Invited Paper

8.5" analog Driven Electrowetting Displays for e-paper Applications

Johan FEENSTRA*, Jo AUBERT*, Jan MENNEN*, Chiara COMETTI*, Ivar SCHRAM*, Mark van WEERT*, Nicolas BERGERON*, Eric DERCKX* and Anthony SLACK*

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In this paper we demonstrate the scalability of electrowetting display technology by presenting 8.5" diagonal active matrix displays. The rapid increase of the maximum display size of the electrowetting technology in the last year is a clear demonstration of its scalability. This scalability is enabled by a large degree of overlap in manufacturing technologies with the LCD manufacturing process. In addition, the grey scales on these displays are generated by analog driving, which ensures low power consumption also at large display sizes. The prototypes presented illustrate a good uniformity across the display.

Keywords: Electrowetting displays, Active matrix, Scalability

1. Introduction

The eReader market is presently showing a number of trends. On the one hand there is a strong drive towards reduced ASP’s. This is often achieved by offering smaller format devices (around 5 to 6" diagonal) to customers. On the other hand, consumers are clearly keen to have larger display sizes, as the incumbent technology for eReader (electrophoretic displays—EPD) does not support fast scrolling and repositioning of the information on the display. The result is a wide diversity of readers with different sizes.

While all of these sizes are presently served by the same frontplane technology, the industry is clearly still looking for a technology that combines a strong scalability with a very versatile performance, offering color, video, low power consumption and readability under all lighting conditions, all at a low cost price.

A large number of technologies are aiming to fill this gap, as the eReader market is clearly one of the application areas in the display market that shows the largest growth potential. Among these technologies, the main contenders are MEMS technology1, the electrowetting display (EWD) technology that is the subject of this paper2 and unquestionably LCD. The latter has the main advantage of being the mainstream technology with a strong industry push and large economies of scale, thanks to its maturity and increase in substrate size over the years. On the other hand, the deficiencies of LCD’s (high power consumption and the lack of sunlight readability) are also well-known and are particularly pronounced in the field of eReaders.

The other application area that has grown tremendously in recent times is the one of the multimedia tablet. The iPad is the most well-known example, but in the coming period a large number of similar devices will be launched. This field has been served well with LCD’s, as the focus has been on existing multimedia applications, which are presently not be supported by EPD.

Both novel technologies mentioned above, MEMS and EWD, are positioned to offer the readability of an eReader and the multimedia capability of an LCD, combining the best of both worlds in terms of performance. Both combine the low power consumption and readability under a wide range of lighting conditions with high fidelity video and color, enabling for the first time truly uncompromised mobile solutions.

In this paper, we focus on two significant additional advantages offered by electrowetting displays: analog grey scaling and scalability of manufacturing, both leading to the capability of larger size displays that retain the benefits of high optical performance and low power consumption. We illustrate both aspects by showing working prototypes with an 8.5" diagonal, driven by analog grey levels.

2. Electrowetting display principle

In Fig. 1 the principle of an electrowetting display is shown. Fig. 1 (a) shows the optical stack, comprising a transparent electrode, a hydrophobic insulator, a colored oil layer and water. In a display these layers will be sandwiched between glass or polymeric substrates. In equilibrium, the colored oil naturally forms a continuous film between the water and the

* Liquavista B. V. Zwaanstraat 1, Building TAM 5651 CA Eindhoven The Netherlands
hydrophobic insulator (Fig. 1(a)) due to the fact that this is the lowest energy state of the system. At the typical length scales used in displays (pixel sizes below 200 \( \mu m \)) the surface tension force is more than 1,000 times stronger than the gravitational force. As a result, the oil film is stable in all orientations and also remains in position when the display is mechanically stressed.

When a voltage difference is applied across the insulator, the system lowers its energy by moving the water into contact with the hydrophobic surface, thereby displacing the colored oil (Fig. 1(b)).

The balance between electrostatic and surface tension forces determines how far the oil is moved to the side. In this way the optical properties of the stack when viewed from above can be continuously tuned between a colored off-state and a transparent on-state, provided the pixel is sufficiently small so that the eye averages the optical response. The electrowetting optical switch is intrinsically transparent, except for the colored oil layer. This means that the switch can be used to form the basis of transmissive, reflective and transflective displays.

The photographs in the insets of Fig. 1(a) and (b) show a typical oil retraction obtained for a group of pixels with a size of \( 160 \times 160 \mu m^2 \). The photograph in the inset of Fig. 1(b) confirms the 80% white area required for a display reflectivity as high as 55%. Part of the electrode is omitted in the lower left corner of each pixel to control the oil motion. In the photographs it can be seen that the control of oil motion strongly improves pixel-to-pixel homogeneity and hence the display uniformity.

3. Manufacturing process and scalability

The manufacturing process for electrowetting displays is published in detail in reference\(^6\) and is shown schematically in Fig. 2.

The starting point is a conventional active matrix substrate that is made with the same processes and the same number of mask steps as a substrate for an LCD. On top of the active matrix substrate, the electrowetting frontplane is built using a small number of steps. With the exception of one step, all of the processes used for electrowetting displays are already used in mass manufacturing environments for LCD’s. The only exception is the so-called Fill & Couple process, which is used to get the two liquids (a polar liquid and a non-polar liquid) in the display before coupling the cover plate and closing the display cell. For this, Liquavista uses a proprietary process, which is now ready for industrialization with dedicated equipment for volume manufacturing.

4. 8.5” displays

In this section we present the 8.5” prototypes and discuss a number of their properties in more detail.

4.1 Display Prototypes

Photographs of examples of our 8.5” prototypes are shown in Fig. 3. Shown here is a monochrome display with XGA resolution (1024x768). The display is driven by a combination of analog grey levels (3-bit) and PWM (2-bit). More details on the grey scaling are given below. The upper photograph in Fig. 3 illustrates the number of grey scales showing a good uniformity across the display.

In the lower photograph in Fig. 3 the dynamic range of the display is shown, along with the grey scales, illustrating the high brightness and the excellent contrast ratio that can be achieved on electrowetting displays.

4.2 Up-scaling display size

In order to produce displays larger than the previously
reported 6" diagonal, no significant changes needed to be made
to the process. The first three steps as shown in Fig. 2-layer
deposition, surface treatment and pixel wall definition—are all
steps that are in use already in LCD fabs up to the highest
generations, so scalability of these is already well-established.
For the only step in the electrowetting display manufacturing
process that is different from LCD’s (Fill & Couple) we use a
simple self-assembly process, utilizing the chemical nature of
the patterns of hydrophobic pixel surfaces surrounded by the
more hydrophilic pixel walls. This process has shown a large
degree of scalability, having been used for very small devices
(<1” diagonal) all the way up to the display size of 8.5” as
presented in this paper. This rapid increase in size of
electrowetting displays is illustrated in Fig. 4, where we show
the timeline of our current 8.5” active matrix displays, going
from 1.8” displays early in 2009 up to the full color version of an
8.5” display in the 2nd quarter of 2010, shown on the right hand
side.

4.3 Grey scaling
As part of the program established to develop the 8.5”
displays we also implemented the use of analog grey levels,
driven by commercially available driver IC’s. To this end, a
simple driving scheme is used, as the electro-optical curve of
electrowetting display pixels is relatively shallow and as such
allows for a large number of analog levels to be generated. In
this case, the commercially available driver IC only had 3-bit
analog capability, so a hybrid scheme was implemented where
the analog drive levels were combined with a small number of
grey levels (±2 bit) that were generated in the time domain
(i.e. pulse width modulated-PWM). The result is a reflective

Fig. 3 Photographs of 8.5” electrowetting display showing 5 bit grey scale
(combination of 3-bit analog and 2-bit PWM).
display with 5-bit grey scales and competitive power consumption, thanks to the presence of the analog grey levels. As we continue to reduce the drive voltage for electrowetting display, a larger number of commercially standard driver IC's will become available to transition the 5 or 6-bit grey scale to become full-analog, which clearly has the advantage of the lowest power consumption. At product introduction, we expect that the drive voltage of the display will be 18 V or less. As we are running our displays in dc-mode, this is comparable to an ac–drive voltage (as used for instance for LCD's) of 9 V. This is a voltage level where a host of driver IC's are available commercially, to further reduce the cost of electrowetting displays.

5. Conclusions

In this paper, we have demonstrated a further increase in size and scalability for electrowetting displays. We have shown that the technology is perfectly compatible with a very rapid scaling up of display size, thanks to the use of well-established, large-scale manufacturing processes. Furthermore, with the 8.5” displays, we have shown a 5-bit grey scale capability, including 3-bit analog grey levels, proving that the technology is as well scalable in terms of optical performance and fidelity. The presence of analog grey levels strongly reduces the power consumption and extends the dynamic range of performance. We have shown both monochrome and full-color versions.

References


Johan Feenstra
He received his PhD in Solid State Physics from the Rijksuniversiteit Groningen in the Netherlands in 1997. After that he spend 1.5 year as a post-doc at the University of Maryland working on microwave microscopy, a technology that is now being commercialized. In 1999 he moved to the Philips Research Labs in Eindhoven, the Netherlands where he has worked on electrowetting and its applications ever since. He is co-inventor of electrowetting displays and was founder of Liquavista. After the recent acquisition of Liquavista by Samsung, he became CEO of the Samsung LCD Netherlands R & D Center (SNRC). Johan Feenstra is the author of more than 65 papers in internationally refereed journals, book chapters and patents pending.
Jo Aubert
He received his Bachelor of Engineering in Electronics in 1988. His research interests focus on video processing, LCD and EWD. He applied several patents related to EWD driving.

Jan Mennen
He received his Bachelor of engineering in electronics from Fontys University of Applied Sciences Eindhoven in 1985. He worked for Philips FPD and Mobile Display Systems from 1991 until 2009 as developer of LCD modules for mobile and automotive applications. During this time he built a lot of expertise in LCD driving architectures and data processing. In 2010 he joined Liquavista and is now working on developing driving schemes for Electrowetting displays.

Chiara Cometti
She graduated as MSc Materials Engineering in 2006 at Politecnico di Milano. She has worked as research engineer at Media Lario technology in the EUVL team, developing and implementing high reflectivity coating on EUV optics. Since 2008 she works at Liquavista BV, as senior development engineer. Her job is mainly focused on barrier layer coating and characterization.

Ivar Schram
He has a bachelor degree in Physics from the university of Eindhoven. He has 15 years of experience in the display Industry and worked in research, development and manufacturing departments on various display techniques like LCD, PALC, PDP, Foil and electro-wetting displays. He has over 15 granted patents in the fields of Ink jet printing, nano imprint lithography and electro wetting. Ivar currently has the position of Process Industrialization Manager at Liquavista.

Mark van Weert
He has a Bachelor in Chemical Technology/Materials Science. In the period of 1992–2009 he worked for Philips Research and various Philips product divisions (Semiconductors, Displays, Lighting) as a process development engineer. On December 1st 2009 he joined Liquivista B. V./SNRC and currently is responsible for developing new and improving existing front-end processes.

Nicolas Bergeron
He received his bachelor degree in electronics from a French university in 1994. He joins group of Samsung (former Liquavista) after 9 years working for Philips in the electronics display industry, bringing a large experience and knowledge on display product, device & optical design, and skills on project platform management. He is currently working on bringing electrowetting display technology to the next stage in the industrialization phase by further reinforcing our technology portfolio and platform carriers.
Field of interest is definitely in the display area and especially in novelties to integrate it to a display.
Eric Derckx

Eric received engineering degrees in Electrical Engineering (cum laude) and Technology Management. After his graduation he joined Philips, where over the years he worked on and successfully managed various system engineering and technology development programs for Semiconductors and Mobile Display Systems. Doing so he developed his expertise in display and semiconductor related system architectures, building and managing multi-disciplinary/multi-cultural programs and teams, setting up and maintaining development partnerships with key-suppliers and supporting marketing and sales organizations managing strategic customer relations. After the recent acquisition of Liquavista by Samsung, he continued the position of VP Engineering at the Samsung LCD Netherlands R & D Center (SNRC), being responsible for all system engineering activities, bridging between fundamental electrowetting technology, display cell manufacturing, strategic partnerships and the market.

Anthony Slack

He graduated with BEng (Hons) in Electrical & Electronic Engineering, majoring in ASIC design, and an MPhil in Applied Materials, specializing in display applications. He has worked in the field of display development and commercialization for more than 20 years, including working on many of the most significant new technologies to have come to market in that time. Anthony has held positions with Motorola and Philips, and spent 8 years based in S. E. Asia, in a variety of hi-tech roles. Anthony is responsible for all aspects of commercial strategy at Liquavista, including Sales, Marketing and Partnerships, as well as defining technology strategy and outlook.