Prototyping of Transparent and Flexible Electrochromic Displays

Löchtefeld, Markus; Jensen, Walther; Genç, Çağlar

Published in:
MUM 2021: 20th International Conference on Mobile and Ubiquitous Multimedia

DOI (link to publication from Publisher):
10.1145/3490632.3497750

Publication date:
2021

Document Version
Accepted author manuscript, peer reviewed version

Prototyping of Transparent and Flexible Electrochromic Displays

MARKUS LÖCHTEFELD, Aalborg University, Denmark
WALTHER JENSEN, Aalborg University, Denmark
ÇAĞLAR GENÇ, University of Lapland, Finland

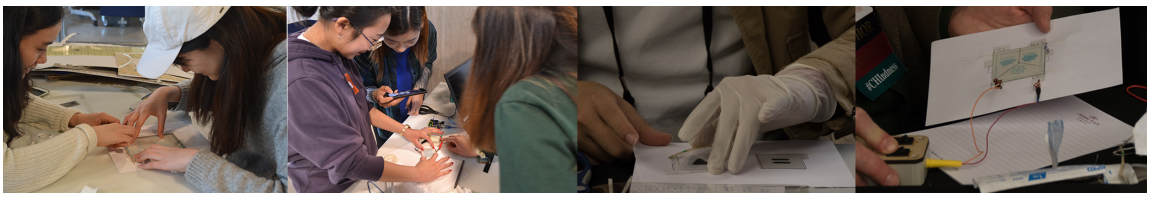

Fig. 1. Impressions of prior workshops.

This course is a hands-on introduction to the fabrication of flexible, transparent free-form displays based on electrochromism for an audience with a variety of backgrounds, including artists and designers with no prior knowledge of physical prototyping. Besides prototyping using screen printing or ink-jet printing of electrochromic ink and an easy assembly process, participants will learn essentials for designing and controlling electrochromic displays.

CCS Concepts: • **Human-centered computing** → **Interface design prototyping**; *Displays and imagers*; User interface design.

Additional Key Words and Phrases: prototyping; electrochromic displays; printed electronics

ACM Reference Format:
Markus Löchtefeld, Walther Jensen, and Çağlar Genç. 2021. Prototyping of Transparent and Flexible Electrochromic Displays. In *20th International Conference on Mobile and Ubiquitous Multimedia (MUM 2021), December 5–8, 2021, Leuven, Belgium.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3490632.3497750

1 BENEFITS & LEARNING OBJECTIVES

Recently, the field of printed electronics has developed to the point at which thin and deformable interactive prototypes can be created at low cost, even by non experts [7, 20]. While printed displays based on electroluminiscent technology have been well established [5, 13, 18], printed displays based on electrochromic (EC) technology has only recently seen an increased interest. Electrochromism is the capability of some materials to reversibly change color stimulated by redox reactions [4, 7]. This means that EC materials can change their optical absorption characteristics or color when an electrical voltage is applied (compare Figure 2). To date, EC technology has predominantly been commercially used in windows and smart glass, enabling dynamic change of optical and thermal characteristics in buildings and cars. Recently however, chemical developments enabled printing electrochromic materials on PET plastics allowing EC displays to be flexible. One of the key traits of these displays is that they are non-light-emissive. Given the negative

Manuscript submitted to ACM

impact of artificial light on human sleep patterns [2], this property is particularly beneficial for ubiquitous always-on displays, e.g. as part of Internet of Things (IoT) solutions. Another advantage of EC displays is that they only require power to change between states and then can keep their state for several hours similar to e.g. E-Ink based displays.

The goal of this course is to introduce participants to a simple prototyping method for EC displays that has been developed as part of the DecoChrom project[1]. One of the major advantages of this method [7] is that it does not require a clean room and it is possible to prototype in a non-laboratory setting. This has been in the past one of the major obstacles for wider adoption of EC display technology, for novel prototypes.

EC displays have already been used in a variety of different applications, from simple user interfaces [1], notifications [17], hybrid board games [12], over ambient lighting [10, 11] to wearables [3, 6, 8]. We hope that this course will motivate participants to develop novel applications for EC displays as well as to investigate the field of printed electronics for HCI further. Especially prototyping transparent displays to support co-located work on a shared visual work space and other scenarios that require a transparent screen [7, 14]. Furthermore, as EC displays are flexible they also allow for easy prototyping of e.g. shape-changing displays [19].

2 COURSE CONTENT

Course topics and content introduce participants to:

- Fundamental concepts and capabilities of EC displays
- Design guidelines for EC displays
- Physical prototyping techniques for EC displays

Over the course of the session, students will learn to:

- Design and Assembly of EC displays
- Control in- and output using EC displays
- Use of EC displays as part of HCI and UbiComp prototypes

The course will allow participants to build their own EC displays to provide a clear sense of purpose, as well as a practical and interesting takeaway. While we will provide basic practical designs (such as On-Off switch, Arrows and Mute-Volume), but also allow participants to modify, extend or completely design by themselves. In this way, they can build something while learning about the basic principles of EC displays. All materials will be supplied by the instructors. The participants will get access to the learning materials comprised for this novel prototyping methodology. Furthermore, the participants of course will be allowed to keep their designed and assembled displays as well as getting accessed to more materials for future projects if required.

3 AUDIENCE & PREREQUISITES

The course is intended for an audience that wants to know about prototyping with flexible displays and printed electronics. Participants should have sufficient technical background to download, install and run the Arduino programming environment on their laptops, and be able to physically handle (or have assistance handling) simple manual prototyping techniques. Furthermore, basic knowledge of graphical design and image editing as well as basic electronics will be an advantage.

This course is an improved variant of the course given at CHI 2019 [16] (it was also accepted at CHI 2020 which however, was unfortunately cancelled due to COVID-19 [15]) with slightly different instructors. But all instructors have

[1] https://decochrom.com/

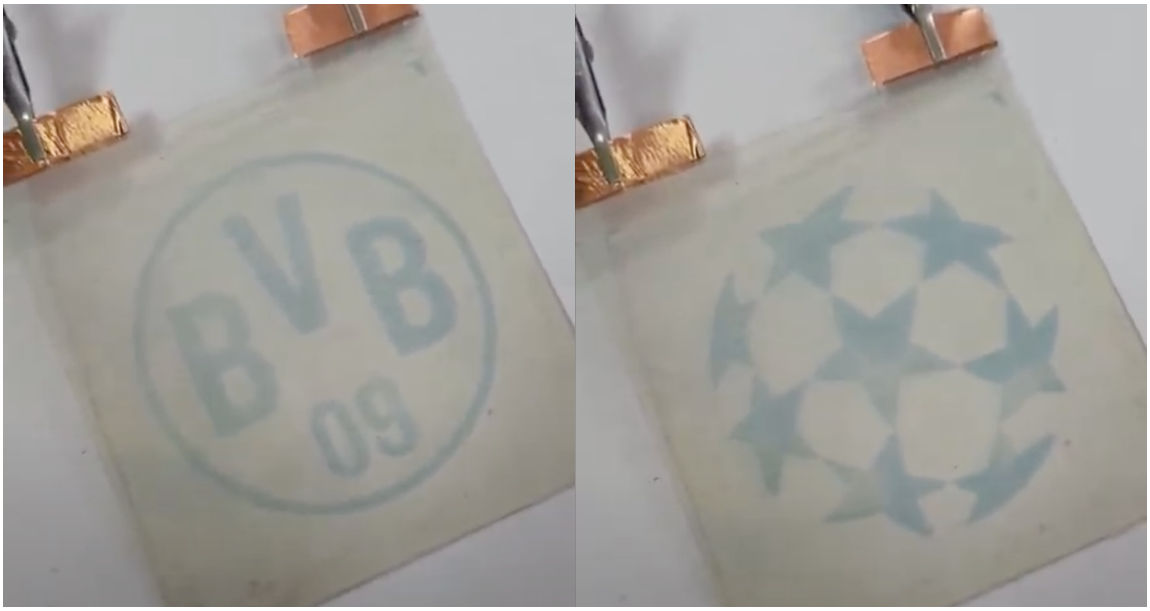

Fig. 2. Example application of EC display with two different states that were created in previous workshops, that allow to switch e.g. a logo, created in [7].

extensive experience from running similar courses for audiences ranging from artists to computer scientists [9] that we arrange as part of the EU funded DecoChrom project. Overall we have run variants of this course over 25 times with more than 300 participants. We have found that providing a short theoretical introduction followed by a hands-on part that is supported by the instructors allows participants to move at their own pace while exploring different design possibilities. Advanced participants (e.g. more familiar with electronics) can spend more time exploring alternatives design variations as well as connect it an Arduino and explore interaction possibilities.

4 PRESENTATION FORMAT

The course will be held as a mixture of brief theoretical and interactive lectures interleaved with individually guided exercises. The first session will introduces the working principles of EC displays, then moves to a short ideation session in which the participants will develop low fidelity of the prototypes they want to design. The session will end with an short rundown of design strategies. The second session will require the participants to design their own displays supported by the instructors and will end with a demonstration by the instructors on how to assemble these displays. The third session then continues with the participants assembling their designed display and finally test it and control it using an Arduino. Overall, this will be a half-day workshop and with a maximum of 30 participants.

5 INSTRUCTOR BACKGROUND

- **Markus Löchtefeld** is an Associate Professor for wearable- and tangible computing in the Department of Architecture, Design and Media Technology at Aalborg University, Denmark. His research is situated at the intersection of HCI and UbiComp particularly focusing on wearable computing as well as novel prototyping and fabrication techniques.

- **Walther Jensen** is a PhD Student in the Department of Architecture, Design and Media Technology at Aalborg University, Denmark. His research focuses on novel fabrication techniques for ambient displays as well as Human-Drone interaction.
- **Çağlar Genç** is a post-doctoral researcher at the University of Lapland, the faculty of Art and Design. His research focuses on the relationship between fashion and computation to design wearable ambient displays.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 760973.

REFERENCES

[1] Ashley Colley, Çağlar Genç, Markus Löchtefeld, Heiko Mueller, Walther Jensen, and Jonna Häkkilä. 2021. Exploring Button Design for Low Contrast User Interfaces. In *Human-Computer-Interaction – INTERACT 2021*, Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Helen Petrie, Antonio Piccinno, Giuseppe Desolda, and Kori Inkpen (Eds.). Springer International Publishing, Cham, 411–415.

[2] Charles A. Czeisler. 2013. Perspective: Casting light on sleep deficiency. *Nature* 497, 7450 (may 2013), S13. https://doi.org/10.1038/497S13a

[3] Çağlar Genç, Ashley Colley, Markus Löchtefeld, and Jonna Häkkilä. 2020. Face Mask Design to Mitigate Facial Expression Occlusion. In *Proceedings of the 2020 International Symposium on Wearable Computers* (Virtual Event, Mexico) *(ISWC '20)*. Association for Computing Machinery, New York, NY, USA, 40–44. https://doi.org/10.1145/3410531.3414303

[4] Claes-Göran Granqvist. 2015. Electrochromic metal oxides: an introduction to materials and devices. In *Electrochromic Materials and Devices*. Wiley-VCH Weinheim, Germany, 3–40.

[5] Ollie Hanton, Michael Wessely, Stefanie Mueller, Mike Fraser, and Anne Roudaut. 2020. ProtoSpray: Combining 3D Printing and Spraying to Create Interactive Displays with Arbitrary Shapes. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376543

[6] Pradthana Jarusriboonchai, Emmi Harjuniemi, Heiko Müller, Ashley Colley, and Jonna Häkkilä. 2019. Linn Dress: Enabling a Dynamically Adjustable Neckline. In *Proceedings of the 23rd International Symposium on Wearable Computers* (London, United Kingdom) *(ISWC '19)*. Association for Computing Machinery, New York, NY, USA, 274–278. https://doi.org/10.1145/3341163.3346934

[7] Walther Jensen, Ashley Colley, Jonna Häkkilä, Carlos Pinheiro, and Markus Löchtefeld. 2019. TransPrint: A Method for Fabricating Flexible Transparent Free-Form Displays. *Advances in Human-Computer Interaction* Article ID 1340182 (2019), 14 pages. https://doi.org/10.1155/2019/1340182

[8] Walther Jensen, Ashley Colley, and Markus Löchtefeld. 2019. VitaBoot: Footwear with Dynamic Graphical Patterning. In *Proceedings of the 23rd International Symposium on Wearable Computers* (London, United Kingdom) *(ISWC '19)*. ACM, New York, NY, USA, 279–283. https://doi.org/10.1145/3341163.3346937

[9] Walther Jensen, Brock Craft, Markus Löchtefeld, and Pernille Bjørn. 2022. Learning through interactive artifacts: Personal fabrication using electrochromic displays to remember Atari women programmers. *Entertainment Computing* 40 (2022), 100464. https://doi.org/10.1016/j.entcom.2021.100464

[10] Walther Jensen, Hendrik Knoche, and Markus Löchtefeld. 2020. "Do You Think It is Going to Be the Cock?": Using Ambient Shadow Projection in Dialogic Reading. In *Proceedings of the 9TH ACM International Symposium on Pervasive Displays* (Manchester, United Kingdom) *(PerDis '20)*. Association for Computing Machinery, New York, NY, USA, 97–103. https://doi.org/10.1145/3393712.3395342

[11] Walther Jensen, Markus Löchtefeld, and Hendrik Knoche. 2019. ShadowLamp: An Ambient Display with Controllable Shadow Projection Using Electrochromic Materials.. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. ACM, New York, NY, USA, Article LBW1510, 6 pages. https://doi.org/10.1145/3290607.3313011

[12] Walther Jensen, Thomas Streubel Kristensen, Christoffer Sand Kirk, Hassan Abdul Hameed, Daniel Bergmann Villadsen, and Markus Löchtefeld. 2020. Hybrid Settlers - Integrating Dynamic Tiles into a Physical Board Game Using Electrochromic Displays. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3334480.3382857

[13] Konstantin Klamka and Raimund Dachselt. 2017. IllumiPaper: Illuminated Interactive Paper. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. ACM, New York, NY, USA, 5605–5618. https://doi.org/10.1145/3025453.3025525

[14] Jiannan Li, Saul Greenberg, Ehud Sharlin, and Joaquim Jorge. 2014. Interactive Two-sided Transparent Displays: Designing for Collaboration. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (Vancouver, BC, Canada) *(DIS '14)*. ACM, New York, NY, USA, 395–404. https://doi.org/10.1145/2598510.2598518

[15] Markus Löchtefeld, Walther Jensen, Jonna Häkkilä, Ashley Colley, and Heiko Müller. 2020. Prototyping Transparent and Flexible Electrochromic Displays. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–4. https://doi.org/10.1145/3334480.3375043

[16] Markus Löchtefeld, Walther Jensen, Heiko Müller, and Ashley Colley. 2019. Prototyping Transparent and Flexible Electrochromic Displays. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. ACM, New York, NY, USA, Article C27, 4 pages. https://doi.org/10.1145/3290607.3298827

[17] Heiko Müller, Ashley Colley, Jonna Häkkilä, Walther Jensen, and Markus Löchtefeld. 2019. Using Electrochromic Displays to Display Ambient Information and Notifications. In *Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers* (London, United Kingdom) *(UbiComp/ISWC '19 Adjunct)*. ACM, New York, NY, USA, 1075–1078. https://doi.org/10.1145/3341162.3344844

[18] Simon Olberding, Michael Wessely, and Jürgen Steimle. 2014. PrintScreen: Fabricating Highly Customizable Thin-film Touch-Displays. *Proceedings of the 27th annual ACM symposium on User interface software and technology* (2014), 281–290. https://doi.org/10.1145/2642918.2647413

[19] Anne Roudaut, Abhijit Karnik, Markus Löchtefeld, and Sriram Subramanian. 2013. Morphees: Toward High "Shape Resolution" in Self-actuated Flexible Mobile Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. ACM, New York, NY, USA, 593–602. https://doi.org/10.1145/2470654.2470738

[20] Jürgen Steimle. 2015. Printed Electronics for Human-Computer Interaction. *Interactions* 22, 3 (apr 2015), 72. https://doi.org/10.1145/2754304