SIMULATION OF MEMS MICROHOTPLATE FOR METAL OXIDE GAS SENSORS: REVIEW

1Manju Ahuja, 2Rajneesh Talwar, 3B. Prasad
1ECE Department, RIMT-IET, Mandi Gobindgarh, Punjab, India
2Principal, Chandigarh college of Engineering, Landran India
3Professor, Electronics Science Department, Kurukshetra University, Kurukshetra, Haryana, India
1manjugulati2007@gmail.com, 2rtphdguidance@gmail.com, 3bprasad2005@gmail.com

Abstract: Simulation of gas sensor with integrated micro hotplate (MHP) of ultra low power consumption is reviewed. Various parameters of gas sensor and MHP as power, temperature, heat insulation, stress analysis and deflection is studied using various Multiphysics simulation tools like ANSYS and Concertware. Microheaters have been widely investigated because of their extensive applications in gas sensors, flow rate sensors and other microsystems. The microheaters are designed to ensure low power consumption, low thermal mass and better temperature uniformity. Thus optimization of micromachined heater for sensing applications is designed to withstand high-temperature.

Keywords: Microhotplate, Gas sensor, Micromachine

1. INTRODUCTION

We are gifted by nature with five senses. We are able to feel and experience the surroundings through our sense of touch, smell, taste etc. As we have progressed we have started to understand the limitations of these senses which we were once very proud of and realized sometimes the sense organs can give unreliable information. Temperature sensing is a classic example. Humans have developed very reliable sensors for temperature, pressure, humidity etc. measurements. Increase in the industrialization, an offshoot of human evolution brought in the need to detect the presence of certain chemical species especially gases. Such sensors are not only required for the qualitative estimates but very often quantitative estimate is necessary for the production. Many of the gases used in the industries could be fatal to humans. So it may be of paramount importance to detect and monitor them outside the work area. So a lot of efforts have gone into the detection and monitoring of gases used in the industry.

Air pollution from various offensive gases has been a serious problem in modern life. Gas detection is important because it is necessary in many different fields, for example, industrial emission control, household security, vehicle emission control and environmental monitoring etc. For example, Methane gas (CH₄) affects global warming 20 times more severely than carbon dioxide gas (CO₂). It is explosive, due to its high volatility and flammability in air and in closed areas, methane gas may cause suffocation. Controlling and monitoring of CO₂ is of great importance in environmental and industrial fields. Similarly Ammonia gas (NH₃) is produced and utilized extensively in many chemical industries, fertilizer factories, refrigeration systems, food processing, medical diagnosis, fire power plants etc. A leak in the system can results in the health hazards. Ammonia is toxic to human at higher concentration. The exposure of ammonia causes chronic lung disease, irritating and even burning the respiratory track etc. Environmental pollution is a burning global issue. So in many aspects of today's life, the use of gas sensors becomes increasingly important.

For evaluating the performance of gas sensors, several indicators should be considered: sensitivity: the minimum value of target gases volume concentration when they could be detected, selectivity: the ability of gas sensors to identify a specific gas among a gas mixture, response time: the period from the time when gas concentration reaches a specific value to when sensor generates warning signal, energy consumption, reversibility: whether the sensing materials could return to its original state after detection, adsorptive capacity (also affects sensitivity and selectivity), fabrication cost [1].

2. METAL OXIDE GAS SENSING

Gas detection can be carried out by a wide range of physical, chemical, electrochemical and optical principles. Broadly, for gas monitoring, different kinds of sensor systems can be used: Spectroscopic, Optical and Solid State are the three main families of gas sensors. Spectroscopic systems are those based on the direct analysis of fundamental gas properties, such as molecular mass or vibrational spectrum. Optical sensor systems are based on the measurement of the absorption spectra after light stimulation and metal oxides are based on the change of physical and/or chemical properties of a sensing material after gas exposure [2].

Metal oxide semiconductor gas sensors are utilised in a variety of different roles and industries. They are relatively inexpensive compared to other sensing technologies, robust, lightweight, long lasting and benefit from high material sensitivity and quick response times. They have been used extensively to measure and monitor trace amounts of environmentally important gases such as carbon monoxide and nitrogen dioxide. Many metal oxides are suitable for detecting combustible, reducing, or oxidizing gases by conductive measurements. The following oxides show a gas response in their
conducitivity: Cr2O3, Mn2O3, Co3O4, NiO, CuO, SrO, In2O3, WO3, TiO2, V2O3, Fe2O3, GeO2, Nb2O5, MoO3, Ta2O5, La2O3, CeO2, Nd2O3. Metal oxides selected for gas sensors can be determined from their electronic structure. The range of electronic structures of oxides is so wide that metal oxides were divided into two the following categories:

(1) Transition-metal oxides (Fe2O3, NiO, Cr2O3, etc.)

(2) Non-transition-metal oxides, which include (a) pre-transition-metal oxides (Al2O3, etc.) and (b) post-transition-metal oxides (ZnO, SnO2, etc.). Pre-transition-metal oxides (MgO, etc.) are expected to be quite inert, because they have large band gaps. Neither electrons nor holes can easily be formed. They are seldom selected as gas sensor materials due to their difficulties in electrical conductivity measurements. Post transition metal oxides are widely used[3].

3. SIMULATION USING MEMS DESIGN TOOL

Any scientific research method involves a mutual interdependence between experimental work and theoretical work. An important bridge between the experimental work and theoretical studies of a specific research is the computer experiment or simulations. The basic idea in computer simulations is to design and simulate the actual physical system and to analyze the simulation results. The main advantage is, complicated physical systems can be easily studied, helping us understand and predict the system by saving time & cost. Therefore, modeling and simulations are required to adjust and optimize the sensor for any specific application, prior to fabrication of the device. Today a broad spectrum of options for simulation is available; researchers use everything from basic programming languages to various high-level packages implementing advanced methods. How much simplification takes place in the translation process helps to determine the accuracy of the resulting model. Much of the physics requires a three dimensional simulations for a more accurate result. The finite element analysis (FEA) tools, Conventorware, ANSYS, COMSOL, ABAQUS can be employed to optimize sensor design [4].

3.1 Microheater/Microhotplate simulation

Metal oxide gas sensor require a device which can produce elevated temperature (250 - 500 °C) with small power consumption. Microhotplate is used to produce the elevated temperature for gas sensing films. Design of heater, analysis of temperature distribution on the sensitive layer and sensitivity, which is temperature dependent, good mechanical stability at higher temperature are main issues of heater for metal oxide gas sensing applications. For these objectives, the thermal characteristics of the microhotplate are optimized by controlling the heat losses, dielectric materials and heater configuration.

Many of existing gas sensors may not be suitable to make high precision measurements of gas concentrations but they can give only qualitative estimate such as presence of given gas. At present, general gas sensors have some common limitations like bulky, low consistency and high power consumption. So there is an urgent need for the development of small, low cost, high sensitivity, good selectivity reliable sensors for control and measuring gases, for automation of services with an excellent performance, reliability and low price. The novel gas sensor based on “micro-electro-mechanical systems (MEMS)” adopts the traditional semiconductor technology, and has many advantages in consistency, homogeneity and microminiaturization, which make it easy to achieve integration and low power consumption. Thus the development of miniaturized gas sensors is an increasingly active area of research. Such devices, particularly when they feature low mass and low power budgets, can impact a broad range of applications including industrial process monitoring, building security and extra terrestrial exploration [5].

Platinum based micro hotplates offer the advantages of reliability, stable temperature coefficient of resistance (TCR) and reproducibility. In literature [6], for microheater design on Silicon substrate there are SiO2 and Si3N4 dielectric layers.

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<tr>
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<tbody>
<tr>
<td>SiO2</td>
<td>395</td>
<td>689</td>
<td>1177</td>
</tr>
<tr>
<td>Si3N4</td>
<td>369</td>
<td>585</td>
<td>945</td>
</tr>
<tr>
<td>Si3N4+a</td>
<td>346</td>
<td>491</td>
<td>733</td>
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</table>

The dimensions of the microhotplate membrane are 220×220 μm². The design consists of a square opening of 200×200 μm² in back side of the Si substrate which is 500 μm thick. SiO2 and Si3N4 layers are 1 μm and 0.35 μm thick respectively and platinum heater is laid over it. The gap between the heating elements and width is 20 μm with thickness .3 μm. The summary of the temperature (K) distribution of platinum-based microhotplate with different dielectric membranes are shown in Table 1.
SiO2 membrane-based microhotplate has the higher temperature in comparison to Si3N4 and both combination of SiO2 and membranes Si3N4 at same power consumption as shown in fig 1. It is because that the thermal diffusivity of SiC is smaller than the thermal diffusivity of Si3N4 and combination of SiO2 and Si3N4 films.

Similarly the effects of various thicknesses of the heater layer on the power consumption of the MHP are evaluated, which is shown in Table 2.

<table>
<thead>
<tr>
<th>Heater Thickness (μm)</th>
<th>Power Consumption 'mW' at 1V</th>
<th>Power Consumption 'mW' at 2V</th>
<th>Power Consumption 'mW' at 3V</th>
</tr>
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<tbody>
<tr>
<td>.3</td>
<td>7.84</td>
<td>31.3</td>
<td>70.5</td>
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<tr>
<td>.5</td>
<td>13.07</td>
<td>52.28</td>
<td>117.64</td>
</tr>
<tr>
<td>1</td>
<td>26.14</td>
<td>104.57</td>
<td>235.29</td>
</tr>
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</table>

Variation of power consumption with thickness of heater layer with voltage in fig 2.

Similarly for modeling and simulation of a micromachined microhotplate (MHP) using (Si3N4) and silicon carbide (SiC) membrane is designed to achieve low power dissipation and uniform temperature distribution on the sensing area at operating temperatures of up to 700°C. Temperature gradient on the MHP decreases as the thickness of the SiC is increased and is a minimum with a value of 0.005°C/μm for SiC thickness of 2 μm and above. A comparison between simulation and mathematically modeled results for power dissipation and current density of the MHP showed close agreement. An optimized simulated device exhibited low power dissipation of 9.25 mW and minimum mechanical deflection of 1.2 μm at the elevated temperature of 700°C [7].

In another paper, a design and analysis of an array of 100nm thin film MEMS based microheater on SOI wafer is presented. The microheater is constructed on a SOI wafer where temperature rise of 200°C is achieved with minimum power consumption of 20mW. Also there is minimum heat loss through the substrate. The temperature rise is concentrated in only the microheater region and there is excellent uniformity in the temperature distribution in both of the microheaters. Maximum stress developed in oxide layer is 326 MPa which is within the range of their breaking stress [8].

3.2 Simulation of gas sensing structure:

In literature novel design of metal-oxide NO2 gas sensor integrated with micro heaters is presented in which thermal simulation of heat insulation between sensing diaphragm and substrate is carried which conclude that heat loss can be neglected when the gap between substrate and sensor membrane is larger than 15 μm. Also Electro-thermo analysis of the micro heater is carried and found when 2V applied voltage temp is achieved at 215°C with uniform temp. distribution ,time response of the heater is less than 0.1s , maximum displacement due to thermal stress is less than 0.26 μm. In stress analysis it was found Maximum Von Mises stress is 127 kPa [9].

4. CONCLUSION

In the study of simulation of gas sensors and microhotplate various parameters power, temperature distribution, stress, displacement with variation of substrate thickness , using different substrate materials ,different heater material ,heater layer thickness are optimized.

5. FUTURE SCOPE

Keeping in the view of the objectives of miniaturization, portability, maximum sensitivity and compatible with existing silicon planer technology Further different heater geometries with different materials can be analysed. As gas detection sensitivity is function of temperature an attempt will be made to make temperature zones in the sensor arrays which could enable us to use the same sensors for different gases using COMSOL Multiphysics especially for toxic gases such as NH3, CH4 & CO2.

REFERENCES


