

Inkjet-printed TiO₂ Nanoparticles for Miniaturized Gas Sensors

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Summary

This work demonstrates the development of a gas sensor based on inkjet-printed titanium dioxide as a step toward multipixel gas sensing platforms. We demonstrate the reliable formulation of ink based on these nanoparticles and the resulting high-resolution deposition on interdigitated electrodes. The measured gas sensing properties are consistent with results obtained for drop-casted TiO₂ material. Through this approach, we aim to significantly address the limited selectivity typically associated with conventional chemiresistive gas sensors, while relying on a fabrication method that is compatible with scalable, industrial-level manufacturing.

Keywords: Inkjet printing, metal oxides, multi pixels, gas sensing

Introduction

Metal-oxide chemiresistive sensors are commonly employed for gas detection because of their strong sensitivity and rapid response times. Their operating principle relies on monitoring changes in the electrical resistance of metal-oxide layers, where these variations are directly linked to the concentration of target gases[1]. Despite these advantages, a key drawback is their limited selectivity, as they tend to respond to a range of gases rather than a single species, making accurate identification more challenging [2].

To overcome this issue, multi-pixel sensor platforms incorporating different sensing materials on each pixel have been proposed. While such approaches have been widely explored in academic research [3], their transition to commercial products remains constrained by the absence of scalable fabrication techniques capable of integrating multiple metal oxides onto a single chip. As a result, most commercially available multi-pixel sensors still rely on identical materials across all pixels, providing little improvement in selectivity compared to single-material devices. Inkjet printing offers a promising solution, as it allows the controlled and selective deposition of diverse materials onto multi-pixel architectures, with strong potential for straightforward scalability.

Description of the New Method

In this study, titanium dioxide nanoparticles were deposited via a drop-on-demand inkjet printing

technique to fabricate miniaturized gas sensors. The resulting thin films exhibited electrical conductivity and showed sensitivity to both oxidizing and reducing gases.

Results

The nanoparticles are spherical, commercially available titanium dioxide (Aeroxide P25). Their primary particle size is around 20 nm; however, they tend to form solid aggregates with dimensions on the order of several hundred nanometers (Fig. 1). The ink formulation contained 5 wt% of these nanoparticles and was deposited using a pre-industrial inkjet printhead with a nominal droplet volume of 30 pL. The nozzle diameter is approximately 40 µm, which ensures stable jetting while minimizing the risk of clogging.

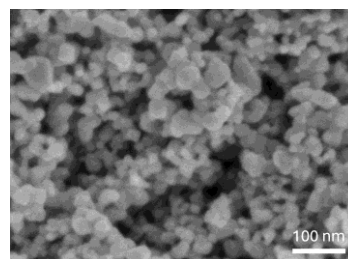


Fig. 1. SEM image of commercial TiO₂ nanoparticles

Individual droplets were deposited onto a silicon substrate. The resulting patterns are uniform, with no observable coffee-ring effect (Fig. 2 (a)). Each droplet has a diameter of approximately 50 µm, corresponding to a resolution comparable to that of electrodes in a multipixel platform.

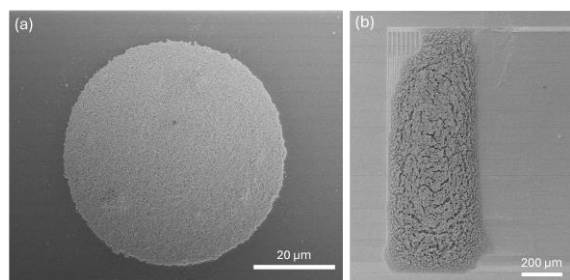


Fig. 2. SEM of inkjet-printed (a) TiO_2 droplet and (b) TiO_2 film on interdigitated electrodes

A carefully optimized ink formulation was developed to achieve both uniform deposition and adequate electrical conductivity. Establishing efficient interparticle contacts is critical to enable charge transport. This strongly depends on the ink composition, which must promote the formation of continuous conductive pathways throughout the film.

As a baseline approach, the optimized ink was inkjet-printed onto interdigitated electrodes (Fig. 2 (b)), using three different thicknesses corresponding to 1, 5, and 15 printed layers.

The baseline resistance of each device was measured at 200 °C under a flow of 100 sccm of dry air. Gas sensing tests were then carried out using diluted gas mixtures in dry air. The applied concentrations were 1 ppm for NO_2 , H_2S , and CO ; 10 ppm for NH_3 ; 21 ppm for MeOH ; and 1000 ppm for H_2 . The corresponding sensor responses are presented in Fig. 3 and expressed using the following relationship:

$$\text{Relative response} = (I_{\text{gas}} - I_b) / I_b \quad (1)$$

Where I_b is the baseline current measured prior to gas exposure, and I_{gas} is the current recorded at the maximum response under the target gas atmosphere.

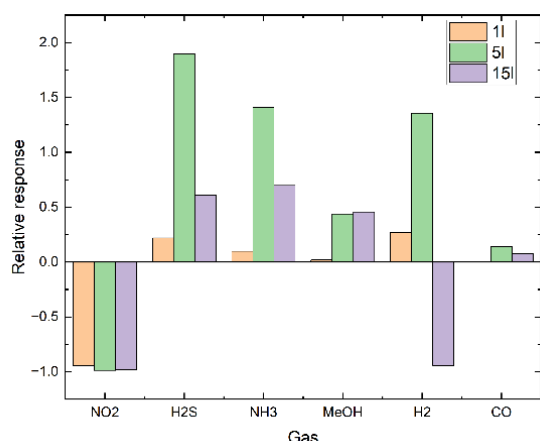


Fig. 3. Relative response of TiO_2 devices (1, 5 and 15 layers) to NO_2 , H_2S , NH_3 , MeOH , H_2 and CO

The film consisting of 5 layers exhibits a higher response than both the 1-layer and 15-layer

samples for H_2S , NH_3 , and MeOH . This behavior is consistent with a model in which a single layer does not provide sufficient percolation pathways for effective charge transport, while the thicker 15-layer film becomes more compact, causing the gas interaction to occur predominantly at the surface while the electrical current must still percolate through the bulk.

In contrast, all three thicknesses show an approximately 100% response to NO_2 , which can be attributed to its strong oxidizing nature and high reactivity.

For H_2 , the 1-layer film shows a weaker response compared to the 5-layer sample, similar to the behavior observed for the other gases. However, for the 15-layer film, the response changes sign and resembles that typically associated with oxidizing gases. This has already been reported for In_2O_3 [4].

None of the three film thicknesses shows a significant response to CO , as expected in the absence of catalytic dopants [4].

Acknowledgements

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