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Screen-printed Tin-doped indium oxide (ITO) films for NH_3 gas sensing

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Abstract

Gas sensors using metal oxides have several advantageous features such as simplicity in device structure and low cost fabrication. In this work, Tin-doped indium oxide (ITO) films were prepared by the screen printing technique onto glass substrates. The granular and porous structure of screen-printed ITO are suitable for its use in gas sensing devices. The resistance of the ITO films was found to be strongly dependent on working temperatures and the nature and concentration of the ambient gases. We show that screen-printed ITO films have good sensing properties toward NH_3 vapours. The observed behaviors are explained basing on the oxidizing or the reducer nature of the gaseous species that react on the surface of the heated semi-conducting oxide.

Keywords: ITO; Thin films; Gas sensors

1. Introduction

Many attempts have been done to introduce thin semiconducting metallic oxide films in gas sensing. Sensors for toxic gases have attracted much attention due to the growing concern of environmental protection and safety. A number of semiconductive oxides such as WO_3, ZnO, SnO_2, In_2O_3 and indium tin oxide (ITO) are used for different gas sensors [1–5]. Most of these sensors are based on the resistance variation when the semiconductor oxide films are exposed to target gases. Recent research has shown that In_2O_3 is a promising material for gas-sensor applications. Indium oxide offers a new advantage in design of metal oxide-based gas sensors, linked with an essential difference in electro-physical and chemical properties between SnO_2 and In_2O_3. Thus, gas sensors based on In_2O_3 are very sensitive to detection of low concentrations of oxidizing gases [6–9]. Although In_2O_3 has been less popular than SnO_2, it is a unique sensing material that allows detection of ozone [10–13], and highly selective detection of reducing gases [14–16]. To be interesting, the devices should have reproducible features, low power, high sensitivity and fast response times (for both switch-on and switch-off times). It is well know that interaction of n-type semi-conductors with reducing gases such as NH_3, results in decrease of the surface resistance. However, the film resistivity decreases while exposed to reducing gases; the decrease rate of the resistivity depends on both operating temperature and ambient atmosphere conditions. As ammonia is a toxic gas, further interest was given to ammonia-gas sensing in controlling systems in various industrial processes. Numerous efforts have been done to develop highly sensitive NH_3 sensors by employing semi-conductive metal oxides [17]. Most of the oxide semiconductor gas sensors normally operate at elevated temperatures and therefore need a heater. The decrease of the operating temperature is one of the needed factors for viable gas sensors in industrial applications. Several

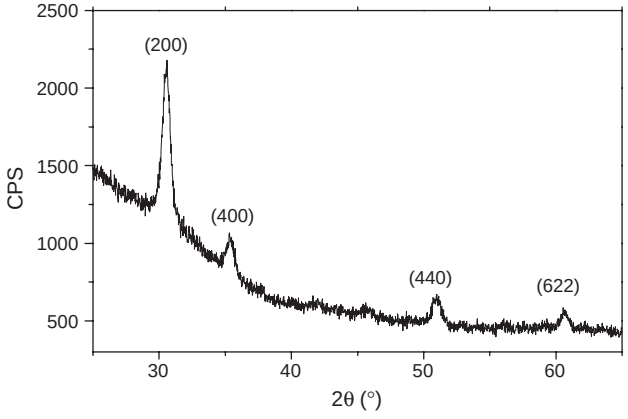

Fig. 1. X-Ray diffraction patterns of screen-printed ITO films.

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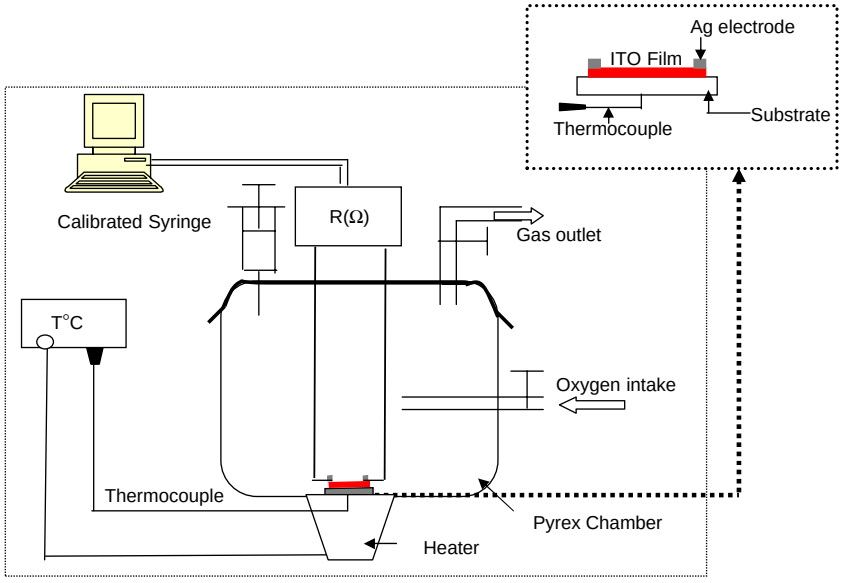

Fig. 2. Schematic diagram of the set-up used for the measurement of the ITO resistance.

techniques were used to prepare In_2O_3 films [18–24]. Recently a micromachining and screen printing technique combination has been used to obtain SnO_2 based thick-film gas sensors [25,26]. The interest of this study is to improve the response of Sn-doped In_2O_3 (ITO) thin films as regard to NH_3 gas at low operating temperature.

2. Experimental

The ITO films were prepared by screen printing a viscous organometallic paste (ESL # 3050, manufactured by Agmet Ltd ESL) of a dissolved combination of metallic indium and tin together with organic compounds, onto glass substrates. The paste is spread out on the top of a stainless steel screen (325 meshes). A squeegee is used to push the paste throughout the opening meshes, and press the screen into contact with the surface of the glass substrates in order to deposit a thick paste layer having a thickness of about 20–30 μm [27]. To avoid the creation of cracking in the material, the samples are dried in air in an oven at a temperature of about 150 °C during 15 min. The ITO films are obtained after crystallization in an infrared furnace at a temperature of about 600 °C for 40 min. X-ray diffraction (XRD) patterns confirm that 40 min is an optimal firing time to crystallise the screen-printed ITO films (Fig. 1). Microprobe analysis shows that the final ITO films are composed of In and Sn atoms in the proportion 90 and 10 at.%, respectively. The sheet resistance of the as-made ITO films is measured using the four points probe method. Ag electrodes were deposited by thermal evaporation, leaving a net sensor surface area of about 200 mm^2. The schematic diagram of the set-up used for the measurement of the ITO resistance, in presence of NH_3 vapours, is shown in Fig. 2. The schematic representation of the device is shown in the inset of Fig. 2. The chamber where NH_3 vapours interact with the ITO films consists of a fixed flask, specially designed to keep it airtight and to inject NH_3 gas through graduated and precise syringes. A heater ensures to change the temperature of the ITO films between 50 and 150 °C. The resistance of the ITO gas sensing films was then measured in ambient. In this study, the NH_3 vapours were introduced into the test chamber using a calibrated syringe having a minimum volume of 10 μl. In ambient atmosphere,

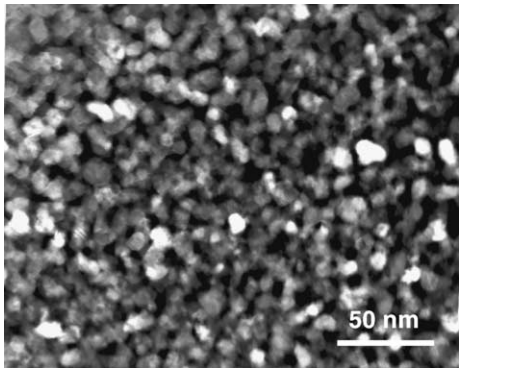

Fig. 3. Surface TEM micrograph of screen-printed ITO.

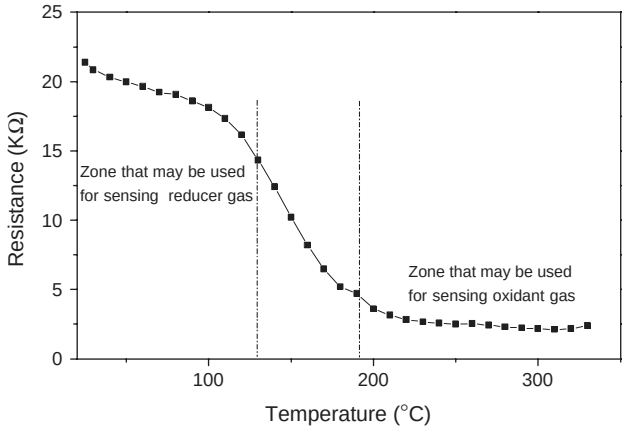

Fig. 4. Resistance behavior of screen-printed ITO thin films at various working temperatures.