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Enhanced Gas Sensing by Individual SnO_2 Nanowires and Nanobelts Functionalized with Pd Catalyst Particles

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ABSTRACT

The sensing ability of *individual* SnO_2 nanowires and nanobelts configured as gas sensors was measured before and after functionalization with Pd catalyst particles. In situ deposition of Pd in the same reaction chamber in which the sensing measurements were carried out ensured that the observed modification in behavior was due to the Pd functionalization rather than the variation in properties from one nanowire to another. Changes in the conductance in the early stages of metal deposition (i.e., before metal percolation) indicated that the Pd nanoparticles on the nanowire surface created Schottky barrier-type junctions resulting in the formation of electron depletion regions within the nanowire, constricting the effective conduction channel and reducing the conductance. Pd-functionalized nanostructures exhibited a dramatic improvement in sensitivity toward oxygen and hydrogen due to the enhanced catalytic dissociation of the molecular adsorbate on the Pd nanoparticle surfaces and the subsequent diffusion of the resultant atomic species to the oxide surface.

Introduction. The large surface-to-volume ratio of one-dimensional (1-D) semiconducting metal oxide nanostructures and the congruence of the carrier screening length with their lateral dimensions make them highly sensitive and efficient transducers of surface chemical processes into electrical signals. Significant progress has been reported in the use of metal oxide nanowires and nanobelts[1−7] as sensors and in other electronic applications. Although promising results of the gas sensing performance of metal oxide nanowires have been reported,[8] the development of highly selective and controllably sensitized devices[9] remains a future challenge for oxides. In practice, the selectivity of gas sensors and catalysts is usually achieved by functionalizing the material with catalytically active metals. In this communication we report the successful and controllable sensitization of the surface of individual quasi-1-D SnO_2 nanostructures with Pd nanoparticles. In addition to the surface chemistry of these systems, we report the atomic-level structure of the metal nanoparticles and the oxide support, obtained using conventional high-resolution as well as scanning transmission electron microscopy. We also report the nucleation and growth dynamics of the deposited metal nanoparticles, providing a preliminary level of understanding of the metal diffusion and island growth processes occurring in systems with reduced dimensionality. In these systems new phenomena might be expected when the diffusion length of the adsorbate becomes comparable with the lateral dimensions of the supporting nanostructure. The metal nanoparticles were also found to form electroactive elements on the surface of the semiconducting metal oxide nanostructure, as determined from the conductance decrease observed during the metal deposition process.

Using the nanostructure as a chemiresistor, we compared the sensing performance of an individual nanostructure (nanowire or nanobelt) before and after it was sensitized with catalytically active Pd nanoparticles. We explain the observed dramatic enhancement in sensitivity in terms of the catalytic action of Pd nanoparticles, which pre-dissociate the adsorbing species delivering atomic (rather than molecular) species to the surface of the nanostructure where they become chemisorbed.

Experimental Section. Pristine quasi-1-D, SnO_2 nanostructures were synthesized using techniques described in refs 10 and 11. Briefly, single-crystal SnO_2 nanowires and nanobelts were vapor-grown in a tube furnace by thermal evaporation of SnO at 1000 °C into an Ar carrier gas (50 sccm, 200 Torr) containing traces of oxygen. The morphology and structure of the 1-D nanostructures and dopant particles were characterized by conventional (phase contrast) high-resolution transmission electron microscopy (HRTEM)

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