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Modeling of Micro-Electronic Fluidic Systems

Oana Tatiana NEDELCU[1], Robert W. BARBER[2], Hans G. KERKHOFF[3], David R. EMERSON[2], Raluca MÜLLER[1], Egbert VAN DER WOUDEN[3]

[1]National Institute for Research and Development in Microtechnology, Bucharest, Romania
[2]Centre for Microfluidics and Microsystems Modelling, CCLRC Daresbury Laboratory, Warrington, Cheshire, UK
[3]MESA+, Research Institute for Nanotechnology, Testable Design and Testing of Nanosystems Group, Enschede, The Netherlands
E-mail: oanan@imt.ro

Abstract. A microelectronic fluidic system is studied using modeling and simulation of fluid flow controlled by applying gate voltage. 2D simulations were used to characterize the fluidic Field Effect Transistor (FlowFET) device under fault-free conditions. The FlowFET operates by applying a voltage from a gate electrode in the insulated side wall of a microchannel, to modulate the ζ-potential at the shear plane. The change in ζ-potential can be used to control both the magnitude and the direction of the electroosmotic flow in the microchannel.

1. Introduction

The miniaturization of fluidic systems implies many functionalities and economical benefits, especially for biomedical and pharmaceutical application, like reducing the fluid amount for analyses and the costs, low energy and reagent consumption, rapid analysis time and a high level of automation. In advanced applications, electronics is merged with the fluidic modules [1], 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 [2]. The working principle is based on manipulating charges in a channel that contains fluid by means of electric fields. The main advantages of these systems are the speed of operation, the use of very small amounts of liquid, on-board detection, and their suitability for mass fabrication.

2. Design and methods

Recently, a new FlowFET has been designed [3] and it is being investigated in the present study. The device consists of a 19 mm long and 18 μm depth U-shaped Pyrex channel, having a diameter of 30 μm at the top and 70 μm at the bottom (Fig. 1). The gate electrode is 175 μm long and it 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.

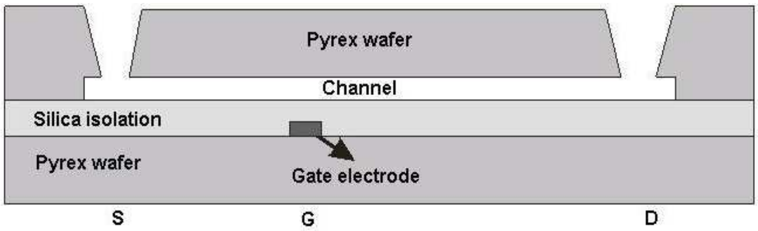


Fig. 1. Schematic longitudinal cross-section of the FlowFET.

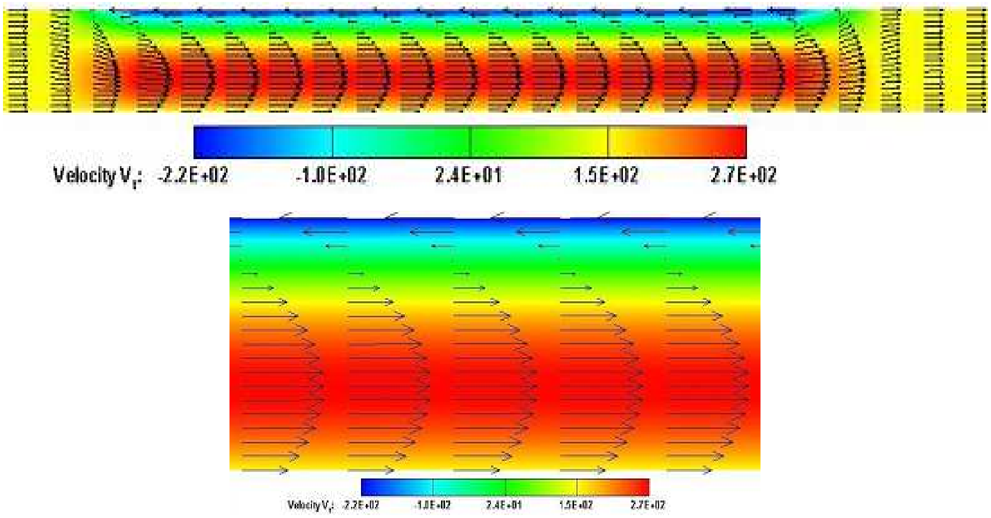
The microchannel is filled with an acetate buffer containing a mixture of sodium acetate and acetic acid. The mixture has a concentration of 5 mM and Ph = 4. At the inlet and outlet boundaries, the atmospheric pressure conditions have been considered. These are valid conditions for electroosmotic flow through long microchannels. As a first boundary condition the voltage between the source (S) and drain (D) is considered to be 285 V, the equivalent of 150 V/cm value for electric field along the channel.

The electroosmotic flow is characterized by ς-potential. When a voltage is applied on the gate electrode (G), the ς-potential has a different value ζ_G on the channel wall corresponding to the gate region, than on the other channel surfaces (–14 mV in our case). In this way, the fluid flow can be controlled by the voltage applied on the gate electrode. In present simulation the voltage in the gate varies between [–36 V... 36 V].

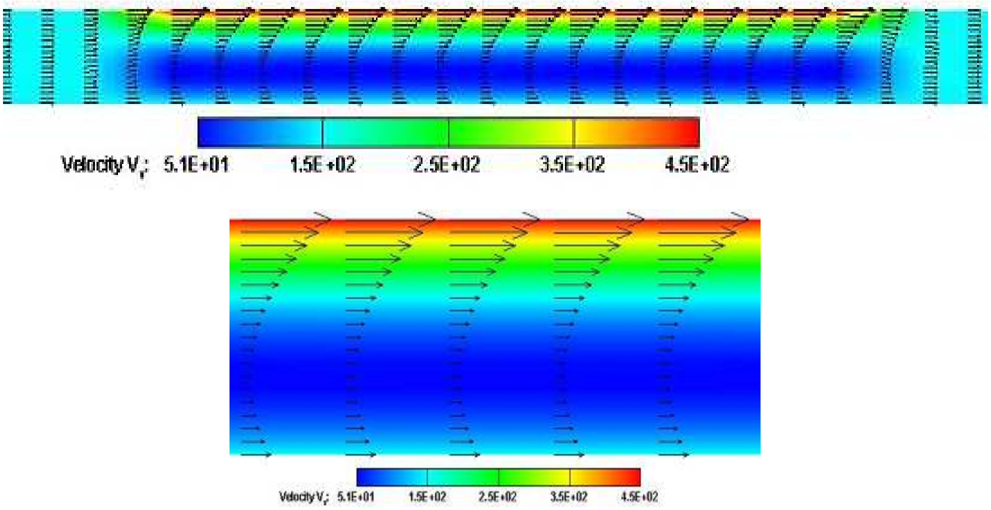
3. Results

The flow simulations were performed using the commercial software packages, COVENTORWARE 2004. The 2D channel model has 19 mm length (meshed with 10 μm element size) and 18 μm width (meshed with 1 μm element size).

Figure 2 shows the velocity profiles in the gate region. For presentational purposes, the channel has been inverted so that the wall surface corresponding to the gate electrode upwards. The simulations were performed for five values of applied voltage on the gate: [36, 18, 0, −18, 36] volts. At V_G = 36 V, the velocities under the gate is reversed, while in the vicinity of the opposite wall have the highest values. The decreasing of gate voltage reduces the reverse flow near the gate electrode. At a long distance from the gate along the channel, the flow establishes an uniform velocity which depends on the gate voltage.



a) V_{Gate} = 36 V.



b) V_{Gate} = −36 V.

Fig. 2. Velocity profiles in the gate region (μm/s).

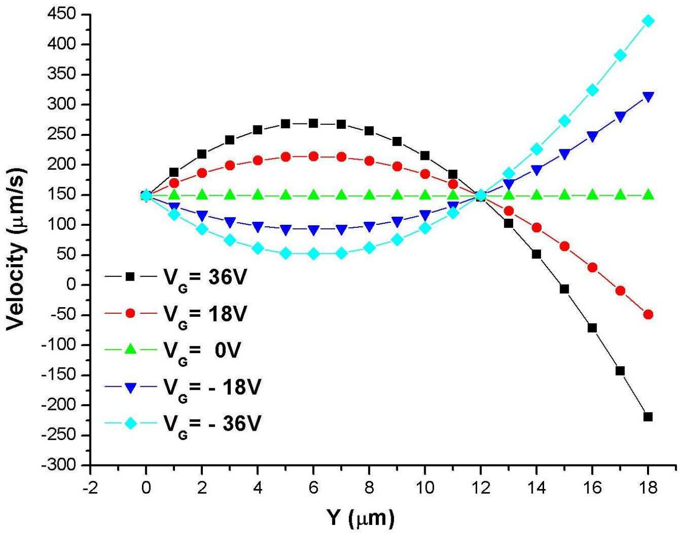


Fig. 3. Velocity distribution corresponding to the middle of the gate, as function of V_{Gate}.

The gate voltage influences the flow through ζ-potential in the gate region. This dependence is illustrated in Fig. 4. The different ζ-potentials induce an abrupt pressure variation in the gate region (Figs. 5–7). Figures 8, 9 show the uniform velocity at a long distance from the gate region and the flow rate variation as function of the gate voltage. In the case $V_G = 0$ V, the ζ-potential under the gate has the same value as ζ-potential on channel walls ($\Delta\zeta = 0$).

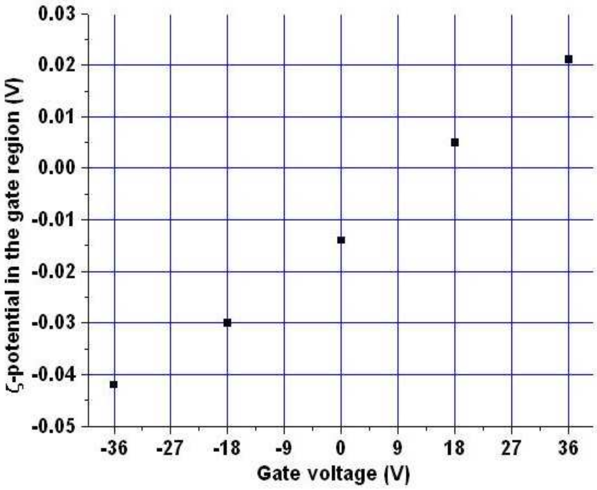
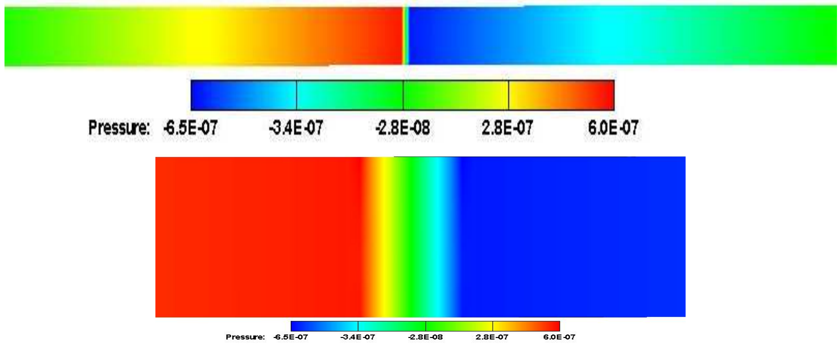
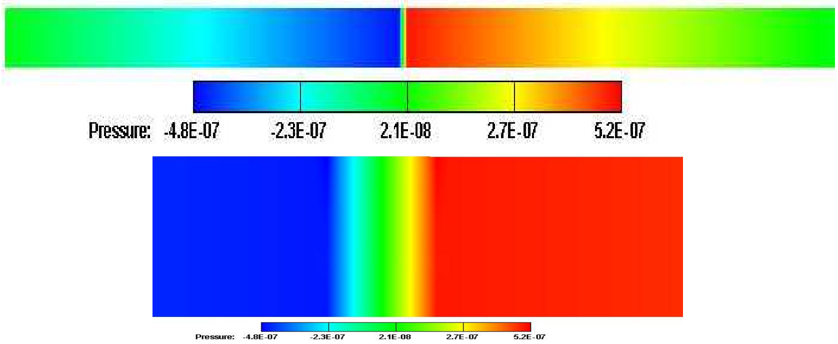


Fig. 4. Variation of ζ-potential as function of V_G.



a) $V_G = 36$ V



b) $V_G = -36$ V

Fig. 5. Pressure variation along the channel.

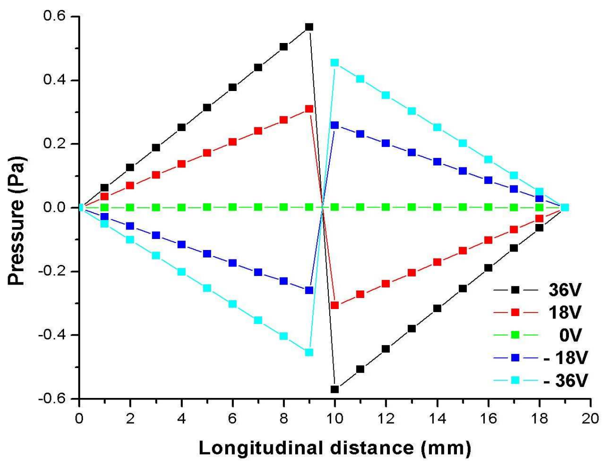


Fig. 6. Pressure variation along the channel (reference pressure = 0).

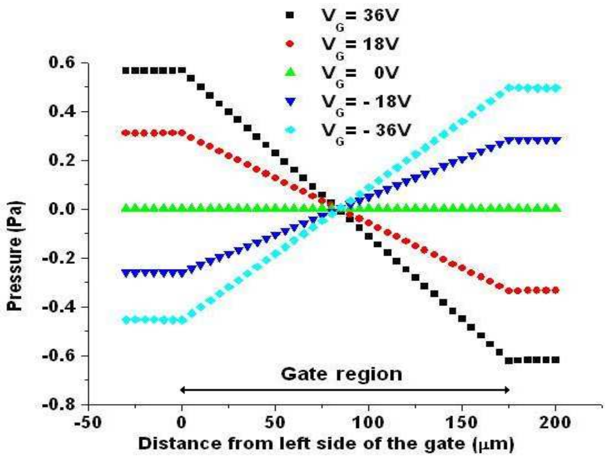


Fig. 7. Pressure variation along the gate region (reference pressure = 0).

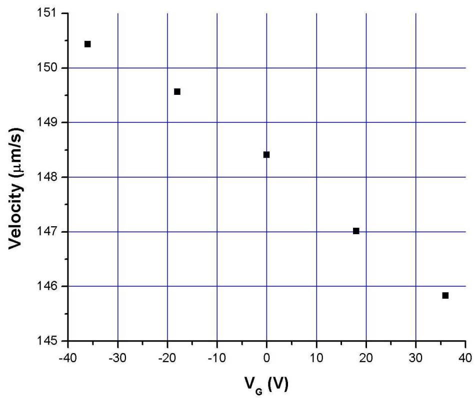


Fig. 8. Uniform velocity at long distance from the gate region.

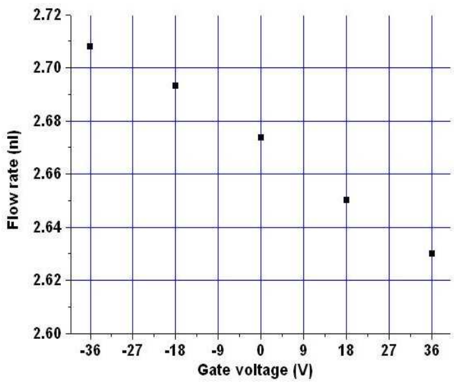


Fig. 9. Change in flow rate (nl) as a function of V_G.

4. Conclusions

The behavior of the electroosmotic flow in a micro-electronic fluidic system has been modeled for operating conditions in a fault-free case. The performed analyses give basis for fault simulations of microelectronic fluidic devices. The results are promising for future developments of FlowFETs.

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