SIMULATION OF MICRO-ELECTRONIC FLOWFET SYSTEMS

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ABSTRACT

A microelectronic fluidic system has been investigated by modeling and 3D simulation of fluid flow controlled by an applied gate voltage. The simulations have helped to characterize a novel FlowFET (a fluidic Field Effect Transistor) device under fault-free conditions. The FlowFET operates by applying a voltage field from a gate electrode in the insulated side wall of a microchannel to modulate the ζ-potential at the shear plane [1]. The change in ζ-potential can be used to control both the magnitude and direction of the electroosmotic flow in the microchannel.

INTRODUCTION

Microfluidic devices and systems have important economical benefits in biomedical and pharmaceutical application. Miniaturization allows the reduction of the amount of chemicals and increases sensitivity and speed of analysis. The new trend in this area is merging electronic with the fluidic modules to perform control, signal conditioning and data processing.

The micro-electronic fluidic (FlowFET) systems contain no moving part valves and are fully controllable by microelectronics [1]. The working principle is based on manipulating charges in a channel containing fluid by means of electrical fields. The main advantages of these systems are speed of operation, on-board detection, and their suitability for mass fabrication.

DESIGN AND METHODS

Recently, a new FlowFET has been designed [2] and this has been simulated in present study. The device is illustrated schematically in figure 1, and consists of a U-shaped Pyrex channel approximately 30 μm at the top and 70 μm at the bottom. The gate electrode is 175 μm long and is separated from the microchannel by a thin 210 nm silicon oxide insulating layer along the lower wall of the channel. The channel length is 19 mm and the depth is 18 μm.

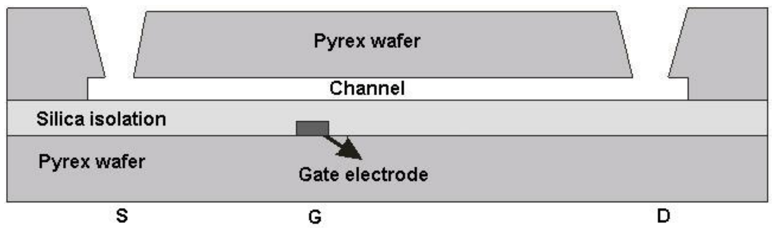


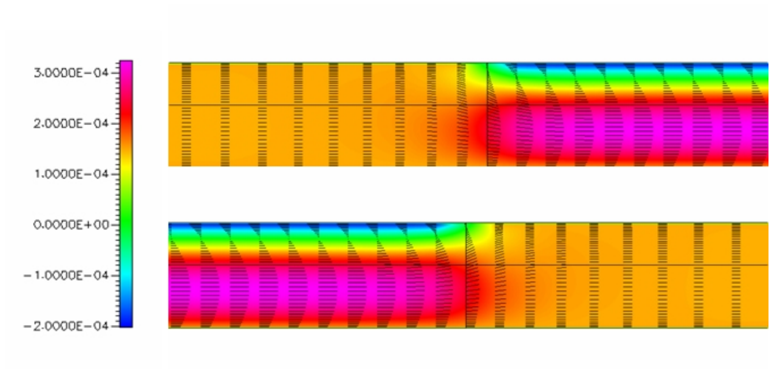
Figure 1: Schematic longitudinal cross-section of the FlowFET

A mixture of sodium acetate and acetic acid (5 mMoles) fills the channel due to capillary forces. At the inlet and outlet boundaries, the atmospheric conditions in pressure have been considered to be zero (atmospheric conditions). The voltage between the source (S) and drain (D) is 285 V, equivalent to an electric field along the channel of 150 V/cm.

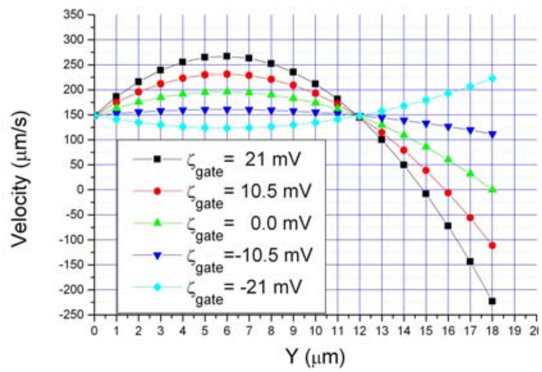
The electroosmotic flow is characterized by ζ-potential, which has a value of -14 mV on the channel walls in our case. When a voltage is applied on the gate electrode (G), the ζ -potential take a different value ζ_{Gate} on the channel wall corresponding to the gate region. In this way, the fluid flow can be controlled by the voltage applied on the gate electrode. The present simulations were performed for a variation between [-0.21 V … 0.21 V] of ζ-potential.

RESULTS

The flow simulations were carried out using the commercial software packages, COVENTORWARE 2004 and CFD-ACE+. A shortened computational domain was used, by taking into account the gate length and 350 μm on its left and right side respectively. For presentational purposes, the images of longitudinal sections have been inverted so that the wall surface corresponding to the gate electrode upwards. The simulations were performed for five values of ζ -potential in the gate region: {-21; -11.5; 0; 11.5; 21} mV. Figure 2 shows the predicted velocity profiles in the gate region as a function of the zeta potential.



a) Velocity profile (m/s) around the left- and right-hand side of the gate: ζ_{gate}=+21mV (CFD-ACE+)



b) Velocity profile (μm/s) in the middle of the gate (COVENTORWARE)

Figure 2 Velocity profiles in the gate region

At ζ_{Gate} = 21mV, the velocities under the gate is reversed, while in the vicinity of the opposite wall are the higest. The decreasing of gate voltage reduces the reverse flow near the gate electrode. At long distance from the gate along the channel, the flow establishes a uniform velocity which depends on gate voltage.

The different ζ-potentials induce an abrupt pressure variation in the gate region (figures 3, 4).

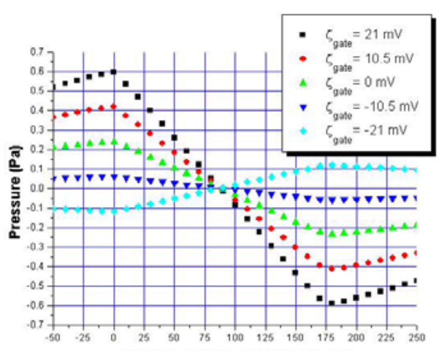


Figure 3 Pressure variation in the gate region

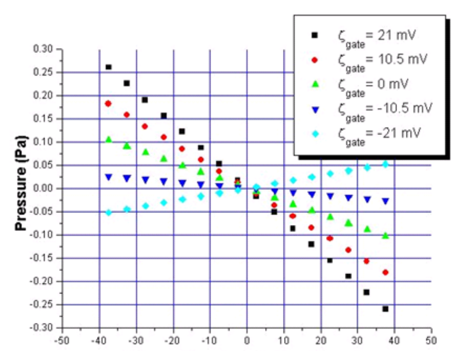


Figure 4 Pressure variation in the middle of the gate

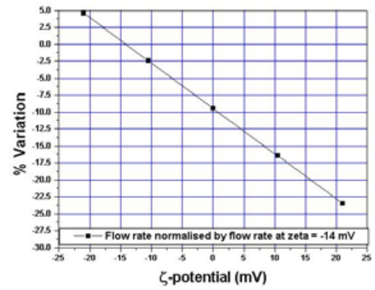


Figure 5 Change in flow rate as a function of ζ-potential on the wall in the gate region

Figure 5 illustrates the induced changes in flow rate as function of ζ-potential. By comparison to ζ_{Gate} = 21mV case, the flow rate change is up to 25%. The increasing of gate length and/or by considering more than one control gate, this effect could be maximized.

CONCLUSIONS

The behavior of electroosmotic flow in a micro-electronic fluidic system has been simulated and analyzed for operating conditions representing a fault-free case. The analysis will be used for fault simulations of microelectronic fluidic devices. The results are promising for future developments of FlowFETs.

ACKNOWLEDGEMENTS

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References

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