Room Temperature Operable semiconducting Metal Oxide Chemi-Resistive NO_2 Gas Sensor

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Abstract

The quest for the room temperature operable semiconducting metal oxide gas sensors has come to an end. We fabricated an InGaZnO based chemi-resistive gas sensor, which is remarkably sensitive and selective to NO_2 gas. Conventional semiconducting metal oxide gas sensors are active at high temperatures or in presence of light, which makes them power-hungry. The fabricated sensor is room temperature operable and requires light only to regenerate the device after exposure. NO_2 has adverse effects on human health at concentration as low as 2 ppm. The measured limit of detection of the sensor is 100 ppb. Comprehensive NO_2 adsorption studies were performed using kelvin probe force microscopy (KPFM) and X-ray photoelectron spectroscopy (XPS). The detailed mechanism of sensing and reviving is proposed. The fabricated sensor is compatible with CMOS process and can be integrated with the CMOS circuitry to make compact sensing system.

Introduction

Toxic gas monitoring in the current scenario is quite essential due to the rising pollution levels globally owing to the industrial and vehicular emissions[1]. NO_2 is one of the toxic gases that have considerable impact on human health even at lower concentrations[2]. Substantial efforts are being made to design inexpensive air quality monitoring systems for accurate environmental monitoring[3]. It requires highly sensitive and selective toxic gas sensors that are inexpensive. Semiconducting metal oxide (SMO) gas sensors are known to be reliable and compact among all the available gas sensors. Nevertheless, they are power-hungry because of inherent power requirements to operate at high temperatures for making them active for sensing and revival[4]. We have demonstrated alternate sensors that can operate at room temperature, such as Metal-organic framework (MOF) based chemi-capacitive sensors for SO_2[5], H_2S[6], and NH_3[7] sensing. In this work we are demonstrating InGaZnO (IGZO) based chemi-resistive sensor where IGZO is the active layer for sensing.

Method

IGZO layer of 10 nm thick was deposited using physical vapor deposition (RF sputtering) on the Silicon dioxide/ n_{++}-Silicon substrate. Au/Ti Interdigitated electrodes on the IGZO layer was deposited by using DC Sputtering and liftoff process. IGZO serves as a semiconducting active layer sensitive to the NO_2. The top interdigitated electrodes of device are connected to the two terminals of the LCR meter. The devices were evaluated for the gas response by measuring resistance vs time in the C_P-R_P mode of the LCR meter at 10 kHz frequency.

Results and Conclusions

The baseline resistance of the semiconducting IGZO channel is in the order of megaohms due to the interdigitated electrode configuration; this allowed us to explore the device as chemi-resistor. The variation in the device resistance was measured in the presence of various toxic gases. It was revealed that the effect of NO_2 is significant on the IGZO resistance. The transient analysis was performed by exposing device to various concentrations(100 ppb to 5 ppm) as shown in Fig 1a and Fig 1b. The device after exposure was revived by using blue LED until it reaches the baseline. The increase in resistance of the device is due to the change in the depletion of charge carriers of the IGZO layer owing to the adsorption of NO_2 molecules. The device wasn't recovered after NO_2 exposure with the nitrogen purge. Photo generated carriers improved the conductivity of the IGZO layer with the illumination of the blue LED. The responsivity in terms of variation in the resistance is multifold; moreover the decrease in the conductivity of the device is exponential with the increase in the concentration of NO_2. Kelvin probe force microscopy (KPFM) and X-ray photoelectron spectroscopy (XPS) studies were performed to understand the effect of NO_2 on the IGZO active layer. Characterization results were consistent with the observed electrical behavior. It was evident from these results that NO_2 molecules adsorb on the IGZO surface and depletes the charge carriers. The device is reproducible and stable in air. Among different toxic gases such as NH_3, SO_2, CO, CO_2, and CH_4, the device is selective to the NO_2.

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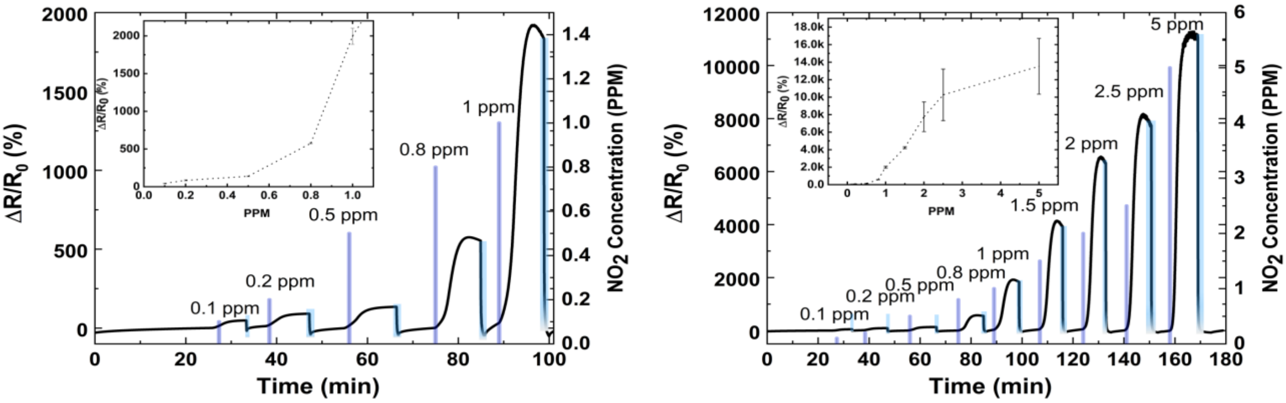

Fig 1. Response of the IGZO sensor in presence of various NO2 concentrations a) from 100ppb to 5 ppm b) 100ppb to the 5 ppm. (Insets shows the responsvity of IGZO sensors)