Development of Stress Relief Suspensions for Micro-Machined Silicon Membranes By COMSOL Multiphysics® FEM Simulations

W. Kronast[1], U. Mescheder[1], B. Müller[1]

[1]Hochschule Furtwangen, Furtwangen, Germany

Abstract

Introduction: A new design concept of a stress relief structure for micro machined silicon membranes used for dynamically activated micro mirrors is developed using FEM simulation with COMSOL Multiphysics®. The need to fabricate silicon membranes of high optical and mechanical quality gets very important in recent years, as they are used in a large variety of MEMS and MOEMS applications. The mechanical quality even in silicon membranes fabricated in SOI (Silicon on Insulator) technology mostly suffer from buckling by residual compressive stress caused by mismatch in the coefficients of thermal expansion between silicon and the buried silicon oxide layer [1, 2]. This often leads to severe distortion of stress sensitive devices such as membrane based micro mirrors [3]. A tensile pre-stress in the membrane increases the stiffness and thus decreases the sensitivity of membrane based sensors. In most applications this leads to severe limitations in functionality. We developed and fabricated a new stress relief structure for a micro mirror device, which reduces the stress induced deformation of membranes and leads to substantially flat mirrors of high optical quality (distortion $< \lambda/10$) [4]. This is achieved by a special tangential beam suspension which allows an in-plane expansion or contraction of the membrane proportional to its inherent compressive or tensile stress.

Use of COMSOL Multiphysics®: The micro mirror was developed and optimized using the MEMS Module of COMSOL Multiphysics®. The challenge was to deduce a membrane suspension, which eliminates a given material pre-stress assumed in the three different layers of a SOI wafer and therefor leads to a membrane with an undisturbed flatness. Different models were created to compare the new stress relief design with a conventional rigidly clamped membrane:
i.) 2D axisymmetric model of a rigidly clamped membrane.
ii.) 3D model for the case of the complete device with the new stress relief layout.
In both cases the influence of mechanical pre-stress in the three layers of the SOI Wafer was investigated parametrically making explicitly use of the initial stress matrix S0 in the structural mechanics interface. Optimized beam structures were determined. Figure 1 shows the 3D COMSOL Multiphysics® model of the membrane, suspended by 12 tangential beams to the surrounding SOI chip.

Results: Figure 2 shows for example a relaxed membrane with out-of-plane displacement of 82 nm with a large compressive pre-stress of σ= -20 MPa. Fabricated membranes were

characterized by optical interference measurements. A comparison of membranes with the new stress relief suspension shows for example for a membrane with 6 mm Ø and 10 µm thickness a distortion of 54 nm (Figure 3) compared to 340 nm of a conventional rigidly clamped membrane. The measured results are in very good agreement with the prediction of the COMSOL Multiphysics® simulation (Figure 4) with 48 nm distortion.

Conclusion: The new stress relief membrane suspension reduces the internal stress of membranes to achieve distortion-free mirrors of high optical quality. This new structure is of general interest as it fits also to other membrane materials such as poly-silicon, silicon nitride or SU8.

Reference

[1] J. Haisma, "Pillar-lattice-assisted stress-free silicon-on-insulator", Applied Physics Letters, Vol. 83, No.16, 2003, pp. 3323-3325
[2] T. Sasaki, K. Hane, "Initial deflection of silicon-on-insulator thin membrane micro-mirror and fabrication of varifocal mirror", Sensors and Actors A 172 (2011) pp. 516-522
[3] W. Kronast, U. Mescheder, R. Huster, "Stressuntersuchung und Optimierung von SOI basierten Membranen", Mikrosystemtechnik Kongress 2009, Berlin, Proc. pp. 590-593, ISBN 978-3-8007-3183-1 © VDE Verlag
[4] W. Kronast, U. Mescheder, B. Müller, R. Huster, "Development of a focusing micromirror device with an in-plane stress relief structure in SOI technology", Proc. of SPIE, MOEMS and Miniaturized Systems XII, Vol. 8616, 86160Z-1 -861602Z-10, (2013)

Figures used in the abstract

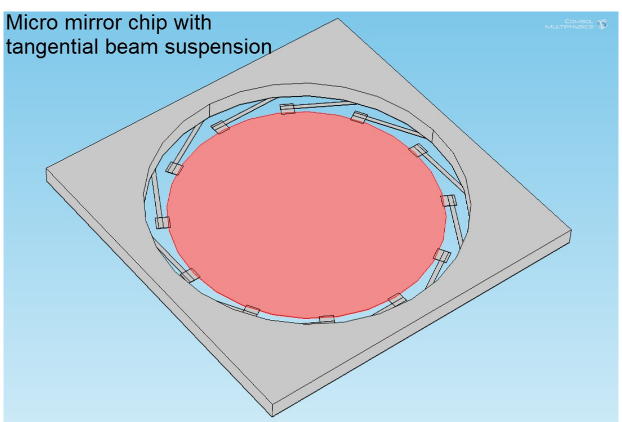

Figure 1: 3D COMSOL Multiphysics® model of the mirror chip with a tangential beam suspended membrane

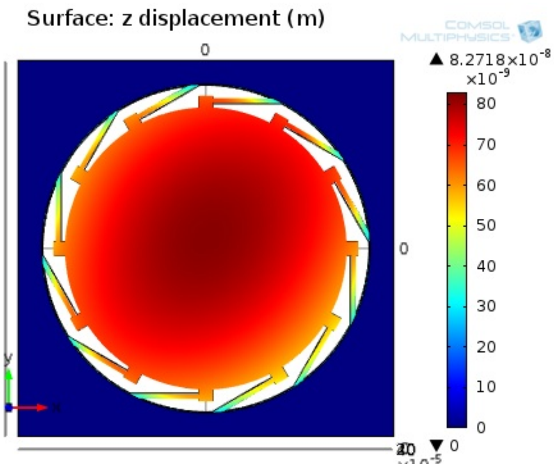

Figure 2: 3D FEM Simulation of a tangential-beam suspended membrane surrounded from silicon chip; membrane compressive pre-stress σ = -20 MPa; out of plane displacement (z-displacement) = 82 nm

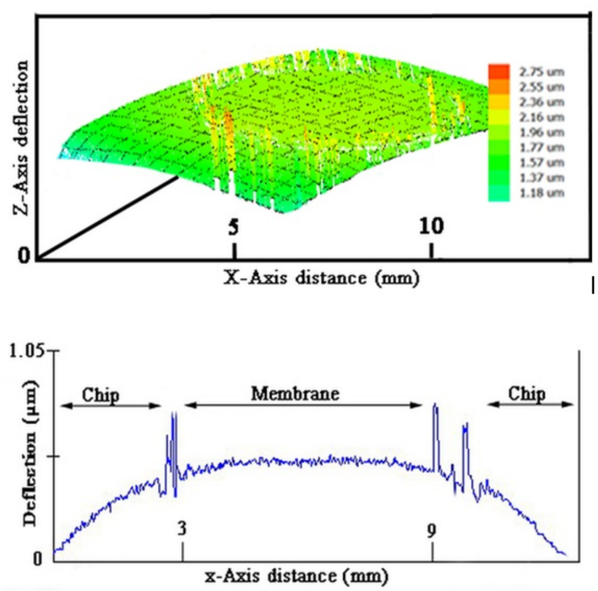

Figure 3: 3D Optical interference measurement and cross section of a micro mirror with a tangential-beam suspended membrane: membrane thickness 10 µm; 6 mm Ø, 1675 µm beam length. Out-of plane distortion of the membrane due to internal stress with reference to the membrane rim: 54 nm

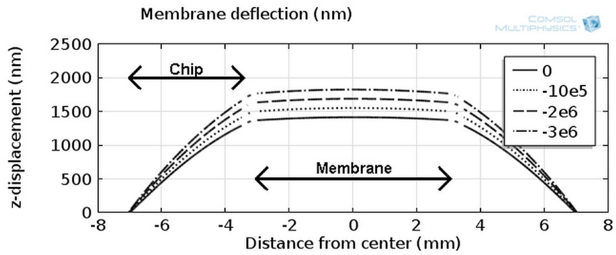

Figure 4: 3D FEM Simulation of a tangential-beam suspended membrane (cross section); intrinsic pre-stress rang σmem= 0 to – 3 MPa. Out of plane distortion of membrane due to internal stress of -1MPa with reference to the membrane rim 48 nm