Hydrogen Sensor Based on Graphene on Ion Sensitive Field Effect Transistor (G-ISFET)

Background and Motivation

Graphene, a stable two-dimensional structure, has attracted tremendous attention worldwide taking advantage of its unique electrical properties and high crystal quality. It is being predicted to have numerous potential applications and influence the next generation of electronic devices. They are of interest for use as building blocks in the bottom-up assembly of nanoscale devices and circuits due to their exceptional electrical and mechanical properties. Devices and circuits using graphene that have been demonstrated include FET, sensors and solar cells. The applications of these types of graphene based devices have been demonstrated as portable gas sensors in flexible electronics (where electronics may be exposed to both high temperatures and humidity). In the past several years, gas and chemical sensors have been developed using carbon nanotubes. However, these sensors show decreased precision with increased noise signals and performance reduction when the network method is used. Consequently, it becomes necessary to develop alternate materials and processes for gas and chemical sensors development that overcomes these disadvantages. Particularly, electronic devices currently in use are silicon based, however the development of Si-based technology is fast approaching an end since silicon is reaching its physical limits. Therefore, graphene which has high mobility of charge carriers at high electric-field-induced concentrations without being affected by chemical doping and has the ability to detect gas molecule makes it an exceptional choice for nanoscale device applications.

Finally, there is very limited research on material aging at the nanoscale. Accelerated aging is the study of a material shelf life and is often performed in a laboratory setting. In this test, the material is subjected to excess oxygen, temperatures and sunlight in order to accelerate its actual aging. Material properties such as the mechanical fatigue, load cycle intake and material stability are evaluated for the prediction of shelf life of the material. Though Europe has favored standard test methods based on aging at elevated temperature, slicing and scaling techniques have been the leading approach in North America. Recently, standard test methods in Canada have been adapted from many industries across US, but these test methods are only defined for the macroscale components. The current test methods involve slicing the material which is possible only for specialized cases at the nanoscale such as Focused Ion Beam (FIB) milling of NWs, and these methods cannot be directly adapted to nanoscale materials. One of the key impacts of the proposed work is the development of ultrasensitive gas sensors, specifically hydrogen sensors using a combination of graphene and ISFETs and predicts the lifetime and reliability of the sensor which currently do not exist for nanoscale materials. The need for these protocols was discussed extensively during the recent IEEE Nanotechnology Council (NTC) meeting in Portland, Oregon on August 15, 2011, for which Dr. Wejinya was a member (2010 – 2012). Thus the research proposed here will address the fundamental knowledge gap in the nanoscience and engineering community, namely "How do nanoscale materials and devices age in extreme conditions and environment?" The resulting research will enable the prediction of material lifetime and reliability for graphene and graphene based hydrogen gas sensors. In addition, the experimental protocols developed during this research will guide future work on aging of nanoscale materials by the research community.

Research Goals and Objectives

The research goals of this proposal are to develop graphene based H_2 sensor AND predict the lifetime and reliability of this nanoscale material based device. To achieve these goals, efforts will be focused on developing and validating an aging protocol for graphene and studying the resulting changes in material properties. The material systems will be aged with temperatures of 125 ^{O}C and above while exposed to oxygen and moisture for accelerated aging with an extreme environment. The material systems will be analyzed with high resolution imaging such as Transmission Electron Microscopy (TEM), Scanning Tunneling Electron Microscopy (STEM) and Atomic Force Microscope (AFM). Accordingly, the research objective of this proposal is to take a systematic and integral approach to develop hydrogen gas sensors using a combination of ISFET and graphene material. The proposed research involves the following specific objectives:

a) Design, fabrication and testing of ISFET on Si chips for the transfer of graphene and transuding.
b) Nanofabrication of nanochannels on the fabricated ISFET for spray deposition of graphene.
c) Simultaneous operation of spray deposition (Chemical Exfoliation) and Dielectrophoresis (DEP) for uniform deposition of graphene.
d) Testing the fabricated graphene layer on ISFET for H_2 gas sensing.
e) Accurately measure (within 5% uncertainty) the sensitivity of graphene based H_2 sensor aged in an extreme environment.