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Engineering approaches to improvement of conductometric gas sensor parameters. Part 2: Decrease of dissipated (consumable) power and improvement stability and reliability

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ABSTRACT

Engineering approaches designed to improve parameters of conductometric gas sensors are being considered in this survey. In particular, in this paper we have analyzed engineering approaches used both for improvement of sensor stability and reliability, and for decrease of power dissipated by conductometric gas sensors. Analysis has shown that those engineering approaches can eliminate some genetic disadvantages of conductometric gas sensors, provide a significant improvement of their exploitation parameters, and expand their application in various fields.

Contents

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1. Introduction

At present a great number of published review papers have been devoted to summarizing results of research focused on optimizing parameters of metal oxides aimed for use in conductometric gas sensors [1–22]. It was established that essential improvement of conductometric gas sensor parameters can be achieved using approaches such as (1) searching new materials with unusual properties [15,20,23–27], (2) optimization of technological routes of gas sensor fabrication [21,28] (3) design of new technologies of gas sensing materials synthesis and deposition [29–37], (4) controlling the thickness of the films, the size and the shape of the grains [38–43], (5) using 1D, hierarchical and hollow metal oxide nanostructures [22,44–46], (6) controlling the porosity of gas sensing matrix [40,47–50], (7) optimization of the phase composition of the gas sensing layer [28,39,51–53], (8) design of new methods of surface and postdeposition treatments [36,54–56], and (9) an increase in the catalytic activity of gas sensing material through introduction of catalytically active additives, using bulk doping and surface modification [39,51,57–59]. However, despite considerable efforts to improve the technology of synthesis, deposition and functionalizing metal oxide materials, it should be recognized that some problems peculiar to conductometric gas sensors, such as insufficient response to some specific gases, low selectivity, instability, temporal drift, and high sensitivity of parameters to the air humidity, are not resolved yet [36,57,59,60].

Studies, conducted during last decades, have shown that existing problems can be partially resolved through engineering approaches which are not related to the changes in the properties of gas-sensitive matrix. However, we have to note that so far there are no published reviews, generalizing results of studies in this area. In the present survey, consisting of two parts, we have tried to overlap this gap. The first part, published recently [61], covers the analysis of engineering approaches used for improvement of sensor sensitivity and selectivity. In the second part we discuss the effectiveness of engineering approaches proposed for the reduction of power consumption and for improvement of stability and reliability of conductometric gas sensors. The nature of this instability has been discussed in the reviews [36,60].

One should note that other types of gas sensors can also have problems in terms of sensitivity, selectivity and stability [20,21]. Therefore, we believe that topics covered by this review might be of interest for researchers working in the field of another solid state gas sensor design as well.

2. Engineering approaches to improvement stability and reliability

Stability is a key quality indicator in the development of gas sensors for real markets. It is known that devices designed for the sensor market should exhibit a stable and reproducible signal for a period of at least 2–3 years (typically 17,000–26,000 h of operation). But still, the temporal drift of operating characteristics of conductometric gas sensors based on metal oxides (MOX), along with the low selectivity of sensor responses, are considered to be major disadvantages of these devices [24,54,62–67]. For example, Fig. 1 shows results of 3 year study of conductivity drift of 6 different TGS sensors, fabricated by Figaro.

It is clear that the sensor aging and environmental disturbances produce changes in sensor responses that make initial statistical models for gas or odor recognition unacceptable for use after a relatively short period of time. This means that analytical devices based on such sensors will have poor repeatability, since sensors during aging produce different responses for the same odor. That is particularly troublesome for electronic noses [61]. Besides, such drift

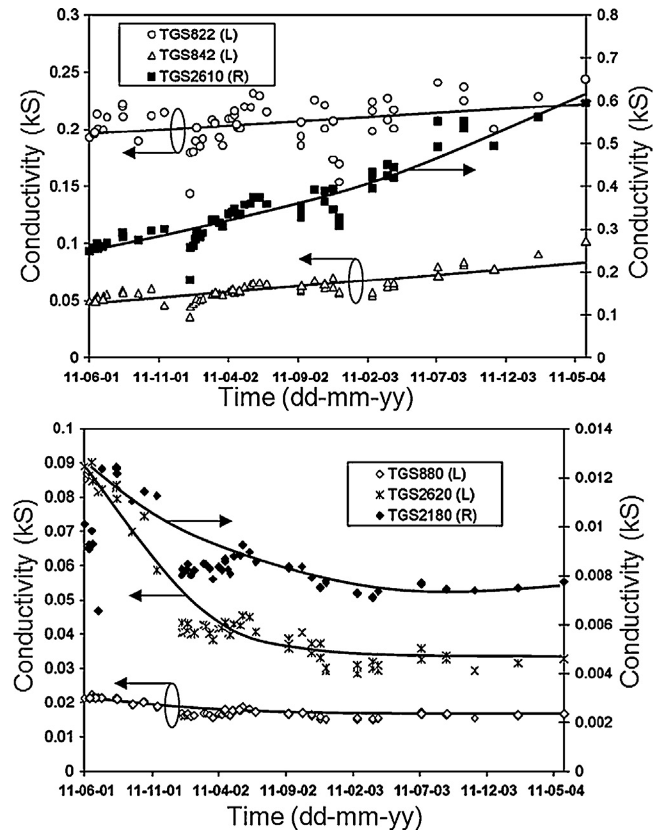

Fig. 1. Conductance time evolution of the six tested TGS sensors during 3 years. (Reprinted from Romain and Nicolas [62]. Copyright 2010 Elsevier.)

substantially limits the ability to measure the absolute value of target gas concentrations. For example, in the alarm system set for a specified level of a poisonous contaminant, the drift terms may lead to a false alarm or a failure to announce a dangerous contamination level. Frequent recalibrations are needed to preserve system accuracy [64,65]. However, when recalibrations involve numerous samples they become expensive and laborious.

Gas sensor drift consists of a random temporal variation of the sensor response when it is exposed to the same analytes under identical conditions. An analysis of current literature allowed us to conclude that instability in the performance of the MOX conductometric sensor (temporal drift) is conditioned by a number of reasons listed below [24,41,60,68–76]:

- Structural transformation, including grain growth, film cracking, etc.
- Phase transformation
- Poisoning
- Degradation of contacts and heaters
- Bulk diffusion, including chemical diffusion of oxygen vacancies
- Errors in design
- Change of humidity
- Variations on flow rate
- Fluctuations of temperature in the surrounding atmosphere
- System sampling nonspecific adsorption
- Interference effects

All of these factors can modify both the baseline and sensitivity of the sensors in different ways, depending on sensor technology. Considering factors influencing sensor parameters, one can conclude that in general sensor drift (temporal instability) can be attributed to two predominant sources [77–79]. First, the ‘real-drift’