Synthesis and Hydrogen Gas Sensing Performance of Pd-functionalised Nanostructures

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In hydrogen sensor, Palladium (Pd) is used as the main sensing element as it selectively absorbs hydrogen gas to form palladium hydride, leading to changes in its electrical resistance or work function. However Pd nanowires alone do not exhibit good sensitivity for hydrogen gas sensing. Enhanced sensing efficiency can be achieved by using semiconductor nanostructures such as carbon nanotubes and semiconductor nanowires / nanotubes that have been functionalized with Pd.

In this paper, semiconductor nanostructures of varying diameters and compositions such as single wall carbon nanotubes (SWNTs), silicon nanowires and tellurium nanotubes were surface functionalized by palladium and their hydrogen sensing properties were studied. The semiconductor nanostructures were pre-aligned across the gap between each pair of microfabricated gold electrodes on a silicon chip using a.c. dielectrophoresis technique. The chip consists of a circular array of 16 pairs of microfabricated gold electrodes with a 3µm-gap in between each pair, pre-patterned on a silicon wafer. The density and alignment of the nanowires/nanotubes were controlled by the applied a.c. field strength and frequency on the electrodes. Stronger a.c. field strengths were required to exert larger forces on the nanowires/nanotubes with larger diameters to facilitate nanowire alignment.

To functionalize the semiconductor nanostructures for selective hydrogen detection, Pd nanoparticles were electrodeposited onto pre-aligned nanowires/nanotube, using a mini three-electrode system, from Pd electrolyte consisting of 0.047M $Pd(NH_3)_2Cl_2$ + 0.1 M NH_4Cl. The diameters and densities of the Pd nanoparticles were optimized by tuning the deposition voltage and time. Fig. 1 shows the SEM images of the Pd nanoparticle-decorated SWNTs across the gap of a pair of gold electrodes, acting as a nanosensor, and its typical gas sensing response when exposed to hydrogen of varying concentrations. Gas sensing measurements were performed sequentially on each of the 16 individual nanosensors on a single platform, via a customized multiplexer-coupled electronic measurement system with Labview program control. Using this method, the hydrogen sensing capability of the materials was optimized for high sensitivity as well as short response and recovery times. Nanosensors formed from non-connected chains of Pd nanoparticles were found to exhibit good sensing properties with linear response of up to 2000 ppm hydrogen and lowest detection limit of 30 ppm hydrogen. The response time increases from a few minutes to tens of minutes with decreasing hydrogen concentration. From this study, Pd-functionalised nanowires/nanotubes have been found to register a resistance change exceeding 60% when exposed to 2000 ppm of hydrogen as compared to bare-Pd nanowires which only registered a change of less than 4%. Therefore, it is evident that Pd-functionalised nanowire/nanotube sensors are more advantageous over bare Pd nanowire sensors in view of the enhanced gas sensing property. The mechanism of the gas sensing properties on various sensor architectures will be discussed and the effect of annealing on the gas sensors will be studied.

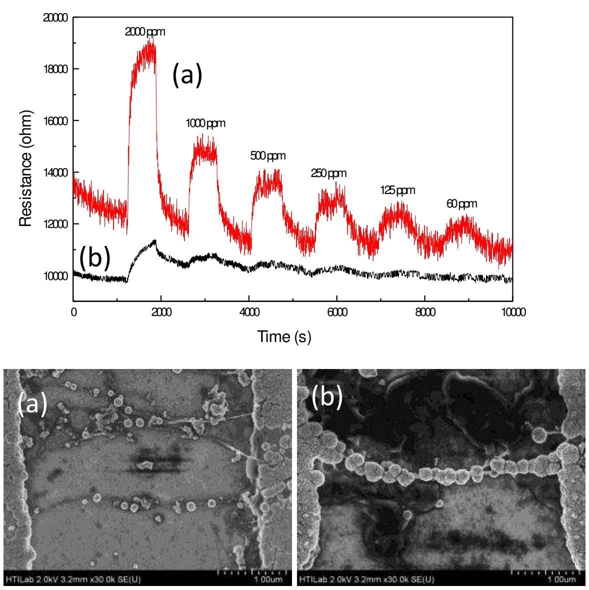

Fig. 1: The sensing performance of SWCNTs functionalized with Pd particles of different sizes and densities, as shown in the corresponding SEM images, when exposed to various concentrations of hydrogen. The Pd nanoparticles were deposited at -0.85 V for 7.7 s and 23.1 s in (a) and (b) respectively.

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