Studies on the Gas Sensing Performance of Single and Multicomponent Oxides for Acetone Detection

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ABSTRACT:

In the recent past, there has been a great impetus to design and develop functional nanomaterials for sensor applications. Among the various materials available, metal oxide semiconductors (MOS) stand out as a promising class of materials for gas sensor development due to their simplicity and low cost. The conductivity of metal oxide nanostructures changes with the surface adsorption and desorption of gas molecules which in turn strongly depend on the shape and the size of the nanostructures. The main lacunae of the semiconductor based thick film sensors however, lies in their high operating temperature and lack of selectivity to any particular gas. Taking into consideration of the importance of detecting acetone as a biomarker in breath for non-invasive detection of diabetes, this thesis work has been focused on developing nanomaterials and sensors thereby for acetone detection. As nanotechnology-enabled sensors offer significant advantages over conventional sensors, our focus was to employ nanomaterials of n-type, p-type and multicomponent oxides to achieve better sensitivity and selectivity, and low operating temperature for developing acetone sensors.

The thesis work has focused on the development of nano-structured semiconducting oxide materials based on TiO_2, Fe_2O_3, WO_3, $BiFeO_3$, Zn_2SnO_4 and other mixed oxides for fabricating sensors to detect acetone. The major emphasis was given on preparation of above mentioned materials having variable size, shape, morphology and surface properties. In-depth characterization of the synthesized materials was carried out in order to understand the size effect on various properties and their response towards acetone. Thick film sensor elements using such materials was fabricated and sensing parameters *viz.* sensitivity, selectivity, stability, reproducibility, response time, recovery time etc. were measured.

Initial work was focused on preparing various phases of TiO_2, their characterization and property evaluation followed by sensing characteristics evaluation. As the response of single phase TiO_2 based materials was not good, we synthesized a composite $Na_{0.23}TiO_2$-anatase TiO_2 nanorod as a sensing material showing higher and significant sensing properties at room temperature towards various concentrations of acetone. As a continuation of this work, next focus was to understand the acetone sensing characteristics of various iron oxides and the effect of different structure on sensing performance. In this work response of the materials have been studied through DC and AC measurements. Here we could establish iron oxide fibers as a better structure exhibiting improved sensing characteristics than other shapes. Improved surface

modified WO_3 fiber samples exhibited 90% acetone sensing at 150°C operating temperature which will be an improved material for developing acetone sensor for practical application due its lower operating temperature.

In this work, we have also focused on ternary metal oxide based sensing materials for acetone sensor development for futuristic applications. Here, our attention has been to discover vacancy-induced sensing properties of sonochemically synthesized p-type $BiFeO_3$ nanoparticle exhibiting rapid response, recovery time, good selectivity, stability and reproducibility. In this thesis work we have also proposed Zn_2SnO_4 exhibiting exceedingly high response time of around 2 seconds towards acetone with 96% response at comparatively lower operating temperature.

Thus, in this thesis work response of various n-type and p-type single component nanostructured oxides and multicomponent oxides towards different concentrations of acetone have been demonstrated along with comparison and understanding of sensing mechanism through AC and DC electrical measurement techniques. Some of the studied materials exhibited exceedingly high response of 96% and above towards acetone which has been projected as potential candidates for developing sensor modules for non-invasive detection of diabetes through acetone sensing from exhaled breath.

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