OPTO-ELECTROWETTING DEVICE FOR DNA AMPLIFICATION

Pooja Ramesh, Ralph Maessen, and Jaap den Toonder*
Philips Applied Technologies, THE NETHERLANDS

ABSTRACT

Electrowetting is a well known approach to achieve “digital microfluids” devices, in which µL-sized droplets can be manipulated over surfaces. Disadvantages of electrowetting are the need for a patterned electrode structure and corresponding complex interface with driving electronics, as well as the fact that the pattern puts restrictions to the droplet size. The use of opto-electrowetting, in which a scanning light beam is used to manipulate the droplets, overcomes these disadvantages since it does not require patterned electrodes. We present an opto-electrowetting device that can be used to perform DNA amplification on the basis of PCR in µL-sized droplets.

KEYWORDS: electroweting, opto-electrowetting, digital micro-fluidics, PCR, DNA amplification

INTRODUCTION

An important trend in medical diagnostics is the miniaturization of equipment, so that in the end a complete diagnostic test runs in a single chip. Such a “lab-on-a-chip” would enable the rapid detection of DNA, proteins, or other biomarkers, using small volumes of bio-fluids and reagents. An ultimate reduction in costs accompanied by an increased flexibility may be obtained by a “digital micro-fluidics” system, in which µL-sized droplets are being manipulated, acting both as carriers of the bio-molecules and as micro-reactors. Electrowetting is the most studied approach to achieve this. It makes use of the effect that a droplet’s contact angle changes when a voltage difference is being applied between the droplet and the conductive surface on which it sits. When applying the voltage difference asymmetrically over the droplet by using a patterned electrode structure, the droplet experiences an imbalance in contact angle which can drive the droplet over the surface. Disadvantages of electrowetting are the need for a patterned electrode structure and corresponding complex interface with driving electronics, as well as the fact that the pattern puts restrictions to the droplet size.

A recently proposed technique that overcomes these disadvantages is opto-electrowetting (OEW), in which droplets can be moved over surfaces using a scanning light beam [1]. As sketched in Figure 1, a droplet, surrounded by a host fluid, is sandwiched between two substrates. The bottom substrate is covered with a continuous electrode, a photoconductive layer, and a dielectric film, whereas the top substrate has just an electrode. When the photoconductive film is locally illuminated, its resistance decreases there by orders of magnitude causing maximum voltage, applied between the electrodes, to drop across the dielectric layer. The drop’s contact angle reduces at this spot, creating an asymmetrical contact angle change which can drive the droplet forward.

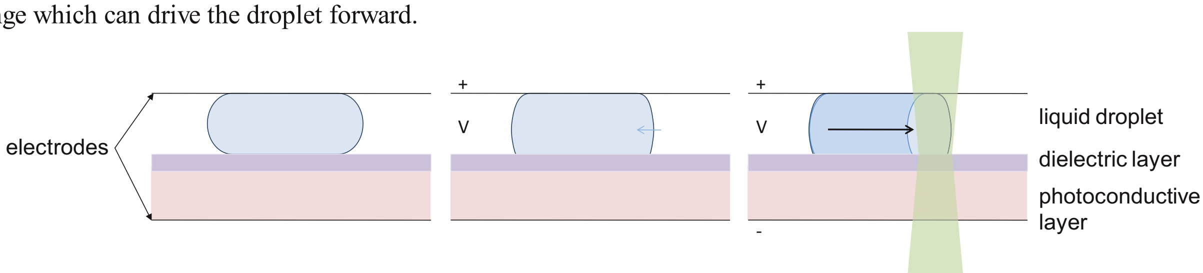

Figure 1: Principle of opto-electrowetting, cross-sectional view: the droplet’s contact angle is locally changed by laser beam illumination which drives the liquid drop to move across the surface.

EXPERIMENTAL

We have designed, fabricated, and tested an OEW device suitable for micro-liter DNA amplification by PCR (Figure 2). The bottom glass substrate was covered with an OEW stack consisting of 100 nm SnO2:F (the electrode), 4 µm amorphous silicon (the photoconductive layer), and 1 µm Parylene-C (the dielectric layer). 100 nm ZnO was deposited on the top glass substrate, forming the counter electrode. Then, a 2% Teflon solution was spincoated on both substrates to achieve hydrophobic surfaces. The substrates were joined and spaced apart through a 450 µm structured double-sided adhesive tape.

The 0.5µL droplet was placed using a graduated pipette and subsequently host liquid was added. A 405nm laser with programmable steering mirror was used to transport the droplet across the device. By integrating thin film heaters and sensors in the device, various temperature zones could be created (Figure 3). The device was placed on a hotplate at 60°C that provided a base temperature. Two of the integrated heaters were set at 60°C and 95°C, respectively.

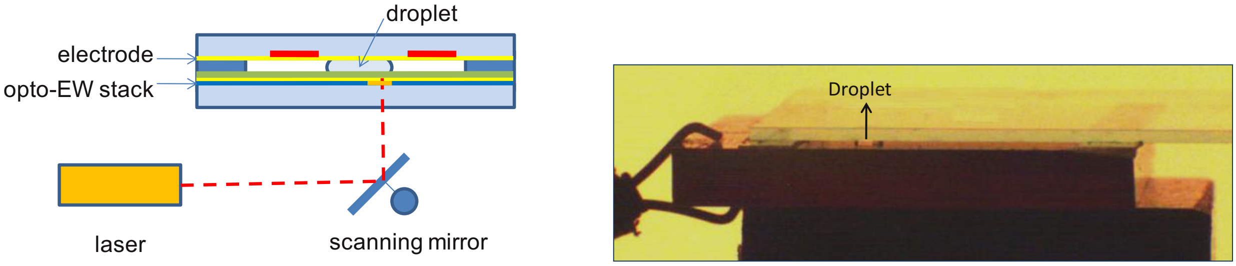

Figure 2: A scanning laser beam moves droplets within the micro-fluidic device. Left: sketch, right: our basic concept device.

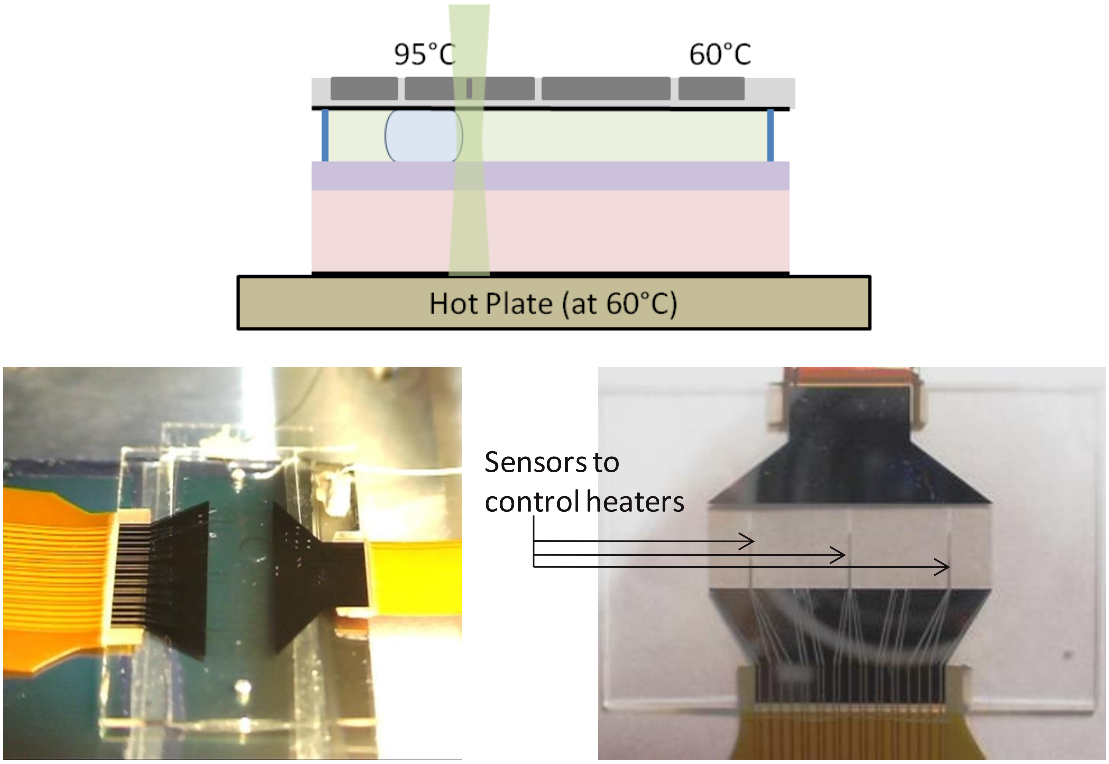

Figure 3: Thin film heaters and sensors are integrated in the device. This makes it possible to create various temperature zones within the device. The droplet can be moved between these zones e.g. for PCR.

RESULTS

We tested various fluids for the droplet and the host fluids, as indicated in Table 1. For the droplet, we used water, a 0.1 M KCl solution, and a liquid containing a PCR master mixture. Four different host environments were tested: air, silicone oil, hexadecane, and mineral oil. The effectiveness of the droplet actuation depended on the choice of the fluids. For some choices of working fluids, speeds of at least 2 mm/s could indeed be reached. In particular, the droplets of PCR mix fluid (which is relevant for our application, DNA amplification), did not move substantially with air or with mineral oil as the host fluid, as indicated in the table. However in silicone oil and hexadecane sufficiently large droplet scanning speeds could be reached, indicated in green in the table. The effect was not compromised by higher temperatures, and the droplet could be moved repeatedly along the same surface track many times.

By moving the 0.5µL droplet consisting of prime/probe mix + LC mix + DNA sample + Mg between the heated zones indicated in Figure 3 by OEW, with silicone oil as host liquid, a PCR reaction was conducted.

Table 1. The results of the opto-electrowetting experiments with various droplet and host liquids. With the right choices, the method is compatible with PCR, and droplet scanning speeds of at least 2 mm/s can be reached.

Host Environment	Droplet	Scanning Speed (mm/s)
Air	Water	≥ 2
	0.1M KCl	≥ 2
	PCR Mix	Stretches, but no movement
Silicone oil 10cst	Water	≥ 2
	0.1M KCl	≥ 2
	PCR Mix	0.4
Hexadecane 3cst	Water	≥ 2
	0.1M KCl	≥ 2
	PCR	0.33
Mineral Oil 14.2-17.2 cst	Water	No data available for this combination
	0.1M KCl	0.167
	PCR	poor EW or OEW

Droplet diameter = 2mm, Beam overlap = 0.5mm to 1mm

CONCLUSION

Opto-electrowetting, in which micro-liter sized droplet can be manipulated over surfaces with a scanning laser beam, is a promising approach to achieve a digital micro-fluidics device. The method does not require patterned electrode structures, as opposed to conventional electrowetting, which eliminates many disadvantages of the latter. With a good choice of host liquid, biochemical processes such as DNA amplification by PCR, can be performed in opto-electrowetting devices.

REFERENCES

[1] Y. Chiou, Sung-Yong Park, and Ming C. Wu, "Continuous optoelectrowetting for picoliter droplet manipulation", Appl. Phys. Lett., 2008, 93, 221110.

CONTACT

*J.M.J. den Toonder, jaap.den.toonder@philips.com