Voltage Controllable Visible Light Range Reflector Display

Adia Radecka, University of Illinois at Urbana-Champaign Department of Electrical and Computer Engineering, *SUNFEST Fellow*

Professor Marc Miskin, University of Pennsylvania Department of Electrical and Systems Engineering

***Abstract*—**
Technology is always evolving to be more reliable, user-friendly, and easy to produce. Developing screen technology in smartphones and tablets using electrophoretic display (EPD) screens instead of Liquid Crystal Display (LCD) screens would lower costs, weight, power consumption, and improve user experience. A downside of EPDs is that they are only reliable in black and white technology. This problem is approached by developing a fabrication process for colored e-ink actuators and voltage probing of the actuators. To achieve reliable and consistent actuators, different actuator designs were developed.

Index Terms— **Electrophoretic Display, Electronic Ink, Liquid Crystal Display, Actuators**

INTRODUCTION

Devices that are reliable and can be produced at a low cost, weight and power consumption are at the forefront of research [1]. These characteristics are sought in widely used devices such as smartphones and tablets. Using electrophoretic displays (EPDs) in these devices would benefit producers and consumers by providing a better user experience. These displays react to an applied voltage all while consuming low power and giving a paper-like response [1]. Typically, devices like the Kindle, and other eReaders use EPDs, which have black and white technology, which would not be ideal for use in smartphones.

The display type used almost exclusively on every device with a screen is a liquid crystal display (LCD). An LCD has pixels that turn on or off when polarized light is rotated, which is achieved by the liquid crystals [2]. The benefit of this display is the range of colors and fast refresh rate allowing videos, games, etc. to run smoothly. The drawbacks of this method falls into the following categories: use in the sun, use in the dark, power consumption, and price [3].

When it comes to reading off a screen in the sun E-Ink has no glare and essentially gives a book-like experience. Using any LCD smartphone in the sun there is a lot of glare making it difficult to see the screen. Night use poses a similar problem. LCD screens tend to be overly bright in the dark, while the E-Ink screens like in the Kindle Paperwhite are less disturbing. Battery life of LCD screens is poor compared to that of E-ink, which can go for weeks without a charge. Finally, E-Ink devices are significantly cheaper than LCD devices. Therefore, developing a reliable fabrication method for colored e-ink could significantly improve the user experience.

This paper aims to demonstrate the viability of developing a reliable color E-Ink fabrication method. To accomplish this microelectronic fabrication technologies are used to develop platinum and titanium actuators on titanium tethers with an aluminum release. A prototype probing station is also used to make electrical contact with actuators. Although voltage drives these actuators, creating consistent and reliable arrays of actuators is a challenge. This challenge will be explored by running voltage probing experiments and changing the design of the arrays.

I. BACKGROUND

A. *Electrophoretic Displays*

EPDs use electronic ink (e-ink) which has black and white charged particles that are placed between two electrodes [3]. These particles are found in microcapsules which can have a negative or positive charge [3]. The white and black particles can actuate when a voltage is applied, which moves the microcapsules. Different tones, like gray, can be achieved by adjusting the voltage applied. The pixels found in EPDs contain the following materials: pixel wall, insulating liquid, colored pigments, charge control agent, and a stabilizer [3].

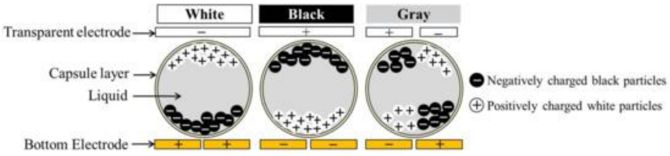

Fig. 1 Electrophoretic Display principle [3]

B. *Actuators*

Nano-actuators are a type of microscopic electronic device that react to their environments resulting in some movement. A change in temperature, pH, and voltage are some of the few environmental stressors [4]. This project uses voltage driven actuators, with the help of a probing station.

The actuator arrays are connected in series and include seven different size samples. The array is split into seven columns and seven rows of squares, which contain ___ actuators. The sizes of the actuators are as follows: 5um, 10um, 15um, 20um, 25um, 50um, and 100um in length and width. A variety of actuator sizes will help characterize the conditions for optimal operation.

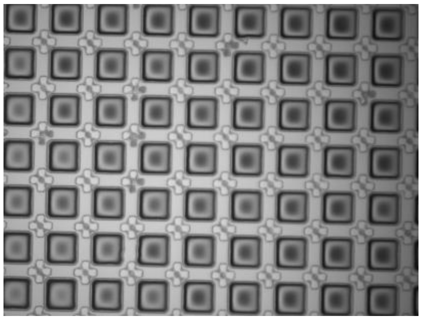

Fig. 2 Example of an array of 25um actuators

C. Key Tools

The fabrication production of the actuator arrays requires a few clean room instruments.

1. The Denton Explorer14 Magnetron Sputterer (PVD-05) for sputtering Aluminum and Titanium
2. Heidelberg DWL 66+ Laser Writer (LW-01) for mask production
3. Oxford 80 Plus RIE (DE-04) for oxygen cleaning samples
4. SUSS MicroTec MA6 Gen3 Mask Aligner (MA-01) for mask alignment and lithography
5. Veeco Savannah 200 (ALD-03) for Platinum deposition
6. Spin coater (SPN-01) for spin coating photo resist

II. METHODS

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The fabrication process has three main features: deposition, etching, and liftoff. The result is a layer of platinum above a gap, which can be controlled with voltage. A fully fabricated sample takes approximately three days to complete. Day one consists of tethering the device, day two consists of building the actuators onto the titanium tethers, and that is followed by a four hour liftoff. The final step is to release the actuators, which can take up to a day.

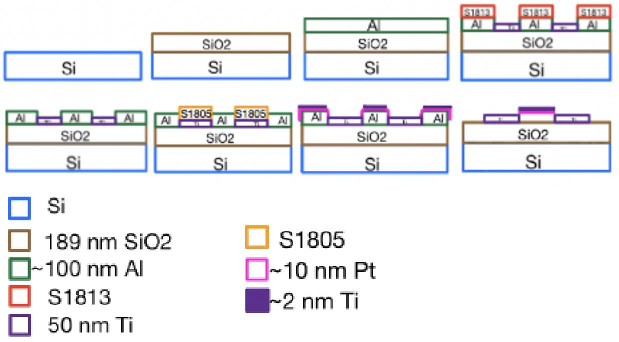

Fig. 3 Device schematic demonstrating the different layers and their thickness.

A. Tethering Devices

1. Take a silicon wafer and deposit 189 nanometers of SiO2 using CVD-01. Refer to NanoSOP or CVD PQual email from staff for recipe parameters. As of 03/01/2022 "Test-SiO2" recipe deposits 286nm per minute.
2. Sputter around 100-120 nanometers of Aluminum at 200W for 600 seconds in PVD-05, which should give an aluminum film of around 120 nm. Ensure chamber pressure reaches 5e-06 Torr before starting deposition.
3. Cleave wafer into chips slightly larger than the area of the mask set you will use, typically around 2.5-3square centimeters in area. Remove silicon dust from chips with nitrogen gun.
4. Oxygen clean samples at 150W for 3 minutes to get a uniform aluminum oxide layer.
5. Measure hot plate temperatures with thermometer and have one ready at 115C.
6. Pre-bake samples in silicon carrier wafer at 115C for 3 minutes.
7. Spin on HMDS at 500RPM for 5 seconds followed by 4000 RPM for 45 seconds.
8. Spin S1813 at 500RPM for 5 seconds followed by 4000RPM by 45 seconds.
9. Pre-exposure bake samples in silicon carrier wafer at 115C for 90 seconds.
10. Clean "Gonzalez Holograms Tethers" mask with acetone and IPA and DI water followed by through nitrogen dry.
11. Expose photoresist in MA6 mask aligner using 'Miskin-1813' recipe with contact lithography at 130mJ of dose.
12. Develop exposed samples in CD-26 for 40 seconds and then immediately dunk in a bath of DI water and agitate for 60 seconds followed by a second dunk in DI water and agitate for 60 seconds. Dry thoroughly with nitrogen gun.
13. Post exposure O2 clean at 150W for 90 seconds.
14. 5 minute pre-etch bake at 115C for 5 minutes, ensure to put samples on carrier wafer.
15. Dunk chips in undiluted transene Aluminum etchant type A for 15 minutes with light agitation for 1 full minute every 5 minutes. At the 15 minute mark, 10 minute mark, and 5 minute mark.
16. Dunk samples in DI water bath and agitate for 60 seconds followed by a second DI water bath dunk and agitation for 60 seconds. Rinse thoroughly with nitrogen gun.
17. Sputter Titanium in PVD-05 at 350W for 300 seconds. Ensure chamber reaches 5e-06 Torr before deposition. 300 seconds at 350W should give around 54 nanometers.
18. 18. Lift-off excess titanium in PG remover heated to 60C with ultrasonication for 4 hours. Then dunk samples in bath of KL remover and lightly agitate for 1 minute followed by dunking samples in bath of DI water for 1 minute with light agitation. Dry

thoroughly with nitrogen gun. **You may pause fabrication here.**

B. Actuator Development

19. O2 clean for 1.5 minutes at 150W.
20. Measure hotplate temperatures in bay 5 and have one ready at 150C and one at 115C.
21. Spin LOR3A at 500RPM for 5 seconds followed by 4000RPM for 45 seconds.
22. Pre-exposure bake LOR3A for 5 minutes at 150C. Ensure to use a carrier wafer to put samples on top of to avoid cross contamination of dirty hotplates with our sample.
23. Spin S1805 at 500RPM for 5 seconds followed by 4000RPM for 45 seconds.
24. Pre-exposure bake S1805 for 90 seconds at 115C. Ensure to use a carrier wafer to put samples on top of.
25. Clean "Gonzalez Hologram Actuators" mask with acetone and IPA and DI water followed by a thorough nitrogen dry.
26. Align sample to mask in MA6 mask aligner, ensure all four alignment marks are in alignment prior to exposure. Switch to 10X objective to ensure alignment marks are where they should be. **Note**: ensure the mask is oriented the right way if you are having excessive trouble aligning sample, alignment is a skill that takes time to develop, be patient and for best practices align to one alignment mark using the X and Y knobs, and align to the alignment mark opposite to the original mark using the theta knob for best quickest results
27. Expose photoresist at 95mJ in MA-01.
28. Develop samples by dunking them in bath of CD-26 with light agitation for 40 seconds followed by dunking them in a bath of DI water for 1 minute with light agitation and then a second bath of DI water for 1 minute with light agitation. Dry thoroughly with nitrogen gun.
29. Post-exposure O2 plasma descum for 90 seconds in DE-04 at 150W.
30. Take a SiO2 coated silicon test chip by ALD-03 tool and O2 plasma descum chip for 90 seconds in DE-04 at150W.
31. Measure SiO2 thickness of test chip for ALD-03 tool in MET-04 and record this value.
32. In ALD-03 chamber at 200C, outgas photoresist of samples for 3 minutes.
33. **NOTE**: Refer to latest Pt thickness as a function of No. of cycles data to determine necessary number of cycles necessary to deposit desired Pt film. Data can be found under "experimental data" folder and then look for "platinum ALD Data" folder. As of 5/12/2022, 120 cycles of Pt should give around 11.5 nanometers of Pt. Run ALD-03 chamber for desired number of cycles.
34. Measure Pt thickness in test chip in MET-04 by fixing model SiO2 thickness from recorded value in step 31and measure Pt by having the tool measure that parameter. Record Pt thickness and update data on Pt thickness per number of cycles as a function of time.
35. Sputter a capping layer of Titanium on PVD-05. I have most recently used a 30 second deposition at 200W.Ensure chamber reaches 5e-06 Torr of pressure before deposition. Refer to latest experimental data on Tide position for guidance.
36. Liftoff excess titanium in PG remover heated to 60C with ultrasonication for 4 hours. Then dunk samples in bath of KL remover and lightly agitate for 1 minute followed by dunking samples in bath of DI water for 1minute with light agitation. Dry thoroughly with nitrogen gun. **Fabrication ends here**

C. Release

37. Release actuators in a 10:1 dilution of DI water to HCl in Singh 105 for at least 16 hours. **Actuators are now ready to be probed in our probe station in Phosphate buffered saline.**

Fig. 4 Image of the whole reflector display demonstrates the small size.

III. COLOR AND VOLTAGE PROBING

Our device is on the order of the wavelength of light. Therefore, when you shine white light, which contains all the wavelengths of the light spectrum of visible light there is some interference. With this structure we can destructively interfere certain segments of the wavelength of light which correspond to colors we perceive. We can also constructively interfere other segments of light that we wish to perceive. Since the actuator can be tuned with nanometer precision, we should be able to tune the reflector to give us exactly the wavelength of light we want to receive.

The reflector displays are voltage probed and as a result they exhibit movement and significant color changes. The reflector displays consist of an upper and lower plate of metal separated by a gap that can be controlled by voltage. When we bias it negative in reference to the solution the upper plate of metal, which is platinum, absorbs negative ions [4]. Due to the properties of platinum this causes surface stress causing bending.

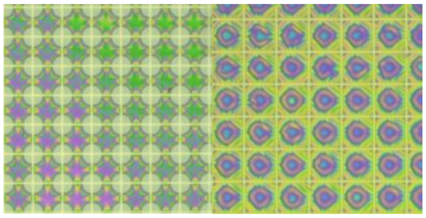

Fig. 5 Voltage probed actuators exhibiting color change

IV. DISCUSSION AND CONCLUSION

The fabrication process requires a few changes to makes the displays more reliable, reproducible, and consistently actuate. Some parameters that were adjusted was the actuator array design, exposure dosages, and photoresist. These changes seemed to improve the resolution of features; however, it is still a work in progress. We will continue to explore these parameters to improve yield of the reflector displays.

ACKNOWLEDGMENTS

The author acknowledges Dr. Marc Miskin, David Gonzalez-Medrano and entire Miskin group of the University of Pennsylvania for an incredible research experience this summer, the National Science Foundation for funding the SUNFEST program with NSF REU grant no. 1062672, Dr. Sue-Ann Bidstrup Allen and Julia Falcon of the University of Pennsylvania for organizing the SUNFEST REU.

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