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

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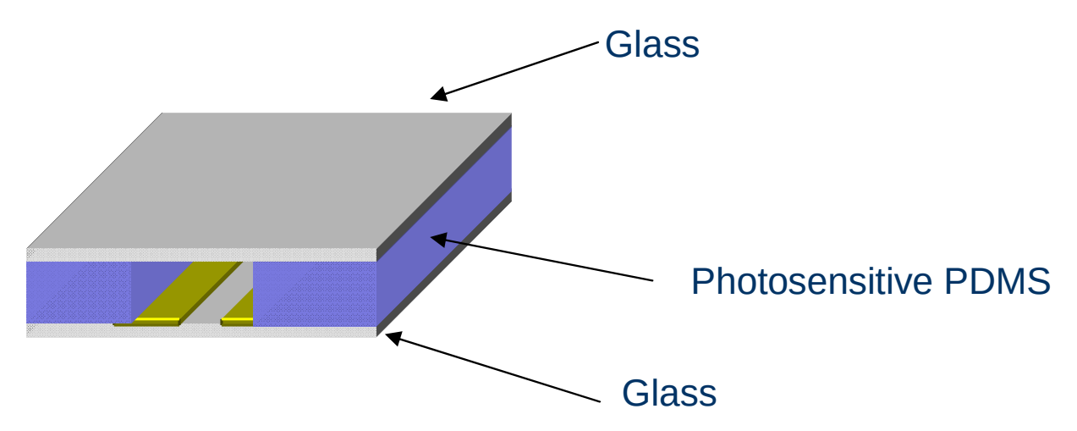
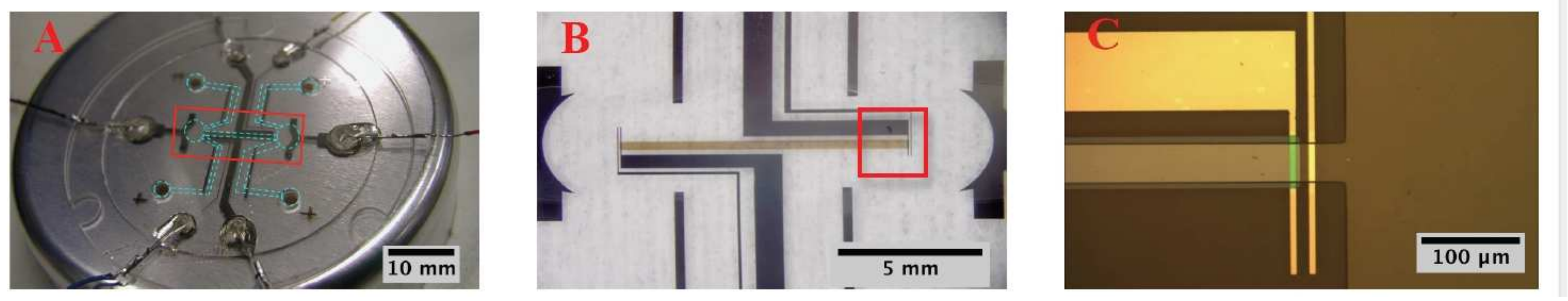
INTRODUCTION

Control of surface charges during electrokinetic migration is a major challenge of MICRO-TAS. Before 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 of crucial importance to the microfluidic flow. We worked on Polarisable Interfaces as a fluidic transistor (PI-FFET) that differs from the metal-insulator-electrolyte (MIE) based FFET that require high voltages for the control of electrokinetic transport. Their integration in microfluidic chips showed a modulation of electrokinetic transport rate with low gate voltages which remains the main advantage of PI-FFET as compared to the MIE components.

MICROFABRICATION

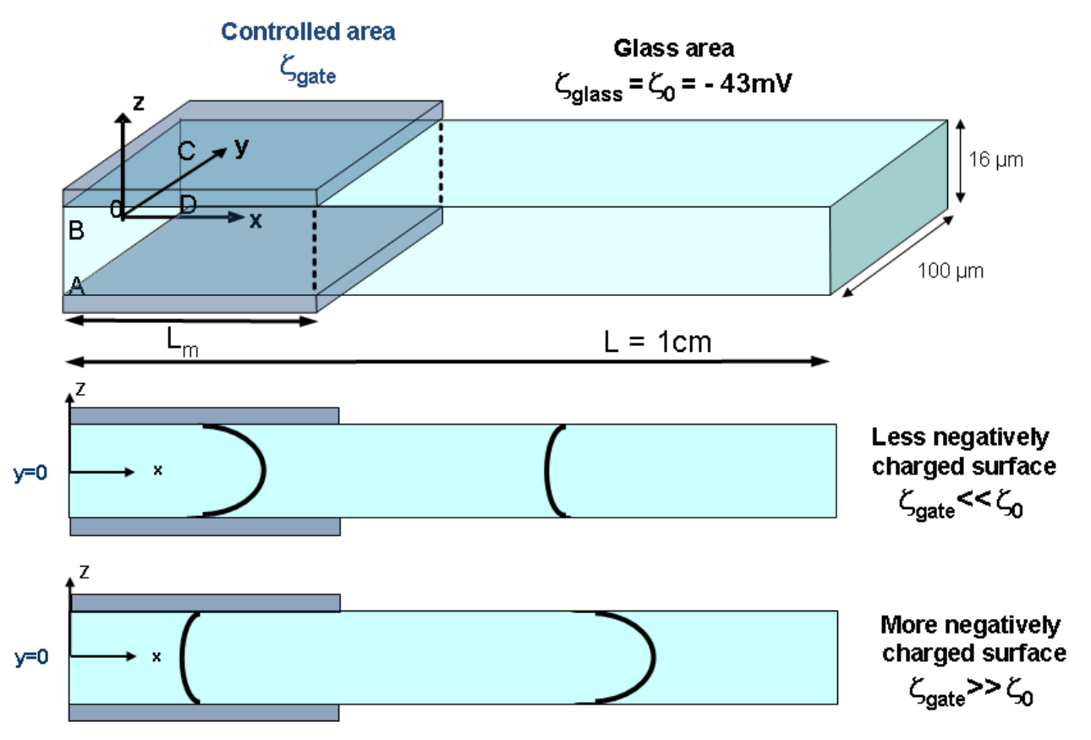


A photosensitive PDMS glass technology was used to fabricate hybrid microfluidic chips in a clean room. The microfabrication method allows to add several electrodes made of platinium. The inlet and outlets of the microchip are sand-blasted on the upper side of the glass.



The three optical pictures show the Wheatstone fluidic bridge that intregrates 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.

COMPUTATIONAL STUDY OF VELOCITY PROFILE

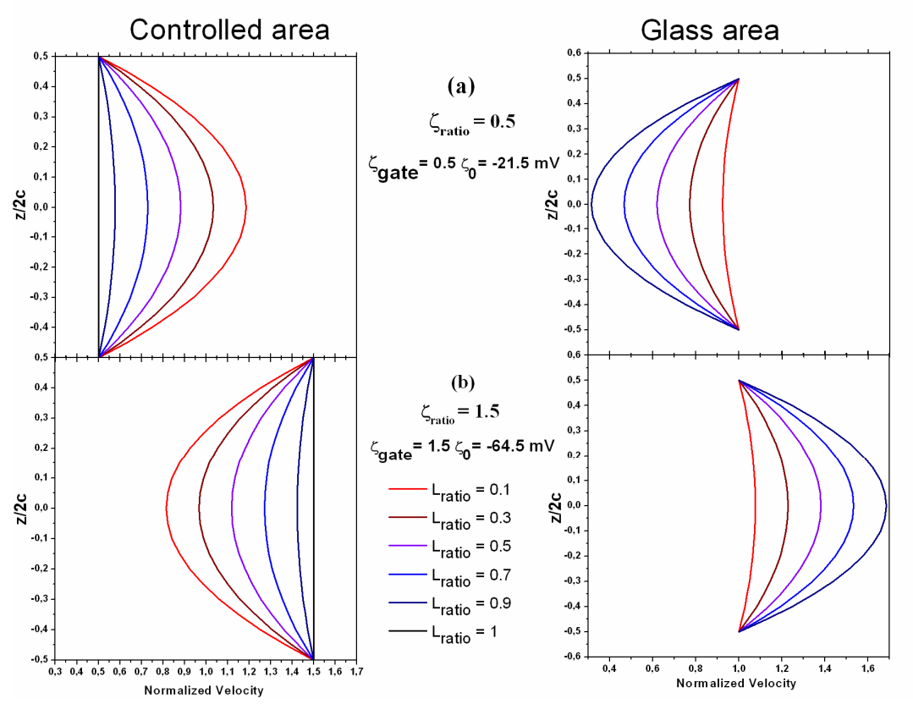


$$u(x,y,z)=-\frac{U_{pp}}{\eta}\frac{dp}{dx}+\frac{\varepsilon_0\varepsilon_r\psi}{\eta}E$$

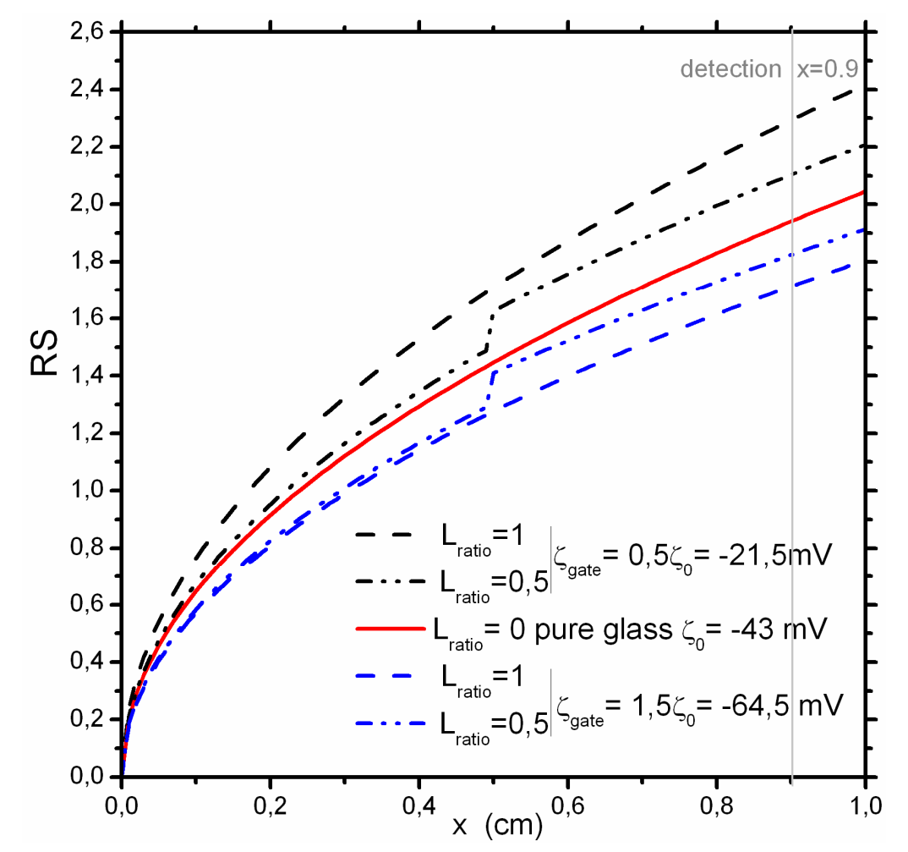
The role of the surface coverage $\mathbf{L_{ratio}=L_m/L}$ of the gate (PI) and of the zeta potential modulation ζ_{ratio} $=\zeta_{gate}/\zeta_{0\,glass}$ on the velocity profile has been studied in a channel bearing a FFET.
Two methods were used: (i) an analytical method based on the Lubrification theory* and (ii) 2D COMSOL simulation model using the Helmholtz-Smoluchowski infinitively thin EDL slip boundary conditions.Resolution can be expressed as function of the two key parameters ζ_{ratio} and $\mathbf{L_{ratio}}$:

$$RS(x)=\begin{cases} RS_{gate}(x)=\sqrt{\dfrac{V}{32D_m}}\dfrac{x}{L}\sqrt{\mu_{eff,glass}(L_{ratio},\zeta_{ratio},x)}\,\dfrac{\Delta\mu_{app}}{\mu_{app,avg-gate}} & \text{if } x\le L_m\\ RS_{glass}(x)=\sqrt{\dfrac{V}{32D_m}}\dfrac{x}{L}\sqrt{\mu_{eff,glass}(L_{ratio},\zeta_{ratio},x)}\,\dfrac{\Delta\mu_{app}}{\mu_{app,avg-glass}} & \text{if } L_m<x\le L\end{cases}$$

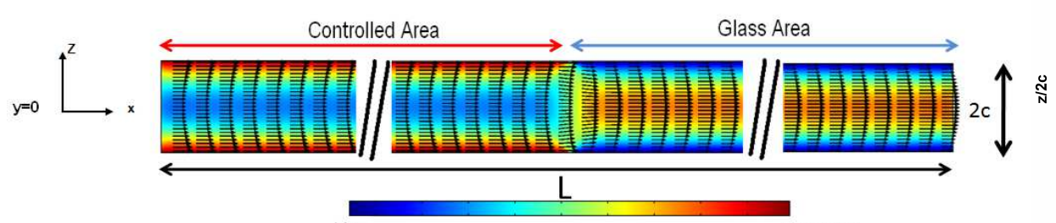
Analytical results

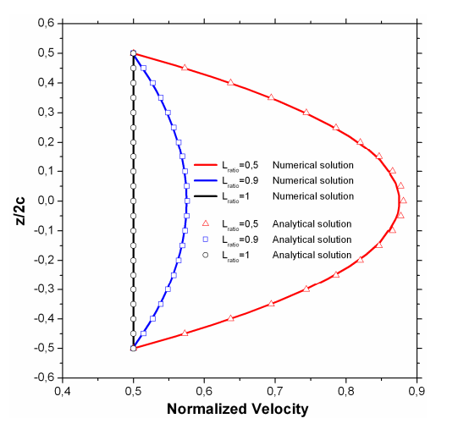


Resolution in hybrid microchips is optimized for EOF modulation with ζ_{ratio} <1 and the fully covered FFET chip (L_{ratio}=1) exhibits the larger RS value of 2.3



2D COMSOL simulations

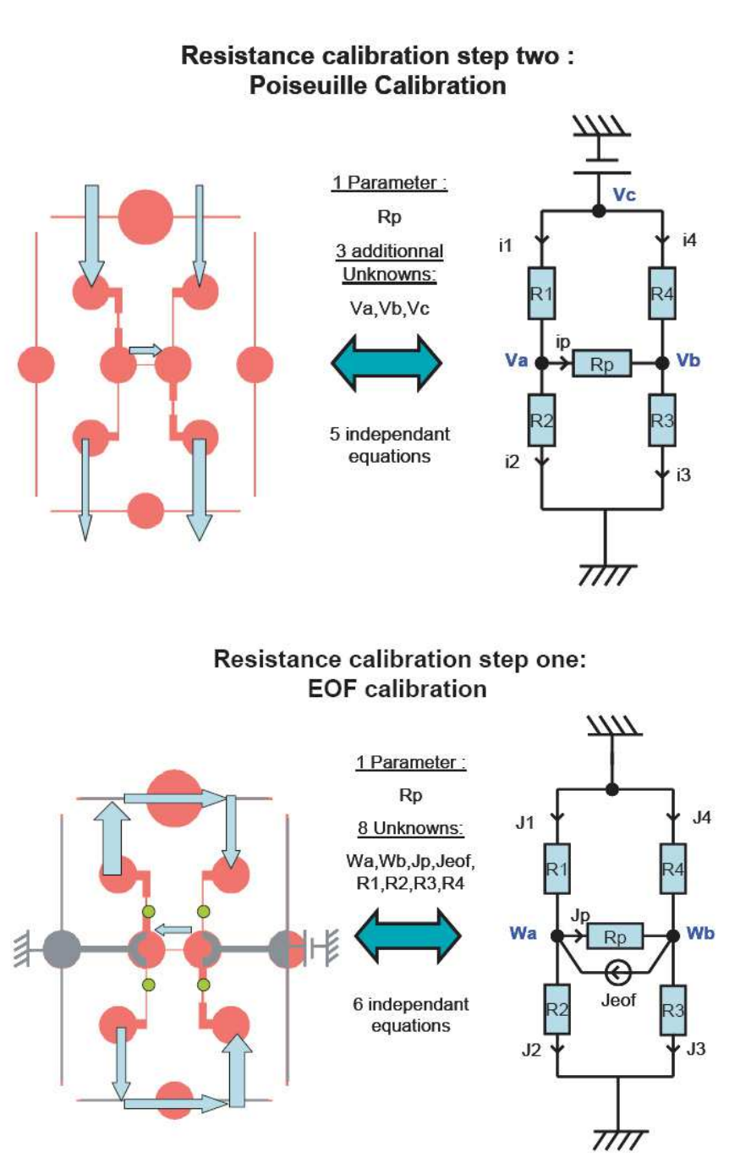




The parabolic velocity profiles in a rectangular microchannel bearing a FFET may lead to highly resolved electrophoresis

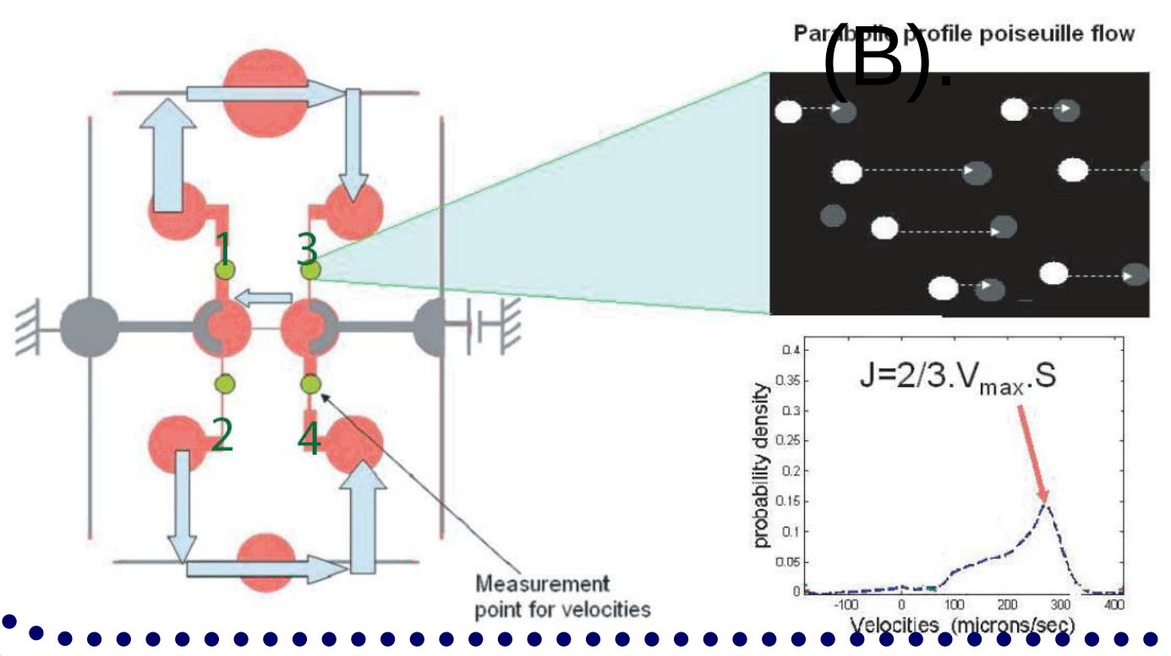
* Datta, S., Ghosal, S., Patankar, N. A., *Electrophoresis 2006, 27, 611-619*

EOF MEASUREMENT AND FFET

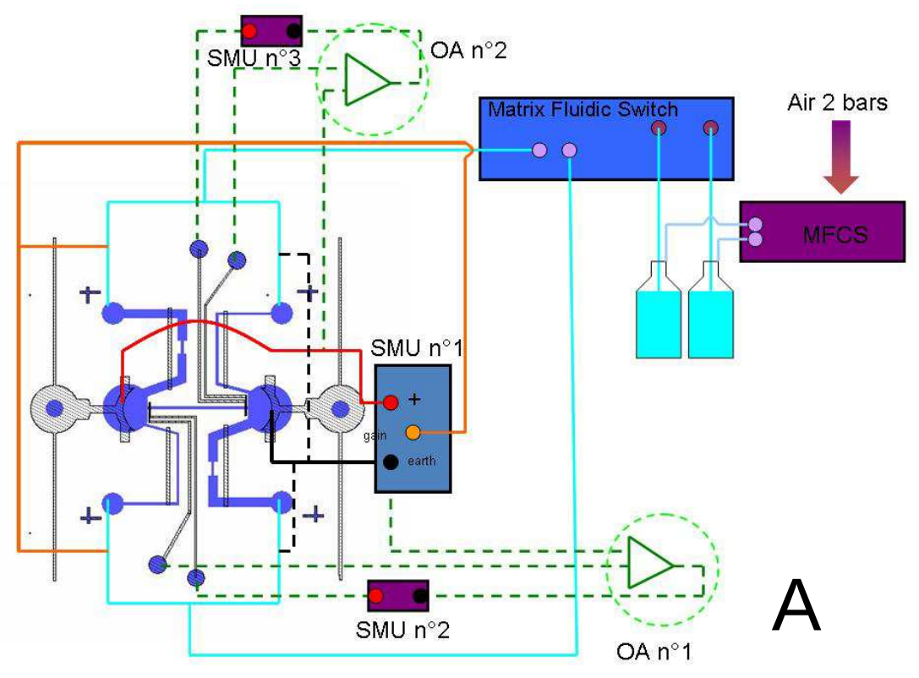


A

First the fluidic resistances of the four side channels are measured with two calibration steps: electrokinetic regime and Poiseuille regime (A). Then the electro-osmotic flow measurement is obtained by particle anemometry in one of the four side channels with a CCD camera (B).

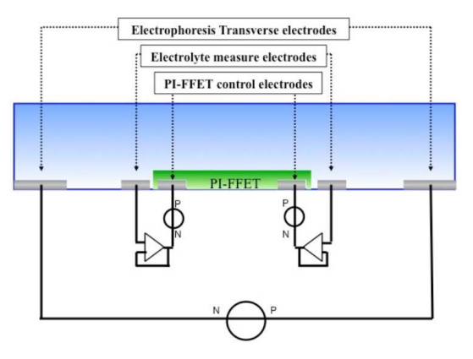


B



A

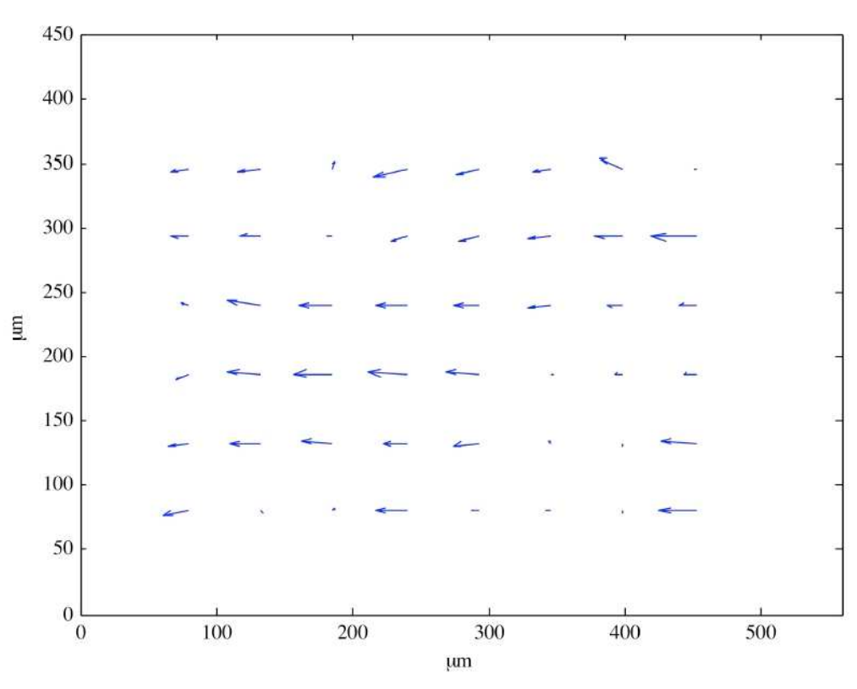
The whole set-up of the EOF measurement is presented in figure (A). It includes fluidic inlet / outlets and electronic to control the fluidic transistor and the electrophoresis. A simplistic view of the central channel of the Wheatstone fluidic bridge (B).



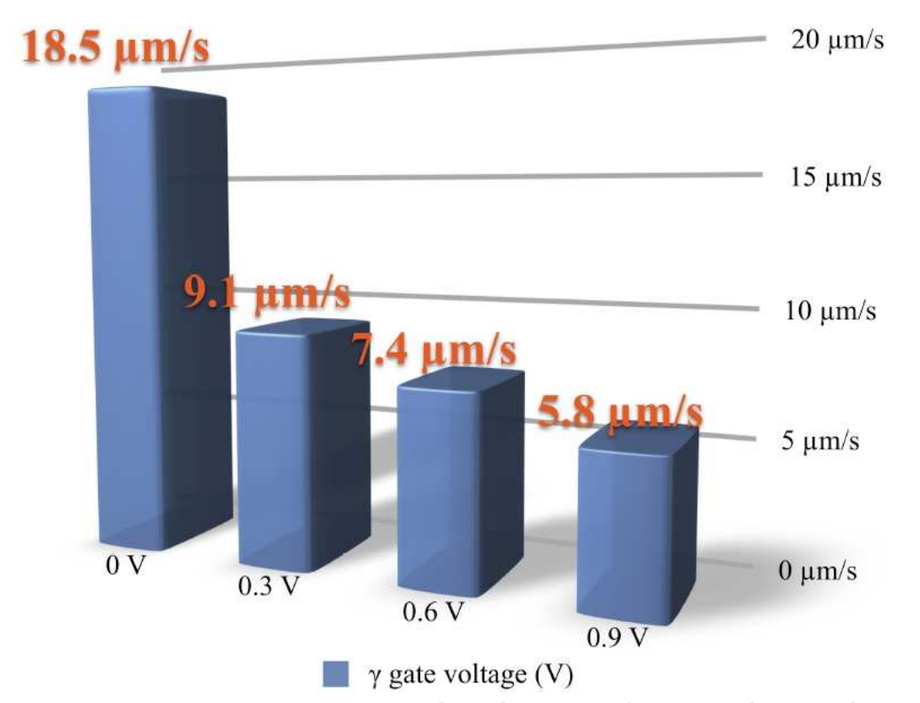
B

EOF MODULATION by FFET

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. 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.



PIV vector field in the lateral channel (300µm width) obtained with a 3.33V/cm electric field.



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

CONCLUSION AND OUTLOOK

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. 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.