Chapter 12

Graphene and CNT Field Effect Transistors Based Biosensor Models

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ABSTRACT

In this chapter, novel ideas of graphene and CNT based electrical biosensors are provided. A liquid gated graphene field effect transistor (LG-GFET) based biosensor model is analytically developed for electrical detection of Escherichia coli (E. coli) bacteria. E. coli absorption effects on the graphene surface in the form of conductance variation is considered. Moreover, the current-voltage characteristic in terms of conductance model is applied 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. Finally, the both of presented models are compared with published experimental data.

INTRODUCTION

Silicon based technologies are approaching their scaling limits. To overcome the limitations of silicon planner devices, new device designs are being explored to replace the existing planar device technology. Hence, smaller dimensions, less power consumption, low energy delay product, very large computing power and high density as well as high speed is demanding for future electronic technology. Nanoelec-

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tronic, is a new field which is opening novel horizons for electronic device industry. Nevertheless, the downscaling procedure of semiconductor device dimensions lead to some drawbacks such as gate leakage current and short channel effect, like in the conventional metal oxide semiconductor field effect transistors (MOSFETs). Therefore, devices based on novel nanomaterials like graphene nanoribbon field effect transistors (GNR-FETs), carbon nanotube based field effect transistors (CNT-FET), nanowire field effect transistors (NW-FETs) and nanoscrolls field effect transistors (NS-FETs) are promising candidates to overcome planner devise constrains.

MODERN SENSOR TECHNOLOGY

In the early 1990s (since the foundation of MOSFET), miniaturization and integration of very small functional units, open a new horizon for future technologies, from micro down to nano and molecular scales. Sensor play a very important role in most products and systems. The development of sensors could not keep pace with the advancements in microelectronic devices and components. Therefore, sensor technology is in restructuring stage for miniaturization and integration in signal processing system (Meixner, 2008). This fact causes technologies that permit manufacturing of sensors and the related electronics with low costs, to be given high importance. In the past two decades, numerous research works has been done in sensor technology area. Among those researches, biosensors have attracted enormous attentions because of their amazing selectivity and sensitivities (Kirsch, Siltanen, Zhou, Revzin, & Simonian, 2013; Kriz, Ramström, & Mosbach, 1997).

Research and development in this field is broad and involves areas such as physical chemistry, electrochemistry, bioreactor science and biochemistry. Majority of the focus was on amperometric biosensors and colorimetric paper enzyme strips. But, nowadays more focus is being given to the research of the different transducer types and their application to biosensors (Chaplin & Bucke, 1990; Taneja, 2012). Biosensors application are growing at an annual rate of 60% where the health-care industries, food quality appraisals and environmental monitoring mainly contribute to this growth. The approximate value of the world analytical market is about 12 billion dollars per year which the share of medical area is nearly a third of total market. Of this total market, only approximately 0.1% accounts for the use of biosensors, hence exhibiting the vast potential growth in this area (Taneja, 2012).

In spite of remarkable advancement in the field of electronics and biosensors in recent years, this area is in the initial steps. Some crucial issues such as selecting ideal biomaterial and improvement of sensing techniques based on electronic detection approaches are getting a lot of attentions (Dankerl et al., 2009; Fromherz, Offenhausser, Vetter, & Weis, 1991; Härtl et al., 2004; Stern et al., 2007; Voelker & Fromherz, 2005; Yang et al., 2002). Because of some reasons such as industrial, technical and technological maturities, silicon is the most popular and commonly used material in this field (Fromherz et al., 1991; Stern et al., 2007; Voelker & Fromherz, 2005). But, because of inherent limitations of silicon, novel nanomaterials are called upon to challenge silicon dominance. Silicon suffers low chemical stability and biocompatibility. Furthermore, silicon platform based biosensors have very complex design and fabrication process. In addition, electronic devices based on silicon have relatively high noise which effect on device sensitivity (Dankerl et al., 2009; Härtl et al., 2004; Yang et al., 2002).

But, superior electrical properties and low noise allow carbon based material such as graphene and carbon nanotubes to be excellent candidates for sensing applications (Galib, 2012; Geim & Novoselov, 2007). One of the most important benefits of these materials is their large surface to volume ratio, which