Fast Biofluid Transport of High Conductive Liquids Using AC Electrothermal Phenomenon, a Study on Substrate Characteristics

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Abstract

Electrokinetics has many applications in a wide range of areas, such as lab-on-a-chip and biomedical microdevices. The electrothermal effect has been used for biofluid delivery systems since it has high pumping efficiency for high conductive liquids (>0.1 S/m) compared to other electrokinetic techniques such as electroosmosis. AC electrothermal (ACET) micropumps are based on the temperature gradient caused by Joule heating or an external heat source, which generates permittivity and conductivity gradients in the bulk of the liquid. When the liquid is subjected to an electric field, the ACET force is created. Several parameters govern the phenomenon. Some of them have been studied in the literature including actuation voltage and frequency [1], planar electrode geometry [2], number of electrodes [3], and non-planar electrodes [4]. In this paper, the effect of substrate thickness and material for two rows of microelectrodes placed on the top and bottom of a microchannel in an ACET micropump were studied. As the substrate material can dramatically affect the pumping efficiency, different combination of silicon (k=1.1 W/mK) and glass (k=131 W/mK) substrates were used and the corresponding simulation data were compared. 2D simulation was performed using COMSOL Multiphysics® software. Electric field distribution along a microchannel was obtained assuming two pairs of coplanar asymmetric microelectrodes, in which the thin electrode was at 7 Vrms, and the wide electrode was grounded. Actuation frequency was kept constant at 100 kHz. Periodic boundary conditions were assigned for side boundaries representing the rest of the electrodes. Zero charge conditions were assigned for the area inside the microchannel not covered by microelectrodes. Figure 1 shows the electric field distribution throughout the system. Heat transfer in fluids and solids were performed for the conductive liquid (σ=0.224 S/m) and the substrates, respectively. Temperature distribution was then achieved assuming Joule heating as the source of heat in the system. Again, side boundaries had periodic boundary conditions, and the outer substrates' surfaces were kept at ambient temperature (T=293° K). Figure 2 shows the temperature distribution in the whole device for two different material configurations, silicon-silicon and glass-glass. Navier-Stokes equations were then solved assuming laminar flow physics. Microchannel boundaries were set to no-slip condition and the side walls were set to periodic condition. Figure 3 shows the resultant ACET fluid flow using the two substrate configurations. The results show that using glass substrates can increase the ACET flow rate up to 230 µm/s at the height of ~10 µm above the electrode surface compared to 113 µm/s for silicon substrates. A comparison between single-row and two-row microelectrode configurations

is depicted in Figure 4. The maximum velocity shown in this figure was taken at the output cross section of the microchannel. It shows that increasing the substrate thickness is more beneficial in the two-row microelectrode configuration compared to the single-row electrodes. In summary, fluid flow simulation of a two-row microelectrode configuration in an ACET micropump can be a potential technique in achieving higher flow rates in electrokinetic based fluid transport.

Reference

1. R. Zhang et al., "Two-phase AC Electrothermal Fluidic Pumping in a Coplanar Asymmetric Electrode Array," Microfluid. Nanofluid., 10, 521-529 (2011).
2. Q. Yuan et al., "Optimization of Planar Interdigitated Microelectrode Array for Biofluid Transport by AC Electrothermal Effect," Microfluid. Nanofluid., 16, 167-178 (2014).
3. A. Salari et al., "AC Electrothermal Micropump for Biofluidic Applications Using Numerous Microelectrode Pairs", IEEE-CEIDP 2014.
4. E. Du and S. Manoochehri, "Microfluidic Pumping Optimization in Microgrooved Channels with AC Electrothermal Actuations," Applied Physics Letters, 96, 034102 1-3 (2010).

Figures used in the abstract

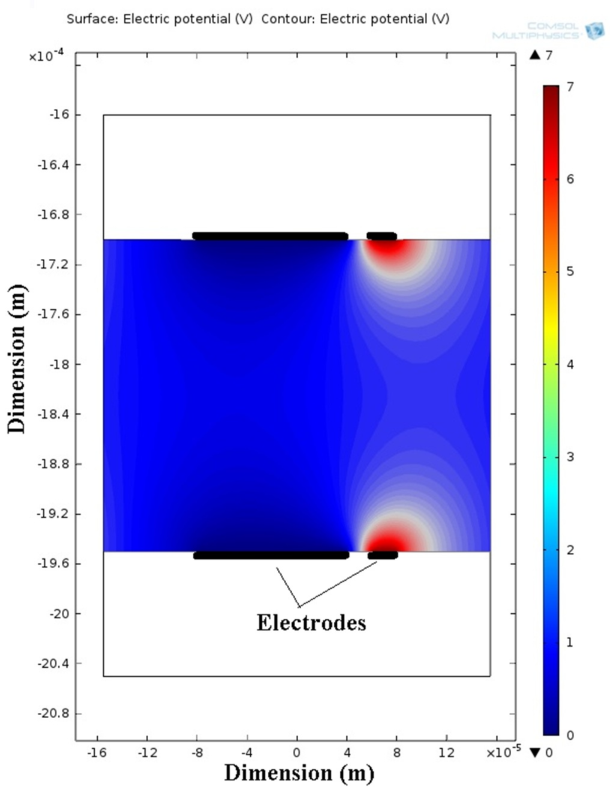

Figure 1: Potential distribution for the ACET micropump. The lines and colors show the potential differences in the system. The highest electric field gradient occurs near the thin electrode as the potential approaches 7 V, while it is almost zero near the wide one. Freq=100 kHz, Vrms = 7, σ= 0.224 S/m.

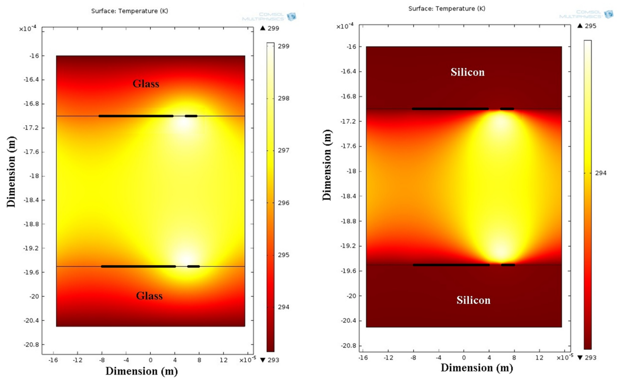

Figure 2: Temperature distribution for two different substrate material configurations; left: glass-glass; right: silicon-silicon. Freq=100 kHz, Vrms = 7.

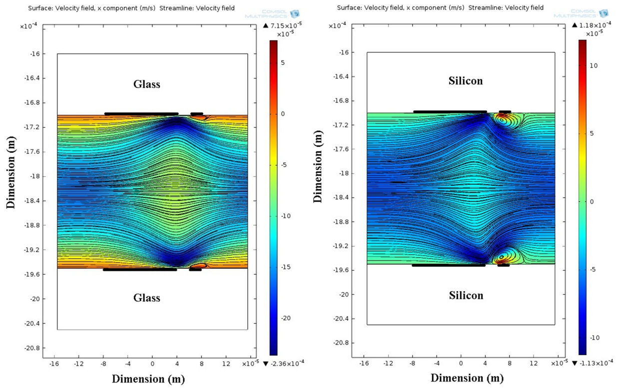

Figure 3: ACET fluid flow for two different substrate material configurations; left: glass-glass; right: silicon-silicon. Glass-glass configuration provides higher flow rates than silicon-silicon one. Also, maximum ACET velocity (x-component) occurs near the wide electrode edge. Freq=100 kHz, Vrms = 7, σ= 0.224 S/m.

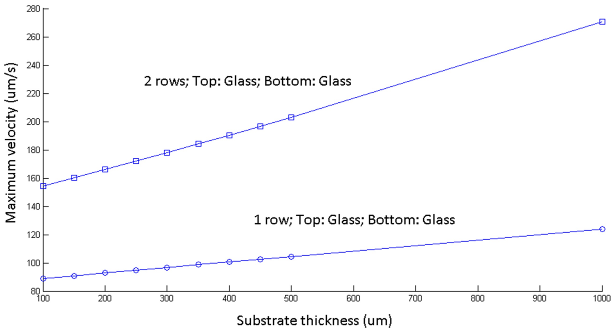

Figure 4: Maximum velocity comparison between one-row and two-row microelectrode ACET micropump. The effect of substrate thickness increase is more observable in one-row microelectrode configuration than two-rows.