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

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Grant Number: DE-FG26-04NT42171; Performance period: 09/01/04-03/31/07

OBJECTIVES

The primary objective of this research is to examine the feasibility of using vertically aligned carbon nanotubes (CNTs) 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 CNTs 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 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.

ACCOMPLISHMENTS

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.

Carbon Nanotube Growth

Growth of the carbon nanotubes is carried out using a flame synthesis technique. In the past, we use acetylene flame 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

Capacitive sensors structures have been fabricated. One structure involves the direct deposition of the top Al electrode on AAO 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. We successfully fabricated Pd-electrode CNT sensor and CNT-supported Pd film sensor for room temperature application. It is found that CNT itself is not sensitive to hydrogen. However, with the help of Pd electrodes, hydrogen sensors based on CNTs is very sensitive to hydrogen with fast response.

FUTURE WORK

We will fabricate CNT-supported platinum (Pt) film sensors, which can withstand even higher temperature. The AAO structure will be modeled for optimum design of sensors.

LIST OF PAPER PUBLISHED

1. Dongyan Ding, Zhi Chen, Suresh Rajaputra and Vijay Singh, "Hydrogen sensors based on aligned carbon nanotubes in anodic aluminum oxide template with palladium as top electrodes," Sensors & Actuators B, in press (2007).
2. T.X. Li, H.G. Zhang, F.J. Wang, Z. Chen, and K. Saito, "Synthesis of carbon nanotubes on Ni-alloy and Si-substrates using counterflow methane–air diffusion flames," Proceedings of the Combustion Institute, vol. 31, 1849-1856 (2007).
3. Hongguo Zhang and Zhi Chen, "A Horizontally Aligned One-Dimensional Carbon Nanotube Array on a Si Substrate," J. Electrochem. Soc., vol. 154, H124-H126 (2007).
4. Chi Lu, Zhi Chen, and Kozo Saito, "Hydrogen sensors based on Ni/SiO_2/Si MOS capacitor," Sensors & Actuators B, vol. 122, 556-229 (2007).
5. Dongyan Ding and Zhi Chen, "Volume-Expansion-Enhanced Pinning of Nanoporous Pd Films for Detection of High-Concentration Hydrogen," Sensor Letters, vol. 4, 331-333 (2006).
6. Dongyan Ding, Zhi Chen, and Chi Lu, "Hydrogen sensing of nanoporous palladium films supported by anodic aluminum oxides," Sensors & Actuators B, vol. 120, 182-186 (2006).
7. Z. Chen and C. Lu, "Humidity sensors: a review of materials and mechanisms," Sensor Letters vol. 3, pp. 274-295 (2005). (Invited)
8. 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).
9. 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. Dongyan Ding and Zhi Chen, "Nanoporous Pd Film Sensors for Detection of High Concentration Hydrogen," the 6th IEEE Conference on Nanotechnology, Cincinnati, OH, July 16-20, 2006.
2. Hongguo Zhang and Zhi Chen, "Growth of Horizontally Aligned One-Dimensional Carbon Nanotubes Array on a Si Substrate," the 6th IEEE Conference on NanotechnologyCincinnati, OH, July 16-20, 2006.
3. Dongyan Ding and Zhi Chen, "Detecting high concentration hydrogen with nanoporous palladium supported by anodic aluminum oxides," the 64th Device Research Conference, IEEE, University Park, PA, June 26-28, 2006. pp. 127-128.
4. 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.
5. 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

1. "NIRT: Molecular and Electronic Devices Based on Novel One-Dimensional Nanopore Arrays," National Science Foundation, PI: Zhi Chen, $1.2M. Award period: 07/15/06-06/30/10.
2. "Building Kentucky's New Economy with EPSCOR: UK Nano Initiative," National Science Foundation EPSCoR Infrastructure, PI: Zhi Chen, $1.95M. Award period: 06/01/05-05/31/08.
3. "State EPSCoR: UK Nano Initiative," Kentucky Council on Postsecondary Education, PI: Zhi Chen, $783K. Award period: 06/01/05-05/31/08.

LIST OF STUDENTS SUPPORTED

1. Chi Lu (Graduate student, partially supported)
2. Dongyan Ding (Postdoctoral associate, partially supported)
3. Hongguo Zhang (Postdoctoral associate involved in the project, not supported by this grant)
4. Tianxiang Li (Research Assistant Professor involved in the project, not supported by this grant)