Using Electrochromic Displays to Display Ambient Information and Notifications

Müller, Heiko; Colley, Ashley; Häkkilä, Jonna; Jensen, Walther; Löchtefeld, Markus

Published in:
UbiComp/ISWC 2019- - 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

DOI (link to publication from Publisher):
10.1145/3341162.3344844

Creative Commons License
Unspecified

Publication date:
2019

Document Version
Accepted author manuscript, peer reviewed version

Using Electrochromic Displays to Display Ambient Information and Notifications

Heiko Müller, Ashley Colley, Jonna Häkkilä
firstname.lastname@ulapland.fi
University of Lapland

Walther Jensen, Markus Löchtefeld
(bwsj;mloc)@create.aau.dk
Aalborg University

ABSTRACT

Ambient Displays are a promising means to reduce notification overload and work towards the vision of Calm Computing. In this paper, we present electrochromic displays as a novel class of displays to convey information. electrochromic displays are non-light-emitting, flexible, free-form, transparent, energy-efficient, easily integrated, and slow-switching, making them ideal candidates for information that changes over time and does not require immediate user attention. We describe the key features of electrochromic displays as well as application areas and provide an outlook into future developments of the technology.

CCS CONCEPTS

• **Human-centered computing** → **Displays and imagers**; **Information visualization**; *Ubiquitous and mobile devices.*

KEYWORDS

ambient displays, notification, electrochromic displays, visualisation, electrochromism

ACM Reference Format:
Heiko Müller, Ashley Colley, Jonna Häkkilä and Walther Jensen, 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 the 2019 International Symposium on Wearable Computers (UbiComp/ISWC '19 Adjunct), September 9–13, 2019, London, United Kingdom.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3341162.3344844

UbiComp/ISWC '19 Adjunct, September 9–13, 2019, London, United Kingdom

ACM ISBN 978-1-4503-6869-8/19/09...$15.00
https://doi.org/10.1145/3341162.3344844

1 INTRODUCTION AND BACKGROUND

The last two sentences of Weiser's seminal article "The Computer for the 21st Century" characterised ubiquitous computing as follows: *"There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods."* [14]. It seems that while we often claim to have reached the age of ubiquitous computing, we are further from it then ever before. Users are constantly connected to the Internet and have access to a tremendous amount of information. However, as part of this constant connectivity an ever increasing amount of notifications is channelled to the users. This can make it difficult for users to divide their attention appropriately.

One promising approach to combat this issue and and work again more towards Weiser's original idea are Ambient Displays. Ambient Displays only draw the attention of the user when needed to convey bits of information [7], allowing to focus on a main task while still having access to potential notifications or other important information of background

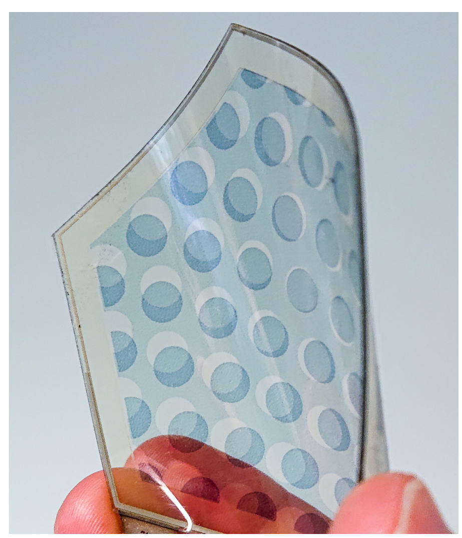

Figure 1: Transparent, flexible, and free-form electrochromic display

tasks. Ambient displays can be implemented in many different forms and shapes e.g. audio [1], haptics [11], ambient light [9], or screen displays [13]. However, especially light emitting visual displays are not always desirable, e.g. in the home's bedroom, or in dark working conditions. In these situations, non-light-emitting, calm computing displays may be a better solution and examples of research in this realm reach over 20 years back with e.g. the Dangling String [15].

Visual Ambient Displays have been around for a long time. Examples range from artefacts that change through physical actuation (e.g. bus display by Mankoff et al. [6]), to screens displaying information (e.g. see the work by Vogel and Balakrishnan [13]), to ambient light displays (for which Matviienko et al. provided an overview in [8]), to name only a few.

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 [12]. While printed displays based on electroluminiscent technology have been well established [4, 10], printed displays based on electrochromic (EC) technology have been largely neglected so far.

In this paper, we aim to extend existing approaches by introducing electrochromic (EC) displays as a means to create ambient displays for information and notification presentation. EC displays are non-light-emitting, flexible, free-form, energy efficient, low contrast, and slow switching displays. We argue that they have the ability to get us closer to Weiser's original vision compared to current display technology.

2 ELECTROCHROMIC DISPLAYS

Electrochromic (EC) inks have the capability to change their optical properties through chemical oxidation or reduction when an electric current is applied to them [2]. Usually the change is from a colour, e.g. blue, to a transparent state. To change from one state to another the inks only require minimal energy and usually switch in a matter of seconds (1-5), which is comparably slow. Otherwise EC inks behave similar to standard inks, and displays made from EC ink are therefore non-light-emitting but can be produced in any shape.

One of the most common applications for EC displays today is self-tinting windows or rear-view mirrors in vehicles. These devices use a layer of EC ink that has been applied in a vacuum or sol-gel deposition process [2]. While this allows for homogeneous coating in large scale production processes it is not at all suited for research prototypes or small scale production. To explore the design space of EC displays, we use a different process, suited for small batch production and rapid prototyping. We follow the TransPrint fabrication process of EC displays described by Jensen et al. [3].

In our case, displays have been created in an screen, airbrush, or ink-jet printing process. We use commercially available PEDOT:PSS or Prussian Blue inks on transparent PET-ITO substrates. The ITO layer provides electric conductivity on the whole printing area. Other substrates layers to print on (e.g. other plastics or ceramics) in combination with conductive materials such as copper tape or silver ink could also be used to create electric connections to the printed ink.

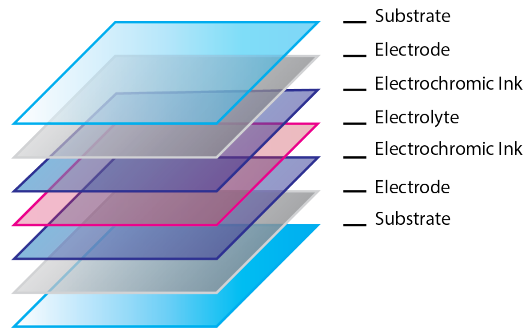

Figure 2: Vertical stack alignment

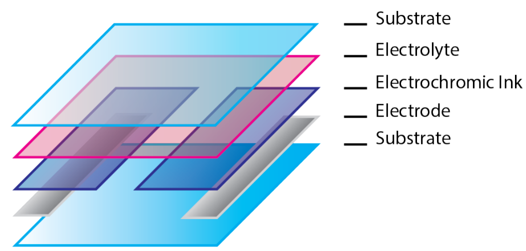

Figure 3: Co-planar stack alignment

While this process is very well suited for prototyping it is not ideal of larger scale production. Besides the aforementioned glass elements, EC inks have also been used in high pressure laminates (HPL), as used in e.g. furniture surfaces, or flooring. Furthermore, EC displays are also robust enough to withstand an injection-moulding process e.g. to be integrated with other plastic elements [5].

There are two basic display alignments. A vertical stack in which electrode and counter-electrode are printed on two sheets of substrate, divided by an electrolyte layer (Figure 2); and a co-planar stack in which electrode and counter-electrode are printed on the same substrate layer, requiring electric separation (Figure 3).

The key properties of electrochromic displays are:

Non-light-emitting Like other visual technologies, e.g. E-ink, electrochromic displays do not emit light, making them suitable for situations, where light is not desirable.

Free-form and Flexible EC displays can be created with a freely chosen form factor. Depending on the substrate used to create the displays, they are flexible to bending and deforming. This allows them to be easily retrofitted onto a large variety of surfaces.

Transparent Depending on the substrate and electrodes, EC displays can be transparent, allowing easy integration with other materials. PET-ITO and coatings with silver nano-wires provide good transparency.

Energy efficient EC displays only consume electric energy while switching. Switching of PEDOT:PSS works well at 1.5v and uses only a few milliwatts of energy. The displays function similar to a capacitor. The displays discharge over time and need to be refreshed every once in a while.

Low contrast The rapid prototyping methods currently provide a rather low contrast ratio. While this is not a desirable property, in combination with the slow switching times it can facilitate changes to the display that can potentially go unnoticed by the user if desired.

Slow switching Depending on the EC ink used and the voltage applied, switching times vary from one to 30 seconds. This slow switching property in addition to the low contrast ratio can be used to an advantage, when displays should avoid triggering an disorienting reflex through sudden changes or on-sets.

Easy prototyping Using off-the-shelf ink-jet or screen-printing technology, producing EC display prototypes is an easy print-and-assemble process.

3 APPLICATION AREAS AND OUTLOOK

There is a wide range of applications for EC displays. We aim to explore a number of these cases ranging from wearables, e.g. garments or shoes with integrated displays, to household or office devices, up to building size installations used in facades or adaptive flooring solutions. The intended prototypes may not all be made for information display, but also for decorative purposes, we aim at demonstrating EC displays as a novel technology for information display.

In the following, we briefly present to early prototypes demonstrating a few of the key properties of EC displays.

Weather Display

The weather display concept (Figure 4) aims towards being a pervasive display embedded to the inner surface of a home's front door. The display provides a glanceable view to the expected weather when stepping outdoors.

The weather display contains five individual EC display segments printed on a single film of PET-ITO. The segments are electrically separated by kiss-cutting the ITO-layer on the PET sheet. Control is achieved through an ESP32 micro-controller that connects to a weather service API and controls the display segments according to the forecast. Each of the segments is individually controlled and has its own counter-electrode. This allows for faster switching times, especially for larger display areas like the cloud-shape, than one central counter-electrode. An overlaid wood veneer layer masks the display's counter electrodes.

Figure 4: Electrochromic Weather Display, indicating stormy weather

The weather display exemplifies the approach to EC display design, being based on dynamic graphical elements, rather than numerals or pixels.

Dishwasher Indicator

Are the dishes in the dishwasher clean or dirty? With a twist of the magnetically-attached dishwasher indicator you can leave a message to your family members or co-workers in the office kitchen (Figure 5).

The display consists of a printed background image of a bowl and spoon, with an EC overlay illustrating either dirty food remains or a sparkling clean bowl. The functionality is achieved with an orientation sensor, triggered based on the orientation of the display. For rapid prototyping and demonstration, we used an Arduino micro-controller to read the orientation sensor and drive the display accordingly. Creating a custom circuit will further reduce space and power demand.

This demo shows the possibility to create EC displays with a non-rectangular form factor, as well as their low power consumption, allowing e.g. one year of operation with a coin cell battery [5].

Outlook

As future work we will add more colours allowing for more complex graphics and increased information display capabilities. Improvements in mass production techniques like over-moulding or high pressure lamination could extend the range of possible applications and integration into everyday items. We are investigating electronics to improve control of

Figure 5: Electrochromic dishwasher status indicator

individual displays as well as combination of displays into larger clusters.

ACKNOWLEDGMENTS

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

REFERENCES

[1] Luke Barrington, Michael J. Lyons, Dominique Diegmann, and Shinji Abe. 2006. Ambient Display Using Musical Effects. In *Proceedings of the 11th International Conference on Intelligent User Interfaces (IUI ’06)*. ACM, New York, NY, USA, 372–374. https://doi.org/10.1145/1111449.1111541

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

[3] 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* 2019 (2019).

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

[5] Terho Kololuoma, Mikko Keränen, Timo Kurkela, Tuomas Happonen, Marko Korkalainen, Minna Kehusmaa, Lucia Gomez, Aida Branco, Sami Ihme, Carlos Pinheiro, et al. 2019. Adopting Hybrid Integrated Flexible Electronics in Products: Case-Personal Activity Meter. *IEEE Journal of the Electron Devices Society* (2019).

[6] Jennifer Mankoff, Anind K. Dey, Gary Hsieh, Julie Kientz, Scott Lederer, and Morgan Ames. 2003. Heuristic Evaluation of Ambient Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’03)*. ACM, New York, NY, USA, 169–176. https://doi.org/10.1145/642611.642642

[7] Tara Matthews, Tye Rattenbury, Scott Carter, Anind Dey, and Jennifer Mankoff. 2003. A peripheral display toolkit. *University of California, Berkeley Technotes, UCB//CSD-03-1258* 168 (2003).

[8] Andrii Matviienko, Maria Rauschenberger, Vanessa Cobus, Janko Timmermann, Heiko Müller, Jutta Fortmann, Andreas Löcken, Christoph Trappe, Wilko Heuten, and Susanne Boll. 2015. Deriving Design Guidelines for Ambient Light Systems. In *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia (MUM ’15)*. ACM, New York, NY, USA, 267–277. https://doi.org/10.1145/2836041.2836069

[9] Heiko Müller, Andreas Löcken, Wilko Heuten, and Susanne Boll. 2014. Sparkle: An Ambient Light Display for Dynamic Off-screen Points of Interest. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI ’14)*. ACM, New York, NY, USA, 51–60. https://doi.org/10.1145/2639189.2639205

[10] 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

[11] Martin Pielot and Rodrigo de Oliveira. 2013. Peripheral Vibro-tactile Displays. In *Proceedings of the 15th International Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI ’13)*. ACM, New York, NY, USA, 1–10. https://doi.org/10.1145/2493190.2493197

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

[13] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology (UIST ’04)*. ACM, New York, NY, USA, 137–146. https://doi.org/10.1145/1029632.1029656

[14] Mark Weiser. 1991. The computer for the 21st century. *Mobile Computing and Communications Review* 3, 3 (jul 1991), 3–11. https://doi.org/10.1145/329124.329126 arXiv:arXiv:1011.1669v3

[15] Mark Weiser and John Seely Brown. 1996. Designing calm technology. *PowerGrid Journal* 1, 1 (1996), 75–85.