Modelling of Low Level Ionic Current Sensing Micro-tip

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ABSTRACT

Sensing of electrical quantities e.g. current and charges at micro and nano level is a challenging task for the researchers. Most of the electrical quantities produced as a result of natural phenomenon are very small and need infinitesimally small sensors to be detected. The authors of this paper are developing an appropriate micro/nano array sensor that is capable of sensing ionic currents in sweat fluid secreted from sweat pores on the finger ridges. In this paper, we have presented the results of preliminary modelling studies of vertically aligned single ionic current sensing tip with 5μm in diameter and 10μm in height. Effect of ionic current and current density response of sensing tip is discussed.

Keywords: Nanosensors, Ionic Current, Sensing tip, sweat fluid, charge density

1 INTRODUCTION

In industrial and consumer applications, sensors are key components in an overwhelming wealth of systems. The developments in micro and nanotechnologies, many new and promising sensors have been introduced in recent years, particularly for biological and chemical detection. The many existing electronic sensors such as biometric fingerprint sensors are based on optical, capacitive, thermal, acoustic and radio frequency based sensing technologies which are acceptable techniques in many systems. However, the future applications require very small, high resolution and extremely sensitive methods, which strengthen reliability, performance and reduce the size and cost of existing sensors. In addition, the novel sensing methods should be proficient to initiate new ideas which support the design of new sensors. It is confirmed from recent published literature [1,2,3,4,5] that the micro/nano structures such as nanowires and nanotubes can revolutionize the sensing techniques and will advance many existing sensing methods. Recently, at Brunel University, the researchers have begun to carry out research and development on novel nanotechnology based fingerprint sensor. The research has instigated the design of a micro-tip which is able to sense the current from sweat secred from finger tips pores.

The size and dimensions of a typical sweat pore are a few microns and we need micro sized metallic tips to measure the ionic activities in such pores. Initially, for this study, experiments were carried out with a specially designed single tungsten micro-tip sensor and the ionic currents were measured from formulated sweat. The same phenomenon is simulated in COMOSL multiphysics software to further investigate and observe the effect of ionic current and current density response of micro-tip.

2 BACKGROUND

For various security access control systems, fingerprint biometrics is the widely used technology in commercial applications. Despite many advantages, fingerprint biometrics technology has been deceived by fake finger stamps [6,7,8] and proved the scarcity of distinguishing between fake and real finger in existing sensing technologies. From that investigation, it becomes essential to detect the liveness from fingertip when it is presented on the sensor surface. Most of the proposed liveness detection techniques are based on an external biomedical hardware connected to the sensor system that will add an extra cost and may spoil the compactness and portability of the current sensor system. However, the proposed solutions have not been practically implemented with any fingerprint sensor yet from that viewpoint, we further investigated and studied properties of fingertip skin in detail particularly, sweat pores (see fig.1a). The sweat pores and glands are different on different parts of our skin on human body and some of them on our fingertip are shown in figure.1 (b)

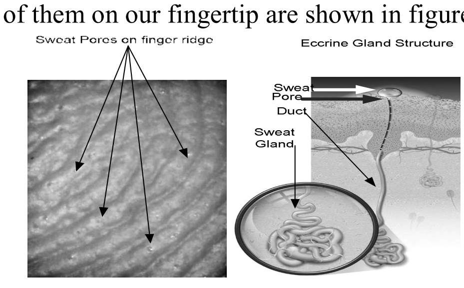


Figure 1: (a) Sweat pores on fingertip ridges (b) Structure of Eccrine Gland underneath the sweat pore

The sweat glands underneath our fingertip are known as Eccrine gland. The eccrine sweat gland is a long, coiled, hollow tube of cells located under the dermis (inner layer of finger tip skin), which is terminated on the skin as an opening or pore. Typical pore diameter is 88 to 200µm and their density is approximately 5 per mm^2 [9]. Sweat secreted from eccrine gland is a type of fluid that is composed of more than 95% water and a range of organic and inorganic compounds and comes out of the pores as a result of thermo regulation or other body functions. The quantity of organic and inorganic substances in sweat fluid depends on individual's physiological characteristics and environmental conditions. For these studies, a standard sample of eccrine gland sweat fluid (EGIF) is formulated with inorganic compounds. Organic compounds are ignored as they don't have any effect in the ionization process. The properties of EGIF sample is near to the composition of the actual sweat secreted from eccrine gland of fingertip skin.

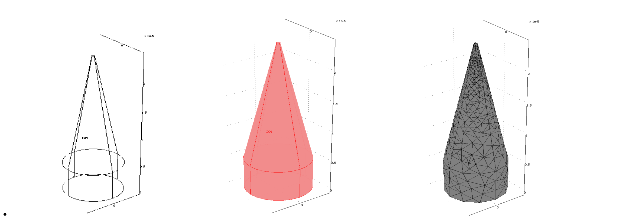
In this study we have presented the modelling studies which illustrate and investigate the effect on the micro-tip when it touches the EGIF at different levels.

3 METHODS

A 3D FE-Model of vertically aligned current sensing micro-tip has been developed using COMSOL multiphysics 3.5 software package. The MEMS module is used to characterize the 3D geometry of micro-tip and its sub-functions such as material properties and conductivity have been used to initialize the sub-properties of micro-tip. The model had two components; micro-tip geometry and an EGIF droplet. Both components developed in the same workspace of COMSOL for investigation and visualize the condition of micro-tip when it touches the EGIF droplet at different distances. The detail of both components is explained in the following section.

3.1 Design of Micro-tip

The geometry of the micro-tip sensor is shown in Figure 2. The vertical height of the cone is 10 µm with support of a circular base with 5 µm radius and 5 µm height... To have precise analysis, sub domain parameters are defined appropriately. The final model of the current sensing micro- tip consists of a conical shape with rounded base with properties of tungsten material (σ =20.0x10^6 S/m). The final shape of micro-tip is shown in Fig. 2 (a) and 2 (b). Meshing algorithm provided by COMSOL Multiphysics has been used to obtain the finest and most refined meshing consists of 24063elements (See Fig 2.c)



a) b) c)

Figure 2:3D COMSOL model of current sensing micro-tip

3.2 EGIF Droplet

From studies and observations of sweat secreted from eccrine gland, it is found that the amount of a single sweat droplet is normally in micro-litre quantity. The exact volume of sweat secreted from fingertip pore is difficult to measure because of their different sizes and different opening and secretion times.

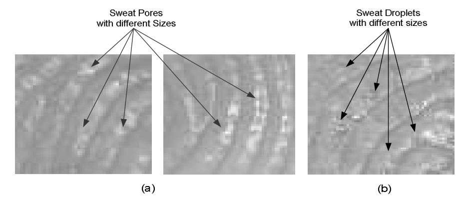


Figure 3: a) Sweat pores with different sizes b) Visible Sweat droplets secreted from sweat pores with different sizes

In COMSOL, the sweat droplet is simulated using an ellipse shape ionic droplet with suitable conductivity and electric charge. Before applying the sub domain condition on EGIF model in COMSOL, the EGIF sample is prepared with the inorganic compounds which are normally present and cause ionization in sweat fluid. The measured conductivity of EGIF is σ =11.95x106 S/m and Q_{j} = 12x10^{-9} A/m^3 is applied as sub domain properties of droplet.

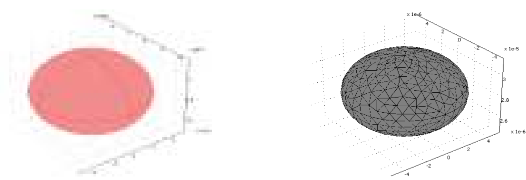


Figure 3: 3D COMSOL model of EGIF droplet

Before the contact of micro-tip with EGIF droplet, condition of EGIF is illustrated in fig 4.

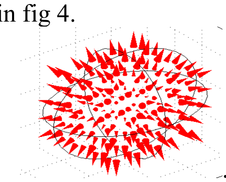
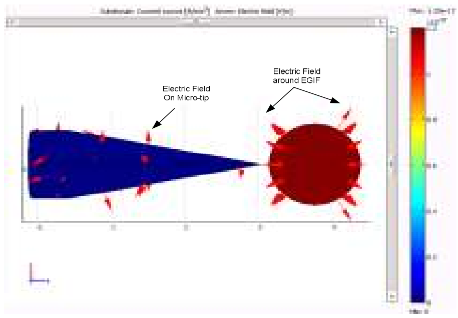


Figure 4: EGIF droplet before contact with micro tip

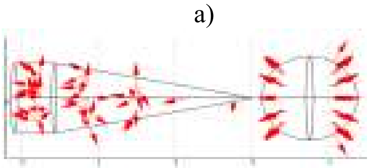
The simulation result of ionic droplet is noticeably packed with high intensity of charges.

3.3 Contact of Micro-tip with EGIF Droplet

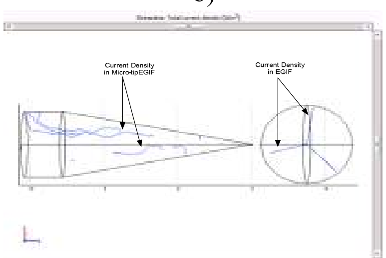
At this stage of simulation, the effect of its contact with EGIF is observed with different distances. In the first step the EGIF and micro tip distance is approximately 2mm (as shown in figure 5. In this step, the sweat droplet is showing highly charged surface and the coupling electric field between the sensor and the droplet is noticeably visible as illustrated in figure 5.a. The electric field is depicted in figure 5 (b)The value of current density at micro- tip is 7.810332 x10^{10} A/m^2 at this distance (see fig. c). The electric field and current density response is reciprocally showed in figure 5 (d).



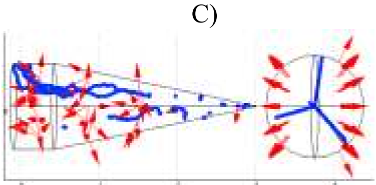
a)



b)



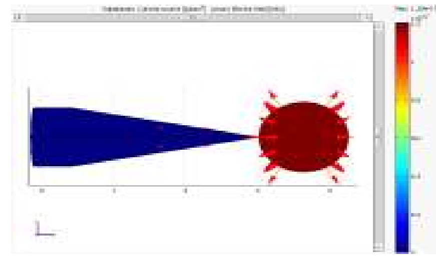
C)



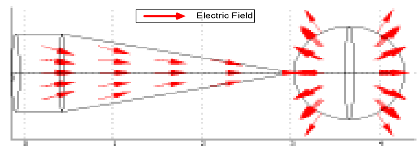
d)

Figure 5: a) Electric field (red Arrows) at ˜ 2mm distance b) Electric field c) Current density d) Reciprocal illustration of Electric Field and Current density on EGIF and micro-tip

In the second step, the sharp edge of micro-tip is moved further close to EGIF droplet and it touches the outer surface of droplet. Without changing any boundary and sub-domain conditions of both components, the three different effects are observed. The simulation results are showing a symmetric effect around the micro-tip. Variation in Current density around the tip is illustrated in Fig. 5 (c). The value of current density in this position is 1.571764×10^9 A/m^2. The sharp edge generally leads to strong electric field at the corners of the active element, which can be seen in Fig. 5 (c).



a)



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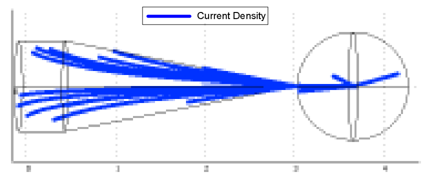

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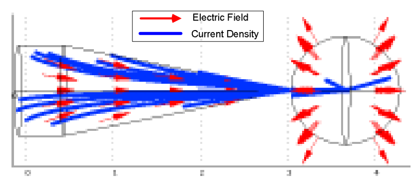
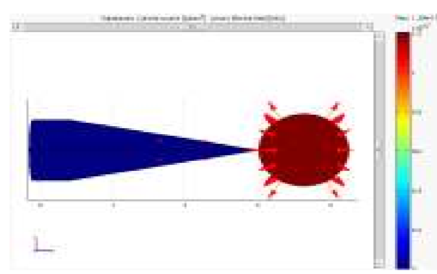
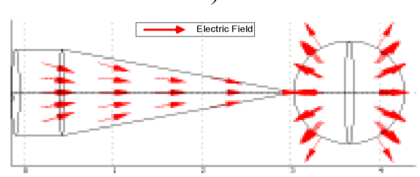


d)

Figure 6 a) Micro- tip exactly touches the surface of EGIF b) Electric Field on micro-tip c) Current Density response d) Mutual representation of Electric Field and Current density on EGIF and micro-tip



a)



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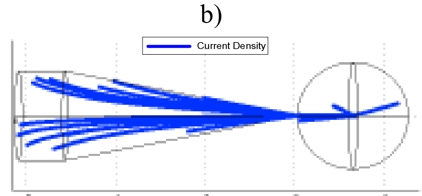

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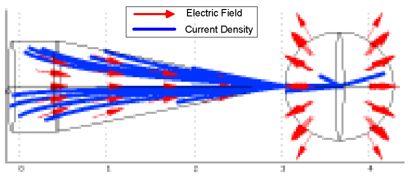
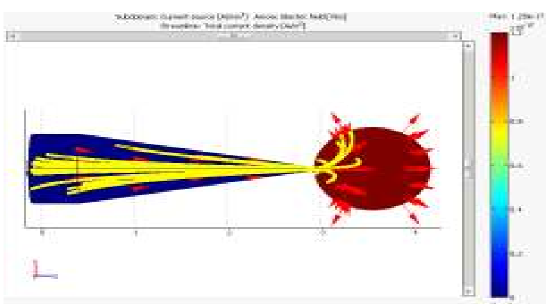


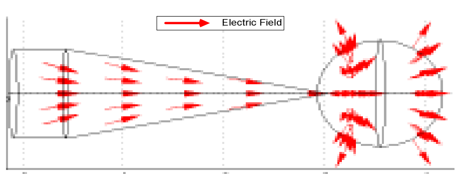
d)

Figure 6 a) Micro- tip exactly touches the surface of EGIF b) Electric Field on micro-tip c) Current Density response d) Mutual representation of Electric Field and Current density on EGIF and micro-tip

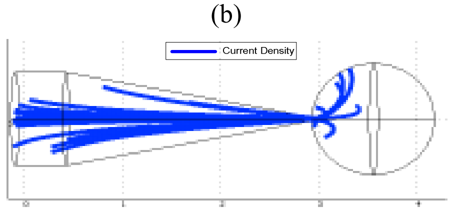
In the final step,˜ 0.5µm of sharp edge of micro-tip is inserted into the EGIF droplet. From the resultant simulation the extra effect of ionic current is observed around the micro-tip as illustrated in figure 7. Impact of ionic current in terms of current density and electric field around the micro-tip are shown in figure. 7 (a) which is higher than the previous position of micro-tip. The electric field is illustrated in figure.7 (b). In Addition, a strong current density is observed at the top-mid region of micro-tip which is clearly depicted in Fig. 7 (c). Total current density at this point is 1.573695×10^9 A/m$^{2.}$



(a)



(b)



(c)

Figure 7 a) Reciprocal plot of micro- tip response by the placing of ˜ 0.5µm area of sharp edge inside EGIF Droplet. b) Electric field on micro tip c) Current density response.

4. SUMMARY

In this paper we have presented the results of preliminary modeling studies of 3D vertically aligned single ionic current sensing tip. In these studies, we have investigated the effect of EGIF on a single micro-tip from three different positions to understand the sensing response and ionic field effect on micro-tip. This study will help us to characterize and modify the parameters such as dimensions and shape of an appropriate micro-tip for novel sensor. Further research is necessary to develop a Micro Sensing Array (MSA) followed by the development of nanowires/ nanotubes based array sensor. The major aim of this research studies is to develop a biometric fingerprint sensor using micro/nano sensing array. The developed array would be able to detect the ionic activity which occurs often in sweat pores on surface of fingertip ridges. It is expected that novel sensor will improve sensitivity, reliability and resolution compared to the existing fingerprint sensors.

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