

List of Figures**Chapter 2**

| | | |
|---------------|---|----|
| Figure 2.1 | Figure depicting the schematic of ISFET device | 16 |
| Figure 2.2 | Schematic representation of site binding model | 19 |
| Figure 2.3 | The Stern and Gouy –Chapman layers in an electrical double layer | 20 |
| Figure 2.4(a) | Charge distribution and potential profile of an EIS system for $\text{pH} > \text{pH}_{\text{PZC}}$ | 21 |
| Figure 2.4(b) | Charge distribution and potential profile of an EIS system for $\text{pH} < \text{pH}_{\text{PZC}}$ | 22 |
| Figure 2.5 | Figure depicting the structure and functional principle of a penicillin sensitive EnFET | 31 |
| Figure 2.6 | Figure illustrating the electrolyte enzyme insulator semiconductor structure | 32 |
| Figure 2.7 | Electrolyte oxide interface potential vs. pH for Silicon dioxide | 43 |
| Figure 2.8 | Drain Current vs. drain to source voltage at various pH | 43 |
| Figure 2.9 | Drain Current vs. gate to source voltage at various pH | 44 |
| Figure 2.10 | Substrate concentration versus diffusion length plot when substrate concentration is less than k_m | 45 |
| Figure 2.11 | Substrate concentration versus diffusion length plot when substrate concentration is greater than k_m | 45 |
| Figure 2.12 | Product concentration versus diffusion length plot when substrate concentration is less than k_m | 46 |
| Figure 2.13 | Product concentration versus diffusion length plot when substrate concentration is greater than k_m | 46 |

Chapter 3

| | | |
|------------|---|----|
| Figure 3.1 | The depleted regions assumed to be in a rectangular shape, with the atoms at equidistant from each other in the same plane and also in the adjacent plane | 61 |
| Figure 3.2 | The plot showing the comparison of threshold voltage of MOSFET calculated using the proposed model and that of standard formulae for the dopant concentration that varies from 10^{13} to $10^{20}/\text{cm}^3$ | 69 |
| Figure 3.3 | Comparison of the current voltage characteristics of the proposed model and that of existing model (standard formulae) for dopant concentration of $10^{13}/\text{cm}^3$ at different gate to source voltage | 69 |
| Figure 3.4 | Variation of threshold voltage of ISFET device with pH values of electrolyte considering the threshold voltage of MOSFET for dopant concentration of $10^{13}/\text{cm}^3$ | 70 |
| Figure 3.5 | The current voltage characteristics of the ISFET device considering both the MOSFET models (proposed and existing) for three pH values of 4, 7 and 10. | 70 |

Chapter 4

| | | |
|------------|--|----|
| Figure 4.1 | Hydrogen ion diffusion into SiO_2 | 79 |
| Figure 4.2 | Figure depicting diffusion of protons and the field caused by it | 80 |
| Figure 4.3 | Variation of threshold voltage with time, considering the diffusion of hydrogen ions into the sensing layer at pH 4 | 85 |
| Figure 4.4 | Variation of threshold voltage with time, considering the field due to the diffusion of hydrogen ions into the sensing layer at pH 4 | 86 |

| | | |
|----------------------|---|----|
| Figure 4.5 | Variation of threshold voltage with time, considering the diffusion of hydrogen ions into the sensing layer, the field caused by the diffusion and the combined effect of both for pH 4 | 86 |
| Figure 4.6 | variation of threshold voltage with time, considering the diffusion of hydrogen ions into the sensing layer, the field caused by the diffusion and the combined effect of both for pH 7 | 87 |
| Figure 4.7 | Variation of threshold voltage with time, considering the diffusion of hydrogen ions into the sensing layer, the field caused by the diffusion and the combined effect of both for pH 10 | 87 |
| Figure 4.8 | theoretical estimation of variation in threshold voltage with time for pH 4 considering both diffusion and field caused by it along with the practical data obtained for SiO ₂ gate pH ISFET when exposed for 36000 seconds (10 hours) in pH 4 | 88 |
| Figure 4.9 | theoretical estimation of variation in threshold voltage with time for pH 7 considering both diffusion and field caused by it along with the practical data obtained for SiO ₂ gate pH ISFET when exposed for 36000 seconds (10 hours) in pH 7 | 89 |
| Figure 4.10 | theoretical estimation of variation in threshold voltage with time for pH 10 considering both diffusion and field caused by it along with the practical data obtained for SiO ₂ gate pH ISFET when exposed for 36000 seconds (10 hours) in pH 10 | 90 |
| Chapter 5 | | |
| Figure 5.1 | Energy band diagram for a n channel SB MOSFET illustrating four states of operation (a) OFF state; $V_{GS} = 0, V_{DS} = 0$ (b) OFF state; $V_{GS} = 0, V_{DS} > 0$ (c) $V_{GS} < V_T, V_{DS} > 0$ (d) ON state; $V_{GS} > V_T, V_{DS} > 0$ | 96 |

| | | |
|---------------|--|-----|
| Figure 5.2 | Figure showing the schematics of the process flow of the fabrication process (a) Thermal oxidation on clean silicon p type wafer (b) First lithography using the first mask (inset) to pattern the region for depositing metal at later stage(c) Second lithography using second mask (inset) defining the active area (d) Metal deposition using the hard mask (e) Casing done using cover slip for safe loading of electrolyte on the active area, (inset: The actual picture of the device) | 100 |
| Figure 5.3 | Figure showing generalized catalytic cycle for P450. Only the heme iron of P450 is shown to represent the active site of the P450. The abbreviations are as follows: Fe, iron atom in P450 heme; RH, substrate; ROH, product; ox and red, the reduced and (1-electron) oxidized states of P450 reductase involved in electron transfers (under “Catalysis by P450s”). | 101 |
| Figure 5.4 | Schematic for the process flow of the ENFET fabrication. From (a) to (e) it follows the same step as described in figure 5.2. (f) device after immobilization(inset picture of the device after immobilization) | 102 |
| Figure 5.5 | Schematic of the process flow of the Hg MOSFET fabrication. From (a) to (e) it follows the same step as described in figure (Figure.5.2). (f) device after mercury is poured on the sensing layer and reference electrode immerse into mercury to complete the circuit (inset picture of the fabricated Hg-MOSFET) | 104 |
| Figure 5.6 | circuit diagram for the device characteristics | 105 |
| Figure 5.7 | Block diagram for measurement set up for output characteristics | 106 |
| Figure 5.8 | (a) The actual measuring setup for device characteristics along with the fabricated device (inset: actual fabricated ISFET device), (b) Measuring setup of the output characteristics using Keithley 6517B electrometer. | 107 |
| Figure 5.9 | Proton NMR of the reaction mixture after the completion of the reaction | 109 |
| Figure 5.10.a | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for pH 4 | 111 |

| | | |
|---------------|--|-----|
| Figure 5.10.b | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for pH 7 | 111 |
| Figure 5.10.c | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for pH 10 | 112 |
| Figure 5.10.d | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for MOSFET | 112 |
| Figure 5.10.e | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for 0.4 M ENFET | 113 |
| Figure 5.10.f | The $\sqrt{I_d}$ vs V_{GS} curve is plotted for 0.5 M ENFET | 113 |
| Figure 5.11 | Variation of threshold voltage with respect to pH values of electrolyte | 114 |
| Figure 5.12 | Subthreshold slope of the Schottky ISFET for pH 7 | 115 |
| Figure 5.13 | Output characteristics for the pH 4, pH 7 and pH 10 of fabricated ISFET , Hg MOSFET and 0.4molar and 0.5 molar ENFET is plotted. F indicates fabricated, FE indicates fabricated ENFET, Hg F indicates fabricated Hg MOSFET. | 116 |
| Figure 5.14 | Variation of V_{GS} with respect to change in pH keeping current constant at 0, 0.5, 1.0 and 1.5 μ A respectively | 118 |
| Figure 5.15 | Variation in V_{GS} value with respect to change in pH for constant current 0.5 μ A for the three devices fabricated in a batch | 118 |
| Figure 5.16 | Variation of V_{GS} with respect to change in concentration of n hexadecane at constant currents 0.5 μ A and 0.75 μ A respectively. | 119 |
| Figure 5.17.a | Variation of V_{GS} with respect to concentration of n hexadecane measured at three consecutive days for constant current of 0.5 μ A | 120 |
| Figure 5.17.b | Variation of V_{GS} with respect to concentration of n hexadecane measured at three consecutive days for constant current of 0.75 μ A | 121 |
| Figure 5.18.a | Hysteresis observed in the fabricated ISFET device | 122 |
| Figure 5.18.b | Hysteresis observed in the fabricated ENFET device | 122 |
| Figure 5.19 | Change in pH with respect to concentration of the | 123 |

| | | |
|----------------------|--|-----|
| | n-hexadecane | |
| Figure 5.20 | Reproducibility of sensor output for a particular current $0.5\mu\text{A}$ for 6 cycles (72 hours; 12 hours each) for 0.1 to 0.5 mol/l | 124 |
| Figure 5.21 | Correlation and regression line for measurement of n hexadecane assayed by the fabricated sensor. | 125 |
| Figure 5.22 | Variation of V_{GS} for the fabricated ISFET device at current $0.5\mu\text{A}$ for pH 4, 7 and 10 with the repeated conversions from ISFET to MOSFET/ENFET and vice versa in a time period of 100 days. | 127 |
| Chapter 6 | | |
| Figure 6.1 | Figure depicting the potential profile of the EIS structure for a planar surface when the reference electrode is placed in the bulk of the solution | 135 |
| Figure 6.2 | Figure depicting the potential profile of the EIS structure for a planar surface when the reference electrode is placed in the diffused layer | 136 |
| Figure 6.3 | Site binding model of the silicon nitride surface | 138 |
| Figure 6.4 | Block diagram of the experimental set up | 144 |
| Figure 6.5 | The complete set up with the data acquisition system | 145 |
| Figure 6.6 | Keithley Electrometer 6517B | 146 |
| Figure 6.7 | The gate voltage signal generated by the DAC | 147 |
| Figure 6.8 | Stepper motor with 1:11 worm gear reduction | 148 |
| Figure 6.9 | The translation mechanism | 149 |
| Figure 6.10 | The micrometer and the dial indicator | 149 |
| Figure 6.11 | Reference electrode and the ISFET immersed in measurand | 150 |
| Figure 6.12.a | The block diagram for the generation of gate voltage | 152 |

| | | |
|---------------|---|-----|
| Figure 6.12.b | Circuit diagram for the generation of the gate voltage and its display in 16×2 LCD | 152 |
| Figure 6.13.a | Protection circuit | 154 |
| Figure 6.13.b | Virtual contact points acting as reference electrode and sensing layer along with the spring mechanism | 154 |
| Figure 6.14.a | Variation of interfacial effective electrolyte insulator potential with respect to distance for pH 4 | 158 |
| Figure 6.14.b | Variation of interfacial effective electrolyte insulator potential with respect to distance for pH 7 | 159 |
| Figure 6.14.c | Variation of interfacial effective electrolyte insulator potential with respect to distance for pH 10 | 159 |
| Figure 6.15.a | Variation of effective insulator/electrolyte interface potential with increase in distance of the reference electrode from sensing layer ranging from 0 mm (i.e. the sensing layer) to 9 mm (i.e. three times of Debye length for pH 14). | 160 |
| Figure 6.15.b | figure showing 90 different equidistant points between the sensing layer and 3 times of Debye length, chosen for the data extraction for pH 14 | 161 |
| Figure 6.16.a | Variation of effective insulator/electrolyte interface potential with increase in distance of the reference electrode from sensing layer ranging from 0 mm (i.e. the sensing layer) to 2.7 mm (i.e. three times of Debye length for pH 13). | 162 |
| Figure 6.16.b | Variation of effective insulator/electrolyte interface potential with increase in distance of the reference electrode from sensing layer ranging from 0 mm (i.e. the sensing layer) to 0.9 mm (i.e. three times of Debye length for pH 12). | 163 |
| Figure 6.17 | Effective insulator electrolyte interface potential (Φ_{eo_eff}) vs. pH with the reference electrode positioned at 100 μ m from the OHP. | 164 |

List of Tables

| | | |
|-----------|---|-----|
| Table 3.1 | Table for comparison of the threshold voltage of MOSET calculated by the proposed model and the standard formulae | 67 |
| Table 5.1 | Comparison of various sensors used for hydrocarbon detection | 128 |
| Table 6.1 | Table for Debye length values for corresponding pH of the measurand for a Si_3N_4 surface | 155 |