

Engineering the Active Layer of SnO₂ Chemoresistive Sensors: Influence of Deposition Methods and Film Thickness on NO₂ Detection

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Summary:

The influence of deposition technique and film thickness on SnO₂ chemoresistive sensors for NO₂ detection was investigated. Films were fabricated by screen-printing, drop-casting, and spin-coating, achieving thicknesses from ~380 nm to 30 µm. Thin spin-coated films enabled detection down to 0.2 ppm without saturation up to 10 ppm, while thick films showed early saturation due to diffusion limitations. The best device reached a response of 186 with high stability and repeatability. These results demonstrate that thickness control is a key parameter for optimizing gas sensor performance.

Keywords: Chemoresistive gas sensors, SnO₂ thin films, NO₂ detection, Film thickness, Deposition techniques.

Introduction

Chemoresistive gas sensors based on semiconducting metal oxides have been widely studied due to their high sensitivity, low cost, and simple device architecture [1]. Among these materials, SnO₂ stands out as one of the most widely used sensing layers for NO₂ detection, owing to its favorable electronic and surface properties. However, sensor performance is not determined solely by the intrinsic characteristics of the material. Processing parameters, particularly the deposition technique and resulting film thickness, play a critical role in defining film microstructure, gas diffusion pathways, and charge transport mechanisms, thereby directly impacting sensing behavior [2].

In this work, the influence of different deposition methods on the functional performance of SnO₂-based chemoresistive sensors is systematically investigated to establish structure–performance relationships governing gas sensing behavior. Films are fabricated using screen-printing, drop-casting, and spin-coating, enabling the production of sensing layers with a wide range of thicknesses and morphologies. The relationship between deposition technique, film architecture, and gas-sensing performance is evaluated through NO₂ detection tests, with emphasis on sensitivity, detection limit, stability, and repeatability.

Methodology

SnO₂ sensing films were fabricated from commercial nanopowder (<100 nm) using screen-printing, drop-casting, and spin-coating. For screen-printing, pastes were prepared with propylene glycol at 20–35 wt%. Drop-casting dispersions were prepared at 20 mg.mL⁻¹ in isopropanol. Spin-coating was performed using a Laurell WS-400B-6NPP/LITE system, depositing 25 µL per cycle at 2000 rpm for 10 s, producing films with 10–40 layers and intermediate drying at 70 °C for 3 min. All devices were thermally treated at 400 °C for 2 h after deposition to remove organic residues and promote film calcination.

The thickness of screen-printed and drop-cast films was determined by cross-sectional analysis via controlled substrate fracture, followed by SEM-FEG (JEOL JSM-IT500HR). Multiple regions were analyzed to obtain representative average thickness values. For spin-coated films, thickness was measured using focused ion beam (FIB, FEI Helios NanoLab 600i) after deposition of protective platinum layers and cross-section milling.

Electrical characterization was performed in a controlled stainless steel chamber, with resistance monitored using a Keysight DAQ970A system. Heating (100–300 °C) was controlled via a PID system with a PT100 sensor and a Sorensen DLM 40-15 power supply. Gas flow (200 sccm) was regulated by MKS controllers

with dry air as baseline. Sensors were exposed to NO₂ (0.2–10 ppm) using 20 min exposure and 60 min recovery cycles. Stability and drift were evaluated under continuous exposure (1–10 ppm, 2 h per step), while reproducibility was assessed over 20 cycles at 4 ppm. Response time and relative standard deviation (RSD) were calculated from cyclic measurements at 4 ppm, while stability was further evaluated through RSD and temporal drift rate at the same concentration.

Results

Screen-printed films exhibited average thicknesses ranging from 14 to 30 µm. These sensors showed a detection limit of 0.4 ppm; however, signal saturation was observed from 2 ppm onward. This behavior is attributed to the large film thickness, which likely hinders gas diffusion and limits effective charge transfer within the sensing layer.

In contrast, spin-coated films presented significantly lower thicknesses, ranging from ~380 nm (10 layers) to ~900 nm (40 layers). These devices enabled detection down to 0.2 ppm and did not exhibit saturation up to 10 ppm, indicating improved gas diffusion and more efficient surface interaction.

Among the investigated techniques, the best performance was achieved with the 40-layer spin-coated film, which exhibited a response of 186 at 10 ppm of NO₂. Repeatability tests over 20 cycles showed a RSD of 3.54% and a response time of 340 s. Stability tests at 4 ppm revealed low signal fluctuation, with an RSD of 1.4% and a drift rate of 4.30% h⁻¹ during continuous exposure.

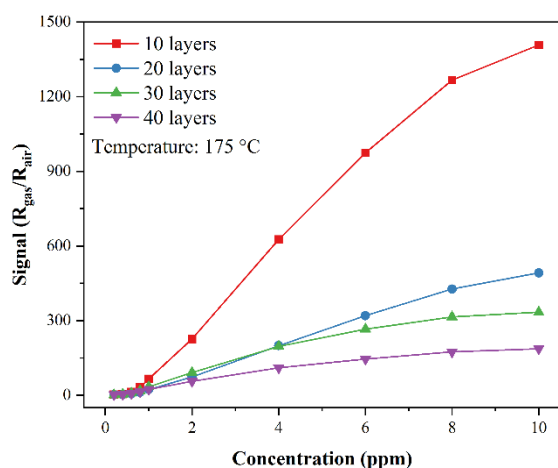


Fig. 1. Detection response of SnO₂ sensors fabricated by spin-coating under NO₂ exposure.

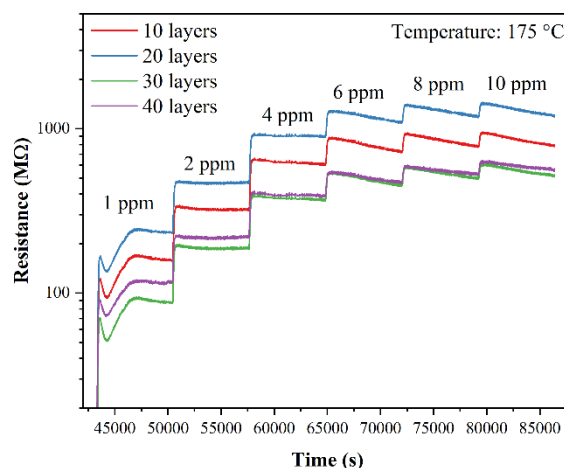


Fig. 2. Electrical stability of the SnO₂ sensor during 2 h of continuous NO₂ exposure.

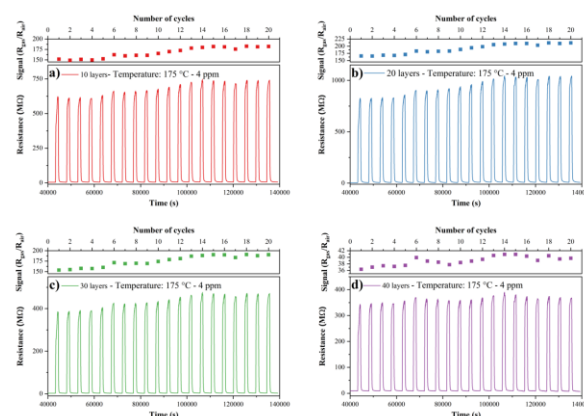


Fig. 3. Repeatability assessment of the SnO₂-based sensor over 20 consecutive exposure/recovery cycles to NO₂ at 4 ppm.

Overall, thinner films demonstrated enhanced sensitivity, improved stability, and more consistent signal profiles, highlighting the critical role of deposition technique and thickness control in optimizing the performance of SnO₂ chemoresistive sensors for NO₂ detection [3].

References

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