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Lupan O[1,2,3], Postica V[3], Wolff N[4], Su J[5], Labat F[5], Ciofini I[5], Cavers H[2], Adelung R[2], Polonskyi O[6], Faupel F[6], Kienle L[4], Viana B[1], Pauporté T[1].

Author information

1
Institut de Recherche de Chimie Paris-IRCP, Chimie ParisTech , PSL Université , rue Pierre et Marie Curie 11 , 75231 Paris Cedex 05 , France.

2
Functional Nano Materials, Institute for Materials Science, Faculty of Engineering , Kiel University , str. Kaiserstraße 2 , D-24143 Kiel , Germany.

3
Center for Nanotechnology and Nanosensors, Department of Microelectronics & Biomedical Engineering , Technical University of Moldova , Stefan Cel Mare Av. 168 , MD 2004 Chisinau , Republic of Moldova.

4
Institute for Materials Science, Synthesis and Real Structure , Christian Albrechts University Kiel , str. Kaiserstraße 2 , D-24143 Kiel , Germany.

5
i-CLeHS, Chimie ParisTech , PSL University , rue Pierre et Marie Curie nr. 11 , 75231 Paris Cedex 05 , France.

6
Faculty of Engineering, Chair for Multicomponent Materials , Christian-Albrechts University of Kiel , str. Kaiserstraße nr. 2 , D-24143 Kiel , Germany.

Low-Temperature Solution Synthesis of Au-Modified ZnO Nanowires for Highly Efficient Hydrogen Nanosensors

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Abstract

In this research, the low-temperature single-step electrochemical deposition of arrayed ZnO nanowires (NWs) decorated by Au nanoparticles (NPs) with diameters ranging between 10 and 100 nm is successfully demonstrated for the first time. The AuNPs and ZnO NWs were grown simultaneously in the same growth solution in consideration of the $HAuCl_4$ concentration. Optical, structural, and chemical characterizations were analyzed in detail, proving high crystallinity of the NWs as well as the distribution of Au NPs on the surface of zinc oxide NWs demonstrated by transmission electron microscopy. Individual Au NPs-functionalized ZnO NWs (Au-NP/ZnO-NWs) were incorporated into sensor nanodevices using an focused ion bean/scanning electron microscopy (FIB/SEM) scientific instrument. The gas-sensing investigations demonstrated excellent selectivity to hydrogen gas at room temperature (RT) with a gas response, I_{gas}/I_{air}, as high as 7.5–100 ppm for Au-NP/ZnO-NWs, possessing a AuNP surface coverage of ~6.4%. The concentration of $HAuCl_4$ in the electrochemical solution was observed to have no significant impact on the gas-sensing parameters in our experiments. This highlights the significant influence of the total Au/ZnO interfacial area establishing Schottky contacts for the achievement of high performances. The most significant performance of H_2 response was observed for gas concentrations higher than 500 ppm of H_2 in the environment, which was attributed to the surface metallization of ZnO NWs during exposure to hydrogen. For this case, an ultrahigh response of about 32.9 and 47 to 1000 and 5000 ppm of H_2 was obtained, respectively. Spin-polarized periodic density functional theory calculations were realized on Au/ZnO bulk and surface-functionalized models, validating the experimental hypothesis. The combination of H_2 gas detection at RT, ultralow power consumption, and reduced dimensions makes these micro-nanodevices excellent candidates for hydrogen gas leakage detection, including hydrogen gas monitoring (less than 1 ppm).