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Nanoporous Materials for Light and Heat Activated Gas Sensing

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Summary:
In this work, we investigate the influence of optical and thermal activation of metal oxides on the gas sensing performance. This has been achieved by combining micro-hotplate-based gas sensor devices with UV-LEDs emitting at different wavelengths. Nanoporous films of nickel oxide and tin oxide were printed by spark ablation and the gas sensing performance was investigated towards 5 ppm toluene.

Keywords: gas sensing, nanoporous structures, thermal and optical excitation

Introduction

Indoor air quality (IAQ) monitoring plays an important role in public health and well-being, Poor IAQ has been linked to a variety of health issues ranging from transient discomfort and headache, to respiratory diseases and cardiovascular problems. In particular in harsh environment, such as industrial settings or mines, AQ monitoring is key to maintain a safe working environment.

Conductometric gas sensors, which detect changes in the electrical conductance of gas-sensitive materials in response to the surrounding gas, are very good candidates for IAQ. Mostly, metal oxides (MOx) like SnO_2, ZnO, NiO or CuO are used because of their high sensitivity to a large variety of gases [1]. For effective air quality monitoring, selectivity—the ability to accurately detect a specific target gas within a complex mixture—is a critical challenge.

A very promising approach to achieve a high degree of selectivity is using optical (light) and thermal activation (heat) of the gas sensitive materials. Since photons can also supply the energy needed to exploit the surface ionization scheme [2], which opens an entirely new parameter space for chemical sensing. Moreover, this approach promises a lower power consumption [3] of the sensor device compared to the just heated one.

Sensor and Materials

In this work, SiN-based micro-hotplate chips with integrated heating structure (up to 500°C) and Pt electrodes was used. The materials were printed on the micro-hotplates using a spark ablation generator VSP-G1 (VSParticle B.V.). For the deposition of NiOx and SnOx, two pairs of 6 mm Ni and Sn rods (99.99 % purity) were used. Argon was used as a carrier gas with a 1 l/min flow, and in both cases the sparkling potential and current were set at 1 kV and 10 mA, respectively. The generator was connected to an impaction printer VSP-P1 (VSParticle B.V.) that operated at 0.15 mbar and room temperature. The nozzle diameter was 100 µm. The substrate was placed in a holder that can be moved in the XYZ directions allowing prints without the requirement of lithography technology. A 500 µm long line was printed between the electrodes. The substrate-nozzle distance was fixed at 300 µm. The printing speed (100-1000 µm/s) and the number of passes (2-18) were varied to adjust the nanoparticle layer (NPL) thickness. To stabilize and oxidize the NPL, the chips were annealed at 400°C in flowing synthetic air for 10 minutes. The micro-hotplates were mounted on a Kyocera socket and wire bonded.

Measurement setup

All sensors have been measured simultaneously in an automated gas measurement setup. As background gas synthetic air with tunable humidity level was chosen. In this work the humidity was set at 50%. The operation of the temperature is kept constant during a measurement (25°C, 150°C and 300°C). The target gases are subsequently introduced into the setup for 5 min with flow meters. Presently commercial LEDs are employed, which are mounted on a PCB in two groups of 4 LEDs opposite of 2 sensor sockets. The LED chips emitting at 4 different emission wavelengths (415, 385, 365, and 270 nm) which are employed to screen the impact of optical excitation on the sensor response.

The relative resistance changes due to the interaction with the test gas, i.e. the sensor response S, has been calculated according to:

$$S = \frac{R_{air} - R_{gas}}{R_{air}} \quad (1)$$

where R_{gas} is the sensor resistance in the presence of the test gas and R_{air} is the sensor resistance in pure synthetic air.

Results

We investigated the gas properties of Ni- oxide (Figure 1) and Sn- oxide (Figure 2) nanoporous films towards 5 ppm toluene for different operation temperatures (25°C, 150°C and 300°C). As shown in Figures 1 and 2, without illumination, the response of the metal oxides towards toluene is increasing with increasing operation temperature. Afterwards we have investigated the influence of optical excitation - illuminating the samples with LEDs with different wavelengths – on the responses. In case of the Ni oxides the illumination shows very low to none effect on the responses (Figure 1).

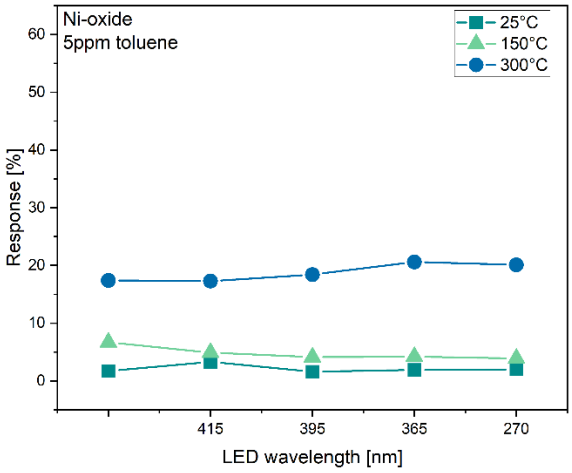

Fig. 1. Response Ni- oxides sensor towards 5 ppm toluene at 25°C/ 150°C/300°C operation temperature without and with 415nm/ 395nm/ 365nm/ 270 nm LED exposure.

However, this is not the case for the Sn- oxides. For lower operation temperatures the optical excitation increases the response except for the LED with a wavelength of 270nm (Figure 2). At an operation temperature of 300°C the optical excitation reduces the responses. This effect can mean that the optical and thermal excitation start to interfere with each other at a certain temperature. A maximum response was reached for the LED with a wavelength of 395nm at room temperature.

In the present work, it is evidenced that combining optical/thermal excitation on nanoporous layers, is a suitable approach to increase sensor selectivity.

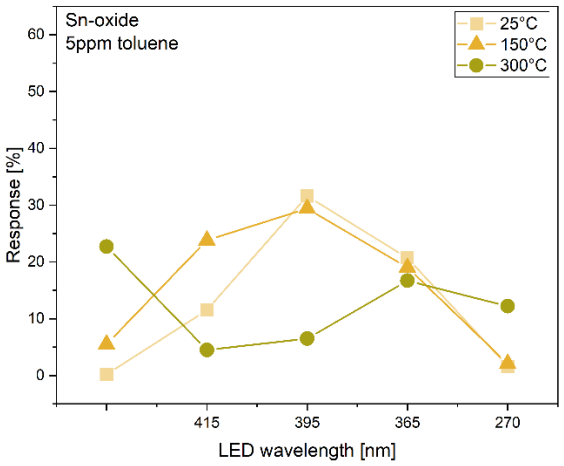

Fig. 2. Response Sn- oxides sensor towards 5 ppm toluene at 25°C/ 150°C/300°C operation temperature without and with 415nm/ 395nm/ 365nm/ 270 nm LED exposure.

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