Preface

Sensor is an important device with capability to detect physical quantities of materials such as gas, liquid and molecules in the surrounding area. Its feedback in the form of electrical parameters can be measured experimentally. Sensor can be defined as a device that responds to environmental changes and converts these physical quantities into various types of signals which can be analyzed or interpreted by the instruments. As a sensor greatly depends on the material characteristics such as properties, performance and sensitivity, choosing the right one should be considered as an essential decision. Graphene has recently become an important material in the disciplinary field of carbon nanoscience and condensed matter physics. It has attracted attention because of unique properties such as high sensitivity, high mobility and biocompatibility. Furthermore, Graphene/Carbon as a novel material with organic nature is intrinsically sensitive to diversity of molecules and atoms.

*Handbook of Research on Nanoelectronic Sensor Modeling and Applications* is planned to support researchers in nanotechnology related sensor modeling. It is deliberately planned as a research handbook, which illustrates to the researcher the process of sensing phenomenon to formulate physical effect of molecules in the form of electrical response, conventionally investigated by experimental results. The extensive modeling part of the book is focused on the graphene based sensors and extends the technology of electronic devices to nanoscale sensor modeling and simulation. The physics of sensor device in nanoscale area, which reflects quantum mechanical effects with inter-atomic interactions, is explored in this book. The handbook presents valuable research information on nanoscale sensor modeling and simulation. The electrical response of sensing phenomenon in the form of physical models is employed and numerical algorithms are improved to investigate nanoscale sensor devices.

The book is organized into 17 chapters. Chapter 1 introduces the basic ideas related to the carrier statistic on field effect transistor as a sensor platform for understanding the nanoscale sensor working phenomenon. In addition, the application of new material such as carbon nanotube (CNT) in device technology is discussed. In this chapter, the platform of CNT sensors such as transistor-based sensors, chemiresistors, chemicapacitance and resonator sensors are discussed in detail. Using CNT as a sensor platform although has great advantages, it does not have sufficient sensor reliability. Some of the technical challenges related to CNT-based sensors including Schottky contact formation and non-selective synthesisation have been outlined in this chapter.

Chapter 2 highlights application of graphene nanoribbon (GNR) in high-speed electronics. Additionally, trilayer graphene nanoribbon (TGN) as one of the most common multilayers of graphene is discussed in this chapter.
Chapter 3 provides details on the compatibility of silicene with existing semiconductor techniques and the need for new materials to continue Moore’s law. It is clear that this material can be used as a sensor and field effect transistor platforms. Silicene electrical properties such as electrical conductance, carrier concentration, mobility, and magneto-conductance of 2D silicene are modeled which shows that silicene nanoribbons and nanopores can be used in sensor technology. Specially, their use in DNA sequencing and efficient thermoelectric power generation has been described in this chapter.

Chapters 4 and 5 focus on graphene/CNT based gas sensors. It is known that both graphene and CNTs experience changes in their electrical conductance when exposed to different gases, such as, CO2, NO2, and NH3. In these chapters, several gas sensor models are proposed by employing the Field Effect Transistor structure. In the suggested models, different physical properties such as conductance, capacitance, drift velocity, carrier concentration, and the current-voltage (I-V) characteristics of graphene/CNTs have been used to model the sensing mechanism. An Artificial Neural Network model has also been developed for the especial case of a CNT gas sensor exposed by NH3 to provide a platform to check the accuracy of the models.

Chapters 6 through 9 continue the focus on gas sensors. In Chapter 6, a chemiresistive gas sensor based on conducting polymer is considered. These gas sensors are commonly based on polyaniline (PANI), polypyrrole (PPy), polythiophene (PTh), and their derivatives as a transducer. Common configuration and response mechanism of these sensors are reported in this section. Some factors that induce selectivity to these sensors are discussed. Different materials (conductor or insulant) can be used as a substrate of polymerization. Type of substrate, selective membranes, surface modification of conducting polymer, and so on can change the response behavior of these sensors. Chapter 7 is divided as follows: In the first part, a description of the main topologies and materials (carbon nanomaterials plus polymers, metals, ceramics or combinations between these groups) used to fabricate gas sensors based on graphene and carbon nanotubes, which are operated by conductance or electrical resistance, is presented. Next, different mathematical models, that can be used to simulate gas sensors based on these materials, are described. In the third part, the impact of the graphene and carbon nanotubes on gas sensors is exemplified with technical advances achieved until now. Finally, an analysis of the role of gas sensors based on carbon nanomaterials in the next decades is provided. In Chapter 8, the focus is on NO2 detection. Additionally, the defect effect on graphene structure and its consequence in sensing is explored. The World Health Organization (WHO) estimates that each year about 4.6 million people die directly from causes of air pollution. This will be a serious threat to human health. Therefore, there is a growing demand towards highly sensitive, cheap, low consumption, user-friendly devices which can monitor the quality of air indoor and outdoor areas for protecting human health. In Chapter 9, the effect of nitrogen dioxide (NO2), oxides of carbon (COx), and hydrocarbons as main air pollutants on carbon based sensors are discussed.

Chapter 10 focuses on the study and development of graphene-based DNA sensor model for detection of DNA. This study includes modeling and simulation of carrier concentration, conductance, and current-voltage characteristics of graphene-based sensors on the field effect transistor (FET) platform. The main challenge is to validate the developed model with the experimental data. In this research, firstly, numerical model is developed which shows the dependency of current-voltage characteristics on the DNA concentration factor. The iteration method is used for developing the numerical model as well.

Chapter 11 focuses on BGNR quantum capacitance variation effect by the prostate specific antigen (PSA) injected electrons into the FET channel as a sensing mechanism. Also, carrier movement in BGNR as modeling parameter is suggested. Additionally, the effect of PSA adsorption and local pH value on injected carriers in the surface of BGNR is modelled. Carrier concentration as a function of control
parameters is predicted. Furthermore, changes in charged lipid membrane properties are electrically detected by graphene based electrolyte gated Graphene Field Effect Transistor (GFET). In this chapter, monolayer graphene-based GFET with focus on conductance variation by membrane and thickness is studied.

In Chapter 12, the idea of graphene and CNT based electrical biosensors is discussed. A liquid gated graphene field effect transistor (LG-GFET) based biosensor model is analytically developed for electrical detection of Escherichia coli (E. coli) bacteria. An E. coli absorption effect on the graphene surface is considered in the form of conductance variation. Moreover, the current-voltage characteristic is applied in terms of conductance model to evaluate the performance of the biosensor model. Furthermore, the CNT-FET platform is employed for modeling biosensor in order to detect Glucose. For diagnosing and monitoring the blood glucose level, glucose oxidase (GOx) based enzyme sensors have been immensely used. According to the proposed CNT-FET structure, charge based analytical modeling approach is used. The charge-based carrier velocity model is implemented to study electrical characteristics of CNT-FET. In the presented model, the gate voltage is considered as a function of glucose concentration.

Chapter 13 presents an appropriate structure to ISFET device for the purpose of electrical measurement of different pH buffer solutions. Electrical detection model of each pH value is suggested using conductance modelling of monolayer graphene. In addition, ISFET based on nanostructured SWCNT is studied for the purpose of electrical detection of hydrogen ion concentrations. Electrical detection of hydrogen ion concentrations by modeling the conductance of SWCNT sheets is proposed. pH buffer as a function of gate voltage is assumed and sensing factor is defined.

In Chapter 14, first of all, a method for refractive index investigation of graphene based structures is introduced, and then the effect of carrier density variant in the form of conductance gradient on graphene based SPR sensor is modeled. The molecular properties such as electro-negativity, molecular mass, effective group number, and effective outer shell factor of the molecule are engaged. In addition, each factor effect in the cumulative carrier variation is explored analytically. The refractive index shift equation based on these factors is defined, and related coefficients are proposed. Finally, a semi-empirical model for interpretation of changes in SPR curve is suggested and tested for some organic molecules.

Chapter 15 presents a review of silicon based fast neutron detectors. Specifically, proton recoil methods are surveyed. Furthermore, carbon nanoparticles (CNPs), having simple and low cost preparation methods and exceptional electrical properties, have widely been used in nanoelectronic applications such as radiation sensors. In this chapter, fast neutron detectors using carbon based semiconductor, back-to-back Schottky diode type, and polyethylene as convertor are developed, and the Am-Be fast neutron source is used in experimental measurements.

In Chapter 16, the design procedures and characteristics of sensor amplifiers are explained. The important parameters of sensor amplifiers are input and output resistance, gain, unity gain bandwidth and etc. One of the most important characteristics of amplifiers is the linearity of amplification in a way that it must have uniformity for all amplitude voltages or currents in all frequencies of the bandwidth. For this purpose, firstly, the operational amplifier is completely discussed, and then the linearity of feedback operation is explained.

Chapter 17 describes nanotechnology importance in enabling the development of devices in a scale ranging from one to a few hundred nanometers, which can perform tasks such as sensing, data storing, computing, and actuation. These nano devices will be able to cover larger areas and perform more complex tasks through communication. Wireless nanosensor networks (WNSNs) are collections of nanosensor devices with communication capability. The key components of a WNSN include nano-nodes, nano-
router, nano-micro interface, and gateway. WNSNs have numerous potential biomedical, environmental, industrial, and military applications. This chapter provides an overview of the architecture, applications, and issues associated with the development of WNSNs.