

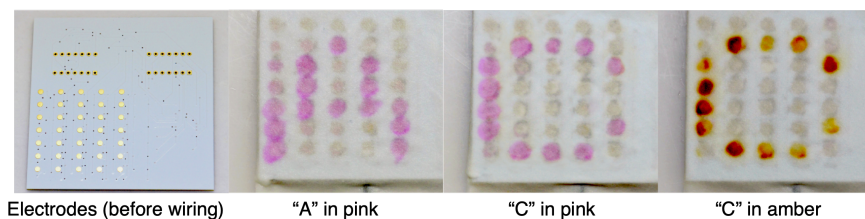
# Electrolysis Ion Display on Wet Surfaces

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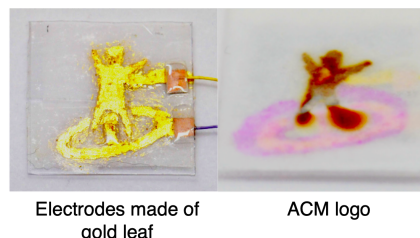
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(a) Dot-matrix electrodes



(b) Customized-shaped electrodes



**Figure 1.** (a) The prototype with the dot-matrix electrodes. “A” is displayed in pink, then “C” is displayed in the same color. It is also possible to display “C” in amber by applying a current in the opposite direction. (b) The prototype with the customized-shaped electrodes.

## ABSTRACT

We present a novel method to render color patterns using electrolysis applied onto open wet surfaces. By implementing electrodes within a wet object and electrifying them, electrolysis can occur and generate ions. Using color indicators reacting to such ions, we can create a color-forming display. By applying common techniques, such as a printed circuit board, arbitrary patterns can be displayed by computer control. By reversing the polarity of electrodes and varying the number of ions, it is possible to fade the existing pattern and display a contrasting color. The proposed method can be used to create a color-forming display using various objects more common in everyday life than those used in conventional substantial displays.

## Author Keywords

Substantial display; Electrolysis; Ion; Color-forming; Ephemeral user interface; Edible.

## CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI)**; *Displays and imagers*;

## INTRODUCTION

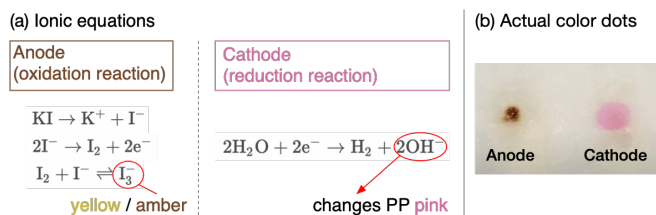
Modern technology enables us to access information anytime, anywhere. We usually access information through a flat and rigid computer display such as a liquid crystal display (LCD).

On the other hand, the physical objects that abound in our daily lives are often soft, curved, and organic. An emerging stream of research has focused on making use of daily objects to create substantial displays that are integrated into our everyday lives. For example, researchers have used bubbles [2, 3, 5], water drops [11, 4], and water condensation [8, 10] as such material. In addition, thermochromic ink is a dye that changes color when temperature changes and is often used to enable clothes to become display systems by soaking it into fabric or yarns [12, 6, 1, 9]. Besides methods using these materials, information presentation methods using chemical reactions of objects have also been proposed. Organic Primitives [7] enables multi-modal sensors and displays to be created by using pH-reactive materials. The reaction is achieved by dropping acid or basic liquid onto a physical object that is covered by pH-reactive materials. However, to create an everyday display, a low-cost computer controllable mechanism should be developed to activate the chemical reaction. We thus present a novel method to render ionic color patterns onto open wet objects using computer-controlled electrolysis (see Figure 1).

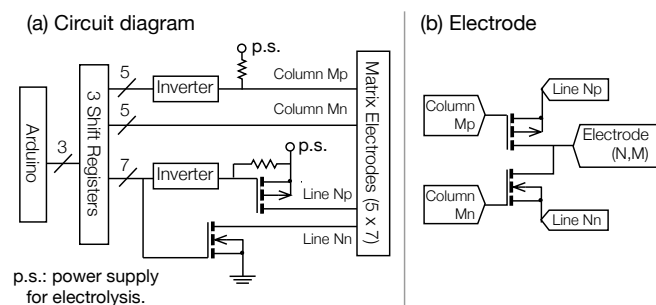
## ELECTROLYSIS ION DISPLAY

We propose a method to render color patterns onto open wet surfaces. Our system performs electrolysis on the surface of an object. By implementing electrodes within a wet object (e.g. a wet sheet or sponge) and energizing them, electrolysis occurs. The number of ions around the electrodes can be increased or decreased due to oxidation and reduction reactions by the electrolysis. Using a color indicator which changes its color in accordance with the number of such ions, we can create a color-forming display. By reversing the polarity of the electrodes and varying the number of ions, it is possible to fade the existing pattern and display a contrasting color. Moreover, by applying common techniques, such as a printed

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**Figure 2.** (a) Ionic equations of the reactions happening near the anode and cathode. (b) Examples of electrolysis using a solution containing both KI and PP. We placed a filter paper soaked with the solution on a pair of dot-like electrodes made of gold leaf.



**Figure 3.** Circuit diagram showing the wiring of Line N and Column M ( $N = 1$  to 7, and  $M = 1$  to 5). A pair of wires connected to P and N-channel MOSFET (“Np” - “Nn”, and “Mp” - “Mn”) is used in N-th line and M-th column wiring.

circuit board (PCB), arbitrary color patterns can be displayed by computer control.

## IMPLEMENTATION

### Electrolytic Solution

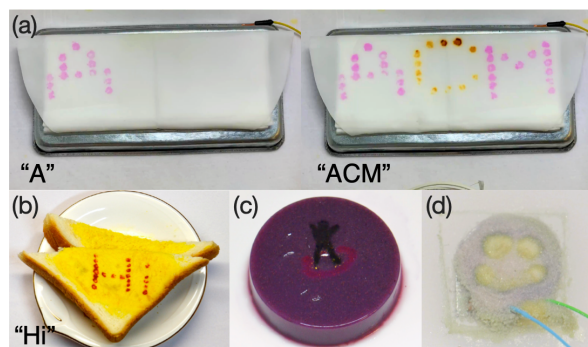
We used a solution containing a mixture of potassium iodide (KI, 1% w/v) and phenolphthalein (PP, 0.01% w/v) as the electrolytic solution (see Figure 2). While electrolysis, iodide ions ( $\text{I}^-$ ) are oxidized on the anode and water ( $\text{H}_2\text{O}$ ) is reduced on the cathode. Oxidized  $\text{I}^-$  changes to iodine ( $\text{I}_2$ ), and reduced  $\text{H}_2\text{O}$  generates hydroxide ions ( $\text{OH}^-$ ). Generated  $\text{I}_2$  dissolves again in the solution to become triiodide ion ( $\text{I}_3^-$ ), and this substance turns yellow to amber on the anode side. With an increase in  $\text{OH}^-$ , the pH will be alkaline and PP turns pink on the cathode side. We soaked a filter paper about 0.3 mm thick with this solution and placed it on the electrodes.

### Electrodes

We implemented two types of prototypes with different electrodes: dot-matrix electrodes (Figure 1(a)) and segment pattern electrodes (Figure 1(b)).

**Dot-matrix electrodes.** We fabricated the dot-matrix planar electrodes on a PCB. We applied a platinum foil on each pattern to prevent the pattern from eluting. These dots are about 2 mm in diameter and are arranged in a  $5 \times 7$  matrix. The interval is 5.1 mm in long and 7.6 mm wide, and the approximate display area is  $33 \times 33$  mm.

Figure 3 shows a circuit diagram of the dot-matrix prototype. We applied an active-matrix circuit similar to one used in the previous study [5] to this system. The 35 pixel electrodes are



**Figure 4.** (a) A user can stamp an arbitrary character onto a wet paper with two colors. (b) Bread in turmeric sauce with “Hi” stamped in red. (c) Berry panna cotta with the ACM logo stamped on the surface. (d) Smiling face pattern on white sand.

connected to an active-matrix circuit that is controlled by an Arduino microcontroller board. In contrast to the previous study, each electrode can be switched to three states (anode, cathode, and insulator) by commands from Arduino. To switch the polarity of the electrodes, we used both N-channel metal-oxide-semiconductor field effect transistors (MOSFETs) and P-channel MOSFETs for all lines and intersections of lines and columns. To switch an electrode to the anode state, the P-channel MOSFET is switched on, and to switch it to the cathode state, the N-channel MOSFET is switched on. When both of the MOSFETs are switched off, the electrode is isolated.

**Segments Electrodes.** Figure 1(b) shows an example of customized-shaped electrodes for a specific purpose. These electrodes are made from gold leaves and attached to a plastic plate. We can control these electrodes by connecting them to a microcontroller with wires. By using a stencil mold made by a laser cutter, the gold leaf can be attached to any pattern and enable the users to make electrodes that display a personally customized pattern.

## APPLICATION EXAMPLES AND DISCUSSION

We explore applications of the proposed system in a variety of everyday situations. We prototyped a stamp that can change their transfer pattern and its color dynamically without any moving parts or ink (see Figure 4(a)). It is possible by pressing the dot-matrix electrodes, which are energized in an arbitrary pattern, onto a wet paper. This method can also be applied to some moist foods that contain pH-reactive substances such as anthocyanins or curcumin (see Figure 4(b) and (c)). Moreover, an interactive display using water in sand as the substrates of the electrolytic solution was implemented (see Figure 4(d)). The patterns on the sand appear by sprinkling water containing non-toxic pH-reactive substances (e.g., anthocyanins) owing to electrodes installed under the sand.

As shown in these examples, the proposed method uses everyday objects with moist and soft surfaces, while the conventional ubiquitous displays such as LCD are composed of dry, hard, and artificial components. The range of colors used in the display is limited. We are investigating other possible pH indicators that improve the color range.

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