advantages of oxide backplate with electrowetting display technology .In this work, the Regular videos can be played by the electrowetting display EPD, and refresh rate up to 60HZ. reflectivity of single color mod is 38.5%, reflectivity of full color mod is 12%. The panel specifications are shown in Table 2. Although we have successfully developed a color video electrowetting display EPD that can play video, there are still many problems to be solved. There are still many defects in the display. From the picture, we can clearly see the following problems. The display effect is poor. The reflection is Low , and the color is not right, etc.

**Table 2.** The specifications of electrowetting display EPD

| Spec. Items | Specification |
|---|---|
| Display Size | 10.3 inch |
| Resolution | 1536(gate) * 1152 (source) |
| Pixel Size | 136.5μm x136.5μm |
| Aperture Ratio | With BM 90.3% |
| Storage capacitor | 2.1pF |
| Frame Rate | 10~60Hz |
| Reflectance of Single color | 38.5% |
| Reflectance of Full color | 12% |

**Figure 5.** The electrowetting display EPD of 10.3 inch

## 4. Conclusion

We has successfully developed a 10.3 inch full color electrowetting based e-paper, which can play the regular videos, and refresh rate up to 60HZ, reflectivity of single color mod is 38.5%, reflectivity of full color mod is 12%. But there are still many problems to be solved. Display quality and reliability are the two key problems of electrowetting based e-paper. The requirements of electrowetting based e-paper for TFT backplate are very high. Because oil and water will be packaged on the TFT backplate, it is required that the TFT backplane has a strong water and oxygen barrier. At the same time, there are many high temperature processes in the EWD process, which will also affect the stability of TFT devices. Mass production of electrowetting based e-paper is still challenging, and a series of problems such as TFT backplane and electrowetting process flow need to be ready at the same time. For the advantages of electrowetting based e-paper, It is expected to become one of the new display technologies for the future of mainstream display markets.

## 5. Acknowledgements

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