FLOW FIELD EFFECT TRANSISTOR WITH POLARISABLE INTERFACE FOR ENHANCED SAMPLE SORTING IN MICRO-TAS

Sébastien Méance[1], Adrien Plecis[2], Syrine Chebil[1], Sonia Korchane[3, 4], Issam Charhrouchni[1], Antoine Pallandre[3, 4] and Anne-Marie Haghiri-Gosnet[1]

[1]*Laboratoire de Photonique et de Nanostructures, CNRS – UPR 20, Marcoussis, France,*
[2]*Elvesys, Pépinière Paris Santé Cochin, Paris, France,*
[3]*Univ Paris-Sud, Faculté de Pharmacie, Châtenay-Malabry, France*
[4]*Institut Galien Paris-Sud, CNRS – UMR 8612, Châtenay-Malabry, France*

ABSTRACT

We propose a novel route to build Flow Field Effect Transistors thanks to the deposition of ITO/SiC bilayer in microfluidic chips. We demonstrate the ability of this thin microfluidic component to tune the velocity of latex beads in during pure electrokinetic sequences. A Wheatstone fluidic bridge geometry was used to measure velocities by particle image velocimetry (PIV) in real time of the fluorescent latex beads. The low electric potential applied in those experiments opens an opportunity to integrate such transistors in future portable microfluidic devices.

KEYWORDS

Microfluidic transistor, electrophoretic separation, electroosmotic flow, polarizable interface

INTRODUCTION

Control of surface charges during electrokinetic migration is a major challenge of MICRO-TAS. Since Van den Berg's group introduced Flow Field Effect Transistors (FFET) in the late 90's, the protonation/deprotonation phenomena as well as the distribution of ionic species in the thin interfacial layer were showed to be of crucial importance to determine the microfluidic flow [1]. We worked on Polarizable Interfaces as a fluidic transistor (PI-FFET) that differs from the Metal-Insulator-Electrolyte (MIE) based FFETs that require high voltages for the control of electrokinetic transport. The integration of PI-FFET in microfluidic chips allows a modulation of electrokinetic transport rate with low gate voltages that remains the main advantage of PI-FFET as compared to the MIE components [2, 3]. In this paper, we report our latest results to tune the transport of charged analytes with an ultralow voltage configuration.

EXPERIMENTAL

A glass photosensitive-PDMS glass technology was used to fabricate sandwich microchips in a clean room. This study was achieved using a microfluidic Wheatstone bridge technique [4]. We investigate the potential of this new generation of PI-FFET that integrates a 200nm thick ITO/SiC gate electrode (Figure 1) in direct contact with the electrolyte to precisely tune the electrokinetic flow. The global hydrodynamic flow was controlled in the Wheatstone bridge by adjusting the electric potential at both ends of the fluidic transistor.

The instrumentation coupled with the electronic configuration of our platform (Figure 2) was able to finely modulate the fluidic stream under a 5V transverse electrical voltage with a gate voltage lower than 1V. In order to obtain a stable flow control, platinum measurement electrodes were integrated at a 20µm distance from the PI-FFET gate control electrodes (see figure 1C). These electrodes that were connected to voltage follower with operational amplifiers were used as reference electrodes to perfectly adjust PI-FFET gate voltage according to the liquid potential measured at channel entrance. The challenging voltages used in our platform were achieved because the potential of the electrolyte can be determined without current leakage in order to finely adjust the gate voltage that controls the flow distribution all over the fluidic network. This original approach enabled us to minimize electrochemical deterioration of polarizable interfaces reported before [2] and to proceed to systematic evaluation of charged particle transport through our gate channels.

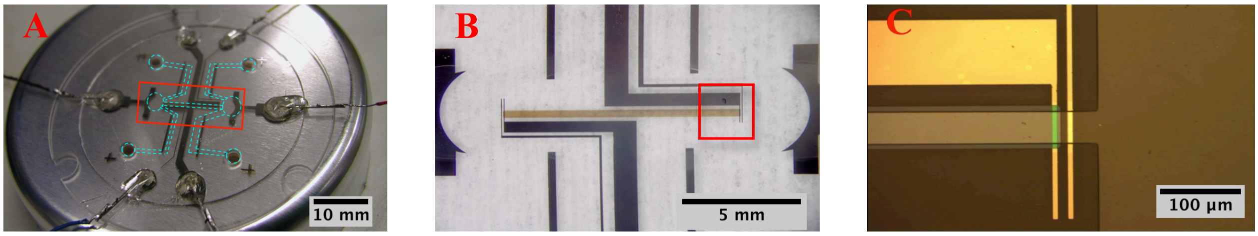

Figure 1. The Wheatstone fluidic bridge that integrates a PI-FFET in the central channel: (A) the whole chip with additional blue dashed lines to show the fluidic network (B) a zoom of the PI-FFET in the central channel showing the SiC/ITO interface in brown (C) a second zoom at one end of the polarizable interface corresponding to the red line rectangle in A and B that shows the gate control electrode on top of the ITO/SiC bilayer and the reference electrode for a precise measurement of the liquid potential at the entrance of the channel.

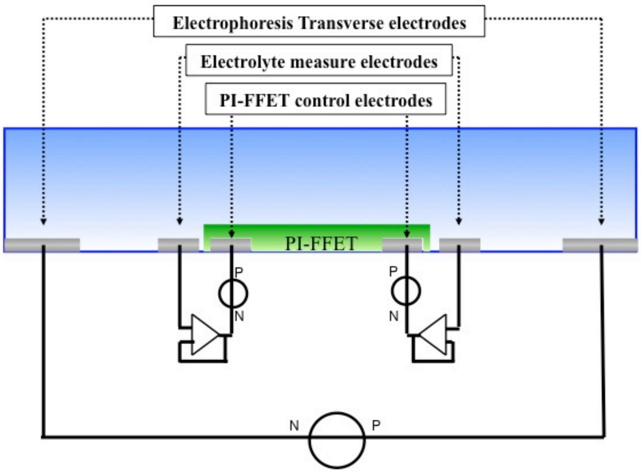

Figure 2. The 3rd generation of PI-FFET: schematic view of the central channel that integrates control and references electrodes with specific electronics for voltage adjustment.

RESULTS AND DISCUSSION

The transport rate of carboxylated polystyrene beads was measured at gate channel entrance using cross-correlation particle imaging velocimetry (Figure 3). The transistor enslaves the electrophoretic flow in the center channel of the chip, while electrophoretic motion of the particles remains constant. At moderate ionic strengths (1mM KCl), the mean velocity of particles decreases as a function of the gate voltage by a factor up to three (Figure 4). We could observe that the control of the electro-osmotic counter flow remains maximal under 300mV.

The design and microfabrication of the polarizable interface, i.e., the thin bilayer of ITO/SiC was chosen since the expected parallel resistance model was not experimentally verified. A very thin conductive layer of ITO shall improve the control length of the polarizable SiC layer and its attachment to inner wall of the microfluidic channel. It could allow a better distribution of the charge at liquid/transistor interface. Moreover the electrochemical reactions may occur at higher voltages. Under these conditions the removal of residual diluted gas in the KCl solution helps to prevent such destructive reactions. However, the originality of our approach is based on the introduction of reference electrodes that are connected to two independent voltage followers in order to apply the correct gate voltage inside the polarizable window of the interface. These references electrodes avoid any destruction of the SiC/ITO interface. Indeed electrochemical characterization of this bilayer has been also performed in conventional glass cell to determine the polarizable window of the gate and thus the range of usable gate voltage.

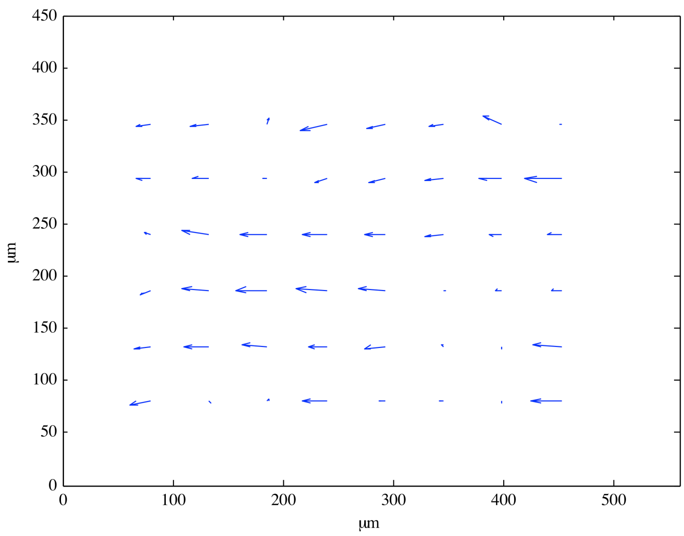

Figure 3. PIV vector field measured in a lateral channel (300µm) at a 1 cm distance away from the PI-FFET. The 3.33V/cm electric field is generated in the center channel.

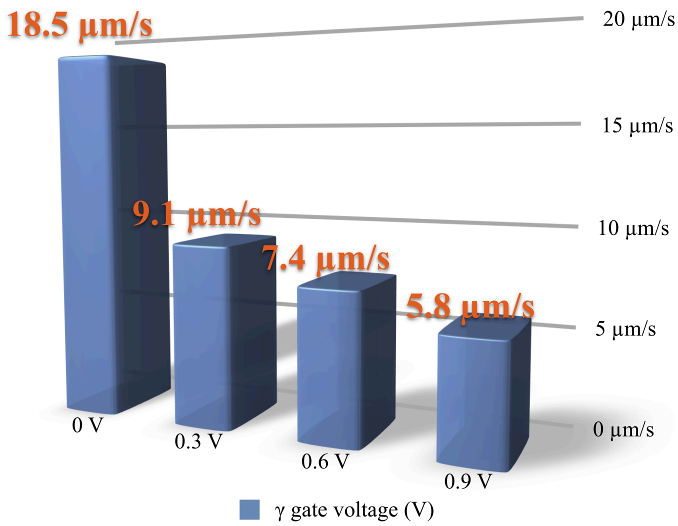

Figure 4. PIV mean velocity of carboxylated polystyrene microbeads as a function of gate voltage applied symmetrically on the PI-FFET control electrodes.

CONCLUSION

With this new generation of bilayer ITO/SiC polarisable interface, we succeeded in precisely tuning the transport rate of particles in PI-FFETs using low electric consumption system. The transverse and gate voltages used during these experiments (< 5V) point out that PI-FFET could be implemented in portable MICRO-TAS [5]. The mobility control in the gate channel opens the route to a new kind of sample sorting. The lateral reference electrodes also enabled us to adjust the local potential of the PI-FFETS independently of the transverse electric field. These PI-FFETs could represent a new opportunity to massively integrate such molecular transistors in MICRO-TAS.

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CONTACT

A-M Haghiri-Gosnet +33 1 69 63 61 22 or anne-marie.haghiri-gosnet@lpn.cnrs.fr