Steady-State and Transient Electrothermal Simulation of Microheater for Gas Sensing

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INTRODUCTION: Metal oxide-based MEMS gas sensors can detect various gases such as CO, CH_4, NO_2 and C_3H_8 by means of observing their electrical conductivity change during the presence of those gases. The sensing layer effectively reacts with gases when they are heated up to an operating temperature range (400 – 600 °C). Hence, an underlying microheater device is required to transfer heat to the sensing layer. In this work, we simulate the steady state and transient response of a microheater device.

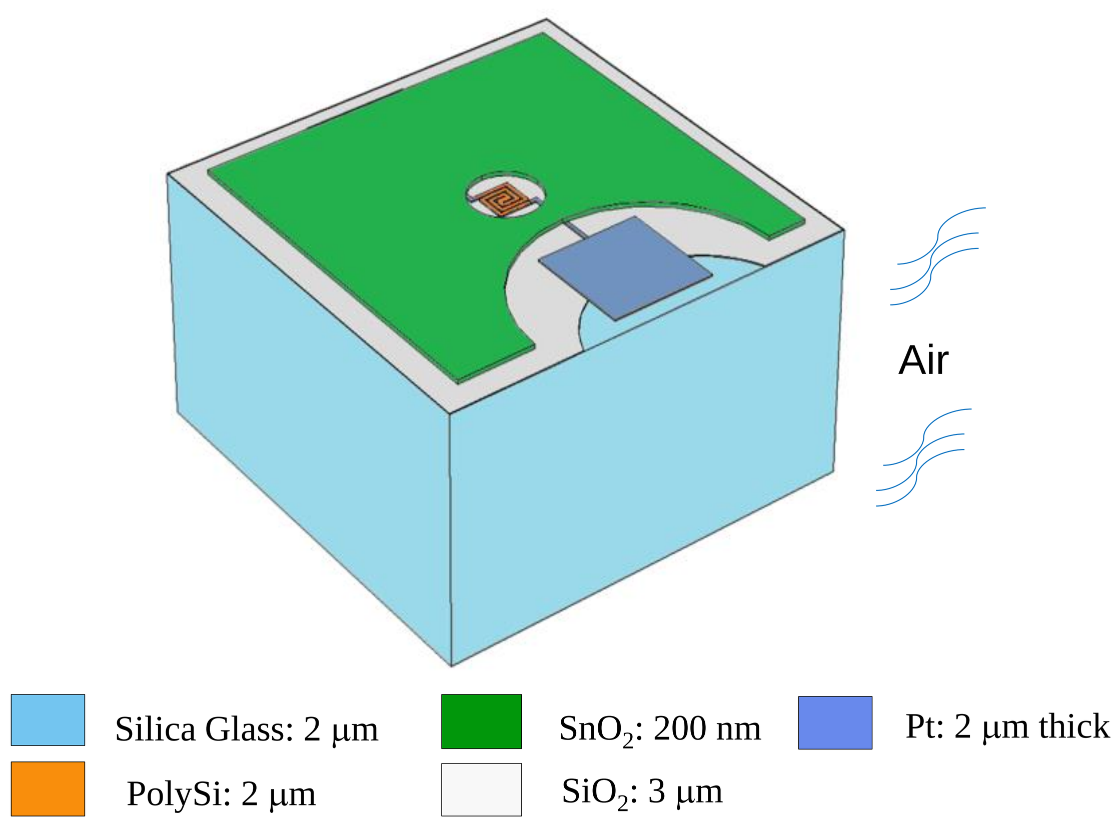

Figure 1. A 3D schematic of our gas sensor chip. (The graphical semicircle sectioning is to show the underlying layers and is not part of the actual design.)

Mathematical Equations:

1. Heat equation:

$$\rho C_p \frac{dT}{dt} - \Delta(k\,\Delta T) = Q$$

2. Joule heating:

$$Q = J\,E = J\left(\frac{J}{\sigma}\right) = \frac{1}{\sigma} J^2 = \rho J^2$$

3. Linearized resistivity:

$$\rho(T) = \rho_O[1 + \alpha(T - T_O)]$$

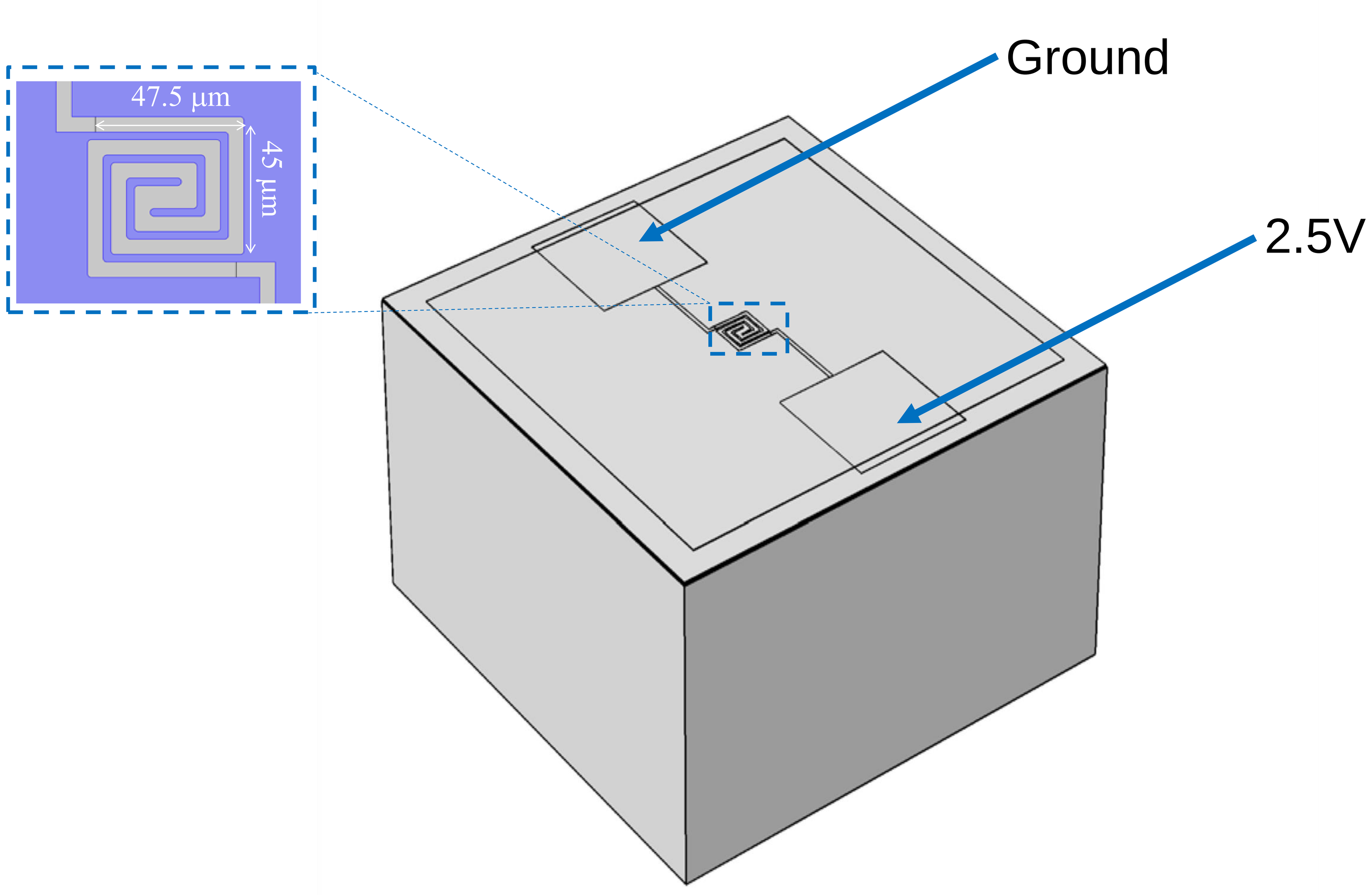

Figure 2. The 3D microheater model, with the inset a close-up view of the spiral heater.

RESULTS:

- The steady-state analysis showed that when a 2.5V was applied across the platinum pads, the polysilicon heater generated a temperature gradient in the y-direction. The max temperature was ~960 °C near the platinum-polysilicon junction.

- In the transient thermal response, the platinum-polysilicon heater reached the max temperature in 5s.

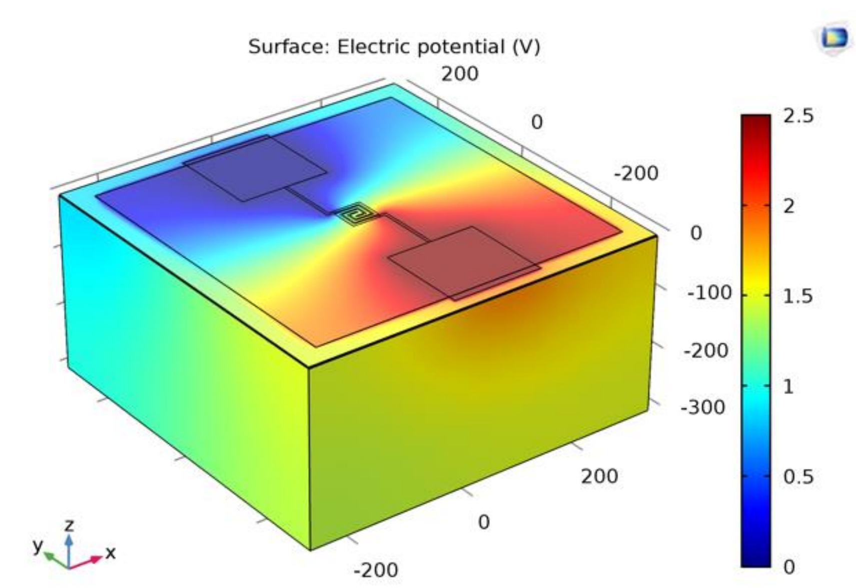

Figure 3. Steady-state surface electric potential distribution

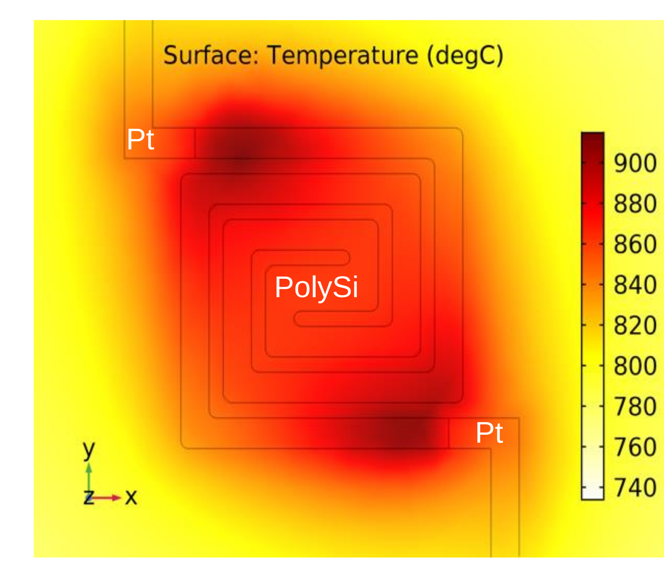

Figure 4. Steady-state surface temperature distribution

Property	Value	Unit
Density	2320	kg/m³
Thermal conductivity	678	J/kg.k
Reference resistivity	2e-5	Ω.m
Temperature coefficient	1.25e-3	K⁻¹

Table 1. Polysilicon material properties

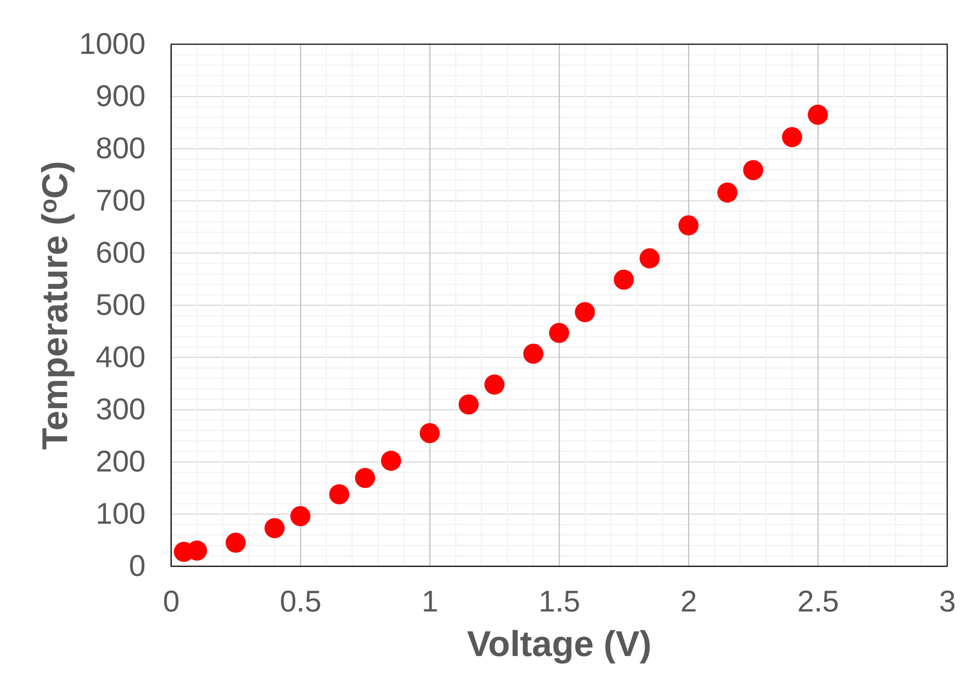

Figure 5. Temperature versus applied bias

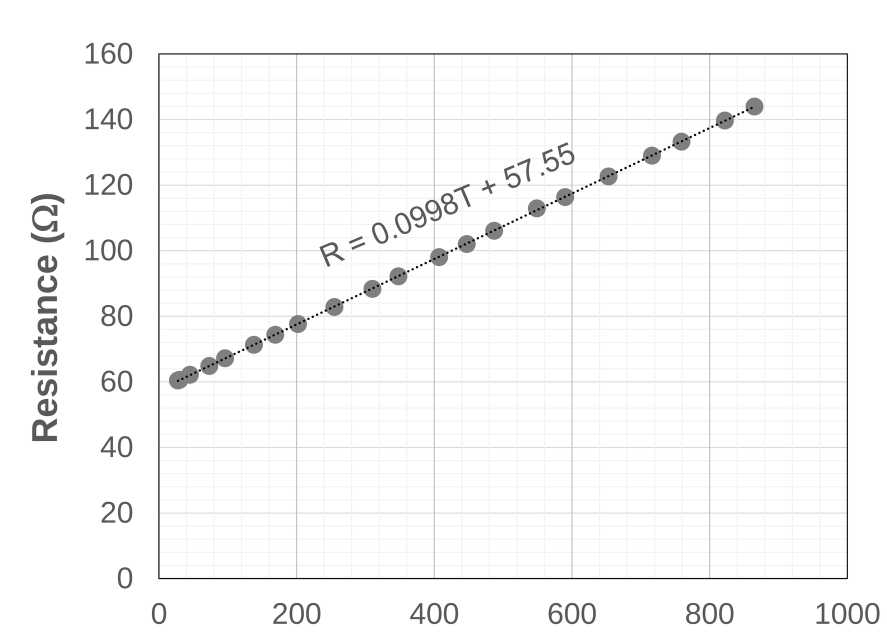

Figure 6. Resistance versus temperature

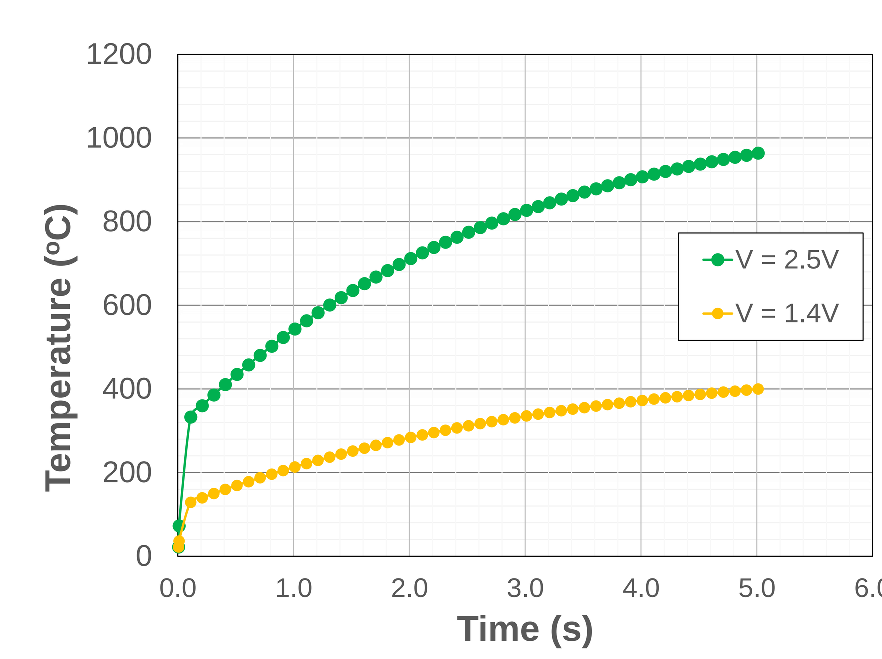

Figure 7. Transient thermal response

CONCLUSION: We simulated a 3D gas sensor device with all of its underlying layers by using COMSOL™. We optimized the heater geometry and layer thicknesses in order to obtain a uniform steady state temperature distribution. Also, we designed the thermal response time to reach a temperature of 400 °C in 350 ms. COMSOL™ can be utilized to simulate a gas sensor's response time, which is one of its key performance indicators.

REFERENCES:

1. A. P. Mammanaa, et al., Resistance behavior of thin SnO2 films at high temp., IDRC, (2012)
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Excerpt from the Proceedings of the 2018 COMSOL Conference in Boston