Handling droplets in 3 dimensions for Lab-on-Chip applications

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HANDLING DROPLETS IN 3 DIMENSIONS FOR LAB-ON-CHIP APPLICATIONS

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Abstract
A programmable device in which droplets can be handled in the 3 dimensions is presented. We explain vertical motions of droplets with theoretical keys and experimental observations. The device used to handle droplets is described and the handling of droplets of about 1 µL is demonstrated.
Keywords: 3D motions, droplet, Lab-on-Chip, electrostatic, lifting force

1. Introduction

Methods based on electrical fields have numerous assets in fluid management. EWOD devices are currently employed to move droplets in the micro-litre range on horizontal surfaces [1] while only few studies deal with vertical displacements [2]. Our aim is to adapt an EWOD device to move droplets also vertically by an electrical actuation. Droplets can be lifted to an upper position where they can be maintained during a controlled residence time and brought back to the initial lower surface.

2. Theory

Physics of the droplets interaction with a conducting plane are understood by studying the model of a spherical particle resting upon a single plane electrode. Lebedev & Skal'skaya [3] have calculated the so-called Maxwell electrical charge, acquired by a conducting sphere in contact with a perfectly conducting plate electrode, as well as the force acting on the sphere when the electrical field is considered uniform at a great distance. They showed that the force is independent of the orientation of the electrical field and that the force is always a lifting force. As a consequence, a sphere heavier than the surrounding dielectric medium and located on a plane electrode can be moved upwards with an appropriate electrical field.

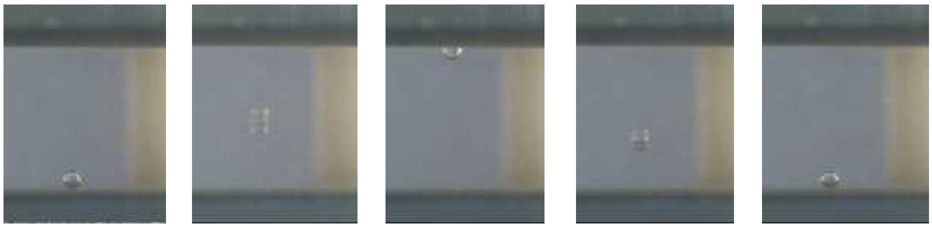
To build a theoretical model of the behavior of a droplet between two parallel plate electrodes, we adapt the model of Lebedev & Skal'skaya to take into account the wetting on surface. ElectroHydroDynamics equations are solved in appropriate coordinate systems to provide closed form expressions.

3. Experimental studies

A water droplet surrounded by mineral oil, located in a parallel plate condenser and lying on the lower electrode of the condenser is moved upwards (figure 1) when a voltage is applied between he upper and lower electrodes (about 1.5kV/cm). According to the theory, when the droplet is in electrical contact with an electrode the electrical force tends to detach the droplet thus when the droplet gets in electrical contact with the upper electrode the electrical force turns downwards.

In order to control the droplet position, the upper electrode is covered with a dielectric layer. Droplets cannot transfer their electrical charge with the upper electrode so the electrical force remains an upwards force and droplets are kept on the layer. Droplets are moved downwards by reversing the applied electrical field.

Capillarity forces are often undesirable because they would stuck droplets on a position (lower or upper position). In our experiments layers were chosen hydrophobic or treated to be hydrophobic.



(a) (b) (c) (d) (e)

Figure 1 : Experimental study of a water droplet in a parallel plate condenser. The distance between the electrodes is 10mm, the Teflon dielectric layer is about 1mm thick, the mineral oil used is from *Sigma*, the voltage sequence is 0V, +1600V, -1600V, 0V. The average speed of the droplet going upwards is about 29mm/s. (a) A droplet of water is resting on an electrode. (b), (c) Under an electrical field, the droplet is moved to the upper position onto the dielectric covering the upper electrode and kept in this position. (d), (e) Afterwards, the droplet is moved back to the lower electrode.

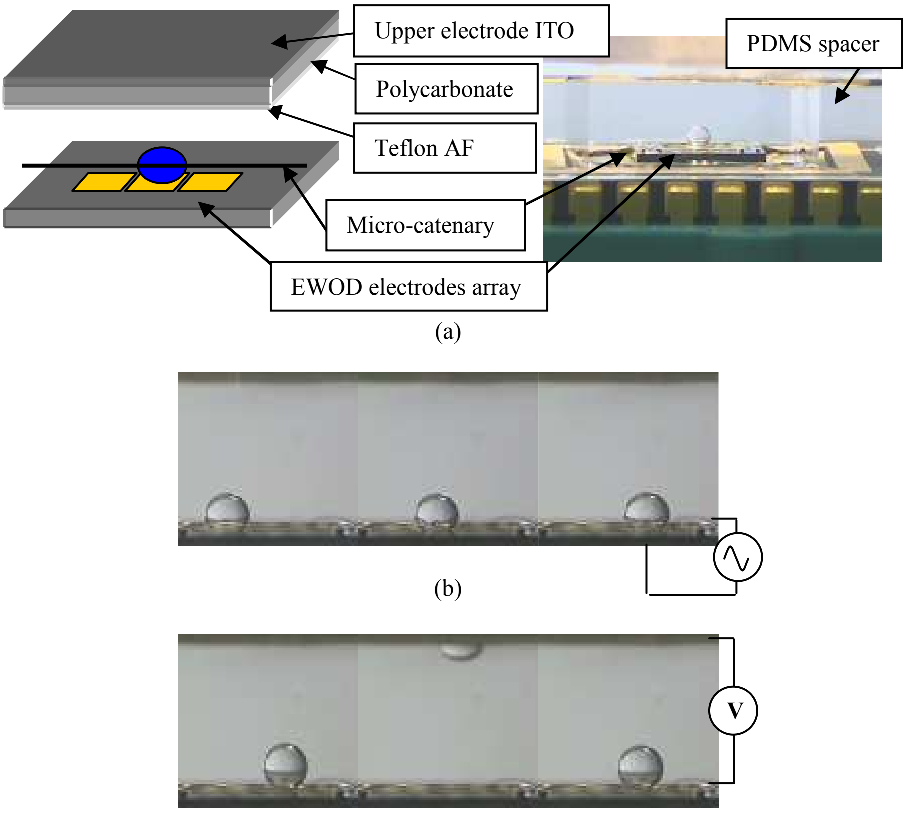
4. Chip design

The EWOD devices [1] we are currently developing use a gold micro-catenary as the electrical contact with the droplets to generate the horizontal motions on the electrode array. In addition with an extra upper isolated electrode, this catenary is also used to move droplets upwards and downwards by applying a vertical electrical field. The droplet displacement between the two plates is precisely controlled and reversible, droplets being handled along the 3 space dimensions. Such displacements are detailed in figure 2. The electrical field exerts a lifting electrical force on droplets which overcomes the gravity and the capillary forces. Afterwards, the charged droplet in contact with the top dielectric can be brought back by changing the sign of the electrical field.

The micro-catenary used in our EWOD devices to move droplets horizontally is also used as the lower electrode described above. The upper electrode is made of polycarbonate and an ITO layer and covered with a hydrophobic and dielectric layer of Teflon (figure 2). The PDMS spacer surrounds the device filled with mineral oil and observations are made through the spacer.

Electrowetting can retain droplets on the lower position even if an electric field is applied between the catenary and the upper electrode. As a consequence, droplets to move verticaly can be chosen.

This extra 3D droplet motion enlarges the scope of chemical and biological applications. One example could be to move quickly a droplet from the top surface to the bottom surface, both surface having temperatures necessary for thermal cycling. The ability to use the top and the bottom of a device permits to reduce the overall size of the chip and to tune finely reaction times.



(a)

(b)

(c)

Figure 2 : Horizontal displacement & Vertical displacement: A droplet of water (1µL) is handled by electrostatic actuation in mineral oil. In each case a schematic description of the device is given and pictures of the droplet in the situation described are shown. (a) Picture and schematic description of the device. (b) The droplet is resting on the lower surface and can be moved horizontaly by electrowetting ($60V_{rms}$, 3kHz). (c) Applying an electric voltage of 1600Volt, the droplet is moved to the upper position, the upper ITO electrode covered with dielectric layers of polycarbonate and Teflon AF 3% and located about 5mm above the lower position, and is kept on this position. The average speed of the droplet going upwards is about 31mm/s. Afterwards, the droplet is moved back from the upper position to the lower electrodes array and can be displaced again by electrowetting.

References

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