Abstract—A compact n-type carbon nanotube (n-CNT) based junctionless field effect transistor (JLFET) for acetylcholine detection has been fabricated by integrating chitosan/nickel oxide as sensing membrane with CNTFET using chemical solution process. To improve the sensing performances higher than Nernstian, dual gated junctionless CNTFET has been considered here. Electrical response has been carried out after immobilization of acetylcholine esterase using digital multimeter in presence of phosphate buffer saline of 50 mM & pH 7 in a glass pot. Experimental results show good linearity for acetylcholine concentration from 0.01 to 0.2 mM and improved sensitivity of 1.25 V/decade at room temperature. Limit of detection and Michaelis-Menten constant have been found to be 0.37 μM and 0.2 mM, respectively. Insignificant interference observed while the sensor was tested with other clinical parameters.

Index Terms— Acetylcholine, acetylcholine esterase, carbon nanotube, junctionless field effect transistor, solution process.

R...
A. Preparation of solution

B. Sensor fabrication
to understand ISFET’s theory. Where \( q, k, T \) are the charge, temperature

potential \( \Psi_0 + \phi_{S}^f \) and surface potential \( \psi_{S} \).

\[ \Delta \Psi = \frac{\alpha}{\Delta \phi_S} \]

The biocatalytic transformation stimulated by acetylcholine (0.01 stock solution of

The basic building block of ISFET is a surface potential \( \psi_{S} \) that modulates channel current.

\[ \Delta \Phi = \frac{\alpha}{\Delta \psi_S} \]

Eq. (5)

Where, \( R_{\text{NS}}, R_{\text{REF}}, R_{\text{G}}, R_{\text{S}}, R_{\text{C}}, R_{\text{sol}} \) are the capacitances of
top gate \( C_{\text{top}}, C_{\text{ox}} \), and bottom gate \( C_{\text{bottom}}, C_{\text{ox}} \) respectively.

[\Delta \Omega = \frac{\alpha}{\Delta \psi_S}]

Eq. (4)

According to this model, the sensing membrane is a surface potential \( \psi_{S} \) that modulates channel current.

\[ \Delta \psi = \frac{\Delta \phi_{S}}{\psi_{S}} \]

Eq. (3)

The chemical reactions to degrade acetylcholine by \( \text{AChE} \) have been added by micropipette

- \( \text{AChE} \) to choline and \( \text{H}^+ \) by releasing \( \text{H}^+ \) acid by releasing \( \text{H}^+ \) acetatic acid:

\[ \text{CH}_3\text{COO}^-\text{(CH}_2\text{)}_2\text{N}_\text{OH} + \text{CH}_3\text{COOH} + \text{H}^+ \rightarrow \text{CH}_3\text{COO}^-(\text{CH}_2\text{)}_2\text{N}^+ + \text{H}^+ + \text{H}_2\text{O} \]
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The sensitivity characteristic of the sensor from 0.01 M to 0.2 M using the same procedure and condition as mentioned and only for one time samples (graph shown below).

Fig. 1. (a) DMM, (b) Glass Pot, (c) Acetylcholine, AChE, CH/NO, PBS, RE

Acetylcholine concentration obtained from different concentrations (graph not shown) by noting the drain currents for every acetylcholine concentration.

The Linweaver Burk plot for these samples (Fig. 3a) was obtained using Eq. (5) at room temperature 25º C and pH 7.

The standard deviation of the response has been observed.

This lower value of K has been found to be 0.2 µM.

The curve is linear at temperature 25º C and pH 7. The curve is linear up to 0.4 mM acetylcholine concentration.

The thickness of top gate insulator has been kept constant as 10 nm.

The thickness of bottom gate insulator provides bottom gate leakage current.

The threshold voltage has changed from 0.01 V to 1.9 V.

The surface potential has been calculated using the basic equation [13] and found to be 0.37 V.

The dielectric constant of bottom gate insulator is 3.98.

The inverse of dielectric constant of bottom gate insulator provides bottom gate leakage current.

The optimum thickness of bottom gate insulator provides bottom gate leakage current.

Thus, optimum thickness of bottom gate insulator is found to be 90 nm while thickness of top gate insulator is varied from 0.1 µm to 100 µm.

Again low dielectric constant of top gate insulator reveals the surface potential.

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The maximum change in threshold voltage is more than as stated by Nernst [9] and depends on the ratio of capacitances of top and bottom gates. The change in threshold voltage with respect to acetylcholine concentration (0.01–0.2 mM) has been plotted [Fig. 4(a)].

Mathematically, the sensitivity in terms of threshold voltage is defined by Eq. (7) [13].

\[
\Delta V_{TH} = \frac{\Delta V}{\Delta C_{in}}
\]

Where, \( \Delta V_{TH} \) is the change of threshold voltage due to change in the concentration of electrolyte solution, \( \Delta C_{in} \).

The slope of the graph [Fig. 4(a)] gives the sensitivity and has been found to be 1.25 V/decade at room temperature.

The effect of temperature on this device has been investigated by measuring drain current using same procedure as mentioned earlier for 0.2 mM of acetylcholine solution in PBS of pH 7 and varying temperature from 15 to 45 ºC. The maximum response has been found in the temperature range from 30 to 37 ºC as shown in Fig. 4(b).

Optimization of pH has been studied using the same procedure and varying pH from 5 to 9 at room temperature in PBS for 0.2 mM of acetylcholine solution. The maximum response has been found at pH 7–8. Above this value, reaction activity of acetylcholine esterase becomes slower and hence response decreases as shown in Fig. 5(a).

The interference on acetylcholine (0.2 mM) solution due to the presence of urea (0.2 mM), glucose (0.2 mM), uric acid (0.2 mM), ascorbic acid (0.2 mM), dopamine (0.2 mM), lactic acid (0.2 mM) and heparin sodium (0.2 mM) have been studied at the same environmental conditions. The results show no significance change in the response as shown in the Fig. 5(b).

The percentage of interference can be calculated by using Eq. (8) [14].

\[
\text{% Interference} = \frac{I_{Int} - I_{ACh}}{I_{ACh}} \times 100
\]

Where, \( I_{ACh} \) is the drain current for acetylcholine only and \( I_{Int} \) is the drain current for acetylcholine with other mixtures.

It has been found that average percentage of interference of acetylcholine with other solution is ~1.5%.

The experiment has been performed at the same environmental conditions in every week for 8 months and has been found that the device has ~99% activity for acetylcholine detection. Two
Acetylcholine in Fabrication and characterization of effect transistor for cholesterol, vol. 45, pp. 181.

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This has shown the gate dependence just like output characteristics of MOSFET linearity up to drain voltage from 0 to 0.2 V/decade.

Thus, the sensor has response has been observed.

REFERENCES


