Abstract

With growing industrialization and technological advancement, the environment is experiencing an exponential degradation. Hence, monitoring breathable air and drinkable water quality has become indispensable. Among different sensing technologies, electrochemical sensor occupies majority of market share. However, these suffer from low life time (typically 6 months to 1 year) and are expensive due to semi-automated fabrication and costly electrolyte. In this respect, resistive sensors have recently gain popularity. This is because of their simpler structure and CMOS compatibility thereby facilitating batch fabrication. Resistive sensor often has metal oxides (e.g. commercially available Taguchi sensor uses tin oxide) as sensing layer. However, these sense gases at elevated temperature (200-400^{o}C), have poor selectivity and are sensitive to humid environment. In this regard, p-type transition metal oxides (TMOs) (e.g. CuO, NiO etc.) can play a crucial role due to their excellent catalytic activity, simple fabrication process and humidity insensitiveness. Among them, nickel (II) oxide (NiO) have not been explored much. Bulk NiO though have shown very less sensitivity towards gases and heavy metals. This work is aimed at establishing NiO based (i) gas and (ii) Heavy metal ion sensors for internet of things (IoT) based environmental monitoring. The selectivity and operating temperatures were tuned by (i) varying nanostructure morphologies (ii) metal doping onto NiO lattice and (iii) fabricating junction devices.

Two different morphologies of nickel oxide nanostructure were synthesized. The first one was a **hierarchical coral-like nanostructure,** synthesized via mild hydrothermal route. This was found to be optically active and sensed formaldehyde at 300^{O}C in presence of light. The second one was liquid exfoliated (followed by calcination) $Ni(OH)_2$ **nanosheets** (**two to few layers**) which remained dispersed in dimethylformamide solution for six months without significant precipitation. The nanosheets selectively sensed acetone at 200^{O}C.

The coral like nanostructures were doped by (i) Cu and (ii) Fe. Doping Cu in NiO ($\mathbf{Cu_{0.1}Ni_{0.9}O}$) lattice showed sensitivity towards humidity (at room temperature) and several VOCs (methanol, ethanol, toluene and acetone) at 300^{O}C. Hence Principal Component Analysis (PCA) was adopted to improve selectivity. The same material showed sensitivity towards Cr(VI) ions in water. The iron doped sample, $\mathbf{Fe_{0.1}Ni_{0.9}O}$, showed excellent toluene sensing and was insensitive in presence of varying humidity. In case of heavy metals, it was selective towards As(V) ions and was also bio-compatible. It was demonstrated as an in-vivo As(V) ion sensor in living systems.

A new heterojunction non-linear device was fabricated to replace conventional resistive gas sensors. The devices, when operated in the linear region showed tunable selectivity. Two devices were fabricated: (i) **$Fe_{0.1}Ni_{0.9}O$/NiO** and (ii) **ZnO/NiO** heterojunctions. The first one is a p-p heterojunction which showed tunable selectivity towards 2-propanol, toluene and formaldehyde vapors depending on the operating temperature. The tuning of selectivity could be achieved due to exponential increase of thermal carriers. The second one was a p-n heterojunction which demonstrated voltage tunable selectivity among 2-propanol, toluene and formaldehyde vapors. Both the devices were operated under forward bias. Finally, an Arduino microcontroller based sensor interfacing circuit was designed and fabricated that can support four sensors simultaneously. This would facilitate an easy integration of the physical node to the IoT.

Keywords: nickel (II) oxide, resistive sensors for volatile organic compounds, resistive sensors for heavy metal, re-usable sensor