Bi-Stable and Wide Temperature - Range Electrowetting Displays

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Abstract

Moving a droplet by electrowetting is the basis of our novel displays. This enables mechanical bi-stable and high reflective monochrome as well as color systems. Since no high temperature process is required, plastic substrates can be used. Our prototypes show promising performance in terms of a wide temperature range, contrast ratio and color.

1. Introduction

Electrowetting is a well known effect in physics dealing with changes of fluid contact angels due to an external electric field, see Fig. 1.

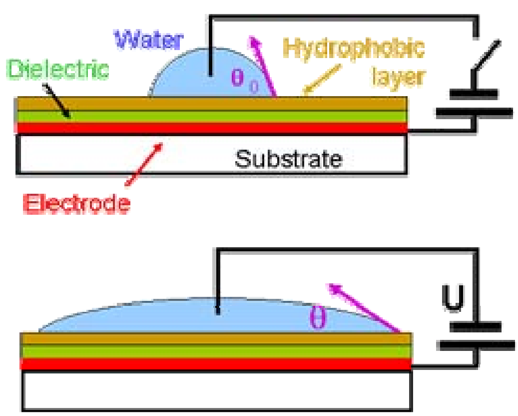

Fig. 1. Electrowetting principle: Water droplet on hydrophobic layer is contracted without voltage (top) and relaxed when an appropriate voltage is applied (bottom), [1].

A well described overview of electrowetting basics can be found e.g. in [2]. Here we will focus in brief on the Lippmann-Young equation (1), which describes the relevant parameters for designing electrowetting based displays:

$$\cos\theta = \cos\theta_0 + \frac{\varepsilon_0 \varepsilon_r \cdot U^2}{2 \cdot \gamma_{LG} \cdot d} \qquad (1)$$

In order to achieve low driving voltages U, the dielectric constant ε_r should be as high as possible and the surface tension γ_{LG} as well as the thickness d of the dielectric low.

The electrowetting effect can be used for displays in two different ways: contracting and relaxing of a locally fixed (e.g. by surrounding walls or a pixel grid) droplet as introduced by Liquavista [3] or by moving a droplet. The last approach bases on micro-fluidics and visualized in Fig. 2. Our work uses a moving droplet for the first time in a display application (some earlier results are described in [5]).

Motivation for this kind of display technology was their high transmission of light suitable for reflective devices and colors generation by subtractive color mixing like printers. Another important reason was furthermore the bi-stability of the drop-moving approach which allows low cost Multiplex and Passive Matrix driving opposite to contracting which requires AM. Therefore PM displays enable easier integration on flexible plastic substrates.

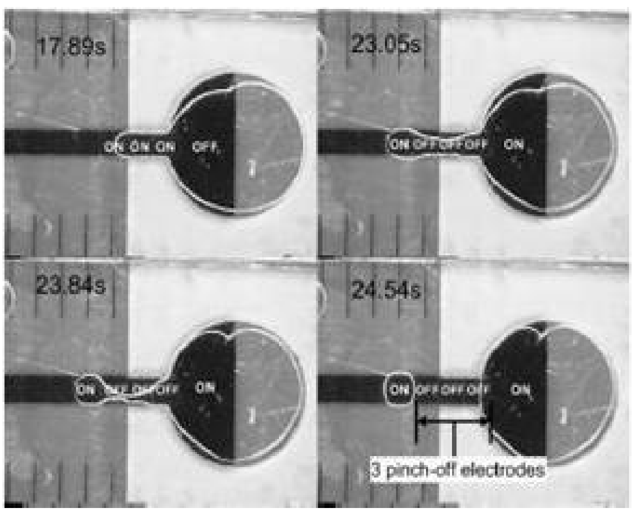

Fig. 2. An electrowetting micro-reactor separating a small droplet (bottom right) out of a reservoir (top left), [4].

In electrowetting on dielectric (EWOD) for displays, water droplets in a channel filled with oil as shown in Fig. 3 are moved: Applying a voltage between segmented control electrodes (here E_1 and E_2) and a common electrode makes it possible to move the droplet from one position to another.

When the electric field appears on the edge of the droplet (here E_2) the change of contact angle leads to a movement towards E_2. The droplet shape is distorted and dissolves further over electrode E_2. If the electrode layout and the driving signal are well chosen, the droplet contracts over E_2 when the voltage is switched off. This leads to bi-stable pixels. The electrode voltage increases with the droplet size and lays in the range between 10 and 80 Volts DC or AC.

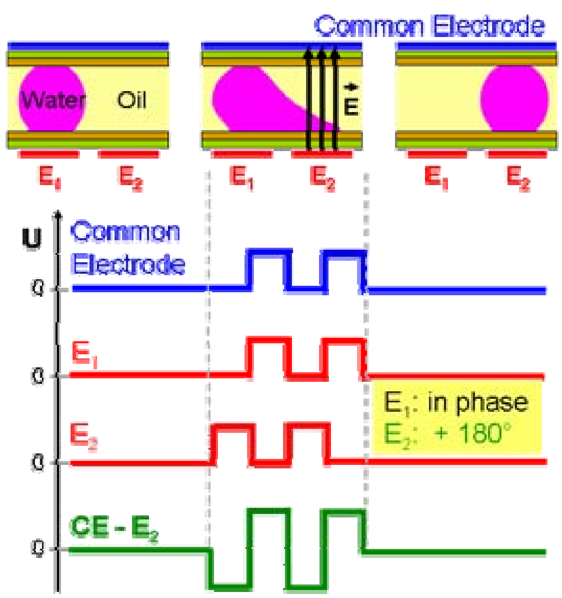

Fig. 3. Droplet driven EW principle with common electrode and control electrodes E_1 and E_2.

2. Experimental

Our prototypes of electrowetting displays base on an optimized mechanical structure (see Fig. 4), which fixes the droplet in each position, so that an enhanced bi-stability is reached which withstands environmental changes and lasts significantly longer than bi-stability in, e.g., e-paper displays. This approach is called ‘binary’ because there is only an ON and an OFF state. The transparent electrodes were optimized to keep driving effort low.

In order to evaluate and to demonstrate the performance of droplet-driven EW displays, a programmable driving system (block diagram see Fig. 5, hardware see Fig. 6) was developed. It allows single pixel, multiplex or Passive Matrix schemes. The data to be displayed are transferred from a PC to the microcontroller via RS232 interface and converted to the driving scheme for the electrodes. This resulting waveform is sent to the display output drivers. Voltage, frequency and sequence can be set in a wide range.

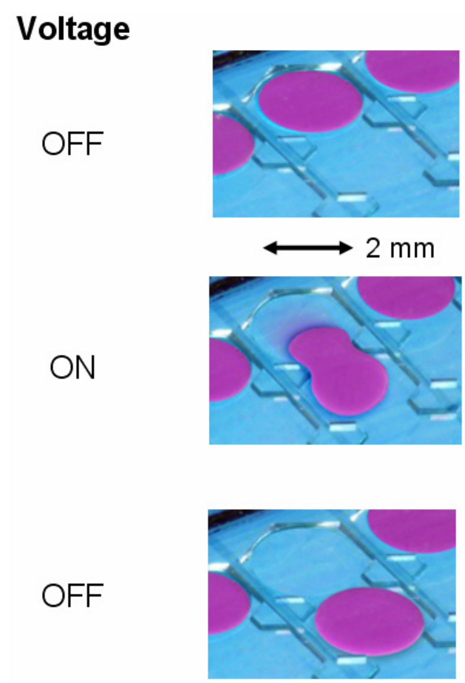

Fig. 4. Binary pixel layout with a droplet moved from one position (top) to another (bottom) with mechanical bi-stability by constriction.

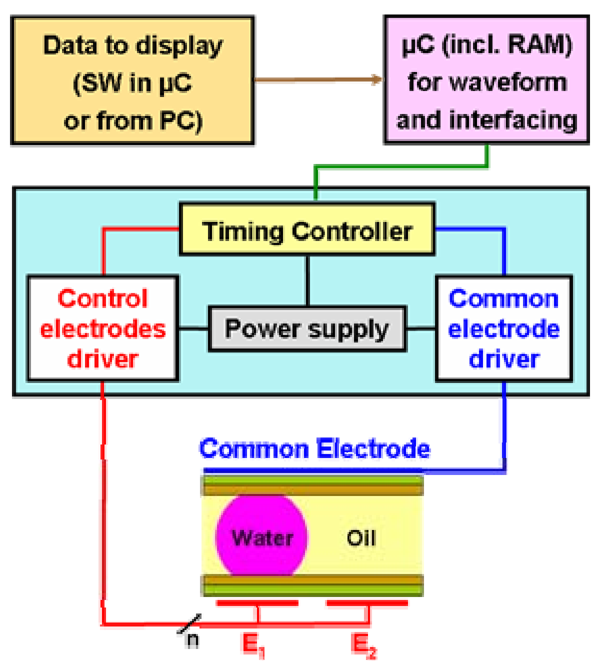

Fig. 5. Block diagram of a droplet-driven electrowetting display system.

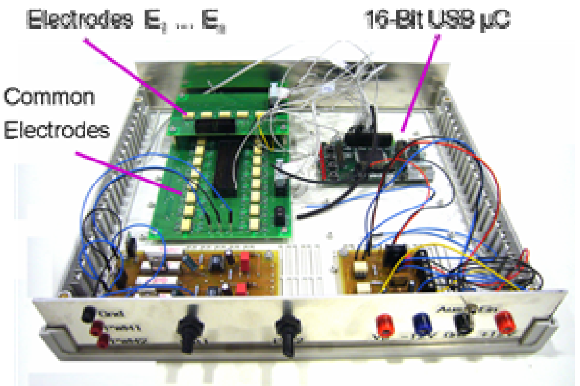

Fig. 6. Universal display driver system for EWOD by droplet moving displays.

3. Results and discussion

After studying single pixel properties, we stepped forward to prototypes with 10 'binary' pixels in a row (sticks, see Fig. 7), the layout of each pixel is the same as in Fig. 4. Due to bi-stability, each pixel can be set sequentially. The duration from switching from one position to the other is about 1 s, which would result in 10 s for these prototypes. However if the pixel position needs no change from one image to the next one, this pixel can be skipped lowering to addressing time. For 'real' displays, only the 'visible' area should be observed, hence to other one has to be covered, e.g. by another stick.

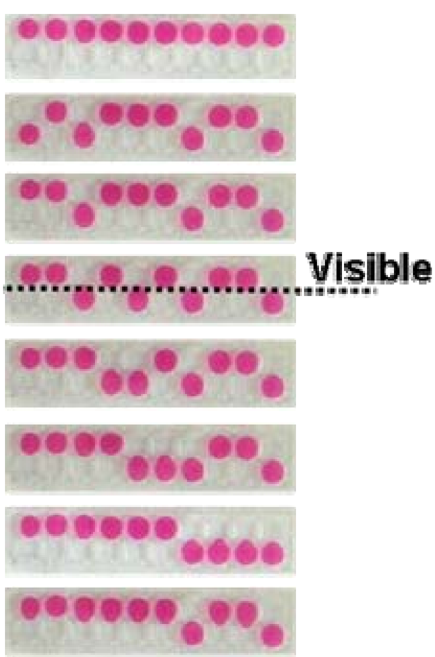

Fig. 7. Examples of 10-pixel-in-a-row layout with individual pixels driven by sequential multiplexing of the display.

Various electro-optical and optical tests were performed; Fig. 8 shows a result of transmission measurements. The overall reflection of a 'transparent' pixel (oil, paper as reflector) is over 85%. Water with standard color inks enables printer-like displays opposite to the usual RGB lateral approach. A full color display can be achieved through stacking three layers (Cyan, Magenta, Yellow, see Fig. 9) to reproduce colors by subtractive color mixing comparable to printers.

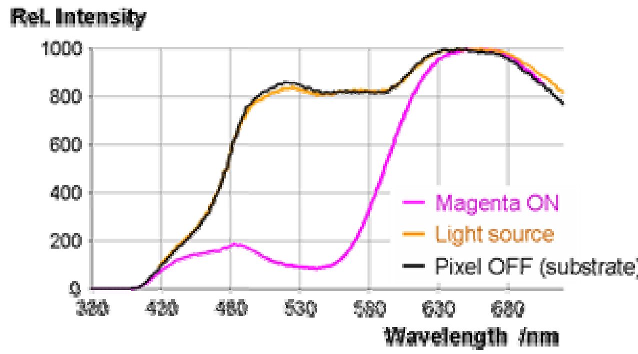

Fig. 8. Spectrum of a pixel with and without magenta droplet. The transmission is > 85%, the intensity was normalized to 650 nm.

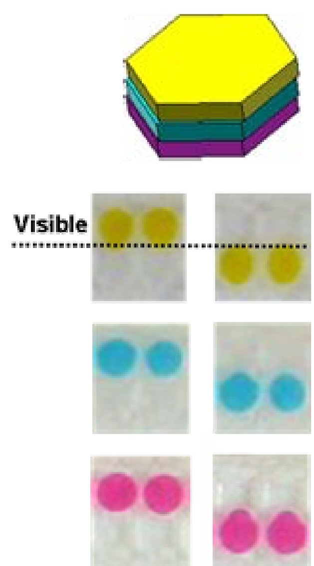

Fig. 9. Stacked arrangement for subtractive color mixing by CMY (top), individual pixels are shown below.

To demonstrate the stacked CMY color approach we build up a prototype with 10 pixel sticks, where all the pixels can be driven individually. First prototypes of this approach (see Fig. 10, color degradation due to white balance of the camera) show promising results.

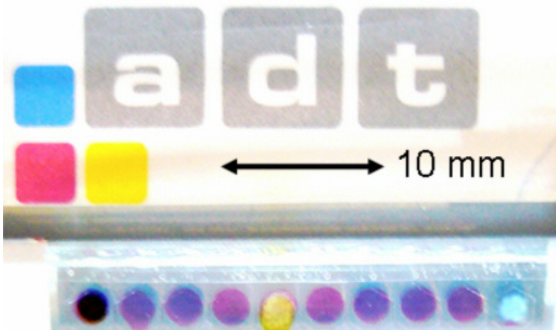

Fig. 10. CMY stacked color prototype displaying several primaries by 2 mm droplets.

Beside color, grey scale representation is also a must for modern display technologies. There are two ways to achieve this: spatial dithering (like printing) with 'binary' pixels as described above or partially filling of cavities which is shown in Fig. 11. The visible area is the hexagon on the right hand side, the pixel size is about 2 mm. 5 steps with non-linear increment of the covered area A allow optimized grey shade representation according $A_{color} \sim gs^{\gamma}$ (gamma function). Which approach is more suitable for an electrowetting displays on droplet moving basis needs further analysis taking driving effort and electrode layout into account.

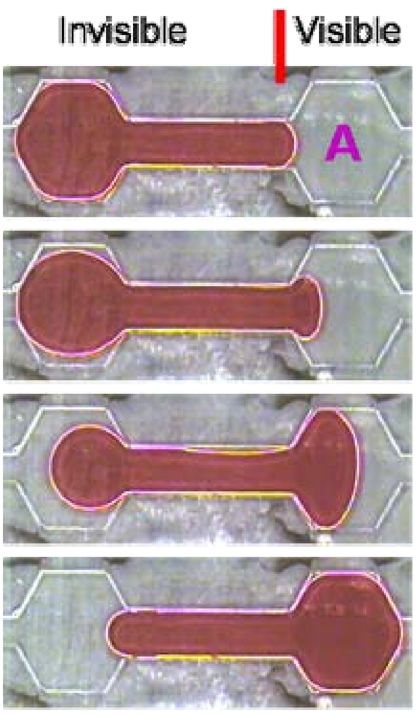

Fig. 11. Demonstrator of a hexagonal pixel: Droplet 'off' (invisible, top), droplet partly in the active area (middle) and 'visible' pixel completely filled (bottom).

4. Summary

We developed a novel display technology basing on the electrowetting on dielectric approach by moving droplets. Driving of these displays in the droplet moving way has the advantage of mechanical bi-stability which is probable infinite in time. Unlike conventional display technologies it is furthermore possible to show movements of a single droplet making it attractive for low content displays and design applications like meters. The following optical and display characteristics could be reached so far:

- Contrast ratio > 10:1 (paper like)
- 4 Bit grayscale
- Both spatial RGB additive and stacked subtractive (CMY) color generation
- High reflective (transmission > 85%)
- Pixel/droplet sizes from 0.5 to 3 mm
- Passive Matrix (voltage driven, bi-stable)
- Driving voltage 10 … 80 V
- Extended temperature range : -40 … + 90°C

Those displays are scalable from low content (signage) to high resolution tiled applications. Furthermore it is possible to realize this technology on flexible substrates because of absence of temperature processes and Passive matrix driving. Our prototypes will be commercialized by the Swiss-based company ADT AG. In opposite to the electrowetting approach by contracting and relaxing droplets via Active Matrix our droplet moving technology is bi-stable and can be driven by less expensive Passive Matrix addressing.

5. References

1. K. Blankenbach, *Displays & Optoelelektronik*, **5/2007**, p38 (2007)
2. H. Moon, S. K. Cho, R. L. Garrell, C. J. Kim, *Journal of App. Physics,* Vol. **92[7],** p4080, (2002)
3. R. A. Hayes, B. J. Feenstra, I. G. J. Camps, L. M. Hage, T. Roques-Carmes, L. J. M. Schlangen, *SID'04 Technical Digest*, Vol. **2**. p. 1674, (2004)
4. R. B. Fair, V. Srinivasan, H. Ren, P. Paik, V. K. Pamula, M. G. Pollack, *IEEE International Electron Devices Meeting (IEDM), Duke University Durham*, (2003)
5. K. Blankenbach, A. Schmoll, A. Bitman, F. Bartels, D. Jerosch, *SID'07 Technical Digest*, Vol. **1**, p618, (2007)