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Microhotplate Gas Sensor

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Summary. A benchmark for the heat transfer problem, related to modeling of a microhotplate gas sensor, is presented. It can be used to apply model reduction algorithms to a linear first-order problem as well as when an input function is nonlinear.

14.1 Modeling

The goal of European project Glassgas (IST-99-19003) was to develop a novel metal oxide low power microhotplate gas sensor [WBP03]. In order to assure a robust design and good thermal isolation of the membrane from the surrounding wafer, the silicon microhotplate is supported by glass pillars emanating from a glass cap above the silicon wafer, as shown in Figure 14.1. In present design, four different sensitive layers can be deposited on the membrane. The thermal management of a microhotplate gas sensor is of crucial importance.

The benchmark contains a thermal model of a single gas sensor device with three main components: a silicon rim, a silicon hotplate and glass structure [Hil03]. It allows us to simulate important thermal issues, such as the homogeneous temperature distribution over gas sensitive regions or thermal decoupling between the hotplate and the silicon rim. The original model is the heat transfer partial differential equation

$$\nabla \cdot (\kappa(\mathbf{r}) \nabla T(\mathbf{r},t)) + Q(\mathbf{r},t) - \rho(\mathbf{r}) C_p(\mathbf{r}) \frac{\partial T(\mathbf{r},t)}{\partial t} = 0 \qquad (14.1)$$

where $\mathbf{r}$ is the position, t is the time, κ is the thermal conductivity of the material, C_p is the specific heat capacity, ρ is the mass density, Q is the heat generation rate, that is nonzero only within the heater, and T is the unknown temperature distribution to be determined.

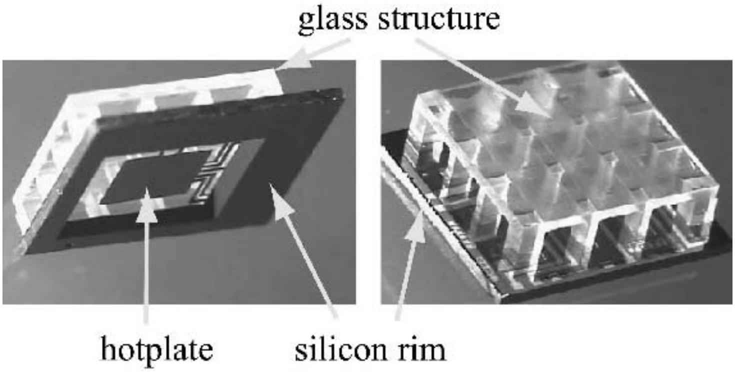

Fig. 14.1. Micromachined metal oxide gas sensor array; Bottom view (left), top view (right).

14.2 Discretization

The device solid model has been made and then meshed and discretized in ANSYS 6.1 by means of the finite element method (SOLID70 elements were used). It contains 68000 elements and 73955 nodes. Material properties were considered as temperature independent. Temperature is assumed to be in degree Celsius with the initial state of 0°C. The Dirichlet boundary conditions of $T = 0°\text{C}$ is applied at the top and bottom of the chip (at 7038 nodes).

The output nodes are described in Table 14.1. In Figure 14.2 the nodes 2 to 7 are positioned on the silicon rim. Their temperature should be close to the initial temperature in the case of good thermal decoupling between the membrane and the silicon rim. Other nodes are placed on the sensitive layers above the heater and are numbered from left to right row by row, as schematically shown in Fig 14.2. They allow us to prove whether the temperature distribution over the gas sensitive layers is homogeneous (maximum difference of 10°C is allowed by design).

Table 14.1. Outputs for the gas sensor model

Number	Code	Comment
1	aHeater	within a heater, to be used for nonlinear input
2-7	SiRim1 to SiRim7	silicon rim
8-28	Memb1 to Memb21	gas sensitive layer

The benchmark contains a constant load vector. The input function equal to 1 corresponds to the constant input power of 340mW. One can insert a weak input nonlinearity related to the dependence of heater's resistivity on temperature given as:

$$R(T) = R_0(1 + \alpha T) \tag{14.2}$$

where $\alpha = 1.469 \times 10^{-3} K^{-1}$. To this end, one has to multiply the load vector by a function:

$$\frac{U^2 274.94(1 + \alpha T)}{0.34(274.94(1 + \alpha T) + 148.13)^2} \tag{14.3}$$

where U is a desired constant voltage. The temperature in (14.3) should be replaced by the temperature at the output 1.

The linear ordinary differential equations of the first order are written as:

$$\begin{aligned} E\dot{x} &= Ax + Bu \\ y &= Cx \end{aligned} \tag{14.4}$$

where E and A are the symmetric sparse system matrices (heat capacity and heat conductivity matrix), B is the load vector, C is the output matrix, and x is the vector of unknown temperatures. The dimension of the system is 66917, the number of nonzero elements in matrix E is 66917, in matrix A is 885141.

The outputs of the transient simulation at output 18 (Memb11) over the rise time of the device of 5 s for the original linear (with constant input power of 340 mW) and nonlinear (with constant voltage of 14 V) model are placed

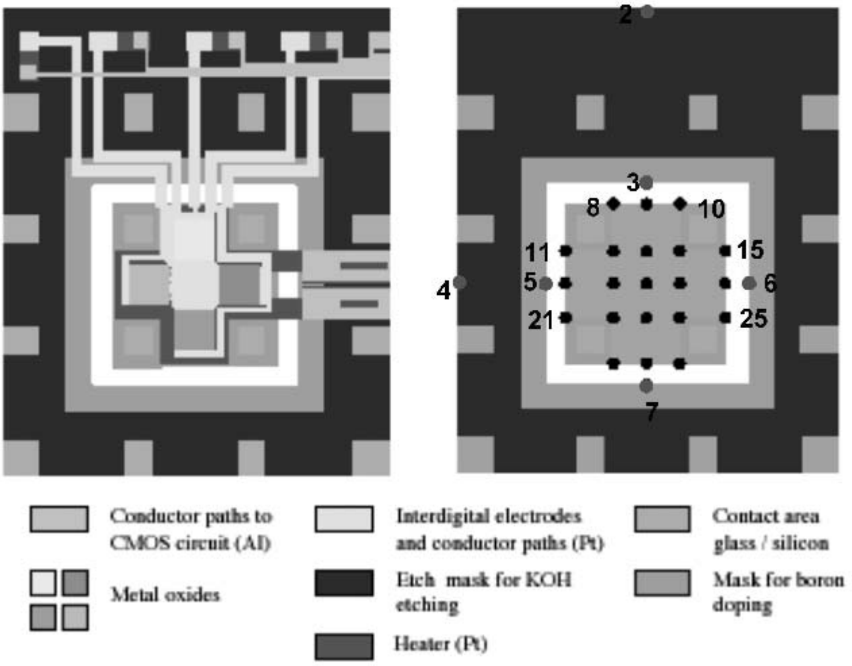

Fig. 14.2. Masks disposition (left) and the schematical position of the chosen output nodes (right).

in files `LinearResults` and `NonlinearResults`, respectively. The results can be used to compare the solution of a reduced model with the original one. The time integration has been performed in ANSYS with accuracy of about 0.001. The results are given as matrices where the first row is made of times, the second of the temperatures.

The discussion of electro-thermal modeling related to the benchmark including the nonlinear input function can be found in [BHWK04].

14.3 Acknowledgments

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References

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