"Electrowetting displays, progression toward large area and high brightness flexible displays"

Wei Yuan Cheng[1], Kuo Lung Lo [1], and Jason Heikenfeld[2]

[1]Display Technology Center, Industrial Technology Research Institute, Chu tung/Hsinchu, Taiwan 310, R.O.C.

TEL:+886-3-591-3503, email: weiyuan.cheng@itri.org.tw.

[2]Dept. of Electrical and Computer Engineering, University of Cincinnati, Ohio 45221 U.S.A.

Abstract

Since 2006, the Industrial Technology Research Institute and the University of Cincinnati have been jointly exploring approaches for high brightness flexible electrowetting displays (EWDs). Recently, ITRI demonstrated for the 1st time a 6" AM-EWD reflective display panel. To create flexible AM-EWDs, Cincinnati has developed low-temperature processing and improved pixel structures.

1. Introduction

These days, displays can be more than flexible, they have even been demonstrated to even be rollable [1]. For flexible displays, at least three core technologies are needed: flexible substrates; a flexible active matrix backplane; and a flexible optical layer. A large variety of flexible organic or metal substrates are now available, the latter allowing even high temperature processing. Both organic and hybrid inorganic/organic active matrix backplanes have been shown to be fully flexible. What is clearly lacking, however, is a high performance technology for the flexible optical layer. No matter how flexible, rollable, or wearable, a display will not become a mass-commercialized product unless it provides a bright and high contrast full color images. This is driven by customer demands, which recently have cause the disappearance of many transflective displays in portable electronics. In recent years, many different optical layer technologies have been proposed for use in flexible reflective displays [2-5]. One of the emerging technologies is electrowetting due to its high contrast ratio, video speed and low power consumption.

An electrowetting display (EWD) can be argued as a powerful approach for flexible displays because it can be thin, fabricated at low temperature, and because it can provide near paper-like brightness. In this paper we will review progress toward creating large area and bright electrowetting displays. In particular, we will review the particular challenges and advantages for flexible electrowetting displays.

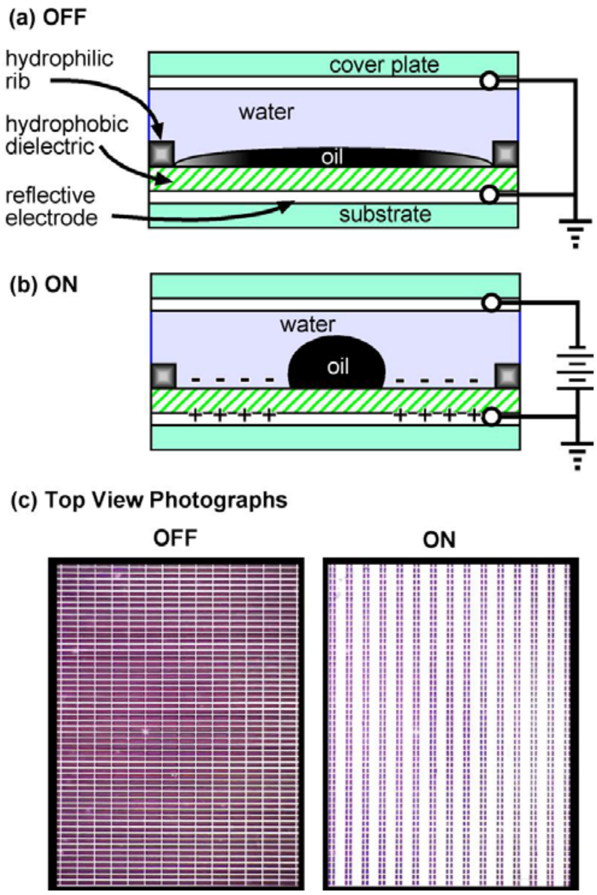

Fig. 1. Schematic diagram of 1-layer architecture reflective EWD without color filter.

2. Basic EWD Pixel Operation

Electrowetting involves applying a voltage to a conductive liquid resting on a hydrophobic dielectric and a ground electrode. At no voltage, the hydrophobic surface causes the system to exhibit a very large contact angle. With less than 10V, the contact angle can be reduced by as much as 100°. An electrowetting pixel is also an extension of the basic electrowetting system. The water contact angle can reach θ~170° for a water/oil/fluoropolymer system. Therefore the oil contact angle is only ~10° (is complimentary to the water contact angle). For displays, given the very small contact angle of the oil it nearly forms a film against the fluoropolymer. If non-polar dyes are added to the oil, it renders color to the surface that it covers. Next, when voltage is applied to this system the water contact angle decreases and the oil contact angle must increase. Thus the oil transitions from a film (~100% visual area) to a partial sphere geometry (~20% area). A diagram and operation of an electrowetting pixel is shown in Fig. 1.

3. Rigid AM-EWD Process

At ITRI, 6” EWD panels have been fabricated in Gen. 2 LCD facility. First, a Si_3N_4 layer was deposited on the 370 mm × 470 mm glass substrate (with TFT-array or ITO) by using PECVD. The Si_3N_4 thickness is ~150 nm and is preferred over SiO_2 because early results show that Si_3N_4 is more resistant to electrochemical attack (aging). On the SiN, a fluoropolymer was deposited by solution coating. After pre-bake of the fluoropolymer, a plasma treatment technique was adopted to improve the wettability and the adhesion of photoresist used to form the hydrophilic grid. After the hydrophilic rib of ~10 μm height was fabricated, colored oil was dosed into the unit pixel cell accurately by ink-jet printing. Then, the water was dosed over the entire 6” array to cover the oil, and a second glass substrate with ITO layer was used to assemble the EWD panel. The flow chart of the EWD panel fabrication processes is shown in Fig. 2. A photograph of a completed 6” diagonal AM-EWD is shown in Fig. 3. The switching and grayscale is analog, like a liquid crystal display, with one difference. The difference is that the pixel capacitance for an electrowetting display increases as the pixel becomes brighter (i.e. smaller oil area, see Fig. 1).

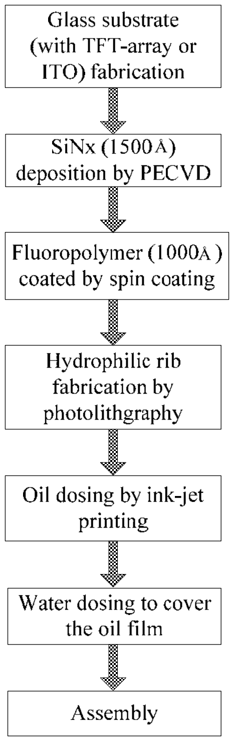

Fig. 2. Flow chart of AM-EWD EWD panel fabrication processes.

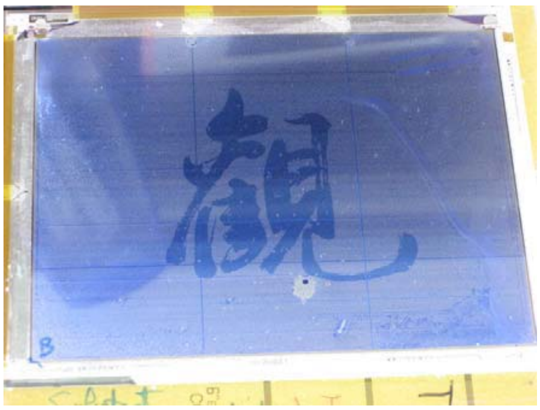

Fig. 3. The 6-inch reflective EWD display developed at ITRI and demonstrated at SID 2008.

3. Can EWDs Be Flexible?

Although not yet demonstrated, it can be readily understood that if low temperature EWD fabrication can be achieved, the backplane could be an organic, hybrid organic/inorganic, or inorganic on metal foil approach. There is nothing inherently about electrowetting operation that precludes implementation on a flexible display. To explain further, key steps to realizing a flexible display are next outlined

Fabrication Temperature: The insulating dielectric can be sputter deposited and good electrical reliability achieved. At the Univ. of Cincinnati, a new suite of aqueous solutions have been developed that help prevent electrolysis at dielectric pinholes. Therefore low temperature sputtering in place of higher temperature PECVD processing can be utilized. Fluoropolymers such as Asahi Cytop or DuPont Teflon AF, typically require annealing at ~160 Celsius or greater. This temperature is on the higher end of what is desired for a flexible display. Also developed at Cincinnati, and used in the 6" active matrix demonstrator shown by ITRI, is a fluoropolymer that can be annealed as low 100 Celsius, thus fully compatible with flexible substrates. The hydrophilic rib can also be processed at low temperature (as low as 100 Celsius, as demonstrated at Cincinnati). Therefore AM-EWDs can be fabricated on flexible substrates.

Cell Gap Dependence: Electrowetting displays work like a simple color filter (the colored oil). So there are no cell-gap issues. However, it should be noted that a minimum thickness of ~40 µm is needed for each electrowetting pixel. That is because if a 4 µm colored oil layer decreases in horizontal area by 10X (10:1 contrast), then its height must approximately increase by 10X. This 40 µm height is thin enough to even allow for a rollable display (<100 µm total display thickness). The electrowetting pixels can also be in an open cell format. However, a spacer feature must be formed, and because of potential alignment issues the spacer feature must be formed on the lower backplane substrate. If proper spacers are developed, it can be concluded that cell-gap dependence will not prevent an EWD from becoming flexible.

Moisture or Gas Permeation: Electrowetting pixels can lose several % of their liquid volumes before display operation is substantially altered. This is a huge amount of moisture or gas permeation compared to that required for OLEDs and other water/gas sensitive technologies. Therefore, it can be concluded that existing substrates used for flexible OLEDs, or other flexible displays, should be more than satisfactory for electrowetting displays. One bit of caution, the backplane should be resistant to water degradation, because the electrowetting liquids are very close to the backplane (i.e. not separated by a substrate). A variety of non-aqueous solutions work in electrowetting, but water is still the highest performance liquid to date (water + additives to extend the temperature range).

4. What Is the Maximum Optical Performance? Bistable?

So with the potential to be flexible, we return to the key question posed in the introduction. Can EWDs provide the optical performance that consumers demand? Realistically, a display must have full color to be a mass-product. Furthermore, the full color reflectance should be at least ~40% (not the 15% achieved with most technologies). This requires a maximum white reflectance of ~80-90% for a simple black/white pixel and use of an RGBW (4-subpixel) color architecture. Reviewing the performance in table 1, standard 1st generation EWDs cannot achieve the target of 40% full color reflectivity. However, in second

Table 1 – Potential Reflective Performance of EWDs

1st Generation Rigid EWDs

Reflector	White Area	Max Reflect	Min Reflect	Bitable?
90%	60%	>50%	<10%	No.

2nd Generation Rigid and Flexible EWDs

Reflector	White Area	Max Reflect	Min Reflect	Bistable?
90%	85%	>70%	<10%	Maybe.

Novel Cincinnati EWD Device Structure

Reflector	White Area	Max Reflect	Min Reflect	Bistable?
90%	92%	>80%	<5%	Yes.

generation EWDs reducing the minimum electrowetted oil area to ~15% is achievable and would result in a white state reflectance of >70%. This is close to what would be required for mass-consumer acceptance. As shown at the bottom of Table 1, new pixel architectures developed at the Univ. of Cincinnati could allow 40% RGBW reflectance. These new results will revealed in future publications. The issue of bistability should also be discussed. Many applications for flexible displays, such as e-paper, strongly desire the ability for video speed and bistable pixel operation (zero power). There are several approaches that can allow EWDs to be bistable, such as surface energy patterning proposed by LiquiaVista. However, much work remains in determining what is the best bistable EWD approach.

5. Summary

EWDs have now been demonstrated by ITRI in the form of 6" AM demonstrator units. Key materials and processing for allowing flexible displays have also been demonstrated at Cincinnati. It is projected that electrowetting displays are a strong candidate for flexible displays. However, EWDs must demonstrate reliable substrate spacers and compelling optical performance before flexible EWDs could be considered a mass-commercialized display product.

5. References

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