Abstract

In this thesis, first time, we reported a state-of the art method for the synthesis of metal oxide nanoparticles in atmospheric air using laser ablation techniques for the rapid prototyping of formaldehyde (HCHO) gas sensor. Formaldehyde gas is most common indoor air pollutants which causes various adverse human health problems if its limit goes above 0.75 ppm as per OSHA (Occupational Safety and Health Administration (OSHA), USA) guidelines. It is also noticed that some dishonest fish merchants are using formalin solution (formaldehyde gas dissolved in water) to preserve freshly caught fish during their transportation to the fish selling market to prevent the spoilage. So, various health issues have been occurred due to the ingestion of formalin contaminated fish. Thus, we need a miniature, low cost, ultra-low sensitive formaldehyde sensor for the development of smart or IoT-enabled portable system for the measurement of formaldehyde gas level in indoor area and as well, their presence in fish.

Microhotplate is an essential part of any metal oxide based gas sensors. Hence, in the first part of the study, co-planner Au microheater based gas sensor platform was fabricated by laser micropatterning using a 355 nm Q-switched solid state laser source. The heat distribution profile of the fabricated microhotplate was observed via IR thermal imaging camera. Furthermore, the long-term reliability, power versus operating temperature of the microhotplate were systematically studied. In addition with this, heat distribuiton profile of a Nichrome heater based gas sensor platform having a hollow alumina tube on which two gold electrodes had been printed at each end, was also investigated.

The next set of analysis, the formaldehyde gas sensing performance was studied using pristine SnO_2 and ZnO metal oxide materials. Formaldehyde gas sensing behaviour was studied by depositing thin film of SnO_2 layer onto the external surface of alumina tube based gas sensor platform. The sputtered deposited SnO_2 thin film sensor exhibited gas response of 1.2 towards 1 ppm of formaldehyde vapor with a response time of ~ 32 s and a recovery time of ~72 s at 300°C. Next, to explore the formaldehyde sensing capabilities of nanoparticles, we have synthesized pristine ZnO nanoparticles by scanning a high power laser beam on the top surface of ZnO pellet in open air atmosphere and the laser-ablated ZnO NPs were directly deposited onto the alumina tube based gas sensor platform. The gas-sensing properties of the ZnO NPs has been carefully investigated in the presence of formaldehyde gas molecules. ZnO NPs-based sensor exhibited the response of about 1.8 towards 50 ppm formaldehyde gas at 350°C with response time 25 s and recovery time 12 s.

To further enhance the sensitivity and selectivity towards formaldehyde gas, we have fabricated n-ZnO/n-SnO_2 n-n heterojunction by combined processes of physical vapor deposition (PVD) by sputtering SnO_2 thin film on the alumina tube based gas sensor platform and decorated it with ZnO nanoparticles. After decoration of laser ablated ZnO nanoparticles on thin film SnO_2 sensor, it exhibited high response of 20 towards 50 ppm of formaldehyde with quick response (4 s) and recovery time (30 s) at lower operating temperature (250°C) compared to that of pure SnO_2. After obtaining good results from the previous investigations with heterojunction, the present research has further been extended. The p-type NiO NPs were synthesized in atmospheric air by laser ablation of cylindrical shaped solid Ni pellet. We have fabricated p-NiO/n-SnO_2 p-n heterojunction via decoration of laser ablated NiO nanoparticles over sputtered deposited n-type SnO_2 thin film. We have explored the formaldehyde sensing behaviour of NiO/SnO_2 sensor and compared with pristine SnO_2 senso. The NiO/SnO_2 sensor exhibited higher response of about 29.8 towards 50 ppm formaldehyde with fast response and recovery time (3 s and 90 s) at lower operating temperature (about 210°C) with good selectivity.

In the last part of the thesis, enhanced formaldehyde sensing mechanism of ZnO/SnO_2 and NiO/SnO_2 sensors has been described. From the experimental gas sensing performance data of NiO/SnO_2 sensors, we have also extracted the various gas sensing parameters such as response time (τ_{res}), recovery time (τ_{rec}), surface coverage (θ), adsorption (K_a) and desorption rate constant (K_d) using Langmuir gas adsorption-desorption model via curve fitting method.

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