Time-regulated Actuation Signal for Enhancement of Droplet Transportation in Digital Microfluidics

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Abstract

Digital Microfluidics (DMF) is an attractive technology for biological/chemical micro-reactions due to its distinct droplet manageability via electronic automation. However, the limited velocity of droplet transportation has hindered DMF from being utilized in high throughput applications. Here we introduce two novel control-engaged electrode-driving techniques: Natural Discharge after Pulse (NDAP) and Cooperative Electrodes (CE). NDAP is based on a series of DC pulses and multi-cycle natural discharging coordinated with the droplet dynamic motions, facilitating real-time droplet position sensing. CE is an early-charging of the target electrode before discharging the current one to avoid droplet deformation and local vibration at the gaps between two electrodes. By combining NDAP with CE, we have for the first time increased the droplet transportation efficiency without compromising the lifetime of electrodes in DMF. This work, together with our previous publications, should be valuable for scientists and engineers working on enhancing the throughput and the reliability of control-engaged DMF systems for automated applications.

Materials and Methods

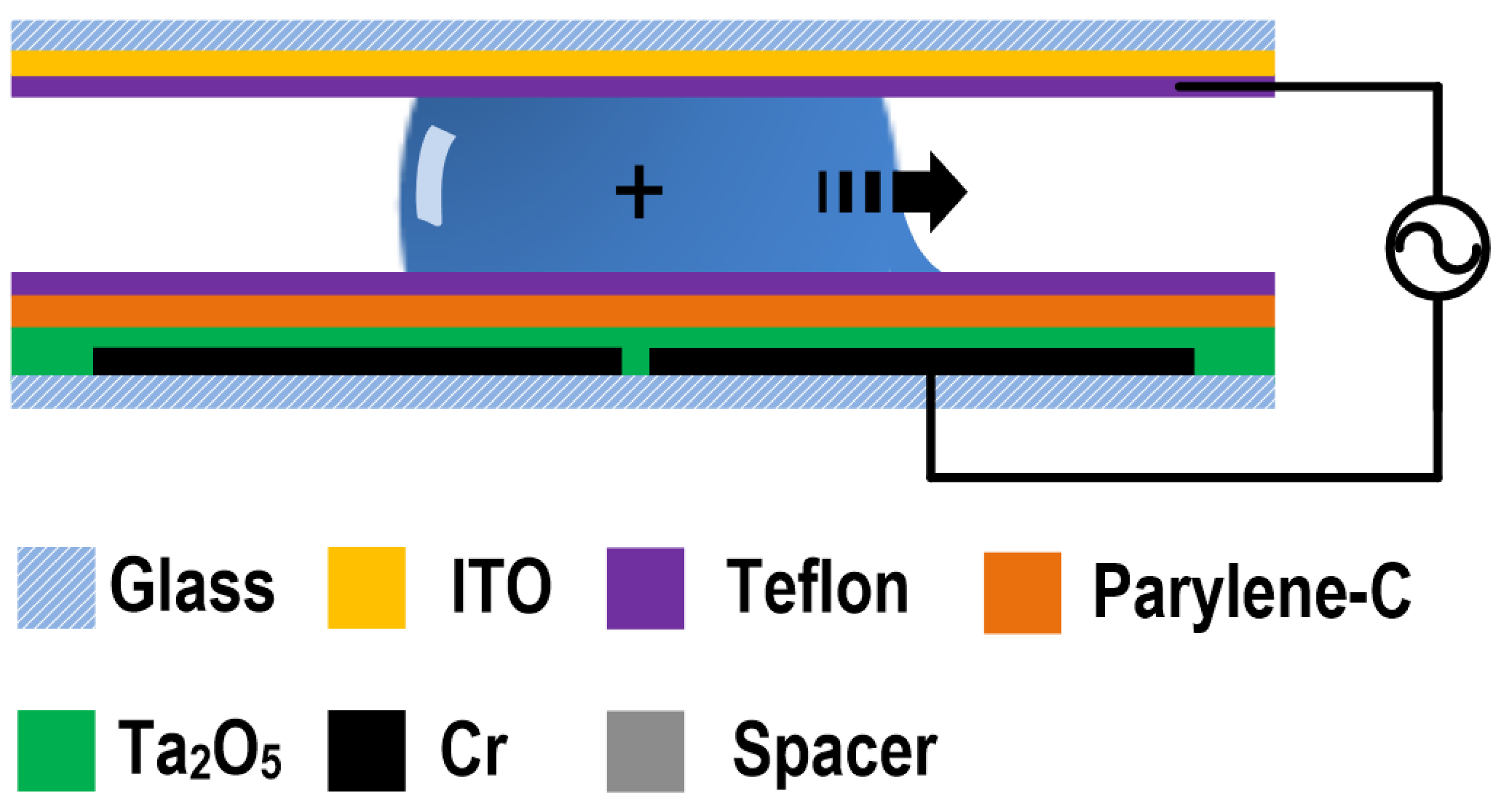

Fig. 1. Cross-section schematic of a typical DMF device configuration, where the droplet is sandwiched between two electrode planes and surrounded by silicone oil or other immiscible liquid or gas. The upper plate contains a single continuous ground electrode while the lower plate contains an array of independently addressable control electrodes each slightly smaller than the size of the droplet footprint. Both surfaces are hydrophobic and the control electrodes are electrically insulated from the liquid.

When a voltage is applied between electrodes above and beneath a liquid droplet, the induced electric field on only one side of the droplet creates an imbalance of interfacial tension which can drive bulk flow of the droplet.

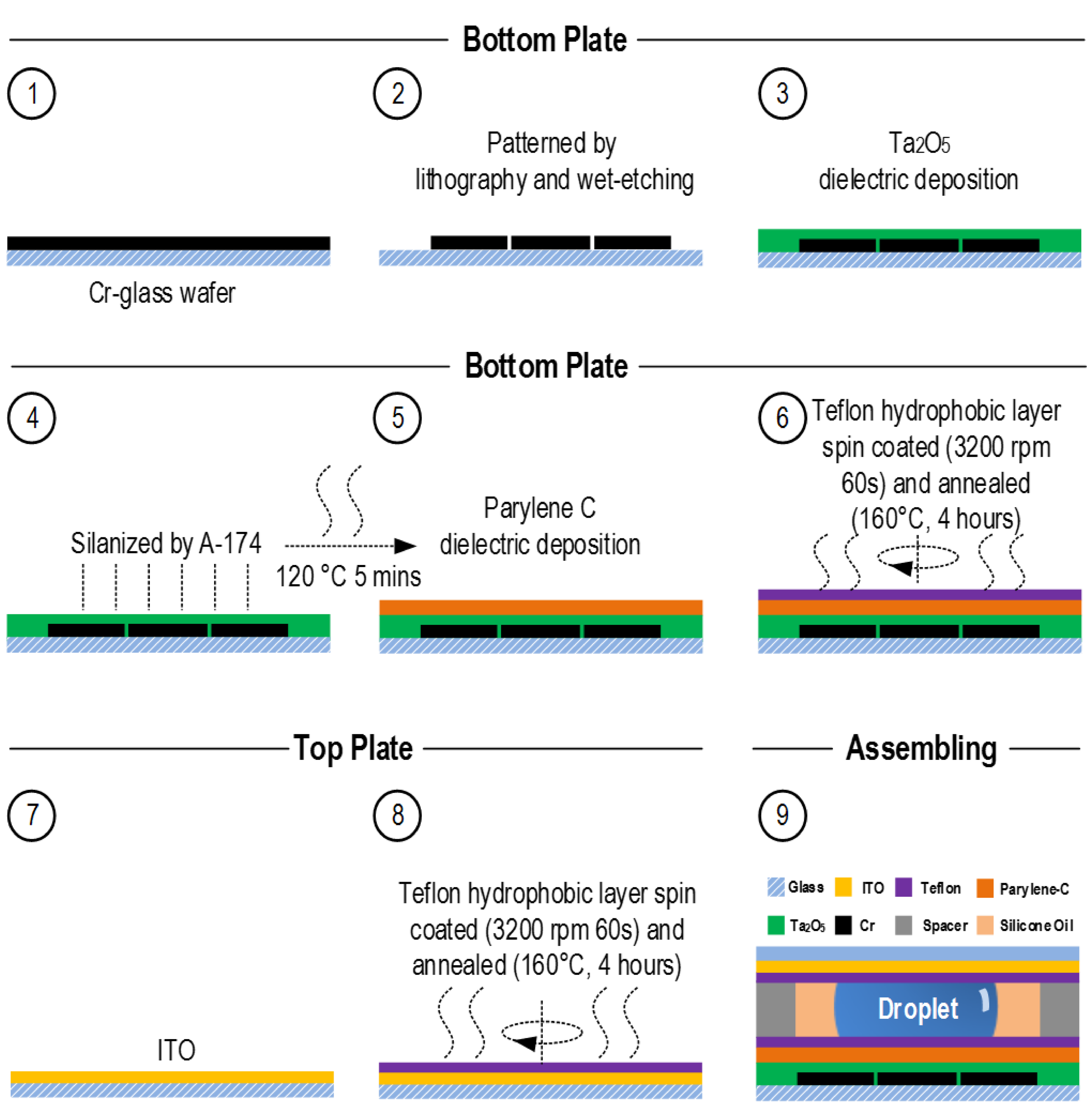

Fig. 2. Fabrication procedure of Ta2O5/Parylene C-insulated two-plate DMF chip. The fabrication of the bottom plate (steps 1 to 6), was conducted on a Cr glass with standard lithography and wet etching. Ta2O5 and Parylene C were deposited on top of electrodes as dielectric layers with spun-on Teflon offering hydrophobicity; the top plate (steps 7 and 8) was made from ITO glass after it was treated with Teflon. Separated by a spacer, droplets and oils were applied on the bottom plate. The two plates were placed facing each other and assembled to complete the DMF chip (step 9).

Materials and Methods (cont.)

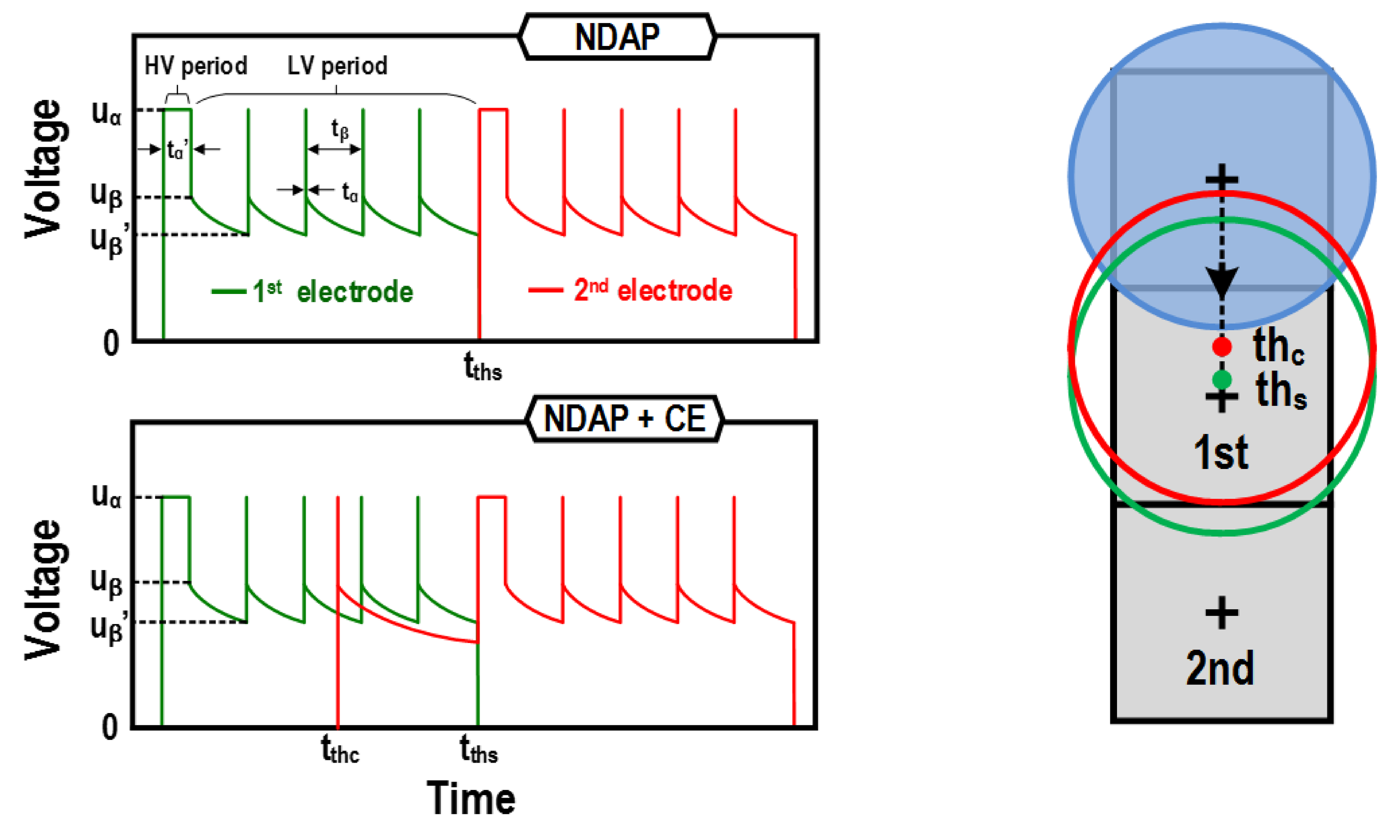

Fig.3 Sketches of Natural Discharge after Pulse (NDAP): The high-voltage (HV) period lasts shorter, while the low-voltage (LV) under natural discharge lasts longer with short pulse recharging periodically. We tailor HV periods to kick off the droplet movement and LV period ensures there is sufficient charge to facilitate the tracking of electrode's capacitance for precise real-time droplet positioning. (b) Droplet moving toward two target electrodes and location of the two thresholds on the first target electrode. The electrode was grounded when the charging was done in all schemes.

Results

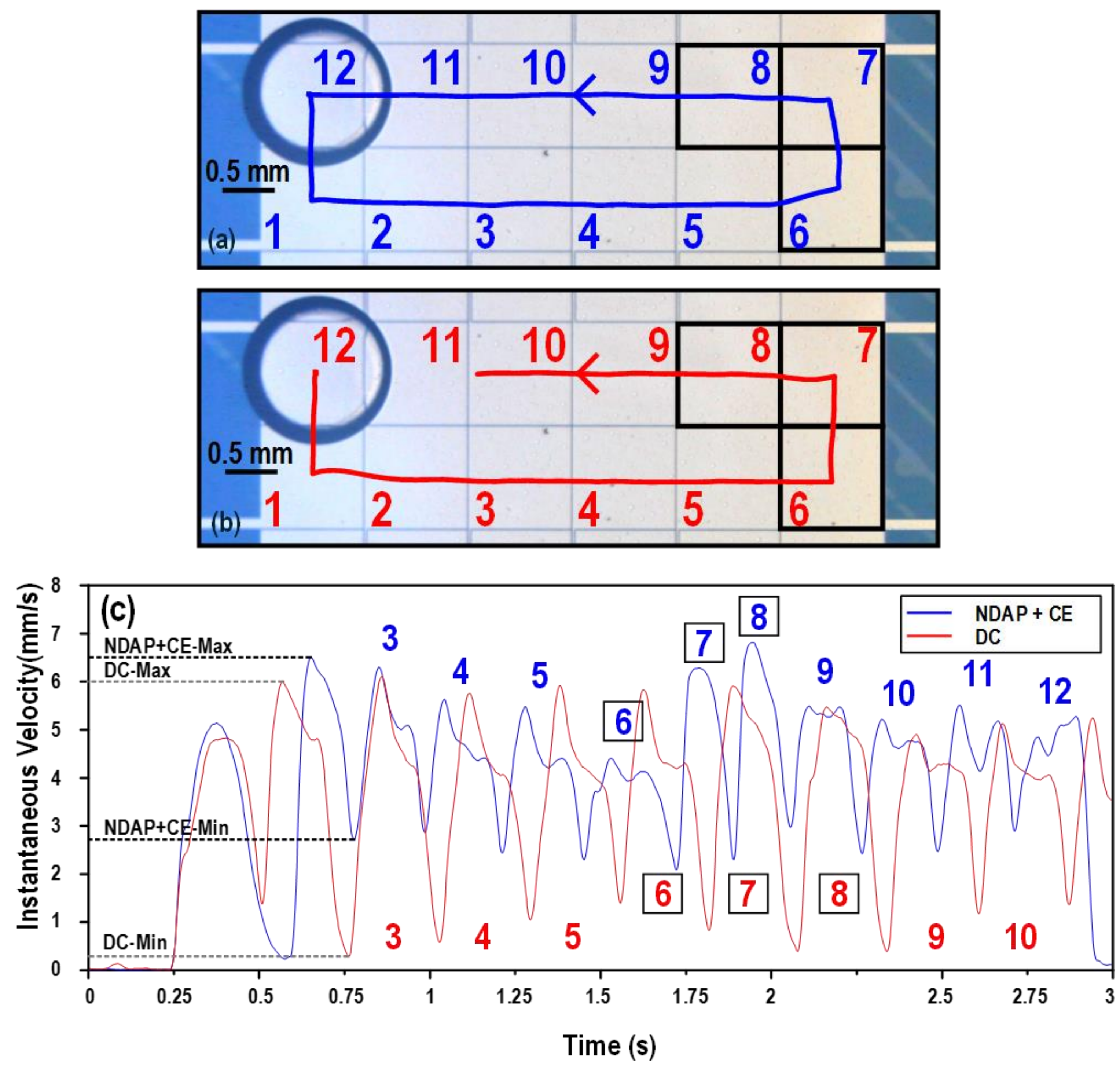

Fig. 4 Comparison between the proposed (NDAP + CE and high-speed feedback) and classical (DC) schemes for droplet movements in a long run of 3 s: (a) Droplet successfully moved across 12 electrodes when it was controlled by NDAP+CE. The path of the droplet's center had been shortened at electrode No. 6 by CE, which charged electrode No. 7 before the droplet reached electrode No. 6, resulting in an upward move of droplet in advance. The whole droplet transportation was recorded in video (Multimedia view). (b) Droplet failed to complete movement in 3 s due to its lower speed. The moving path was close to the right angle at the two corners. The whole droplet transportation was recorded in video (Multimedia view). (c) Instantaneous velocity of the droplet moving across the electrodes. As expected, droplet controlled by the proposed scheme moved across electrode No. 6-7-8 using a much shorter time than that of the classical procedure.

Conclusions

In summary, we have introduced two electrode-driving techniques, Natural Discharge after Pulse (NDAP) and Cooperative Electrodes (CE), with a real time feedback control in DMF and speeded up the droplet movement beyond those achieved by conventional actuation signal via matching the droplet dynamics with the strength and duration of the applied electric field. The entire scheme involves only low-cost electronics and software programming. That gives the feasibility to be upgraded for further researches, customized to other applications, and easily repeated by others.