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Novel chemical sensor device enabled by simultaneous thermal-optical excitation

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Summary:

We present a novel chemical sensor device based on ultrathin metal oxide films functionalized with metallic nanoparticles, which combines both thermal as well as optical excitation into a single system. This is achieved by a modular setup employing SiN-based micro-hotplate (µhp) chips, and LEDs, which are mounted opposite of the µhp chips. First results show that the sensor response is dramatically improved in case of optical excitation: Activation of SnO_2 sensors functionalized with Cu-nanoparticles by LEDs emitting at 270 nm results in a sensor response of 32% at room temperature towards 20 ppm HC_{mix} in synthetic air (50% rh). By combining this dual excitation mode, we open an entirely new parameter space for chemical sensors, which has not been explored yet.

Keywords: metal oxide, nanomaterials, nanoparticles, gas sensors, sensor array

Introduction

Chemical sensing of gaseous molecules has become a vital necessity for a huge variety of applications. Since people in Europe or US spend 90% of their time indoors, air quality (AQ) monitoring is of tremendous importance for private homes and offices, for vehicles and transportation. Air pollution is considered a "silent killer" causing an estimated 7 million premature deaths every year [1].

Despite extensive efforts, conductometric gas sensors enabling identification and quantification of a variety of different gases remain elusive due to major cross-sensitivity issues.

Using optical (light) instead of thermal activation (heat) of the gas sensitive materials is a very useful strategy to lower power consumption [2] of the sensor device. Moreover, photons can also supply the energy needed to exploit the surface ionization scheme [3], which opens an entirely new parameter space for chemical sensing.

Sensor Components

We are developing a novel sensor device, which combines thermal and optical activation of the gas sensitive nanomaterials into a single sensor system:

- SiN-based micro-hotplate (µhp) chips incorporating a heating structure (up to 500°C) and electrodes, are used as carriers for the sensing films. First, a negative lift-off resist mask is structured by photolithography. Then the chips are coated with 50 nm SnO_2 or CuO, using reactive magnetron sputtering. This is followed by a lift-off process to structure the sensing films into a circular shape (diameter 450 µm) and an annealing process at 400°C in dry synthetic air. Finally, the sensors are functionalized with Ag and Cu nanoparticles (NP) via magnetron sputter inert gas condensation. 4 sensors are mounted on a single Kyocera socket, 2 sockets with a total of 8 sensors are characterized simultaneously in the gas measurement setup.

- LED chips emitting at 8 different emission wavelengths (631, 589, 525, 467, 415, 385, 365, and 270 nm) are employed to screen the impact of optical excitation on the sensor response. Presently commercial LEDs are employed, which are mounted on a PCB in two groups of 4 LEDs opposite of 2 sensor sockets.

Sensor System

In a first (Gen1) approach, we employ a modular scheme, where the LED-PCBs are mounted opposite of the µhp chips (Fig.1). A group of 4 LEDs optically excites 4 sensor dies. This setup enables to systematically screen the influence of LED wavelength and LED intensity on the sensor response in an automated gas measurement setup. Synthetic air, with controlled relative humidity (rh), serves as the background gas. A variety of target gases can be introduced into the setup with well-defined concentrations.

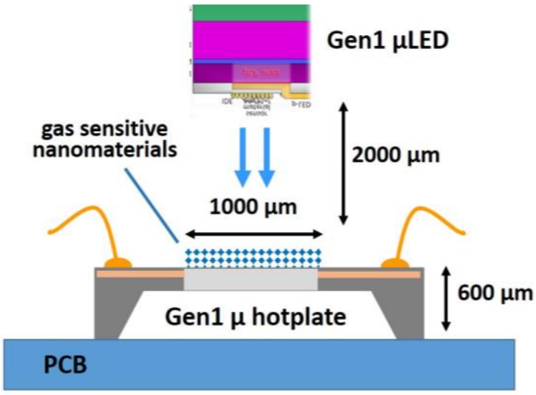

Fig.1 Modular setup of sensor system combining thermal and optical excitation schemes. This is achieved by using a SiN-based µhp chips, and LEDs, which are mounted above the µhp chips.

Results and Conclusion

All sensors are characterized simultaneously in the gas measurement setup. After 10 min in synthetic air, the target gas is introduced for 5 min followed by 10 min in synthetic air.

Fig.2 shows the resistance behaviour and the response of a SnO_2 sensor functionalized with Cu-NPs towards a concentration of 20 ppm of a hydrogen carbon gas mixture (acetylene, ethan, ethen, propen = HC_{mix}) in synthetic air (50% rh). Without LED illumination, at room temperature (RT) the sensor has no response at all, but shows a response of 17% at 150°C operation temperature (left). In case of LED illumination (wavelength 270 nm), the sensor exhibits a response of 32% already at RT (middle), which increases up to 58% at 150°C operation temperature (right). This clearly demonstrates the impact of LED illumination on the sensor response. This effect might be attributed to the surface ionization effect, where the gas molecules are ionized by the photons, and the electrons are transferred into the SnO_2 film.

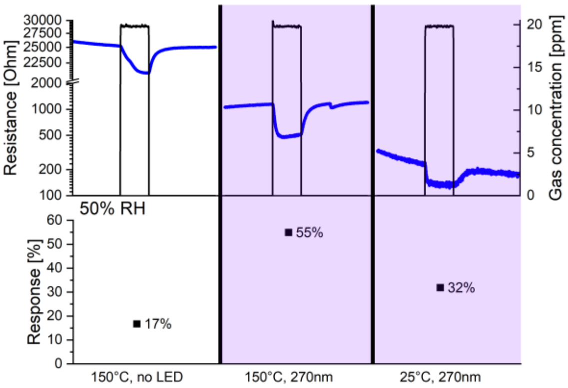

Fig.2 Response of SnO_2 sensor functionalized with Cu-NPs towards 20 ppm HC_{mix} in synthetic air (50% rh). With the LED switched off (left), the sensor shows a response of 17% at 150°C operation temperature. With a 270 nm LED switched on (middle), the sensor exhibits a response of 32% at RT (middle), which increases up to 58% at 150°C (right).

By combining this dual excitation mode – heat and light – into a modular sensor setup, we open an entirely new parameter space for chemical sensors. First results show that the sensor response is dramatically improved in case of optical excitation with LEDs. We will systematically explore this new parameter space to find the ideal combination of wavelength, light intensity, and operation temperature for selective detection of the target gases.

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