Characterization of SnO$_2$-based H$_2$ gas sensors fabricated by different deposition techniques

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Thick and thin films of SnO$_2$ are extensively used for resistive gas sensors. Characteristics are compared for films produced by four different techniques – chemical vapour deposition (CVD), spray pyrolysis, vacuum evaporation and screen printing. The films are characterized for H$_2$ sensing only, using a static measurement system to investigate their temperature selectivity. The samples are tested at a concentration of 300 p.p.m. H$_2$ gas, a typical value for comparison. No selective peak is observed for CVD and spray deposited samples, and the selective peak for vacuum evaporated samples has a low sensitivity. But the selective peak for screen printed samples has a sensitivity of 55% ($\delta R/R_{\text{ref}}$). And what is more, the screen printed samples have a repeatable response.

1. Introduction
Due to the increased use of toxic gases in domestic and industrial processes, there is a growing need to develop low cost and portable gas sensors. Existing sensors – based on electrochemistry, chromatography, calorimetry, mass spectroscopy or pH – are very costly or are not easy to use. Because of these limitations, semiconductor gas sensors are gaining importance over conventional sensors/systems, although they are not as specific as spectroscopy for a particular gas.

Semiconductor gas sensors, particularly resistive sensors, fulfill the requirements of portability, low cost, small size, etc., and are compatible with electronic systems. Among them, attention is mainly focused on SnO$_2$-based gas sensors [1–4] because they have the advantages of relatively low operating temperature and long-term stability. The dominance of SnO$_2$-based gas sensors over other types is indicated by their higher coverage in the literature. After studying various materials [1–4], the recent trend is to study the SnO$_2$ material in detail and to enhance its performance perhaps by using a catalyst [5–9] for selectivity towards a particular gas, by using different deposition processes and techniques [14–20], by surface modification [12, 13] of the sensor, by thickness variation [5, 10, 21] or by deposition under a different gaseous environment [11].

Gas sensing methods using SnO$_2$ exploit the fact that its conductance in air ($G_{\text{air}}$) can be changed ($\delta G_{\text{air}}$) by the presence of reducing/oxidizing gases in the atmosphere. The extent of the relative change in conductance ($\delta G_{\text{air}}/G_{\text{air}}$) can be directly related to the concentration of reducing/oxidizing gases in the atmosphere. SnO$_2$ sensors can be broadly divided into three types: sintered pellet [16], thin film [14–18] and thick film [19, 21]. There has been considerable progress in developing sintered and thick film gas sensors.

Thin film sensors are prepared using various techniques like physical vapour deposition, chemical vapour deposition, RF sputtering, spray pyrolysis, laser ablation and electron beam evaporation. RF sputtering has proved to be one of the most successful techniques. Thick film sensors are prepared using standard screen printing technology.

This paper presents a comparative study of SnO$_2$ deposition techniques by investigating the electrical characteristics and surface morphology of the films they produce.

2. Experimental procedure
2.1. Sample preparation
2.1.1. Thin film sensors
Thin films of SnO$_2$ are prepared by using chemical vapour deposition (CVD), physical vapour deposition (PVD) and spray pyrolysis.

2.1.1.1. Chemical vapour deposition
SnO$_2$ films are prepared by using CVD techniques. For preparation of SnO$_2$, SnCl$_2$–2H$_2$O is used as a precursor. A 10 g mass of SnCl$_2$–2H$_2$O is kept in a glass bubbler, which is heated to 265°C. The alumina substrate (1 cm x 1 cm) is kept on a graphite-coated stainless steel susceptor inside the reaction chamber. The temperature of the substrate and the temperature of the reactants in the bubbler are set by separate temperature controllers; the substrate temperature is set at 375°C. A heating cord keeps the inlet and outlet tubes of the bubbler at a temperature of about 150°C. After heating to the required temperature, oxygen gas is passed through the bubbler, as a carrier, at a flow rate...