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Switching Dynamics of Electrowetting Pixels

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ABSTRACT

While greyscale switching of an LCD can be described as a continuous process, electrowetting pixels can display various modes of opening dependent on the voltage transition profile. Careful control of switching field and slew rate are needed to ensure reproducible greyscale reproduction.

1 Introduction

Electrowetting displays depend on the principle of moving colored ink on the surface of a hydrophobic pixel enclosure [1] (fig. 1).

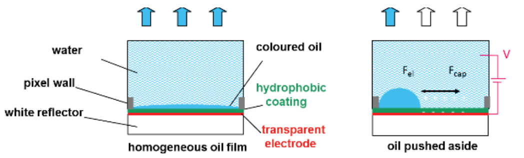

Figure 1: Switching principle of an electrowetting display

Greyscale switching of electrowetting displays is straightforward, in first approximation. Increasing field leads to decreased water contact angle, and thus to increase in aperture. However, there are many ways in which a film of absorbing oil can be distributed across the glass surface, not all of which have the same aperture. This means opening modes require careful control.

2 Pixel switching modes

If a voltage is applied, the opening direction of the oil has to be regulated. If this is not the case, the oil will either contract into random corners, or under the influence of an uncontrolled factor, the oil will contract in specific directions within certain domains (Fig. 2).

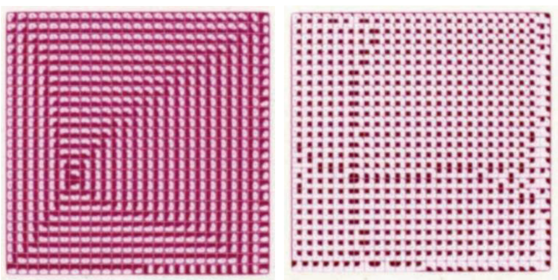

Figure 2: Uncontrolled switching direction

2.1 Static control of pixel opening

If the pixel voltage is gradually increased, the oil film in the pixel tends to rupture in a predictable place. The oil film rupture is a process with a surface tension barrier, and therefore the luminance level of the pixel will “jump” depending on the energy of the barrier. After opening, the luminance level will increase gradually with voltage, until a certain saturation voltage is reached.

In order to improve addressability of grey levels (more specific: darker grey levels), a method is used to reduce the opening threshold. One method is to introduce a dielectric “mesa” that will locally create a thinner oil film,

as well as increase the electric field on the top of the mesa (fig. 3). An alternative for the mesa is a small dot of conducive material, having the same effect:

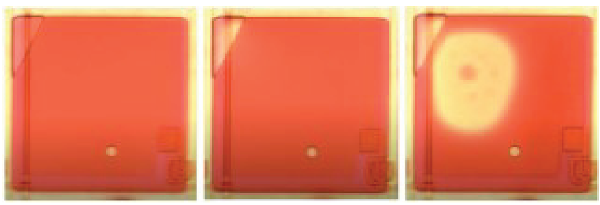

Figure 3: Opening structure using "mesa"

Locally increasing the field. As a result, the oil film will preferably rupture at the top of the mesa (or at the conductive dot), at a lower voltage than would be the case if a mesa were not present. Ideally, of course, the voltage would be reduced to the level where no rupture threshold would exist. However, this is very difficult to achieve. Effectively, driving the lower grey levels will need to be effectuated by implementing a drive waveform that first applies an opening pulse, and then reverts back to the intended grey level.

2.2 Propagation of pixel opening

After the oil film has opened, increasing the voltage leads to an increase of the aperture in the oil film. Due to symmetry considerations, the oil film can contract in a multitude of ways: Either towards one of four pixel corners (usually preceded by a state where one edge of the pixel is opened, Fig. 4), or split into multiple droplets moving to opposing corners.

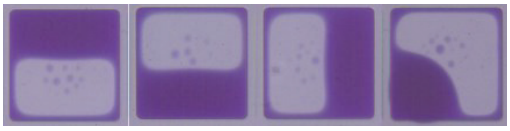

Figure 4: Random opening directions of a symmetric pixel

In order to provide uniform pixel opening, measures must be taken to eliminate pixel symmetry, and create low-energy states for the residual oil droplet.

A starting point is the afore-mentioned “mesa” or conducting dot. If this is placed in the corner of a square pixel, the opening position will force the oil to contract towards the opposing corner. However, this still leaves two intermediate states for the pixel opening path, because there still is two-fold symmetry.

This symmetry can be broken by applying a small structure off the symmetry axis of the pixel, thus driving the opening of the oil in one specific direction.

As an additional measure, an opening can be created in the pixel electrode, locally reducing the field, creating a low energy position for the contracting oil droplet.

Figure 5: Symmetry-breaking element added to pixel

2.3 Dynamic control of pixel opening

As was reported earlier, if the voltage on a pixel is applied too fast, the oil will no longer open at a single position, but will respond like a vibrating membrane, opening in certain “nodes”, dependent on voltage and field slew rate. [2], (Fig. 5) It should be clear that this is undesired behavior since the opening direction of the pixel can no longer be controlled.

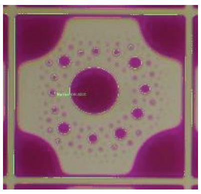

Figure 6: Multi-node opening of pixel using steep voltage pulse

The only way of counteracting this is to make sure the voltage is applied to the pixel gradually. The first line of approach is therefore to make sure the RC-time of the pixel electrode is below the time of the first harmonic of the oil membrane. Obviously, this applies to the transition from closed to open oil film.

2.4 Greyscale transitions

Without further measures, slowly opening the pixel will result in a structured, but undesired, opening pixels will open predictably and homogenously. Grey levels can be reproduced accurately, and grey-grey transitions are easy to achieve.

To our surprise, greyscale transitions have uneven transition times: mid-grey levels take longer to switch than light- or dark-levels. A clear reason for this has not yet been found yet, but accurate, predictive driving can .

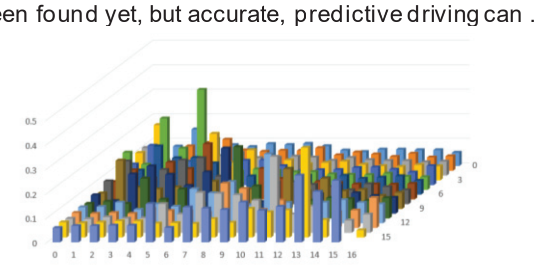

Figure 7: Switching times of greyscale transitions

3 Conclusions

By implementing the correct, symmetry-breaking features in an Electrowetting pixel, it is possible to accurately control the opening directions of the oil films. Additional optimization of driving waveforms is required to accurately reproduce greylevels.

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References

[1]. R. A. Hayes and B. J. Feenstra, Video-speed electronic paper based on electrowetting, Nature 425 , 383–385

[2]. T. Biao, J. Groenewold, M. Zhou, R. A. Hayes & G. F. Zhou, interfacial electrofluidics in confined systems, Nature Scientific Reports 6, Article number: 26593 (2016)