Bistable, Multi-color Electrowetting Displays

K.M. Charipar, N.A. Charipar, and A. Piqué

Naval Research Laboratory, 4555 Overlook Ave., SW, Washington, DC 20375, USA

kristin.charipar@nrl.navy.mil

Abstract We have designed, fabricated, and characterized multi-color, bistable electrowetting displays. By using a unique in-plane electrode, it has been shown that these devices remain bistable, without the need for power, on the order of days.

1. Introduction

Recently, electronic paper, or e-Paper, for use in displays has seen rapid growth due to its advantages over traditional display technologies [1]. With the capability of high contrast in direct sunlight, wide viewing angles, and low power consumption, electrowetting displays (EWDs) have become an emerging technology in the e-Paper market. EWDs rely on the modification of the wetting properties of a surface by applying an electric field [2]. Here, we have developed a EWD architecture that exhibits multi-color, bistable pixels using laser processing techniques. By using in-plane electrodes, liquid can be moved in and out of plane, allowing colored oil to be displaced. The oil remains in its position even after voltage is removed, reducing the power necessary to drive the display.

2. Fabrication

Devices were fabricated using both lithographic and laser processing techniques. ITO-coated glass substrates were laser patterned (Nd:YVO₄, $\lambda=355\text{nm}$) to make the device electrodes [3]. A dielectric layer (MicroChem SU-8) was then spin-coated onto the substrate surface, followed by another dielectric layer which was patterned to yield the electrowetting pixel structures. A hydrophobic coating (Cytop 809M) was then spin-coated onto the sample. Devices were dosed underwater, using capillary forces to move colored oil into the channels. The electrodes were patterned such that the channels and pixels can be actuated independently. A schematic of the device and its operating principle is seen in Fig. 1. To create a multi-color device [4], two independent devices were fabricated on each side of a double-sided ITO substrate. By doing this, extra ITO and glass interfaces are minimized. This configuration allows for one device to be dosed with blue, while the other is dosed with red. This yields four different color possibilities, depending on which device is actuated, including red, blue, purple, and white. Further experimental details, including specific fabrication parameters and oil dye selection, can be found elsewhere [5].

Figure 1. EWD schematic, where voltage is applied to (a) the channel electrode and (b) the pixel electrode. (not to scale)

3. Results

Both optical microscopy and spectrophotometry were used to characterize the optical properties and behavior of the devices. The contrast ratio of the pixels (reflectance of 'on' state to 'off' state) was determined by several different factors, including pixel geometry, oil concentration, and applied voltage. Several different geometries were evaluated, including square and rectangular pixels of varying sizes. In addition, the height of the pixels and the width of the channels were investigated. The optimal dimensions for these parameters are determined by balancing contrast ratio with operating voltage. For example, thicker pixels allow for more ink to be stored in channels, making the contrast higher, but requires higher voltage to actuate. The best performance was determined to be for $300 \times 900 \mu\text{m}$ pixels, each $22\mu\text{m}$ thick with a $100 \mu\text{m}$ channel width, as seen in Fig. 2(a-d). The contrast ratio can be determined using data seen in Fig. 2(e), where the reflectance for each color (red, blue,

purple) has been normalized to the white, or “off” state. It is seen that the contrast ratio is dependent on ink color and wavelength, but has a peak value of ~ 3.9 for purple ink at 418nm.

Figure 2. Multi-color, bistable pixels being actuated with four different color combinations, including (a) before actuation, (b) after both blue and red actuation, (c) after red actuation only, and (d) after blue actuation only. Reflectance data for these EWD pixels normalized to the white state can be seen in (e).

Bistability can also be seen using various pixel geometries, including the square geometry seen in Fig. 3, where it is apparent that even after voltage is removed, the colored oil remains in its current position. This result is critical because it implies that power is only needed to switch the device, not to hold its state. It has been shown that the device remains stable over the course of several days after power has been removed.

Figure 3. Square pixels (500 μm) exhibiting bistability after actuation.

The results obtained in this study indicate that this EWD technology could be potentially used for video speed applications, due to the fast switching rate of each pixel ($< 36\text{ms}$). In addition, the fabrication techniques are compatible with flexible substrate processing. We have demonstrated this architecture using ITO-coated PET as a flexible substrate, with similar performance to that of the rigid ITO-coated glass substrate.

In conclusion, we have demonstrated an electrowetting display using bistable, multi-color pixels fabricated via laser processing.

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