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Multispectral Readout System for Detecting Tiny Color Changes of Gas Sensitive Colorimetric Dyes

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Summary:
We present a simple sensor setup for detecting very small color changes of gasochromic materials. The sensor includes up to ten LEDs for capturing different spectral channels, ranging from ultraviolet to the near infrared. In order to detect diminutive color changes of dyes at gas concentrations in the sub ppm range, the system includes a differential photodiode circuit, as well as two additional photodiodes to determine the absolute reflectance of the dyes.

Keywords: optical readout, color, gas sensor, colorimetric, carbon monoxide

Motivation

Current smoke detectors for residential use are predominantly based on the stray light principle. Detecting the light scattered by smoke particles, they feature two main disadvantages: The detection method can hardly differentiate between particles emitted from fires and harmless dust or fog particles. In addition, the detectors can only identify fires, which emit larger amounts of smoke particles. Especially for smoldering fires, this is not always the case.

In order to overcome these disadvantages, the combination with sensors for the detection of gases, emitted by fires, is advantageous [1]. The emission of carbon monoxide (CO) is a very specific indicator for burning processes and therefore, the detection of CO is ideally suited for this application. Measuring CO at an early fire stage requires a highly sensitive and selective detection method. The colorimetric gas sensing principle (also known as gasochromic principle) meets these requirements. It relies on a color changing chemical reaction of the target gas with a specifically tailored dye. In this work, we present a setup that is able to read out even very tiny color changes of gasochromic dyes in the presence carbon monoxide for fire detection purposes.

Readout System for Gas Dependent Color Change

In the presented measurement system, the color detection is accomplished by illuminating the dye with ten LEDs of different wavelengths and measuring the reflected light intensities in their respective spectral ranges.

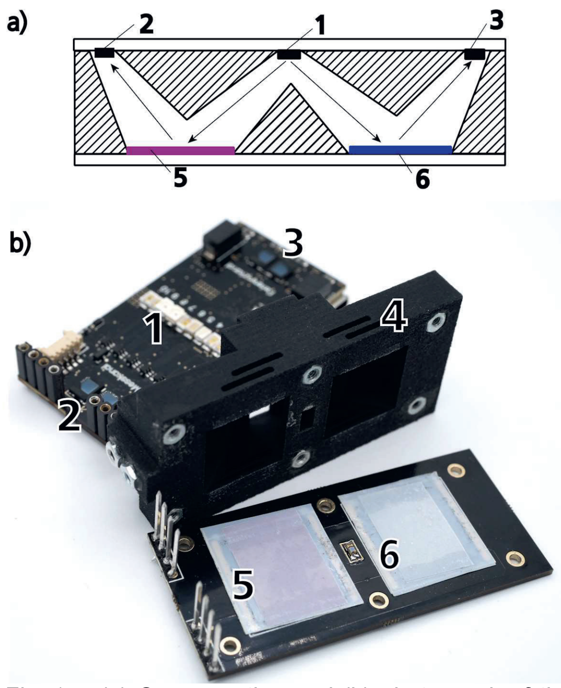

Fig. 1. (a) Cross section and (b) photograph of the sensor system with LEDs (1), measurement detectors (2), reference detectors (3), enclosure (4), gas sensitive dye (5) and reference dye (6).

For a concertation variation in the sub ppm range, the reflection change can be as small as 10^{-3} %. The reflection or scattering of light that does not interact with the dye reduces the apparent color change in addition. In order to resolve the small color change, we use a differential detection principle consisting of two antiparallel photodiodes with a symmetrical arrange-

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ment (see Fig. 1). One of the photodiodes receives the reflected light from the gasochromic dye, while the other one receives it from a reference dye that does not react to the target gas. The antiparallel interconnection of the photodiodes enables a differential measurement where only the refection difference, which primarily depends on the gasochromic dye, remains. For an absolute reflection measurement, there are two single channel photodiodes placed beside the differential detectors.

As shown in Fig. 1, the system comprises a 3D printed enclosure with a W-shaped beam path. This ensures a defined symmetrical light distribution, while absorbing stray light that does not interact with the colorimetric dye.

The ten LEDs with wavelengths ranging from 395 to 940 nm are driven successively. The photo current of the single channel diodes is amplified with $2.7 \cdot 10^6$ V/A, while the photodiode signal of the differential channel is amplified with $2.7 \cdot 10^8$ V/A. An average LED current of 400 µA is modulated sinusoidal at 20 kHz, while the detector signals are captured and filtered by a digital lock-in algorithm having 1 s averaging time and running on an onboard PSoC6 microcontroller. Fig. 2 shows the upper part of the system with activated LEDs.

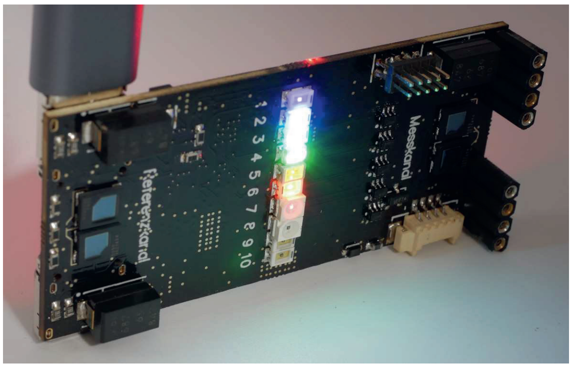

Fig. 2. Picture of the system's upper part, containing LEDs, photodiodes, analog and digital electronics, and an USB interface. The reference photodiodes are on the left while the measurement photodiodes are placed on the right. Deviant from the normal operation, all LEDs are activated simultaneously.

Measurement Setup for CO

In order to detect CO with the developed sensor system, it is equipped with a gasochromic dye based on a binuclear rhodium complex, which was synthesized as described in [1]. The complex reacts with CO, showing a color change from purple to yellow. It is adsorbed on nanostructured silica particles, which were glued to PET foil and applied to the sensor system using double-sided tape. As reference dye, uncoated silica particles were used (shown also in Fig. 1). The measurements with the developed setup were performed at the Fraunhofer IPM gas laboratory. The sensor system was placed in a gastight box with a volume of 500 cm³. A flow of synthetic air through the box with 50% r.h. at 2 l/min was established. By adding CO to the gas mixture, concentrations of 1, 10 and 100 ppm CO were realized.

Gas Measurement Results with the Rhodium Complex Based Dye

The experimental results of the sensor system (three spectral channels with the highest color change) are shown in Fig. 1. A signal drift, originating from the step of ambient CO and humidity to synthetic air, can be observed. The three spectral channels at 430, 490 and 630 nm resolve all CO steps. The blue channel (430 nm) shows a reaction of 0.4 a.u. to 1 ppm CO during the first 30 s. With the single channel data, this reaction can be estimated to correspond to an absolute reflection change of $3 \cdot 10^{-4}$. The blue channel shows a 6σ noise of 0.03 a.u. Therefore, less than 100 ppb of CO might be resolvable with the system.

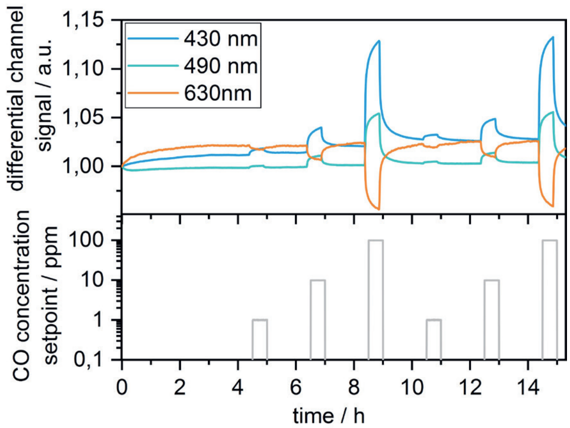

Fig. 3. Normalized signal of the differential detector for the spectral channels with the highest color change together with the CO concentration set point plotted over the measurement time.

Conclusion

Within the scope of this work, we developed a multispectral readout circuit, which enables the detection of diminutive color changes of gasochromic dyes. Our measurement results, with a rhodium complex based dye, show the possibility to detect 1 ppm CO with an SNR >10.

References

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