Topic No. 2.06 Digital microfluidics and digital assays **Abstract Reference No: 3114**
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DIGITAL MICROFLUIDICS: ELECTROWETTING TECHNOLOGY FOR MOTION, DISTURBING, AND SPLITTING

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Using lab-on-PCB technology, microfluidic devices can be commercialized at a low cost through upscaling, standardization, and integration through the established PCB technology, which has been used to mass-produce electronic circuits for many years. This allows LoCs to be made at low costs and integrated efficiently into systems. Demonstrated prototypes of lab-on-PCB microfluidics, complex μTASs, and biosensors indicate technology readiness for commercialization and standardization. Microfluidics in chemical reaction technology offers precise control, efficient heat and mass transfer, and reduced toxic agent consumption. Traditional microchannel flow systems have demonstrated success- ful reactions but face issues like clogging and complex networks. Digital microfluidics (DMF) using the electrowetting-on-dielectric (EWOD) principle provides an alternative by eliminating channels and pumps [**1**]as shown in Figure 1. This droplet-based flow prevents cross-contamination and supports multi-step reactions. We've prioritized cost-effectiveness, seeking out materials that balance quality and affordability. EWOD technology holds immense promise, particularly in the realm of diagnostic devices such as PCR [**2**], ELISA [**3**], DNA synthesizers, pyrosequencing, and nanopore sequencing [**4**]. Major industry players such as Illumina and Baebies have capitalized on this technology, exemplified by products like VolTRAX from Oxford Nanopore Technologies. The project was strategically divided into three pivotal segments: first, understanding the intricate dynamics of droplet motion; second, fine-tuning the dispensation process for optimal performance; and third, achieving precision in the art of droplet splitting.

The chip was fabricated using a square electrode process with the following specifications: an electrode pitch of 4 mil, spacing between electrodes of 2.75/16 mm, an overlap of 0.18 mm, and a square pad with size of 2.75 $\times$2.75 mm^2 as shown in figure 2. The electrodes were designed in Altium Designer to incorporate a zig-zag pattern with 2.5 teeth and reinforced corners for durability and stability (Figure 3). The silicone oil used as the filling insulating oil was selected because of its superior electrowetting properties, which include excellent reversibility, low contact angle hysteresis, and low volatility. An ethanol-pretreated PTFE membrane was carefully positioned on top of the control electrode after being cut to size and pre-treated with ethanol. A drop of silicone oil was applied after the ethanol had evaporated, which then penetrated the pores of the PTFE membrane through capillary action, resulting in an infused membrane with stable properties. By their strong affinity with the PTFE surface, organic oils were able to spread and remain stable within the pores of the material due to their hydrophobic properties [**5**].

Heat treatment and stretching were used to reduce the PTFE film's thickness from 0.1 mm to 0.05 mm, ensuring uniformity across different sections. Micrometers were used at five different points to verify thickness consistency. It exhibited high hydrophobicity and enabled precise control over droplets of 1 ul, due to its air/oil-filled polytetrafluoroethylene composite membrane. The droplet was saturated with KCl to enhance its sensitivity to electric fields. The whole system is shown in Figure 4.

Efforts have been made to optimize not only extrinsic factors, such as applied voltages but also intrinsic properties, such as dielectric constants and hydrophobic materials, that could enhance EWOD effectiveness. A continuous movement of droplets at 550V (DC) was observed without apparent degradation, and microparticles did not discolor on electrodes or exhibit imperfections in hydrophobic materials or dielectric layers. EWOD operations were challenging due to the high voltage's significant L-DEP force that completely soaked the droplet, necessitating a compromise between speed and stability at a maintained velocity of 2.75mm/s. You can show Figure 5-7 the motion, distribution, and splitting of the droplet, respectively.

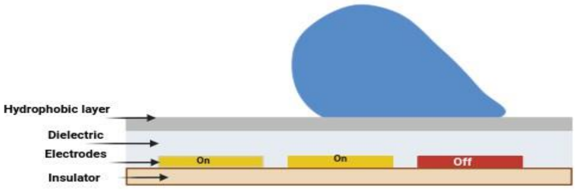

Figure 1: schematic diagram of the open EWOD system. Presented here is a schematic that illustrates the primary components of the system and their interactions together within the system. Emphasis is placed on the simplicity and functionality of the open configuration of the system.

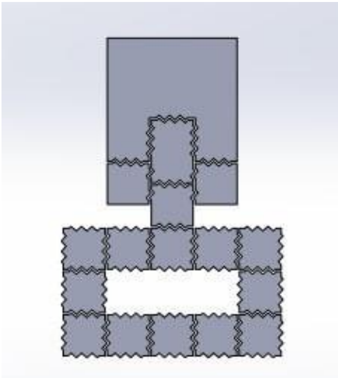

Figure 2: PCB electrode modeling. Model showing the intricate design and layout of the electrodes needed for the EWOD system, highlighting the precision required to operate effectively.

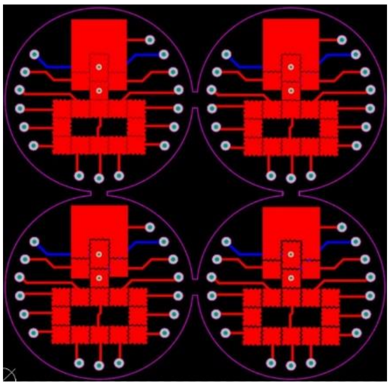

Figure 3: A PCB with electrodes with different gaps. A PCB's unique electrode geometry is a key factor in achieving electrowetting effects and efficiently manipulating droplets.

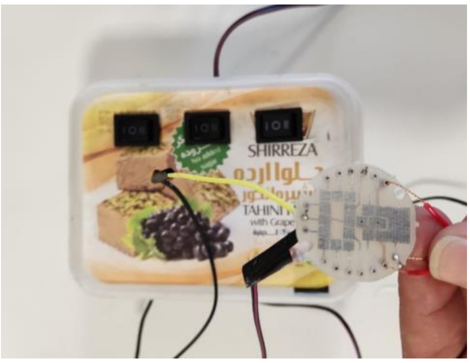

Figure 4: Fabricated chip with electronic device to switch electrodes on and off. This figure displays the completed chip, including the electronic switch- ing mechanisms that enable precise control over the electrode activation and droplet movement.

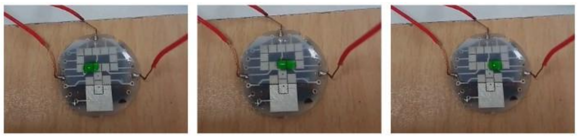

Figure 5: Motion of droplet on the EWOD system

Figure 6: Distribution of a droplet on three electrodes.

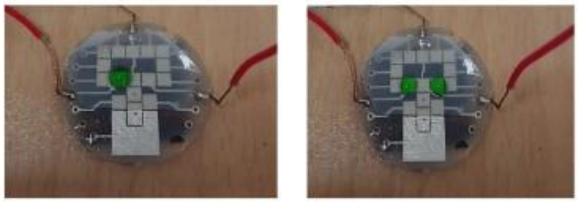

Figure 7: Splitting of a droplet on three electrodes.

References

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