Abstract

The main motivation of the present thesis work is to develop wafer scalable fabrication processes for efficient, selective room temperature operated gas sensor prototypes and their integration with MEMS (Microelectromechanical systems) for societal applications. To fulfill this motivation, different sensors were designed, fabricated and tested using metal oxides, transition-metal-dichalcogenides (TMDCs) and porous silicon. Introduction of metal oxides on nanostructured silicon (Si) enhances the sensitivity and lowers down the operating temperature of the sensor. One such material is nano Si or nano-porous silicon (NPS) or commonly called porous silicon (PSi). Towards the end, prototypes comprising of packaged sensor, microcontroller, display, analog-to-digital converter (ADC) etc. were developed. A user-friendly display screen shows the concentration of vapors exposed to the sensor. With this, new kind of semiconductor nanostructures based heterostructure type sensors were developed in the present research work. The thesis has been organized to meet the above stated aims and outlined in six chapters. First chapter of the thesis describes the literature and current state of the art of gas sensors and the last chapter discusses work summary and scope of future research work.

Second chapter is on development of a miniaturized prototype sensor based on TiO$_2$ nanotubes/porous silicon heterojunction for selective ethanol sensing in sub-ppm range. Both silicon and Ti were sequentially anodized to form PSi and nanotubes respectively. The sensor was packaged onto a 12-pin header and tested in presence of different Volatile Organic Compounds (VOCs) with concentration ranging from 0.5 to 100 ppm. Sensitivity of such a sensor improved manifold in comparison to the response of pure PSi and pure TiO$_2$ based sensors. The formation of heterojunction, selective response to ethanol, sub-ppm level sensing at comparatively low operating temperature is discussed. This study unfolds the collective properties of TiO$_2$/PSi heterojunction and demonstrates the potential of wafer scale integrated repeatable ethanol sensor tested at sub-ppm level.

Third chapter presents the development of an extremely sensitive and selective acetone sensor prototype which can be used as a platform for non-invasive diabetes detection through exhaled human breath. The miniaturized sensors were produced in high yield with the use of standard micro-fabrication processes. The sensors were based on a heterostructure composed of MoO$_3$ and NPS. Features like acetone selective, enhanced sensor response and 0.5 ppm detection limit were observed upon introduction of MoO$_3$ on the NPS. The sensors were found to be repeatable and stable for almost 1 year, as tested under humid conditions at
room temperature. It was inferred that the interface resistance of MoO$_3$ and NPS played a key role in the sensing mechanism.

Fourth chapter is on the development of a highly selective ethanol sensor based on MoS$_2$ functionalized PSi. The uniqueness of the sensor includes its method of fabrication, wafer scalability, affinity for ethanol, and high sensitivity. MoS$_2$ nanoflakes (NFs) were synthesized by sulfurization of oxidized radio-frequency (RF) sputtered Mo thin films. The MoS$_2$ NFs synthesis technique is superior in comparison to other methods, because it is chip-scalable and low in cost. With the effect of MoS$_2$ on PSi, an enhancement in sensitivity and a selective response for ethanol were observed, with a minimum detection limit of 1 ppm. The ethanol sensitivity was found to increase by a factor of 5, in comparison to the single-layer counterpart levels. This impressive response is explained on the basis of an analytical resistive model, the band gap of MoS$_2$/PSi/Si, the interface formed between MoS$_2$ and PSi, and the chemical interaction of the vapor molecules and the surface. MoS$_2$ with PSi paves the way for efficient, highly responsive, and stable sensors.

Fifth chapter presents, design, simulation, IC compatible fabrication and testing of integrated MEMS micro-heater with sensor platform using planar MEMS technology. Metal oxide based gas sensors are known for operating at high temperatures which results in high power consumption. This drawback limits their application in battery operated devices as well as system on chip (SOC) applications. The micro-heater was integrated with TiO$_2$ and nano-silicon heterostructure using a simple fabrication process. The sensor had shown optimum sensing response at 100 ºC and selective detection of ethanol vapors. In comparison to the crystalline Si, the power consumption of the nano-Si based platform was almost half. The formation of heterostructure, selective response to ethanol, repeatable ppm level ethanol sensing at comparatively low operating temperature is reported. The results show the TiO$_2$/nano-Si integration with MEMS micro-heater and demonstrate the reduced power consumption of 18 mW by nano-Si which is very less in comparison to what is consumed by crystalline-Si. The temperature profiling carried out using IR-camera ensures the uniform temperature of 100 ºC over the suspended sensing structure.
List of Patents and Publications

Patents

- Molybdenum trioxide and nano silicon for acetone detection, No. 201711002327 on 20 January 2017. Indian patent filed (PCT filed).
- Cantilever sensor device based on suspended metal oxide and Silicon nanostructures and fabrication method thereof, No. 201711029361 and dated August 18, 2017. Indian patent filed.
- Method for fabrication of MEMS integrated sensor and sensor thereof, No. 201811014593 and dated April 17. Indian patent filed.

International Journals


6. Priyanka Dwivedi, Samaresh Das and Saakshi Dhanekar, “Polymer functionalized nanostructured porous silicon for selective water vapor sensing at room temperature” Superlattices and Microstructures 104 (2017) 547-552.

