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Fabrication and Characterization of p-NiO/ZnO-n nanowire heterostructures for gas sensing

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Abstract:

Nitrogen dioxide (NO_2) is a well known hazardous gas species, which plays an essential role in certain industries, healthcare and farming. Hence, the detection of this gas species by mean of efficient and stable gas sensor is indeed very important. In this work, novel p-NiO/ZnO-n nanowires (NWs) based heterostructures were fabricated by vapor phase growth method, consisting of long NiO nanowires covered by ZnO nanowires on top. The surface morphology of NiO nanowires and NiO/ZnO heterostructures were investigated with FE-SEM. Lastly, based on these heterostructures, a set of conductometric sensing devices have been prepared and different concentrations of NO_2 have been detected at different working temperatures.

Key words: nanowire, heterostructures, nickel oxide, zinc oxide, gas sensing

Introduction

In recent years, the interest in the fabrication of p-n metal oxide-based nanostructures has increased, especially for advanced applications such as gas sensors and photocatalysis [1, 2]. ZnO is an n-type semiconductor (bandgap 3.22eV), and has been intensively studied as a gas-sensing material [1]. On the other hand, NiO (bandgap 3.6-4.0eV) is a p-type semiconductor, it possesses interesting chemical/physical properties but is limitedly explored by the reseachers in the filed of gas sensors [3]. Moreover, heterogeneous micro/nanostructures have also attained special attention in past few years due to their enhanced gas-sensing properties [2].

In the area of environmental studies and gas sensing, NO_2 is considered as one of the most dangerous air pollutants gases, and it plays major role in the formation of ozone and acid rain. A frequent or continued exposure to NO_2 concentrations higher than air quality standard may cause increased incidence of intense respiratory illness [2]. Under such situations, a compact, low cost and highly senstivie sensor for the detection of very low NO_2 concentrations is strongly required.

Therefore, in this work the synthesis and characterization of p-NiO/ZnO-n NWs heterostructure, and their sensing behavior toward low concentration of NO_2, have been presented.

Experimental

NiO nanowires were synthesized on Au-catalyzed alumina substrates using vapor-liquid-sloid (VLS) mechanism inside an alumina tubular furnace [3]. To fabricate the NiO/ZnO NWs heterostructures, ZnO nanowires were grown directly on NiO nanowires using Vapor-Solid (VS) mechanism. Growth process of ZnO nanowires was performed without using any metal catalyst inside the tubular furnace at evaporation temperature of 1200ºC, 10mbar pressure and 100 SCCM argon flow.

Results

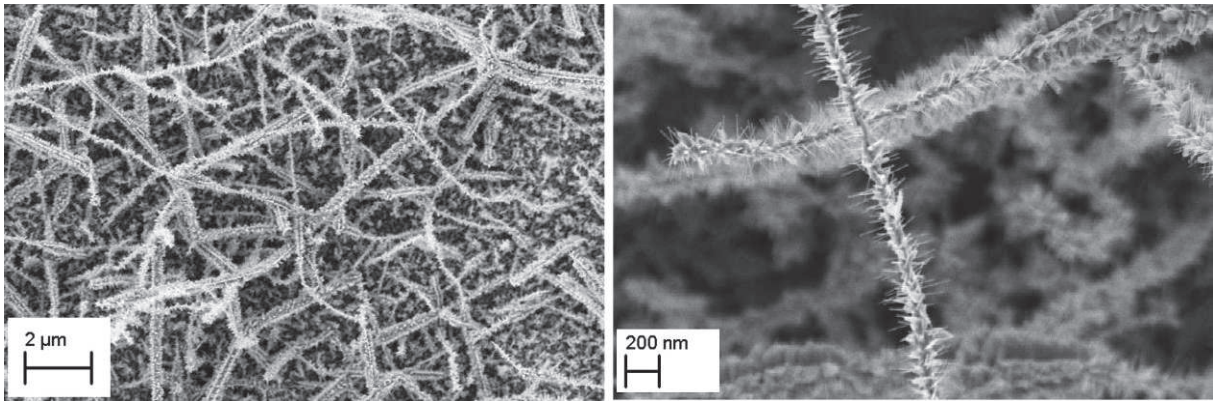

Fig.1. SEM image of NiO/ZnO heterostructure nanowires.

Figure 1 shows the SEM images of NiO/ZnO heterostructures prepared on alumina substrates. The small ZnO nanowires cover completely the long NiO nanowires. Afterwards, conductometric sensing devices based on these heterostructures were prepared, and their performances towards NO_2 gas at different concentrations (0.1-0.2-0.5ppm) and at a range of temperatures have been evaluated. Figure 2 shows the response curve for the sensing devices with respect to different temperatures ranging from 200°C-400°C at fixed concentration (0.5ppm) of NO_2. As it is clearly observed from figure 2, the optimal working temperature of the sensors has been found at 200°C.

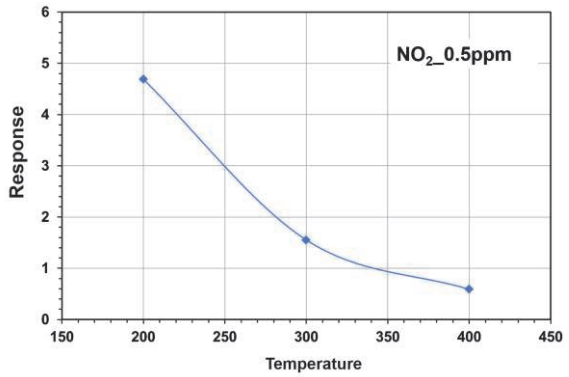

Fig. 2. Response of NiO/ZnO sensors towards 0.5ppm of NO_2 at different temperatures (200C-300C-400C). RH=50% @ 20°C

Furthermore, these sensors have also been used to detect the acetone(30ppm) and ethanol(20ppm) at same optimal working temperature i.e. at 200°C.

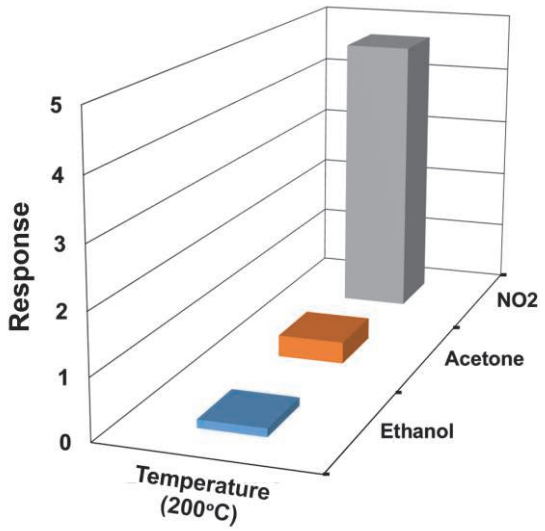

Fig. 3. NO2 selectivity investigation of NiO/ZnO sensors.

Clearly as observed form figure 3, these heterostructure devices, shows superior performance towards NO_2 gas as compared to others.

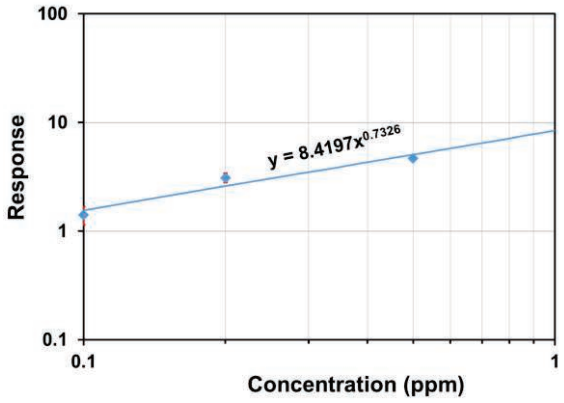

Fig. 4. Calibration curve of NiO/ZnO sensor devices towards NO_2 at optimal working temperature of 200°C. Relative humidity of 50% @ 20°C.

On the other hand, calibration curve for heterostructure sensors has been drawn in Figure 4 at optimal working temperature and concentration range from 0.1 to 0.5ppm. This curve was fitted by the typical power trend law for metal oxide sensors, and values of constants A and B was found to be 8.42 and 0.73 respectively. Considering a minimum response value of 1, the detection limit was found to be 0.054ppm (54ppb) for NiO/ZnO NWs heterostructures sensors.

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