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Hybridization of Zinc Oxide Tetrapods for Selective Gas Sensing Applications

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Abstract

In this work, the exceptionally improved sensing capability of highly porous three-dimensional (3-D) hybrid ceramic networks toward reducing gases is demonstrated for the first time. The 3-D hybrid ceramic networks are based on doped metal oxides (Me_xO_y and $Zn_xMe_{1-x}O_y$, Me = Fe, Cu, Al) and alloyed zinc oxide tetrapods (ZnO-T) forming numerous junctions and heterojunctions. A change in morphology of the samples and formation of different complex microstructures is achieved by mixing the metallic (Fe, Cu, Al) microparticles with ZnO-T grown by the flame transport synthesis (FTS) in different weight ratios (ZnO-T:Me, e.g., 20:1) followed by subsequent thermal annealing in air. The gas sensing studies reveal the possibility to control and change/tune the selectivity of the materials, depending on the elemental content ratio and the type of added metal oxide in the 3-D ZnO-T hybrid networks. While pristine ZnO-T networks showed a good response to H_2 gas, a change/tune in selectivity to ethanol vapor with a decrease in optimal operating temperature was observed in the networks hybridized with

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Fe-oxide and Cu-oxide. In the case of hybridization with $ZnAl_2O_4$, an improvement of H_2 gas response (to ~7.5) was reached at lower doping concentrations (20:1), whereas the increase in concentration of $ZnAl_2O_4$ (ZnO-T:Al, 10:1), the selectivity changes to methane CH_4 gas (response is about 28). Selectivity tuning to different gases is attributed to the catalytic properties of the metal oxides after hybridization, while the gas sensitivity improvement is mainly associated with additional modulation of the electrical resistance by the built-in potential barriers between n-n and n-p heterojunctions, during adsorption and desorption of gaseous species. Density functional theory based calculations provided the mechanistic insights into the interactions between different hybrid networks and gas molecules to support the experimentally observed results. The studied networked materials and sensor structures performances would provide particular advantages in the field of fundamental research, applied physics studies, and industrial and ecological applications.