Identification of Material Properties of MEMS Devices via Parametric Model Order Reduction and Optimization

Tamara Bechtold(1), Dennis Hohlfeld(2), Evgenii B. Rudnyi(3)

(1) Marie-Curie Research Training Network COMSON, University of Wuppertal, Gauss Str. 20, 42119 Wuppertal, Germany, E-mail: Tamara.Bechtold@math.uni-wuppertal.de
(2) Holst Centre / IMEC, High Tech Campus 32, 5656 AE Eindhoven, The Netherlands
(3) CADFEM GmbH, D-85567 Grafing b. München, Germany

In this paper we present a novel approach to determine material thermal properties of a silicon nitride employed in a micro hotplate structure. We build a parameterized reduced-order model from a finite element (FE) model and fit it to transient temperature measurements. The use of parameterized reduced-order models within the optimization iterations produces almost the same results as the full FE model, but speeds up the transient solution time by several orders of magnitude.

Problem definition: An important engineering task is to build a validated model for each characterized novel micro-electro-mechanical (MEMS) device. As in most MEMS applications the whole temperature field has to be known, a FE model is usually employed. Unfortunately, a common problem is that the material properties of the employed thin film materials strongly depend on fabrication conditions and may also be specific for the device under test. One can address this issue by fabricating dedicated test structures to determine the material properties. In this work we propose a scheme to find the material properties on the MEMS device itself.

MEMS Case Study: A silicon-nitride membrane with integrated heater and sensing element was fabricated by low-frequency plasma enhanced chemical vapor deposition. The square membrane is 500nm thick with a side length of 550μm, and the thin-film heater is made from 150nm platinum with a 50nm titanium adhesion layer (see Fig. 1). The unknown material properties are the specific heat, thermal conductivity and mass density of the membrane material, and the heat transfer coefficient between the membrane and the ambient air. We have used a full 3D model (see Fig. 2) with 66.000 nodes, which considers the heat conduction through the solid material and the air beneath the membrane as well as convection to the air above the membrane.

Parameter Extraction Method: We suggest a new method for the determination of the unknown material thermal properties and the heat transfer coefficient, based on parametric model order reduction (pMOR) and optimization. We were able to reduce the time for transient integration of the FE model by using multivariate-moment-matching-based pMOR [1], by a factor of 100. A parametric reduced model has only 117 degrees of freedom (DOF) but still provides high accuracy (see Fig. 3). Material parameters and the heat transfer coefficient are preserved as parameters within the reduced model and can be altered in each iteration of the optimization process. By defining an objective function, which characterizes the difference between simulated and measured results, data fitting cycle according to the algorithm in Fig. 4 is performed. Note that, thanks to pMOR, no new FE model must be built and reduced in each iteration, as done in [2] and [3].

Measurements, Simulation and Optimization Results: Fig. 5 shows the comparison between the measured temperature curve and the initial FE model, in which the thermal properties have been set to literature values [4]. (2.5W/(m*K) for the thermal conductivity, 975*10^3J/(m^3*K) for the product between heat capacity and mass density of the membrane and 10W/(m^2*K) for the heat transfer coefficient between the membrane and the ambient air). The temperature dependence of the material parameters has been neglected, as the measurement results were obtained at comparatively low temperatures. Fig. 6 shows the measured and the simulated temperature response after 57 cycles of optimization. An optimum fit could be obtained with 4.1W/(m*K) for the thermal conductivity, 575*10^-3J/(m^3*K) for the product between heat capacity and mass density of the membrane and 20W/(m^2*K) for the heat transfer coefficient.

References
Fig. 1 Microstructured silicon-nitride membrane.

Fig. 2 FE mesh with 66,000 nodes.

Fig. 3 Comparison between the full FE model with 66,000 DOF and the parametric reduced model with 117 DOF for the initial parameter values.

Fig. 4 Algorithm for fast determination of material properties via parametric model order reduction.

Fig. 5 Measured and simulated transient curves for the initial parameter values.

Fig. 6 Measured and simulated transient curves after 57 cycles of optimization.