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Integration of capillary and EWOD technologies for autonomous and low-power consumption micro-analytical systems

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Abstract

This work presents a miniaturized system combining, on the same microfluidic chip, capillarity and electrowetting-on-dielectric (EWOD) techniques for movement and control of fluids. The change in hydrophobicity occurring at the edge between a capillary channel and a hydrophobic layer is successfully exploited as a stop-and-go valve, whose operation is electronically controlled through the EWOD electrodes. Taking into account the variety of microfluidic operation resulting from the combination of the two handling techniques and their characteristic features, this work prompts the development of autonomous, compact and low-power consumption lab-on-chip systems.

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1. Introduction

Lab-on-chip (LoC) devices are miniaturized systems able to perform biochemical analysis by integrating, in a small chip of few centimeters square, several modules that implement the functionalities of a standard laboratory for biomedical analysis and diagnostics [1, 2, 3]. The involved analytical and diagnostics aspects imply the movement of solutions along microfluidic channels. Actually, capillary microfluidic systems allow to obtain an autonomous flow

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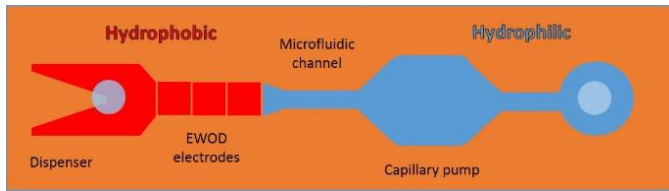


Fig. 1. Top view of the basic device.

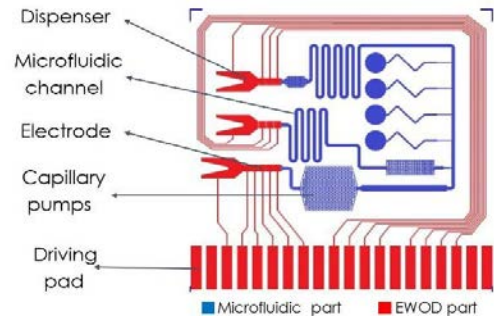


Fig. 2. Design of the device.

without the need for external pumping system and bulky connection, but timing and synchronization of lab-on-chip operations are not easily controlled [4, 5].

In order to overcome these issues, our microfluidic system combines two different techniques to drive liquids through a microfluidic network: the capillarity, that takes advantage of the surface tension effect, and the electrowetting-on-dielectric (EWOD) approach, that changes from a hydrophobic to a hydrophilic status the wettability of a surface through an electric field. The main idea of this paper is to use the EWOD technique to control the dispensing of a fluid in a capillary-driven micro-channel only when an appropriate voltage is applied on the electrodes. In particular, in the implemented system, the electric fields applied over the hydrophobic regions control the starting time of the fluid injected in the dispenser. When it reaches the hydrophilic region, the capillary flow forces move the fluid through the microfluidic channels [6, 7].

These two technologies have been integrated on a single glass substrate. To this aim, the technological steps for the fabrication of regions characterized by different hydrophobicity have been designed and optimized taking into account the hydrophobic materials characterization. The performed tests prove the suitability of the proposed microfluidic chip as low-power consumption, autonomous and compact lab-on-chip system.

2. Device design

The integration of EWOD and capillary technologies on the same glass substrate has been implemented through the basic device depicted in Fig. 1. The fluid is injected in a hydrophobic dispenser and it goes along the hydrophilic channel driven by capillary forces only when a sequence of specified voltage is applied to the EWOD electrodes [8]. The complete system is reported in Fig. 2: a 5×5 cm² glass substrate hosts the EWOD dispenser, the electrodes and their relative metal connections (red regions) and the capillary-driven micro-channels (blue regions).

Characterization of hydrophobic materials (Teflon AF2400 and Cytop) has been initially done through contact angle measurements with standard needle set-up in open configuration as a function of the applied voltage. The Cytop film allows to obtain the same contact angle variation applying lower voltage with the advantage to have lower baking temperature than Teflon. The variation of contact angle between the droplet and the Cytop surface as function of the applied voltage is reported in Fig. 3 that also shows how the wetting behavior of the liquid depends on the polarity of the applied voltage.

As shown in Fig. 3 a significant contact angle variation from 110° to about 71° is achieved applying a voltage around 15V in case of 2.6µm-thick dielectric layer. A good agreement between experimental results and the Lippmann-Young equation [9, 10] shown in (1) has been achieved.

$$\cos \theta = \cos \theta_0 + \frac{\epsilon_0}{2d_{EDL}\gamma_{lv}} (V - V_0)^2 \tag{1}$$

A contact angle saturation is observed applying positive voltages: according to literature this effect results from the trapped charges in the dielectric and/or hydrophobic layer upon voltage application [11, 12].

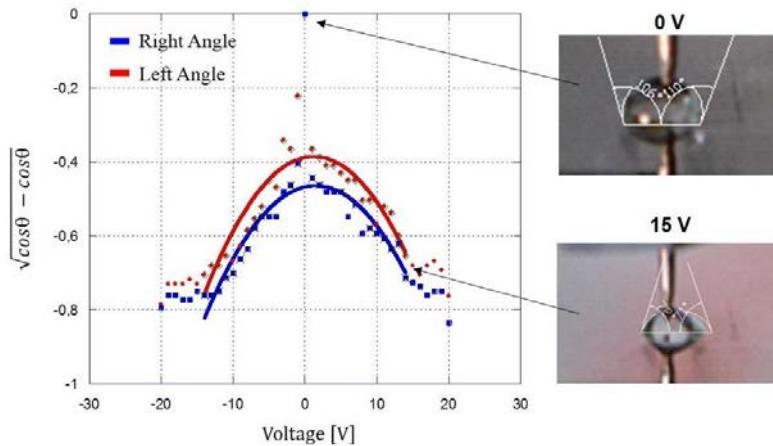


Fig. 3. Contact angle as a function applied voltage with Cytop hydrophobic layer. Lines refer to the Lippmann-Young equation, symbols to the experimental measurements.

3. Device fabrication and testing

The first technological step has been the fabrication on the same glass substrate of spatially selected hydrophilic and hydrophobic regions. This has been achieved through an optimization of the Cytop deposition parameters. Fig. 4 demonstrates the successful patterning: a glass substrate is covered with a hydrophobic surface having hydrophilic spots to capture the blue colored water droplets.

A cross section of the basic configuration, together with the used materials, is shown in Fig. 5. It includes a top and a bottom patterned glass substrates, which are coupled and bonded together through two mirrored SU-8 microfluidic networks. The device fabrication required the optimization of different technological steps and in particular of the SU-8 thickness and bonding pressure.

The process steps for the fabrication of the bottom layer are:

- Deposition of a stack Cr/Al/Cr layer (300Å/1500Å/300Å) acting as electrode and its patterning by photolithography;
- Spin coating of a SU-8 3005 layer acting as dielectric layer and its lithography to cover the metal electrodes;
- Spin coating of a Cytop as hydrophobic layer and its patterning through lift-off process to cover the electrodes;
- Spin coating of a SU-8 3050 layer and its lithography to create microfluidic channels.

The process steps for the fabrication of the top layer are:

- Cleaning of a glass already covered with Indium Tin Oxide (ITO);
- ITO wet etching to define a conductive layer in correspondence of the bottom layer electrodes;
- Spin coating of the Cytop hydrophobic layer with same process of bottom layer;
- Spin coating of a SU-8 3050 layer and its lithography to create microfluidic channels, dispenser, capillary pumps and the space over the electrodes;
- Drilling holes at the end of the capillary pumps and at the inlets.

The last step is the alignment of the two layers and their bonding using 0.04 kg/cm² pressure at 160°C for 40 minutes.

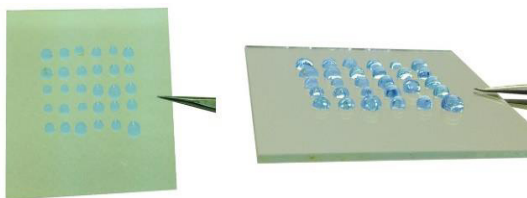


Fig. 4. Glass substrate with hydrophobic and hydrophilic area.

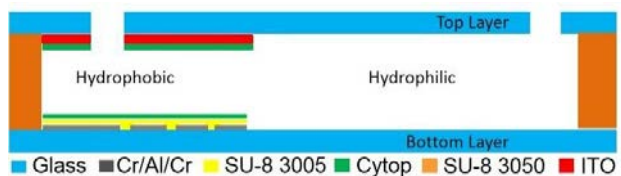


Fig. 5. Cross section of the basic device.

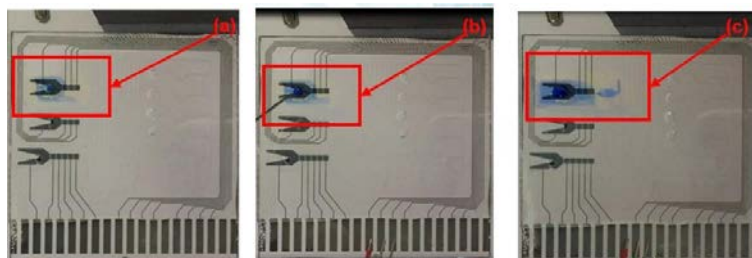


Fig. 6. Device operation showing EWOD dispensing and capillary flow.

Sequence of voltages applied to the EWOD electrodes: a) Dispenser: ON; first, second and third electrode: OFF. b) Dispenser, first electrode: ON; second and third electrode: OFF. c) Dispenser, first electrode: OFF; second and third electrode: ON.

A detailed sequence of the basic structure operation is shown in Fig. 6. At first, the fluid is injected in the dispenser, which is a hydrophobic region. When a voltage equal to 30V is applied, it becomes hydrophilic and fluid flows at the border of the first electrode (Fig. 6a). Applying the voltage sequence reported in the caption of Fig. 6, the fluid covers progressively the EWOD electrodes (Fig. 6b) until reaches the hydrophilic microfluidic channel (Fig. 6c).

4. Conclusion

This work demonstrates the successful combination of two techniques (EWOD and capillarity) and the possibility to develop autonomous and compact microfluidic networks, whose operations are electronically controlled. This is a very important result because the capillary action permits the development of miniaturized, low-consumptions systems while the EWOD technique allows the implementation of several microfluidic functions (triggering, mixing, dispensing, separation).

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