**8th. World Congress on Computational Mechanics (WCCM8)**
**5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)**
**June 30 – July 5, 2008**
**Venice, Italy**

# TOPOLOGY OPTIMIZATION OF REINFORCED POLYSILICON THIN PLATES FOR MEMS BASED MICROPHONES

***C. Calaza[1], S. Colpo[1], V. Mulloni[1], F. Giacomozzi[1], B. Margesin[1]**

[1] MEMS group, FBK-irst.
Via Sommarive 18, 38050 Povo Trento ITALY
carlos@fbk.eu

**Key Words:** *MEMS microphone, Reinforced thin plates, Residual stress, FEM.*

## ABSTRACT

The sensitivity of a silicon condenser microphone, which essentially consists of a rigid backplate and a thin movable diaphragm, mainly depends on diaphragm performance. There is the possibility to use diaphragms working either in a membrane or in a plate mode, with tensile forces or bending forces governing the sensitivity to sound pressure respectively. In this study, the numerical simulation of a reinforced polysilicon thin plate is conducted in order to optimize the overall performance of a MEMS condenser microphone. The geometrically nonlinear finite-element method is adopted to analyze the mechanical sensitivity of the diaphragm, and stress stiffening is included in the analysis since the out-of-plane stiffness of the diaphragm can be drastically affected by the state of in-plane residual stresses [1]. The influence on the diaphragm performance of reinforcement parameters and the material residual stresses are studied, and optimum geometric designs are determined to accomplish a range of microphone specifications.

The microphone movable electrode under study will be created with a doped polysilicon layer. It mainly consists of a piston type diaphragm, anchored to a silicon substrate by four flexible radial supporting beams, and stiffened with an array of vertical ribs. These stiffeners will be obtained by filling deep trenches previously etched in silicon substrate with a DRIE process. The main goal will be the realization of a piston diaphragm that remains parallel to the fixed backplate while moving under the applied sound pressure. For this purpose the supporting springs will be designed without stiffeners, to be much more flexible than the rigid diaphragm, in order to take up most of the deformation. The stiffening ribs must be properly designed (width $b_s$, depth $h_s$, and spacing B) in order to obtain the desired rigidity for the movable electrode without affecting the flexibility of the supporting beams. Main advantage of vertical stiffeners is that high rigidities can be obtained by depositing thin polysilicon layers, while obtaining contained masses that allow the achievement of high resonant frequencies without affecting other microphone features. The polysilicon film will be doped with a boron implant and, subsequently, a high-temperature annealing will be performed in order to reduce the polysilicon internal stress. The layer will be finally patterned and etched to define the diaphragm geometry.

Figure 1 shows the results attained with the finite element model used for the reinforced diaphragm. Four-node finite strain shell elements associated to a layered section are used to model the thin diaphragm, while the reinforcement sections were modelled with 2-node linear finite strain beam elements associated to a rectangular section. Because of the geometric symmetry, only 1/8 of the structure has to be analyzed. For the boundary conditions, it is assumed that the supporting rims have infinite rigidity and the edges of the support springs are clamped. The selection of material properties plays an important

role to achieve accurate results. Plate simulations were performed using a Young's modulus E=163 GPa, a Poisson's ratio $\nu$=0,22 and a density $\delta$=2330 kg/m$^3$ for polysilicon. The diaphragm thickness used is $h_m$=1,3 µm and its half-width is $L_m$=500 µ m. In view of some process limitations, the depth and spacing of the reinforcements have been set to $h_s$=15 µm and B=40 µm, with a width $b_s$=2.2 µm.

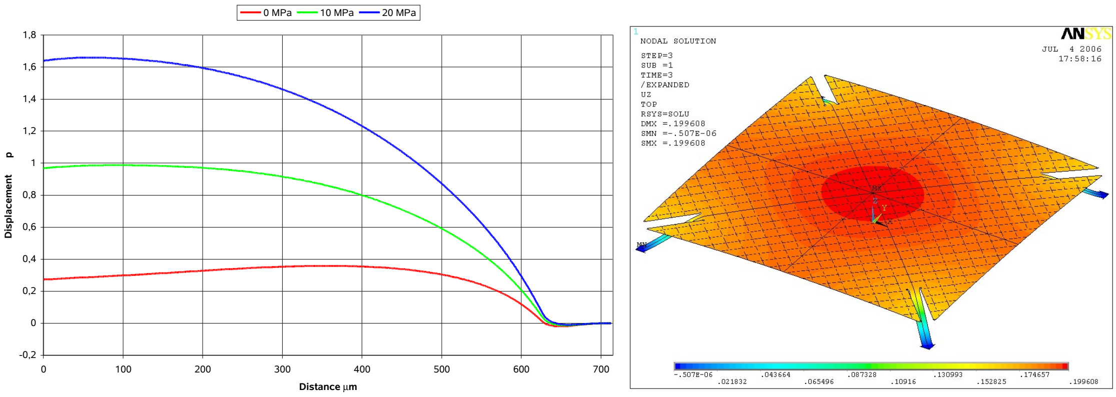

**Figure 1. a) Stress-induced deformation due to stress mismatch between plate and reinforcements b) Simulated deflection of the diaphragm under a sound pressure of 20 Pa.**

The residual stresses depend on the fabrication process, and it is difficult to establish its exact value for all diaphragm parts. While a 32 MPa tensile stress has been measured for the plane doped polysilicon layer with the wafer curvature method the reinforcement sections are expected to show higher values, as they will not be affected by the boron implantation. Figure 1a shows the profiles expected for the stress-induced deformation when considering mismatches between plate and reinforcements stress, $\Delta_{stress}$=0, 10, 20 MPa. With uniform stress in the polysilicon parts only a small upward deflection is obtained due to the presence of a thin $Si_3N_4$ layer in the plate, intended as electrical isolation. In the case of higher stress differences a bending effect that reduces the effective acoustic gap between plates can be noted. The thickness of the nitride isolation layer (1,27 GPa tensile) can be raised to partially correct this bending effect, even if this additional stress makes the diaphragm stiffer and reduces the microphone sensitivity.

The topology of the supporting springs has been optimised such that the deflection of the reinforced diaphragm under a sound pressure of 20Pa (120 dB) matches the value established with the electro-mechanical equivalent model used for acoustic modelling of the microphones [2]. This one-dimensional model is used to establish an optimized spring constant for the diaphragm, according to the desired acoustic specifications (sensitivity, frequency response…). A FEM parametric simulation of the membrane, using supports width and length as parameters is performed to attain supporting springs matching this equivalent spring constant. Figure 1b shows the static deflection for a polysilicon reinforced membrane with a 32 MPa tensile stress. The overall diaphragm mechanical sensitivity was obtained by observing the difference of the mean membrane deflection under 0 and 20 Pa pressure loads.

## REFERENCES

[1] P.R. Scheeper, W. Olthuis and P. Bergveld, "The design, fabrication and testing of corrugated silicon nitride diaphragms" J. Microelectromech. Syst. **3** (1994) pp 36-42.

[2] B. Margesin, A. Faes, F. Giacomozzi, A. Bagolini, M. Zen "Fabrication of a Piston-type Condenser Microphone with Structured Polysilicon Diaphragm", in Proceedings AISEM 2004, Ferrara, February 8-11, 2004, pp. 382-387.