January 2022

MEMS Piston Mirror Arrays for Computer Generated Holography

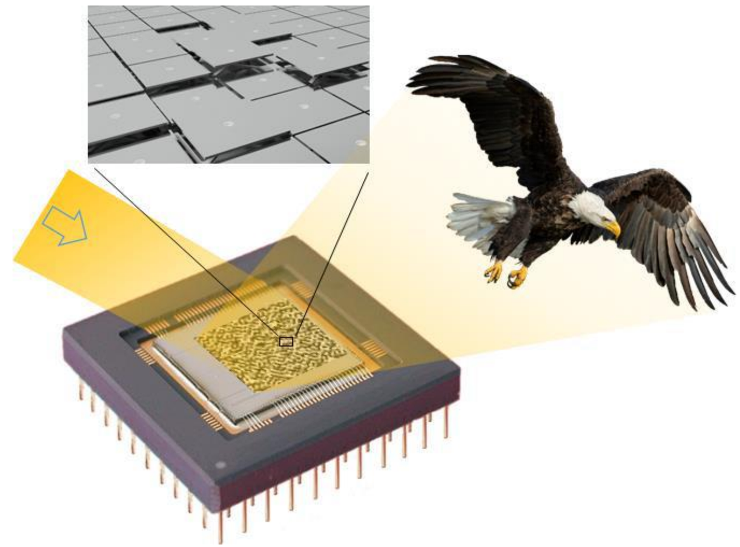
Peter Duerr, Andreas Neudert, Mario Nitzsche, Christoph Hohle, Fraunhofer IPMS
Hagen Stolle, Johannes Pleikies: SeeReal Technologies

FRAUNHOFER INSTITUTE FOR PHOTONIC MICROSYSTEMS IPMS
Maria-Reiche-Straße 2
01109 Dresden
Germany

www.ipms.fraunhofer.de

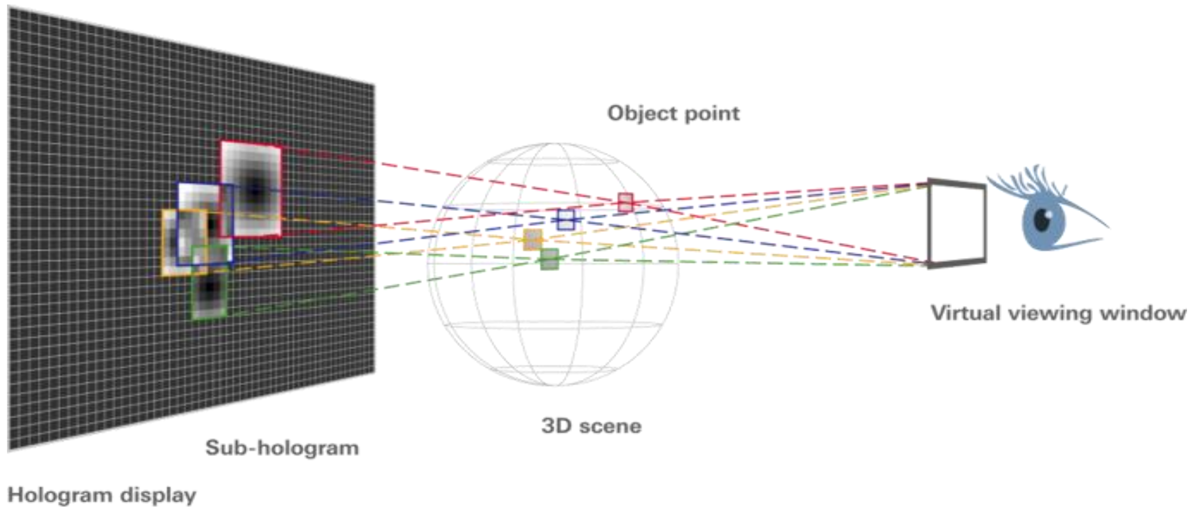
Contents

- Motivation
- REALHOLO project
- Parallel plate actuator drawbacks
- Comb drive actuator and optimization
- Summary



Introduction

- holographic displays have been a fascinating prospect for a long time
- only real holography can provide a fully natural viewing experience
- the data volume is generally prohibitively huge
- due to the progress in computer power and by restriction to small viewing windows real holographic displays are now becoming feasible
- SLMs remain a challenge



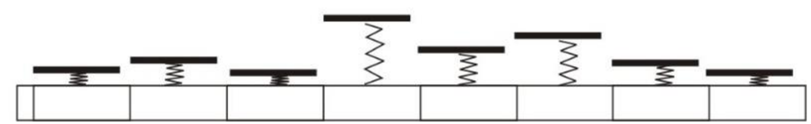
SeeReal Technologies
Fraunhofer IPMS

Challenges for SLMs in Holography

- very many pixels
- pixels as small as possible for large diffraction angle (→ low drive voltage)
- phase modulation is better than intensity modulation
- analogue modulation of light
  - binary modulation is inferior, pulse width modulation not feasible

→ DLP-SLMs are sub-optimal

- high frame rates
- high precision, stable deflection, low cross-talk

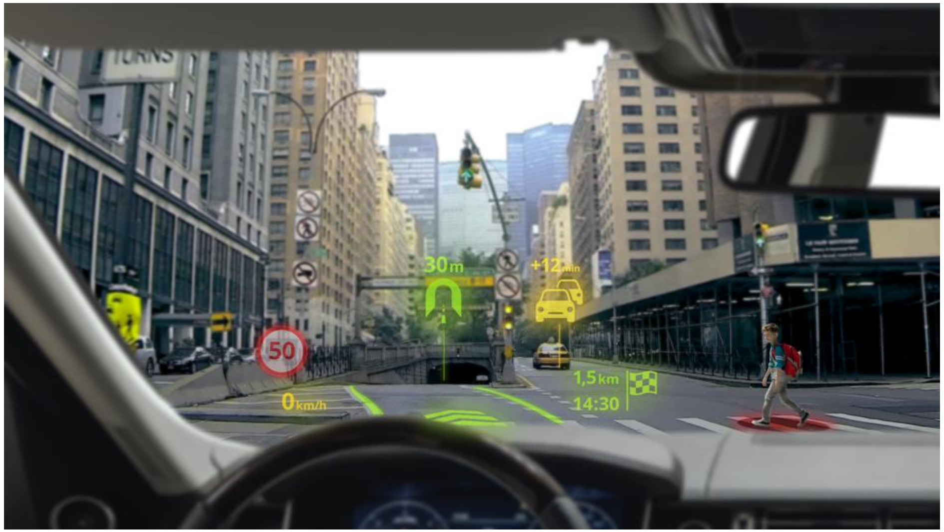


→ LCoS-SLMs are sub-optimal

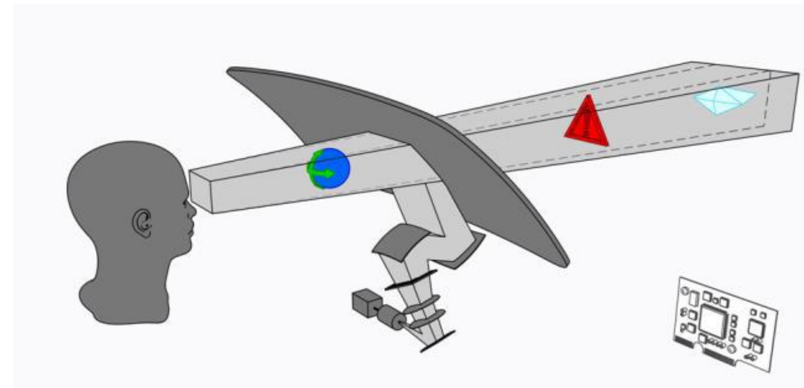
- micro mirrors work independent from polarization
- low power dissipation

→ analogue piston mirror SLMs are perfect for holography, but development is needed

Application Example: Automotive 3D Head-up Display



- Marking of potential risks
- Lane guidance
- Vehicle data
- Additional traffic signs



Added value over conventional HUD

- Information is displayed with correct spatial 3D placement, updated in real time
- No eye fatigue or misperception
- Real driver assistance, not distraction

SeeReal Technologies

Fraunhofer IPMS

RealHolo Project Consortium

EU Horizon 2020 Project 'REALHOLO', Project duration: Jan. 2021 … Dec. 2024

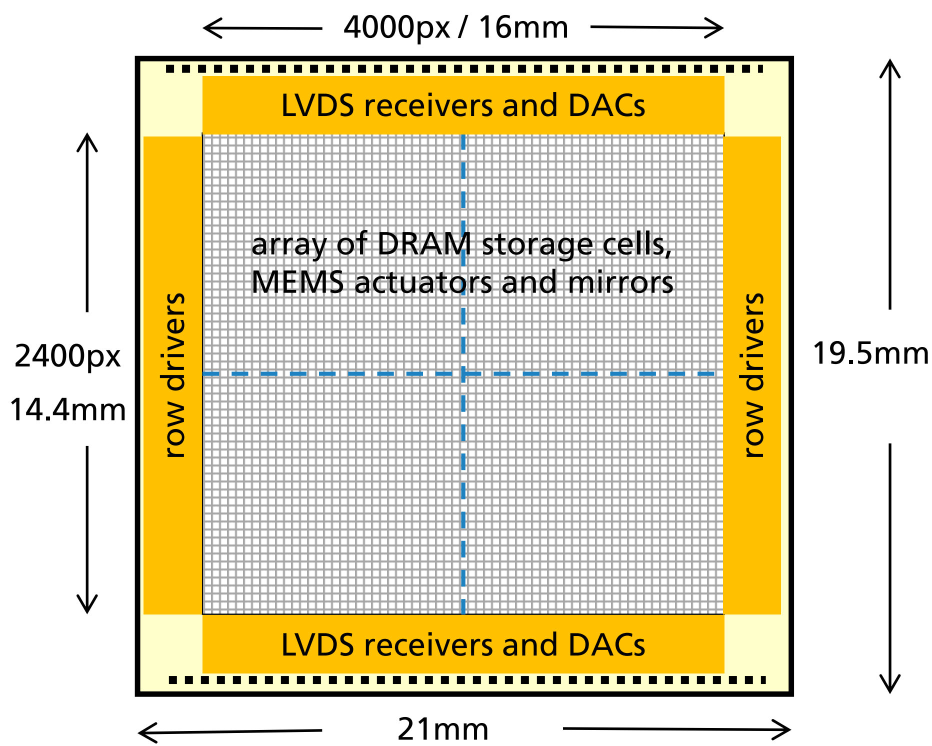
partner	country	task
TECHNIKON	AT	management
SeeReal Technologies	DE	system development
Fraunhofer IPMS	DE	MMA development
nSilition Smaller, Smarter, Stronger	BE	CMOS design
OmniChip	PL	addressing electronics
Valeo	FR	display demonstrator
sencio functional packaging center	NL	packaging
XFAB	FR	CMOS backplane

The **REALHOLO** project receives funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement 101014977.

This project is an initiative of the Photonics Public Private Partnership.

https://realholo.eu

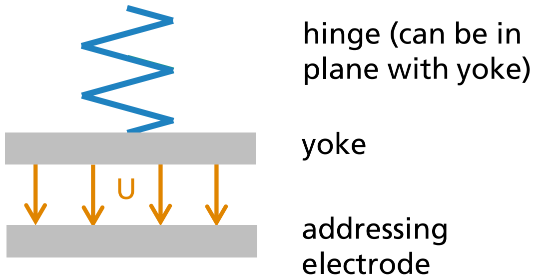
RealHolo MMA Key Parameters

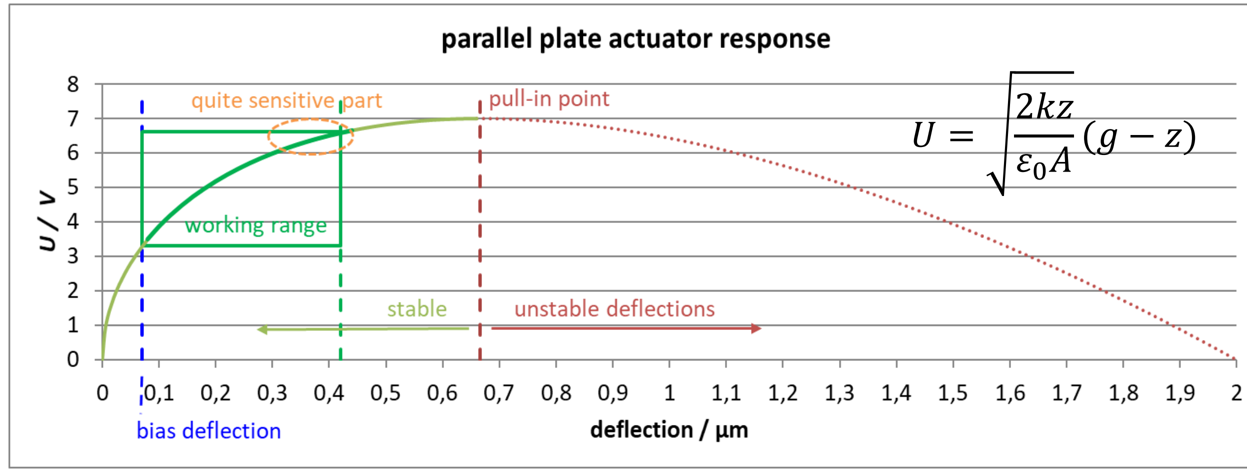


Parameter	Target
pixel size	4µm x 6µm
pixel count	4000 x 2400
active area	16mm x 14.4mm
vertical deflection	0 … 350nm
tilt error	< 0.1° (< 1.75mrad)
frequency	> 1kHz
duty cycle	> 20%
power consumption	< 2.5W
pixel voltage	0V to 3.3V
deflection precision	8bit

- the pixel area is divided into 4 subareas which are addressed from the edges

Parallel-Plate Actuators Need Large Actuator Gaps

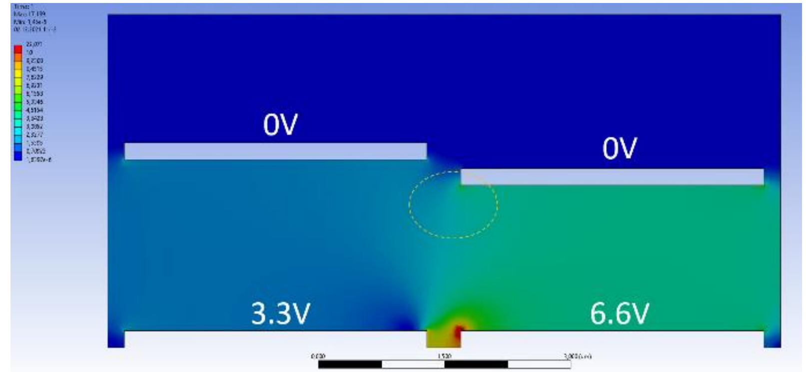


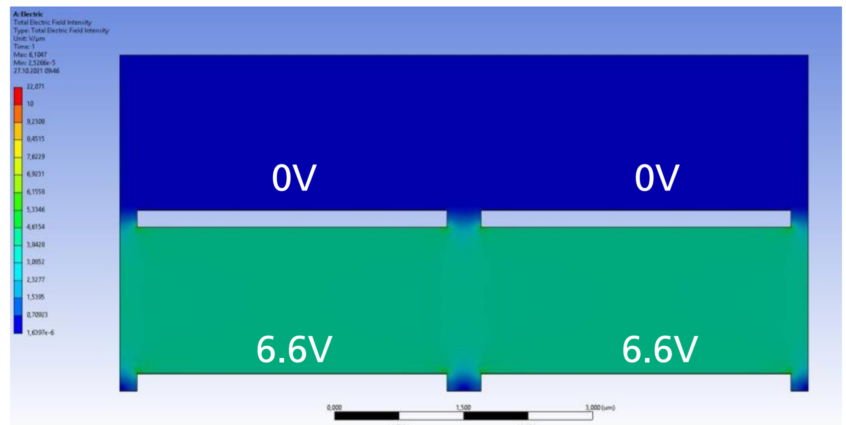


- Analytical model with linear spring and plate capacitor
- Force equilibrium between mechanical force $F_m = -k \cdot z$ and electrostatic force $F_{el} = \frac{\varepsilon_0 A U^2}{2(g-z)^2}$
- Force equilibrium can be solved analytically for deflection curve
- Electrostatic pull-in happens at gap/3
- a maximum deflection of about 60% of the pull-in deflection or 20% of the gap can be used

Parallel-Plate Actuators

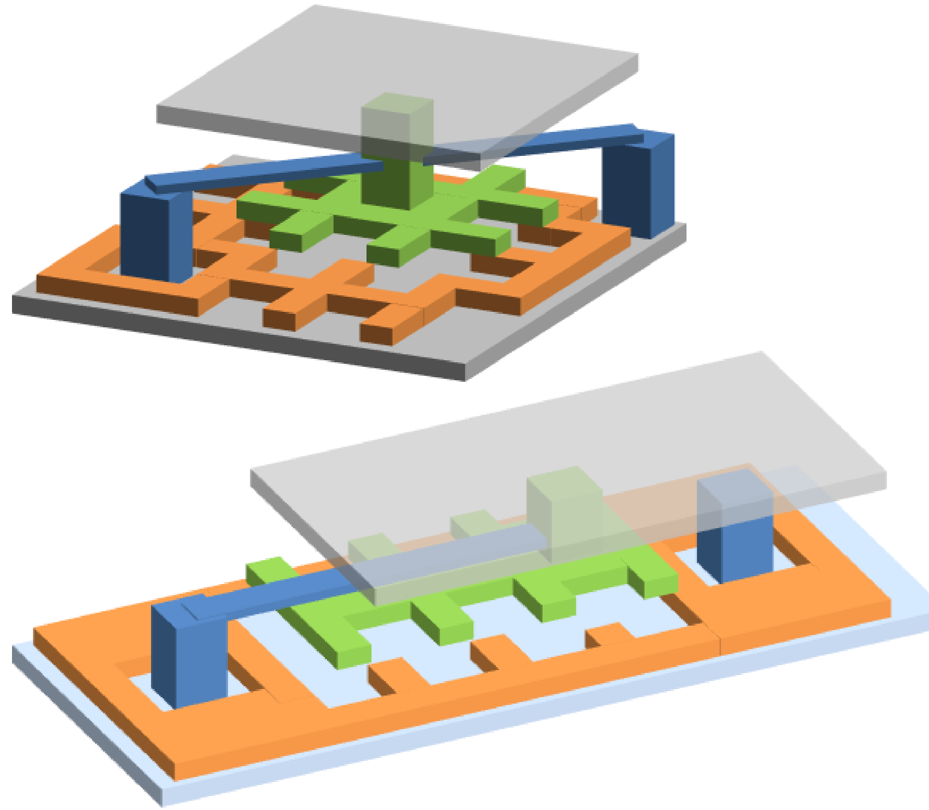
- deflection needs to be $\lambda/2 \approx 350$nm for red light
- the actuator gap needs to be about 2µm, which is only twice the pixel width
- due to the large gap the total electrostatic force is small: ~1.5nN
- and the electrostatic cross-talk is large
  - simulated cross-talk of ~3.5% at one edge
  - would be ~14% for 4 neighbor pixels





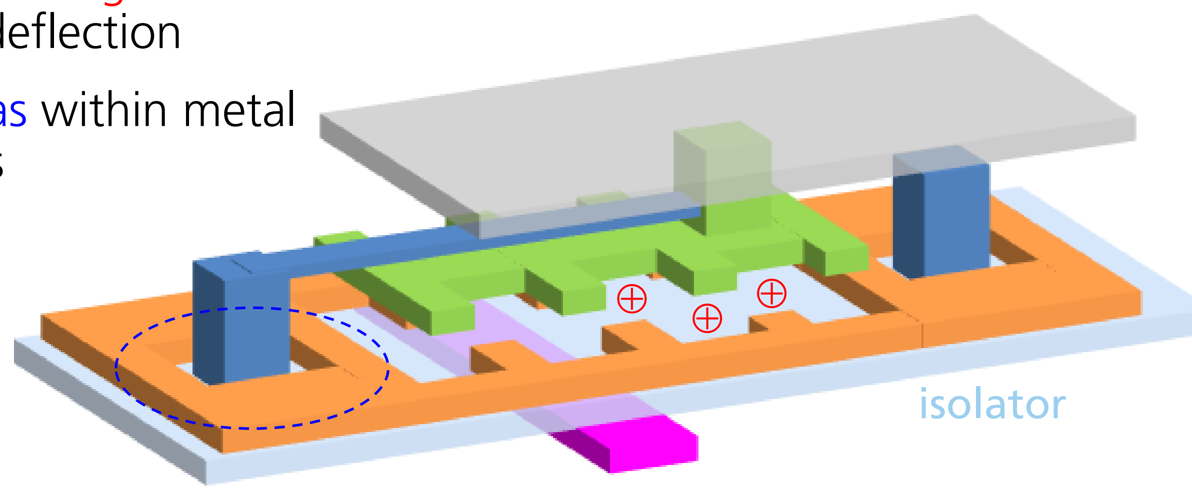
Novel Comb Drive Actuator Concept

- comb-drive actuators have no pull-in effect (in direction of intended deflection)
- the actuator gap may be very small → ~10x larger electrostatic forces in spite of electrode small area
- the cross-talk may be very small due to the concentrated electrostatic field around the fingers
- a one-sided hinge allows for compliant, linear behavior and can still produce tilt-free deflection



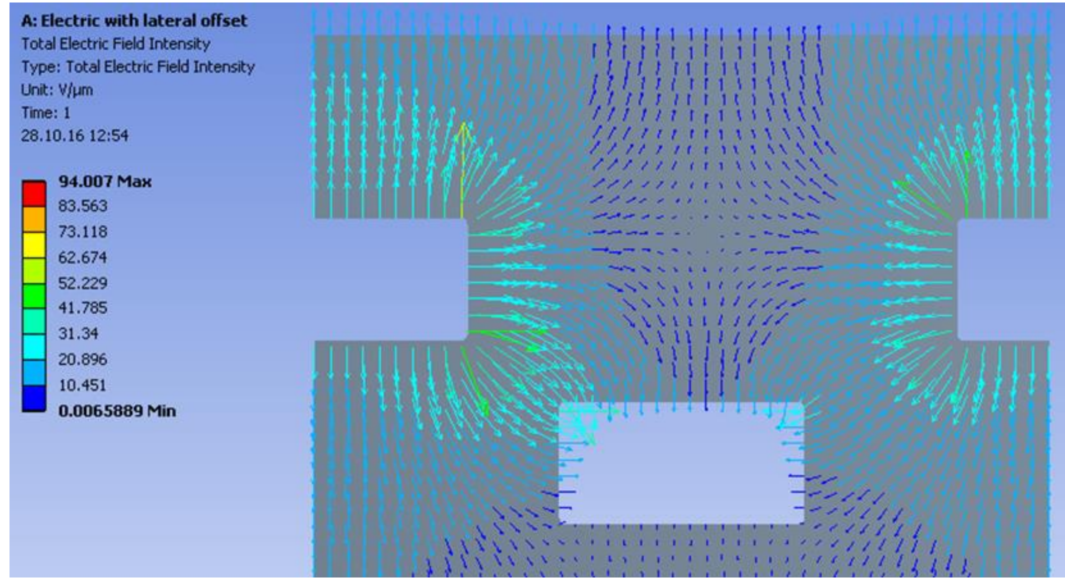
Possible Issues with the Comb Drive Actuator (I)

- the underlying circuitry may directly attract the yoke
  → deviation from desired deflection
  - an electrical shield could again cause pull-in
- isolators may have trapped charges
  → deviation from desired deflection
- small defects in critical areas within metal layers may cause short cuts
  → pixel defect
- small area for connection MEMS to backplane
- high aspect ratio posts are difficult to fabricate

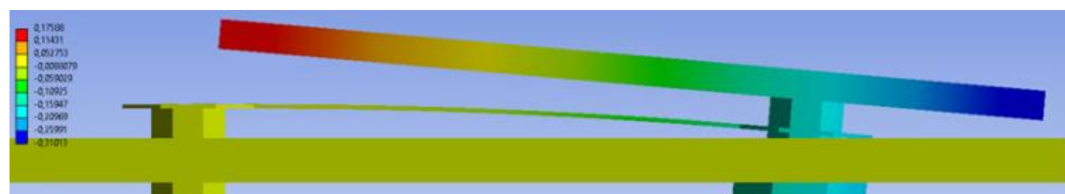


Possible Issues with the Comb Drive Actuator (II)

- an overlay error or other asymmetry of the combs causes large horizontal forces and an imbalance of the vertical forces → tilting mirror or even horizontal pull-in



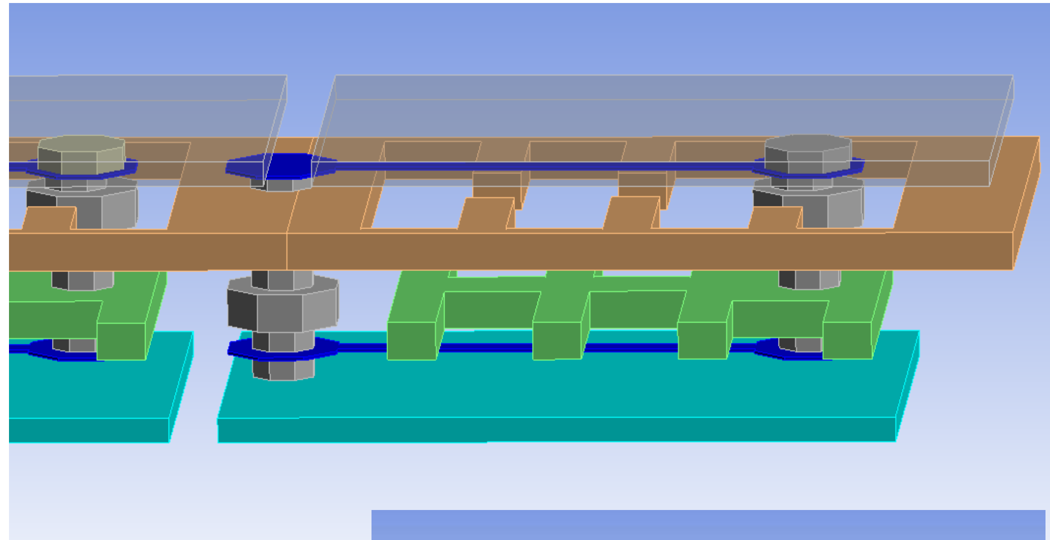
- even small stress gradients in the hinge cause strongly tilted actuators, here 100MPa → 4.8° tilt

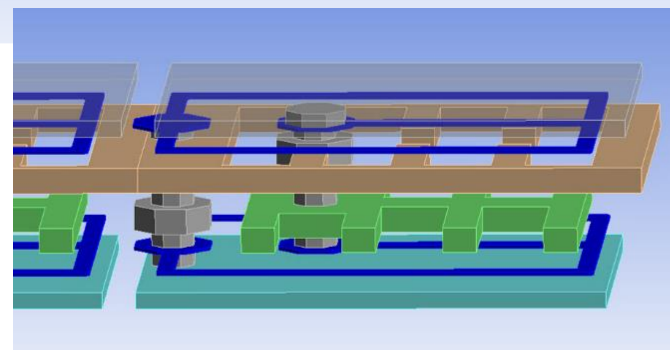


SeeReal Technologies

Fraunhofer IPMS

Optimized Comb Drive Actuator for Holography





optimized basic concept of the comb drive actuator

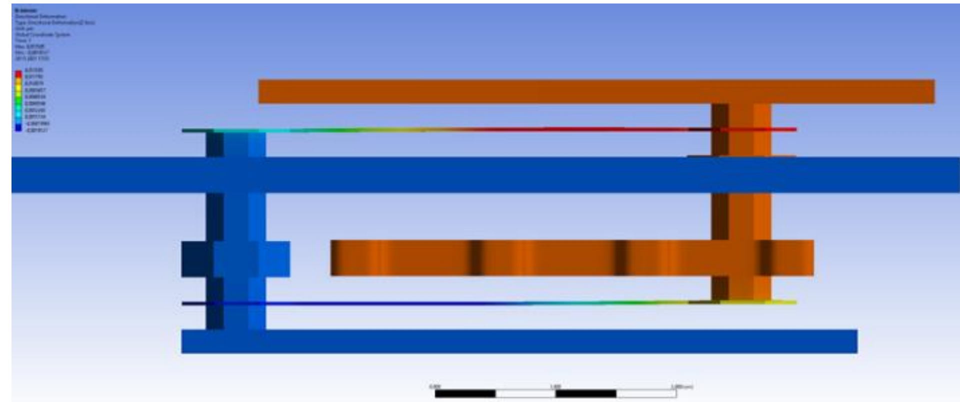
- two hinges make for a parallelogram guidance mechanism for tilt suppression
- baseplate, lower hinge, and yoke are on the same electrical potential
  → no charging expected here
- stator, upper hinge and mirror are on the same electrical potential
  → no charging and no cross-talk at mirror edges
- low risk of shortcuts in insulating posts
- for the same total stiffness, each hinge may still be 79% of the thickness of a single hinge

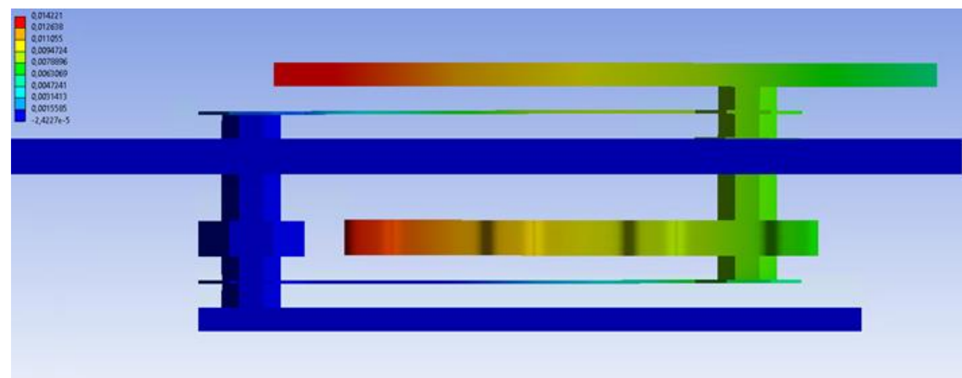
SeeReal Technologies

Fraunhofer IPMS

Hinge Stress Gradients and Stress Mismatch

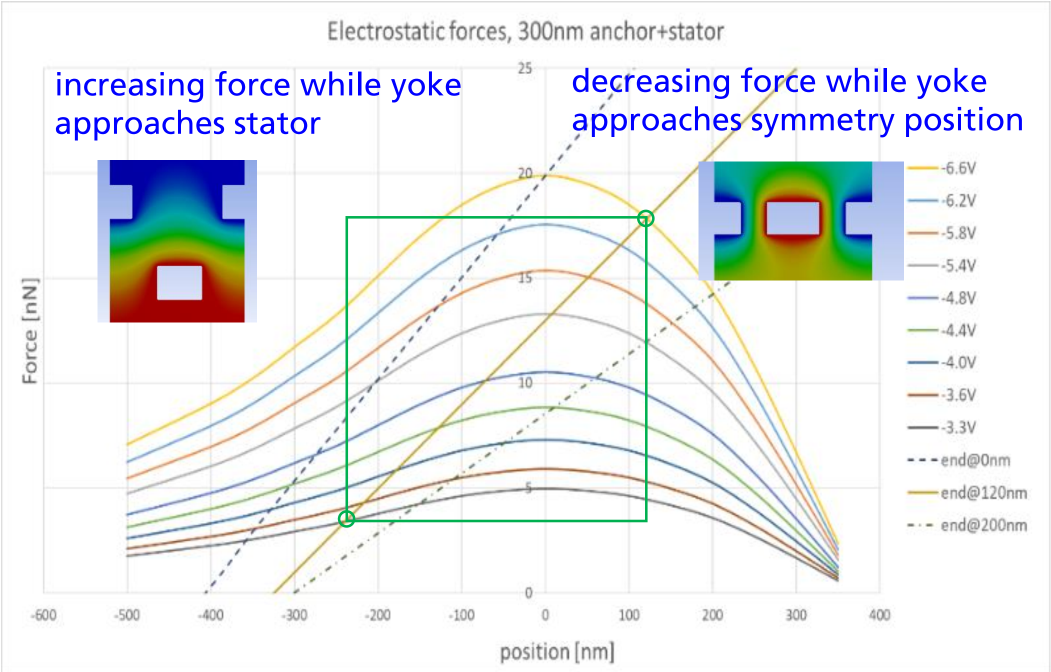
- with double hinges, a stress gradient of 100MPa in both hinges yields a negligible tilt (<0.00°)
- double hinges are in principle sensitive to stess mismatch, but we get only a 0.06° tilt for 100MPa stress mismatch due to the large vertical separation
- response curves are more difficult to simulate due to coupling of electrostatic and structural domain





Simulation of Response Curves (I)

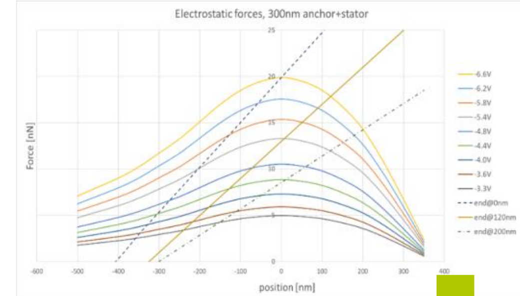
- at first only the 3D electrostatic field is simulated for given geometry and a range of actuator positions to get the forces for a fixed voltage
- forces for other cases scale with voltage squared
- two end points for the deflection range may be chosen
- the hinges oberve Hooke's law
- from this follow the required spring constant and the zero-voltage vertical gap



$$k = \frac{F(max.\ voltage) - F(bias\ voltage)}{stroke}$$

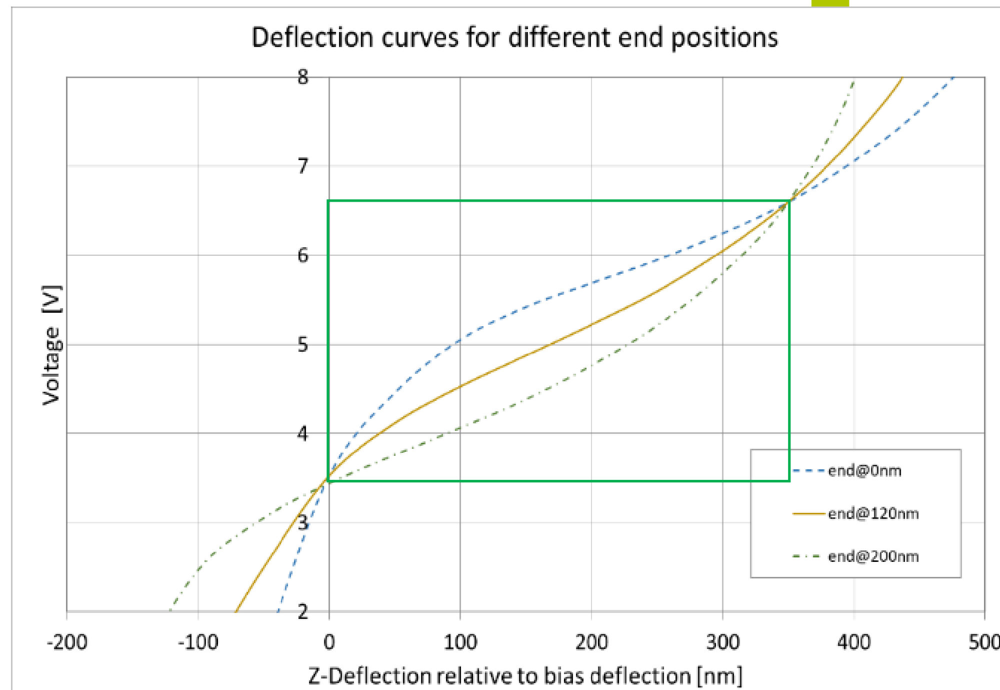
$$zero\ voltage\ gap = gap\ at\ bias\ voltage - \frac{F(bias\ voltage)}{k}$$

Simulation of Response Curves (II)



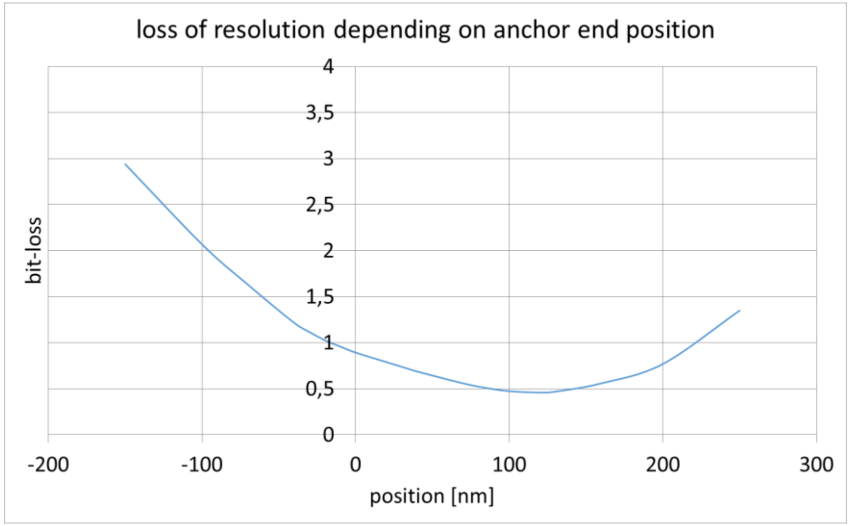
- for each choice of the two deflection range end points (and given geometry of the combs) one gets a response curve from the force equilibrium at each deflection
- the best choice is the response closest to linear
- some choices yield unstable responses
- we evaluate the linearity at the minimum slope (smallest voltage difference for a given deflection change) by:

$$loss\ of\ resolution = \log_2\left(\frac{average\ slope}{minimum\ slope}\right)\ [bit]$$



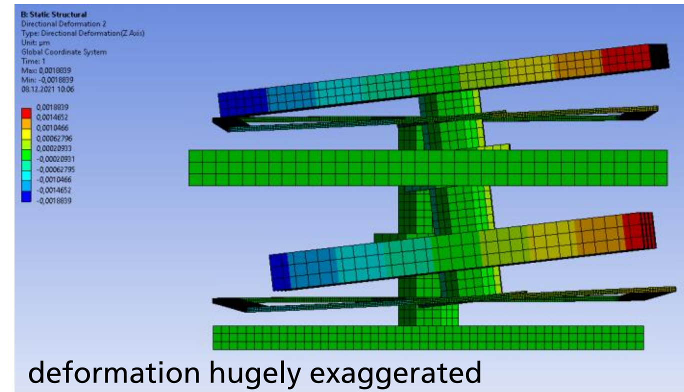
Compromize Choice of Parameters

- we find that an end deflection of about 100nm overlap of the combs yields the best linearity with still near maximum spring constant
- this translates to a 250nm comb separation at bias voltage and about 320nm zero-voltage actuator gap, which is very convenient for manufacturing
- the 'loss of resolution' may be as low as 0.5 bit

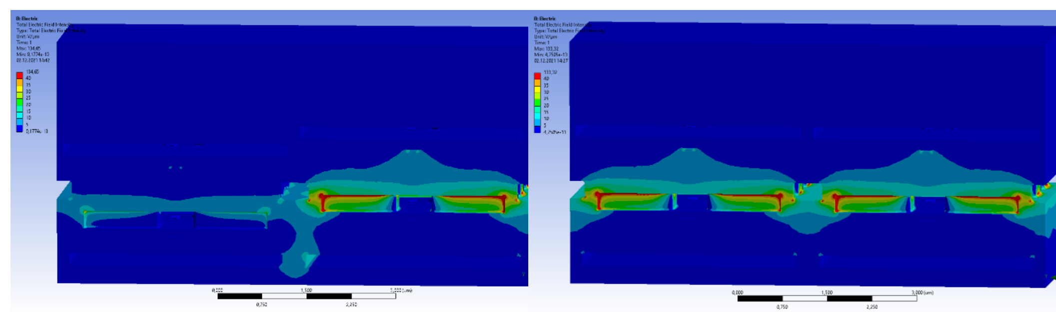


First Results on Tilt due to Overlay Errors and Cross Talk

- tilt is found to be within spec limits for overlay errors up to 20nm
- cross talk in the first design is about 0.6%, which is still more than the desired resolution (0.4%)
- this could be ok when compensated by adjusted addressing voltages
- shorter fingers help reduce the cross talk, but they also reduce the total actuator force
- other options for improvement are being investigated



deformation hugely exaggerated



Summary

- Fraunhofer IPMS together with SeeReal and partners is developing an MMA-based SLM optimized for real holographic displays
- the SLM features millions of comb-drive actuators for precise positioning of micro mirrors
- the SLM will exhibit optical properties superior to existing alternatives
- the high quality of the modulated light will allow a natural viewing experience in AR, VR, and MR applications