MANIPULATION OF MULTIPLE DROPLETS ON NxM GRID BY CROSS-REFERENCE EWOD DRIVING SCHEME AND PRESSURE-CONTACT PACKAGING

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ABSTRACT

This paper reports two recent breakthroughs in our development of EWOD-based (ElectroWetting On Dielectric) digital (droplet) microfluidic circuits: a driving scheme and a packaging scheme, both of which greatly simplify fabrication and make large-array chips a reality. This paper will explain (*1*) the concept of cross-reference driving, which allows single-layer electrode fabrication, including the techniques to allow simultaneous driving of multiple droplets and (2) pressure-contact connection, which greatly simplifies packaging and assembly for high-density EWOD devices. The efficacy of the driving concept is demonstrated by transporting four droplets simultaneously, each along its own path, on a 9x9 grid and performing essential fluidic functions such as creation, cutting, merging, and mixing of droplets.

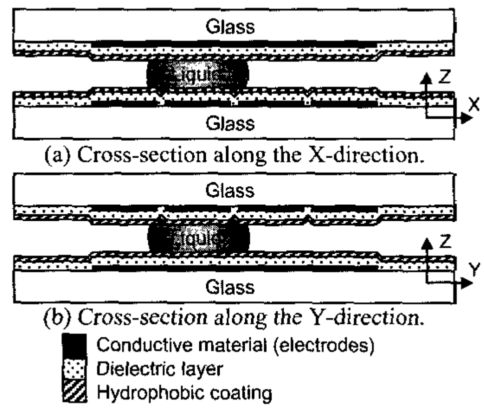
INTRODUCTION

Direct-Reference EWOD Devices

We previously presented basic microfluidic functions using EWOD actuation between two parallel plates with only one of them active, i.e., EWOD occurring mainly on one substrate [1,2]. The active plate has driving electrodes patterned on it, while the other plate has an unpatterned reference electrode layer to provide an electric ground. EWOD actuation is simply determined by the individual driving electrodes, i.e., the surface above active electrode is wetting; therefore, we call this rather obvious driving configuration "direct-referencing." However, unless multi-layer processing is used for driving electrodes, the grid patterns are limited to 1xN or 2xN in practice [1,3]. To fulfill "reconfigurable digital microfluidic circuits [4]," true 2-D electrode grids (NxM) are necessary.

Cross-Reference EWOD Devices

Although a large 2-D *direct-reference* EWOD grid could be achieved by using multi-layer electrodes fabrication, we invented a simple approach to achieve a 2-D grid, which conserves using only a single-layer of patterned electrodes on both of the parallel plates [5]. *In this method, electrode rows are patterned on each* plate and placed orthogonally, as shown in Fig. 1. The original concept of this device configuration lies in alternating reference and driving electrodes. For instance, when driving a droplet along the X-direction (Fig. 1(a)), electrode rows on the bottom plate serve as driving electrodes, while electrode rows on the top plate serve as reference ground electrodes. However, when the droplet is driven in the Y-direction (Fig. 1(b)), driving electrodes are the top electrodes and reference ground electrodes are the bottom ones. The beauty is that this design not only prevents the need of multi-layer processing of electrode but also allows control of a NxM grid with only N+M electrodes. This novel driving concept has been tested with different electrode row designs [5] and introduces a new driving concept of "cross-referencing."



(a) Cross-section along the X-direction.

(b) Cross-section along the Y-direction.

Figure 1. Cross-sections of an EWOD device with single-layer electrode rows on both glass plates [5].

CROSS-REFERENCE GRID

A series of electrode row designs and tests of the device shown in Fig. 1 revealed several important design factors [5]. As a result, electrode rows with interdigitating fingers [3] are abandoned and simple rectangular electrode rows are currently used in the EWOD devices. Fig. 2(a) shows a recorded video frame of a droplet transported on a 5x5 grid with 5+5 electrodes. In this device, electrode rows on the bottom plate are made of Au/Cr (shown vertical). Electrode rows on the top plate are made of transparent conductive ITO (Indium Tin Oxide, oriented horizontally and barely noticeable) for observation purposes. Fig. 2(b) schematically explains the driving scheme by highlighting (shown dark) the activated electrodes corresponding to Fig. 2(a). Note that to position one droplet, two electrodes need to be active (one in electric high voltage "H" state, the other in

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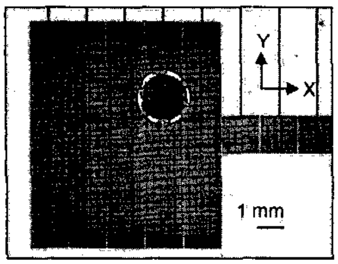
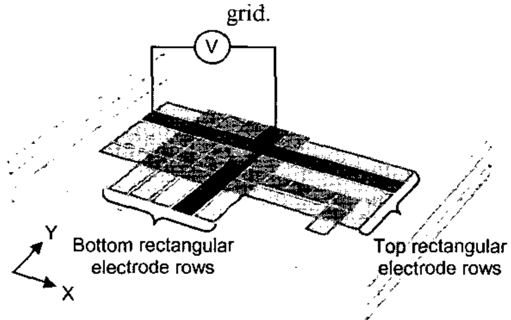
electric ground "L" state), and the non-active electrodes are in an electric floating "F" state. Since EWOD occurs at the cross point of the two active electrodes, we call the devices with this configuration "cross-reference" EWOD devices.



(a) A video frame of droplet transportation on a 5x5 grid.



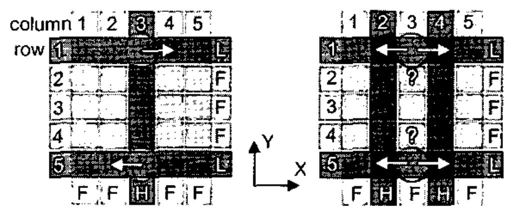
(b) The activated (dark) electrodes corresponding to (a) are highlighted.

Figure 2. Test of cross-reference driving scheme [5].

DRIVING ON CROSS-REFERENCE GRID

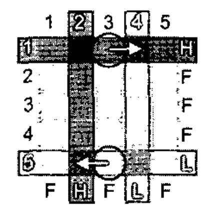
Special care has to be taken when manipulating multiple droplets (multiple EWOD actuation spots) on this cross-reference grid to avoid undesired EWOD spots. To explain this, an interesting example is given. Fig. 3(a) shows two droplets sitting on the grid with row 1, row 5, and column 3 activated (i.e., spots <1,3> and <5,3> are on). Obviously, driving these two droplets in the same direction along the X-direction can be simply done by activating one of the neighboring columns. However, driving these two droplets in the opposite direction is no longer straightforward. In order to drive the droplet at <1,3> to the right, column 4 needs to be activated and in order to drive the droplet at <5,3> to the left, column 2 needs to be activated. In this unfortunate case, shown in Fig. 3(b), the undesired spots <1,2> and <5,4> are turned on as well as the desired spots <1,4> and <5,2>, resulting in uncertainty of droplet transportation and possibly even droplet splitting.

The above discussion prevails when we classify the status of electrode only by active and non-active. However, let us look more carefully into the electrical state of each electrode. As shown in Fig 3(b), the undesired EWOD spots are caused by activating with only one state on a given plate, i.e., active electrodes keep ground "L" on one plate and high voltage "H" on the other. Our solution to drive droplets with both "L" and "H" as activation states on a plate. In Fig 3(c), the previously undesired EWOD spots (<1,2> and <5,4>) are now the cross points of electrodes with same electric potential. Therefore, EWOD occurs at only <1,4> and <5,2> but not at <1,2> and <5,4>. Two droplets can then be driven independently and simultaneously.



(a) Current position and desired motion.

(b) Uncertain next position.



(c) left: Solution: activate with both "L" and "H" on a given plate.

Figure 3. Problem and solution of manipulating multiple droplets.

FABRICATION AND TEST

The cross-reference device consisted of two glass plates with single-layer patterned electrodes covered with dielectric layers. For observation purposes, we used ITO electrodes at least on the top plate. The fabrication processes are as follows: (1) Deposit and pattern ITO on top plate and ITO or Au/Cr on bottom plate. (2) Deposit and pattern Au/Cr soldering pads if necessary. (3) Deposit PECVD Oxide on both plates. (4) Remove Oxide on top of soldering pads. (5) Deposit Teflon® on both plates. (6) Solder wires to soldering pads. (7) Assemble top and bottom plates. The channel height is determined by the thickness of spacers between the two plates.

Rather diverse fluidic functions have been successfully demonstrated using this novel cross-reference driving scheme.

Mixing

With 2-D capability and the ability to transport two droplets independently, mixing can be programmed on this cross-reference grid. Shown in Fig. 4 are two different concentration dye droplets. Since ITO is used on both top and bottom plates for better mixing observation, the electrode patterns are not visible. The two droplets first follow their own independent path to be brought together. After merging, mixing is enhanced by passing the joined droplet through a programmed loop described in [6]. Briefly, proper looping dramatically increases interface between the two liquids, which is not obtainable in conventional continuous microfluidics.

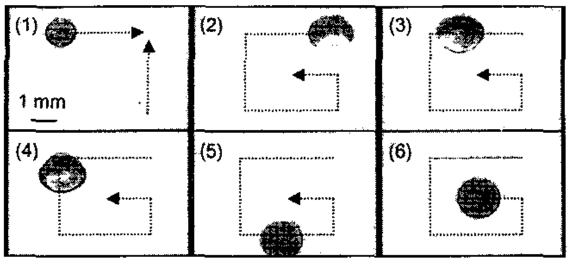
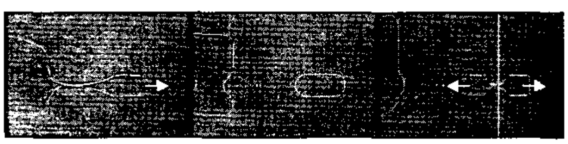


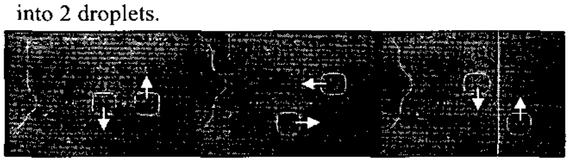
Figure 4. Mixing of two droplets with cross-reference driving. Two discrete droplets (1) merge (2) and pass through a mixing enhancement path [6] (3-6).

Multiple Functions

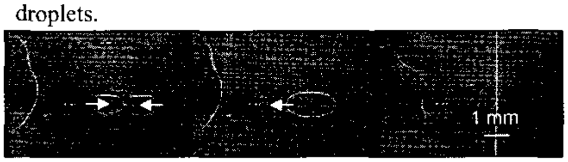
Fig. 5 shows several frames of a video in which a droplet is first created from a reservoir (or a large droplet). The droplet is then split into two, which are transported independently and simultaneously, merged, and finally return back to the reservoir. This operation demonstrates the versatility of the reported actuation scheme, showing that all the basic microfluidic functions can be programmed and performed.



(a) A single droplet is created from a reservoir and split into 2 droplets.



(b) Independent and simultaneous transportation of two droplets.



(c) Merging of two droplets and returning to the reservoir.

Figure 5. Multi-functions can be "programmed."

Four Droplets Transportation

More than two droplets, four shown on a 9x9 grid in Fig. 6, can be driven independently, although there remain a few minor limitations to be aware of. Two droplets can be driven with no conflicts, as described in the previous section, by using both "L" and "H" as activation states on a given plate. However, addition conflicts arise for more than two droplets, limiting the path of droplets from being arbitrary. We will report the problems and our solutions in details elsewhere.

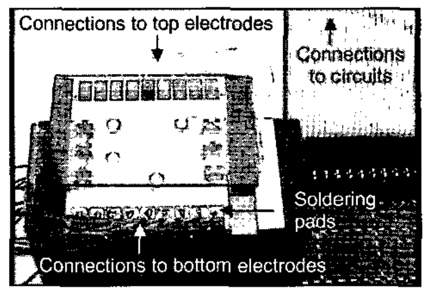


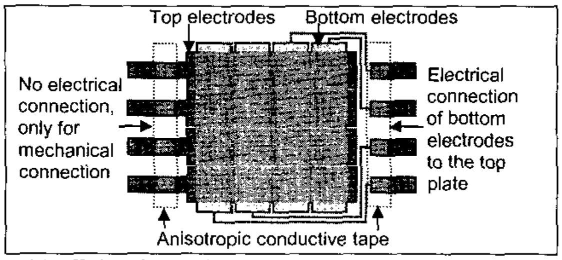
Figure 6. Independent driving of four dye droplets. Connections between electrodes and the circuits have later been simplified by developing the packaging and assembly shown in Fig. 7.

PACKAGING

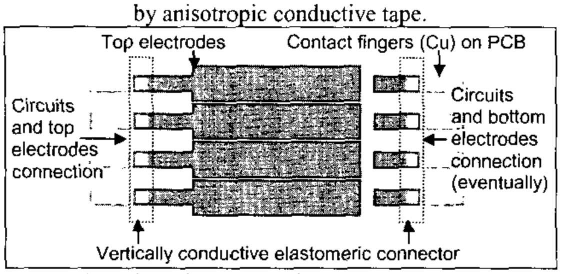
Since electrodes are patterned on both plates, wiring would be daunting for device packaging. To solve the problem, a pressure-contact connection scheme has been introduced in the device packaging.

To simplify the device packaging, we first plan to make all the wire connections on one side of the device. Anisotropic electrical conductive tape, shown in Fig. 7(a), is used to provide an electrical connection on high-density contact pads between the top and bottom plates. With a corresponding contact pads design on both plates, bottom electrodes are electrically connected to the top plate by a strip of the anisotropic electrical conductive tape (shown right in Fig. 7(a)). It also provides a strong packaging force between top and bottom plates. The thickness of the tape determines the device channel height. To have an even channel height, another strip of tape is placed on the opposite side of the device, which provides only mechanical but not electrical connections. This tape is pressure sensitive and the packaging is performed at room temperature, which is desirable for EWOD devices coated with Teflon®.

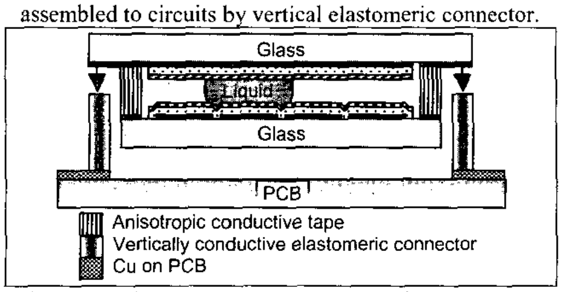
A packaged EWOD device, shown in Fig. 7(b), is then electrically and mechanically connected to a PCB (Printed Circuit Board) with a reusable vertically conductive elastomeric connector. This benefits the assembly and disassembly of the system and greatly simplifies packaging of EWOD devices with high number of contacts.



(a) EWOD device (top and bottom plates) is packaged by anisotropic conductive tape.



(b) Packaged device (only top plate shown) is assembled to circuits by vertical elastomeric connector.



(c) Assembly of a packaged EWOD device to circuits.

Figure 7. New packaging and assembly developed procedure for large array devices.

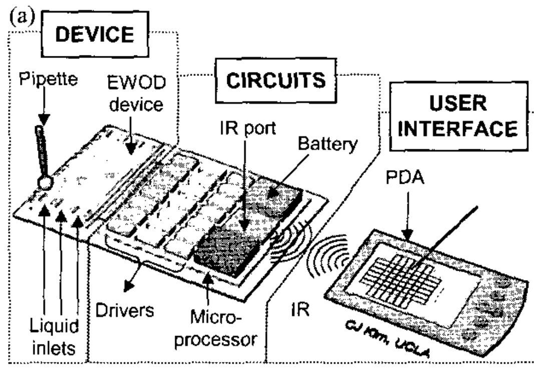
PORTABLE SYSTEM

To facilitate the use of this EWOD device, we are completing a portable system with control circuits and an user interface as shown in Fig. 8(a). Relays are currently used in the circuit to provide different states (i.e., "L", "H", and "F") of the electrodes. The user interface is through a PDA (Personal Digital Assistant), which gives portability to the system. CodeWarrier software is used to develop the PDA interface program. One frame of the program is shown in Fig. 8(b) with its basic functions.

CONCLUSION

Multiple microfluidic functions are demonstrated on a cross-reference EWOD device, showing the versatility and programmability in application. The design of cross-reference not only simplifies the device fabrication (single-layer electrodes), it also decreases the number of control electrodes (N+M for a NxM grid). The novel room temperature pressure-contact packaging dramatically simplifies device fabrication (soldering pads not required), packaging, and assembly.

(a)



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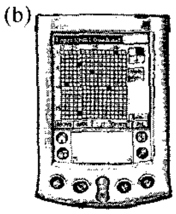

Figure 8. Prototype development.
(a) Portable EWOD system: device, circuits, and user interface.
(b) User interface: move, mix, cut, create, and expel functions. Data can be sent through IR communication.

ACKNOWLEDGEMENT

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