

LIST OF TABLES

Table No.	Title	Page No.
2.1.	Various FET based biosensors developed as reported in literature	20
2.2.	Preparation of phosphate buffer saline at 25 °C	44
3.1.	Value of parameters used for fabrication of JLCNTFET	51
3.2.	Output results obtained from cholesterol JLCNTFET	63
3.3.	Comparison of this work with other reported FET based cholesterol biosensors	63
4.1.	Value of parameters used for fabrication of DG–JLCNTFET	69
4.2.	Output results obtained from acetylcholine DG–JLCNTFET	81
4.3.	Comparison of acetylcholine DG–JLCNTFET with other reported ENFETs	81
5.1.	Value of parameters used for fabrication of graphene FET	87
5.2.	Output results obtained from cholesterol graphene FET	98
5.3.	Comparison of graphene based cholesterol FET with other FET based biosensor	98

LIST OF FIGURES

Figure No.	Title	Page No.
Fig. 2.1	Structure of free cholesterol	10
Fig. 2.2	Structure of cholesterol oxidase	12
Fig. 2.3	Structure of acetylcholine	12
Fig. 2.4	Structure of acetylcholine esterase	13
Fig. 2.5	Site-binding model of electrical double layer	16
Fig. 2.6	Electrochemical cell circuit	17
Fig. 2.7	Electrical response measuring set up	18
Fig. 2.8	Structure of first ENFET	19
Fig. 2.9	Chirality of CNT from graphene sheet	31
Fig. 2.10	Structure of polyaniline	33
Fig. 2.11	Structure of polypyrrol	33
Fig. 2.12	Structure of polyethylene imine	34
Fig. 2.13	Structure of chitosan	34
Fig. 2.14	Lineweaver-Burk Plot	38
Fig. 2.15	Denton vacuum DU-502A evaporator	40
Fig. 3.1	Schematic of JLCNTFET for cholesterol detection	49
Fig. 3.2	Electrochemical mechanism of PANI/ZnO/K/CNT	49
Fig. 3.3	Effect of potassium concentration in CNT and PANI concentration in ZnO	50
Fig. 3.4	DC characteristics of JLCNTFET for different V_{gs}	52
Fig. 3.5	Electrochemical response measuring apparatus	54
Fig. 3.6	Reference voltage Vs. Drain current at $V_{DS} = 0.3$ V	54

Fig. 3.7	Drain characteristics of JLCNTFET for different cholesterol concentrations	55
Fig. 3.8	Transfer characteristics at $V_{DS} = 0.3$ V	56
Fig. 3.9	Lineweaver–Burk Plot for cholesterol concentration	57
Fig. 3.10	Sensitivity calculation for cholesterol concentration	58
Fig. 3.11	Effect of temperature on cholesterol responses	59
Fig. 3.12	Effect of pH on cholesterol response	60
Fig. 3.13	Interference on cholesterol response	61
Fig. 3.14	Plot of three data for repeatability of the device	61
Fig. 3.15	Reproducibility plot of two devices	62
Fig. 3.16	Stability plot of the device	62
Fig. 4.1	Schematic of dual gated JLCNTFET for detection of acetylcholine	68
Fig. 4.2	Proposed electrochemical mechanism of CH/NiO/HfO ₂ /PEI/CNT	68
Fig. 4.3	Effect of chitosan concentration in NiO and PEI concentration in CNTs	69
Fig. 4.4	DC curves of DG–JLCNTFET outside liquid at different V_{gs}	71
Fig. 4.5	Electrochemical response measuring apparatus for acetylcholine	72
Fig. 4.6	Reference voltage for acetylcholine concentration at $V_{DS} = 0.4$ V	73
Fig. 4.7	Drain characteristics for different acetylcholine concentrations	73
Fig. 4.8	Linearity for different acetylcholine concentrations at $V_{DS} = 0.4$ V	74
Fig. 4.9	Lineweaver–Burk Plot for acetylcholine concentration	75
Fig. 4.10	Sensitivity calculation of acetylcholine concentration	76
Fig. 4.11	Effect of temperatures on acetylcholine response	78
Fig. 4.12	Effect of pH on acetylcholine response	78
Fig. 4.13	Interference on acetylcholine with other biomolecules	79
Fig. 4.14	Plot of the three data for repeatability of the device	79
Fig. 4.15	Reproducibility plot of two devices	80

Fig. 4.16	Stability plot of the device	80
Fig. 5.1	Schematic of graphene based FET for cholesterol detection	86
Fig. 5.2	Proposed electrochemical mechanism of PPy/K/CNT/ZrO ₂	86
Fig. 5.3	Effect of PPy and potassium concentration in CNT	87
Fig. 5.4	DC characteristics of graphene FET outside liquid for different V _{gs}	89
Fig. 5.5	Electrochemical response measurement setup	90
Fig. 5.6	Electrochemical response of graphene FET at temperature 25 °C.	91
Fig. 5.7	Linearity of graphene FET for cholesterol detection at V _{DS} = 0.2 V	91
Fig.5.8	Lineweaver–Burk Plot for cholesterol	92
Fig. 5.9	Sensitivity calculation of graphene FET	93
Fig. 5.10	Effect of temperature on graphene FET	94
Fig. 5.11	Effect of pH on graphene FET	95
Fig. 5.12	Interference on cholesterol with other biomolecules	96
Fig. 5.13	Plot of three data for repeatability of the device	96
Fig. 5.14	Reproducibility plot of two devices	97
Fig. 5.15	Stability plot of the device	97

LIST OF ABBREVIATIONS AND SYMBOLS

CNT	Carbon Nanotube
MWCNT	Multi walled CNT
SWCNT	Single walled CNT
FET	Field Effect Transistor
g-FET	graphene FET
ENFET	Enzyme Field Effect Transistor
ISFET	Ion Sensitive Field Effect Transistor
CNTFET	Carbon Nanotube FET
JLCNTFET	Junctionless CNTFET
DGJLCNTFET	Double Gated JLCNTFET
BioFET	Biologically modified FET
MOSFET	Metal oxide semiconductor FET
IUPAC	International Unit for Pure and Applied Chemistry
N ₂	Nitrogen gas
IC	Integrated Circuit
ITO	Indium Tin Oxide
DMM	Digital Multimeter
PBS	Phosphate Buffer Saline
ECD	Electrochemical Deposition
RE	Reference Electrode
WR	Working Electrode
CE	Counter Electrode
<i>LoD</i>	Limit of Detection

PANI	Polyaniline
PEI	Polyethylene imine
PPy	Polypyrrole
ChOx	Cholesterol Oxidase
AChE	Acetylcholine Esterase
K	Potassium
PDMS	Polydimethylsilaxane
Ag/AgCl	Silver/Silver chloride
NaCl	Sodium Chloride
V_{REF}	Reference Voltage
V_{GS}	Gate Voltage
PGSTAT	Potentiostat/Galvanostat
V_{DS}	Drain Voltage
I_{DS}	Drain Current
ZnO	Zinc Oxide
ZrO ₂	Zirconium Dioxide
HfO ₂	Hafnium Dioxide
CH	Chitosan
NiO	Nickel Oxide
AChE	Acetylcholine Esterase
GOx	Glucose oxidase
H ₂ O ₂	Hydrogen peroxide
KOH	Potassium hydroxide
NH ₄ OH	Ammonium hydroxide
ZrCl ₄	Zirconium tetrachloride

$(\text{Zn}(\text{CH}_3\text{COO})_2)$	Zinc acetate
Al	Aluminum
Pt	Platinum
κ	Dielectric constant
S	Source
D	Drain
CVD	Chemical vapor deposition
mV	Mili Volt
V	Volt
mM	Mili Mole
μM	Micro Mole
mg	Mili Gram
dL	Deciliter
K_m	Michaelis-Menten constant
A_V	Intrinsic voltage gain
μS	Micro Siemen
μl	Micro Littre
H^+	Proton
$\Delta\Psi_0$	Interfacial potential difference
Ta_2O_5	Titanium Pentoxide
Si_3N_4	Silicon Nitrite
dec	Decade
$\text{C}_{27}\text{H}_{46}\text{O}$	Cholesterol
$\text{CH}_3\text{COO}(\text{CH}_2)_2\text{N}^+(\text{CH}_3)_3$	Acetylcholine

ANS	Autonomic nervous system
PNS	Peripheral nervous system
CNS	Central nervous system
PLs	Phospholipids
TGs	Triglycerides
CEs	Cholesterol Esters
HDL	High density lipoprotein
LDL	Low density lipoprotein
VLDL	Very low-density lipoprotein
CM	Chylomicron
CA	Control amplifier
CF	Current follower
CR	Control resistance
DA	Differential amplifier
GC	Glassy carbon
DNA	Deoxyribonucleic acid
n^+ / p^+	High n -dope/ p -dope
μ_e / μ_p	Electron/hole carrier mobility
C_{ox}	Oxide capacitance
V_{TH}	Threshold voltage
χ^{sol}	Dipole potential of solvent
ϕ_{Si}	Work function of silicon
Q_{ox}	Oxide charge of FET
Q_{ss}	Fixed surface charge of FET
Q_B	Bulk charge of FET

ϕ_f	Fermi potential of silicon
$2\phi_f$	Surface inversion potential of silicon
Φ_{CNT}	Work function of CNT
nm	Nano meter
SiO ₂	Silicon dioxide
IEP	Isoelectric point
A	Area of sensing film
ρ	Density of deposited material
δ	Thickness of deposited film
M	Mass of deposited substance
R	Gas constant
v	Reaction velocity
σ	Standard deviation
S	Slope of curve
[S]	Concentration of analytes
mm ²	Millimeter square
cm ²	Centimeter square
q	Electronic charge $\sim 1.6 \times 10^{-19}$ C
k	Boltzmann constant $\sim 1.38 \times 10^{-23}$ J/K
t	Time
\wedge	Impingement rate
N_{av}	Avogadro's number
η	Concentration of aluminum gas
ζ	Pressure of gas
ζ_0	Initial pressure of gas

ω	Pumping speed,
O	Rate of outgoing gas
χ	Regression coefficients
γ	Interference
R_s	Shunt resistance
X	Volume of chamber
\circ	
π	Molarity of substance