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EWOD STABILIZATION OF TWO LIQUID STREAMS ALONG A MICROCHANNEL AND EHD-INDUCED ENHANCEMENT OF INTERFACIAL MASS TRANSFER

Y. Ishida¹, L. Davoust², A. Glière¹, J. Gratier¹ and N. Sarrut¹

¹ CEA – LETI, MINATEC, 17, rue des Martyrs, 38054 Grenoble cedex 9, FRANCE

² CNRS, LEGI, BP 53, 38041 Grenoble cedex 9, FRANCE

ABSTRACT

This paper presents a new micro-device for liquid-liquid extraction in which two immiscible liquids flow in parallel along a microchannel located after a T-junction. Two electrical phenomena, electrowetting on dielectrics (EWOD) and electrohydrodynamics (EHD), respectively allow for the stabilization of the meniscus between the two liquid streams and the enhancement of interfacial mass transfer.

Keywords: Electrowetting, Electrohydrodynamics, Interface, Micro-extractor

1. INTRODUCTION

A large number of microchips using both microfluidic and electrical fluid control for performing chemical analyses have been demonstrated. For instance, electrical processes have been used for handling reagents, dispensing liquid samples, separating or transferring chemical species [1]. This paper presents a new micro-device for liquid-liquid extraction in which two immiscible liquids flow along a micro-channel located after a T-junction. Our approach to enhance mass transfer differs from usual strategies developed in the literature [1, 4-7] since both electrohydrodynamics (EHD) [2] and electrowetting on dielectrics (EWOD) [3] are involved. The top and bottom walls of the micro-channel are made of ITO-coated glass and silicon, respectively. The side walls are made of dry resin (Ordyl, Elga Europe). The whole inner surface of the channel is hydrophobically coated.

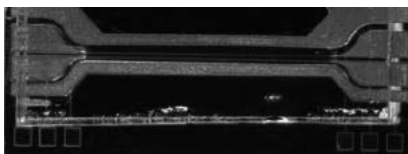


Figure 1. A snapshot of the micro-extractor.

3. EWOD STABILIZATION

Chemical transfer in integrated microfluidic devices strongly depends upon the possibility to stabilize fluidic streams in microchannels. The stability of the meniscus separating liquid streams is usually dictated by their internal geometry and the pressure heads applied between the ends of the channels. Here, by properly designing the microchannel manifold, one provides EWOD stabilization of the interface using a simple voltage-control circuit (Figures 1, 2, 5a). A gold electrode is patterned on one half of the microchannel silicon substrate and then covered with a thin dielectric film. The contact line at the bottom of the meniscus is electrically pinned and Laplace jump pressure is balanced by capillary and electrostatic pressure. It is thus possible to stabilize the location of the liquid-liquid interface during microchannel filling (Figure 3). When EWOD actuation is turned off, the water/cyclohexane interface is proven to be unstable and a plug flow arises.

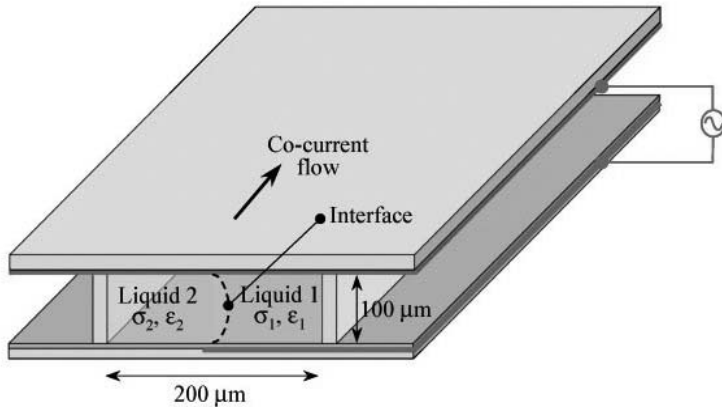


Figure 2. Geometry of the micro-extractor as sketched. Both liquids are in contact with the top electrode while the half-width bottom electrode is buried under a thin dielectric film.

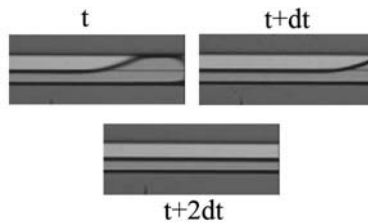


Figure 3. EWOD stabilization of the liquid streams (cyclohexane/colored water) along the micro-channel observed through the transparent top electrode during filling process.

4. EHD-INDUCED MIXING

Interfacial EHD is used to enhance mass transfer across the meniscus. Here, mixing within the micro-extractor typically occurs by the interplay of molecular diffusion and EHD-driven convection at the interface. In usual applications, the Schmidt number is so large that even a weak convective flux is capable of enhancing significantly interfacial mass transfers. Considering the approximation of electro-quasistatics in moving fluids and assuming that the Ohmic current is much larger than the displacement current, it can be shown that the only non-vanishing electric charges accumulate at the liquid-liquid interface, provided the dielectric permittivities of the liquids are different. The bottom electrode occupies only one half of the cross-section whereas the upper electrode is standing all over the channel. Therefore, the electric field at the interface exhibits both tangential and normal components responsible for the arising of a tangential electric stress along the interface. This surface electric stress balances a viscous stress and this gives rise to a recirculating fluid motion within the bulks. By considering that the ratio of the EHD velocity to the axially pressure-driven velocity is a small number, a perturbation technique is carried out, which allows for calculating the axial flow independently of the EHD recirculating motion, provided that the electric Reynolds number remains small. EHD-induced mixing is shown in figures 4 and 5b when the interface is perfectly plane or curved. Regarding mixing efficiency, a realistic situation is proposed with a 70° wetting angle and an AC voltage whose peak amplitude and frequency are 50V and 3 KHz.

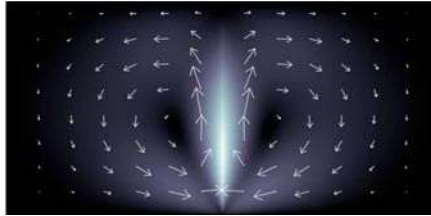


Figure 4. EHD recirculating flow when a perfectly plane liquid-liquid interface is assumed. The velocity module is represented by the background grayscale colormap. (max. velocity: 0.0175 mm/s, applied bias: 50V, frequency: 3 KHz).

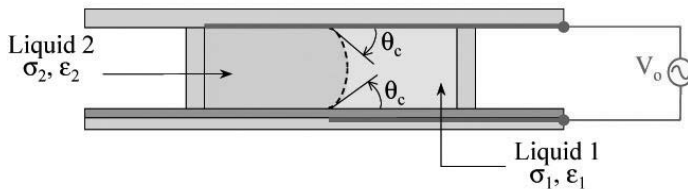


Figure 5a. The case of a EWOD-driven meniscus with a wetting angle $\theta_c=70^\circ$.

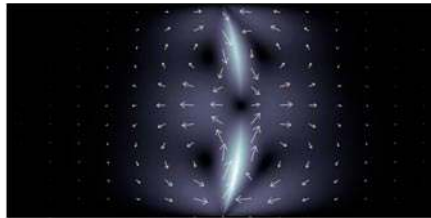


Figure 5b. EHD vortices as computed with the curved meniscus sketched in Figure 5a. The velocity scales favorably (max. velocity: 0.16 mm/s, applied bias: 50V, frequency: 3 KHz).

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