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Simultaneous Thermal and Optical (De-)Activation of Microhotplate-Based CMOS-Integrated SnO_2 + Ag NPs Gas Sensors

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Summary:
In this paper, we report on the light activation of SnO_2-based gas sensing films decorated with Ag nanoparticles (NPs). The sensing layers were deposited by spray pyrolysis, and the metallic NPs were sputter-deposited on CMOS-integrated microhotplate-based gas sensor devices. The response towards the target gas CO can be tuned by different LED wavelengths. From the results achieved, we conclude that the combined thermal-optical excitation of the gas sensing materials can make a significant contribution to optimizing chemo-resistive MOx-based gas sensor devices.

Keywords: metal oxide, optical activation, gas sensing, metallic nanoparticles, CMOS technology

Background

Air quality control has become a critical global issue due to pollution from fine particulate matter and hazardous gases [1]. Conductometric chemical sensors based on metal oxides offer a practical approach for detecting these harmful species, as their operation relies on changes in electrical resistance in the presence of specific target gases. [2] This principle provides a significant advantage in terms of measurement simplicity. While metal oxide gas sensors demonstrate high sensitivity to various gases, they are often affected by cross-sensitivity. To address this limitation, LED light has been successfully employed to activate or deactivate the response of thin film metal oxide-based gas sensors. In this study, we report the performance of SnO_2 thin films integrated on CMOS-based micro-hotplate (µhp) devices, functionalized with silver nanoparticles, and activated under light illumination at 395 nm and 270 nm.

Description of the System

The CMOS-integrated µhp chips have been fabricated by ams AG. This is a unique device where a single chip contains 8 µhps. Each µhp contains 2 single sensing layers suitable for 4-point measurement. The SnO_2 sensing layer was deposited by spray pyrolysis with a thickness of 50 nm and functionalized with Ag nanoparticles by magnetron sputtering. The chip was then glued and contacted on a specific PCB (sensing-PCB) and mounted in the gas measurement chamber face-to-face to a PCB with LEDs (LED-PCB).

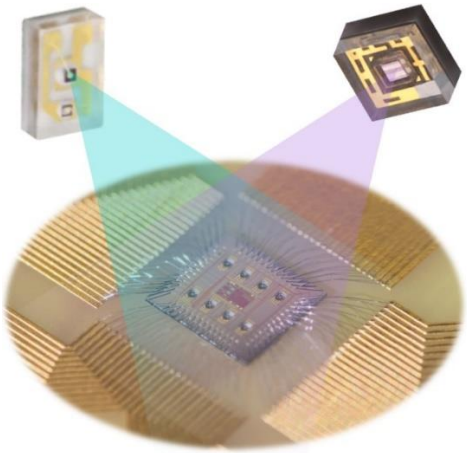

Fig. 1. Scheme of LED radiation on the CMOS-based gas sensing device.

Gas measurements were performed by an automatized setup with synthetic air (80% N_2, 20% O_2) as a background gas and a constant flow rate of 1000 sccm. The humidity level of 50% was kept constant for all measurements and the gas concentration of carbon monoxide was 50 ppm. The temperatures of the µhp were in the range of 100-200°C. The response was calculated as follows:

$$Response = \frac{R_{air}-R_{gas}}{R_{air}} * 100\% \quad (1)$$

where R_{air} is the resistance of the sensor in synthetic air (50% rH) before each gas pulse and R_{gas} is the resistance of the sensor in the presence of the test gas.

Results

Responses of the SnO_2 sensor functionalized with Ag NPs towards a concentration of 50 ppm carbon monoxide are shown in Fig. 2. Without illumination the sensor shows 10% response at 100°C, which increases to 53% at 200°C. With 270 nm illumination, the response can be deactivated/decreased to 2% at 100°C, and 30% at 200°C. With 395 nm radiation, the response can be activated/increased up to 37% at 100°C, and up to 71% at 200°C. This means that the optical and thermal excitation can both be used to optimize the sensing system and work as a switch (ON/OFF) of the sensor response.

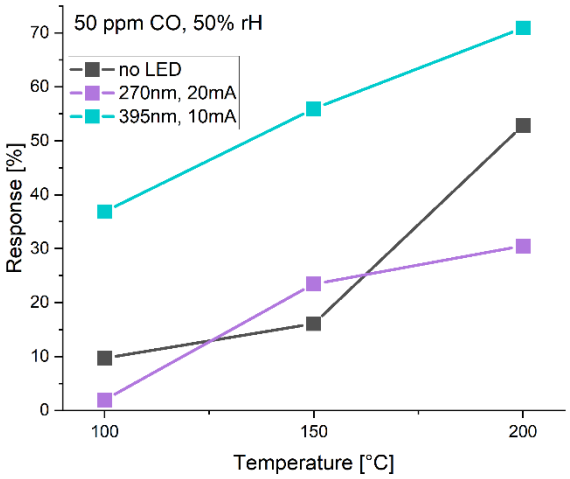

Fig. 2. Response of the SnO_2-sensor functionalized with Ag NPs towards 50 ppm of CO in 50% rH, at 100-150-200°C.

The sensor behaviour can be attributed to two primary phenomena. The first is the photoconductivity of the sensing layer under optical illumination [3], which is evidenced by a decrease in the resistance of the metal oxide layer. This effect results in an increased availability of surface electrons, thereby enhancing the number of active sites for gas detection [4] (see Fig. 2 – 395 nm). The second phenomenon involves the increased desorption rate of gas molecules under higher energy radiation (270 nm, UV range), which leads to a reduced interaction between the gas and the sensing layer, and consequently, a lower sensor response. [5]

These results clearly demonstrate the potential of combining thermal and optical excitation to tune the response behaviour of metal oxide sensors. The ability to activate and deactivate the sensor response through light illumination offers a promising strategy for enhancing selectivity toward specific target gases.

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