2008-02-01

Gas Analyzing System Based on Semiconductor Sensors for Providing Safety of Oil and Gas Pipeline Operations ; Strategic Insights, v. 7 issue 1 (February 2008)

Tolbanov, O.; Anisimov, O.; Sachkov, V.; Sakovich, G.; Vorozhtsov, Alexander; Eisenreich, N.; Krausa, M.

Monterey, California. Naval Postgraduate School

Strategic Insights, v.7 issue 1 (February 2008)
https://hdl.handle.net/10945/11444

Gas Analyzing System Based on Semiconductor Sensors for Providing Safety of Oil And Gas Pipeline Operations

Strategic Insights, Volume VII, Issue 1 (February 2008)

by O. Tolbanov, O. Anisimov, V. Sachkov, G. Sakovich, Alexander Vorozhtsov, N. Eisenreich, and M. Krausa

Abstract

The present paper describes the development of automatic gas analyzing system which contains a control and detection unit and a network of semiconductor sensors allocated along the oil and gas pipeline and connected with each other by five-wire line. The system provides permanent control of explosive gases (CxHy) in the range of 0 ÷ 100 percent LEL and automatic and hand-operated scanning of all sensors for determining the exact location of a signaling sensor. The reliability of the system is improved by applying software methods allowing compensating automatically the influence of the external factors such as environmental temperature (in the range of -55 ÷ +55℃) and humidity (in the range of 0÷100 percent) on the sensors performances.

Keywords: SnO_2 thin film gas sensors, inflammable gases, environment temperature and humidity

Introduction

The development of portable gas detectors and analyzers of explosive gases is a topical problem caused by necessity to improve the safety of oil and gas pipelines' operation, working conditions at mining and industrial processes and home safety. The lack of reliable and efficient gas sensors at the market restrains the development of portable control and analyzing equipment of various gas mediums.

SnO_2 based materials are widely used for gas sensor applications. They demonstrate sensitivity to the majority of toxic and inflammable gases. Due to the reaction of reducing gas molecules with chemisorbed oxygen species (O_2- or O-) on the semiconductor surface, the potential barrier between the oxide particles is reduced by releasing electrons to the conduction band of SnO_2 . The gas response of the sensor film is determined by the ratio R_{air}/R_{gas}, where R_{air} and R_{gas} are the sensor resistance in air without and with a reducing gas. However, low stability and poor selectivity restrict their application area. Electrical properties of SnO_2 sensing element are influenced not only by molecules of the target gas but also by other gases and environment conditions (environment temperature and humidity).

Selectivity and stability of a semiconductor gas sensor can be improved by several methods: modification of the sensing material, e.g. by doping with catalytic and electroactive admixture and optimization of the working conditions.

We developed and tested tin oxide thin films with various additives in order to create a reducing gas sensor. The sensitive elements, made by microelectronic technology (Figure 1), have low power consumption, small size, fast gas response and low cost. The selectivity to particular gases is provided by sensor type, manufacturing technology and working temperature. The reliability of the sensing system is improved by applying software methods allowing compensating automatically the influence of the external factors such as environment temperature (in the range of -55 ÷ +55 °C) and humidity (in the range of 0÷100 percent RH) on the sensors' parameters.

The sensitive elements consist of sapphire substrate of 1.2x1.2x0.15 mm size. SnO_2 thin films (~ 100 nm) are obtained by RF magnetron sputtering of the tin target with additional 1.5 percent of antimony in oxygen-argon plasma. The superthin layers of catalytic Pt are received also by RF magnetron sputtering. The working temperature of a sensor is kept by platinum heater that is deposited by magnetron sputtering method on the other side of substrate prior to the deposition of the semiconductor film. The films are annealed in an air for 24 h at 400°C. The working elements are mounted onto TO-8 socket (Figure 2).

Figure 1: The Sensitive Elements Based on SnO_2 Thin Films

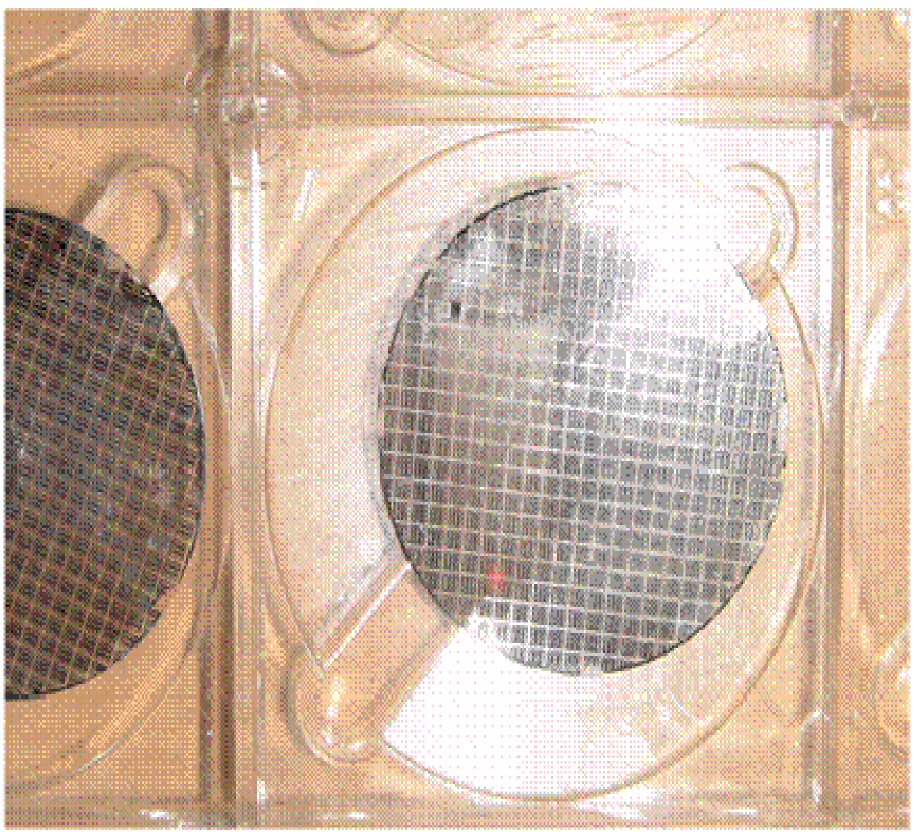

Figure 2: Gas Sensors Based on SnO_2 Thin Films

In order to stabilize the working parameters the gas sensor operates in pulse mode: two hours heating of the sensor with temperature stabilization at 430℃, three seconds cooling of the sensor up to 95℃. The resistance of the sensor is measured in two points of the each impulse for automatic compensation of the environment influence. For calculating the current concentration of explosive gases in the air the analytic expression has been obtained which allows compensating the drift of the sensor parameters at the change of temperature and ambient humidity:

$$C_i = C_0 \cdot 10^{\frac{1}{m}(\lg R_0 - \lg R_{i1})} \cdot 10^{-n(U_i - U_0)} \cdot 10^{k(\lg R_0 - \lg R_{i2})},$$

where C_i = numerically calculated gas concentration; m = concentration coefficient; n = temperature coefficient; k = humidity coefficient; R_{i1} = value of sensor resistance at room temperature; R_{i2} = value of sensor resistance at room humidity; U_i = value of the heater voltage at room temperature; C_0, R_0, U_0 = constants.

In Figure 3, the methane response of the sensor depending on the ambient temperature and humidity is showed. It is calculated applying the expression mentioned above. It is clear the inclusion of adjustment coefficient allows providing independence of the sensor parameters from environment condition.

Figure 3

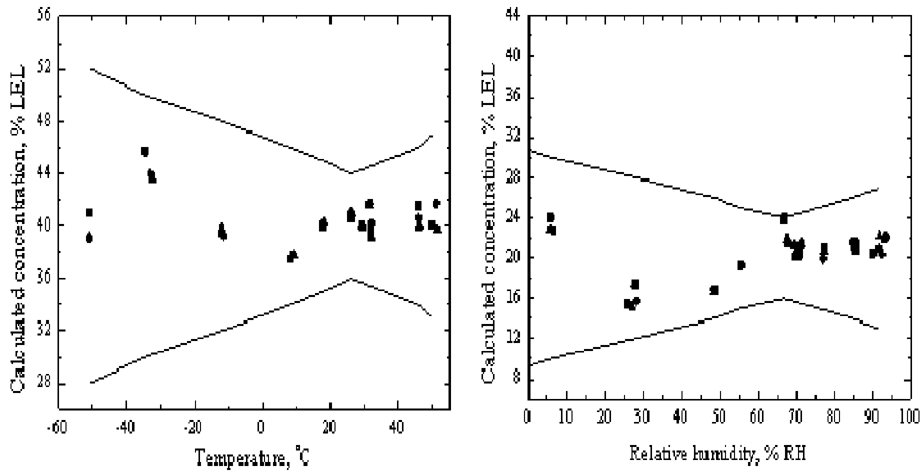

Fig. 3. Calculated signal of the sensor at 40 and 21 % LEL methane depending on the ambient temperature and humidity.

Developed gas analyzing system represents a network of detectors connected with each other and attached to a single processing and signalization unit. Each detector (Figure 4) consists of a gas sensor, heating and temperature stabilization system, conductivity measuring unit, signal processing and exchange unit. Connection between detectors and the main unit is established applying RS-485, and each detector has its own unique address.

Figure 4: CxHy-Detector Based on Semiconductor Sensor

The advantages of the developed gas analyzing system are the following:

- high sensitivity and stability of detectors;
- personal address of each detector;
- continuous automatic testing and autocalibration of each detector;
- wide range of climatic conditions of the system operation.