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Sensing performances of pure and hybridized carbon nanotubes-ZnO nanowire networks: A detailed study

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In this work, the influence of carbon nanotube (CNT) hybridization on ultraviolet (UV) and gas sensing properties of individual and networked ZnO nanowires (NWs) is investigated in detail. The CNT concentration was varied to achieve optimal conditions for the hybrid with improved sensing properties. In case of CNT decorated ZnO nanonetworks, the influence of relative humidity (RH) and applied bias voltage on the UV sensing properties was thoroughly studied. By rising the CNT content to about 2.0 wt% (with respect to the entire ZnO network) the UV sensing response is considerably increased from 150 to 7300 (about 50 times). With respect to gas sensing, the ZnO-CNT networks demonstrate an excellent selectivity as well as a high gas response to NH_3 vapor. A response of 430 to 50 ppm at room temperature was obtained, with an estimated detection limit of about 0.4 ppm. Based on those results, several devices consisting of individual ZnO NWs covered with CNTs were fabricated using a FIB/SEM system. The highest sensing performance was obtained for the finest NW with diameter (D) of 100 nm, with a response of about 4 to 10 ppm NH_3 vapor at room temperature.

Functionalization of semiconducting oxides via hybridizing them with appropriate metallic or carbon nanostructures is known to be a very powerful strategy to strongly enhance and likewise to control the oxides' electrical, chemical and physical properties, particularly nanoscopic dimensions and hence adequate applications[1–6]. Thus, these approaches are widely adopted and investigated, especially in the field of new nanomaterials for sensing applications[2,3,5,7–10]. The combination of two materials often leads to apparition of new and unique effects. Due to excellent sensing properties of carbon based nanomaterials (e.g. CNTs) in detection of NO_2 and NH_3 at room temperature, the combination of CNTs and metal oxides is widely used for fabrication of highly selective sensors operating at room temperatures. Additionally, monitoring of NH_3 gas for indoor and outdoor applications is a very important task due to an increasing rate of atmospheric pollution with ammonia in recent years[11]. For example, Wei *et al.* observed that hybrid CNT/SnO_2 gas sensors exhibit much higher sensitivity and recovery properties in detecting of NO_2 gas at room temperature than a pristine SnO_2 sensor[12]. Deng *et al.* fabricated reduced graphene oxide (rGO) conjugated Cu_2O NW mesocrystals for high-performance NO_2 gas sensors[13]. Van Hieu *et al.* demonstrated much better response and sensing rapidity to NH_3 gas of SnO_2/multiwalled carbon nanotubes (MWCNT) composites compared to pristine SnO_2 or CNT structures[14]. Therefore, these carbon-nanotubes based hybrid nanomaterials are going to play a lead role towards reliable sensing devices.

Another important advantage of hybridization of semiconducting oxides and CNT heterostructures is their high efficiency in separation of photogenerated electron-hole pairs, for example in ZnO[15]. Dutta and Basak reported the fabrication of MWCNTs/ZnO NW composites with enhanced UV sensing properties which were attributed to surface plasmon resonance mediating a rapid electron transfer between ZnO and MWCNTs[7]. Furthermore, Wang *et al.* fabricated high-performance UV sensors based on a rGO decorated hydrangea-like ZnO film on a PDMS substrate for flexible electronics[16]. Another interesting UV sensing application was demonstrated by Jin *et al.* by fabrication of high-performance UV photodetectors based on graphdiyne:

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