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Research article

Green synthesis of zinc oxide nanoparticles using *Plectranthus cyaneus* leaf extract for ethanol sensing

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A B S T R A C T

In this work, zinc oxide (ZnO) nanoparticles (NPs) were green-synthesized using *Plectranthus cyaneus* leaf plant extract as a reducing agent. The synthesized ZnO NPs were characterized using X-ray Diffractometer (XRD), Scanning Electron Microscope (SEM), and Ultraviolet-Visible spectrophotometer. The XRD confirmed the crystal as a hexagonal wurtzite crystal structure with space group $P6_3mc$. The crystallite size was determined and found to increase with calcination temperature from 37.80 nm at 300 °C to 49.5 nm at 700 °C. The crystalline strain and dislocation density decreased from 1.538×10^{-4} to 1.144×10^{-4} and from 3.386×10^{-2} nm^{-2} to 2.919×10^{-2} nm^{-2} respectively. The SEM images of the ZnO NPs reveal fine spherical particles with less agglomeration at higher temperature, thus enhancing surface area. The optical band gap decreased with an increase in temperature from 3.26 eV at 500 °C to 3.22 eV at 700 ℃. The synthesized ZnO NPs were used to fabricate an ethanol gas sensor on an interdigitated Indium doped tin oxide (ITO) coated glass substrate, which was exposed to various concentrations of ethanol, isopropanol, acetone, and methanol. The fabricated sensor exhibited high sensitivities of 27.6%, 10.7%, 9.9%, and 8.2% for ethanol, isopropanol, acetone, and methanol, respectively, at a working temperature of 200 ℃. The sensor exhibited fast response and recovery times of 17.90 s and 21.12 s for ethanol, respectively. The sensors' selectivity of ethanol in the presence of other analyte were 36.16%, 38.77%, and 29.57% for isopropanol, methanol, and acetone, respectively. Therefore, our study provides a green route for synthesizing ZnO nanostructures as potential candidate for ethanol gas sensing.

1. Introduction

Ethanol is a colorless, odorous and volatile liquid obtained after yeast fermentation of plants and fruit sugars during both local and commercial production processes [1]. Ethanol is commonly used as a biofuel in gasoline, a laboratory solvent in pharmaceutical industries, and a vital ingredient for alcoholic beverages, personal care products, and disinfectants. However, the excess use of ethanol by human beings has both short-term and long-term effects, which include dizziness, drowsiness, loss of coordination and balance, slow reaction time, impaired judgement, lack of concentration, cancer risks, increased heartbeat, and liver damage. Hence, there is a need for ethanol detection at low concentrations during critical decision-making points, such as in driving, security, and machine operations [2]. In addition, we have selected Ethanol as our target analyte because it represents a critical class of volatile organic compounds (VOCs) that are routinely monitored for public safety, automotive diagnostics, and clinical breath analysis. Compared to more toxic, non-flammable, and highly prevalent baseline molecules like carbon dioxide (CO_2) or carbon monoxide (CO), ethanol possesses a highly reactive hydroxyl (-OH) group and a non-zero dipole moment, which ensure lower adsorption energy and optimal Lowest Unoccupied Molecular Orbital (LUMO) alignment with the ZnO sensing material. This unique chemical structure combining a polar -OH group with a hydrocarbon backbone drives a robust oxidation-reduction reaction at the sensor's surface. When exposed to the target, ethanol molecules interact with chemisorbed oxygen species, releasing trapped electrons into the conduction band to facilitate rapid, significant, and easily measurable changes in electrical resistance [3].

Nanotechnology is explored in numerous applications like detection of gases, catalysis, optoelectronics, among others owing to the large surface area and tunable properties of nanomaterials. They exhibit exiting properties over bulk materials. Metal oxide (MO)

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