Nanorod and Nanotube Based Gas Sensors

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Planned Completion = March 31, 2007

Research Goals and Objectives

- To develop ZnO nanorod sensors with ppm sensitivity for selective detection of hydrogen at room temperature and combine these ultra-low power sensors with self-powering wireless communication circuits.
- applications of such systems would include:
  detection of fuel leaks in spacecraft or hydrogen distribution systems, with wireless data transmission to a central monitoring site
- our objective is to exploit nanotechnology to achieve superior detection sensitivity and low power consumption.

Relevance to Current State-of-the-Art

- President Bush's Hydrogen Fuel Initiative in 2003.

Integration of sensor device, wireless communication circuit, and energy harvesting device.
Novel nano-sensor devices to improve sensitivity, reliability, and robustness, while reducing power consumption.
High efficiency and low power wireless communication circuit.
Self-powered by energy harvesting devices for energy efficient, long lifetime operation.

Relevance to NASA

- Why hydrogen sensing? Safety!
-detection of fuel leaks in space craft using lightweight sensors (Hydrogen has been used as fuels in many NASA's space exploration missions).
- Production, Storage, Transport
Hydrogen concentration in air reaches a dangerous level at 4%. ppm-level detection is needed.

Budget, Schedule and Deliverables

- Budget $70K in FY04
- Deliverables: A prototype of integrated nanorod sensor, detailed schematics, simulation of the sensor performance, and test result.

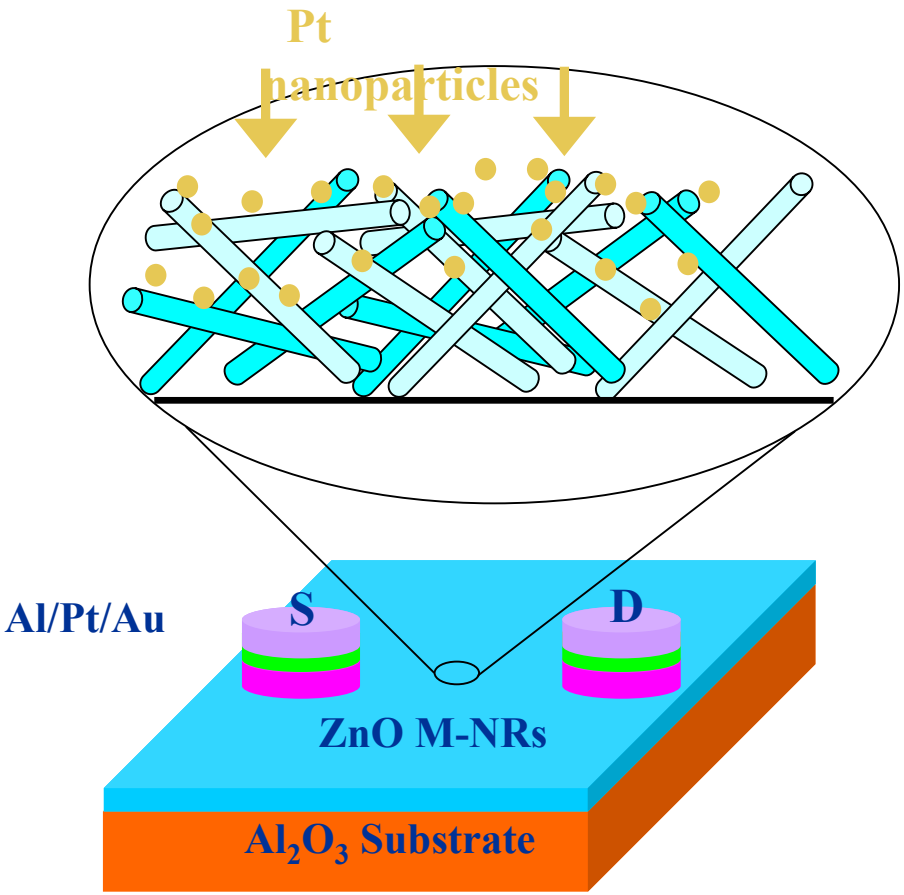
Anticipated Technology End Use

- Ultimate wireless sensor network
  - Low power, small size, lightweight, low cost, long lifetime, low maintenance effort
- Low power, small size, lightweight, low cost → Nano-sensors and Nano-electronics
- Long lifetime, low maintenance → Self-powering.
- → Self-powered wireless hydrogen sensor

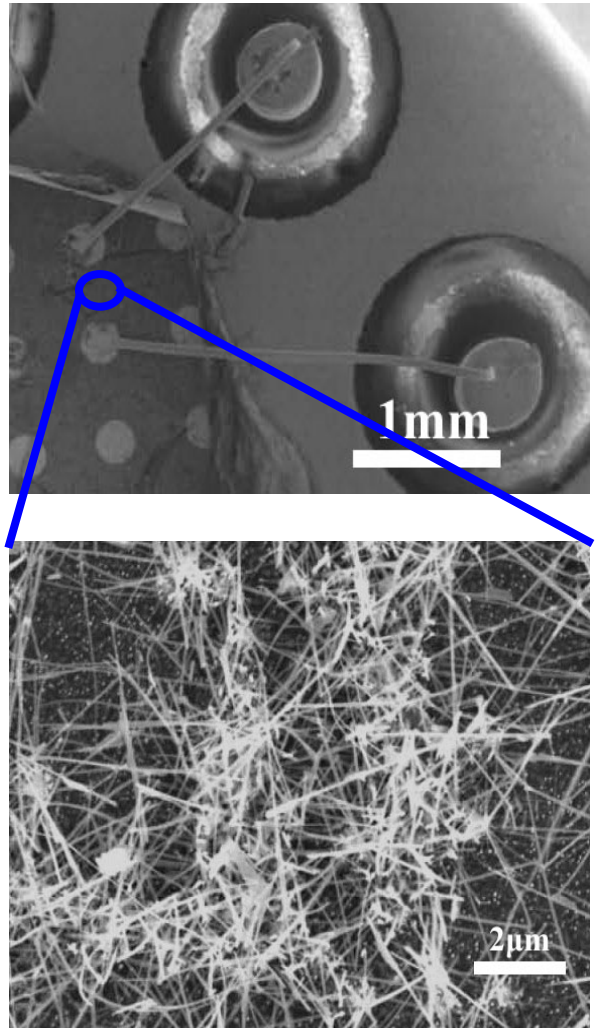
Accomplishments and Results

- Pt-coated ZnO multiple nanorods improves the sensitivity to ppm level H2 by a factor of 10; Pd-coated device improves by a factor of 5.
- Completely selective for hydrogen detection (not sensitive to oxygen at room temperature)
- Activation energy ~12 kJ/mol; The sensing mechanism dominates by the chemisorption of H2 on Pd/Pt surface.
- ~90% recovery by air in 5mins shows practical application capability.
- Pt-coated single nanorod device is 5 times more sensitive than Pt-coated multiple nanorods.
- Power consumption of multiple nanorods device is 0.4mW; 0.03mW for single nanorod device.

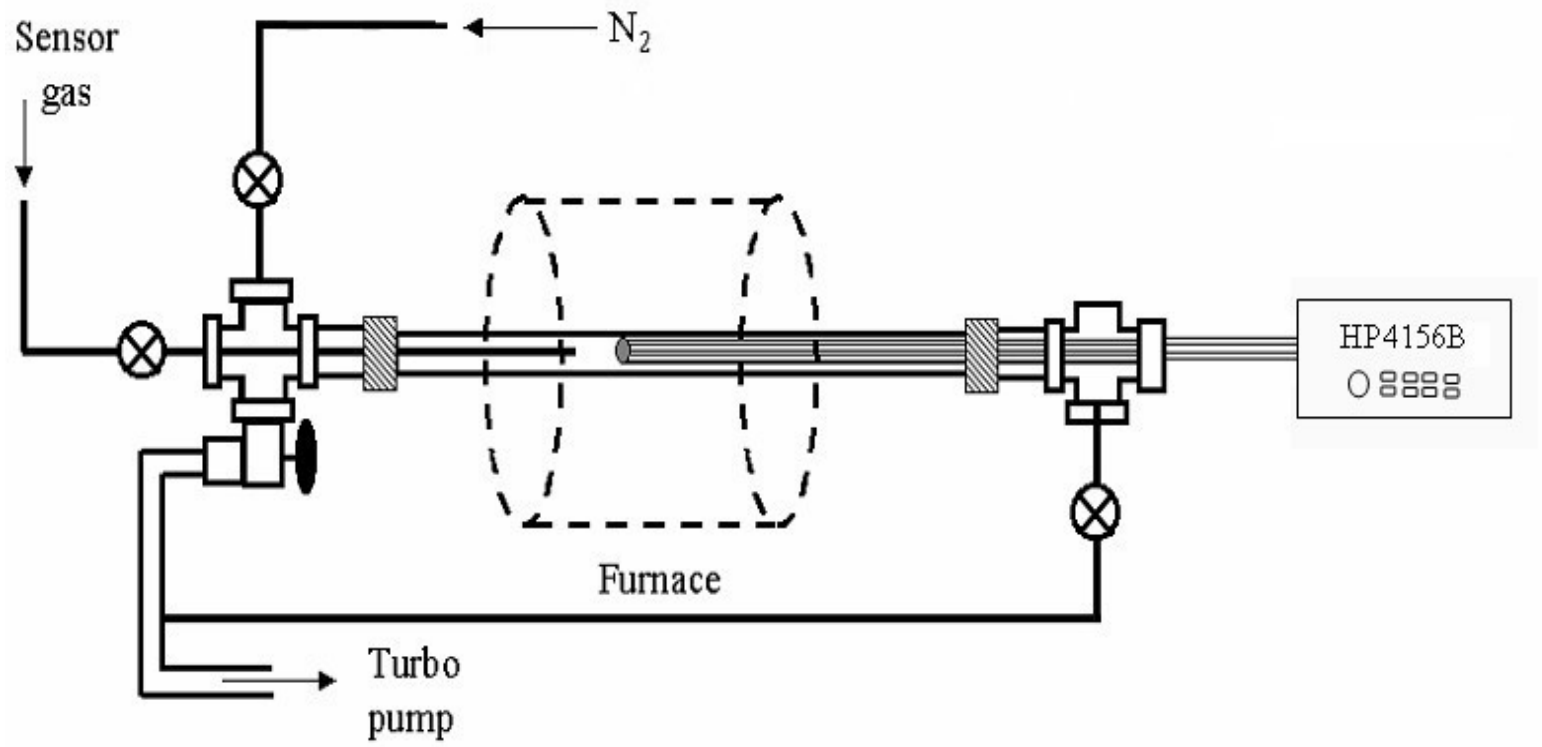
Device Fabrication-Multiple Nanorods



Schematic of multiple ZnO nanorod sensor

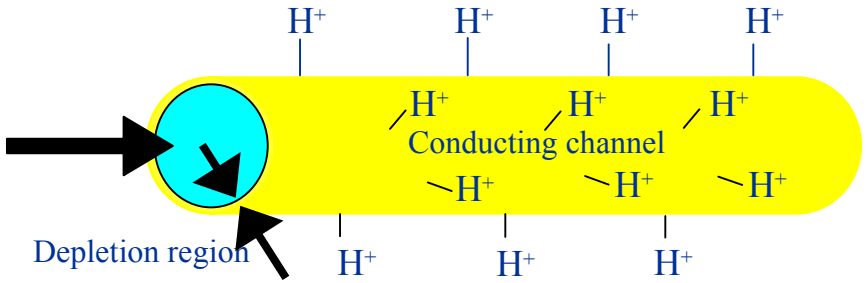


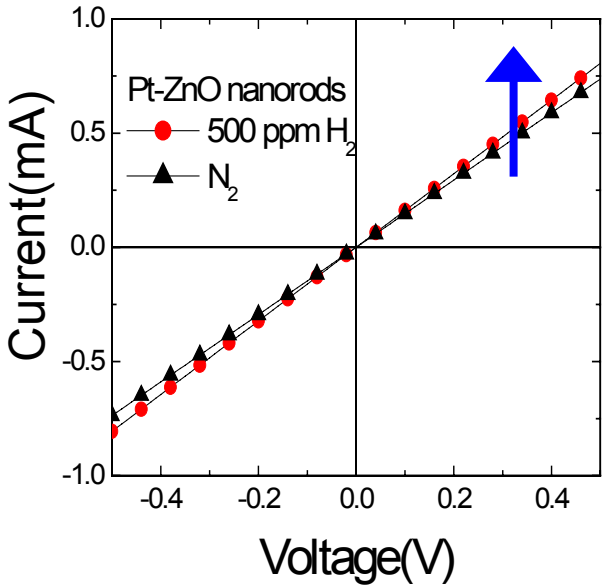
Hydrogen Sensing Test



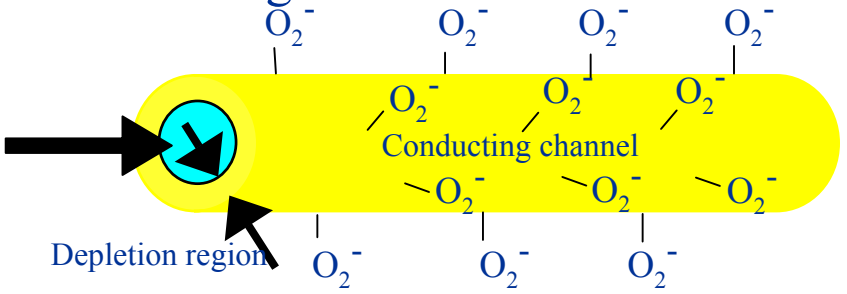
Schematic illustration of gas sensor system.

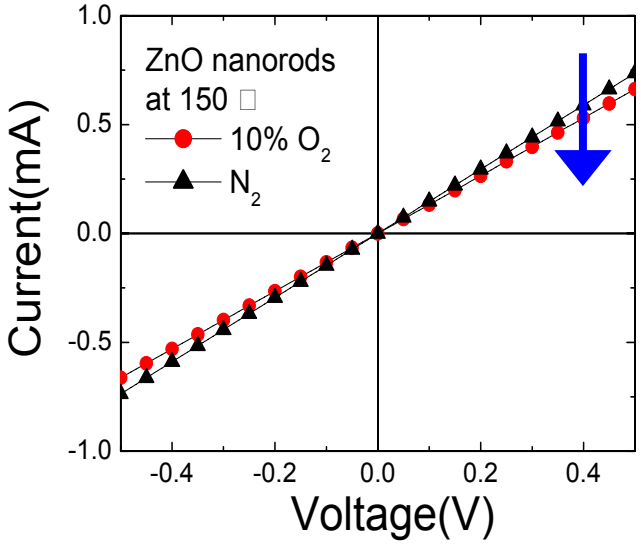
Sensing Mechanism





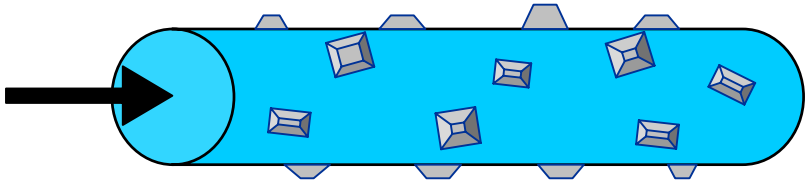
(a) H_2 environment
(electron donating species)

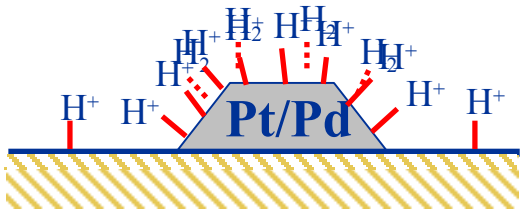




(b) O_2 environment
(electron withdrawing species)

Pt/Pd Effect



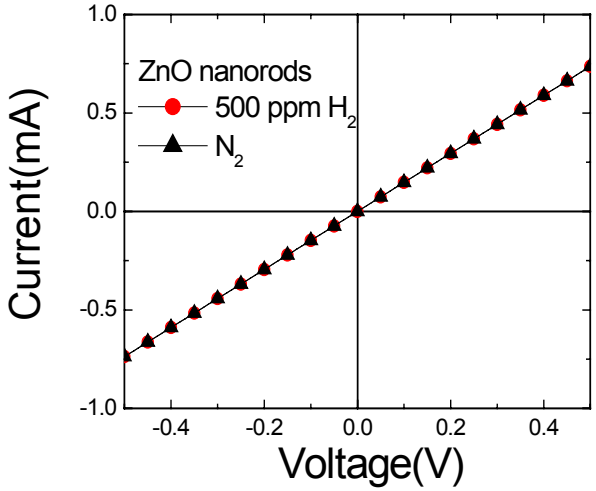


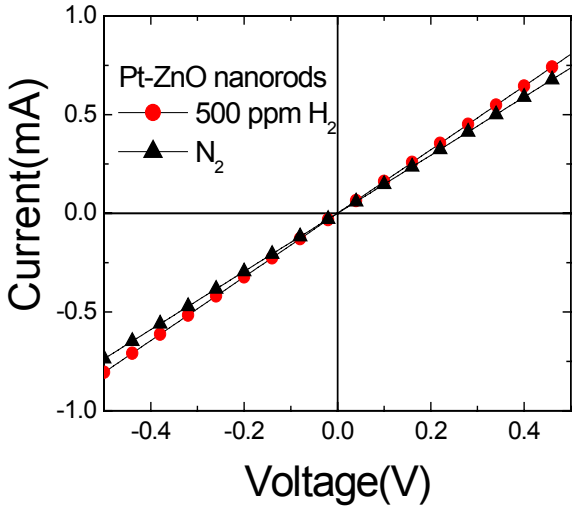
ZnO nanorod surface

:depletion region

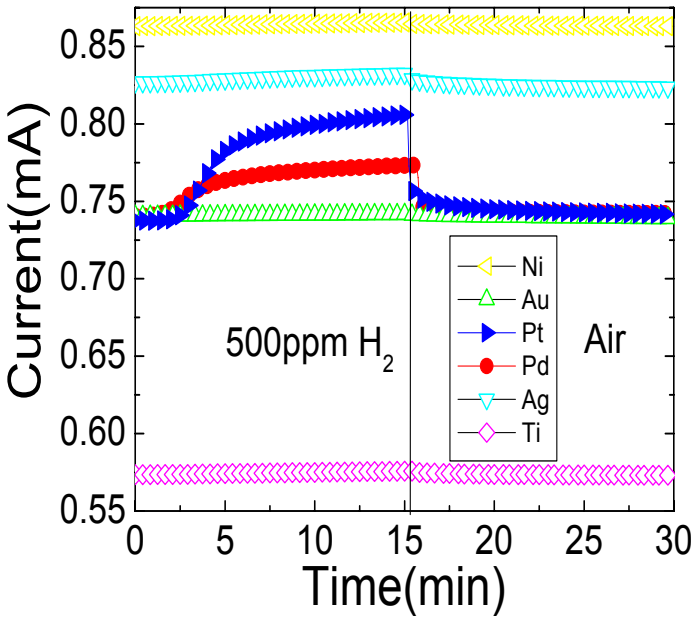
Reversible chemisorption reaction:

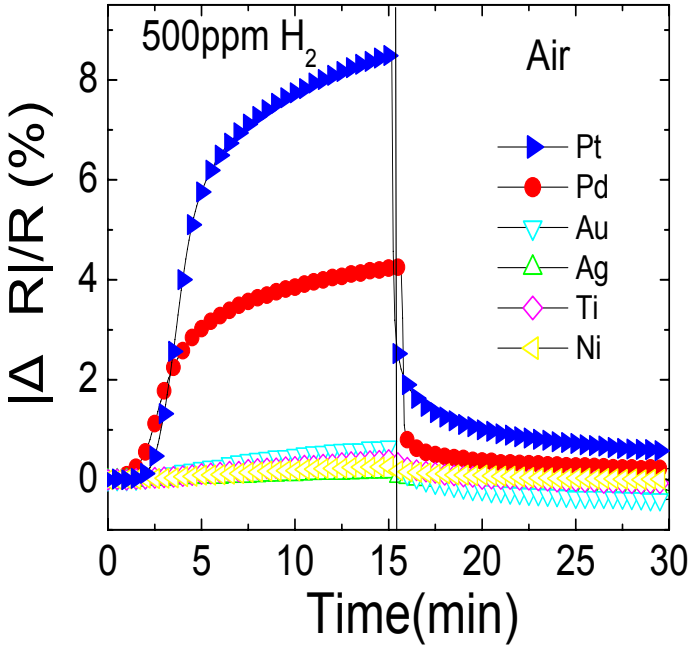
$$H_{2\,(gas)} \overset{Pd/Pt}{\leftrightarrow} 2H^{+}_{(s)} + 2e^{-}$$





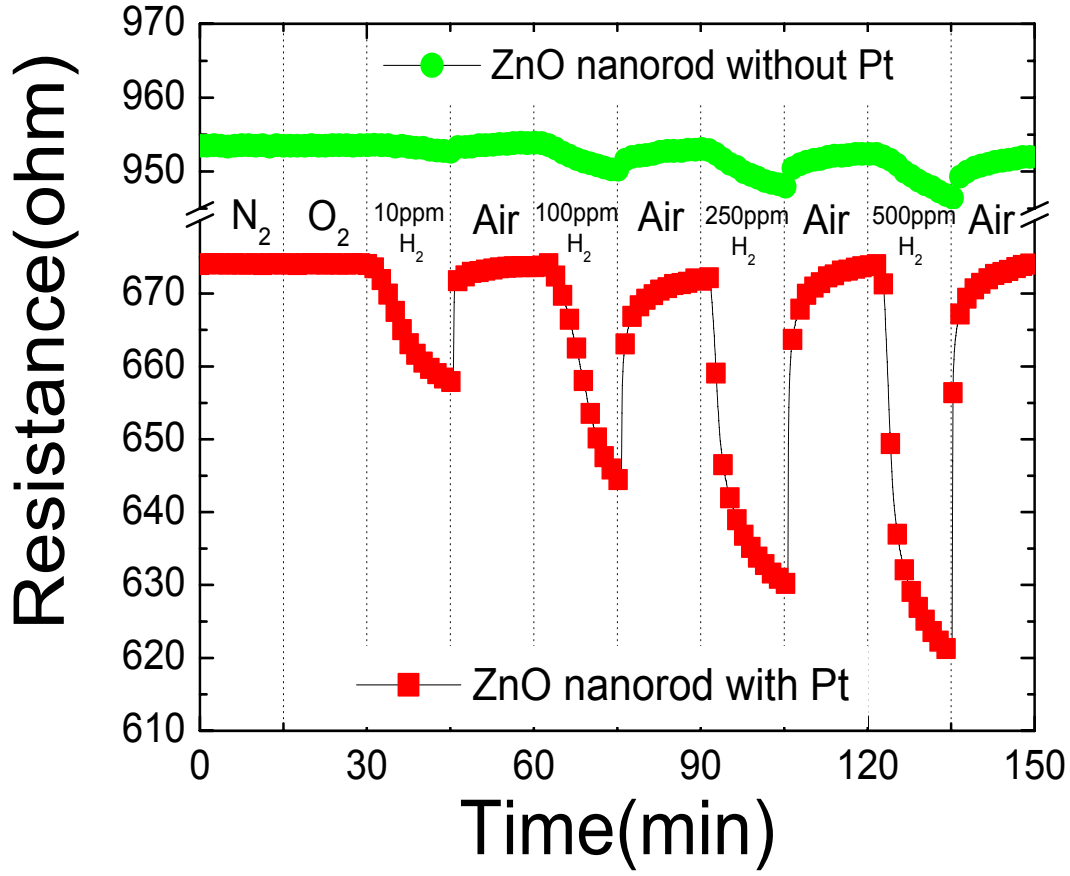
Effect of Metallization





500ppm hydrogen detection by catalyst-coated ZnO nanorods

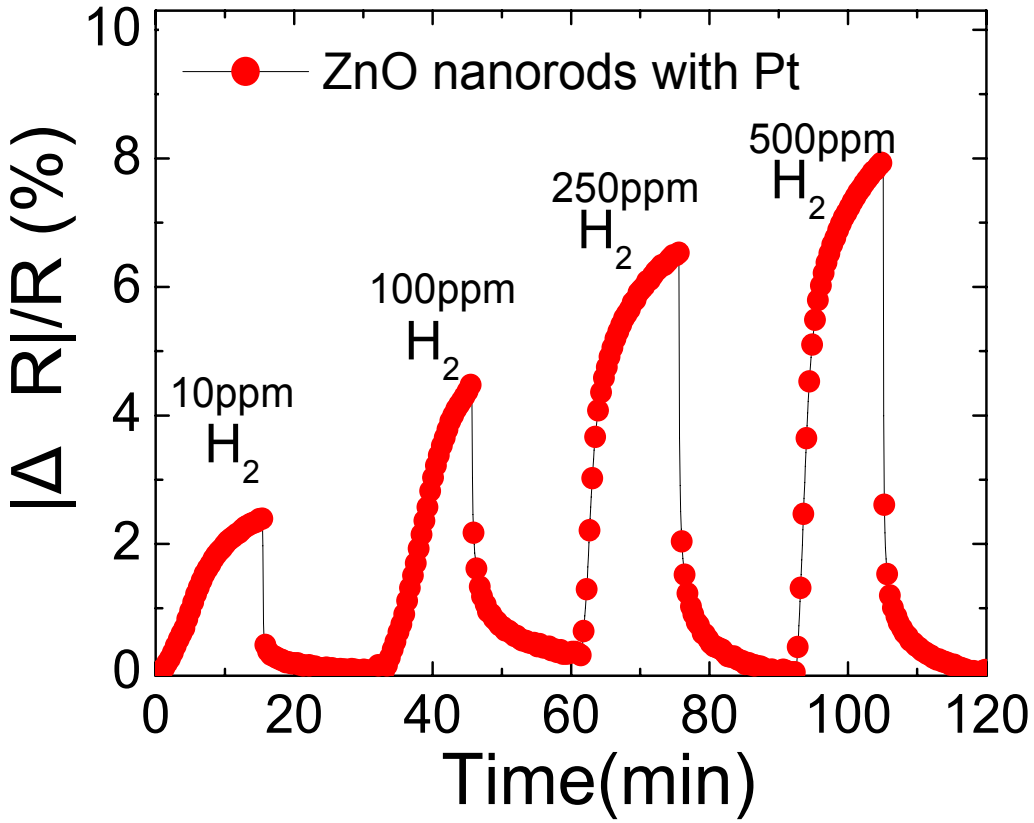
ZnO Multiple Nanorod Sensors



Multi-injection tests of with and without Pt-coated ZnO nanorods (V=0.5V).

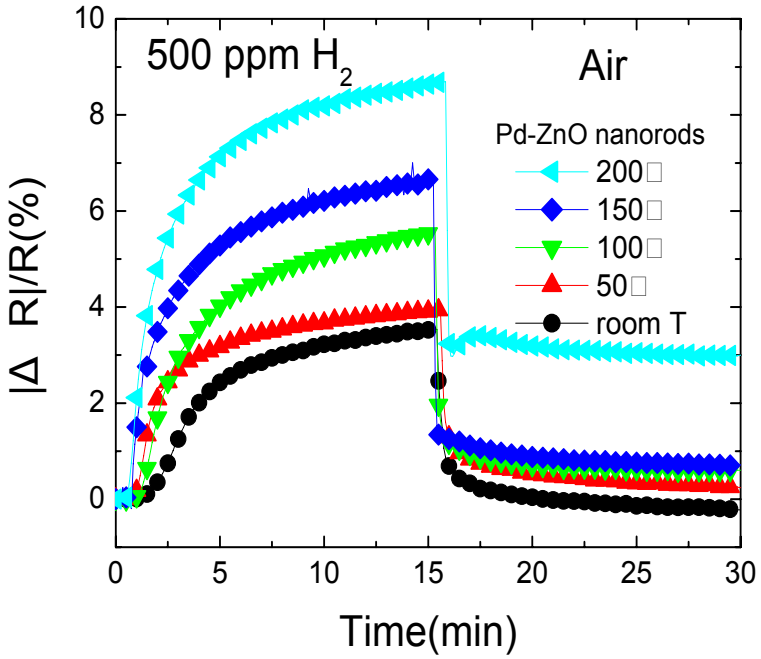
No sensing for oxygen

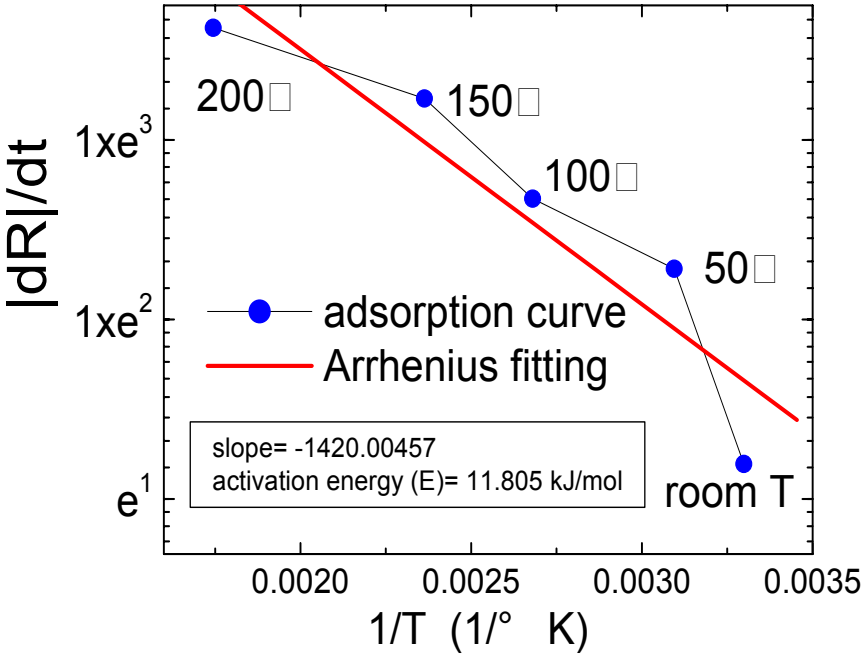
Pt-ZnO Multiple Nanorod sensor



Sensitivity as function of H_2 concentration.

Activation Energy Calculation





Sensitivity vs. time plot of 500 ppm H_2 tests at different temperatures.

Arrhenius' Law: $k. e^{-E/RT}$

Activation energy, E= 11.805 kJ/mol

Future Plans

- Testing of the nanowire sensors at temperatures below room temperature, as suggested by NASA monitors previously, to simulate the environment in some terrestrial applications.
- Integration issues of the nanorod sensors with micro-temperature control circuit, bias control circuit, current-voltage detection circuit, and signal transmission circuit. Fabrication of the integrated sensor.
- Simulation and testing of the prototype.