APPLICATION OF SEMICONDUCTOR SENSORS TO GAS ANALYSIS

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A device was set up based on semiconductor sensors, which made it possible to study the conditions of the sensor response to a change of the concentration of combustible gases and vapours in the atmosphere monitored. The conditions were established under which the method can be applied in atmosphere analysis to the determination of the concentration of a combustible gas or vapour.

The common property of semiconductors that in contact with combustible gases or vapours they change rapidly their resistivity can be utilized for the construction of a sensor[1-4], which makes it possible to set up analyzers for continuous monitoring of the concentration level of a combustible gas or vapour in a given atmosphere[5-7]. For the construction of such a device we employed both a commercial sensor and a sensor of own construction. We studied the conditions on which the sensor response to a concentration of the combustible gas depends. We established the influence of the basic connexions of the sensor on the sensitivity of its response and the possible range of their analytical application.

EXPERIMENTAL

A semiconductor sensor Figaro TGS 202 (Japan) was used. It consists of a semiconductor, dimensions approximately 2 × 3 mm, in which are built iridium-palladium alloy electrodes, diameter 90 μm, resistance approximately 2 Ω each. The electrode ends are soldered to nickel plugs 1 mm, which enable the connection of the detector to a suitable base. The detector is covered with a stainless steel double gauze, capable of cooling down the flame inside the detector even with the explosive mixture hydrogen–oxygen 2 : 1. As a rule, sensors were employed which had been kept alive for at least two months.

The basic connexion of the detector for the measurement with a constant voltage supply is drawn in Fig. 1. The measurements were performed in a chamber 335 × 430 × 350 mm made of organic glass, fitted with a septum for the sample injection and with a fan for the homogenization of the medium. Calculated volumes of the pure gases were injected. The liquid samples were injected by means of a microsyringe through the septum onto a strip of filter paper heated with a 40 W lamp or onto a boat coiled with a resistance wire connected to an autotransformer for the control of the heater voltage. The concentration of the gases in the chamber was considered as standard and was not checked by another method.

RESULTS AND DISCUSSION

The response of the semiconductor sensor TGS 202 to the presence of a combustible gas or vapour appears instantly, and so does it drop after the removal of the detector from the medium of the gas. The sensitivity of the sensor is governed by several factors, the most significant of which is the working temperature of the detector. This is controlled by the heater voltage applied to the heating electrode of the detector. The temperature distribution over the detector surface is not uniform (Fig. 2*), yet it is well reproducible within the limits shown in Fig. 3.

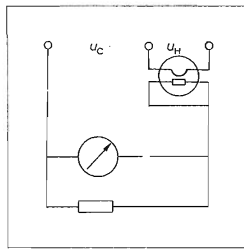

FIG. 1

Basic Connexion of the Sensor for the Direct-Current Feeding of the Sensor from a Constant Voltage Supply

U_c Measuring voltage applied to the detector, U_H heating voltage of the heating coil of the detector.

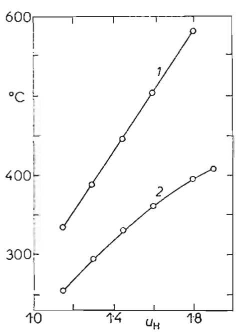

FIG. 3

Dependence of the Temperature of the Heated *1* and Unheated *2* Ends of the Sensor on the Heater Voltage

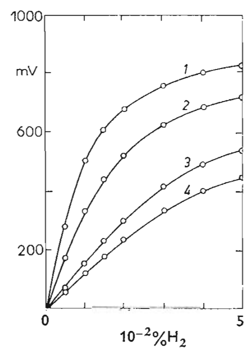

FIG. 4

Dependence of the Semiconductor Sensor Response to Hydrogen on the Sensor Heater Voltage

Heater voltage: *1* 1·30 V, *2* 1·50 V, *3* 1·73 V, *4* 1·90 V.

* See insert facing page 2602.

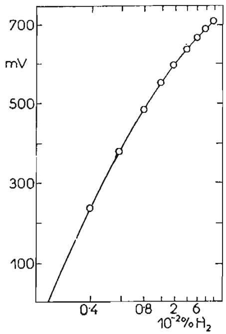

FIG. 5

A Typical Calibration Curve for the Determination of a Combustible Gas by the Semiconductor Sensor

$2 \cdot 10^{-3}$ to $8 \cdot 10^{-2}\%$ H_2, U_H 1·3 V, 0·5 mA, semilogarithmic scale.

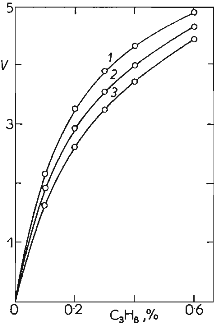

FIG. 6

Calibration Curves for Propane at Various Temperatures

Constant voltage supply 1·3 V; propane temperature *1* +40°C, *2* +25°C, *3* —25°C.

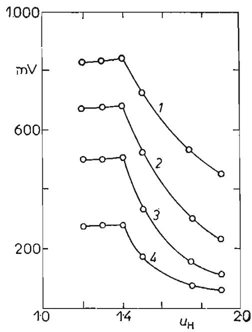

FIG. 7

Dependence of the Sensor Response on the Heater Voltage U_H for the Determination of Hydrogen

Hydrogen concentration (U): *1* $2 \cdot 10^{-2}$, *2* $1 \cdot 10^{-2}$, *3* $4 \cdot 10^{-3}$, *4* $2 \cdot 10^{-3}$.

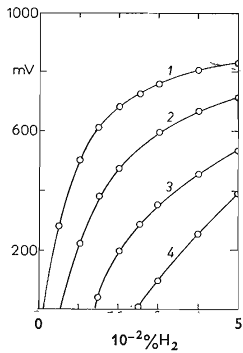

FIG. 8

Dependence of the Sensor Response on the Hydrogen Concentration

Heater voltage 1·3 V, current (mA): *1* 0·3, *2* 0·5, *3* 0·8, *4* 1·2.

The rise of the semiconductor sensor response with the increasing concentration of the combustible gas or vapour is not linear: it follows a characteristic curve (Fig. 4), which is not straight even in the semilogarithmic scale (Fig. 5); still in this representation the precision of the reading from the curve in different concentration regions can be seen better.

The response of the sensor varies partly with the temperature of the medium measured. Fig. 6 presents the curves of the dependence of the response on the concentration of propane in a relatively wide temperature region. The reproducibility of the determination was obtained from 10 measurements of each value. The ranges and standard deviations of the determinations, calculated from a series of values of propane determination in contents 0·1, 0·3, and 0·5% propane and at temperatures +40, +25, and −25°C are given in Table I.

TABLE I

Range (*R*) and Standard Deviation (*s*) for the Determination of Propane at Various Temperatures

% C_3H_8	+40°C		+25°C		—25°C	
	R	$10^3 s^a$	*R*	$10^3 s$	*R*	$10^3 s$
0·1	0·025	7·53	0·020	6·85	0·020	6·85
0·3	0·040	11·5	0·040	13·9	0·030	11·5
0·5	0·060	18·9	0·050	16·5	0·50	15·8

[a] Calculated from 10 measurements.

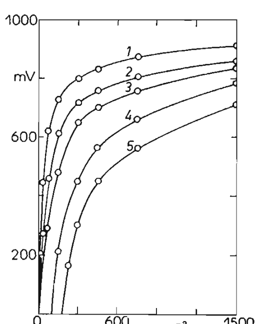

FIG. 9

Dependence of the Sensor Response on the Concentration of Acetone Vapours

Heater voltage 1·2 V, current (mA): *1* 0·5, *2* 0·8, *3* 1·2, *4* 1·6, *5* 2·0.

Considerably more markedly is the response of the sensor dependent on the temperature of the sensor itself; the measure of the temperature is the better accessible value of the heater voltage at the sensor (Figs 4, 7).

The sensitivity of the sensor for the determination of combustible gases can be also varied by using different current values in the detection circuit. Fig. 8 shows the dependences of the sensor response on the concentration of hydrogen for different currents. As an example of determination of combustible vapours by means of the semiconductor sensor, the dependences of the response on the concentration of acetone vapours for different currents are plotted in Fig. 9.

The results indicate that semiconductor sensors can be used in appropriate connexions for the determination of concentrations of combustible gases and vapours in the atmosphere. Although the calibration curve is not linear, it is in the conditions applied well reproducible and allows a precise reading of the amount determined. Using the basic connection of the sensor feeding with standard current, it is possible to achieve a variation of the sensitivity of the detector by changing the current value, whereby the concentration can be more precisely read off in the less steep parts of the calibration curve using a lower current. The sensitivity of the detector can be also varied, as has been shown, by changing the heater voltage of the detector, hence by changing its own temperature. The sensitivity of the detector usually drops with its increasing temperature.

As follows from the cited example of determination of hydrogen, the sensitivity of determination of combustible gases is very high; the case in question indicates that the determination of hydrogen is feasible in the concentration region of 20 to 200 ppm.

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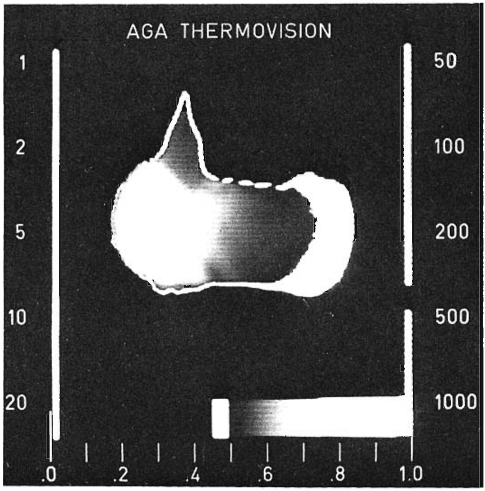

Fig. 2
Heating of the Sensor Figaro TGS 202 by the Coil Using the Power 0·7 W