Novel Carbon Nanotube-Based Nanostructures for High-Temperature Gas Sensing

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OBJECTIVES

The primary objective of this research is to examine the feasibility of using vertically aligned multi-wall carbon nanotubes (MWCNTs) as a high temperature sensor material for fossil energy systems where reducing atmospheres are present. The research will be pursued in three main areas: 1) study the growth mechanisms of MWCNTs using the flame synthesis technique and modification of the nanotemplate to improve the quality of the nanotubes for use in a gas sensing platform, 2) transform the modified vertically aligned CNTs into a capacitive type hydrogen sensor prototype to assess feasibility for high temperature applications, and 3) pursue theoretical modeling and numerical simulation of nanostructures, hydrogen gas sensors, and the flame synthesis for large-area nanotube growth.

ACCOMPLISHMENTS TO DATE

Nanostructure Modification and Characterization

Vertically aligned carbon nanotubes are currently fabricated using anodic aluminum oxide (AAO) nanotemplate. The pore size or diameter of nanotubes is varied using different voltages, electrolyte, and temperature. The pore wall and barrier layer are variables in modifying the nanotemplate through control of the acidic solution strength. The nanostructure of the template has been studied in detail using SEM.

Nanotube Growth

Growth of the carbon nanotubes is carried out using flame synthesis technique. In the past, we use acetylene flame in the presence of cobalt catalyst to grow CNTs. After CNT growth, we found thick amorphous carbon film formed on the surface of AAO templates where CNT grew. This amorphous carbon film is very hard to remove to obtain a clean surface, which is necessary for fabrication of CNT sensors. After numerous trials by varying time, temperature, atmosphere, and catalyst size, we finally obtained a clean surface with perfect CNTs by changing ethylene to methane with correspondingly adjustment of some flame parameters.

Fabrication of Hydrogen Sensors

Two types of capacitive sensors structures have been fabricated. One structure involves the direct deposition of the top metal electrode (Al) on the aluminum oxide embedded with nanotubes. The other structure has an insulator layer between the metal and the aluminum oxide embedded with nanotubes. The sensors did respond to a reducing gas (hydrogen). However, the sensitivity is very limited. In order to improve the sensors' sensitivity, we studied the Pd as the top electrodes because of its good solubility. We have studied the hydrogen sensing properties of dense Pd films on SiO_2 substrates and nanoporous Pd films on AAO substrates. AAO-based nanoporous Pd films exhibit much higher sensitivity (over 10 times) than the dense Pd films at low concentrations (<1000 ppm). At high hydrogen concentrations, its sensitivity is about 2-3 times higher than the dense Pd films. Therefore, AAO-based Pd films will be a better candidate for hydrogen sensing. In addition, a high temperature test setup for hydrogen sensors has been established with temperature ranging from room temperature to over 100°C.

FUTURE WORK

Fabrication of Hydrogen Sensors for Use in High Temperature

Capacitive sensors will be fabricated based on the nanotube-based nanostructures, which are able to withstand high temperature up to 1000°C. Special electrodes and connection wires being able to withstand high temperature will be used.

Hydrogen Sensor Modeling

The sensors will be modeled on considering the gas molecule diffusion into the nanotubes and the electrical models will be constructed on considering the 3-D structure.

LIST OF PAPER PUBLISHED

1. D. Y. Ding and Z. Chen, "Volume-expansion-enhanced pinning of nanoporous Pd films for detection of high-concentration hydrogen," Submitted to Appl. Phys. Lett.
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3. H. G. Zhang and Z. Chen, "A Horizontally Aligned One-Dimensional Carbon Nanotube Array on a Si Substrate," Submitted to J. Electrochem. Soc.
4. T.X. Li, H.G. Zhang, F.J. Wang, Z. Chen, and K. Saito, "Synthesis of Carbon Nanotubes in Counterflow Methane-Air Diffusion Flames," Submitted to Carbon.
5. D. Y. Ding, Z. Chen, and C. Lu, "Hydrogen Sensing of Nanoporous Palladium Films Supported by Anodic Aluminum Oxides," Sensor & Actuators B (in press).
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7. Z. Chen and H. G. Zhang, "Mechanisms for formation of a one-dimensional array of nanopores by anodic oxidation," J. Electrochem. Soc. vol. 152, no. 12, pp. D227-D231 (2005).
8. H. G. Zhang, Z. Chen, T. Li, and K. Saito, "Fabrication of a one-dimensional array of nanopores on a silicon substrate," J. Nanosci. & Nanotechnol. vol. 5, pp. 1745-1748, 2005.

LIST OF CONFERENCE PRESENTATIONS

1. H. G. Zhang, Z. Chen, T. X. Li, and K. Saito, "Fabrication of 1-D AAO Nano-Pore Arrays on Si Substrates", 2005 KY Innovation & Enterprise Conference, Louisville, KY, March 30, 2005.
2. H. G. Zhang, Z. Chen, T. X. Li, and K. Saito, "Fabrication of Quasi 1-D AAO Nano-Pore Arrays on Si Substrates", 11th Annual Kentucky Statewide EPSCoR Conference, Louisville, KY, May 13, 2005.

LIST OF AWARDS RECEIVED

"Building Kentucky's New Economy with EPSCOR: UK Nano Initiative," National Science Foundation EPSCoR Infrastructure, PI, Co-PIs: V. Singh, T. Hastings, Janet Lumpp, I. St. Omer, et al., $1.95M. Award period: 06/01/05-05/31/08.

"State EPSCoR: UK Nano Initiative," Kentucky Council on Postsecondary Education, PI, Co-PIs: V. Singh, T. Hastings, Janet Lumpp, I. St. Omer, at al., $783K. Award period: 06/01/05-05/31/08.

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