EVALUATION OF MATERIAL PROPERTIES OF A SQUARE-FORM POROUS NANOFILTER

Ádám Kovács[1], **András Kovács**[2]

[1] Department of Applied Mechanics, Budapest University of Technology and Economics, PO Box 91, 1521 Budapest, Hungary
[2] Institute for Applied Research, Hochschule Furtwangen University of Applied Sciences, 78120 Furtwangen, Robert-Gerwig-Platz 1, Germany

Introduction

Perforated and porous membranes are often used in various engineering applications. As an example, they can serve for micro- and nanofiltering purposes in micro-electromechanical systems.
The investigated porous silicon (PS) layer was formed in a thin p-type crystallized silicon (c-Si) membrane from the frontside of the wafer by electrochemical etching. Measured porosity was 75% with a mean pore size of 4.85 nm. To achieve sufficient stability an upper perforated silicon nitride (SiN) layer was used as masking structure during electrochemical anodization (Fig. 1).

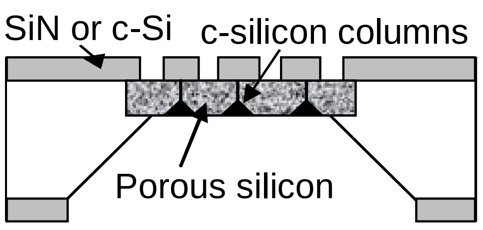

Fig. 1 Schematic view of the multi-layer membrane

Due to this special masking structure, anodization current was mainly directed in vertical direction and therefore, residual c-Si columns were formed between the etched SiN-structures. RIE-technique was used to remove the residual c-Si at the backside of the wafer after the anodization. The crystalline silicon support layer can be controlled by the anodization conditions, RIE etching time and distance between the perforations.

Experimental

For the characterization of the mechanical properties (elastic modulus and fracture strength) maximum deflection and bursting pressure were measured experimentally for square-form membranes by a triangulation system (LC-2400, Keyence) and by a computer controlled pressure set-up, respectively, shown in Fig. 2. The bursting pressure was recorded by a differential pressure sensor (917, PCE).

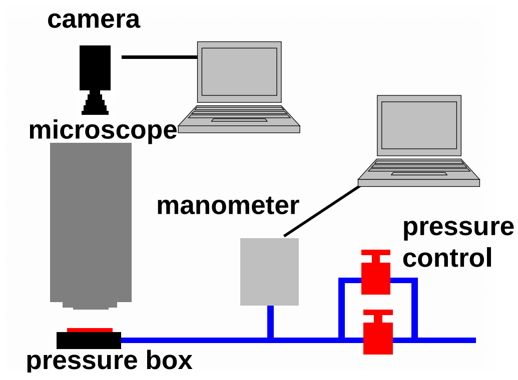

Fig. 2 Experimental set-up for breaking tests

Different filter-configurations have been analyzed. They differed in the thicknesses of SiN and PS layers as well as the etching rate and column-width of crystallized silicon [1].

Numerical evaluation

In order to evaluate the experimental results and to determine effective material parameters for the multi-layered structure, an equivalent closed-plate finite element model was built. The model was validated by comparing the maximum deflection of the porous layer (Fig. 3). The elastic modulus and the fracture strength for full structures have been determined by experiments for different layer-thicknesses (Figs. 4-5). The same parameters for perforated and porous layers were then calculated by the following estimates:

$$E_p = (1-P)^{e} E,\ \sigma_{Bp} = (1-P)^{f} \sigma_B .$$

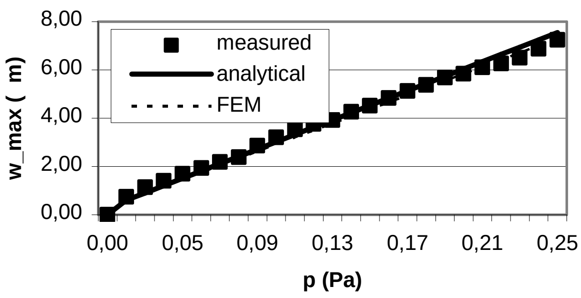

Fig. 3 Measured and estimated maximum deflection of a three-layer nanofilter membrane

In the above equations *P* is the porosity and *e*, $f > 1$ are material constants. Their values were determined by simulations [2].

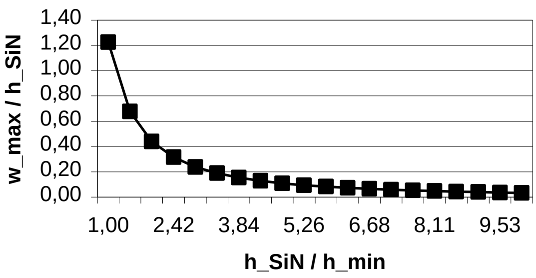

Fig. 4 Measured relative maximum deflections

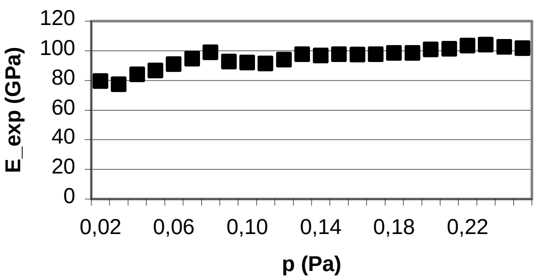

Fig. 3 Evaluated elastic modulus

Once the material constants had been determined for SiN- and PS-layers, c-Si reinforcement was replaced by an equivalent third layer. The thickness of this layer has been calculated by the equivalence of bulk volumes. Effective material parameters (E_{eff}, σ_{Beff}) were then defined as an average of the layers' parameters weighted by the thickness [3]. The mechanical response has been determined numerically.

Results and Discussion

The performance of filters highly depends on the porosity. In order to obtain higher filtration rate the porosity should be as high as possible [4] which diminishes the strength, and consequently, the load capacity of the device. This effect could be compensated by the application of a SiN support layer and c-Si columns as a support grid within the porous Si layer.

Evaluated elastic moduli varied between 5.9 GPa and 14.6 GPa, reflecting the increase of strength by residual c-Si columns. Fracture strength could be also increased from 251 MPa (at least amount of reinforcement) to 304 MPa.

Since elastic modulus and fracture strength are both dependent not only on the porosity but also on the thickness of layers [5], the use of effective material properties could simplify the numerical estimation of bursting pressure in the design phase.

Conclusion

Multi-layered closed plate model served for the numerical evaluation of effective material properties for a complicated porous nanofilter structure. Elastic modulus was determined from the measurement of maximum deflection, fracture strength was calculated from the measured bursting pressure. The effect of porosity on the material properties could be taken into account by a simple reduction formula.

References

1. Kovács, A., Kovács, Á., Pogány, M., Mescheder, U. Mechanical investigation of perforated and porous membranes for micro- and nanofilter applications. *Sensors & Actuators B*, **127** (2007) 120-125.
2. Kovács, Á., Kovács, A., Mescheder, U. Estimation of elasticity modulus and fracture strength of thin perforated SiN membranes with finite element simulations. *Comp. Mat. Sci.*, **43** (2008) 59-64.
3. van Rijn, C.J.M., van der Wekken, M., Nijdam, W., Elwenspook, M. Deflection and maximum load of microfiltration membrane sieves made with silicon micromachining. *J. of Microelectromechanical Systems*, **6** (1997) 48-54.
4. van Rijn, C.J.M. *Nano and Micro Engineered Membrane Technology*, Elsevier, (2004).
5. Lange, V., Higelen, G. Static and dynamic characterization of Si-membranes. *Sensors and Actuators A*, **46-47** (1995) 47-50