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(54) Title: ELECTROMAGNETIC INDUCED FIELD EFFECT TRANSISTOR (EMIFET)

(57) Abstract: An improved field-effect transistor for measuring biochemic properties in aqueous form by detecting the dielectric of the objects.



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Electromagnetic Induced Field Effect Transistor (EMIFET)

Field of the Invention

5 The present invention relates to a biochemical sensor, particularly it relates to an improved field-effect transistor for measuring biochemical properties in aqueous form by detecting the dielectric of the objects.

Background of the Invention

10 The field-effect transistor (FET) is composed of four terminals which are source, gate, drain and body (substrate). In FET, the drain-to-source current flows via a conducting channel that connects the drain region to the source region. The channel conductivity is varied by electric field that is produced when voltage is applied between the gate and source terminals.

20 Electro-Magnetic Induction Field Effect Transistor (EMIFET) is developed from the construction of Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) which comprises of a layer of metal gate, an insulating layer of oxide, and a layer of semiconductor.

25 The gate of EMIFET is a metal material that is separated away from the channel. Usually, the metal-like material of choice is polysilicon because its capability to form self-aligned gates.

30 The gate is modified by placing the metal further away from the channel. Both the gate electrode and the channel are covered with a thin insulator namely gate insulator and channel insulator respectively to

protect the sensor surface against contamination from the material under test (MUT). EMIFET revises the previous generation of biosensors namely Ion - Sensitive Field Effect Transistor (ISFET) by simplifying its measurement concept through elimination of sensitive layers on both
5 channel-insulator and reference-electrode (referred to as gate-electrode in EMIFET) which requires non-corrosive type of metal and more complex fabrication process. EMIFET can be fabricated using CMOS fabrication process. The measuring concept is based on dielectrometric approach where the dielectric properties of the MUT are measured by biasing the
10 gate electrode with AC signal within a range of frequencies. EMIFET's drain region will be biased with DC signal and the drain-source DC current produced will be measured as output.

Summary of the Invention

The ISFET is a device constructed by modification of MOSFET whereby the gate electrode or reference electrode is being relocated at a certain distance from the channel. By biasing a DC signal to the gate electrode, the ISFET can measure the characteristics value of an aqueous solution. The reference electrode is typically made from bare metal electrode such as Au/Cr, Pt, Ag/AgI, Ag/AgCl, Pd/Au, and Pd-Pt which some of them are coated with Kalium Chloride (KCl) gel and treated with chlorine plasma in order to protect the bare electrode from corrosion due to interaction between the electrode and the aqueous solution. The aqueous medium in ISFET acts as an extension that connect the gate electrode with the channel insulator and the channel. The channel insulator is coated with sensitive layer material for sensing chemical elements available in the aqueous solutions such as sol-gel-derived lead titanate (PbTiO_3); SnO_2 sol gel; $\text{TiO}_2/\text{SiO}_2/\text{Si}$ structures for pH ISFET, $\text{SiO}_2/\text{Si}_3\text{N}_4/\text{PVA}$ (Poly Vinyl Alcohol) for detecting urea and ionosphoric layers for detecting chloride etc. The requirement of specific gate electrode and sensitive layer material in ISFET contributes to complexity of the fabrication process.

It is intended in the present invention to improve the above disadvantages by providing an improved field effect transistor by covering the reference-electrode (such as polysilicon which is usually used in CMOS fabrication process) and the channel with a thin insulated layer namely as gate-insulator and channel-insulator respectively. An aqueous medium of an unknown dielectric medium available between the gate electrode/gate insulator and channel insulator/channel acts as an extension that connect the gate region and the channel region. The gate electrode are then biased with AC signals and the drain electrode with DC signals to induce an electromagnetic effect which indirectly produce DC

currents from the drain-source region. This configuration has led to an improved field effect transistor and is referred to as Electro-Magnetic Induction Field Effect Transistor (EMIFET). The EMIFET could improve and simplify the fabrication process of ISFET which requires the use of
5 specific reference-electrode and sensitive layers materials.

Brief Description of the Drawings

The above description of the present invention is further described by way of example and with reference to the accompanying drawings in which:

Figure 1 shows the cross section of EMIFET dielectrometric sensor

Figure 2a shows the simplification of EMIFET in Figure 1

Figure 2b shows the capacitance above the channel

Figure 3 shows top view of EMIFET dielectrometric sensor.

Detailed Description of the Present Invention

The present invention will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of the present invention are presented herein for purpose of illustration and description only.

As illustrated in Figure 1, EMIFET consist of one or several gate-electrode (1) located near a drain-source region (region where the drain and source terminal are located). The body or substrate of the EMIFET is a silicon substrate. The drain (3) and source (4) may be heavily doped with p-type or n-type region within n-well or p-well (5) respectively, depending on the type of EMIFET to be used. EMIFET should be protected with p-type or n-type well (6) which are complemented from the well of EMIFET. Top surface of EMIFET is provided with a section for containing and sensing material under test (MUT). As shown in Fig. 1 the section has a beaker-like structure (7) with wall (8). An insulating layer namely gate insulator (9) covers the gate electrode and channel insulator (10) covers the channel electrode (13) to protect the EMIFET from the being contaminated with an aqueous solution. The contact pad of drain (11) and source (12) region should be located outside the structure (7). Channel (13) of p-type or n-type (depend on the type of EMIFET) is the channel that connects drain (11) and source (12).

To operate the EMIFET, the gate-electrode (1) should be biased with an AC signal ranging from few Hertz (Hz) to hundreds of Megahertz (MHz) whereas the drain (3) will be biased with a DC signal. Subsequently, the gate electrode (1) will cause the gate-insulator (10) to induce electromagnetically and as a result, channel (13) below the gate-insulator (10) will be indirectly induced as well. The channel (13) built under the channel insulator will thus connect the drain (3) and source (4)

region resulting in the DC current namely drain-source DC current being produced. The drain-source DC current will vary upon the variation of the induced channel (13).

5 The cross section of EMIFET as shown in Figure 1 could be simplified for calculating the capacitance. The simplified model is illustrated in Figure 2a. Figure 2b shows the capacitance above the channel (13) which consists of three main parts i.e. the thin channel-insulator (10) above the channel (13), the measuring MUT (the aqueous solution) and the gate insulator (9) above the gate-electrode (1).
10 Therefore, the total medium capacitance ($C_{MED-TOT}$) will be as follows

$$\begin{aligned}\frac{1}{C_{MED-TOT}} &= \frac{2}{C_{INS}} + \frac{1}{C_{MED}} \\ &= \frac{2C_{MED} + C_{INS}}{C_{INS}C_{MED}}\end{aligned}$$

or

$$15 \quad C_{MED-TOT} = \frac{C_{INS}C_{MED}}{2C_{MED} + C_{INS}} \quad \text{Eq.1}$$

meanwhile,

$$C_{INS} = \epsilon_{INS} \frac{A}{t_{INS}} \quad \text{Eq.2}$$

and

$$20 \quad C_{MED} = \epsilon_{MED} \frac{A}{t_{MED-EFF}} \quad \text{Eq.3}$$

where C_{INS} is the insulator capacitance with thickness t_{ins} (14) which can be assumed has permittivity constant for all frequency range ϵ_{INS} , C_{MED} is the medium or solution capacitance which is frequency
25 dependent with effective thickness $t_{MED-EFF}$ (15) and has frequency

dependent permittivity ϵ_{MED} . A is area of plate which build the capacitance and equals to WL wherein W (16) is width of EMIFET and L (17) is the length of the channel (13). The $\epsilon_{MED} = \epsilon_0 \epsilon_{r-MED}$ where ϵ_{r-MED} is the frequency dependent relative permittivity of the medium and ϵ_0 is the air permittivity. The total capacitance, therefore will be

$$C_{MED-TOT} = \frac{\epsilon_{INS} \epsilon_{MED} A}{2\epsilon_{MED} t_{INS} + \epsilon_{INS} t_{MED-EFF}} \quad \text{Eq.4}$$

or the total capacitance per unit area will be

$$C_{MED-TOT-A} = \frac{\epsilon_{INS} \epsilon_{MED}}{2\epsilon_{MED} t_{INS} + \epsilon_{INS} t_{MED-EFF}} \quad \text{Eq.5}$$

Due to $t_{INS} \ll t_{MED-EFF}$ therefore $\epsilon_{MED} t_{INS} \ll \epsilon_{INS} t_{MED-EFF}$ then the total capacitance per unit area will be

$$C_{MED-TOT-A} = \frac{\epsilon_{MED}}{t_{MED-EFF}} \quad \text{Eq.6}$$

The drain-source DC current of the EMIFET could be defined as

$$I_{DS} = K_{TOT-MED} [2(V_G - V_T)V_D - V_D^2] \quad \text{Eq.7}$$

with

$$K_{TOT-MED} = \frac{\mu \epsilon_{MED}}{2t_{MED-EFF}} \frac{W}{L} \quad \text{Eq.8}$$

where V_G is voltage-bias for the gate-electrode (1) which EMIFET should be AC signal of frequency dependent. V_D is the drain (3) voltage-bias and V_T is threshold voltage. Such drain-source DC current as illustrated in Equation 7 representing the linear region at I_D vs V_{DS}/V_T curves. For the saturation region Eq.7 will be formulated as follows

$$I_{DS} = K_{TOT-MED} (V_G - V_T)^2 \quad \text{Eq.9}$$

Meanwhile, the threshold voltage V_T will be defined as

$$V_T = V_{FB} - \frac{Q_B}{C_{MED-TOT}} + 2\phi_F \quad \text{Eq.10}$$

where V_{FB} is the flatband voltage, Q_B is the depletion charge in the silicon and ϕ_F is the Fermi-potential. The flatband voltage will be similar as expressed in MOSFET except the capacitance insulator-medium $C_{MED-TOT}$ and capacitance charge of MUT (7) plus gate-insulator (9) and channel-insulator (10) as defined by

$$V_{FB} = \frac{\Phi_M - \Phi_{Si}}{q} + \frac{Q_{SS} - Q_{MED-TOT}}{C_{MED-TOT}} \quad \text{Eq. 11}$$

There are some important information as mentioned above such as the total capacitance as in Eq. 5 or 6 which consists of insulator capacitance and the MUT capacitance, the drain-source DC current as stated in Eq. 7 for linear region and Eq. 9 for saturation region, the influence of threshold voltage within the drain-source DC current, the effect of flatband voltage inside the threshold voltage, and the influence of total capacitance within the flatband voltage. During measurement, some values of MUT capacitance which is inherently represented by the

drain-source DC current for some frequencies. These values will be unique for every mixture material within the aqueous solutions.

For measuring purposes, the basic device of EMIFET could be seen
5 as in Fig. 3 which illustrates the top view of the device. The number of devices in a measuring system minimally one as well as the number of gate-electrodes.

Claims

1. A electromagnetic induced field effect transistor (EMIFET) comprising:
a silicon substrate;
5 drain and source terminals of p-type region within n-well;
at least one gate electrode located near the terminals;
a channel electrode connecting the terminals; and
insulators covering the channel electrode and the gate electrode
forming a section for containing and sensing an aqueous solution.
10
2. A electromagnetic induced field effect transistor (EMIFET) according to
Claim 1 wherein the drain and source terminals each further
comprising a contact pad.
- 15 3. A electromagnetic induced field effect transistor according to Claim 1
wherein the gate electrode is biased with a AC-signal while the drain
terminal is biased with a DC-signal to allow the insulators to induce
electromagnetic effect.
- 20 4. A electromagnetic induced field effect transistor (EMIFET) according to
Claim 3 wherein the electromagnetic effect induce the channel.
5. A electromagnetic induced field effect transistor (EMIFET) according to
Claim 4 wherein the induced channel connecting the drain and source
25 terminals that produce DC current.
6. A electromagnetic induced field effect transistor (EMIFET) comprising:
a silicon substrate;
drain and source terminals of n-type region within p-well;
30 at least one gate electrode located near the terminals;
a channel electrode connecting the terminals; and

insulators covering the channel electrode and the gate-electrode forming a section for containing and sensing an aqueous solution.

7. A electromagnetic induced field effect transistor (EMIFET) according to
5 Claim 6 wherein the drain and source terminals each further comprising a contact pad.

8. A electromagnetic induced field effect transistor (EMIFET) according to
10 Claim 6 wherein the gate electrode is biased with a AC-signal while the drain terminal is biased with a DC-signal to allow the insulators to induce electromagnetic effect.

9. A electromagnetic induced field effect transistor (EMIFET) according to
15 Claim 8 wherein the electromagnetic effect induce the channel.

10. A electromagnetic induced field effect transistor (EMIFET) according to
20 Claim 9 wherein the induced channel connecting the drain and source terminals that produce DC current.

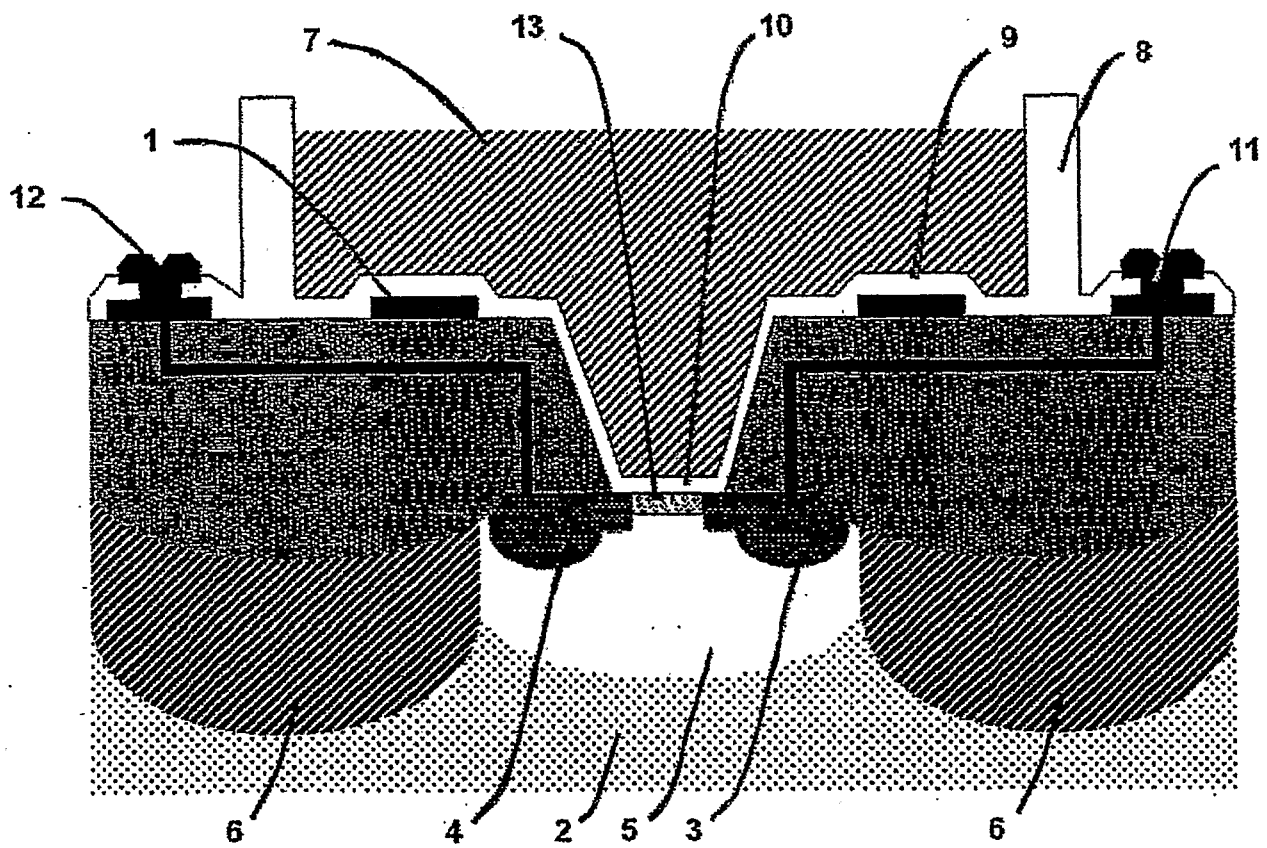


FIGURE 1.

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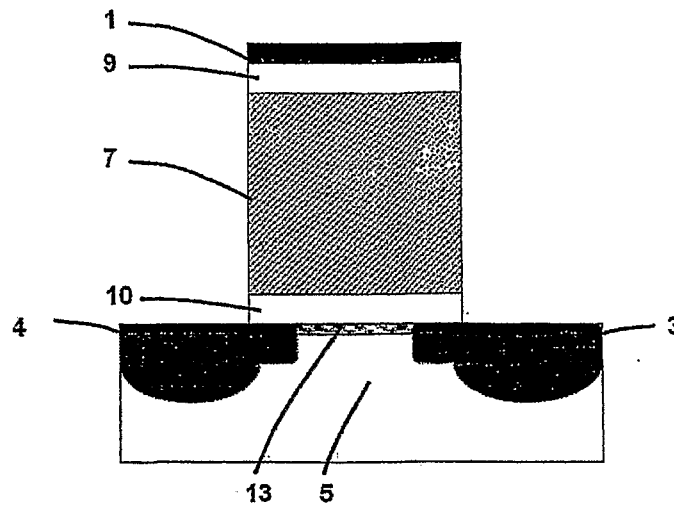


FIGURE 2 (a)

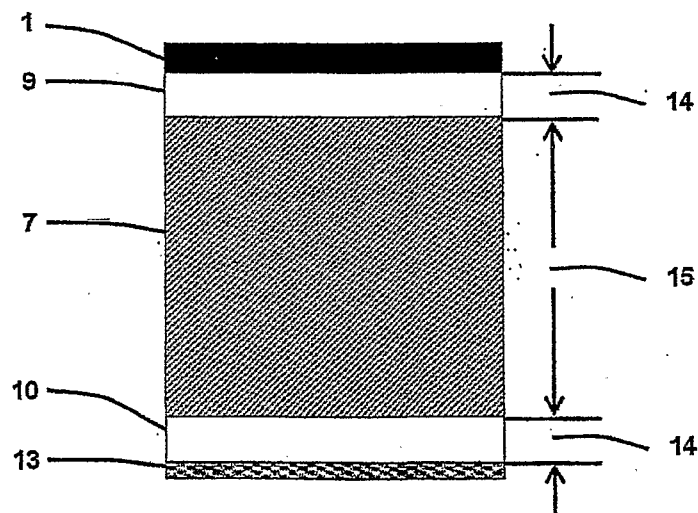


FIGURE 2 (b)

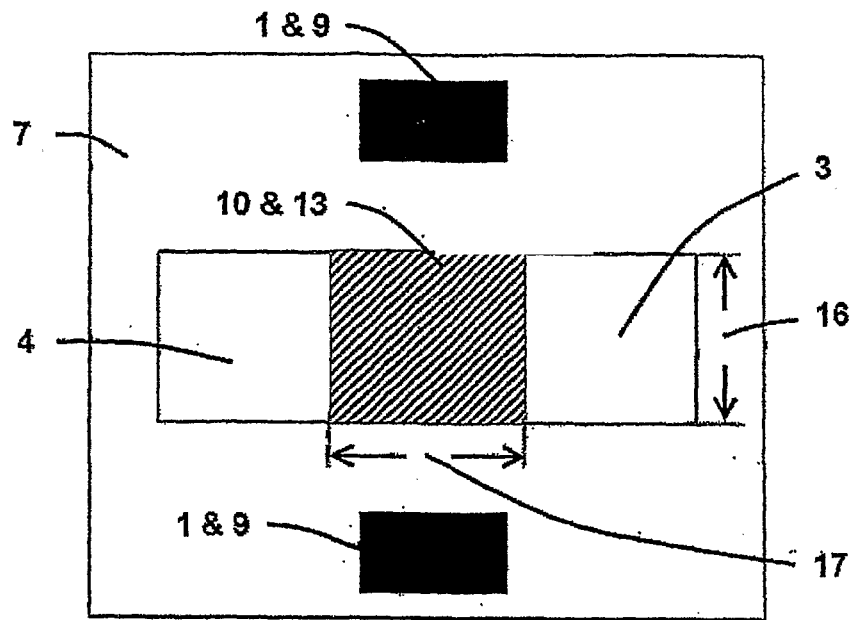


FIGURE 3.