COPLANAR DIGITAL MICROFLUIDICS USING STANDARD PRINTED CIRCUIT BOARD PROCESSES

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ABSTRACT

We report three novel demonstrations: 1. Coplanar electrowetting 2. Electrowetting on a printed circuit board (PCB) and 3. Transport and mixing in an "open" microfluidic substrate. Similar to "soft" lithography which enabled many researchers to easily prototype and experiment with continuous-flow microfluidics, this work allows researchers to easily experiment with discrete-flow microfluidics (digital microfluidics). The flexibility in design afforded by this coplanar and "open" structure facilitates novel applications, particularly in areas of clinical diagnostics and reconfigurable chip cooling. Furthermore, it provides digital microfluidic systems with an inexpensive and rapid turn-around process.

Keywords: coplanar, digital microfluidics, electrowetting, PCB

1. INTRODUCTION

Digital microfluidics is an emerging liquid-handling paradigm that employs the phenomenon of electrowetting to independently manipulate discrete sub-microliter sized droplets through electrical manipulation of the interfacial tension of the droplets [1]. A digital microfluidic chip typically consists of two parallel electrode plates – a ground plate and an addressable drive electrode array. Droplets are sandwiched between the two plates, and are surrounded by an immiscible fluid. The drive electrode array is insulated from the liquid and surfaces of both plates are hydrophobized. Hitherto, digital microfluidic chips have been fabricated using microfabrication techniques [1], requiring expensive vacuum deposition processes. Recently, an alternative approach has been demonstrated where interconnects were formed on a multi-layer PCB, but the electrodes were still formed using vacuum deposition processes [2]. Furthermore, all electrowetting-based droplet manipulation systems demonstrated thus far require a conductive top plate to provide continuous ground to the droplet, imposing additional material constraints to the top plate. In this paper, we demonstrate digital microfluidics using a readily available PCB process without significant post-processing. Additionally, we eliminate the need for a conductive, or any, top plate by implementing coplanar ground electrodes either in the same conductive layer as the electrodes or another conductive layer on top of the insulator [3].

2. EXPERIMENTAL SETUP

Chip Fabrication – A schematic view of a digital microfluidic chip for both a confined (i.e. with a top plate) and an open (i.e. without a top plate) structure on PCB (using a 3/3 mil linewidth/spacing) is shown Figure 1. Electrodes (1.5×1.5 mm^2) are patterned on ¼ oz (~8.5 μm) copper with a final thickness of ~25μm due to electroplating. 150μm via holes are drilled into each electrode to provide electrical contacts to the backside of the board. Ground electrode rails are patterned alongside all the drive electrodes to provide a continuous ground connection to the droplets, and a liquid photoimageable (LPI) soldermask (~17 μm) is patterned to act as an insulator, exposing only the ground rails. As

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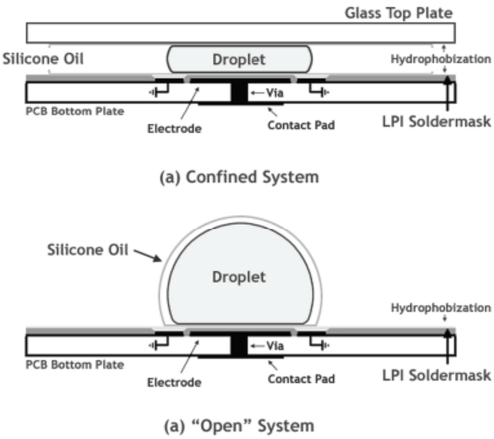

Figure 1 – Side view schematic of a digital microfluidic chip on PCB in (a) a confined system and (b) an open system. Note: droplet transport occurs perpendicular to the plane of the page.

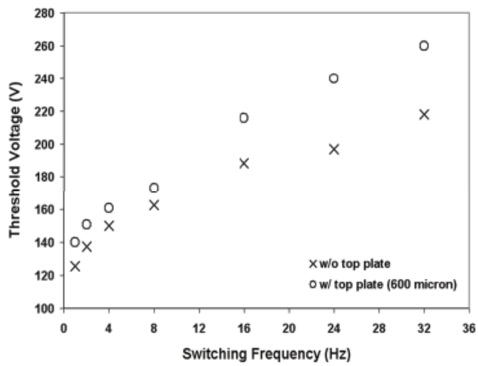

Figure 2 – Minimum voltage requirements for droplet transport at a given switching frequency.

the only post-processing step, Teflon AF is brush-coated to render the entire surface hydrophobic.

Droplet Transport – Droplets of a polarizable and conducting liquid (1M KCl) were transported in both confined and open systems. For a confined system, the volume of each droplet was 2.5µl, and the entire chip was filled with silicone oil to facilitate transport. In an open system, each droplet was 6µl in volume and a small drop of silicone oil (2µl) was added and appeared to surround the droplet. The minimum actuation voltages required to successfully transport the droplets were measured for each system at switching frequencies ranging from 1 to 32 Hz. Details of droplet transport via electrowetting can be found in [1].

3. RESULTS AND DISCUSSION

As shown in Figure 2, the operating voltages for droplets in a confined and open system ranged from 140-260V and 125-220V, respectively, depending on the switching frequency of the droplets. This suggests that droplet actuation is facilitated by the absence of a confining top plate, possibly due to the reduced drag experienced by the unconfined droplet. Electrolysis of the droplets, typically due to improper coverage of the insulator as shown in Gong *et al.* [2], was not observed using LPI soldermask as an insulator up to the maximum tested voltage of 350V. However, insulator charging as observed beyond 300V.

A sequence of time-lapsed images demonstrating droplet transport is shown in Figure 3. Mixing is also shown, where the mixing of two 2.5µl droplets in a confined system was completed within 5s and the mixing of two 6µl droplets in an open system required only 1.8s to complete.

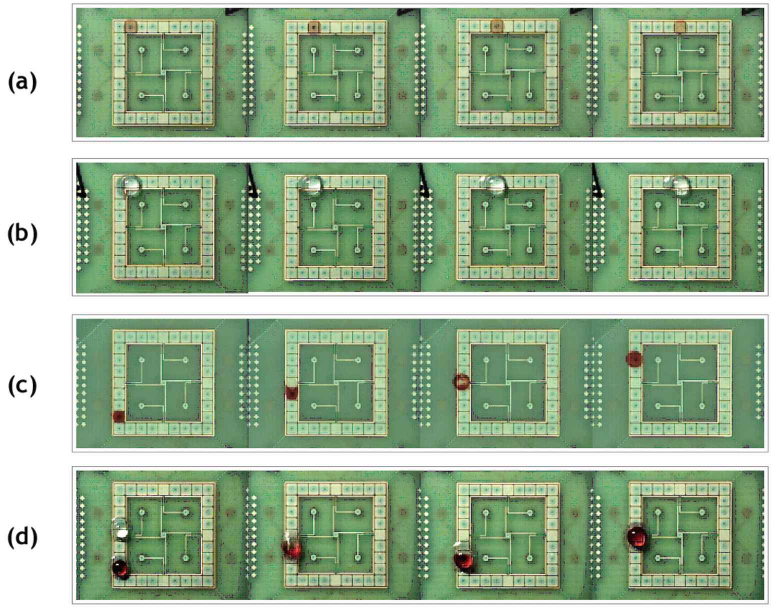

Figure 3 – Top view of an image sequence demonstrating transport (a) and mixing (c) for droplets confined by a top plate (600µm), and transport (b) and mixing (d) for droplets in an "open" system. Mixing was performed at a switching frequency of 8 Hz and completed within 5s for two 2.5µl confined droplets, and within 1.8s for two 6µl droplets in an "open" system. Mixing in an "open" system is observed to be faster than that studied in a confined system [3].

4. CONCLUSIONS

The initial results presented here enable researchers to design digital microfluidics based on the widely available PCB process. We have also demonstrated a viable solution for an inexpensive and fast turn-around process to fabricate digital microfluidic systems. We have successfully demonstrated droplet transport and mixing in both a confined and open system. Furthermore, the manipulation of droplets in an open system, unconfined by a top plate, makes the droplets easily accessible and allows for a wide range of unique applications.

ACKNOWLEDGEMENT

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