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The Pitfalls of Researching and Developing Semiconductor Gas Sensors

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Summary:

There are more than one million score on google scholar using the search term "semiconductor AND gas AND sensors", more than ten thousand in this year. Authors, reviewers, and publishers make significant efforts to ensure that articles are of high quality. Nevertheless, certain trends can be observed, frequently occurring shortcomings that often occur in the research of semiconductor gas sensors and the publication of scientific results. This article collects the shortcomings and mistakes that researchers make most often.

Keywords: semiconductor gas sensors, pitfalls, adsorption, desorption, investigation mistakes

Introduction

Significant efforts have been made in the development of semiconductor gas sensors over the past 50 years. However, there are some pitfalls and mistakes during this work, which have not generally been discussed in the literature. The information collected in this article derives from the author's twenty years of experience in reviewing articles on gas sensors submitted to various journals, as well as his forty years' work in the gas sensor field, reading books, articles, reports and making his own mistakes as well [1], [2].

About semiconductor gas sensors in general

There are many possible physical realisations of semiconductor gas sensors [3]. Simple thin semiconductor film, thin film with catalytically active metal particles (agglomerated ultrathin metal layer [4]), pure thick film, thick film with metal additives, and semiconductor nanocrystals are often referred to as homogeneous gas sensor layers, in spite of the microscopic inhomogeneity of these structures [5], [6], [7] [8]. The latest realizations of these resistance-type semiconductor gas sensors have layers doped with polymers [9], [10].

Diode or MOS like (macroscopically inhomogeneous) structures are realised on monocrystalline semiconductor base, mainly on Si, GaAs, or, for higher temperature application on SiC [11].

Sources of pitfalls

One source of error can be the design and realization of the equipment used to test the sensors. The gas concentration surrounding the sensor may depend on several factors, such as the rate of mixing and gas adsorption on the vessel wall and pipelines of the gas system.

Articles often lack a comparison between the measured static and dynamic characteristics of the sensors, which would take into consideration the theory of sensor operation and adsorption phenomena. In many cases it is possible to find some theoretical connection between the surface adsorption (gas partial pressure) and the electrical output signal (resistance, threshold voltage, etc.), i.e., derive the static characteristics.

According to the adsorption theory the pressure axis should be scaled with *p* on *1/n* power. Using that kind of scale, it is possible to estimate some parameter of adsorption. The proper scale for the sensor response depends on the nature of the output signal of the given sensor construction. For example, the surface work-function, as sensor response is usually proportional to the surface coverage, thus linear scale is proper solution for work-function type (MOS and diode) sensors. For the case of fully depleted semiconductor resistive type sensors the sensor resistance depends exponentially on the chemical potential (work-function) of the surface, thus the proper scale on the y axis is logarithmic [2], as well as the diode type sensors, when the current is plotted as output signal.

A common shortcoming in articles dealing with semiconductor gas sensors is that the authors neglect the above considerations and choose the simplest solution, i.e. logarithmic scaling on both axes, without any other justification or consideration. This solution seems reasonable in many cases, since many characteristics can appear as straight lines when represented in the log-log coordinate system, and the pressure (concentration) range is not too broad. Nevertheless, the logarithmically scaled partial pressure (concentration) axis, if it is plotted in a wide pressure range, would offer a good opportunity to establish the parameters of the sensor characteristic.

A common pitfall when evaluating the results is that the time function of the output signal rising or falling is not examined, not even in cases where there are otherwise measurement results on the dynamic behavior of the sensors.

Sometimes, especially at lower temperatures a long time is required for reaching a steady state situation of the sensor output signal, thus experimenters tend to forget waiting for this to happen. Of course, there are cases where the researchers do not wait for the sensor to set up, because like the case of high gas concentration, long exposure to gas can cause irreversible changes in the chemical composition on the surface of the sensor.

Resistive type semiconductor gas sensors are often tested with a series pull-up resistor and voltage source. This arrangement eliminates the sensor instability at the high resistance range, as the pull-up resistor voltage is always very small in the case of high sensor resistance. The honest way is to plot the real sensor resistance instead of current or voltage of the pull-up resistor.

A common characteristic of semiconductor gas sensors is that they usually contain an integrated heating element operating with electrical power which can disturb the response of the sensor. Even in the case of more complex sensor designs, it is not advisable to forget about the proper separation of the heating circuit and the sensor circuit.

Conclusion

Looking at the frequent shortcomings and missed opportunities during the research, we can conclude that the authors usually carry out careful experimental work. However, it often happens that some factors that may affect the results are not considered during the experiments. During the evaluation of the measurement results, it happens that even relatively simple options are not used to draw deeper conclusions, and to finding the connection between the measured results and the theoretical background of operation.

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