Electronic and Gas Sensing Properties of Semiconducting Metal Oxide Nano-Heterostructures

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Synopsis
The most promising recent advances in resistive-type gas sensors have come from semiconducting oxide nano-heterostructures which incorporate two or more sensor materials on the nano-scale in either core-shell, decorated nanowire or hierarchical structures. Rapid progress in new synthesis routes has made it possible to engineer and optimize specific types of nano-heterostructures for a given application but a lack of fundamental understanding of the mechanisms of these heterostructures limits progress in nano-heterostructure design, especially since many parameters can affect an oxide’s gas sensing properties. At CISM, our goal is to systematically study how these materials operate as gas sensors to lay the groundwork for a bottom-up approach to gas sensor design.

Nanoheterostructure Synthesis
The heterostructure synthesis process begins by growing the base nanowire structure. Single crystal SnO$_2$ nanowires are grown on gold-coated silicon p(100) wafers using a vapor-liquid-solid (VLS) method at 950°C under a flow of Argon using an upstream source of SnO$_2$ powder.

Device Fabrication
Nanowire devices are fabricated by depositing the synthesized structures onto substrates with pre-fabricated electrodes to allow for electrical connections to establish. A state-of-the-art four-point probe station is used to conduct sensor measurements.

Probing the Fundamental Mechanisms
Impedance spectroscopy is a powerful tool that can be used to gain important insights into the mechanisms governing the operation of gas sensors. By applying this technique to both single and multi-nanowire devices and carefully analyzing the data with a proper equivalent circuit, one can separate out different contributions of the sensor response to the overall change in impedance in different atmospheres.

Proper analysis of impedance data is supported with knowledge of the electronic properties of the material system and the physiochemical processes producing the system’s response. This is achieved by properly characterizing the material’s properties with the aid of techniques such as electron microscopy, photo/cathodoluminescence, XPS, Fourier Transform InfraRed Spectroscopy (FTIR) for gas analysis among other techniques.

Role of Defects
Defects play an important role in the mechanisms of gas sensing. Understanding their role and behavior in the process is one important step towards bottom-up design of sensors. The figure shows varying mid-gap defect states in SnO$_2$ nanomaterials.

Areas of Focus

ODORS Database
An Open-access Database Of Resistive-type gas Sensors (ODORS) is being developed by the group to aid gas sensor researchers all over the world. The database will include a simple online form for researchers to input their published data as well as a search function to sort through data stored on the database. This will allow for large amounts of data to easily be sorted through to answer questions such as:

- “What material(s) typically have the best response toward H$_2$S?”
- “Do p-type or n-type materials have a better response toward xylene?”
- “What work has been published with NiO doping of SnO$_2$?”
- “What SnO$_2$ heterostructure gives the best selectivity toward ethanol?”

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