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50. Internationales Wissenschaftliches Kolloquium
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Thermal and mechanical modelling of gas sensing microsystem based on GaAs microstructures

ABSTRACT

The aim of this work was to prove and optimize the design of a GaAs Gas Sensor Microsystem (GAGS) for achievability of its anticipated thermal and mechanical properties, particularly a high effective thermal resistance of the sensor's core, enabling temperatures above 300°C by less than 25mW of input power, maintaining at the same time a reliable mechanical structural integrity in harsh environments.

INTRODUCTION

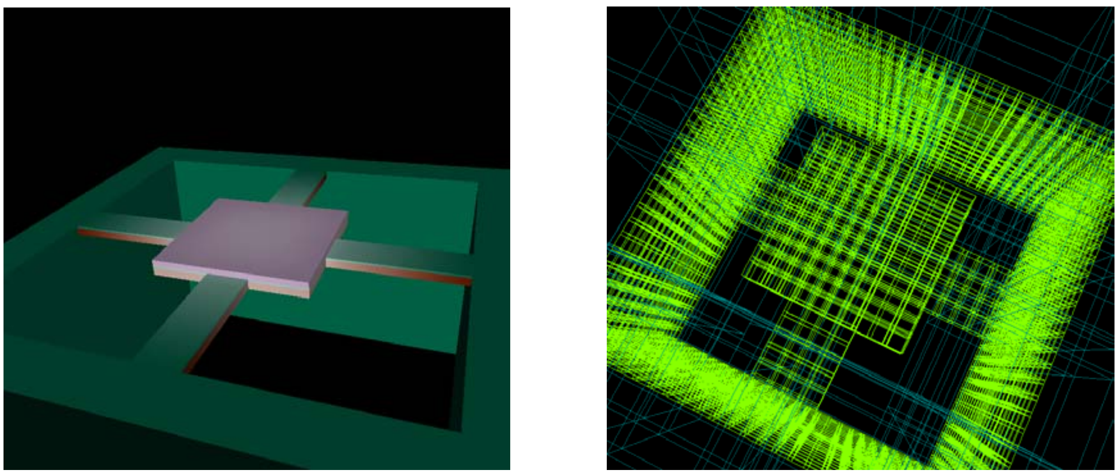
Simulation of micromachined systems and sensors is becoming increasingly important. The motivation here is similar to that of the simulation of purely electronic VLSI circuits: before fabricating a prototype, one wishes to virtually build the device and predict its behavior. This allows for the optimization of the various design parameters according to the specifications. As it is a virtual device, parameters can be changed much more quickly than actually fabricating a prototype, then redesigning and fabricating it again. This considerably reduces the time to market and also the cost to develop a commercial device [1]. To be able to study the microsystem's responses to contradictory requests for thermal and mechanical performance from one point of view, we decided to create a joined parametric thermo-mechanical model. The model is in fact a closed-form polynomial relation of performance indicators on microsystem mechanical dimensions and material composition, where polynomial parameters result either from thermal and mechanical numerical modelling or from analytical approximations.

THERMAL SIMULATION

For the thermal part of the model, we decomposed the microsystem to isolated sensor core surrounded by air, and to four AlGaAs/GaAs cantilevers based in GaAs bulk carrying the core. The effective thermal conductance is given simply by adding the conductance fraction adjacent to the air thermal conductance with the conductance contributed by the four cantilevers. Air thermal conductance fraction was derived by means of numerical modelling of the steady-state heat flow from the isolated core through the air to the boundaries kept at ambient temperature. As the air thermal conductance relies mostly upon the area of the sensor core, we provided simulations of the thermal flow for several distinct sensor core sizes. Then, using the simulation data, we parameterized the air-adjacent conductance fraction over the sensor core size in the form of a second-order polynomial dependence. The thermal conductance fraction adjacent to cantilevers was derived analytically, realizing that further air thermal flow from cantilevers is due to its relatively small area. So in the thermal model, parameters like sensor core size and cantilever dimensions appear as well as composition and thermal properties of the cantilever and sensor core layers. For a 400 μm microsystem topology with core size 150 μm, the model is predicting thermal resistance of 16.6 K/mW. The parametric model has been proved in a static thermal flow simulation of the complex microsystem and found sufficiently accurate, splitting in less than 2% from the complex microsystem simulation results (probably due to the neglected thermal flow from the cantilevers). For thermal numerical steady-state modelling, we used the novel simulation method called DEETEN (Differential Equation Efficient Treatment by Eliminative Nesting), based on finite-difference discretization in regular cubic mesh domains that are overlapped and nested, if needed, enabling drastic reduction in necessary computer resources.

MECHANICAL PARAMETRIZATION

Mechanical parameterization has been based on numerical modelling only. We investigated several distinct topologies of the microsystem for response to static and dynamic stress and then used the data to derive closed-form dependences.



a) b)

Fig. 1: 3D mapping of temperature field simulation by DEETEN programme for SiC-AlGaAs-GaAs micromechanical structure (a), perspective view on generated domain field.

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[1] S. Beeby, G. Ensell, M. Kraft, N. White, MEMS Mechanical Sensors, Artech House, Inc. Boston, 2004.

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