

LIST OF TABLES

Table No.	Title	Page No.
Table 2.1.	Parameters obtained after constant field and constant voltage scaling	15
Table 2.2.	The enzymes used as bioreceptors and analyte used for detection	23
Table 3.1.	Sensitivity of different dielectrics at 25 °C	63
Table 4.1.	Values of important parameters considered for G-ENFET modeling	81
Table 5.1.	Values of various parameters considered for CNT-ENFET modeling	95
Table 6.1.	Values of various parameters considered for CNT-DG-ENFET modeling	108

LIST OF FIGURES

Figure No.	Title	Page No.
Fig. 2.1.	Structure of n-channel MOSFET	11
Fig. 2.2.	The n-channel structure of an ISFET	20
Fig. 2.3.	PENFET (penicillin sensitive ENFET) structure and functional principle [86]	22
Fig. 2.4.	Basic setup for three-electrode system (1) working electrode; (2) counter electrode; (3) reference electrode	25
Fig. 2.5.	Lineweaver-Burk Plot	27
Fig. 2.6.	$I_D - V_G$ curve showing ELR technique [78]	28
Fig. 2.7.	Site binding and electrical double layer model of ISFET [27]	35
Fig. 2.8.	N-doped graphene	42
Fig. 2.9.	B-doped graphene	42
Fig. 2.10.	Showing formation of different CNT structures using graphene sheets	44
Fig. 2.11.	K-doped CNT	45
Fig. 2.12.	PEI-doped CNT	45
Fig. 2.13.	Structure of cholesterol	46
Fig. 2.14.	Structure of acetylcholine	47
Fig. 3.1.	General structure of high- κ dielectric nanomaterial based ENFET device	50
Fig. 3.2.	Surface potential variation with pH for different dielectric materials depicting variations in sensitivity	63
Fig. 4.1.	Schematic of fabricated G-ENFET for Cholesterol Detection [8]	67
Fig. 4.2.	Structure of formation of K/PPy/CNT composite with ZrO ₂ [8]	67
Fig. 4.3.	Output characteristics of G-MOSFET	69
Fig. 4.4.	Transfer characteristics of G-MOSFET to extract $V_{TH,G-ENFET}$ using ELR technique	70

Fig. 4.5.	Output characteristics of G-ENFET	71
Fig. 4.6.	Transfer characteristics of G-ENFET	72
Fig. 4.7.	Description of G-ENFET structure with respect to diffusion length (x)	73
Fig. 4.8.	Substrate and product concentration variation with diffusion length at different time	75
Fig. 4.9.	Substrate and product concentration variation with diffusion length at different enzyme layer thickness (L_e)	76
Fig. 4.10.	Substrate and product concentration variation with diffusion length at different n_{enz} with $L_e=10^{-5}$ cm.	77
Fig. 4.11.	Diffusion length vs pH with decreasing substrate concentration	77
Fig. 4.12.	(A) Comparison of modeling and experimental results for $\psi_{0,G-ENFET}$ vs pH (B) Comparison of modeling and experimental results for $V_{TH,G-ENFET}$ vs pH	79
Fig. 4.13.	Output characteristics of G-ENFET showing comparison between modeling and experimental results	80
Fig. 5.1.	Schematic of fabricated CNT- ENFET for Acetylcholine Detection	84
Fig. 5.2.	Structure of formation of CH/NiO composite with ZrO ₂ and CNT	85
Fig. 5.3.	Output characteristics of CNT-MOSFET	87
Fig. 5.4.	Transfer characteristics of CNT-MOSFET to extract $V_{TH,CNT-ENFET}$ using ELR technique	88
Fig. 5.5.	Output characteristics of CNT-ENFET	89
Fig. 5.6.	Transfer characteristics of CNT-ENFET	89
Fig. 5.7.	Description of CNT-ENFET structure with respect to diffusion length (x)	90
Fig. 5.8.	Substrate and product concentration variation with diffusion length at different time	91
Fig. 5.9.	Diffusion length vs pH with increasing product concentration	92

Fig. 5.10. (A) pH vs $\psi_{0,CNT-ENFET}$ plot showing comparison between modeling and experimental data. (B) pH vs $V_{TH,CNT-ENFET}$ plot showing comparison between modeling and experimental data	94
Fig. 5.11. Output characteristics of CNT-ENFET showing comparison between modeling and experimental results	94
Fig. 6.1. Schematic of fabricated CNT-DG-ENFET for Acetylcholine Detection [7]	98
Fig. 6.2. Structure of CH/NiO composite with HfO ₂ and CNT [7]	98
Fig. 6.3. Output characteristics of CNT-DG-MOSFET	100
Fig. 6.4. Transfer characteristics of CNT-DG-MOSFET	100
Fig. 6.5. Output characteristics of CNT-DG-ENFET	101
Fig. 6.6. Transfer characteristics of CNT-DG-ENFET	101
Fig. 6.7. Description of CNT-DG-ENFET structure with respect to diffusion length (x)	102
Fig. 6.8. Substrate and product concentration variation with diffusion length at different time	103
Fig. 6.9. Diffusion length vs pH with increasing product concentration	103
Fig. 6.10. Product concentration vs pH with varying diffusion length	104
Fig. 6.11. (A) pH vs $\psi_{0,CNT-DG-ENFET}$ plot showing comparison between modeling and experimental data. (B) pH vs $V_{TH,top}$ plot showing comparison between modeling and experimental data.	106
Fig. 6.12. Output characteristics of CNT-DG-ENFET showing comparison between modeling and experimental results	106

LIST OF ABBREVIATIONS AND SYMBOLS

MOSFET	Metal Oxide Semiconductor Field Effect Transistor
ISFET	Ion Sensitive Field Effect Transistor
ENFET	Enzyme Field Effect Transistor
CNT	Carbon Nanotube
MWCNT	Multi walled CNT
SWCNT	Single walled CNT
G-ENFET	Graphene ENFET
CNT-ENFET	Carbon Nanotube ENFET
CNT-DG-ENFET	Carbon Nanotube Dual Gated ENFET
ITO	Indium Tin Oxide
POC	Point of Care
CVD	Catalytic Vapor Deposition
ELR	Extrapolation in Linear Region
DMM	Digital Multimeter
PBS	Phosphate Buffer Saline
ECD	Electrochemical Deposition
RE	Reference Electrode
WE	Working Electrode
CE	Counter Electrode
PEI	Polyethylene imine
PPy	Polypyrrole
ChOx	Cholesterol Oxidase
ACh	Acetylcholine
AChE	Acetylcholine Esterase
PDMS	Polydimethylsilaxane
Ag/AgCl	Silver/Silver chloride
SS	Subthreshold Swing
E	Enzyme
S	Substrate
P	Product
ES	Enzyme substrate intermediate

ZnO	ZnO
ZrO ₂	Zirconium Dioxide
HfO ₂	Hafnium Dioxide
CH	Chitosan
NiO	Nickel Oxide
H ₂ O ₂	Hydrogen peroxide
KOH	Potassium hydroxide
KCl	Potassium chloride
NH ₄ OH	Ammonium hydroxide
ZrCl ₄	Zirconium tetrachloride
Zn(CH ₃ COO) ₂	Zinc acetate
SiO ₂	Silicon dioxide
Al	Aluminium
Pt	Platinum
ρ_s	Density of substance to be deposited
M_s	Mass of substance to be deposited
A_s	Area of sensing film
I_{DS}	Drain to source current
V_{DS}	Drain to source voltage
V_{TH}	Threshold voltage
μ	Mobility of the channel
W	Width of the channel
L	Length of the channel
C_{ox}	Oxide capacitance
A	Area of capacitor
Φ_M	Work function of gate material
Φ_S	Work function of semiconductor
q	Elementary charge
k	Boltzmann constant
Q_{ox}	Oxide charge of MOSFET
Q_{ss}	Fixed surface charge of MOSFET
Q_B	Bulk semiconductor charge of MOSFET
Φ_f	Fermi potential of semiconductor

$2\Phi_f$	Channel inversion potential
ψ_0	Surface potential at the oxide electrolyte interface
E_{ref}	Interfacial potential
χ_{sol}	Dipole potential of solvent
V_T	Thermal voltage
I_{SubTH}	Subthreshold current
T	Temperature
κ	Dielectric constant
ϵ_0	Permittivity of free space
t_{ox}	Oxide thickness
K_M	Michaelis Menten constant
K_a	Acidic equilibrium constant
K_b	Basic equilibrium constant
N_S	Number of sites
β	Dimensionless sensitivity parameter
C_{eq}	Equivalent capacitance
pH_{pzc}	pH at the point of zero charge
D	Diffusion Coefficient
d	Diameter of CNT
a	Lattice distance
$V_{pp\pi}$	C-C tight binding overlap energy
a_{c-c}	Nearest neighbor distance between C-C bonds
E_g	Energy band gap
a_M	Maximal enzyme activity for one enzyme unit
n_{enz}	Number of enzymatic units per volume unit
x	Diffusion length
L_e	Length of enzymatic layer
t	Time
K_e	Water ionic product
η	Viscosity of fluid
ρ	Fluid volumic mass
N_{AV}	Avogadro's number

A_f	Fluid dependent constant.
M	Molar mass of the molecule under study
W	Channel width
L	Channel length
r_j	Source/drain region's radius of curvature
W_d	Width of the depletion region
L_t	Length of the channel region in contact with the gate oxide
V_{PT}	Punch through voltage
v_{sat}	Carrier saturation velocity