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NO_2 Gas Sensor with Inkjet-Printed Zinc Oxide and Boron-Doped Diamond Layer

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Summary:

In this paper, we present a gas sensor with a sensing layer composed of Zinc Oxide (ZnO) and Boron-Doped Diamond (BDD) nanoparticles, deposited via inkjet printing technology. The sensor operates at room temperature and uses UV illumination to enhance its sensitivity and stabilize its responses. We investigated the gas-sensing capabilities of the ZnO-BDD layer for detecting low concentrations (ppm level) of NO2 in synthetic air.

Keywords: boron doped diamond, zinc oxide, ink, inkjet printing, UV light, gas sensor.

Introduction

The detection of gaseous substances, especially toxic ones, is crucial across various sectors such as automotive, aviation, agriculture, security, healthcare, defense, industry, and environmental monitoring. This includes applications in food freshness and quality prediction [1].

Inkjet printing is an attractive method for fabricating micro and nano functional structures due to its low cost and good material compatibility. This technology allows for the deposition of layers with small thicknesses and larger surface areas, potentially enhancing the sensitivity of gas sensors. Inkjet printing accommodates a wide range of liquids, optimized for various substrates, including non-flat, rigid, or flexible ones. Furthermore, it enables short production times, low costs, and highly efficient material usage [2].

Metal oxide nanomaterials are widely used in advanced technologies due to their unique structure, morphology, and chemical, optical, and electrical properties [2]. These materials are particularly valued in the fabrication of gas sensors because of their high sensitivity, fast response and recovery times, low cost, and flexibility [3]. Additionally, UV light irradiation has been employed to enhance the sensing characteristics and sensitivity of these sensors [4]-[5].

Experimental

Solvothermal synthesis was used for preparation of ZnO nanoparticles. Zinc acetate dihydrate (0.66 g) was dissolved in methanol (30 mL), and the solution was transferred into a 50 mL Teflon insert of Berghof DAB-2 pressure vessel. The vessel was heated to 150 °C for 12 h, and then cooled to room temperature spontaneously. The particles were collected by exhaustive centrifugation and washed in three cycles of redispersion in ethanol followed by centrifugation. For preparation of the ZnO ink, a fine fraction of particles was isolated by two consecutive mass fractionation steps. These steps involved centrifugation in water and ethylene glycol-water mixture at 262 and 116 rcf (relative centrifugal force), respectively, after which the corresponding supernatants were separated. The final ink was prepared in the ethylene glycol – water mixture (1:1), and its concentration was adjusted to ~4 mg(ZnO)g^{-1}.

The BDD ink was prepared by mixing a commercially available aqueous suspension of B-doped nanodiamonds with the mean size of 50 nm with ethylene glycol in volumetric ratio of 1 : 1 under application of ultrasound agitation. The so-obtained suspension with the concentration of 2.5 mg/mL was directly used for the inkjet printing (see Figs.1 and 2).

Both inks exhibit stable printing properties, and no degradation was observed when stored at room temperature for several months. Printing was conducted using a drop-on-demand Fujifilm DMP-2831 inkjet printer equipped with a piezoelectric Dimatix Cartridge-Samba G3L printhead under the following conditions: a nozzle diameter of 17 µm, a native drop volume of 2.4 pl, a cartridge height of 750 µm, and an ink printing resolution of 2540 dpi. The print mode was set to 4 times 1 pass, involving two layers of ZnO ink and two layers of BDD ink (four layers in total), with each layer being printed onto a completely dry previous layer. The jetting frequency was 2 kHz, the drop velocity was 9.5 m/s, the cartridge temperature was 32 °C, and the substrate temperature was 40 °C.

Optimal printing conditions were achieved using Ohnesorge theory and piezoelectric waveform optimization. Optical images (Fig.4) show the patterning capability over an active area of 1.2 x 1.2 mm^2 on a Micrux ED-dIDE1-Au substrate with interdigital electrodes (30 pairs of Ti/Au interdigital electrodes, 10 µm electrode width and 10 µm gap). The thickness of the BDD-ZnO active layer was approximately 100 nm.

Gas sensing measurements were performed using an in-house developed setup [6]. The baseline resistance of the sensor is approximately 500 kΩ under UVLED at 365 nm with an intensity of 50 µW.cm^{-2}. The graphs indicate relatively stable responses (Fig.5).

Results

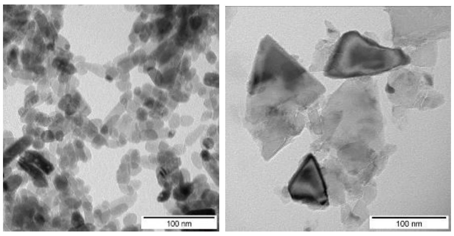

Fig. 1. Transmission electron micrograph of ZnO (left) and BDD (right) nanoparticles (Philips CM 120).

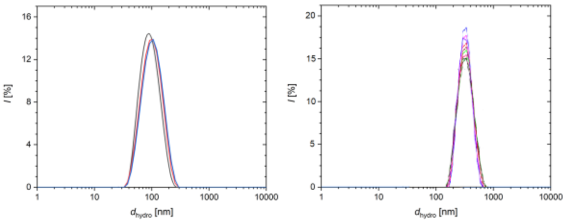

Fig. 2. Intensity distribution of hydrodynamic size of ZnO (left) and BDD (right) nanoparticles in ethylene glycol – water mixture (1:1) based on dynamic light scattering measurements at 25 °C (DLS, Malvern Zetasizer Nano ZS).

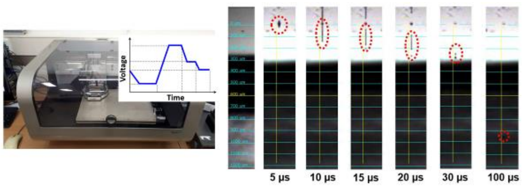

Fig. 3. Waveform for the printing process of both the ZnO and BDD inks, and view of firing droplets.

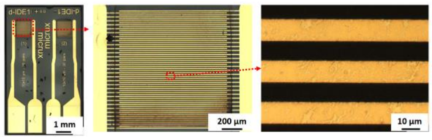

Fig. 4. Optical images of the realized sensor with inkjet printed ZnO-BDD active layer(Olympus BX-60).

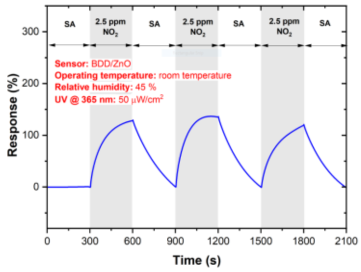

Fig. 5. Dynamic sensing response curves of the sensor with inkjet printed ZnO-BDD active layer for constant concentration of NO_2 at room temperature.

Conclusions

We demonstrated the fabrication and characterization of gas sensors featuring a printed nanoparticle ZnO-BDD active layer that operates at room temperature. Perspective inkjet printing technology was used for the selective deposition of Diamond-ZnO nanoparticles.

Acknowledgment

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