A facile coplanar reverse electrowetting-on-dielectric configuration for more flexible and integratable force/motion sensing applications

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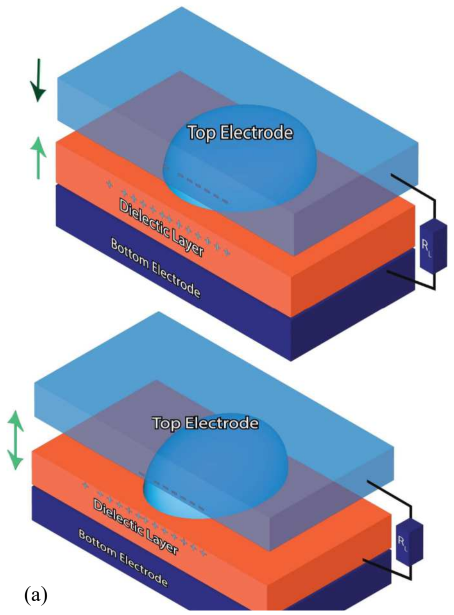
***Abstract* — Reverse electrowetting on dielectric (REWOD) has been a reliable approach to harvesting energy from low frequency excitations. Previous studies have looked at applying this technology to power various types of sensors using a two-plate electrode structure. This study aims to use REWOD for direct sensing applications using a single plate coplanar structure. The single electrode structure allows for better versatility in materials and applications, as well as making it easier for transportation.**

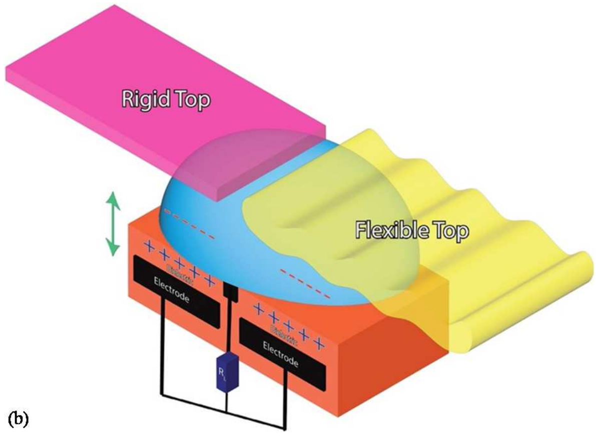
Keywords — Reverse-Electrowetting on Dielectric, Electric Double layer, Energy Harvesting

I. INTRODUCTION

In recent years, the Reverse Electrowetting-on-Dielectric (REWOD) technology has become one of the major focus in the nano-energy harvesting community, where liquid droplet kinetics have been utilized to generate electricity as an efficient way to power applications such as self-powered wearable sensors [1-3]. Until now, very few researchers have utilized this energy transformation as a sensing mechanism itself, apart from a few groups [1, 4-6]. However, all of these researchers have employed a “two-plate” REWOD configuration where both top and bottom structures contain conductive electrodes with bias voltage applied as shown in figure 1a.



(a)



(b)

Fig. 1. (a) Showing the traditional structure of REWOD energy harvesters/sensors during the wetting and dewetting cycles (b) Showing the coplanar design for REWOD sensing that doesn’t require a conductive top electrode, which can be used with either a rigid or flexible top

We hereby propose an alternative system design, where both sensing and biasing voltage electrodes are integrated to the bottom structure of the device (figure 1b-c). By freeing up the material and design option of the top structure, this approach has a great potential to significantly broaden the types of sensing applications. For example, we could potential introduce a flexible/stretchable top structure used in tactile sensing and soft robotics motion sensing.

Electrowetting is the phenomenon of utilizing electricity to alter droplet dynamics [2]. It is possible to reverse this process and use droplet motion and modulation to generate electricity [1-7], where the amount of energy that can be harvested by a REWOD process is proportional to the capacitance of the system. Most REWOD systems [1, 2, 4-7], use a two-plate structure with an electrode on the top and the bottom to form the required electrical field. This structure may limit the possible applications because the need for a top plate makes the design less versatile. the Coplanar structure will also require less material as only the bottom electrode is required, and the droplet can be deformed employing any material that is sufficiently hydrophobic.

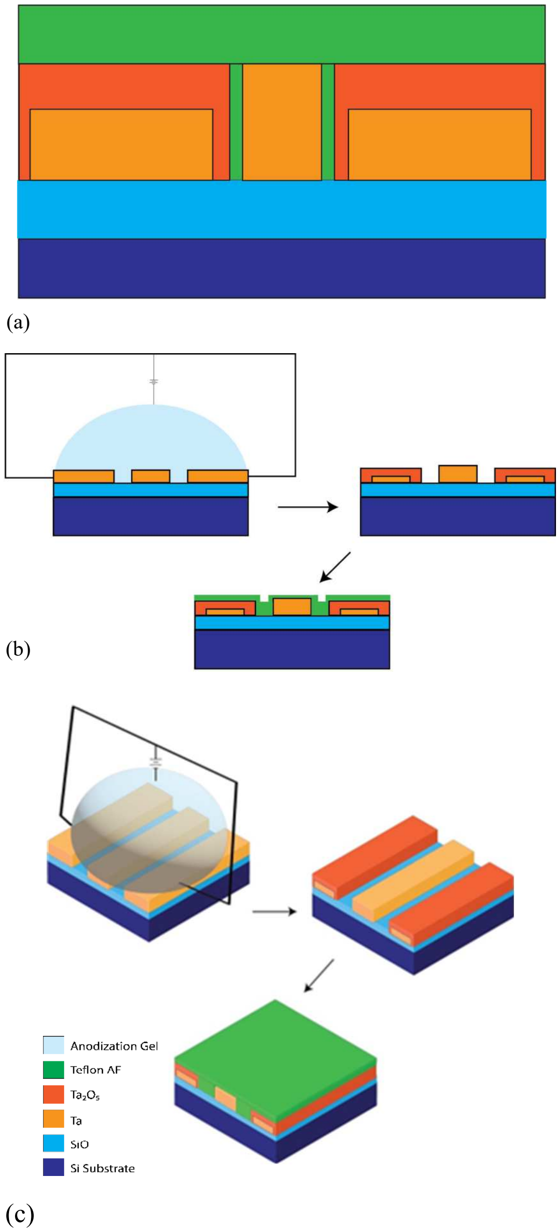


Fig. 2. (a) Showing a cross-section of the materials that make up the Coplanar electrodes. (b) The anodization and spin coating process flow for the Coplanar electrodes. (c) a 3D representation of the process flow.

A recent development in converting droplet kinetic energy to electricity has employed a top-plate-free structure as reported in [3], where ions in tap water droplets moving between coplanar electrodes generating nano-currents without any bias voltage inputs. In our proposed method (figure 1b and 1c), Figure 2 shows the different stages of droplet deformation using an acrylic plate as the nonconductive top plate. This configuration also means that it will be easier and cheaper to manufacture.

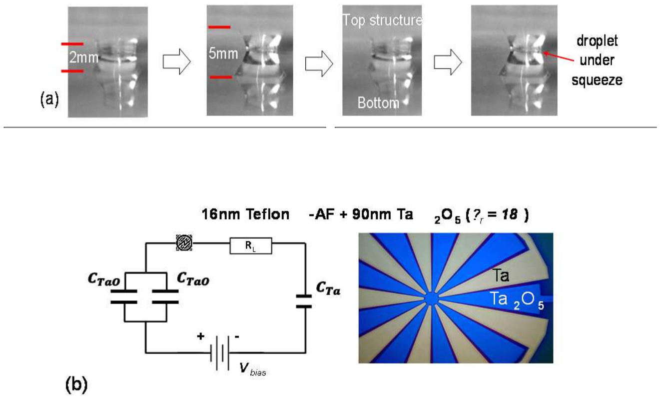


Fig. 3. The different stages of droplet deformation and overlap with coplanar electrode, from minimum to maximum overlap

II. Experimental and Results

System Set-up to test the sensing capabilities of Reverse electrowetting on dielectric, a water droplet was placed on the coplanar electrode which was connected to a 9V bias and an Oscilloscope (Rigol 1054z). The droplet was modulated at various frequencies using a voice coil and a function generator (figure 3). A static acrylic plate was placed slightly above the droplet and served as the means of deformation when the droplet was modulated. The function generator modulated the droplet at various frequencies to give an indication of the sensitivities that are possible. A high-speed camera was set up to capture the process.

The initial experiments showed that a voltage peak of at least 6.08V (the result could be beyond this but it is not discernible due to a glitch that caused saturation at this value) was attainable from a modulation frequency of 13.33hz.

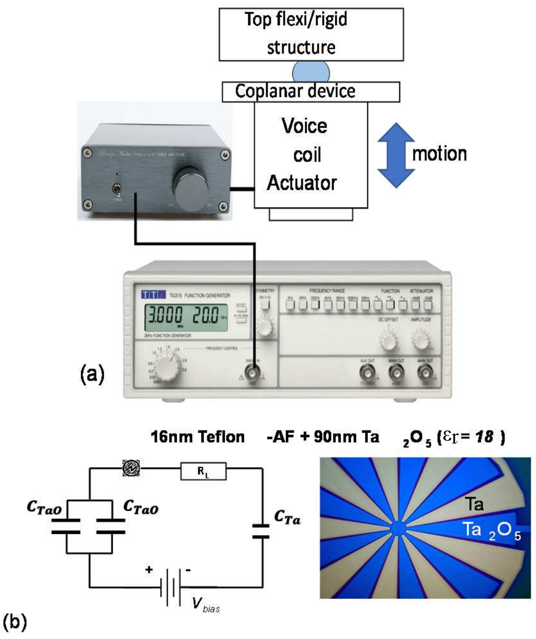


Fig.4. (a) Experimental setup of function generator and voice coil attached to the REWOD system. (b) circuit diagram of experimental setup and top down view of coplanar electrode design.

III. INITIAL RESULTS

Figure 5 shows the wave form for the instantaneous voltage output that is achievable at 9V bias. This high voltage peaking has the potential to translate to high sensitivity for sensing applications.

Though the results we obtained were promising, to maximize the voltage and current output, which will subsequently maximize the sensing sensitivity, improvements in the design must be made.

First, a lot of the data for slight deformations of the droplet was lost because of the inherent noise of the system, so the true sensitivity of the setup is not discernible below 50mv. An effort was made to minimize the effect of noise by wrapping the wires with shielding material. This reduced some of the noise and allowed for larger deformations to become visible. As we proceed with the experiments, we plan on placing the experimental setup into a faraday cage to eliminate a significant portion of unwanted interference, allowing for more accurate readings of the sensitivity.

I will do investigations without the application of a voltage bias instead using the Electric double layer (EDL) effect as a method facilitating charge transfer to see if it is a workable approach[8-11]. In order to do this, the excess noise will need to be eliminated, so that the expected smaller peaks will be visible on our measuring apparatus. The removal of the voltage bias will allow the system to be more flexible and increase the number of applications[5]. It will also allow the system to be a truly self-powered sensor with no reliance on external circuitry.

Another important next step is adding a hydrophobic coating to the acrylic plate to decrease droplet adhesion to the plate and increase the amount of wetting the droplet has on the coplanar electrode. Increasing the wetting increases the overlap area, hence increasing the charge transfer, which will increase the effective of the sensor. EQ1 [2] shows the amount of energy that can be extracted from a REWOD system.

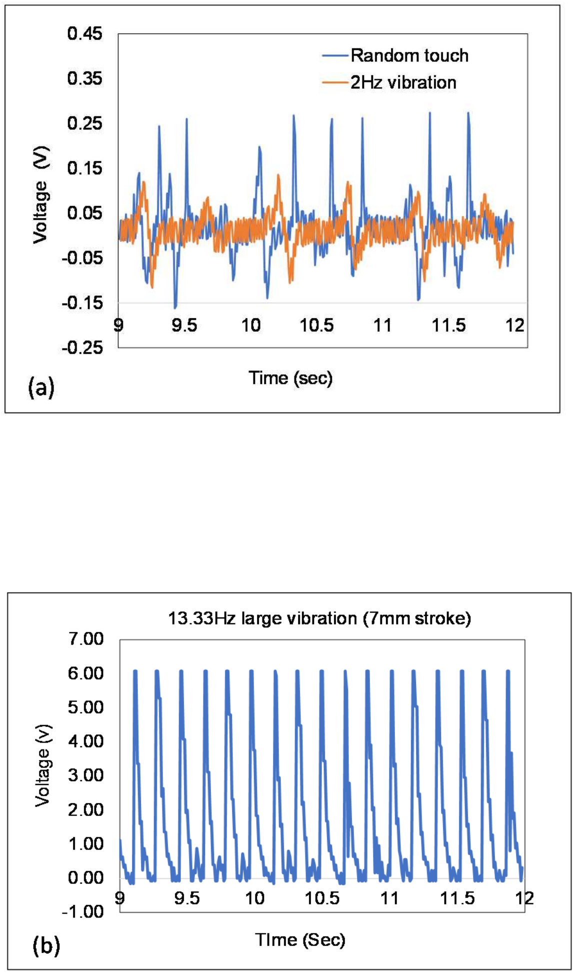


Fig. 5. (a) Voltage peaks for random modulation compared against modulation of two pulses per second. (b) Modulation of 13.33hz allowing for voltage peaks of (at least) 6.08V

$$E = \frac{5}{4}V^2C_0[1 - tanh(\frac{1}{2}(1 - log(\omega RC_0)))\ \ (1)$$

Where the maximum capacitance for a variable capacitor $C_0 = \varepsilon_0 kAh^{-1}$,V is the Bias voltage, R is the load impedance, h is dielectric film thickness, $\omega = 2\pi f$, where f is frequency of wetting dewetting cycle, A is the overlap Area of the droplet and the electrodes.

As the research continues, an investigation into the effects of droplet characteristics on the sensitivity of the system will be conducted. Droplets of various sizes will be tested to see how this affects the capabilities of the system. Droplet composition will also be investigated with initial tests starting with deionized water, tap water and saline solutions and eventually experiments with other materials including hydrogels. This will also be part of a plan to eventually move the system away from rigid restrictive structures in favour of flexible configurations that can accommodate a variety of requirements.

In the long run, this inherent flexibility can be used to integrate the REWOD technologies with other energy harvesting systems for more efficient functions. This integration could include solar energy harvesting using an optically transparent top plate and coplanar electrode design, but the details of this are outside the scope of this paper.

Finally, a comparison of the energy harvesting capabilities of traditional REWOD devices against the coplanar design will be conducted to assess the capabilities of the coplanar design against the benchmarks that previous experiments have set.

IV. Conclusion and Discussion

In conclusion, we believe the results obtained from our initial experiments have proved promising for using a coplanar REWOD system for sensing. The high output voltage both with random modulation and the 6.08V from a modulation frequency of 13.33hz. though the experimental setup can be improved in the ways detailed in the last section, with these developments we believe we will get significant results. The benefits of using a self-powered coplanar REWOD system over conventional battery powered capacitive sensors and traditional REWOD set ups that harvest energy to power external sensors are plentiful and we aim to build on this.

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