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Polydimethylsiloxane material as hydrophobic and insulating layer in electrowetting-on-dielectric systems

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ABSTRACT

Open and closed electrowetting-on-dielectric (EWOD) systems based on a spin coated polydimethylsiloxane (PDMS) layer are presented. The PDMS layer acts as both insulation and hydrophobic material. Characterization, through sessile drop experiments, shows the hydrophobic behaviors of the PDMS and saturation of the contact angle at negative bias voltage applied to the droplet. This behavior is ascribed to trapped carrier in the PDMS layer and explains the movement of the droplet toward the grounded electrode found in the EWOD experiments.

An electronic board controls all the signals needed for the actuation and sensing functionalities of the EWOD systems. Detection of drop position along the electrode array is successfully achieved by implementing the time-constant method, which evaluates the variation of electrode capacitance induced by the droplet presence on the PDMS surface corresponding to the metal electrode.

The microfluidic operations (movement, dispensing and splitting) in both open and closed configurations have been verified and accomplished at voltages around 200 V.

1. Introduction

Lab-on-Chip (LoC) devices are miniaturized systems able to perform complex bio-chemical analysis by integrating, in a small chip of few square centimeters, several modules that implement the functionalities of a standard laboratory for applications such as DNA and protein analysis, and biomedical diagnostics [1–4].

These analytical and diagnostic aspects imply the movement of solutions along microfluidic channels using continuous liquid flow that is achieved, in most cases, by using off-chip actuators, as peristaltic pumps and valves [5]. However, the complexity arising from the connections required to couple the mechanical parts to the LoC and the need of large mechanical or electrical energy sources to move solutions through the system have prompted the investigation of different fluid movement techniques [6,7].

An interesting alternative to continuous-flow microfluidics is electrowetting-on-dielectric (EWOD) technology. The EWOD technique is able to handle very small fluid quantity (down to picoliter) varying the contact angle of an electrically conductive liquid droplet placed on a hydrophobic surface by means of an external electric field [8–10].

Fig. 1 shows the typical EWOD structure, constituted by a metal electrode and an insulation hydrophobic layer, without (Fig. 1a) and with (Fig. 1b) a voltage applied between the droplet and electrode.

The contact angle change as a function of applied voltage is regulated by the Young–Lippmann equation [10] where γ_{LG}, γ_{SG}, and γ_{SL} are, respectively, the liquid–vapor, solid–vapor and solid–liquid surface tension, d is the thickness of the dielectric layer, ε_0 is the permittivity of free space, ε_r is its relative dielectric constant and V is the applied voltage. θ is the contact angle at the applied voltage V, while θ is the contact angle without applied voltage [10,11].

Two different electrowetting configurations are usually implemented: open and closed electrowetting. In the open configuration, the droplet of liquid is placed over a plate consisting of a substrate (usually glass) covered by patterned electrodes coated with a stacked structure of dielectric and hydrophobic layers. The electrode array provides the movement path; the dielectric sustains the electric field needed for the technique avoiding electrolysis while the hydrophobic layer provides the surface properties for the contact angle variation. In the closed configuration, the liquid is placed between two coplanar plates, the bottom and the top plate, separated by a spacer. The bottom plate is identical to the plate of the open configuration. The top plate, instead, consists of a substrate

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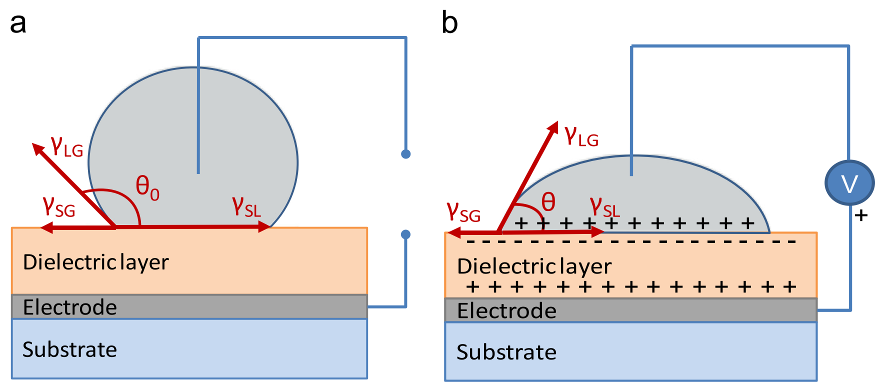

Fig. 1. Contact angle in a basic EWOD structure without (a) and with (b) an applied voltage between the droplet and the electrode.

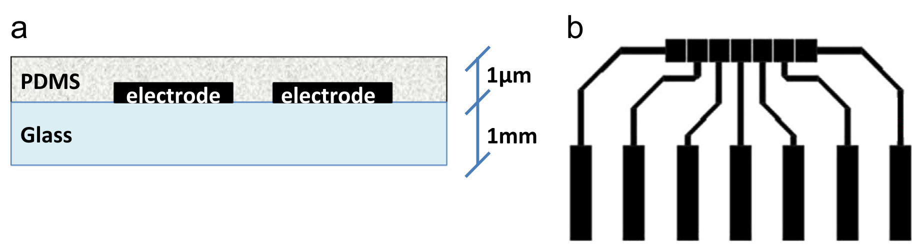

Fig. 2. Cross section (a) and top view (b) of the open configuration.

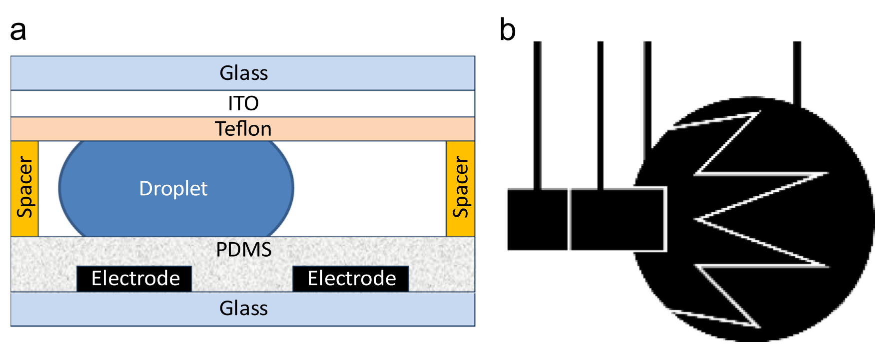

Fig. 3. (a) Cross section of the EWOD closed configuration and (b) particulars of the EWOD electrodes in the closed configuration showing the reservoir and the first electrode of the electrode array.

(usually glass also in this case) covered by a conductive layer, which acts as a counter-electrode, in turn coated with a thin hydrophobic layer.

The open configuration enables displacement and mixing operations, while the closed configuration adds dispensing of droplets from a reservoir and splitting of droplets in two parts [12–15].

In this paper, a spin coated polydimethylsiloxane (PDMS) layer is utilized as dielectric and hydrophobic material in both open and closed EWOD configuration. The thin film properties of PDMS as material for EWOD applications have already been investigated [16], and it has been shown, in a sessile drop experiment, that a large change of the contact angle can be induced and that the contact angle can almost return to the initial value [17]. This prompted us to develop our system where the EWOD functionalities are managed by an electronic circuit that generates all the control signals to achieve the droplet movement and detects the presence of the droplet over the electrodes in order to verify the correctness of the fluid manipulation.

The paper is organized as follows: Section II reports the whole system description including the EWOD systems and the electronic board. Section III presents the experimental results achieved in characterizing the PDMS material and the open and closed EWOD configurations. Section IV draws the conclusions.

2. System description

2.1. EWOD configurations

As reported above, we have implemented both the open and closed configurations. The cross section and top view of the open system are reported in Fig. 2. The device substrate is a 5×5 cm^2 glass on which an array of adjacent thin film metal electrodes has been fabricated in order to create the droplet path. The array is a line of 7 square-shaped electrodes of 1.5×1.5 mm^2 area spaced by 60 μm gaps. Each electrode is connected to a 2×9 mm^2 pad through a 100 μm wide metal line.