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Wireless operation of EWOD by the on-chip CMOS silicon photovoltaic cell array

Yuki Okamoto, Yoshio Mita

Dept. of EEIS, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
Phone: +81-3-5841-6730 E-mail: mems@if.t.u-tokyo.ac.jp

Abstract

We demonstrated the actuation of droplets by electrowetting-on-dielectric (EWOD) powered by a high-voltage (43.2 V) photovoltaic (PV) cell array that is fabricated by a standard silicon 5 V CMOS-LSI technology. The concept is to make an EWOD microfluidic device without any external wired power supply and wired control signal. One millimeter movement of a water droplet was achieved only by LED illumination.

1. Introduction

Microfluidics gives promising methods of bio-chemical and medical analyses by its advantages such as small consumption of samples and short analysis time. In such applications, droplets on a chip are required to be moved, mixed, splitted without limit of fluid, EWOD is a commonly used actuation method in microfluidics [2]. Moreover, it can control droplets without any covers. Hence it is suitable for microscopic observation.

To manipulate droplets on a chip, it must be filled with an array of electrodes. Each electrode commonly needs to be connected to the controller by wire, which means many connected pads and wire are required. For avoiding the inconvenience of wires, some methods for wireless EWOD actuation are proposed [3]. Although these methods can control droplets remotely, they still need to be supplied with power by wire.

In this paper, we propose a remote actuation method of liquid droplets without any external connection by wire. It is realized by using Ta_2O_5 low-voltage EWOD and high voltage PV cells. This concept can remove any electrical connection by wire and reduce equipment settings.

2. Proposal Method

We propose a new method of supplying power to EWOD electrodes using PV cells integrated on the backside of EWOD electrodes (Fig. 1). In this method, power is transmitted not by wire but by light. The wireless operation allows the microchannels to be used like microscope slides, which are observed and replaced one after another.

Generally, EWOD requires a high voltage (e.g. 100 V), whereas a single PN junction on a silicon wafer merely generates 0.6 V. To eliminate this gap, we utilized low-voltage driven EWOD with Ta and Ta_2O_5 electrodes [4] that requires 16–30 V for operation driven by on-chip series-connected PV cells on a standard CMOS-LSI [5].

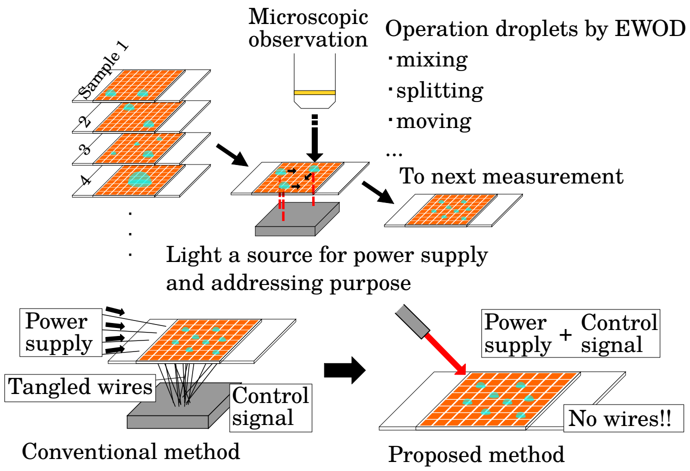

Fig. 1 A concept of wireless operation of EWOD microfluidics device

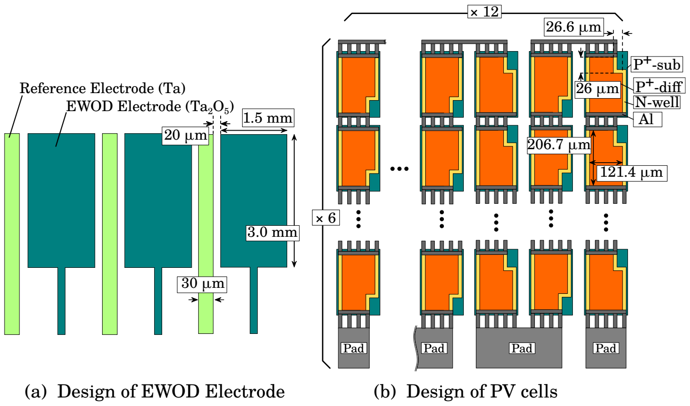

Fig. 2 The design of EWOD electrodes and PV cells. The EWOD electrodes are designed to carry a 50 µL droplet. The PV cells are composed of 72 cells connected in series.

In the following demonstration, the PV chips and the EWOD chips were separately made and connected side-by-side for proof of concept. Integration will be possible by through-silicon-via (TSV)s.

3. Fabrication and Measurements

The layout of the EWOD electrodes and the PV cells are shown in Fig. 2. The electrodes were designed to carry 50 µL droplets, which is sufficient for bio-analysis. Ta_2O_5 layer as an insulator is made by anodization since it can decrease the applying voltage and the thickness of Ta_2O_5 can be controlled by the anodizing voltage. CYTOP is used as a hydrophobic

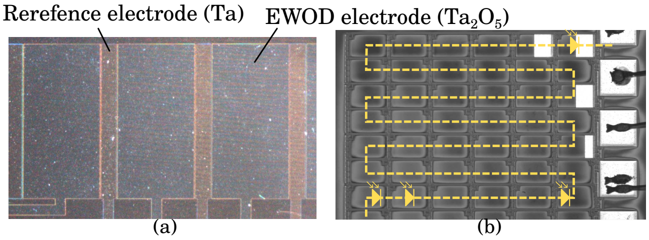

Fig. 3 (a) Microscopic image of the EWOD electrodes. (b) Microscopic image of the PV cells.

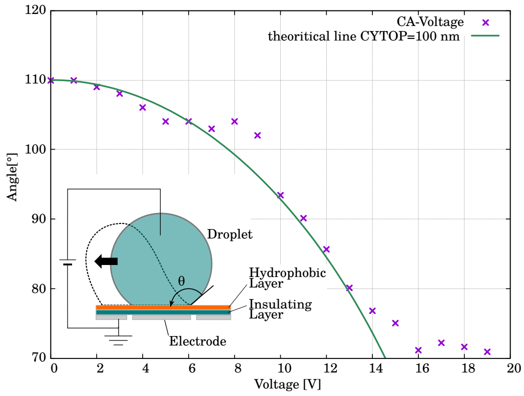

Fig. 4 The dependence of a contact angle at the liquid-solid interface on the applied voltage.

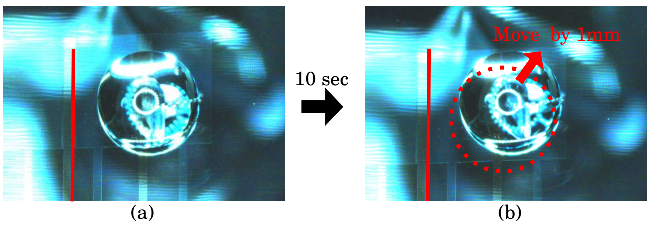

Fig. 5 (a) Initial position when the PV cells are illuminated (b) Position 10 sec after the PVcells are illuminated. One millimeter displacement was obserbed by illuminating the PV cell.

layer. As for the PV cells, 72 PV cells are connected in series.

The EWOD electrodes were fabricated with a 4-inch bulk silicon wafer. On the other hand, the PV cells were made on a silicon-on-insulator (SOI) wafer. PN junctions and wiring were made by a standard CMOS process in an LSI foundry, and then the isolating post-process steps were done in the university's cleanroom.

The open circuit voltage V_{oc} of the fabricated PV cells were measured through a high impedance voltage follower. The V_{oc} under room light illumination was 4.2 V and that under LED illumination was 42.2 V. In the measurement data were averaged to omit electromagnetic coupling from powerline (50 Hz).

The contact angle of the droplet (θ) follows Young-Lipmman's equation [6]:

$$\cos\theta(V_A) = \cos\theta(0) + \frac{1}{2}\frac{\varepsilon}{t\gamma_{LV}}V_A^2, \quad (1)$$

where $V_A, t, \varepsilon, \gamma_{LV}$ are the applied voltage, the thickness of insulator, the dielectric constant of insulating layer, and the interfacial tension between liquid and vapor respectively.

Fig. 4 shows the dependence of the contact angle on the applied voltage. When the voltage was over 10 V, the contact angle decreased. The contact angle was saturated over 16 V. The relative permitivity of Ta_2O_5 electrodes was measured with an LCR meter (HP5284) to be 28.1, and the dielectric constant of CYTOP was 2. Based on these values, the theoretical line calculated from Eq. 1 is also drawn in Fig. 4. From Fig. 4, the contact angle change between illuminated and not-illuminated is sufficient to actuate a droplet.

The droplet moved by 1 mm, in 4 seconds with 6 second latency. The reason of the latency and the moving time can be attributed to slow charging of Ta_2O_5 capacitor. The charging time is calculated from the capacitance value of the insulator (14.4 nF), the output current capacity of the PV cells (83.5 mA/cm^2), and the area of a PV cell (206.7 μm × 121.4 μm). From Fig. 4 the voltage was supposed to be 16 V when the contact angle was fully changed. Considering these values, the total time for charging EWOD electrodes is calculated at 10.6 seconds, and the time matches the demonstration. The speed of droplet movement is a function of the speed of electron charging of the electrodes, and thus the speed can be controlled by light power and the area size of PV cells.

4. Conclusions

We propose a new method of remotely actuation without any wiring connections. In the experiments, the remote EWOD actuation of a water droplet was successfully controlled by LED illumination using low voltage Ta_2O_5 EWOD and high-voltage PV cells.

Acknowledgements

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References

[1] C. Rivet, *et.al.*, *J. Chem. Eng. Sci.*, vol. 66, pp. 1490–1507, 2011.

[2] C. K. Sung, *et.al.*, *J. Micromech. Microeng.*, vol 12, pp. 70–80, 2003.

[3] P. Chiou, *et.al.*, *Sensor. Actuat. A-phys.*, vol 104, pp. 222–228, 2003.

[4] Y. Li, *et.al.*, *J. Solid State Electron.*, vol 9, pp. 1388–1387, 2008.

[5] I. Mori, *et.al.*, *Trans. Inst. Electr. Eng. Jpn. Sect. E*, vol 136, pp. 24–30, 2016.

[6] F. Mugele, *et.al.*, *J. Phys.: Condensed Matter*, vol 17, pp. R705–R774, 2005.