

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

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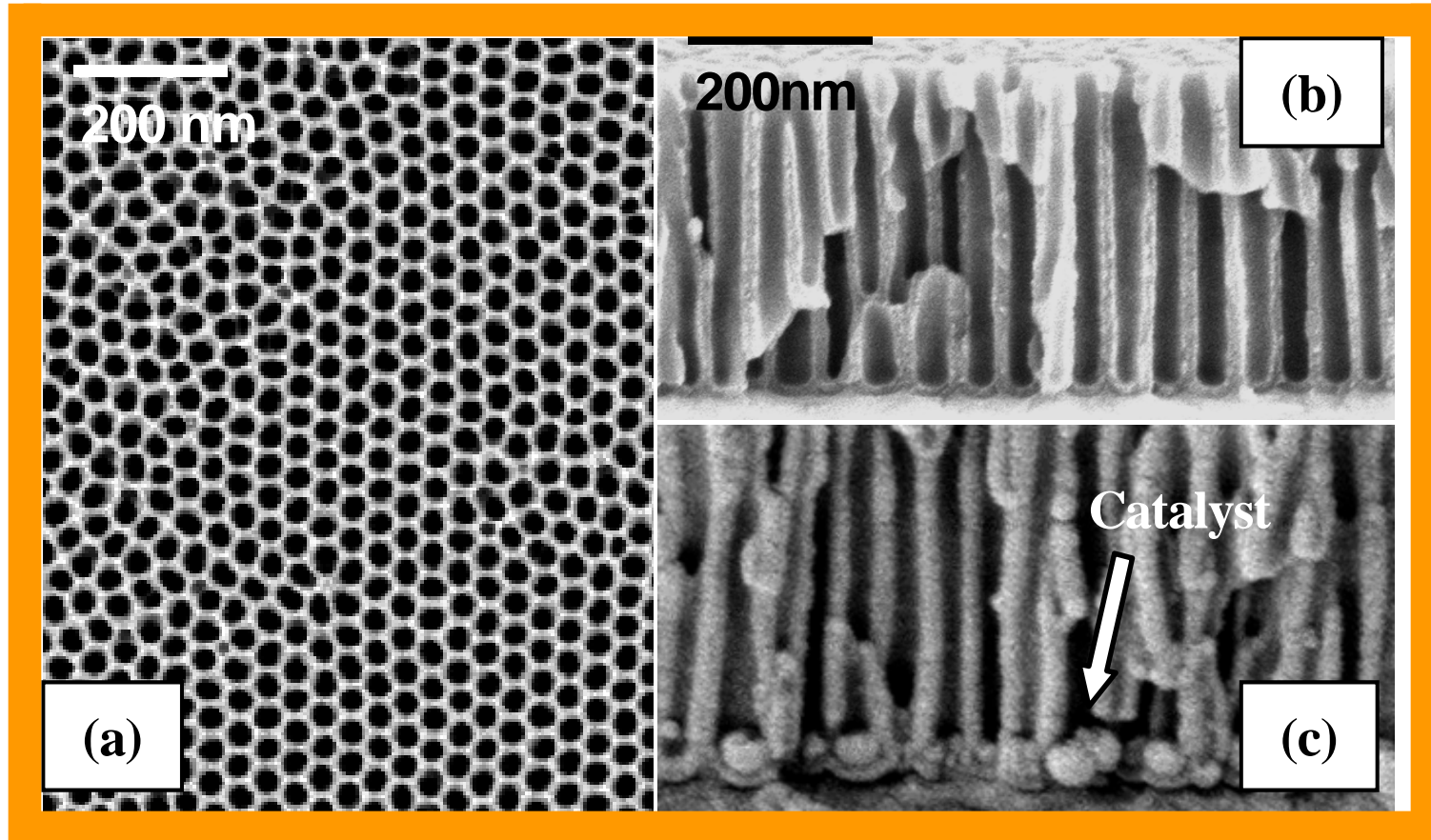
**University of Kentucky**

**Lexington, KY 40506**

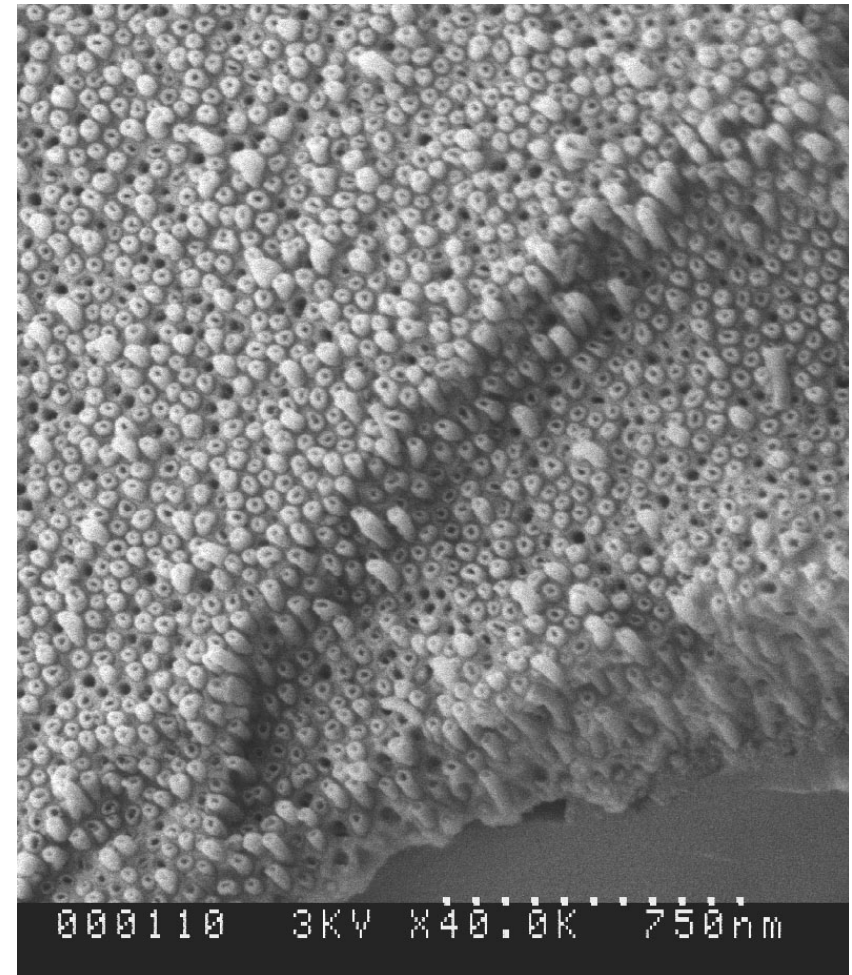
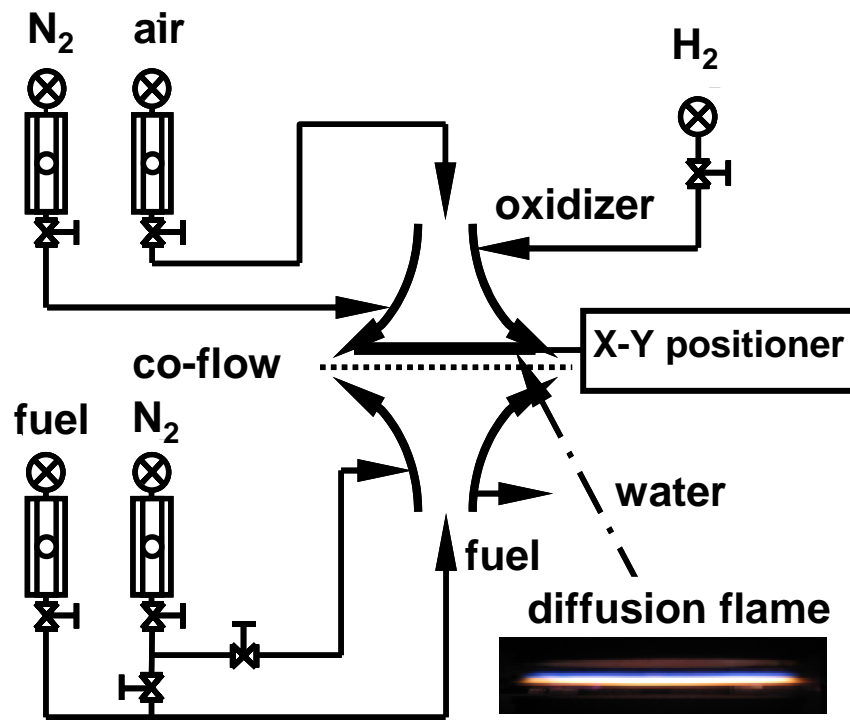
## **Problems of hydrogen sensors**

- **No hydrogen sensors available for temperature  $> 800^{\circ}\text{C}$**
- **Lack of long-term stability due to very high temperature**

## Porous anodic aluminum oxide (AAO) template

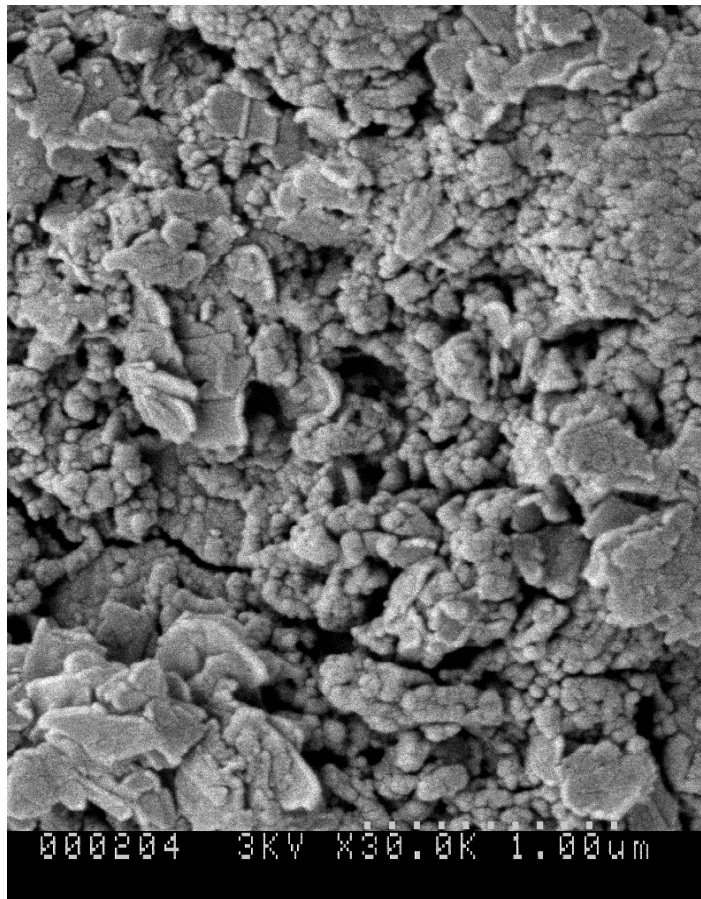


## Growth of carbon nanotubes in AAO templates using flame synthesis

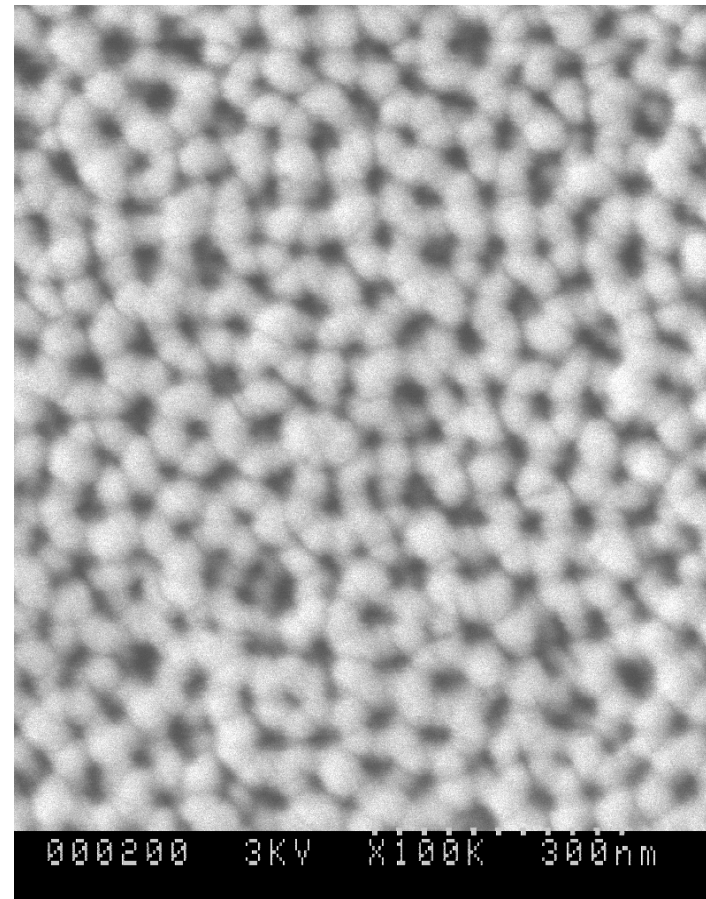


## Improvement of surface cleanness of CNT samples

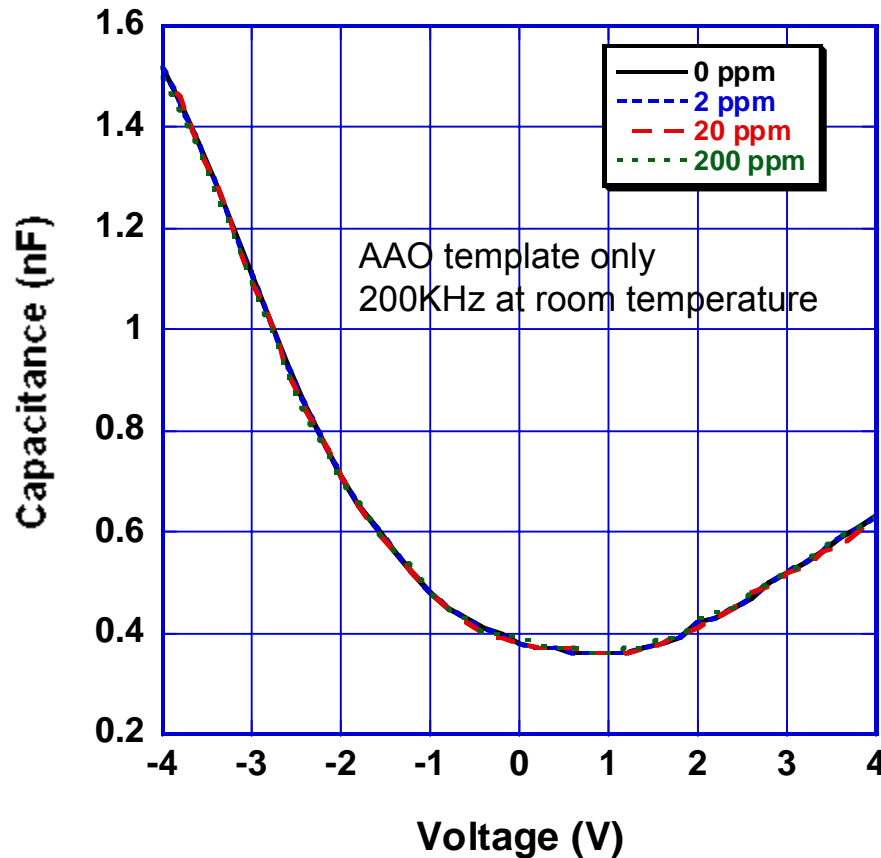
Thick amorphous carbon on sample grown in ethylene



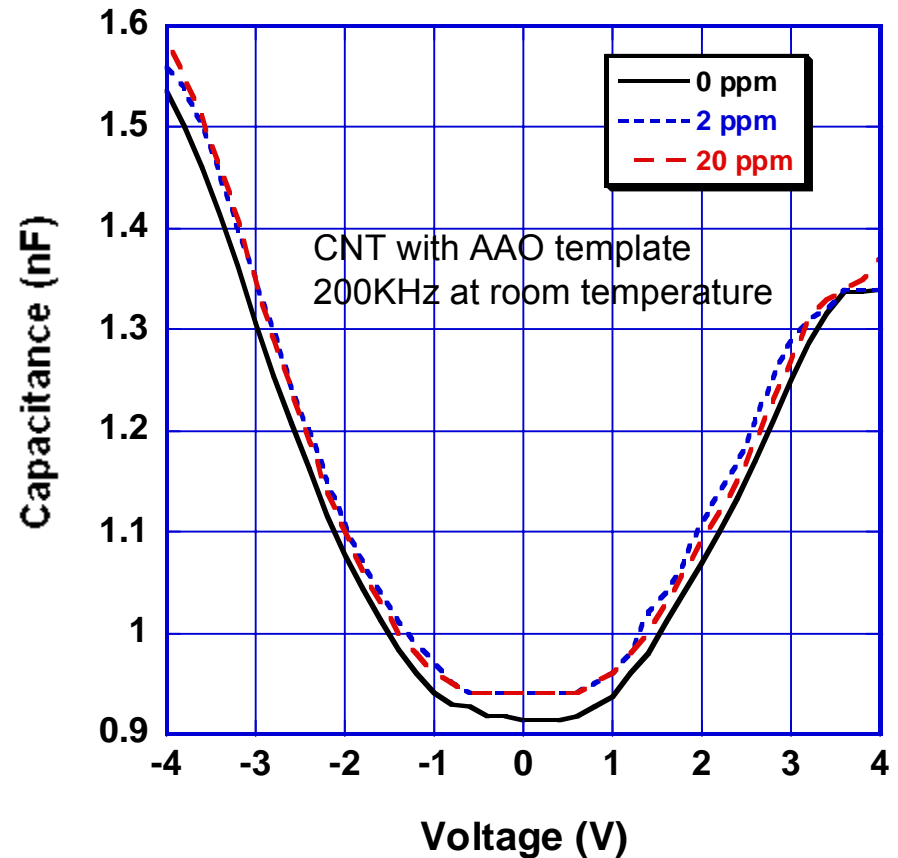
Relative clean surface of a sample grown in methane



## Comparison of AAO with AAO+CNT

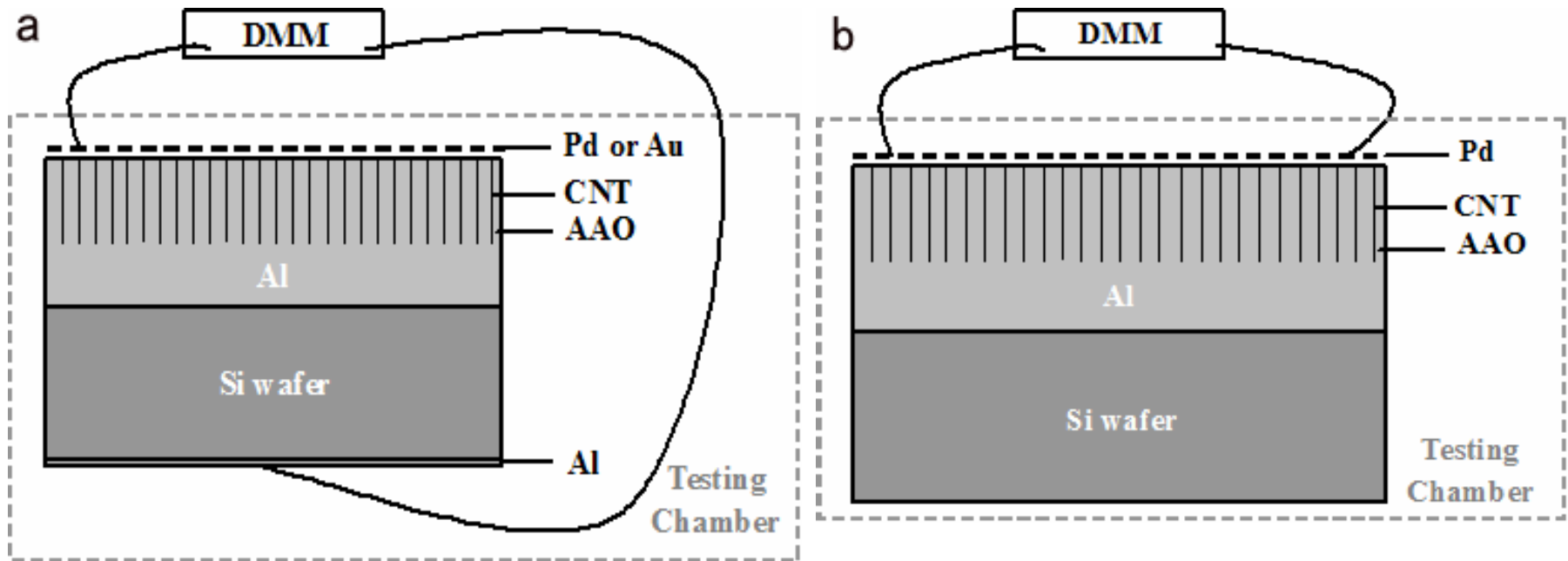


**A control sample consisting of an AAO template only: No hydrogen sensing**



**A sensor based on carbon nanotubes and Al electrode: Limited hydrogen sensing capability**

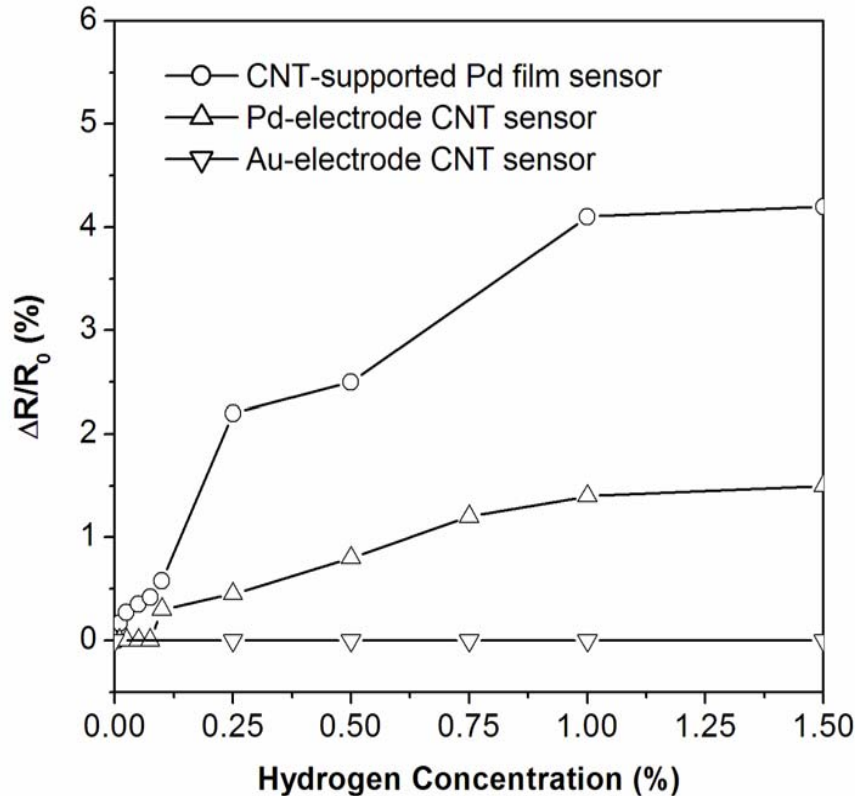
## Improvement of hydrogen sensitivity using Pd electrodes



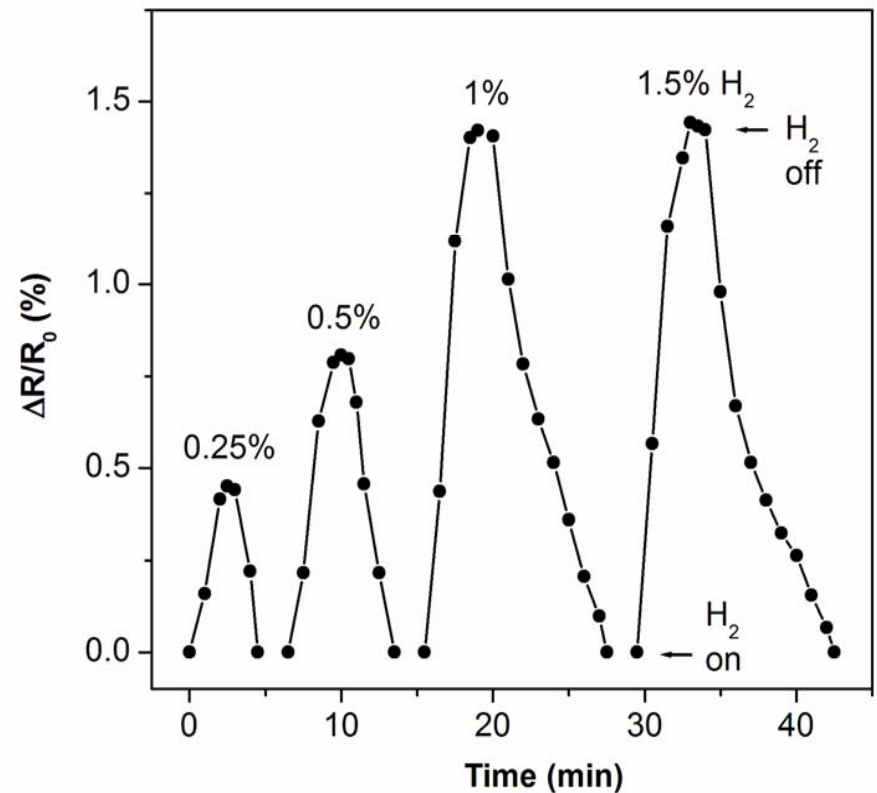
(a) metal-electrode CNT sensor

(b) CNT-supported Pd film sensor

## Two sensor structures



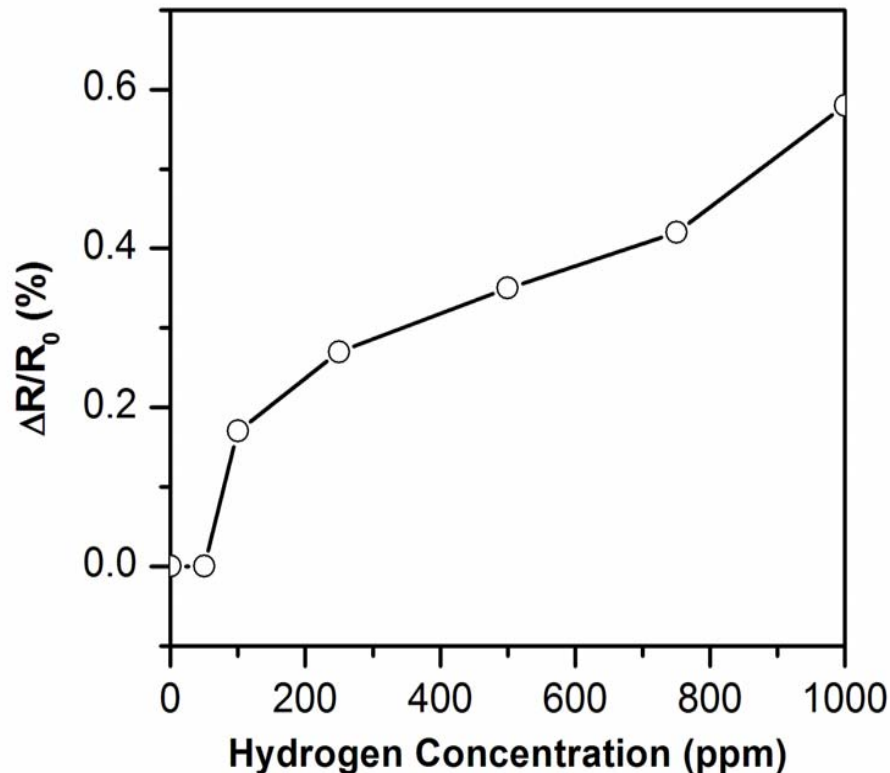
**Steady-state response of metal-electrode CNT and CNT-supported sensors**



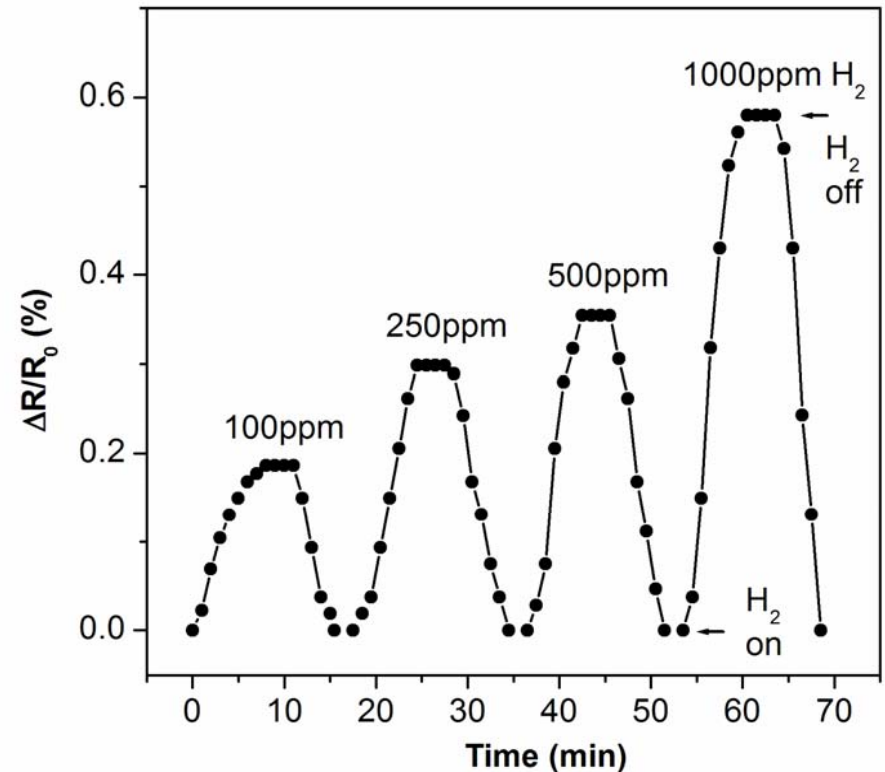
**Response of the Pd-electrode CNT sensor at medium H<sub>2</sub> concentrations**



## CNT-supported Pd film sensor

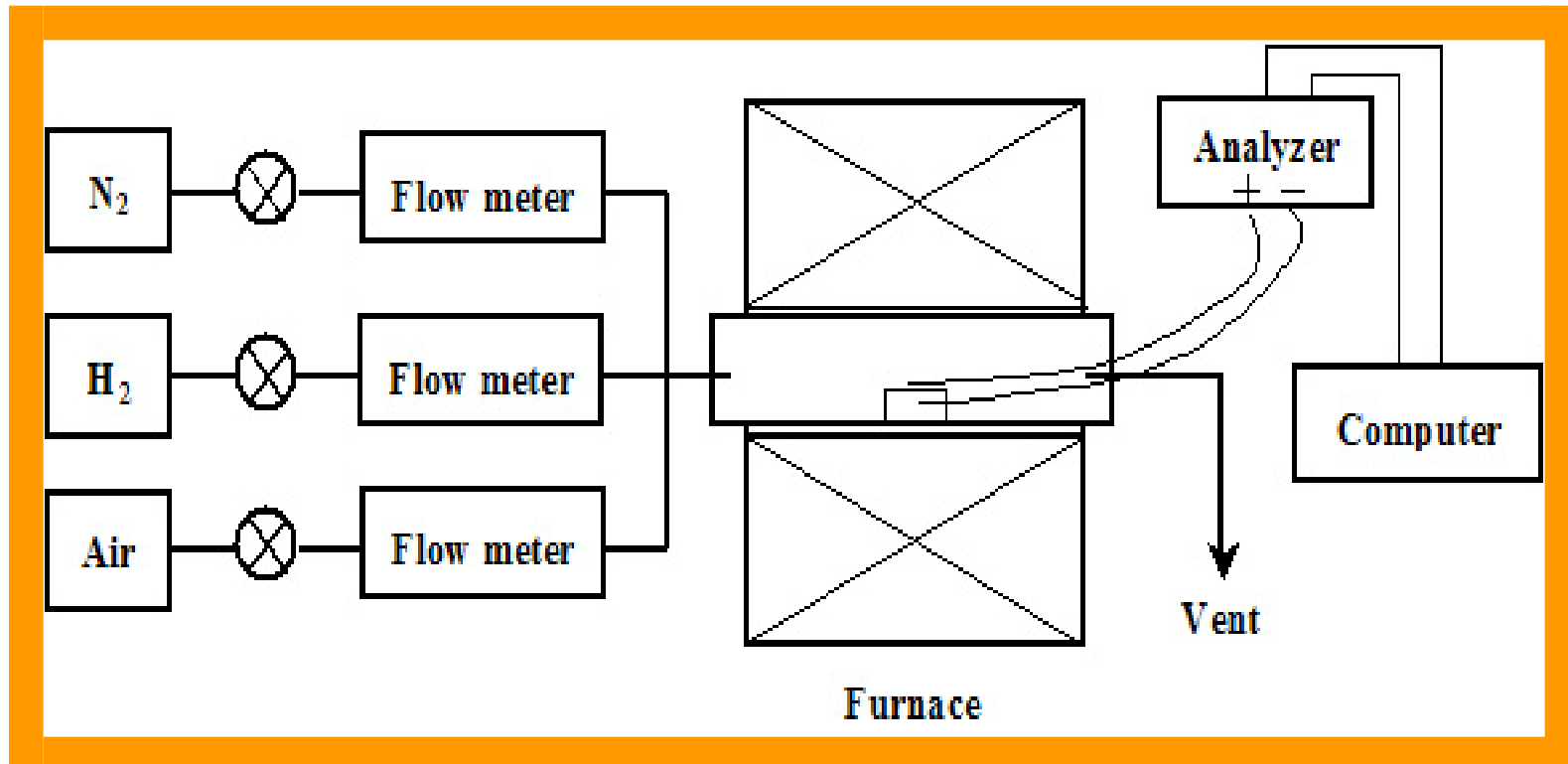


**Steady-state response of the CNT-supported Pd film sensor at dilute  $H_2$  concentrations**



**Response of the CNT-supported Pd film sensor at dilute  $H_2$  concentrations**

## High temperature testing system for hydrogen sensor



Heat-resistant Pt wires and high temperature furnace are used enabling a testing temperature up to 1000°C

## **On-going research**

- **Device optimization including design of heat-resistant metal electrodes (Pt) and bonding of Pt/electrode for high temperature testing.**
- **High temperature testing of the CNT-based sensors.**

## **Accomplishment**

- **AAO Nanostructures are modified and characterized.**
- **We successfully fabricated Pd-electrode CNT sensor and CNT-supported Pd film sensor.**
- **We have published 9 journal papers and 5 conference presentations under the DOE UCR support.**
- **We have received ~ \$4,000,000 research funding based on the DOE UCR support.**

## List of Journal Publications

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<sub>2</sub>/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 Nanotechnology Cincinnati, 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)