Semiconductor Ethanol Sensor Inducted with Visible Light

Yu. Dekhtyar, M. Komars, and M. Sneiders

Abstract

Modern semiconductor sensors are based on an MOS (metal–oxide–semiconductor) structure and their further development is tending to combine them together with UV irradiation. In this paper, a system is presented that can pave the way towards gas analyzers that rely on visible spectrum light. The article presents a semiconductor gas sensor induced with safe optical irradiation delivered from the LED matrix to the semiconductor surface. Different irradiation wavelengths (440, 530, 600, 710 nm) under constant flux were used separately to find the condition for the best sensor response on gas sorption. An output signal was recorded in zero-level emission and in the presence of ethanol. Changes in sensor response and signal rise/relaxation time constant in the presence of saturated ethanol vapor were observed. Sensor response to the ethanol vapor was detected for each used irradiation wavelength and it is approximated by the non-linear falling regression curve with the highest sensor response at 440 nm (R = 104%). In addition, the different rise and relaxation time constant of the signal trace was detected depending on the irradiation wavelength. The time constant ratio is approximated by the non-linear rising regression curve with a maximum value at 710 nm for both signal rise (τ = 0.61) and relaxation (τ = 2.08) parts.

Keywords

LED stimulation • Time constant • Ethanol sensing
Room temperature

1 Introduction

Nowadays, there is increasing concern about the environmental pollution which increases each year, thereby causing irreparable damage and influencing every inhabitant on Earth. Air pollution from industrial gases, from fuel combustion products and other sources, inevitably increases the incidence of diseases, including: lung cancer, asthma, heart attacks and allergies [1, 2].

Modern methods are directed to prevent and even foresee the problem. Studies show that the determination of biomarkers in exhaled air can become a powerful tool for medical diagnostics. Currently, there are certain biomarkers in exhaled air that are accompanied by diseases such as obesity, lung cancer, kidney failure, heart attacks and diabetes mellitus [3, 4].

Along with this, the ethanol concentration in exhaled air may correspond as an indicator of the glucose level in blood [5]. Moreover, the potential endogenous source of ethanol is intestinal bacterial flora [6]. This is a challenging area, as the ethanol concentration in exhaled air is normally much lower than the concentration level in human breath after alcohol ingestion [7].

In the past decade, semiconductor gas sensors have been rapidly developed. The sensors are cheap, easy to use, able to detect a variety of different gases and are stable. Because of this, the sensor gained widespread use. Gas sensor technologies are providing significant progress in the detection of hazardous substances and exhaled biomarkers [8].

Among the actual technologies widely distributed, MOS sensors have several significant drawbacks. They are not appropriate for the detection of inflammable gases with a low autoignition temperature as the sensing area must be heated up to 500 °C. Hence, heating to a higher temperature demands higher power consumption [9, 10]. More often the sensors are combined with UV irradiation. As a result, gases adhere to the MOS surface and the current via the MOS

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L. Lhotska et al. (eds.), *World Congress on Medical Physics and Biomedical Engineering 2018*,
IFMBE Proceedings 68/3, https://doi.org/10.1007/978-981-10-9023-3_1

transistor is influenced [11–13]. However, UV light is potentially harmful for humans and the environment.

As an alternative, optically induced semiconductor gas sensors were designed to provide both high sensitivity without heating the sensing area and a possibility to differentiate the presence of different gases by measuring the output signal and processing time constant at different supply voltages [14]. Furthermore, the electrophysical properties of an optically induced semiconductor gas sensor depending on the irradiation type and measurement of low acetone concentration under UV stimulation at room temperature were shown previously [15]. Despite the progress already made, several knowledge gaps in the working principle still exist.

2 Materials and Methods

The aim for the current research was to conduct sensor response measurements and time constant ratio calculations using optical stimulation under different irradiation wavelengths of visible spectrum light.

For those purposes, a test setup (Fig. 1) was built. The LED matrixes (wavelengths equal to 440, 530, 600, 710 nm) were used to provide homogeneous optical irradiation on the semiconductor sensor surface. By using an LED power supply, the equal photon flux was adjusted for each irradiation wavelength. Arduino controller was assembled to carry out measurements, process signal trace and export data for further processing to a PC.

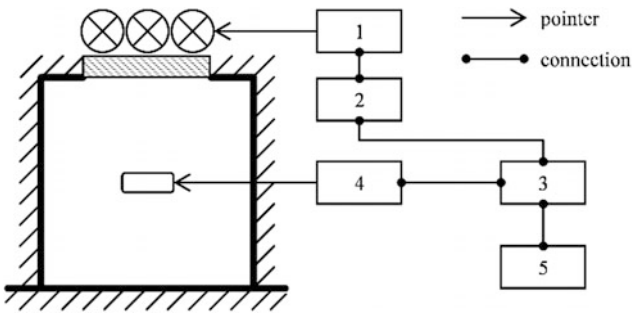

Fig. 1 Experimental test setup for measurements: (1) LED matrix; (2) LED power supply; (3) Arduino controller, used to power the sensor, measure the output signal and adjust LED output power; (4) semiconductor sensor inside gas chamber; (5) PC, used to process the signal and to adjust the Arduino controller. The LED matrix was used as an optical irradiation source to provide homogeneous irradiation (photon flux is 10^{20} $cm^{-2}s^{-1}$) on the sensor surface

2.1 Sensor Response Measurement

During each measurement in zero-level emission and in the presence of saturated ethanol vapor, an output signal was recorded. Finally, the sensor response on ethanol was calculated:

$$R = S(ethanol)/S(ambient) - 1 \quad (1)$$

where S(ethanol)—is the signal peak value in an ethanol environment; S(ambient)—is the zero-level emission signal peak value.

2.2 Signal Rise and Relaxation Time

Trace of the sensor response was recorded and then processed to the time constant through the Arduino microcontroller (Fig. 2).

Signal rise and relaxation time can be characterized using the following definition:

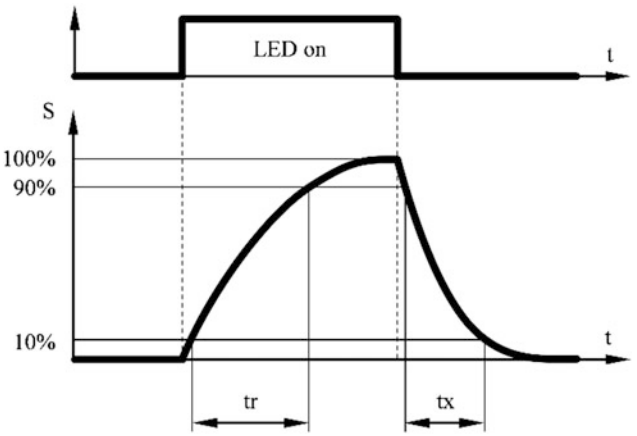

Fig. 2 Graphical interpretation of the signal rise time (tr) and relaxation time (tx) constants

- Rise time (tr)—the interval of time it takes an output signal to increase from 10 to 90% of its peak value;
- Relaxation time (tx)—the time interval required for an output signal to decrease from 90 to 10% of its peak value.

Time constant ratio defined as the ratio between the time constant of the signal in the presence of ethanol and the time constant of the signal in zero-level emission was calculated:

$$\tau = \tau(ethanol)/\tau(ambient) \quad (2)$$

where τ(ethanol)—is the time consonant measured in an ethanol environment; τ(ambient)—is the time constant measured in a zero-level emission.

3 Results and Discussion

3.1 Sensor Response Measurement

The obtained result indicates the non-linear dependence of the semiconductor gas sensor response to the optical irradiation wavelength and can be approximated by a falling regression curve. The maximal signal response was detected at 440 nm and equals R = 104% and the minimum sensor response at 710 nm, R = 39% (Fig. 3).

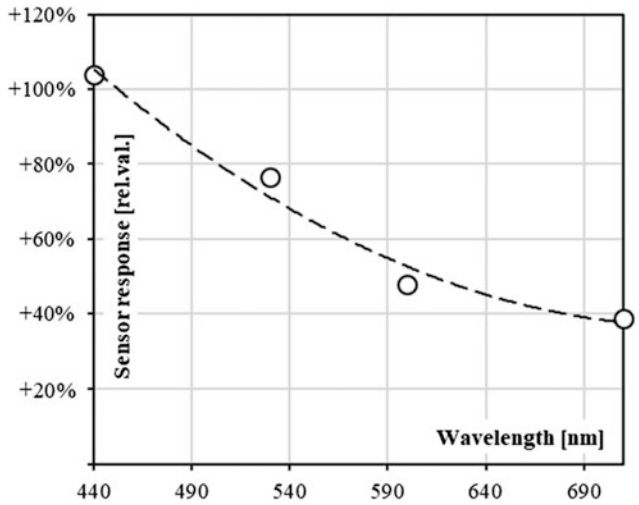

Fig. 3 Semiconductor gas sensor response to the ethanol vapor induced with different irradiation wavelengths

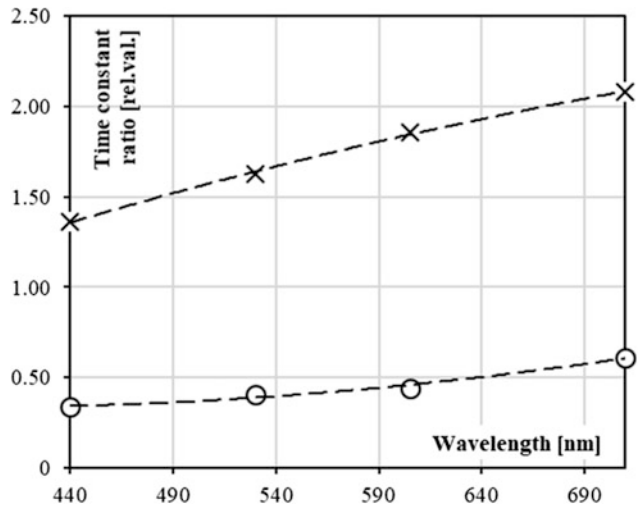

Fig. 4 Processed time constant ratio induced with different irradiation wavelengths: rise time (o) and relaxation time (x)

3.2 Signal Rise and Relaxation Time

Figure 4 shows the processed signal rise and relaxation time from the signal shapes recorded at a different irradiation wavelength.

Obtained results indicate non-linear dependence of processed time constant ratio to optical irradiation wavelength for both rise and relaxation time. Both results can be approximated by a rising regression curve. For both time constant ratios, the minimal value was detected at 440 nm and maximal value at 710 nm.

4 Conclusions

Visible spectrum LED light may be used for an optically induced semiconductor gas sensor to carry out the sensor response measurement of ethanol vapor. Highest sensor response was detected at the lowest tested irradiation wavelength of 440 nm.

Processed values of signal rise and relaxation time ratio may be used to sense the presence of ethanol vapor in air.

A correlation between the sensor response and time constant ratio was not observed and, therefore, both methods can be used jointly to increase the detection quality.

Although results demonstrate potential application of visible light usage to detect presence of ethanol, current results are achieved for saturated ethanol vapor and, therefore, concentration comparison to modern progress cannot be done.

Conflict of Interest The authors declare that they have no conflict of interest.

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