DOI 10.5162/SMSI2020/P2.11

Multiphysics Electro-Thermal Simulation of Pt Microheater Structures for Gas Sensing Application

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Summary:

Air quality sensing is growing fast in several applications, such as monitoring air quality in automobiles, smart homes or industrial processes. Metal-oxide semiconductor-based sensors require a chemical inert microheater with long lifetime and fast response time. To meet the requirements of the next-gen microheaters, a thorough understanding of the complex interplay between the underlying thermal conduction, convection and radiation processes is needed, which is obtained through FE simulations. The results will help to optimize and miniaturize microheater design arrays for next-gen gas sensors.

Keywords: platinum thin film, microheater, gas sensing, high temperature, multiphysics simulation

Motivation

Today the air quality sensor (AQS) market is dominated by the automotive industry. But in the future additional demand is seen from smart homes and wearables for localized information of the environment. A metal-oxide semiconductor (MOS)-based AQS consist of a µ-heater which provides uniform temperature (>300 °C) crucial for the optimal functioning of the MOS gas sensor (Fig. 1a).

Platinum (Pt) µ-heaters are chemically inert, with long lifetime, fast response and allow handling of higher temperature and current density. The next-gen AQS will have low power miniaturized arrays of µ-heaters for improved detection of multiple gases. Understanding of the Pt µ-heater is essential to meet customer product specification at lower production cost (scaling). Therefore, ANSYS thermo-electric simulations of Pt µ-heaters were performed to establish a model of the current µ-heater design. This model can be further used to develop and optimize the next-gen µ-heaters.

Method – Electro-Thermal Analysis

First, a three-dimensional (3D) model is set up in the finite element (FE) program. During the simulation and the result analysis, parameters such as maximum temperature, temperature uniformity, power consumption and current density are considered essential as they affect the performance of the microheater (Fig. 1b). These parameters are determined by factoring in appropriate material characteristics and boundary conditions. From the prospect of simulation, the material characteristics: thermal conductivity of Silicon Rich Nitride (SiRN) as membrane material and the IR-emission coefficient from Pt (ε_{Pt}) are significant – but not available from literature in the temperature range up to 1000 °C precisely [1-3].

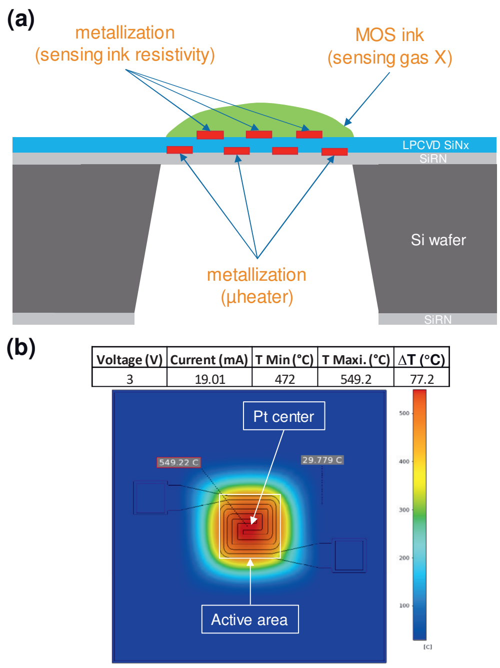

Fig. 1. (a) Cross-section view of the MOS-based air quality sensor. (b) Simulated thermal heat distribution at 3V.

Characteristics of the Pt Microheater

The performance of the Pt µ-heater is given by the maximum temperature vs. applied power curve i.e. for a certain applied power using

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pulse-width modulation (PWM) technique the µ-heater reaches a defined temperature at steady state crucial for the working of the MOS gas sensing film. In our simulation we accounted for the different modes of heat transport i.e. conduction, convection and radiation (Fig. 2). The gray curve shows almost a linear behaviour if only conduction and convection are considered. However, non-linear behaviour was observed when radiation mode was accounted. The orange curve demonstrates the expected non-linear curve when all three modes of heat transport are simulated i.e. at an applied power of 36 mW and 55 mW we obtain temperature of 360 °C and 510 °C, respectively. Furthermore, the radiation impact is less visible from 0 – 65 mW but above 65 mW non-linearity in the curve is observed.

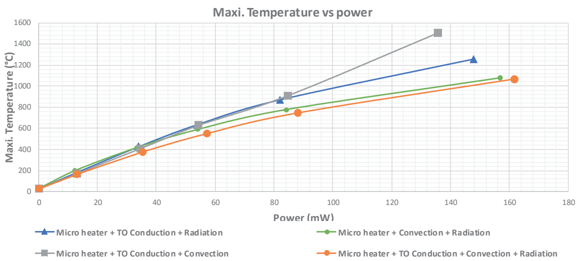

Fig. 2. Simulated maximum temperature vs. applied power curve for combinations of different modes of heat transport.

Different Modes of Heat Transport

Fig. 3 shows the contribution rate with increasing temperature for each mode of heat transport where three distinct regions have been observed.

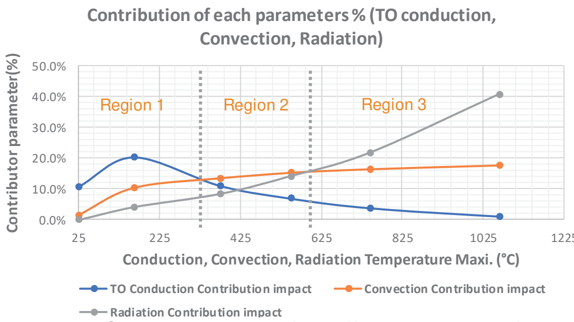

Fig. 3. Contribution rate for different modes of heat transport.

In region 1 (25 °C – 315 °C), conduction dominates i.e. the heat transport takes place via the SiRN membrane (mainly), silicon body and the TO-39 header. In region 2 (315 °C – 585 °C), contribution from convection is more important i.e. heat dissipated to ambient environment. We also observe the radiation and conduction contribution are gradually increasing and decreasing, respectively. In region 3 (> 650 °C), radiation mode dominates as the µ-heater starts to glow red. The convection contribution remains constant through the different regions but the decrease in conduction contribution with increasing temperature is attributed to boundary conditions which results in a qualitative heat analysis of each dissipation modes.

Comparison of I-V Characteristics

The I-V characteristics generated from the electro-thermal FE model (green curve) were compared with fabricated MEMS Pt µ-heater measurement results (blue curve) as shown in Fig. 4. The simulated I-V curve trails very close to the fabricated Pt µ-heater measurement. This implies the developed FE model can be used to predict the thermo-electric behaviour of Pt µ-heater on suspended membranes with reasonable accuracy. The approach will help to miniaturize the microheater design to meet future requirements and predict its electro-thermal behaviour without the need of fabrication, thereby saving cost.

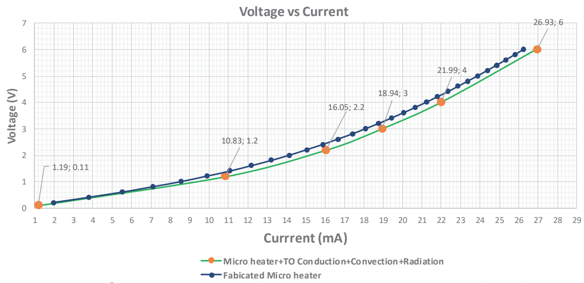

Fig. 4. Comparison of I-V characteristics for fabricated Pt microheater (blue curve) and simulated Pt microheater (green curve).

Outlook

In summary, Pt µ-heater for MEMS-based AQS has been studied in detail. Principle of joule-heating has been discussed to understand the working principle of the µ-heater which satisfies some requirements such as low power consumption and better temperature uniformity with low risk to break and burn through. Crucial parameters such as maximum temperature, temperature uniformity, power consumption and different modes of heat transport have been discussed. In the end, the simulation results from the multiphysics FE model align with real measurements which will help to reduce the development time for next-gen Pt µ-heater arrays.

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