Realization of Full Color Electrowetting Displays for Digital Out of Home Applications

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Abstract

Digital out-of-home displays are a very attractive medium for communicating with the public. LED displays have found many applications in this regard, but wide usage of LED displays is hampered due to their light pollution and power consumption. This drawback creates a unique opportunity for reflective digital displays. Etulipa has developed full-color reflective electrowetting matrix displays which are now undergoing field tests. The displays have deep-saturated colors based on Cyan-Magenta-Yellow color switching; 7 bits greyscales per color; show video content and consume on average 7 Watt/m^2.

1. INTRODUCTION

Out-of-Home (OOH) displays like billboards and information signs are well known in public areas with the goals of presenting advertisements and information to the public. There is a strong trend to update OOH displays into so-called Digital Out-of-Home (DOOH) displays. The first digital billboard installed in the USA was in 2001 by the Lamar Advertising Company [1]. In 2021 Lamar operated 3900 digital billboard advertising displays and 153.800 so-called traditional non-digital billboard advertising displays [2]. Looking at the market size of Lamar it may be assumed that a similar ratio holds for the larger USA market. Considering the digitization of the world within the last two decades, the 3900/153.800 ratio is surprisingly small. At least two fundamental reasons have hampered a faster introduction of digital displays. Digital displays are emissive, usually LED based. A digital display must emit 5000 nits or more in daylight to be seen clearly. This implies a high energy consumption. LED displays may use on average 250 W/m^2 but in bright daylight their power consumption can go up to above 800 W/m^2. This requires a high-power electrical infrastructure. In addition, the power consumption is a considerable fraction of the total cost of ownership. In addition, under low light conditions, for example in the evening, emissive displays emit a bright light far overshining the environment. This light pollution interferes with the quality of life in communities, which leads to the rejection of most requests for permits to install such displays.

Reflective displays do not have these drawbacks. Their brightness automatically scales with the amount of light falling onto them. Their power consumption is extremely low because emissive light does not have to be created. These characteristics makes them ideal candidates for DOOH applications.

2. REQUIREMENTS

However, the requirements for application in the DOOH market are challenging. A display for advertisement purposes needs to present high-quality colorful images including greyscales and video content. In addition, the fact that it is an outdoor application leads to challenging reliability requirements. Typically, displays must operate reliably over a lifetime of up to 10 years in environments with temperatures varying between -40 °C up to above 60 °C due to direct exposure to sunlight and its induced heating.

3. EWD CAPABLIITIES

Electrowetting display (EWD) technology has the capability to fulfill the above-mentioned requirements. Electrowetting cells can change between a closed state and an open state in a selected part of the visible spectrum by altering the wetting behavior of a colored hydrocarbon oil on a hydrophobic surface in a transparent polar liquid environment. This is illustrated in Fig. 1. In Fig. 1a: the incoming light is absorbed by the colored oil film before it reflects back towards the viewer, leading to a black or colored image. Or, when the colored oil film has contracted into small droplets, as indicated in Fig. 1b, then most of the incoming light reaches and reflects from

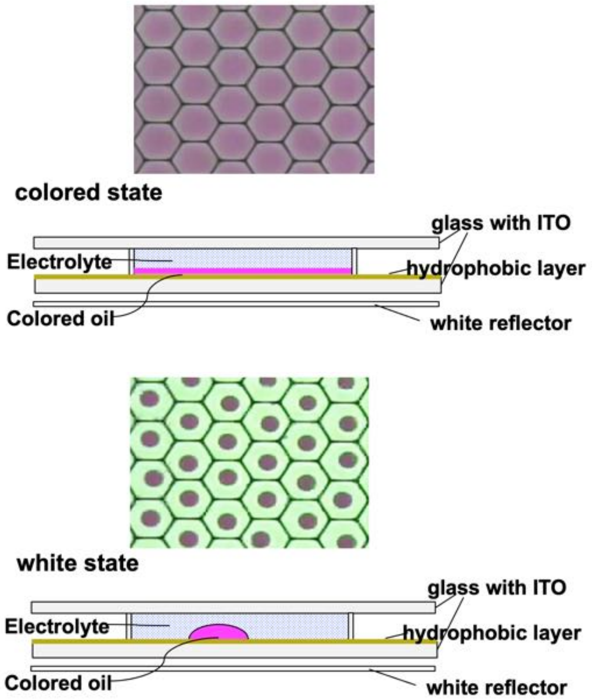

Fig. 1a (top). In the absence of an electric field, a colored hydrocarbon oil fully wets the hydrophobic layer leading to a light-absorbing layer. Only non-absorbed incident light reflects from the reflector.
Fig. 1b (bottom). In the presence of an electric field the colored oil only partially wets the hydrophobic layer to form droplets, thereby creating an optically mostly transparent layer. Most of the incident light reflects from the bottom reflector.

the reflector and is experienced as white light by the observer.

The fundamental advantage of using EWD technology is that this combination of light-absorbing and non-absorbing (transparent) states enables a Cyan-Magenta-Yellow architecture to create bright colors. The CMY architecture allows for a three times higher amount of reflected light than any RGB approach, as explained originally by Heikenfeld [3,4,5]. The principle is shown in Fig. 2. The CMY approach leads to the reflection of all incident light when the cells are set in the transparent state. In the RGB approach, only light passing through a specific color filter can add to the observed reflected light. If the display surface is covered equally with R, G and B filters, only 1/3 of the light can be reflected which will be perceived as greyish white and dull colors.

EWDs can operate throughout a very wide temperature range. The temperature limitations, and thus the operating range of EWDs, are primarily defined through the freezing and boiling

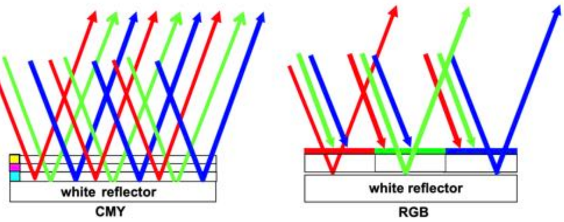

Fig 2. Left: a schematic of a CMY-stack in the open state. The whole area adds to the reflection of incoming light. Right: a schematic of a RGB filter below which a white reflector is created. When ideal color filters are used, only 1/3 of the incoming light is reflected.

points of the used liquids. Suitable liquids have been proposed by Heikenfeld and Mugele [6].

4. MONOCHROME EXPERIENCE

A few years ago, Etulipa developed a monochrome display for information purposes [7]. The active area of this EWD measures 70 x 110 mm^2 with pixel dimensions of 10x10 mm^2. The 7x11 pixel layout is well-suited to display two 5x7 characters in landscape orientation or one 7x11 character in portrait orientation. This display design was tested in climate chambers using guidelines and conditions as defined in the Military Standard 810G [8].

Its first commercial application was a bus-stop in which the display is used to display the time in minutes before the next bus arrives. The project is owned by the New York Department of Transport (NYDOT). The bus-stop consists of 6 Etulipa displays, three on each side, to present data for different bus lines. The system was built by Daktronics and installed by TSI. Telia IOT supplied the communication module. The 6 EWD's only use little power so that an 80-Watt solar panel and a storage battery are adequate to run the bus-stop without any need for external cabling or charging. The system is up and running in New York (NY) since August 2020. Its operating performance gives an enormous confidence in the reliability of the EWD design.

Fig 3. Bus-stop in New York City with 6 electrowetting displays indicating the time to arrival for the next bus. The bus-stop works off-grid and is powered by a solar panel. The electrowetting display has a 7x11 pixel architecture using a direct drive approach with pixels of 10 mm pitch. Photo courtesy of Traffic Systems Inc. and Daktronics.

5. FULL-COLOR EWD

A still image of a movie displayed on Etulipa's first full color matrix display is shown in Fig. 4. A complete video of the display in operation is found on Etulipa's YouTube channel [9]. The display consists of 176 x 84 pixels, each with a 10 mm pitch. The display building block is a panel consisting of 6 CMY bipane tiles. Each panel has an active area of 44x42 pixels and a controller with the electronic Input/Output interface. Each tile comprises 22x14 pixels and consists of a closed housing designed according to the IP65 specification to keep water and dust out. As such the tile comprises stacked C, M and Y bipanes, backlight, back-reflector and electronics. The panel is mounted into and out of the display cabinet using a front access click system. The system runs on an Etulipa proprietary electronic driving solution. During operation, the power consumption can increase up to maximally 5 W/m^2 depending on the content. Power consumption averaged over time is estimated to be 7 W/m^2 by considering that a backlight may be used in evening and night conditions. The system is operated using a solar panel and a battery. On-grid charging is not foreseen.

Fig 4. Etulipa full-color matrix EWD display with a still image of a displayed video. A solar panel is mounted on top of the display for power generation. With a storage battery in the trailer (not seen on the photo) the system runs forever on solar power.

6. DEVELOPMENT CONSIDERATIONS

With respect to the monochrome solution several innovative developments have taken place.

Dimensions: In the monochrome display bipanes are mounted independently from each other to display one or two characters. Bipane seams are hidden behind the front plate. In a matrix display there is no inactive area which implies that any seam becomes visible. In the full-color matrix design the tiles are increased in size while their seams have been narrowed to only a fraction of the pixel size.

Stack: Each tile comprises a stack of optically coupled C, M and Y bipanes. Optical coupling has been done using wet processing to avoid that high pressures are exerted on individual bipanes. Optical coupling material was selected based on the compatibility with the reliability requirements. It is noted that the requirements on individual oil-dissolved dyes are higher in a stacked solution than in a typical monochrome solution. The reason is that overlapping absorption spectra of different dyes may lead to the perception of unwanted colors.

Greyscales: Greyscales can be realized in two ways, either analog or digital: Analog involves a varying voltage and thus electric field across a pixel during the full switching time thereby causing the colored oil droplet to become larger or smaller in diameter. This leads to less or more reflected light, respectively. Digital involves the use of a voltage pulse width modulation. In the presented display this digital approach has been used. To create a certain grey scale, the voltage is set to 100% of its amplitude for only a specified fraction of the switching time. The smaller the fraction, the smaller the effectively experienced electric field over time. An effectively smaller electric field widens the droplet diameter which leads to more absorption of incoming light.

Electronics: A proprietary electronic driving solution has been developed. Standard off-the-shelf solutions are available but use typically 2 to 4 Watt per connection. The Etulipa display is modular on a panel basis. The 8 panels require 8 connections implying that off-the-shelf solutions will require at the very minimum 16 to 32 Watt. Etulipa developed a proprietary electronic driving solution optimized for low power such that the complete 1.5 m^2 display runs on only 7.5 Watt (i.e. 5 W/m^2) when usage of the backlight is excluded.

External lighting: In the bus-stop application no external lighting is necessary. From perception tests it was concluded that during night-time conditions the available streetlight is adequate to meet the specification of a readable display at 80 feet distance. Obviously, this is related to the fact that the bus stop is a monochrome application where contrast is maximal due to the use of a black colored oil for creating the digits on a white back reflector.

A full-color digital matrix display features content in the form of colorful images. An external light source enhances the quality of the images in the dark. The use of a backlight is then most convenient. The alternative of a front light source, for example a LED strip, would have to be mounted at typically a meter distance from the display. Mounting at the top of the display causes disturbing shadows on the display under sunny conditions. Mounting at the bottom would lead to additional fixtures.

Note that the backlight does not have to produce the same amount of light as needed in LCD and OLED displays because of the high transmittance of EWDs in comparison with LCDs or OLEDs. LCDs and OLEDs may have a transmittance below 5% [10].

7. TESTING

Product reliability is critical for adaption of new technology into high volume markets. Full-color displays are tested at different system levels. The individual bipanes have been tested in the design phase using a Highly Accelerated Life Test (HALT) program to understand the limits of operation. Subsequently, tiles are tested under different climate conditions at varying temperatures and humidity's using Mil. Std 810G guidelines [8]. Tiles have also been tested for resistance to physical impacts. Complete panels and a full display have undergone vibration tests to obtain insight in possible degradations due to transport and operation near highways.

In parallel, displays are being delivered to targeted customers to allow their operation under real life circumstances. This provides insight in the perception and responses of audiences to full-color reflective displays. In addition, experience and knowledge is gained with respect to the EWD performance at various locations under a variety of operating conditions.

8. REFERENCES

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