Electrical Study of an Integrated Biomedical Microsensor

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**ABSTRACT**

The silicon-based devices are still in prime position, and are constantly evolving especially in the field of microelectronics and have even touched multidisciplinary fields, Such as bioelectronics and medical electronics (environmental, pharmaceuticals, medical diagnosis). The detection of chemical species present in biological fluids or even in the environment is delicate and often expensive. That’s why an alternative was found of designing devices with equivalent reliability, simplicity, speed, selectivity and significant replication to minimize the cost. Among them: microsystems and biosensors. Our study focuses on the development of a numerical characterization to optimize a biomedical sensor such as ion sensitive biosensor, DNA and chemicals for its integration into an embedded system (medical probe, smart card). This is done by using the capacitance measurements technique, so a functional analysis. The biosensor used is a MISFET whose gate is suspended bridge.

**Keywords:** Biomedical microsensor; MISFET; gap; C (V); blood.

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INTRODUCTION

Since the invention of the first biosensor in 1967 which is an enzyme sensor by Updike and Hicks [1]. The technology has evolved with the development of other technologies like bio impedance that exploits dielectric properties of cells and the electromagnetic properties of biological tissues, the techniques of organic electronics using measurements of pH and electrical resistivity of physiological liquid. But the technique most interesting for us is the use of capacitance measurements to detect ions H+, Na+ and K+ as well as the chemical species. At this moment, we recall that there are three major families of biosensors:

i. The enzymatic sensors.
ii. The immune sensors.
iii. The DNA sensors or microarrays.

The biosensor is composed of a receptor or bioreceptor which is a chemical element, its role is to recognize molecules and a transducer which is a physical element for converting the physico-chemical interactions in most often an electric signal to exploit.

MATERIALS AND METHODS

Classes of transducers (electrodes)

They can be classified into 4 groups:

1. Metal electrodes: as gold and platinum. These electrodes transmit the collision effect of electroactive substance (i.e., enzymes).
2. Semiconductor electrodes: They are the basis of the structures EIS, ENFET, CHEMFET, ISFET, TFT, MISFET and others.
3. Temperature sensitive electrodes (diodes, bipolar transistors): This technique exploits Seebeck effect so the effect detected is the change of temperature.
4. Pressure sensitive electrodes (piezoelectric crystal, piezotransistor, piezoresistor): The effect detected is the change in pressure.

Transducer used

It’s an MISFET (Metal- Insulator- Semiconductor- Field- Effect-Transistor) and its structure is the following:
The insulator is a sandwich of layers (see below) and the method consists of studying the electrical characteristic gate-source.

**RESULTS AND DISCUSSION**

**Study of the Insulation Capacity According to the Relative Permittivity of the gap:**

The total capacitance is an MIS—metal insulator semiconductor—capacitance; the insulator used is an insulating compound of SiO₂-Si₃N₄-gap-Si₃N₄. At the beginning, the gap is the air; than the air is substituted by a chemical substance (blood). We have used the Si₃N₄ in order to detect the H⁺ charges. For example, if you want to detect the charge K⁺ we can use glass in place of Si₃N₄.

The first characteristic studied is the insulation capacity according to the permittivity of the gap regardless of the substance used.

We see that plus the permittivity of the gap is bigger plus we tend to the saturation regime.

**Figure 1 : Structure of the Used Transducer [2].**

**Figure 2 : The Capacitance of Oxide According the Gap Permittivity.**
According to Figure 1 and the above table we see the interest of the study at high frequencies. We have the following table with human blood taken for gap as an example (Table 1).

**Table 1: Variation of the Blood Relative Permittivity Depending on Frequency [3].**

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Conductivity [S/m]</th>
<th>Relative permittivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.7</td>
<td>5260</td>
</tr>
<tr>
<td>1000</td>
<td>0.7</td>
<td>5258.6</td>
</tr>
<tr>
<td>10000</td>
<td>0.70004</td>
<td>5248.2</td>
</tr>
<tr>
<td>100000</td>
<td>0.70292</td>
<td>5120</td>
</tr>
<tr>
<td>1000000</td>
<td>0.82211</td>
<td>3026.3</td>
</tr>
<tr>
<td>100000000</td>
<td>1.233</td>
<td>76.818</td>
</tr>
<tr>
<td>1584900000</td>
<td>1.9022</td>
<td>59.766</td>
</tr>
<tr>
<td>10000000000</td>
<td>13.131</td>
<td>45.109</td>
</tr>
<tr>
<td>63096000000</td>
<td>55.68</td>
<td>11.765</td>
</tr>
<tr>
<td>1000000000000</td>
<td>63.364</td>
<td>8.2988</td>
</tr>
</tbody>
</table>

**Curve C (V) with Metal Electrode:**

The frequency used is 1 MHz; the metal electrode selected is gold. With this type of electrode we can detect cholesterol, D-lactate, glutamate and hydrogen peroxide H₂O₂ [4] [5] [6].

The electrolyte is the blood whose relative permittivity is 3026.3 [3]. The relation giving the voltage of the flat strip is [7]:

\[
\Delta V_{FB} = -(W_s)_{\text{ref}} + \Delta \psi_0 + (W_s)_{sc} \tag{1}
\]

Where \( W_s \text{ ref} \): the work function of gold electrode (gold). \( W_s \text{ sc} \): work function of the semiconductor. \( \psi_0 \): the potential in the electrolyte "potential surface".

If we know the displacement of the flat strip \( \Delta V_{FB} \), we determine the change in potential of the surface \( \Delta \psi_0 \) and consequently the variation in the concentration so the type of substance selected (\( \Delta Cs \)). With several measures, we can group them in the form of charts, for example, to determine the different species.

With the same parameters and if we take a gap constituted of electrolyte –normal blood– we have the curve below.
The semiconductor used is an “N” doped silicon (doping concentration is $N_D = 10^{14} \text{ cm}^{-3}$). The introduction of blood into the gap caused the displacement of the characteristic $C(V)$ to positive potentials. This is due to the increase in the relative permittivity. In reality the physico-chemical reactions on the surface of Si3N4 and the absorption of charges can intervene and divert even more moving the capacitive characteristic.

We can explain this phenomenon by the following theoretical model:

![Graph](image)

**Figure No. 3: Total Capacitance of the Structure with Blood in Place of Airgap.**

*Figure No. 4: Effect of the Absorption of Charges on the Interface [7].*

This shift may be positive as it can be negative depending on the type of charges.

**CONCLUSION**

Our work is just beginning but already it can tell us from now on the importance of embedded systems with microelectronic components especially in medicine and biotechnology. At that moment the search continues in this line with a basic difficulty grafting or immobilization of chemical species. On this side there is much to do.
REFERENCES