A Distinctive Analysis of Fluid Flow Behaviour in an AC Electroosmotic Micropump

Nurul Amziah Md Yunus[1], Farideh Abhari[1], Mohd Nizar Hamidon[1], Zurina Zainal Abidin[1], Izhal Abdul Halin[1], Gerard H. Markx[2] and Nicolas G. Green[3]. [1] Universiti Putra Malaysia. [2] Heriot Watt University. [3] University of Southampton

Email: amziah@eng.upm.edu.my

Introduction

Microfluidic systems are used for chemical and biological analyses, sensing, drug delivery and molecular separation. Many microfluidic systems need a self-contained active pump of a size comparable with the volume of fluid to be pumped. Key considerations are its reliability, power consumption, actuation voltage, ease and cost of fabrication and accuracy.

The Device

A separation device was developed as shown in Figure 1. One side of the device consisted of a micropump, and the other section for dielectrophoretic separation. The micropump consisted of pairs of platinum electrodes forming an array of asymmetric electrodes. The larger electrode of a pair was 15 µm wide and the smaller electrode 5 µm. The gap between a large and a small electrode was 5 µm. The gap between each pair was 15 µm. The total length of the array was 3 mm.

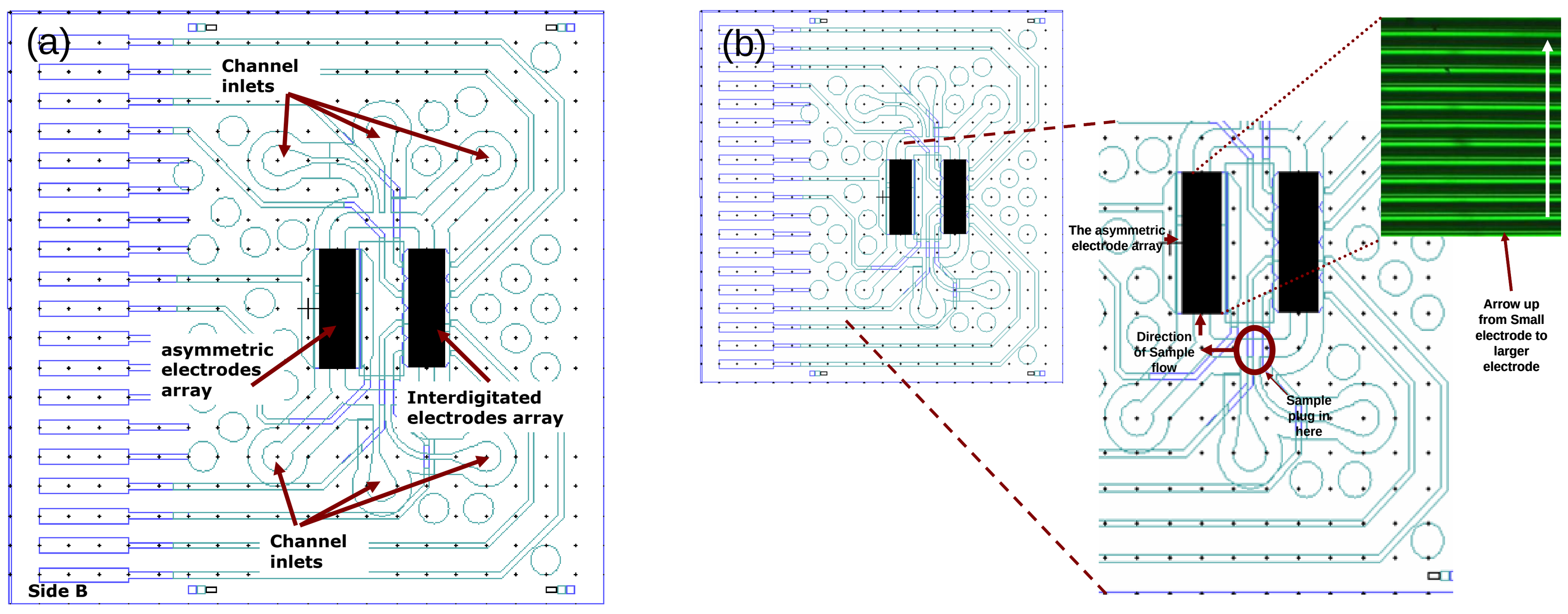


Figure 1: (a) The chip (b) Fluid/sample flow towards the asymmetric array.

How it works and why?

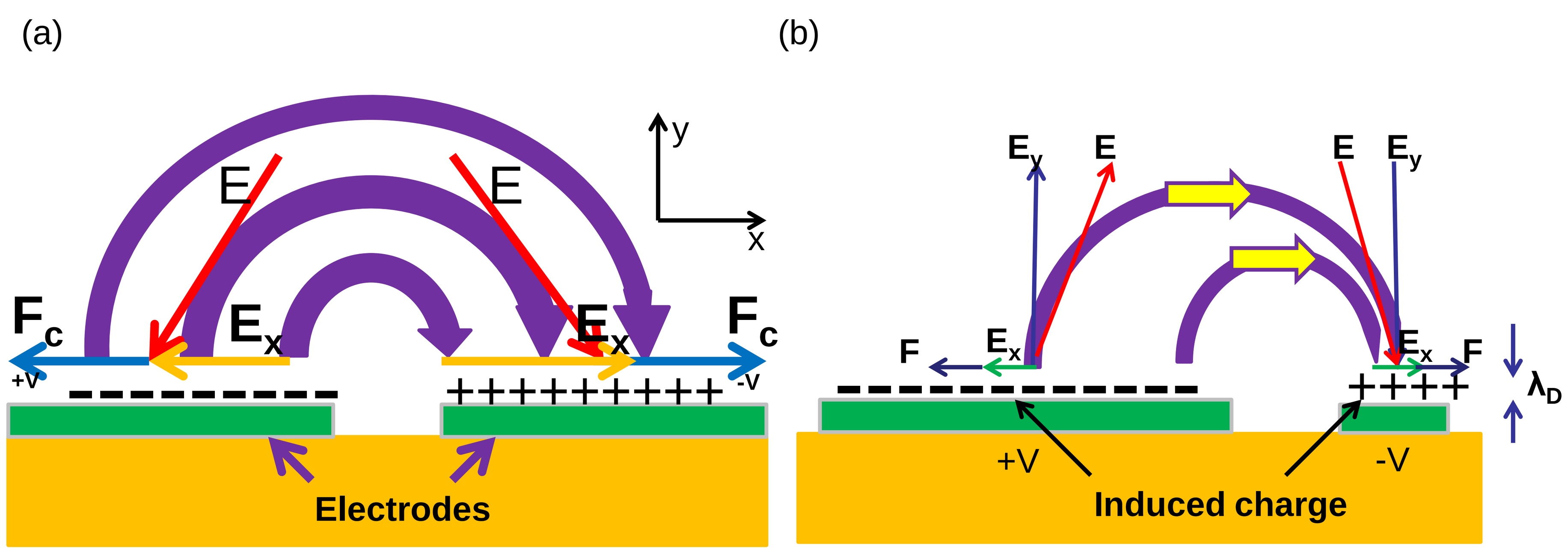
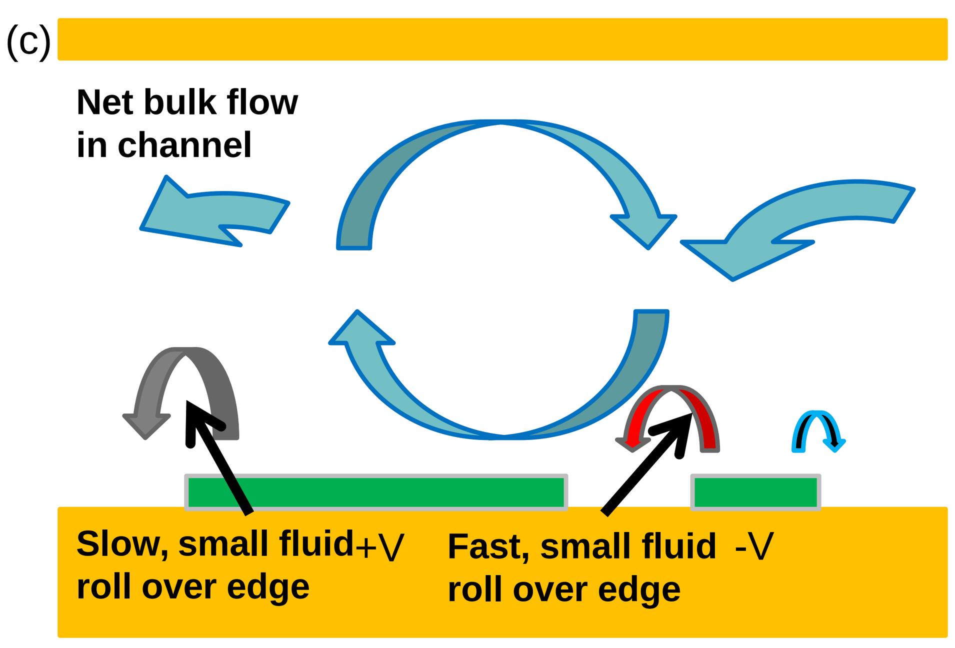


Figure 2: (a) AC electroosmosis (ACEO) using coplanar pairs of electrode. Electro-osmotic flow arises from the force exerted, F_c by a tangential electric field on the electrical double layer which is induced on the electrode surface. In this planar microelectrode arrays used for AC electro-kinetics, divergent electric fields are generated, and as a result a component of the electric field, E_x lies tangential to the electrical double layer. (b) Illustration of forces acting on the surface of the asymmetric electrode in AC electroosmosis (ACEO) after applying AC potential. (c) A schematic diagram of the fluid flows in AC electroosmosis (ACEO) that occur above the electrodes in the open chamber with lid. (Redrawn from N. G. Green, A. Ramos, A. González, H. Morgan, and A. Castellanos, "Fluid flow Induced by Nonuniform AC electric fields in Electrolytes on Microelectrodes. III. Observation of Streamlines and Numerical Simulation," *Physical Review E*, vol. 66, p. 26305, 2002).



The micropump was based on the process of AC electro-osmosis. The AC field induced an electro-osmotic circular flow above each electrode. Because one electrode in a set is larger then the other, a net bulk flow is induced in the fluid.

Experiment

A sample of 2 µm latex beads was prepared in 14.5 µS/m KCl and introduced into the chamber The fluid velocity was determined by observing the speed of the beads in the chamber.

Results

The fluid velocity vs. AC signal frequency in 20 Vpp, in frequency between 2-10 MHz is shown in Table 1 and Figure 3.

Frequency	Number of images captured	Avg. Velocity µm/s
2 MHz	109	5.65 x 10e-2
3 MHz	101	5.24 x 10e-2
4 MHz	84	3.50 x 10e-2
5 MHz	75	3.20 x 10e-2
6 MHz	103	3.10 x 10e-2
7 MHz	86	3.05 x 10e-2
8 MHz	87	3.00 x 10e-2
9 MHz	104	2.90 x 10e-2
10 MHz	109	2.50 x 10e-2

Table 1

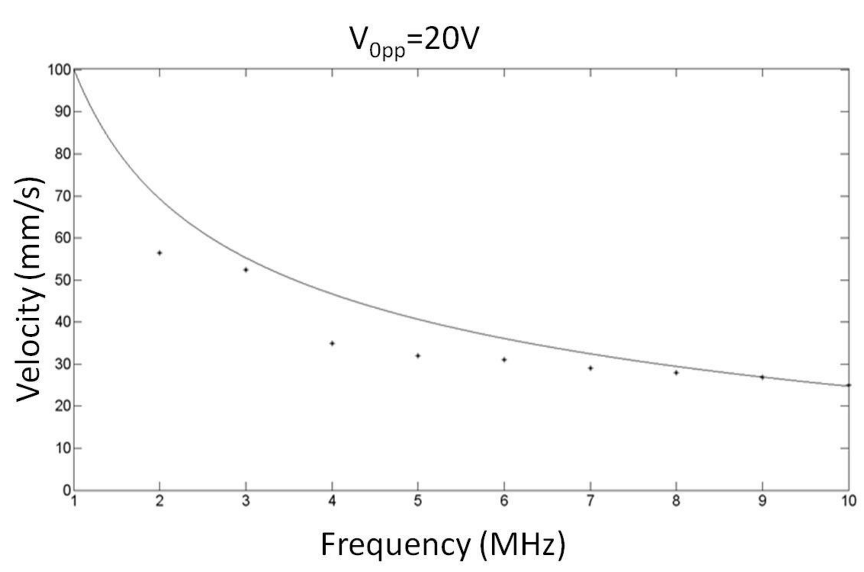


Figure 3: Velocity vs. frequency between 2-10 MHz (Very high frequency).

Results- continued

Theoretical and average experimental fluid velocity vs. frequency between 10-50 kHz (AC signal voltage in 2 Vpp) is shown in Table 2 and Figure 4.

Frequency	Number of images captured	Avg. Velocity µm/s
10 kHz	21	5.80 x 10e-2
20 kHz	25	5.30 x 10e-2
30 kHz	28	2.00 x 10e-2
40 kHz	23	5.00 x 10e-3
50 kHz	25	2.10 x 10e-3

Table 2

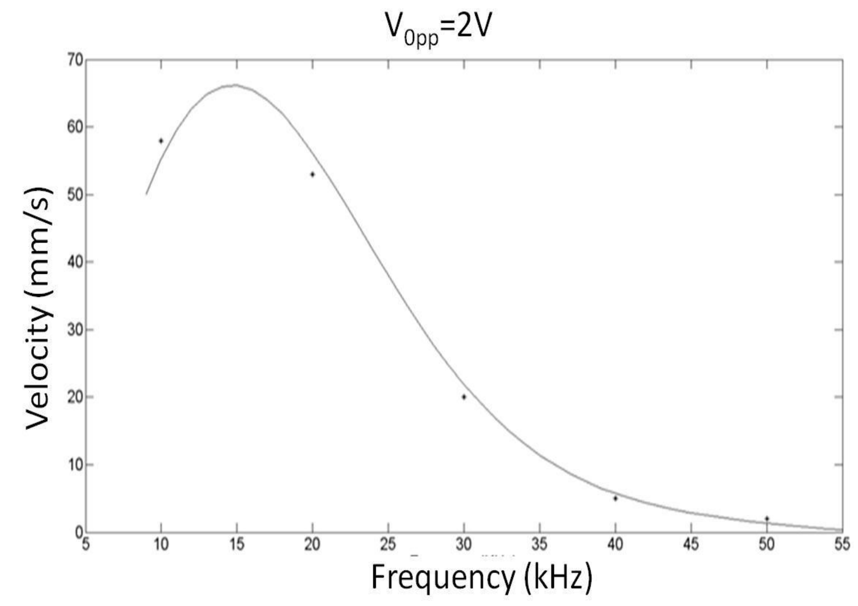


Figure 4: Velocity vs. frequency between 10-50 kHz (Medium frequency) with 2 Vpp AC signal voltage.

THEORETICAL ANALYSIS

The micropump was modeled in two ways:

1) Ramos Slip Velocity Model

$$v_{slip} = \frac{\varepsilon V_0^2}{8\eta r}\frac{\Omega^2}{\left(1+\Omega^2\right)^2}$$

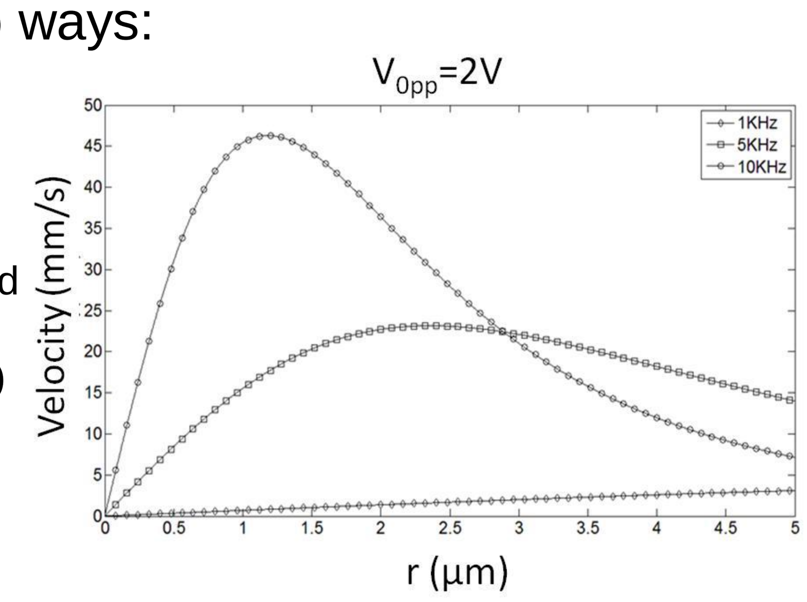


Figure 5: Fluid velocity vs. distance (µm) in 3 different frequencies.

2) Coupled ACEO Numerical Model

$$v_{slip} = -\frac{1}{4}\frac{\varepsilon}{\eta}\frac{\partial}{\partial x}\left|\varphi - V_{app}\right|^2$$

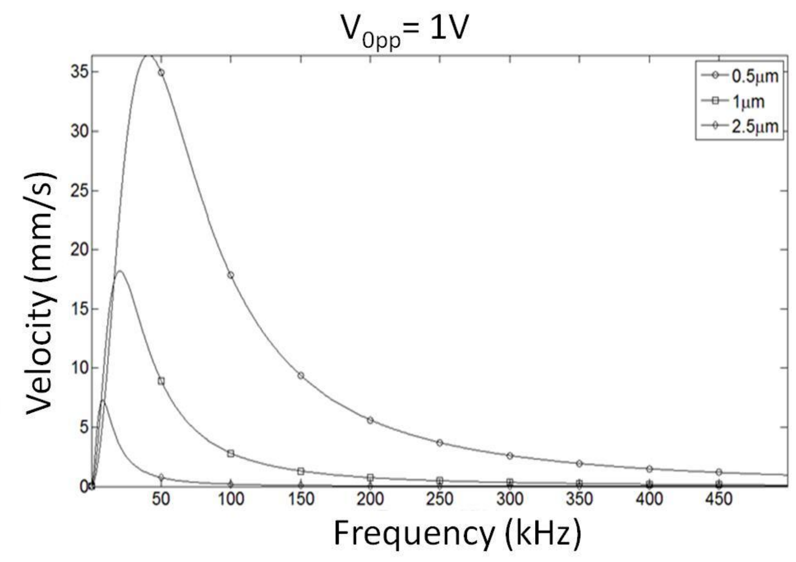


Figure 6: Fluid velocity vs. frequency at 1 Vpp at 3 different distances from the wall.

The parameters used in the models are shown in Table 3.

Table 3: Parameters used for simulation.

Characteristic length, L	$40e^{-6}$ m	Given
Fluid density, ρ	745.5 kg/cm^3	0.001 M , KCl
Dynamic viscosity, η	0.8904 Pa.s	T= 25° C
Electrical Conductivity, σ	148µS/cm	Given
Electrolyte permittivity , ε	79	Given
Debye Length, λ	**9.6 nm**	**Calculated**

Discussion

The velocity was found to strongly depend on the frequency-dependent permittivity, and also with properties of the electrical double layer (EDL) and the applied electric field. The velocity at any position on the surface is zero especially at low and high frequency limits, with a maximum at a characteristic frequency that does depend on the voltage drop across the double layer. The dependency of the velocity on the frequency and distance in the experimental results was most similar to that predicted by the model of Ramos et al (2005) at the voltages and conductivities investigated.

Conclusion

The experimental results were in good agreement with the theoretical model of Ramos et al (2005), but not the coupled ACEO Numerical model.

Acknowledgements:
Ministry of Higher Education Malaysia
University of Putra Malaysia
HERIOT WATT UNIVERSITY
SOUTHAMPTON NANOFABRICATION CENTRE