Abstract

With advancement in technology and growth in industrialization, there is a constant degradation in the environmental aspects. Water and air quality monitoring have become indispensable due to the tremendous degradation in breathable air and contamination of water bodies. Electrochemical sensors are more popular commercially compared to other sensing technologies. However, costly electrolytes and expensive fabrication techniques are the major drawbacks. Alongside, limited life time (less than 6 months) is also an area of concern in these types of sensors. In this regard, resistive and FET-based sensors are gaining popularity. Owing to CMOS compatibility, simpler structure, and ease of operation, resistive and FET-based sensors show great potential to detect air and water pollutants. Batch fabrication of these types of sensors facilitate a reduction in overall cost. Commercially available resistive sensors (Taguchi) based on metal oxides use tin oxide as a sensing material to detect the presence of VOCs in air. These sensors suffer from poor selectivity and sensitivity towards humidity and require elevated temperatures to detect gases, usually 200-400^{o}C. In this respect, n-type transition metal oxides (e.g., ZnO, Fe_2O_3, etc.) and two-dimensional materials (e.g., RGO, MoS_2, WS_2, etc.) can play a vital role due to simple fabrication techniques, excellent catalytic activity, and ease of functionalization.

There have been very few explorations in the areas of defect engineering and functional group optimization of nanomaterials for sensing applications. There is hardly any investigation made to control the channel carriers to enhance the sensitivity of any sensor. This work is aimed at enhancing the sensing performance of a sensor by i) modification of surfaces (addition of surface defects, tuning of functional groups, and addition of functional probes) and ii) introducing field effects to modulate carriers in the sensing area (channel region of a FET). Firstly, the ZnO nanorod surface was modified with surface defects and catalytic nanoparticles to sense acetone at high temperatures. The introduction of pores, oxygen vacancies, and Fe_2O_3 nanoparticles enhanced the sensing performance of ZnO at high temperatures. Due to the shortcoming of ZnO, operating at high temperatures, RGO was studied to detect toxic gases. However, RGO was found to be highly selective towards ammonia, with poor response and speed. Selective removal of functional groups and its optimization led to a tremendous improvement in ammonia sensing characteristics. The sensor's ability to operate at room temperature facilitated its fabrication on a flexible sheet, making it very cost-effective.

Among water pollutants, heavy metal ions are highly toxic and pose a threat to human life. These ions are non-biodegradable and may lead to death. Specifically, in this work, RGO is used as

the sensing layer due to its high surface-to-volume ratio and tuneable surface. An attempt has been made through thiol functionalization of RGO sheets via gold nanoparticles to detect mercury ions with a high degree of selectivity. Water containing arsenic ions, a major concern in many countries, can be detected with a highly sensitive sensing material. Functionalization of RGO sheets with highly selective Fe_3O_4 nanoparticles and leucine imparts a high degree of selectivity with quick response during real-time monitoring. Functionalization with these protein-free probes makes the sensors highly stable and immune to environmental changes. Even though these resistive sensors exhibit highly elevated sensing performance, their sensitivity and response cannot be enhanced after the sensor is fabricated.

With the introduction of field-effect transistor-based sensors, the sensing material in the channel can behave differently under the influence of gate voltage. This property of the field effect transistor is used in the last part of the work to enhance the sensing performance of functionalized ZnO-based arsenic sensors and RGO-based ammonia sensors. The tuneable channel concept is highly promising as it can detect a trace number of analytes present in the ambience. Highly selective materials with FET-based configuration could be the future for the detection of minute quantities of air and water pollutants.