WIRELESS EWOD (ELECTROWETTING-ON-DIELECTRIC) DEVICE USING PLANAR COILS

Sang Hyun Byun[1], Myung-Gon Yoon[1, 2], and Sung Kwon Cho[1]
[1]University of Pittsburgh, USA, [2]Gangneung-Wonju National University, Republic of Korea

ABSTRACT

This paper describes development and experimental verifications of wireless powering for EWOD microfluidics. First, the wireless powering is achieved by planar PCB coils (not by bulky, spool-type, conventional coils), resulting in seamless integration with EWOD array electrodes on a single and compact chip. Second, the obtained voltage for wireless EWOD is over 230V_{rms}, much higher than typically required EWOD voltages. Finally, the amplitude modulation (AM) technique is applied to the present wireless powering in order to oscillate droplets and thus minimize adverse effects of friction (contact angle hysteresis) on lateral transportation of droplets. These accomplishments would facilitate remote application of EWOD microfluidics to hard-to-reach areas (e.g., implantable EWOD microfluidics powered by an external source).

KEYWORDS

Digital microfluidics, implantable devices, amplitude modulation.

INTRODUCTION

Droplet-based microfluidics operated by EWOD on an array of electrodes is one of the promising methods for liquid droplets actuation. Due to its simplicity and versatility, droplet-based microfluidics has been spawned diverse applications including digital lab-on-a-chip, liquid lens, optical display, etc. [1-3] Especially, EWOD enables tiny droplets to be handled on the discrete arrays of electrodes with applications of analytical devices or routine laboratory processing. Up to date, however, most applications have been operated by wired powering, even though EWOD systems are seeking applications in which the systems need to be isolated and employed in hard-to-reach areas and remotely powered such as implantable devices. Therefore, wireless powering of EWOD system and integrating the powering scheme with EWOD devices are of paramount importance.

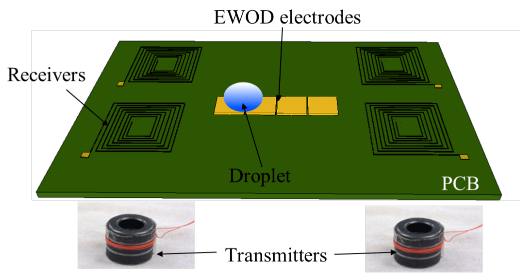

Figure 1. Integrated planar receivers with EWOD array electrodes on PCB (upper plate, 7.5×6×0.15 cm^3). Each receiver coil has a rectangular shape (outer dimension < 2.3 cm) and center-to-center aligned with spool type transmitter coils (bottom).

Mita *et al* first showed wireless EWOD using commercial spool-type coils. [4] The attained voltage was about 15V in limited conditions. Recently, our group presented wireless EWOD in a wide range of operating conditions using spool-type coils. [5] The wireless powering was achieved by magnetic induction between transmitter and receiver coils. Due to difficulty in microfabrication of spool type coils and their monolithic integration with EWOD devices planar type coils are more preferred, especially at the receivers that are eventually implanted. To our best knowledge, wireless EWOD using planar coils has never reported. Fig.1 shows the schematic of a wireless EWOD chip whose receiver is made of planar coils. The wireless powering is based on electromagnetism that interchanges energy from transmitters to receivers. The current flowing through the transmitter creates a magnetic field that induces a voltage in the receiver. The overall configuration is similar to that of the commercial transformer, but the main difference is that there exists an air gap between the primary and secondary coils and the secondary coils (receivers) are patterned on a PCB board.

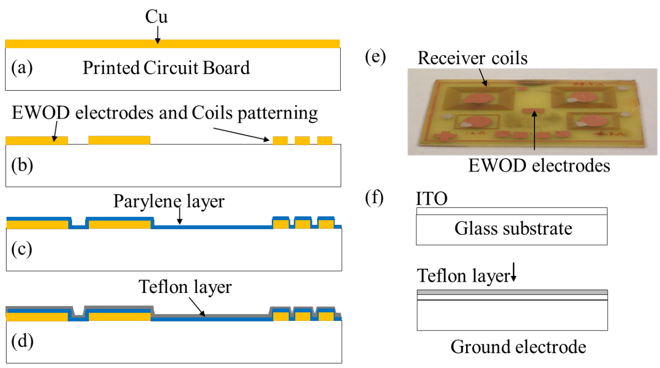

Figure 2. Microfabrication process of wireless EWOD device: (a) Cu layer (15 μm) on top of 1.5 mm of PCB; (b) patterning of receiver coils (width 50 μm and spacing 70 μm) and EWOD electrodes; (c) depositing of 3.1 μm parylene layer; (d) coating of hydrophobic Teflon layer; (e) photo of microfabricated wireless EWOD chip. (f) ITO cover glass coated with Teflon for ground electrode.

This paper describes fabrication and testing of integrated wireless EWOD devices and shows that the wirelessly attainable voltage at the receiver is high enough for droplet actuation. Experiments are carried out to measure the voltage at the receiver and the contact angle of the droplet while the EWOD chip is wirelessly powered. Finally, it is demonstrated that a droplet can be oscillated and laterally transported by an amplitude-modulated (AM) wireless signal.

PLANAR WIRELESS EWOD DEVICE AND CIRCUIT PREPARATION

The wireless EWOD device including four planar receiver coils (outer diameter is 2.3 cm) and EWOD electrodes (1.2 × 1.2 mm^2 square type, 15 μm thick Cu layer) is fabricated simultaneously from PCB using photolithography. The overall fabrication process is illustrated in Fig.2 (a~d). Fig.2 (e) shows a photo of the fabricated device (7.5 × 6 × 0.15 cm^3) after completion of all fabrication process. The inductance of the receiver coil (42~50 turns) measured is in the range of 23~42 μH.

An equivalent electric circuit in wireless powering is shown in Fig.3 (a). Fig.3 (b) shows the induced voltage at the receiver vs. the transmitting frequency. The maximum voltage obtained is 237 V_{rms} at 2.6 MHz when a droplet is not loaded. Fig.3 (c) shows effects of the separation distance between the transmitter and receiver on the voltage at the receiver.

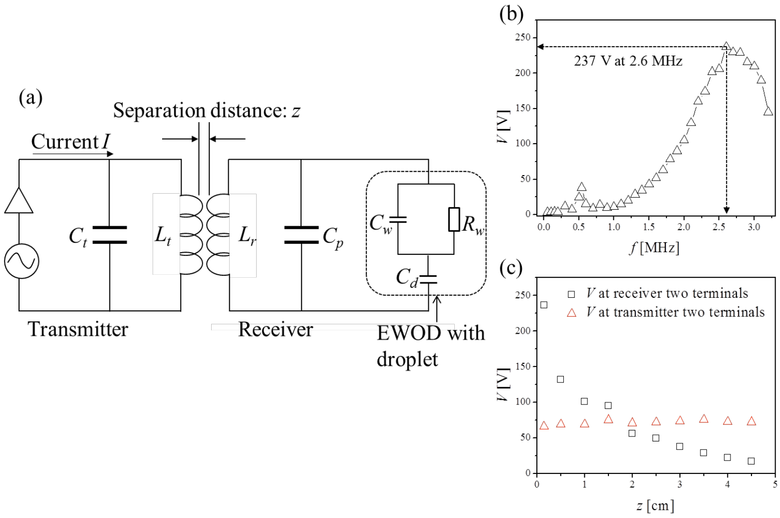

Figure 3. (a) Equivalent electric circuit using magnetic induction. The EWOD part (dielectric C_d including a droplet, C_w and R_w) is connected to the receiver coil in parallel. L_t and C_t is the inductance and capacitance of the transmitter, L_r and C_p is the inductance and parasitic capacitance of the receiver. (b) Induced voltage at the receiver without droplet vs. the transmitting frequency. (c) Separation distance between (transmitter and planar receiver coils) on the induced voltage at the receiver (frequency = 2.6 MHz.

EXPERIMENTS

With a 5 μl sessile droplet (σ = 1413 μS/cm measured at 22.9^{o}C by Orion 3-Star pH meter) loaded at the receiver, the change in the contact angle is measured (Fig. 4) at 1.75 MHz of the wirelessly transmitted signal. The parylene (3.1 μm) and Teflon (0.9 μm) coated on Si wafer cleaved in small piece is used for this experiment. The initial contact angle measured is 119^o. As the voltage at the receiver is increased, the contact angle is monotonically decreased and finally saturated at ~78^o. Figure 4(a) shows the results together with comparison with the Lippmann-Young equation. As the voltage increases, the contact angle decreases. The minimum contact angle (saturation) was observed at 78^o (Δ41^o) when overall voltage was 217 V_{rms} and no further contact angle change was observed even at the higher voltage beyond 217 V_{rms}. The discrepancy between the equation and experimental data is due to the voltage drop across the droplet since the frequency is high.

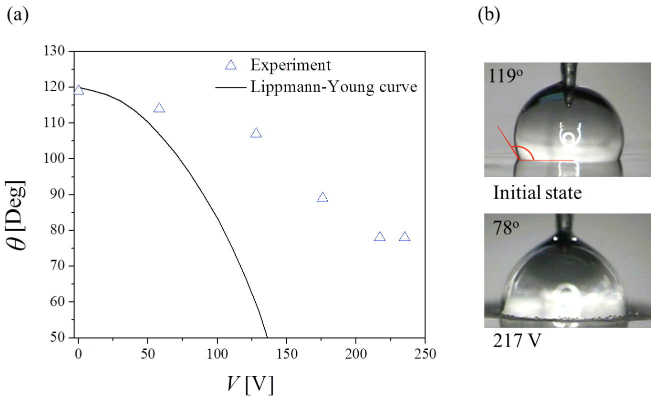

Figure 4. Measurement of 5 μl NaCl (σ = 1413 μS/cm) droplet contact angle vs. voltage in the receiver wirelessly transmitted at 1.75 MHz. The theoretical (solid) line is obtained from Lippmann-Young equation. The initial contact angle is 119^o and the contact angle is 78^o when overall V_{rms}= 217 V. The contact angle saturation was observed at 78^o. Note that (b) shows droplet shapes at the corresponding contact angles.

In order to overcome the friction during droplet transportation, it is common that oscillation (<1 kHz) is introduced to a droplet by using an AC-signal. From the wireless circuit set-up and contact angle experiments, it is confirmed that we can obtain high voltages to achieve the significant contact angle change at the high transmitting frequency (few MHz range). However, it is not confirmed whether a droplet can be oscillated at low frequency by wireless EWOD. Since the present transmitting frequency (MHz range) is too high for droplet oscillation, we amplitude-modulate the transmitting signal with an envelope of low frequency (< 1 kHz). Fig.5 (a) shows the overlaid droplet oscillation at the envelope frequency of 100 Hz while the transmission frequency is still high at 1.75 MHz. The AM signal obtained at the receiver is also shown in Fig.5 (b).

Finally, we demonstrated a droplet transportation using the amplitude modulated signal of 10 Hz with carrier frequency of 1.75 MHz. Figure 6 (a) shows sequential motions of the droplet (2.5 μl in volume) being laterally transported one step left. Sequential activations of the arrayed electrodes generate step-by-step motions in the droplet. We could clearly observe that the droplet oscillated at 10 Hz while in transportation. When the electrodes were activated, the droplet repeatedly expanded and contracted during transportation. Note that the droplet outline is blurred due to oscillation.

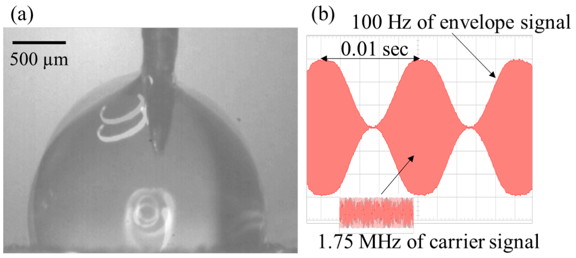

Figure 5. (a) Overlaid high-speed camera images of droplet oscillation; 5 µl NaCl (σ = 1413 µS/cm) droplet oscillation is synchronized with the envelope frequency. (b) AM signal is wirelessly transmitted to the EWOD electrode to oscillate the droplet. The signal is measured at the receiver. The envelope frequency is 100 Hz, and the carrier frequency is 1.75 MHz.

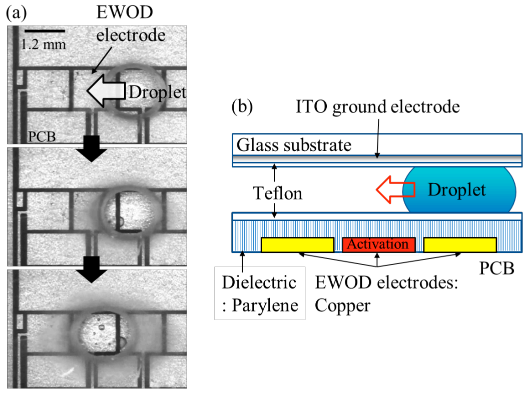

Figure 6. (a) Snapshots of NaCl droplet (2.5 µl) transportation (one-step left) by shifting application of wirelessly transmitted signal from one electrode to another. The driving signal is AM as shown in Fig. 5 (except the envelope frequency = 10 Hz). (b) Cross-sectional view of droplet transportation configuration.

CONCLUSIONS

We developed wireless EWOD actuations based on the inductive coupling by using planar type coils. We achieved voltages as high as 230V at the receiver, which are sufficient to drive EWOD microfluidics. We also confirmed that the contact angle in the droplet is lowered down to 78^o (~ 40^o change). Furthermore, by introducing amplitude modulation, we could oscillate the droplet at low frequency (< 1 KHz). Finally, by integrating the EWOD electrode array with the wireless powering, we accomplished lateral transportation of droplet.

ACKKNOWLEDMENT

This work is in part supported by the National Science Foundation (NSF CMMI-0730460).

REFERENCES

[1] V. Srinivasan, V. K. Pamula and R. B. Fair, *An Integrated Digital Microfluidic Lab-on-a-chip for Clinical Diagnostics on Human Physiological Fluids*, Lab on a Chip, vol.4, no.4, pp.310-315, (2004).

[2] T. Krupenkin, S. Yang and P. Mach, *Tunable Liquid Microlens*, Applied Physics Letters, vol.82, no.3, pp.316-318, (2003).

[3] D. Y. Kim and A. J. Steckl, *Electrowetting on Paper for Electronic Paper Display*, ACS Applied Materials & Interfaces, vol.2, no.11, pp.3318-3323, (2010).

[4] Y. Mita, Y. Li, M. Kubota, S. Morishita, W. Parkes, L. I. Haworth, B. W. Flynn, J. G. Terry, T. B. Tang, A. D. Ruthven, S. Smith and A. J. Walton, *Demonstration of a Wireless Driven MEMS Pond Skater that Uses EWOD Technology*, Solid-State Electronics, vol.53, no.7, pp.798-802, (2009).

[5] S. H. Byun and S. K. Cho, *Electrowetting-on-Dielectric by Wireless Powering*, Journal of Heat Transfer Engineering, (2012), DOI 10.1080/01457632.2013.703102.

CONTACT

Sung Kwon Cho: skcho@pitt.edu