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Demonstration of a wireless driven MEMS pond skater that uses EWOD technology

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ABSTRACT

A silicon swimming robot or pond skating device has been demonstrated. It floats on liquid surfaces using surface tension and is capable of movement using electrowetting on dielectric (EWOD) based propulsion. Its dimensions are 6×9 mm and the driving mechanism involves first trapping air bubbles within the liquid onto the hydrophobic surface of the device. The air bubbles are then moved using EWOD, which provides the propulsion. The device employs a recently reported Ta_2O_5 EWOD technology enabling a driving voltage of ≈15 V, which is low enough for RF power transmission, thus facilitating wire-free movement. A wired version has been measured to move 1.35 mm in 168 ms (a speed of 8 mm s^{-1}). This low voltage-EWOD (<15 V) device, fabricated using a CMOS compatible process, is believed to be the world's smallest swimming MEMS device that has no mechanical moving parts. The paper also reports results of EWOD droplet operation driven by wireless power transmission and demonstrates that such a wireless design can be successfully mounted on a floating EWOD device to produce movement.

1. Introduction

Distributed tiny robots such as smart dust have had an inherent appeal in the MEMS field since the concept was initially proposed in 2001 [1]. Towards that goal, sub-centimetre sized MEMS devices have already demonstrated the capability of walking [2] and flying [3]. However, to the authors' knowledge a microscale swimming MEMS device has yet to be demonstrated. In the macro robotics field the pond skater is a hot topic [4,5] and since our work was presented at ESSDERC 2008 [6], other workers have reported an EWOD based surface tension-driven technology [7]. However, all three of these devices are still centimetre sized.

The realisation of smaller swimming robots clearly requires an innovative approach as standard mechanical propulsion systems are too heavy, as are their power sources. This paper presents what is believed to be the smallest swimming robot reported and investigates the performance of all the elements including the feasibility of wireless power delivery for propulsion.

2. Design considerations

Realisation of a millimetre scale pond skating device presents many challenges, mainly related to weight considerations, which must be such that the resulting system floats using surface tension effects. Clearly, the weight of any power source is an issue and a successful device needs to minimise (or eliminate) such components. In order to account for scaling effects, the method of propulsion should preferably exclude moving mechanisms, as well as having low power requirements. This paper describes the design and development of the basic elements required to implement pond skater technology.

2.1. Low voltage EWOD

Historically EWOD (electrowetting on dielectric) devices have required driving voltages in excess of 80 V [8,9] and although these have been reduced in recent publications the process steps can involve high temperatures [8,10], making them incompatible with post-processing of standard CMOS wafers. Low voltages enable RF power transmission over longer distances and is hence desirable for the proposed pond skater. Recently, we have reported a Ta_2O_5 based dielectric system with a drive voltage <15 V [11].

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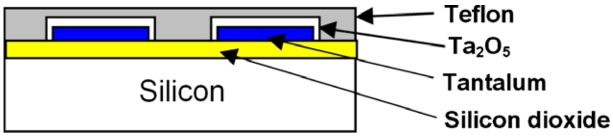

Fig. 1. Schematic of the tantalum pentoxide EWOD architecture.

The device structure shown in Fig. 1 is composed of a Tantalum electrode capped with a 100 nm Ta_2O_5 dielectric, covered with a 16 nm film of Teflon. We have previously defined the driving voltage to move a droplet on an EWOD device as that required to achieve a contact angle change of 40° [9]. Tantalum pentoxide provides a robust pinhole free insulator, which, together with the Teflon layer, reliably generates this contact angle change at 13 V, one of the lowest driving voltages reported for a low temperature dielectric system [11]. The key technology is room temperature anodisation [9] of 0.5 μm sputtered tantalum using a conductive gel with a bias of 50 V. This process results in a dielectric thickness of around 2 nm V^{-1}. The Ta_2O_5 is superior to most EWOD dielectrics such as thick Parylene or SiO_2 in terms of working voltage, but also over published high-κ EWOD materials in terms of its processing temperature. For example, reported dielectrics such as MOCVD deposited (Ba, Sr) TiO_3 (700 °C [8]) and Bi_2O_3–ZnO–Nb_2O_5 (600–800 °C [10]) require temperatures that are not compatible with CMOS post-processing.

This combination of low temperature fabrication and a driving voltage of 15 V makes a future autonomous pond skater feasible when combined with environmental power sources such as solar cells as well as the wireless power transfer discussed later in this paper.

2.2. The propulsion system

Many of the demonstrated EWOD devices have used the architecture shown in Fig. 2a with the cover glass acting as the ground electrode. The proposed application clearly cannot be implemented with a top electrode and so the coplanar architecture shown in Fig. 2b has been implemented. Fig. 3 shows an example of a coplanar EWOD design that uses a Ta_2O_5/Teflon dielectric, and can move water droplets in air.

However, because the EWOD electrodes will be immersed in water, the proposed propulsion system is based on the movement of air bubbles [12]. This approach requires the ability to capture (or generate) an air bubble on one electrode, and then move it by switching electrodes from their hydrophobic to hydrophilic state. This process is shown schematically in Fig. 4, where switching the right electrode in frame three to hydrophilic moves the bubble to the left.

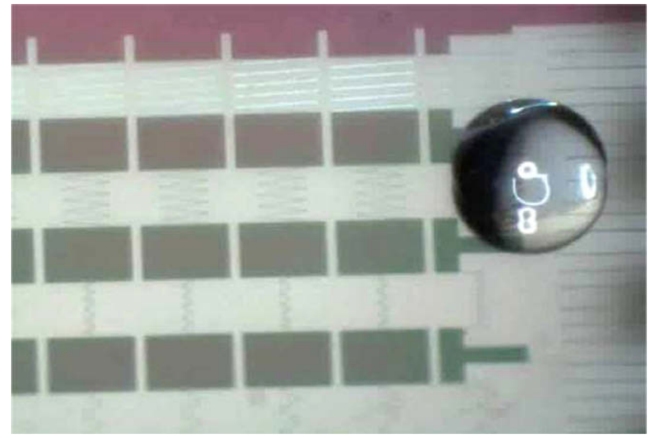

Fig. 3. Coplanar EWOD electrodes with droplet.

Another consideration is that the power source or delivery system used to power the pond skater device must be of a size and weight so as not to adversely affect the flotation provided by surface tension.

In addition, liquid must be prevented gaining access onto the top surface of the device and sinking it. Hence, both surfaces of the chip must be strongly hydrophobic.

3. Prototype systems and experiments

The following section presents details of all the individual elements of the pond skater system.

3.1. EWOD flotation and propulsion system

The prototype design used to demonstrate the EWOD pond skater concept is shown in Fig. 5 and comprises two adjacent 6.8 × 3 mm Ta_2O_5-CYTOP (hydrophobic amorphus polymer produced by Asahi Glass Ltd.) covered electrodes separated by a

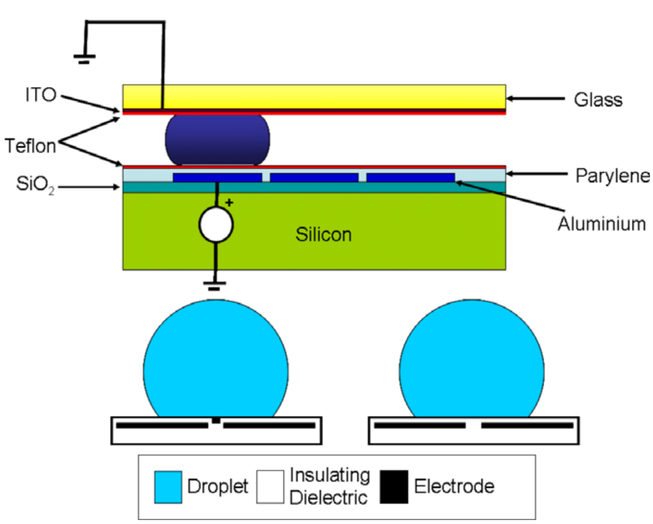

Fig. 2. EWOD system (top) two plate, (bottom) coplanar.

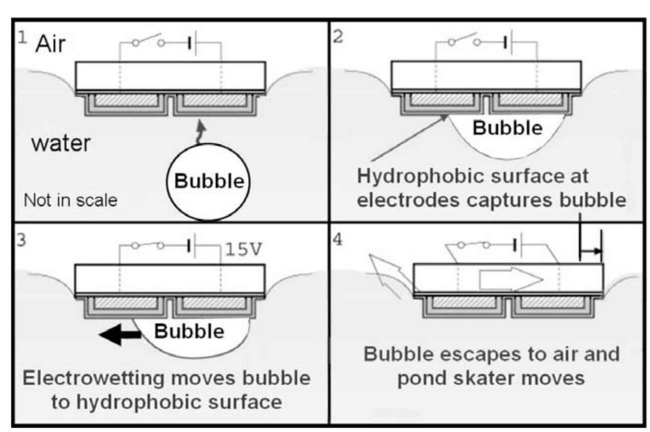

Fig. 4. Illustration of the propulsion mechanism for the EWOD pond skater. (1) Movement of an air bubble towards an electrode. (2) Bubble capture. (3) Fifteen volts applied between the electrodes changes the right electrode surface to hydrophilic, thus moving the bubble to the left. (4) The bubble escapes from the left edge, causing a counter-movement of the pond skater chip. The distance moved is identified.