HYDROPHOBIC ZnO USED IN EWOD TECHNOLOGY AND SAW DEVICES FOR BETTER BIO-FLUID SLIP AT MICROCHANNEL WALLS CONTROLLED BY DC PULSES

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Abstract–*In this paper, we will review the electrowetting on dielectric (EWOD) principles applied to microfluidic devices. We replaced the usually used teflon surface by ZnO transparent film in order to obtain a device with an optical weak absorption in the diapason ranged from VIS to far-MIR and THz waves. We studied the piezoelectric characteristics of ZnO films obtained by RF magnetron sputtering in Ar+O_2 plasma. ZnO films have been grown on SiO_2/Si(100) substrate using a zinc oxide target. The morphological characteristics of the films were investigated by atomic force microscopy (AFM). We present the THz spectra from ZnO films.*

Keywords: *EWOD, Electrowetting, Microdroplet, THz-TDS, ZnO, SAW*

1. INTRODUCTION

Electrowetting is the electrically induced modification of wetting properties of a conductive liquid on a surface. Due to the low power consumption, electrowetting therefore affords an efficient, rapid, reversible, and precise means for actuating and manipulating very small volumes of liquid in microfluidic devices without the need for mechanical components. Since direct electrowetting which is based on a direct contact of the liquid and the electrode, can cause the electrolysis of the liquid before it makes significant contact angle change, an insulator is used to coat the electrode to prevent the electrolysis. This is called electrowetting on dielectric (EWOD) [1, 2].

By application an external electric field on EWOD chip contacts, it becomes possible to actuate or manipulate small volumes of liquid by altering its interfacial tension and hence the macroscopic contact angle or by inducing bulk liquid motion through an interfacial electric stress.

There are many application for EWOD devices, like manipulating droplets by chemical [3], thermal [3], acoustic [4], and electrical [5] means.

2. STRUCTURE, SCHEMATIC DIAGRAM AND DEVICE SIMULATION

In this paper we present the EWOD chip transparent for THz radiation that allows scanning easily any bio-fluid slipping through microchannel. The structure is obtained by thermal oxidation of a (100) Si wafer. The grown SiO_2 on top is 500 µm thick. A positive photoresist (PMMA) was used to configure Cr-Au pads, obtained by liftoff method. ZnO is deposited by RF magnetron sputtering.

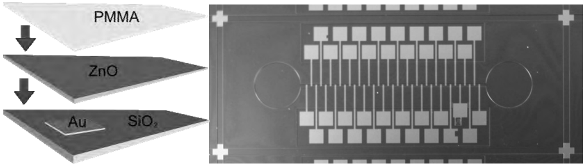

Fig. 1. Technological processes (left), and EWOD device photo (right).

In order to have a structure with hydrophobic surface we left the ZnO material on the surface of EWOD chip. As the undoped ZnO is considered dielectric one, $R=10^5$ Ω□, we remove it from external pads for contacting with microcontroller

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circuit.

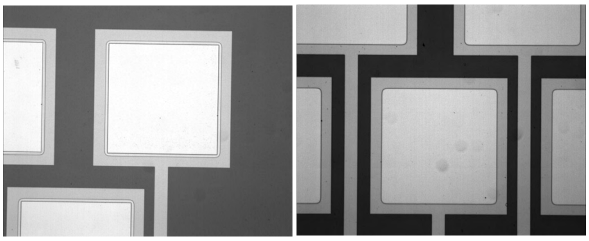

Fig. 2. ZnO removing from pads (left) before removing PMMA, and after (left).

Figure 3 shows a schematic of the EWOD principle. When a voltage (V) is applied between the embedded electrode and the liquid droplet on the dielectric layer, the solid-liquid interfacial tension decreases and it reduces the contact angle from θ_0 to θ_V. Here θ_0 represents the angle between contact surface area and lateral surface of droplet at applied 0 volts, and θ_V after applied voltage (V), respectively (Fig. 4a). If an array of the embedded electrodes is patterned, the droplet can move to the activated area when a partial area of the droplet base is activated by controlling a part of the embedded electrode array (Fig. 4b and 4c). Then the EWOD device can be used to manipulate droplets for dispensing, transporting, splitting, merging, and mixing. For our designed EWOD we chosen a method to manipulate liquid droplets in digital (discrete droplet-based) microfluidics, however, the required voltage for driving a droplet has been several tens to hundreds of volts. We made various attempts to reduce the applied voltage by changing the zinc oxide thickness [6]. At the same time, it can serve as an optical window for most of frequencies especially for IR and THz that we are interested in.

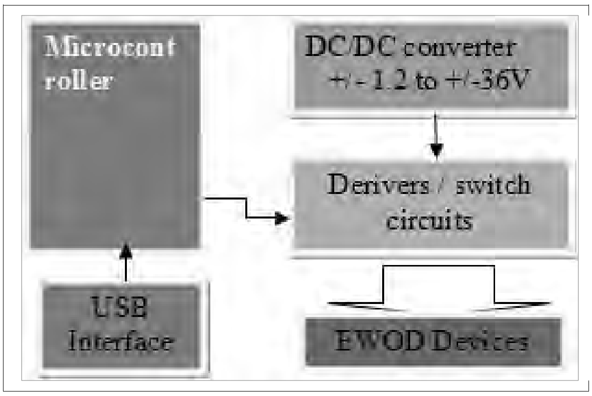

Fig. 3. Block diagram of driving system for EWOD devices.

Lippmann-Young equation gives the relationship between the contact angle change and the applied voltage through the dielectric layer, depending on the liquid-vapor interfacial tension and dielectric properties, as follows:

$$\cos\theta_V = \theta_0 + \frac{\varepsilon_0 \varepsilon_r}{2\gamma_{lv} d} V^2 \qquad (1)$$

where ε_0 is the permittivity of free space, ε_r is the relative permittivity of the dielectric, γ_{lv} is the liquid-vapor interfacial tension, and d is the thickness of the dielectric layer. According to this equation, a thinner dielectric layer with a high permittivity is desired to lower the driving voltage. This paper presents the fabrication and the driving characteristics of a low-voltage EWOD which was realized by using magnetron sputtering deposition of zinc oxide (ZnO).

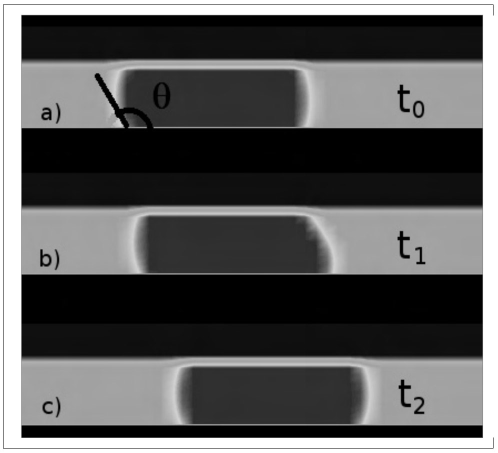

Fig. 4. Moving of microdroplet inside of microchannel. a, b, c) position of the microdroplet for moments of time t_0, t_1 and t_2, respectively.

Figures 4a, b and c represent the moving process inside of microchannel at different moments of time t_0, t_1 and t_2 respectively.

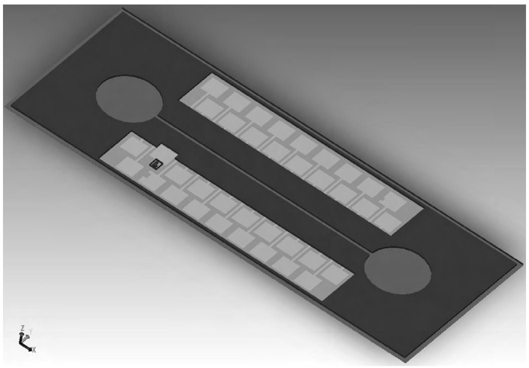

Fig. 5. Coventor and CleWin mask design.

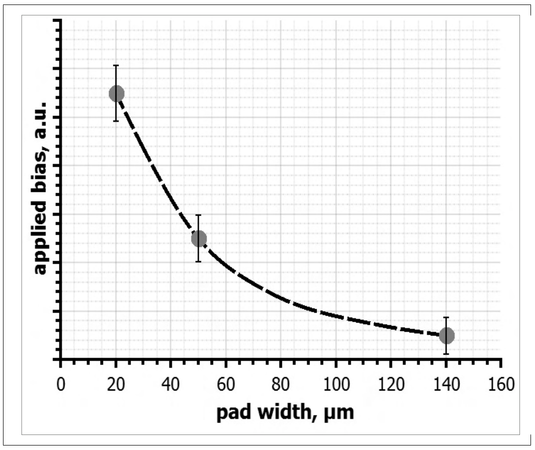

Fig. 6. Applied bias on pads estimated in Coventor software.

The pad form has been optimized in order to have a smooth moving of bio sample through microchannel. The applied bias depends also on width of pads and of the interdistance between them, which was estimated in Coventor software by using BabbleDrop module.

In order to have a THz signal from the bio sample, we need to use preconfigured pads (Fig. 7 and 8), similar to metamaterials [6]. Metamaterials are sub-wavelength composites consisting of shaped metals and supporting dielectrics (Fig. 7 and 8) which are capable of accessing regimes of electromagnetic response difficult or impossible to achieve with naturally occurring materials, such as negative refractive index, cloaking and quite generally, coordinate transformation materials design [7-9]. In connection with EWOD we can scan each microdroplet in real time mode by THz-TDS and identify the biomaterial that at the moment of time t_0 is situated on EWOD THz-pad resonator (Fig. 4). That is shown by markers F1 to F4 in THz spectra (Fig. 9). There are key frequencies for comparison between calculated resonators [6, 7] and for used biosamples.

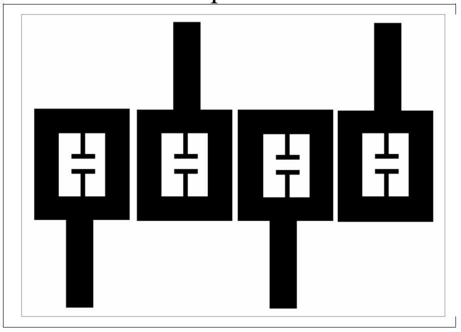

Fig. 7. Optimized EWOD THz-pad resonator based on metamaterial composites.

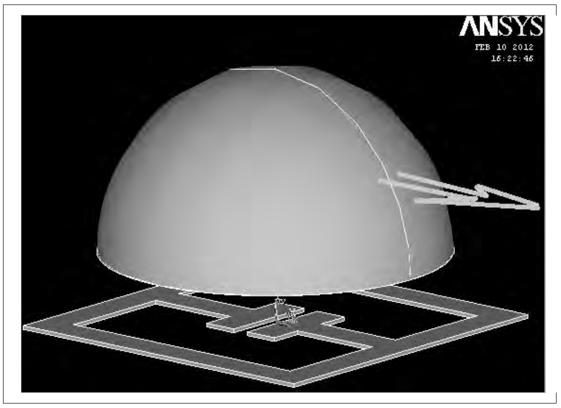

Fig. 8. Direction of bio microdroplet over the THz resonator.

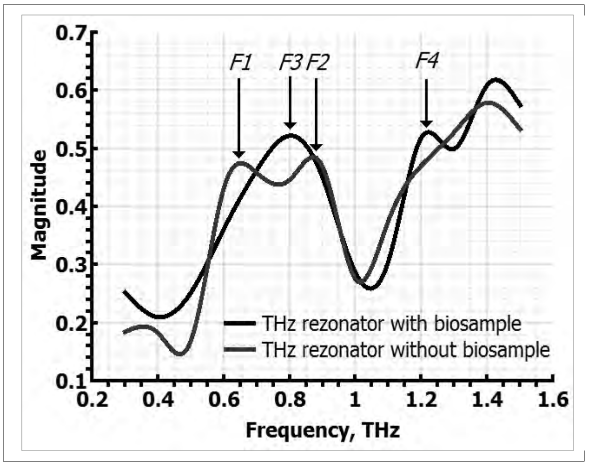

Fig. 9. (up) applied bias on pads, e) spectral analysis for rezonator with and without biosample.

The deposited ZnO film has a 400 nm thickness. In order to estimate the quality of deposited ZnO we studied the Raman scattering [10] and AFM. The roughness has been studied and it was found to be around 220 nm. That means that we have a variation of 400±220nm. We believe that these variations are due to applied potential on the surface (see Figs. 11). In order to understand this effect we suppose that surface acoustic waves (SAW) propagate in the film.

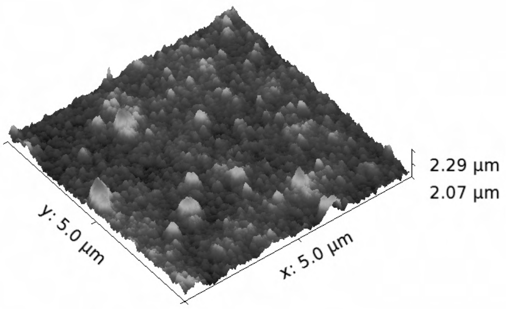

Fig. 10. 3D AFM image of ZnO deposited layer.

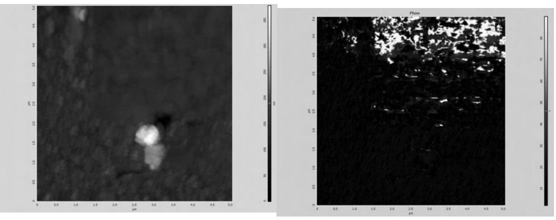

Fig. 11. AFM image of ZnO layer (left) in comparison with phase image (right).

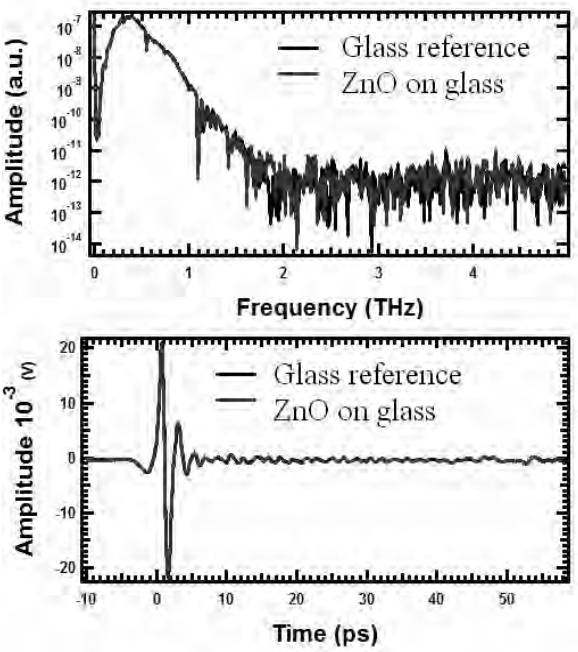

Fig. 12. THz spectra from glass and ZnO deposited on glass.

Since ZnO films are promising for fabrication of THz devices, we tried to implement them into EWOD device. Recently THz birefringence has been reported [11].

The glass has been taken as reference material in studding the THz emission and it has been compared with the ZnO film deposited on the same glass (Fig. 12). One can see from the THz spectrum that significant changes do not occur. We suppose that the weak absorption is due to small thickness of the deposited film.

3. CONCLUSIONS

We developed pads for microchannel that at the same time can serve as reference resonators in THz frequency. In Fig. 2e, the values of markers F1-F4 can be used as a passport to distinguish different types of biosamples. We demonstrate the possibility to fabricate a device that is able to handle with liquids, and to measure the THz spectra in real time. The SAW piezoelectric effect may give us additional information about the bio sample, like mass loading, membrane characterisation, etc.

Acknoledgement–This work was supported by Romanian-Moldavian Bilateral project No. 10.820.05.23/RoA, 433 (2010-2012), young scientist project 12.819.15.20A and partially supported by the FP7 project MOLD-ERA (Grant no 266515). All Coventor/Ansys simulations have been done at IMT-Bucharest.

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