Development of Stress Relief Suspensions for Micro-Machined Silicon Membranes

Wolfgang Kronast, Ulrich Mescheder, Bernhard Müller
Furtwangen University, IAF, Robert-Gerwig Platz 1, 78120 Furtwangen, Germany

Introduction:
Micro machined Silicon membranes manufactured in Silicon on Insulator (SOI) technology often suffer from buckling caused by internal stress of the material. A new concept of a stress relief structure used for dynamically activated micro mirrors, as seen in Fig. 1, has been developed. It reduces the stress induced deformation and leads to substantially flat mirrors of high optical quality [1,2].

![Fig. 1. Schematic (left) and fabricated micro mirror device (right)](image)

A special tangential beam suspension allows an in-plane expansion or contraction of the membrane proportional to its inherent compressive or tensile stress (Fig. 2).

Computational Methods:
- 3D simulation using the MEMS Tool of COMSOL Multiphysics V4.2.
- Influence of material pre-stress of SOI wafer by use of the initial stress matrix \( \sigma_0 \) in the structural mechanics interface.

Geometry:
- Membrane radius: 3 mm, 10 µm thick
- Beams: L/W/H: 1800µm/100µm/10µm
- Chip size: 8 mm x 8 mm

FEM Results:
- In-plane expansion (xy - displacement) of the membrane of 327 nm enabled by the weak flexibility of the suspension beams (Fig. 3).
- Stress relief of compressive pre-stress \( \sigma = -20 \text{ MPa} \) resulting in a flat membrane with only \( \Delta z = 82 \text{ nm} \) out of plane distortion (Fig. 4).

![Fig. 3. xy - displacement (in plane)](image)

![Fig. 4. z - displacement](image)

Comparison with measurements:

Conventional rigidly clamped membrane:
Large distortion \( \Delta z = 335 \text{ nm} \) (simulated for an pre-stress of \( \sigma = -1 \text{ MPa} \)) and \( \Delta z = 340 \text{ nm} \) measured.

![Figure 5. Rigidly clamped membrane distortion; left: FEM, pre-stress \( \sigma = -3 \text{ – 0 MPa} \); right: measured](image)

New tangential beam suspended membrane:
\( z \)-displacement \( \Delta z = 53 \text{ nm} \) (simulated); \( \sigma = -1 \text{ MPa} \) and \( \Delta z = 54 \text{ nm} \) measured.

![Figure 6. Novel design membrane distortion; left: FEM, pre-stress \( \sigma = -3 \text{ – 0 MPa} \); right: measured](image)

Conclusions:
FEM simulation together with measurements prove the novel concept of stress relief suspensions.

References:

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