International Communications in Heat and Mass Transfer 38 (2011) 275–279

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

A parametric study of AC electrothermal flow in microchannels with asymmetrical interdigitated electrodes ☆

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ARTICLE INFO

Available online 2 December 2010

Keywords:
AC electroosmosis
AC electrothermal flow
Asymmetric interdigitated electrodes
Numerical simulation

ABSTRACT

In this study, the AC electrothermal (ACET) flow in a microchannel with asymmetrical planar electrode pairs, in the same configuration as an AC electroosmosis (ACEO) pump, is studied numerically. The electrical, temperature and velocity fields in the microchannel are obtained by solving the coupled electrical, momentum and energy equations. The effects of electrode size, gap and length ratios, electrical conductivity of electrolyte solution, thermal conductivity of microchannel base material, as well as voltage and the frequency of AC on ACET flow are investigated in details. It is found that in the operating frequency range of the ACEO pump, i.e. 100 Hz–100 kHz, the velocity of the ACET flow is frequency-independent and moves in the same direction as the ACEO flow, and effects of electrode size, gap and length ratios on flow velocity have the same trend as the ACEO flow. Because the ACET flow velocity is proportional to electrical conductivities of electrolyte solution linearly and to the fourth power of the applied voltage, while the ACEO flow velocity decreases with the increase of electrical conductivity of the electrolyte solution and is only proportional to the square of applied voltage, therefore the ACET flow should not be neglected in an ACEO pump for the cases of high conductivity of electrolyte solution and relatively high AC voltage where ACEO and ACET effects are comparable.

1. Introduction

Pumping of electrolytes is of great importance for microfluidic devices [1]. Conventional electrolyte pumping in microfluidic devices is based on DC electroosmosis, where high DC voltage up to thousands of volts is imposed at two ends of the microchannel, leading to serious Joule heating effects for high electrical conductivity of electrolytes [2]. Recently, two AC electrokinetic effects, i.e. AC electroosmosis (ACEO) and AC electrothermal (ACET) flow have shown great promises to be used as pumping devices for microfluidics. The advantages of AC electrokinetics for pumping are: (i) it can be operated at very small voltages (as low as 1 V) with very low power consumption and negligible Joule heating effects, and (ii) the electrodes can be fabricated and integrated within microfluidic devices.

The ACEO flow was first reported by Green et al. [3] in an experimental study on AC kinetics above a symmetric electrode pair. Inspired by this study, Ajdari [4] proposed the concept of an ACEO micropump utilizing asymmetric pairs of interdigitated microelectrodes to produce net ACEO flow, which was verified experimentally by Brown et al. [5] at almost the same time. The mechanism of ACEO is explained as the electrical forces exerted on the net charges induced in the diffusion layer (electrical double layer) above the microelectrodes in a non-uniform electrical field [3]. An ACEO micropump normally can only work in the range of 100 Hz–100 kHz, and its velocity is frequency dependent, with an optimal frequency in the range of 1 kHz–10 kHz to achieve the maximum velocity. This is because if the frequency is too high, not enough induced net electrical charge is accumulated, while if the frequency is too low, too much induced charge will screen the electric field above the electrical double layer [3]. The ACEO velocity is linearly proportional to the square of the voltage and decrease rapidly with the increase of electrolyte's conductivity [3]. Therefore, an electrolyte solution of low conductivity is often used in an ACEO micro-pump. The maximum ACEO velocity of 75 μm/s was achieved experimentally with 1 V at the optimal frequency of 1.3 kHz [5] using an electrolyte solution having the electrical conductivity of 0.00123 S/m. The flow velocity in an ACEO pump is affected by the electrode size, which can be optimized through a mathematical model with coupled electrical potential equation, N–S equations and electrolyte concentration equation [6]. Different from planar electrodes with negligible height [5–8], Urbanski et al. [9] proposed three-dimensional asymmetric electrodes with a larger height to get rid of the reverse flow above the small electrode, and they claimed that 20 times faster flow rate than planar electrode was achieved.

The electrothermal flow (ETF) is a well-known phenomenon in electrohydrodynamics, which is caused by electrothermal forces acting on the bulk fluid in the presence of the electrical conductivity

☆ Communicated by W.J. Minkowycz.

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0735-1933/$ – see front matter
doi:10.1016/j.icheatmasstransfer.2010.11.004