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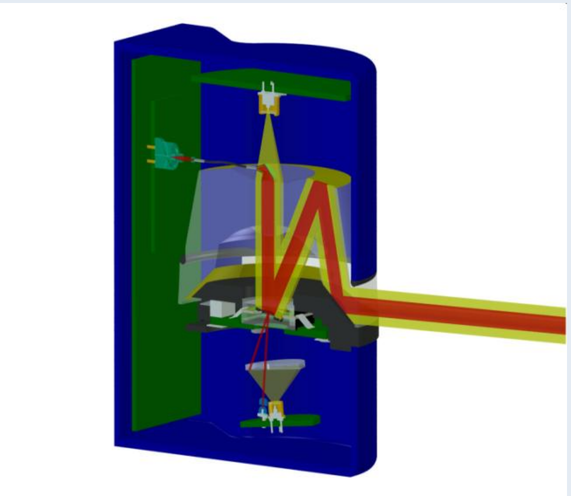
MEMS mirror for low cost laser scanners

Ulrich Hofmann

Outline

- Introduction
- Optical concept of the LIDAR laser scanner
- MEMS mirror requirements
- MEMS mirror concept, simulation and design
- fabrication process
- first results
- summary and outlook

Introduction



Goals of the LIDAR sensor development:

• range:	80 m
• field of view:	250 degrees
• compact size:	6 cm x 6 cm x 8 cm
• low cost:	< 40 €

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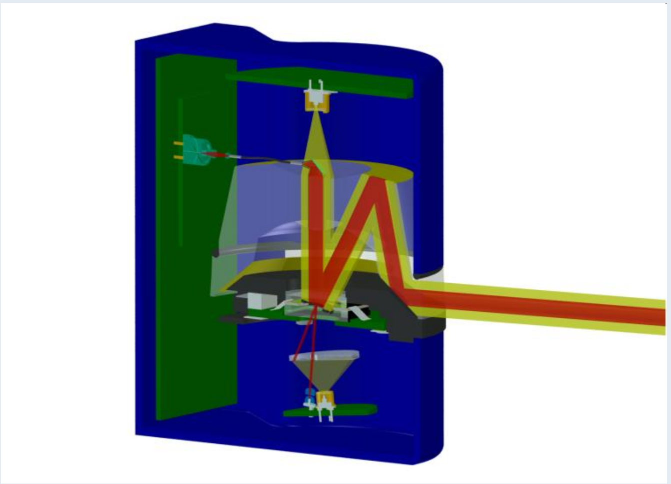
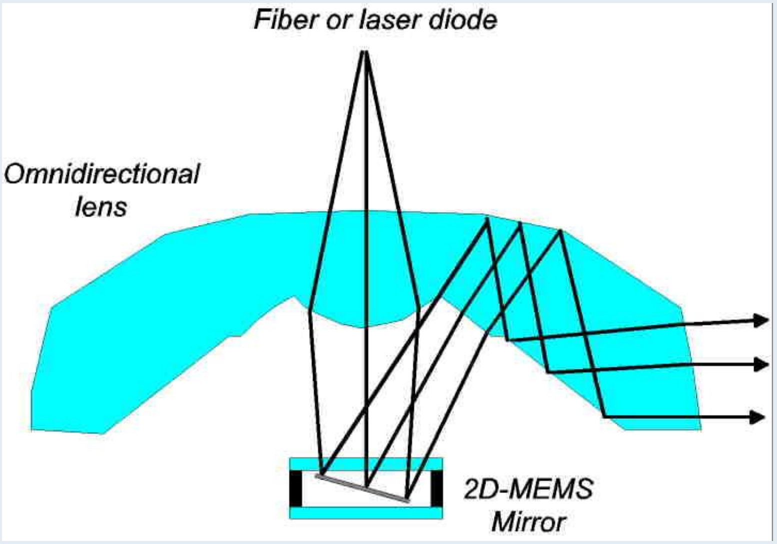
LIDAR sensor optics concept





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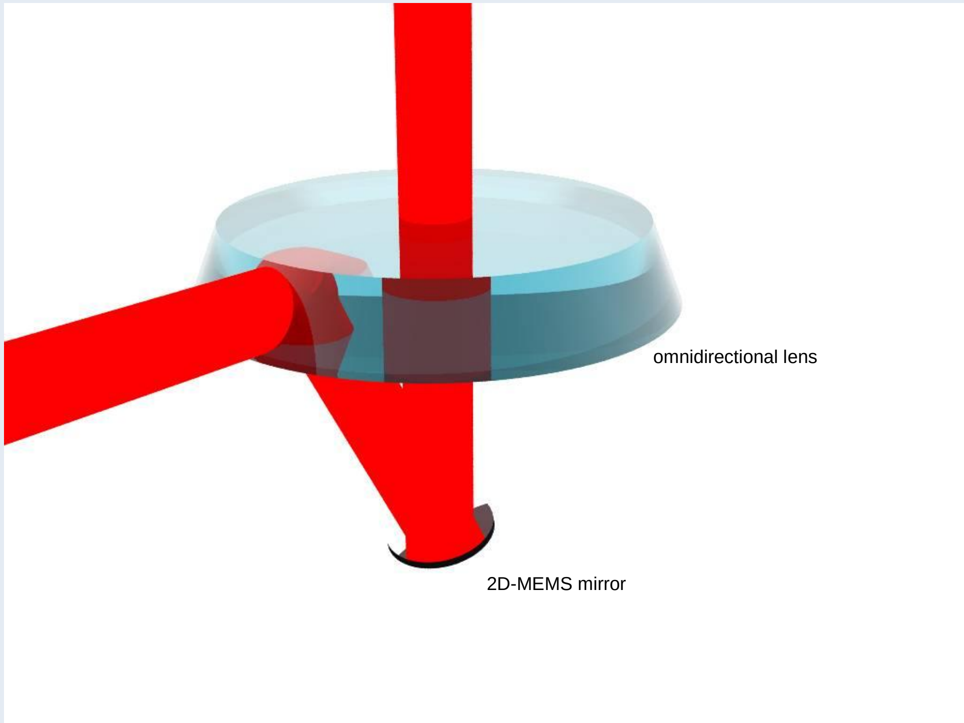
LIDAR sensor optics concept



MEMS mirror requirements

1. large mirror aperture size of 7mm

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2. two-axis laser beam deflection

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6. shock and vibration robust design

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7. full functionality over broad temperature range (-40..+85°C)

MEMS mirror requirements

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3. circular scan pattern => constant azimuth angle
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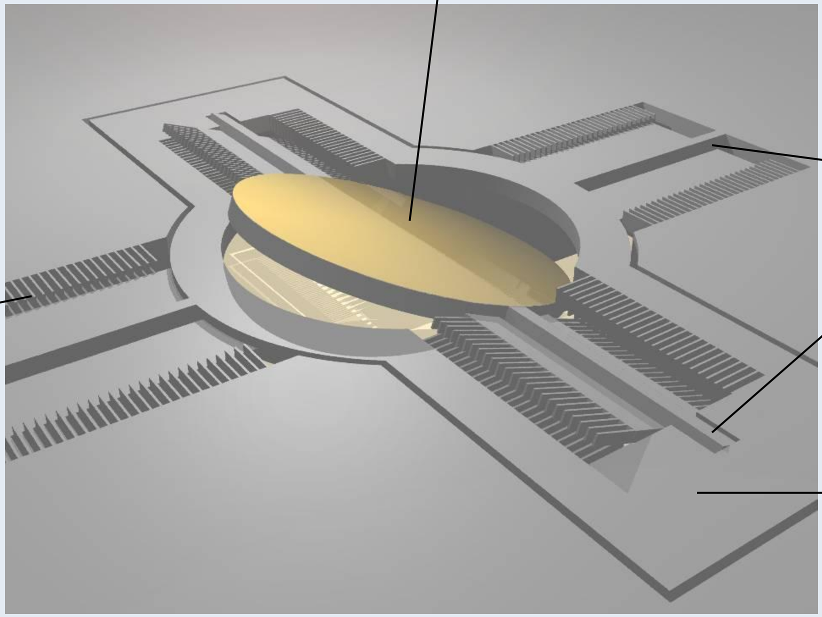
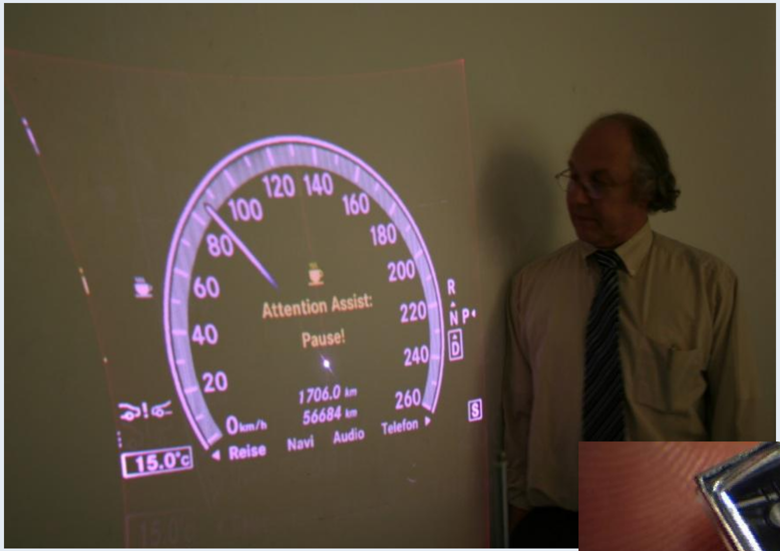
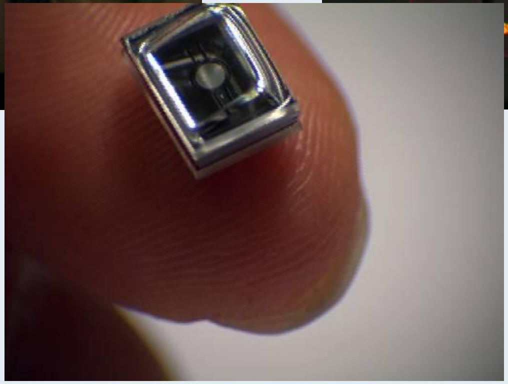
6. shock and vibration robust design
7. full functionality over broad temperature range (-40..+85°C)
8. mass producible at low cost

Standard 2D MEMS mirror design approach: Gimbal mount configuration



Gimbal mount design is the optimum choice for laser projection displays ...



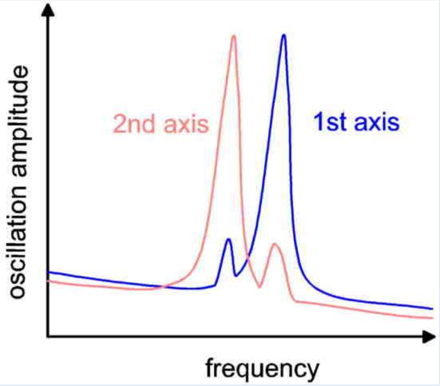


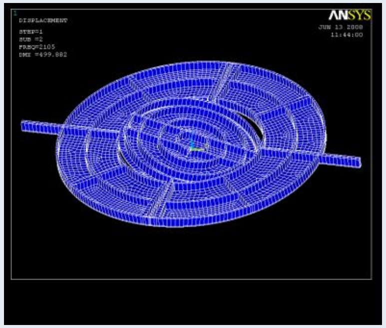
... but not for a 7mm circle scanner

1. circular scanning requires identical resonant frequencies of both axes difficult to achieve with a gimbal design

2. the MEMS scanner would become too large and too expensive

3. disadvantageous eigenmode spectrum

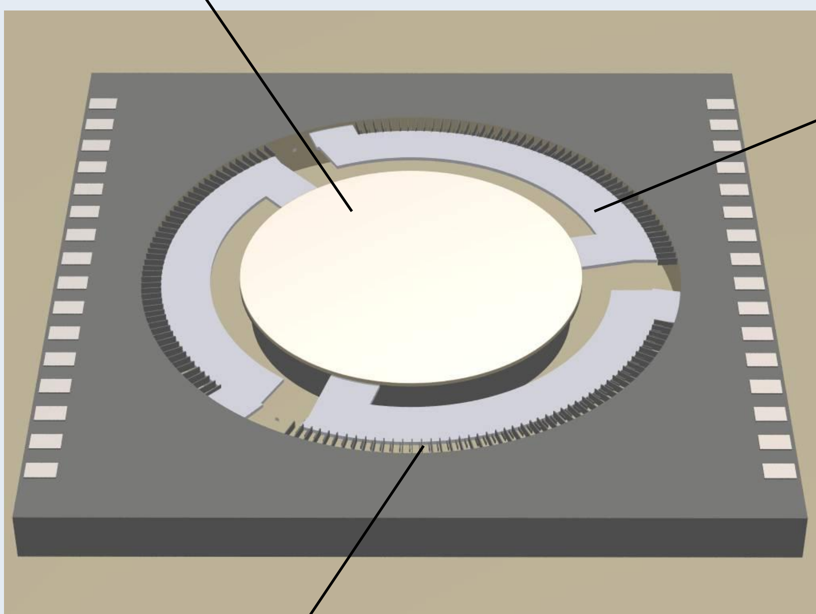




MEMS mirror concept: „Tripod design“

mirror plate (diameter 7mm, thickness 500 µm)

circular bending springs (thickness 40 µm)

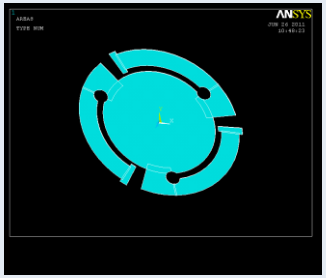


stacked vertical comb electrodes for driving and sensing

- identical resonant frequencies in xy
- minimum chip-size
- circular springs enable large tilt angle
- advantageous eigenmode spectrum

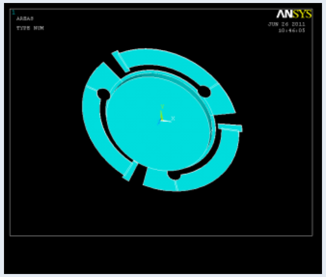
Finite element analysis of dynamic mirror deformation

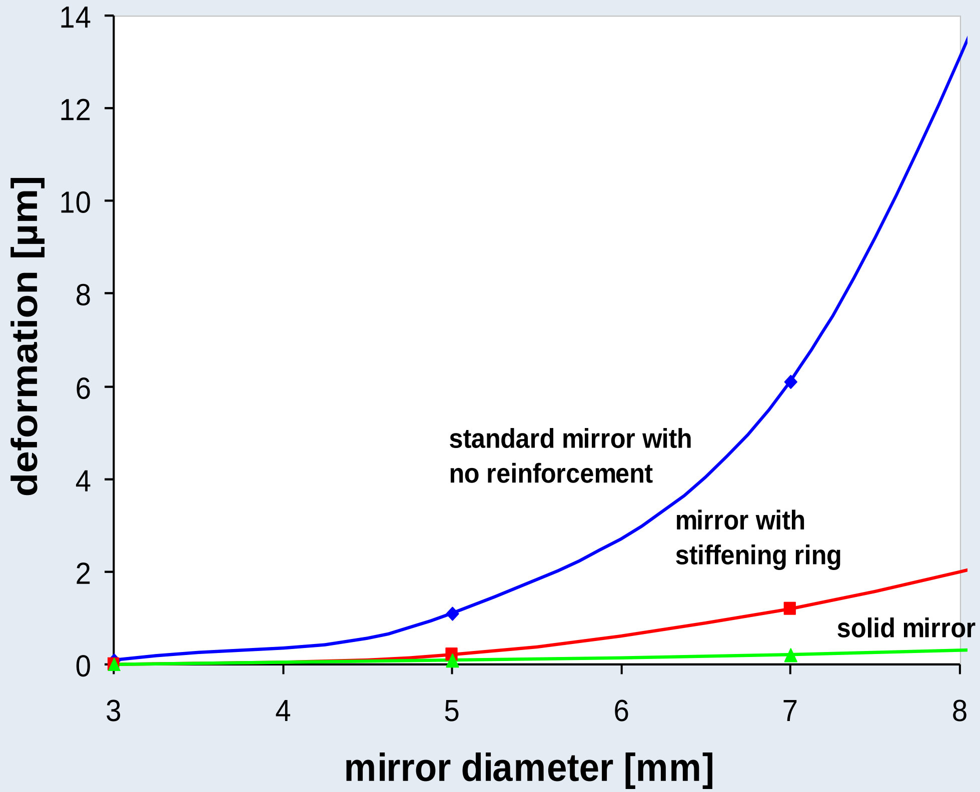
mirror
standard
thickness 80µm



mirror with
stiffening rings
thickness 500µm

solid mirror
thickness 500µm





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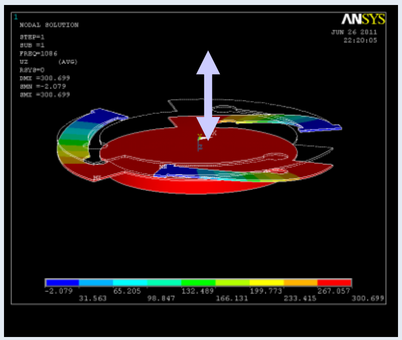
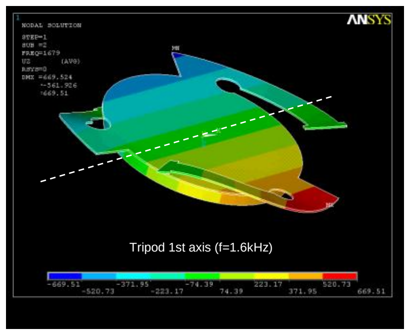
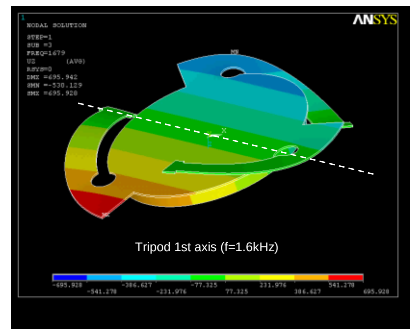
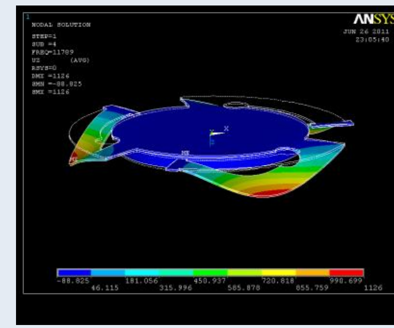
Modal analysis









1st mode:
parasitic piston mode
@ 1kHz

2nd mode:
first scan axis
@ 1.6kHz

3rd mode:
second scan axis
@ 1.6kHz

4th mode:
parasitic mode
@ 11.7kHz

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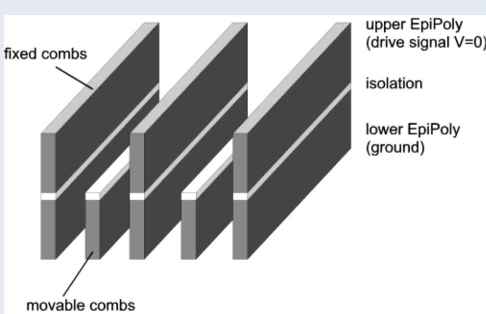
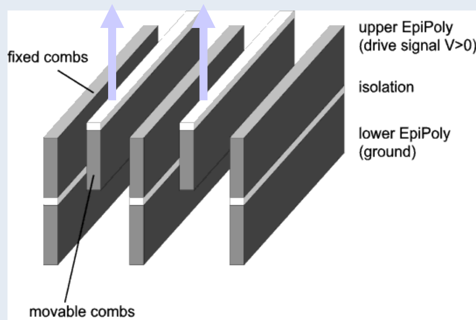
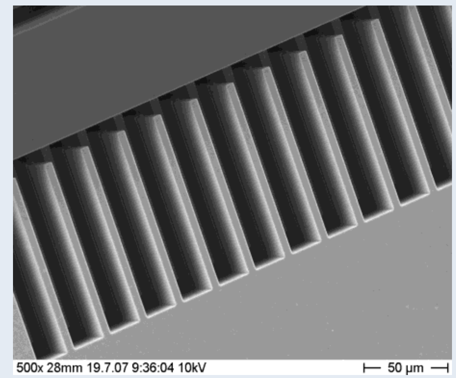
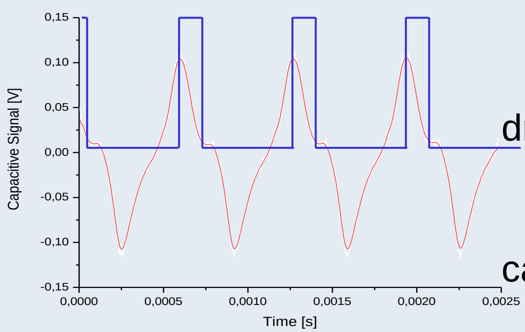
electrostatic out-of-plane actuation by stacked vertical comb drives









drive pulse

capacitive signal → phase control loop

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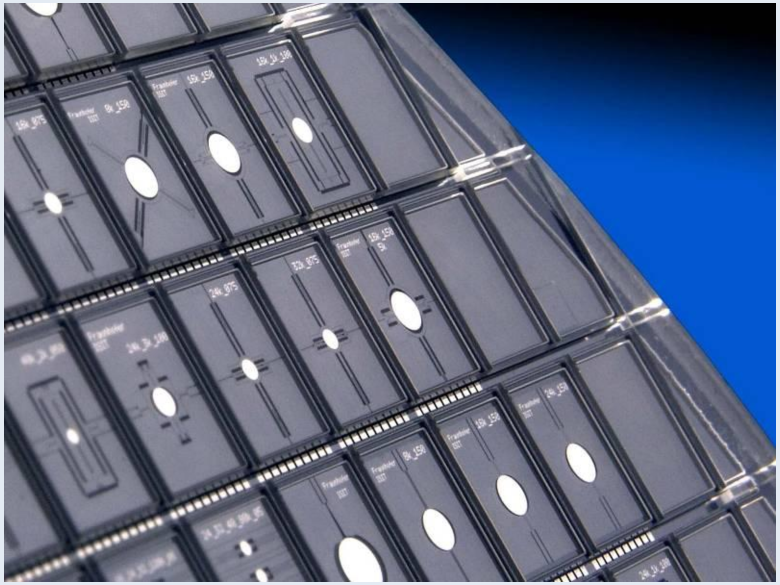
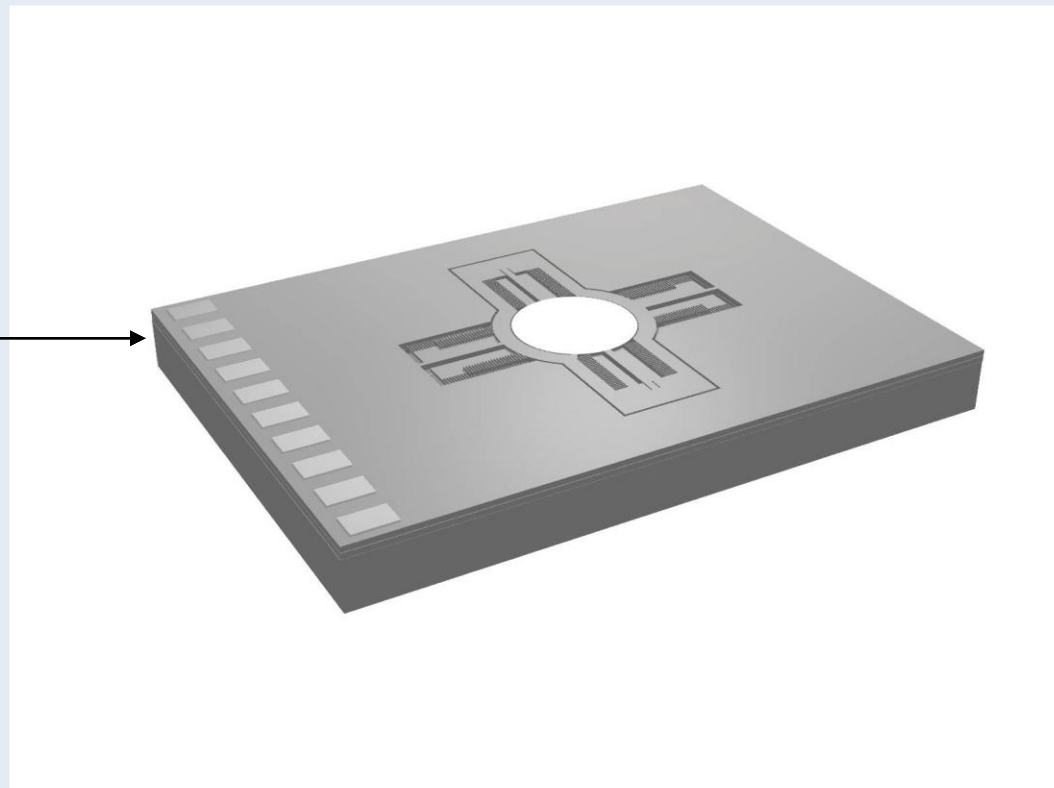
hermetic vacuum packaging of MEMS mirrors on wafer level



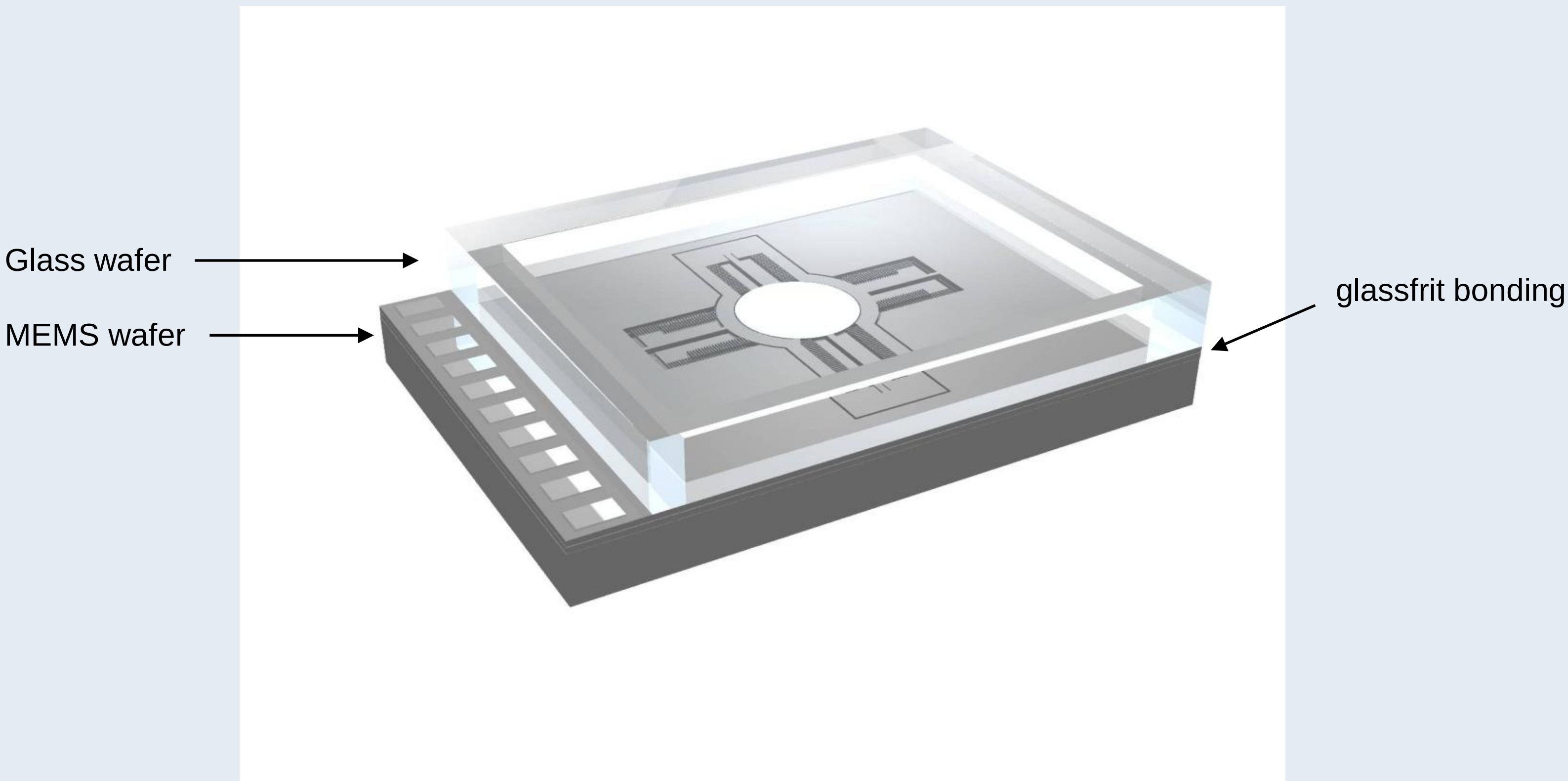
1. minimum damping
2. maximum scan angle
3. low driving voltage
4. effective protection against contamination

vacuum encapsulation of 2D-MEMS mirrors on wafer-level

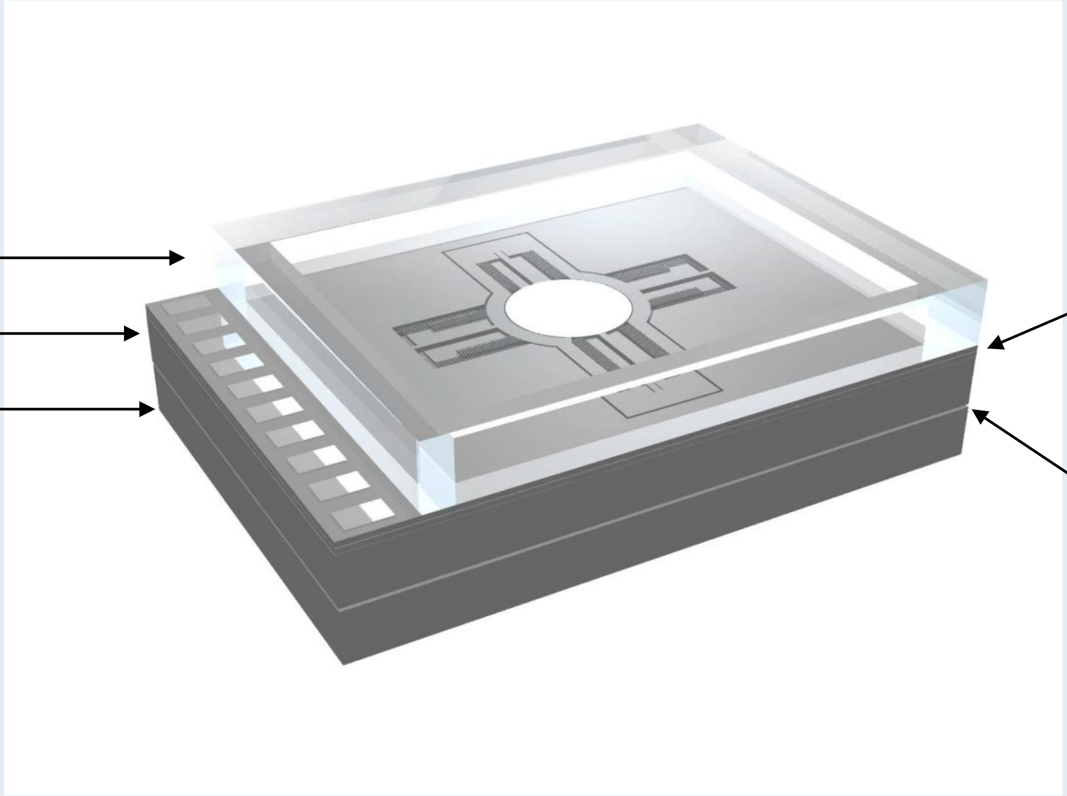
MEMS wafer



vacuum encapsulation of 2D-MEMS mirrors on wafer-level

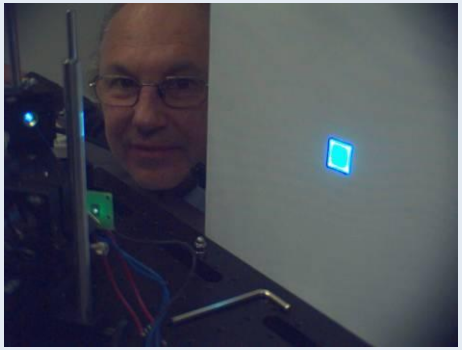


vacuum encapsulation of 2D-MEMS mirrors on wafer-level

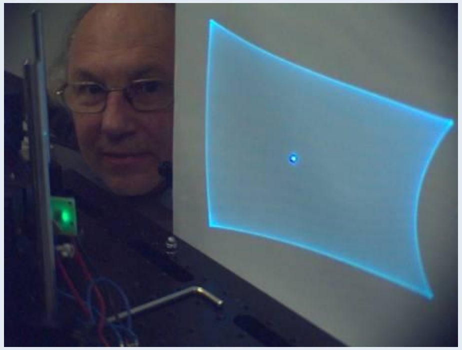


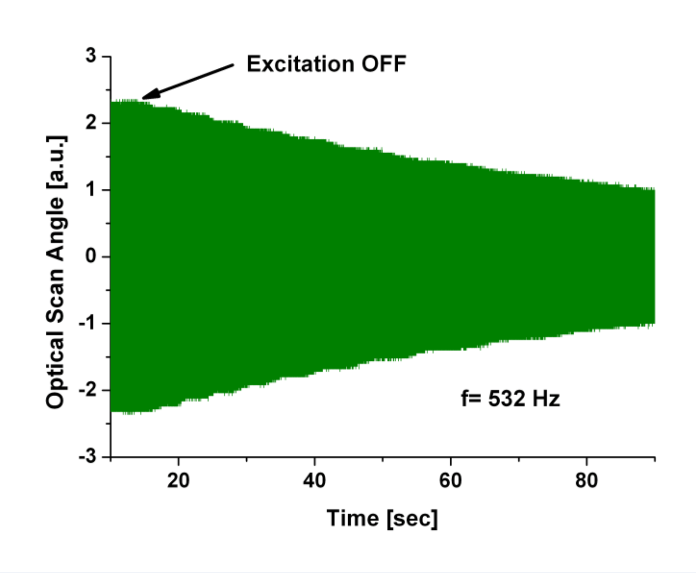
the benefit of vacuum encapsulation of MEMS scanning mirrors

atmosphere



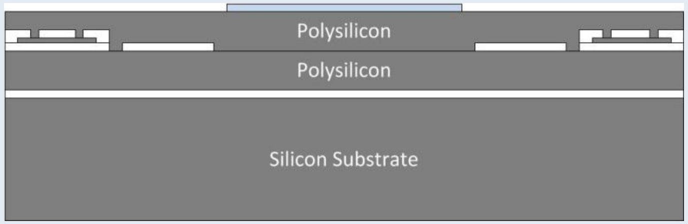
vacuum

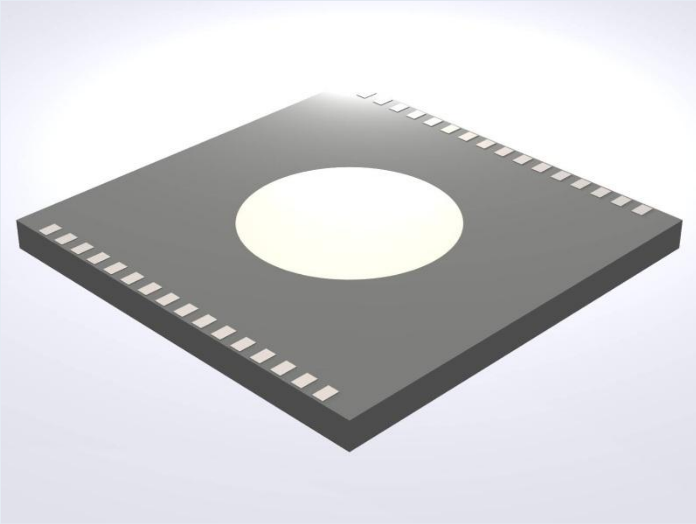




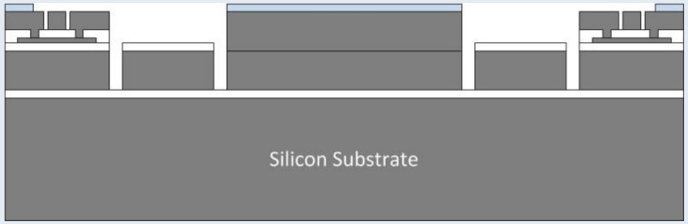
Q-factor > 140,000

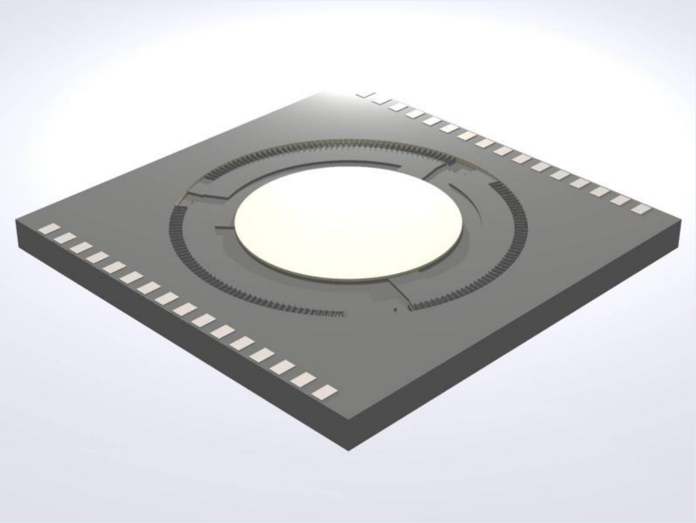
fabrication process based on dual layer 80µm thick polysilicon process



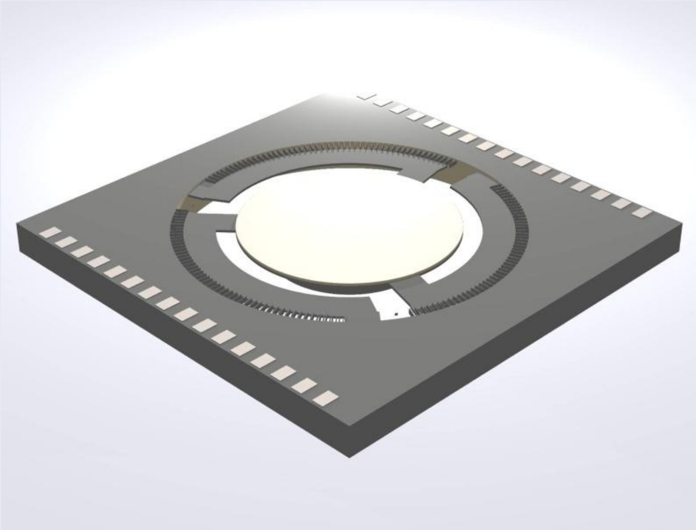


frontside etch

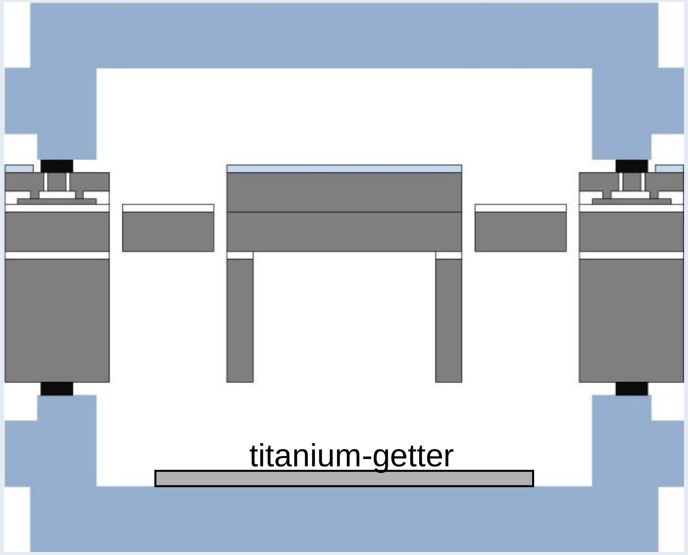


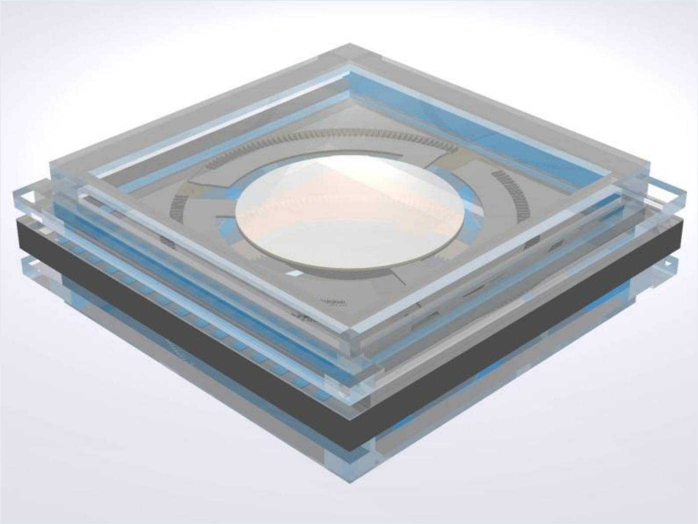


rear side etch

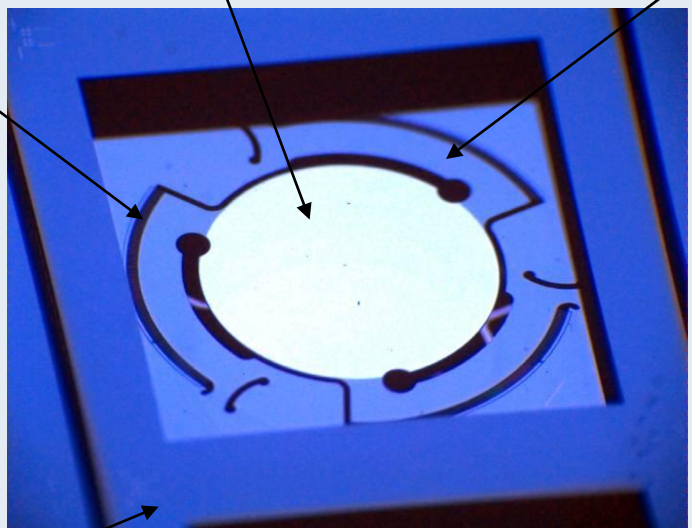


Wafer level vacuum encapsulation (cavity depth > 3 mm)

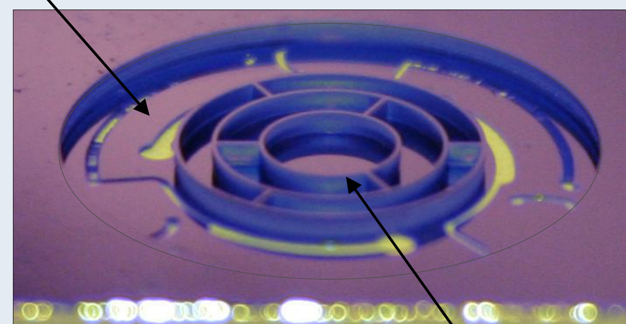




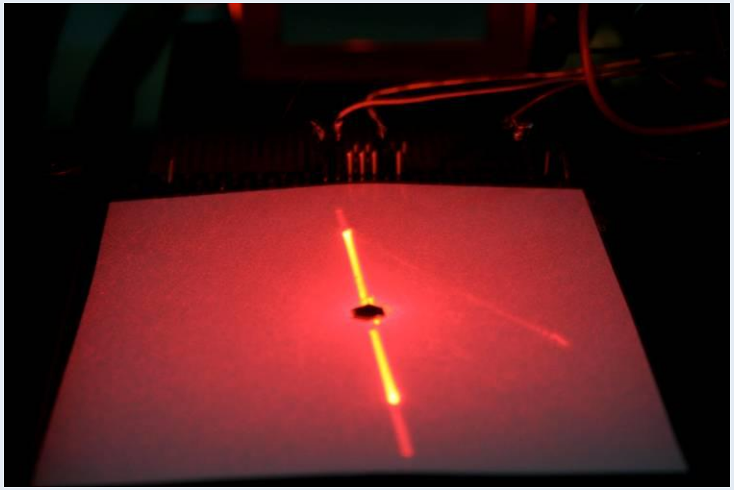
fabricated tripod mirror test structure



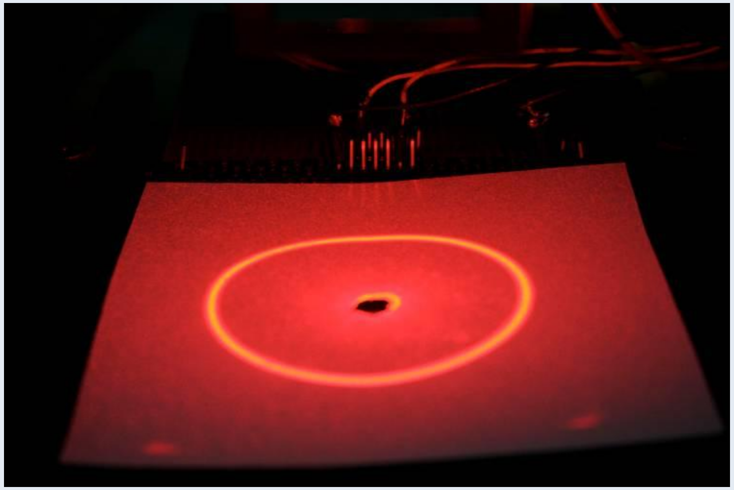
rear side of the mirror



first functional test of tripod mirror test structure

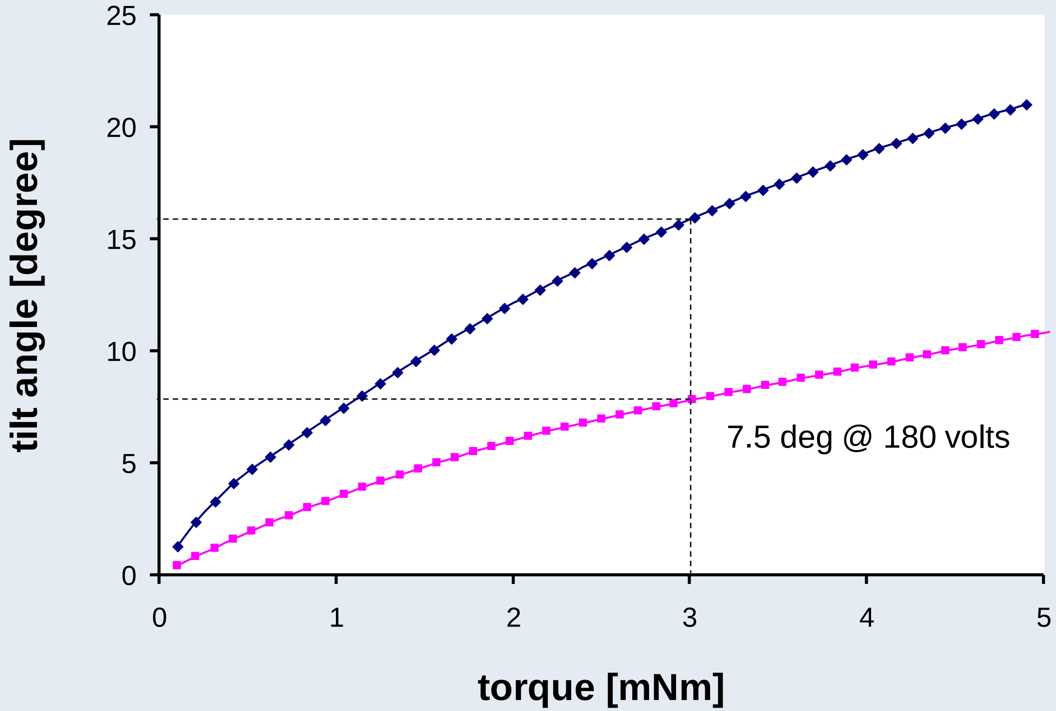


single axis excitation
f=1.5kHz



dual axis excitation
f=1.5kHz

Tripod MEMS mirror design with increased tilt angle – Finite Element Analysis of nonlinear springs



new tripod mirror
f = 0.8 kHz

tripod test structure
f = 1.5 kHz

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Conclusion

- Vacuum packaging is the key for large aperture MEMS mirrors to achieve large scan angles
- A tripod seems to be the appropriate design for a two-axis circle scanning MEMS mirror
- Batch processing on 8-inch silicon wafers enables low-cost mass production of these devices

Acknowledgement

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