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Functional Analysis of a Suspended Gate Transistor Consecrated to Medical Applications

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Abstract— **The use of the microelectronic components for biomedical applications is in full expansion especially as biosensors. In order to optimize the function of these components we must know their response to different changes of their physical parameters. As an example of this kind of studies, we have chosen a suspended gate thin film transistor (SGTFT) which works as a biosensor because of its interesting high sensitivity.**

Just we recall that we have done a similar study for another microelectronic component which was a metal insulator field effect transistor (MISFET) [1].

Keywords— **SGTFT, Air gap, biosensor, physical parameters.**

I. INTRODUCTION AND PHYSICAL JUSTIFICATION OF CHOICE

Biosensing, this is a fairly new technology since the birth of the first biosensor - an enzyme sensor -was in 1967 by Updike and Hicks [2]. Remind that a biosensor comprises a bioreceptor or receiver which is a chemical element having the role of recognition molecules and a transducer which is an element for converting physical and physicochemical interactions in a mostly electric signal for can exploit .

Technology has evolved from the development of other techniques such as bio impedance which operates the dielectric properties of cells and electromagnetic properties of biological tissues, techniques of organic electronics using measurements of pH and resistivity electrical physiological fluids. But the most interesting technique is the use capacitive measurements to detect the ions H + , Na + and K + as well as the chemical species. And the FETs along with their derivatives that excel in this function. It had started with the use of ion selective field effect transistors (ISFET 's) [3] [4] , but there's also the Thin Film Transistors (TFT), especially poly - TFT (poly silicon TFT) which is in development . We studied the latter type to design a biosensor capable of detecting typical ionic concentrations of human beings for biomedical applications. To increase the sensibility and sensitivity to ions must been added more dielectric layers [5], which led us to choose a poly- TFT quite specific case the SGTFT with a dielectric sandwich form (see technological part). Compatibility with aqueous solutions characterizing human (blood, urine) has necessitated the introduction of more air as a dielectric layer among the constituents of the sandwich. That the reason of its name "Air gap TFT". At the beginning the gap is an air, and then the air is substituted by an organic substance. We used the Si_3N_4 in order to detect the ions H +. This explains our choice for biosensors based air gap TFT as a basis for study.

This section will discuss the influence of the permittivity of the gap, and the frequency of replacement of air in the blood containing an analyte on the capacitive response of the biosensor.

II. TECHNOLOGICAL PARTS

The structure of the airgap TFT is similar to that considered with the conventional TFT, having specificity instead of a layer of silica (SiO_2) as insulation, there is a combination comprising (see fig. 1). This combination is comprised of a layer of SiO_2, followed by two layers of silicon nitride (Si_3N_4) separated by an air gap (SiO_2: 350 nm + Si_3N_4: 500 nanometers + air: 500 nm + Si_3N_4: 45nanometers + poly Si: 500 nm). The active layer is that of Si_3N_4. Temperature is ambient (300 k) and doping of 'N' type polysilicon was early $10^{19}cm^{-3}$.

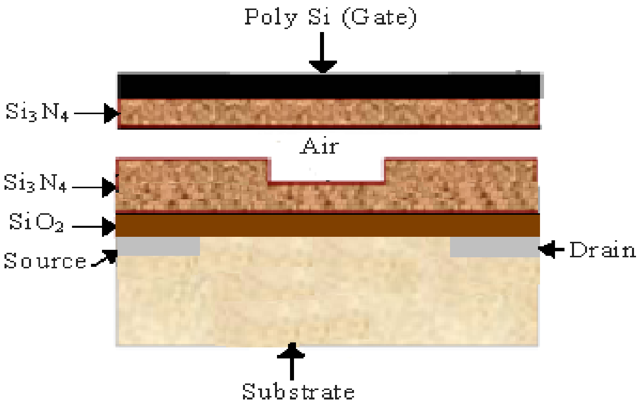

Fig. 1 Structure of the studied poly –Si: SGTFT.

The choice of Si3N4 as an active layer is justified because its high compatibility with blood (biological substance of our study) and it helps in conception of biomedical sensors. [6]

III. RESULTS AND DISCUSSION

A. *Study of the insulation capacitance according to the relative permittivity of the gap*

The insulator used is an insulating compound of SiO_2-Si_3N_4-gap-Si_3N_4. 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 Si_3N_4. 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. [1]
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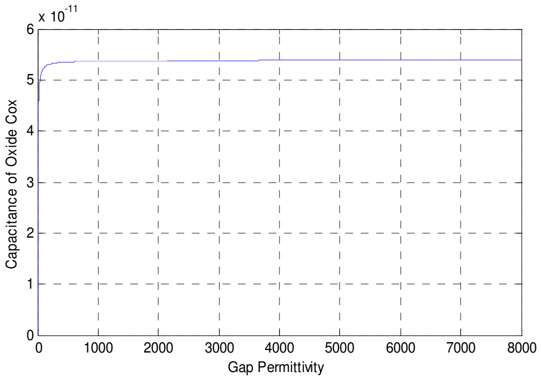

Fig. 2 The Capacitance of Oxide According the Gap Permittivity [1].

B. *Study of the Insulation capacitance according to frequency*

From the Fig. 2, we can deduce the importance of studying at high frequencies. We have taken the blood as biological substance – which replace the air in the gap-. Firstly we can see the impact of the change of frequency on the blood relative permittivity and its variation (see table 1). From this table (table 1), we see that plus the frequency increase, plus the relative permittivity decrease (inversion proportionality) and we can deduce –by using the curve of figure 2- that the insulation capacitance C_{ox} decreased when the frequency is lower than 1 KHz and it's moderately constant when it 's higher -than 1 KHz-.

TABLE I

VARIATION OF THE BLOOD RELATIVE PERMITTIVITY DEPENDING ON FREQUENCY [1] [7].

Frequency [Hz]	Conductivity [S/m]	Relative permittivity
10	0.7	5260
10^3	0.7	52258.6
10^4	0.70004	5248.2
10^5	0.70292	5120
10^6	0.82211	3026.3
10^8	1.233	76.818
1.5849×10^9	1.9022	59.766
10^{10}	13.131	45.109
6.3096×10^{10}	55.68	11.765
10^{11}	63.364	8.2988

Used for compare, we can see the same table but with an air as a gap (see table 2):

TABLE 2

VARIATION OF THE AIR RELATIVE PERMITTIVITY DEPENDING ON FREQUENCY [7].

Frequency [Hz]	Conductivity [S/m]	Relative permittivity
10	0	1
100	0	1
10^3	0	1
10^4	0	1
10^5	0	1
10^8	0	1
630960000	0	1
10^9	0	1
10^{10}	0	1
10^{11}	0	1

For the air we notes that there is no change with the frequency, it's interesting to see the variations when the air is substituted by different bioliquids.

C. Curve C (V)-Total capacitance – Versus change of analyte

Firstly we have taken the air as a gap (physical location of the gate insulation) then we have replaced the air by the blood. We get this curve:

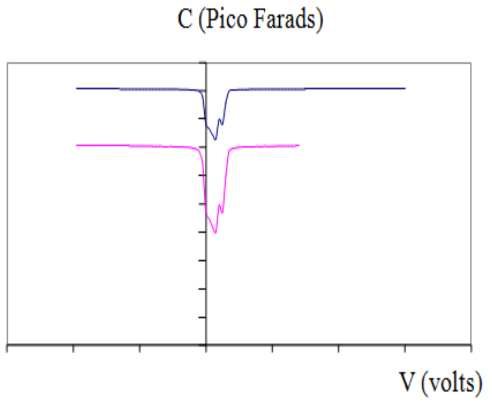

Fig. 3 The capacitance of the normalized structure before and after the introduction of blood into the gap (Polysilicon structure type 'N' and single crystal silicon type 'P') "C (Vp) curve".

The change of analyte causes a decrease of the total capacitance of the structure, this decrease in capacitance is also a result of the effect of the chemical species hooking large (attachment molecules) to the surface of the sensitive layer [8].

D. Study of the capacitance of the structure according to the change of the doping 's silicon single crystal

Was taken as structure: polycrystalline silicon type 'N'-insulator-mono silicon type' N' for a single frequency (1 MHz) and we got this graph:

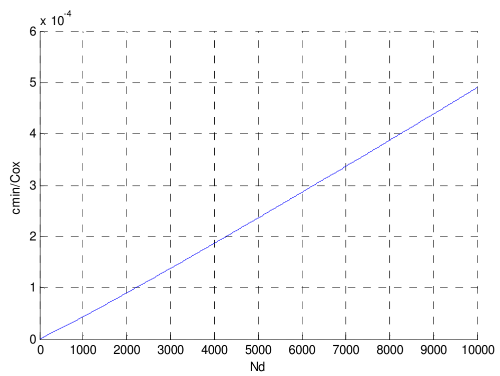

Fig. 4 The minimum capacitance 'High frequencies HF' as a function of substrate doping (N_D).

The used frequency (1 MHz) is high and the capacitance will be minimal like a classical MOSFET (see fig. 5).

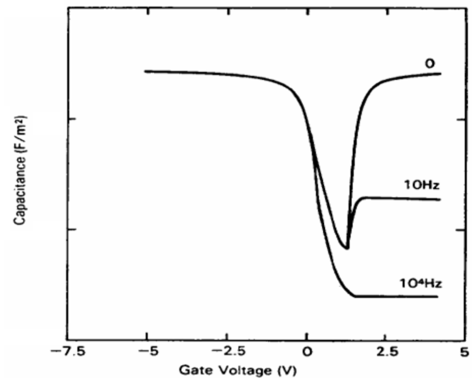

Fig. 5 Dependence of gate capacitance aligned with the gate voltage on different frequencies [11].

We reversed the studied structure of the disposition "polycrystalline silicon type 'P'-oxide- mono silicon ' N '" into "polysilicon type 'N'-oxide –mono crystal silicon P-type". This inversion gave us the following graph:

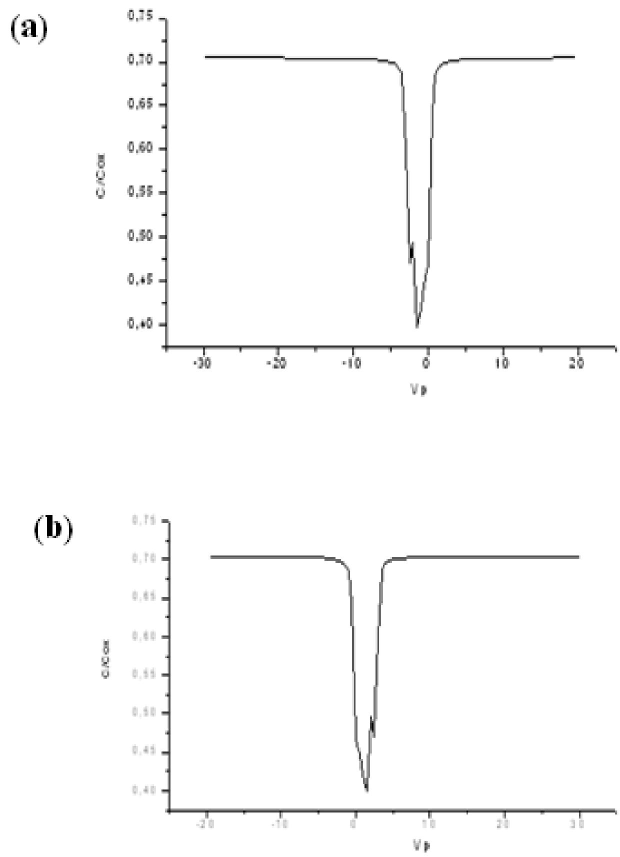

Fig. 6 Effect of inversion-type doping of silicon layers on the shape of the graph of the normalized total capacitance, a: poly Si type P –compound insulator- Si mono type N. b: poly Si type N –compound insulator- Si mono type "P".

The analyte used is blood and frequency consideration is a standard frequency (1 MHz).

It is thus seen that the effect of reversing the structure of the type's silicon generate only a slight effect which results in a right symmetry.

IV. Conclusions

The essential for us in this work was to see the effect of the introduction of blood into the gap, we have seen that this has caused the displacement of the characteristic C (V) down. In reality the physicochemical reactions on the surface of Si_3N_4 and the load absorption may occur and further to deflect the movement of the capacitive characteristic. Our work is just in beginning but already it can tell us soon now the importance of studying microelectronic components especially in medicine and biotechnology.

As perspective of this research, it plans to study the effect of absorption of expenses on the capacitance characteristics so that we can have a complete modelling of biosensors based air gap TFT used in medical diagnosis (electrolytes containing chemical elements : Na , k , Ca , Cl and metabolites : glucose, urea etc.) . The shape is known and it is as follows [8]:

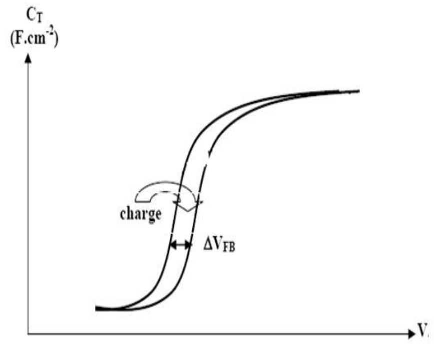

Fig. 7 Effect of the Absorption of Charges on the Interface.

Another reason of this study is to follow the behaviour of the physical parameters of a biomedical sensor constitute by one device. To increase the efficiency of the sensor we can use multi-sensing devices as a system like an array of microelectrodes [12] [13] [14].

To determine the total capacitance of our Polysilicon SGTFT, we have solved numerically the model used by Mr. Predrag HABAS in his paper [9].

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