MEMS based micromirror system for deployment in optical beam steering systems used in Quantum Information Processing

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Overview

- The aim of this study is to highlight the utility and applicability of Microelectromechanical systems (MEMS) technology in addressing the existing challenges of precision control of beams in performing manipulation of two dimensional atomic systems or qubit states in Quantum Information Processor Implementations.
- This study specifically focuses on the applicability of a controllable MEMS based Micromirror that guides a laser beam to address multiple qubit locations in a two-dimensional trapped lattice; an application of pertinent interest to Experimental Quantum Computation.

Motivation

The question

Can we make a MEMS micromirror that is not much susceptible to thermoviscous pressure, acoustic pressure, temperature and external pressure?

- Existing beam steering systems exploit acousto-optic deflectors and electro-optic deflectors. Acousto-Optic deflectors have a heavy power consumption because they require high RF drive power and induce small frequency shifts. Electro-Optic deflectors on the other hand have very high operational voltages and a limited angular range.
- MEMS have been explored as an alternative, to satiate the existing challenges and provide a more compact and flexible beam steering functionality. In this report we explore the properties of a Micromirror.

Background & Prior work

Reference 1

A study on *'Application of aluminum films as temperature sensors for the compensation of output thermal shift of silicon piezoresistive pressure sensors'* was done by V. Stankevič and Č. Šimkevičius in 1998.[a]

[a] V. Stankevič, Č. Šimkevičius, Application of aluminum films as temperature sensors for the compensation of output thermal shift of silicon piezoresistive pressure sensors, Sensors and Actuators A: Physical, Volume 71, Issue 3, 1998, Pages 161 166, ISSN 0924-4247, doi: https://doi.org/10.1016/S0924-4247(98)00178-2

Reference 2

Another work on *'Mems-based optical beam steering system for quantum information processing in two-dimensional atomic systems'* was done in 2008.[a]

[a] C. Knoernschild, C. Kim, B. Liu, F. P. Lu, and J. Kim. Mems-based optical beam steering system for quantum information processing in two-dimensional atomic systems. Opt. Lett., 33(3):273–275, Feb 2008.doi: https://doi.org/10.1364/OL.33.000273

Proposed Design and Architecture I

Structure, Implementation and COMSOL Builder

- The MEMS mirror consists of a mirror plate that rotates about two torsional springs as shown below [**Figure** 1]. The mirror was made out of Aluminium [1], owing to its optical properties so as to enhance reflectivity in the beam steering system and thermal stability [2].

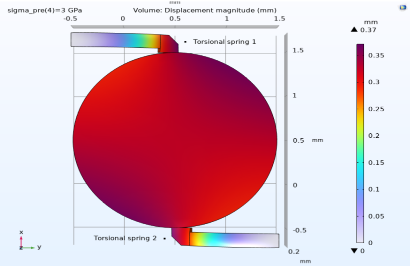

Figure: Structural Design of the micro-mirror I

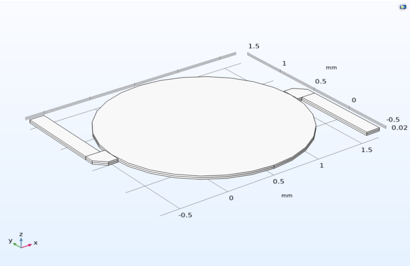

Figure: Structural Design of the micro-mirror II

[1] I. Uvarov, R. Selyukov, and V. Naumov. Testing of aluminium and its alloys as structural materials for a mems switch. Microsystem Technologies, 26, 06 2020. doi: `https://doi.org/10.1007/s00542-020-04748-2`

[2] V. Stankevič, Č. Šimkevičius, Application of aluminum films as temperature sensors ..., Sensors and Actuators A: Physical, Volume 71, Issue 3, 1998, Pages 161 166, ISSN 0924-4247, doi: `https://doi.org/10.1016/S0924-4247(98)00178-2`

Proposed Design and Architecture II

Structure, Implementation and COMSOL Builder

- COMSOL Packages used here are as below;
  - Thermoviscous Acoustics
  - Transient(labelled as `tatd` in the graph)
  - MEMS module
  - Pressure
  - Temperature and other variables

- **Parameter Table**

Center frequency for analysis	f_0	$10.7kHz$
Frequency range	Δf	$500Hz$
Viscous boundary layer thickness in air at f_0	d_{visc}	$0.22mm * \sqrt{100Hz/f_0} = 2.127 \times 10^{-5}m$
Mirror thickness	h_{mirror}	$1\mu m$
Resonance frequency (*eigenfrequency study*)	f_{num}	$(10470 + 148.49i)Hz$
Resonance frequency	$f_r(real)$	10470Hz
Resonance half power width (*frequency sweep*)	df_r	$295.87Hz$

Displacement of the micromirrors I

Displacement under Pressure

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

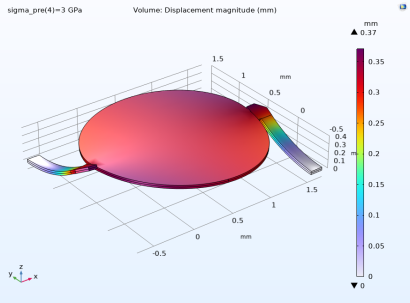

Figure: Displacement of the Aluminium based micro-mirror under $3GPa$ stress (View 1).

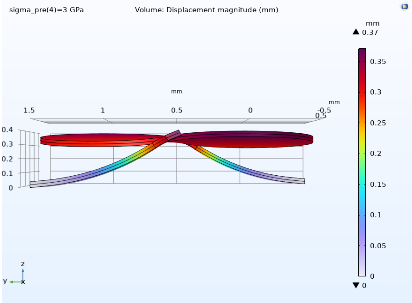

Figure: Displacement of the Aluminium based micro-mirror under $3GPa$ stress (View 2).

Displacement of the micromirrors II

Stress distribution under Pressure

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

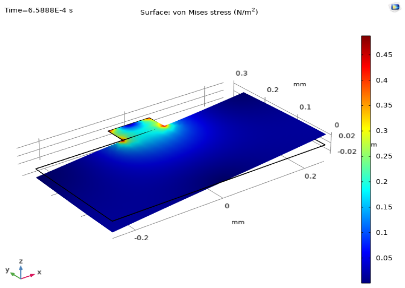

Figure: The displacement of the $2D$ tilt box containing the micromirror. The deflection as seen at time $6.588 \times 10^{-4}s$ (View 1).

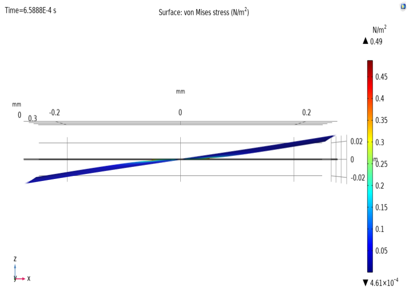

Figure: The displacement of the $2D$ tilt box containing the micromirror. The deflection as seen at time $6.588 \times 10^{-4}s$ (View 2).

Displacement of the micromirrors III

Acoustic Presure distribution

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

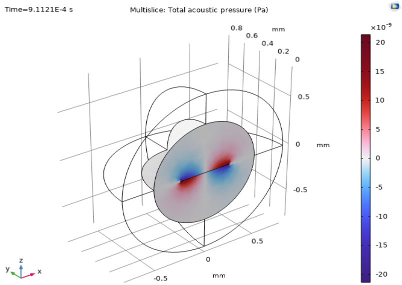

Figure: Plot of the total acoustic pressure variations at time $9.112 \times 10^{-4}s$

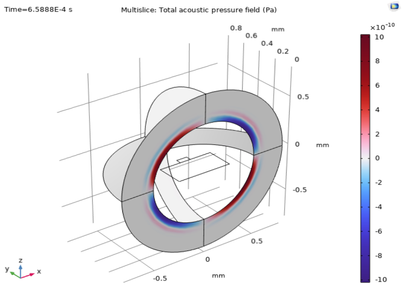

Figure: Plot of the total acoustic pressure at time $6.588 \times 10^{-4}s$

Displacement of the micromirrors IV

Displacement & Instanteous Local Velocity

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

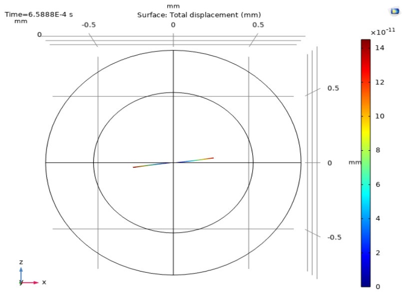

Figure: The displacement of the 2D tilt box containing the micromirror.

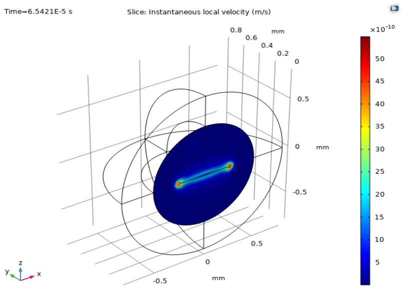

Figure: Corresponding instantenous velocity of each mesh level simulation during time $\in [0, 6.588 \times 10^{-4}]s$

Displacement of the micromirrors V

Mesh level plot and Temperature variation

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

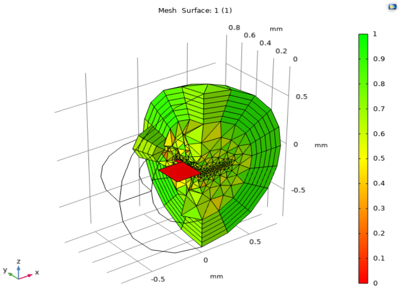

Figure: Mesh surface level view

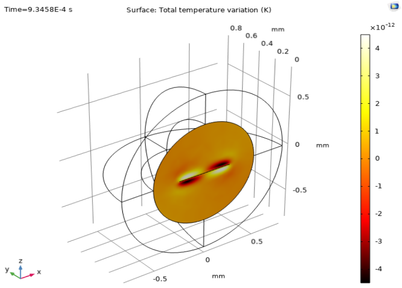

Figure: Temperature variation across the surface of the micromirror in K

Displacement of the micromirrors VI

Frequency sweep analysis

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

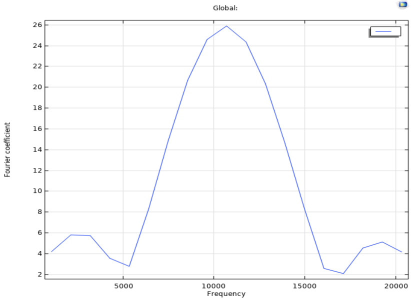

Figure: The variation of Frequency with the Fourier coefficient

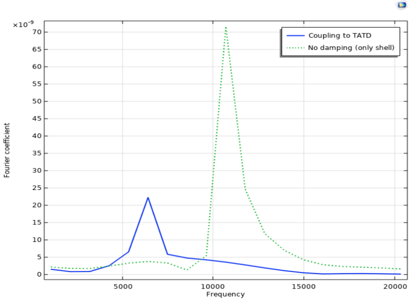

Figure: The variation of Frequency with fourier coefficient considering the surrounding air model as well as the isolated micromirror

Displacement of the micromirrors VII

Harmonic analysis

- Considering these parameters and analysis, the following were the images and plots obtained from the COMSOL console:

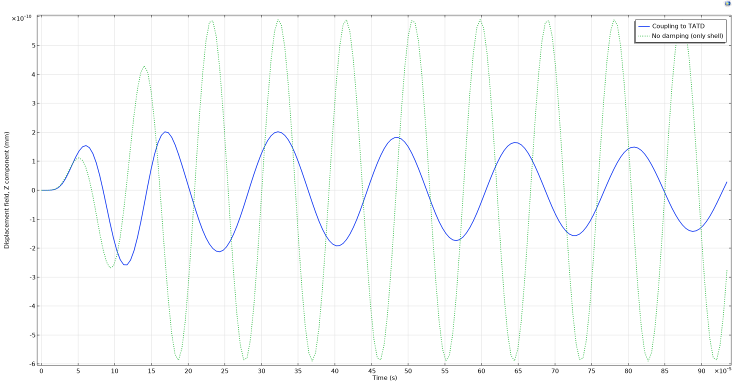

Figure: The displacement field is modeled in mm comparing the two cases; coupled system *vs*. the isolated system. This is in accordance with the goal of deployment that required minimizing settling time of the neutral atom state by maintaining near critical damping.

Conclusion

- The displacement of the micromirror from its mean position especially on application of a large amount of stress , 3GPa for simulating the system is in the order of $(1/100)^{th}$ of a millimeter.
- The temperature variation throughout the surface of the micromirror while being simulated, *i.e.*, during the process of actuation while it is vibrating is in the order of $10^{-12}K$ which ensures thermal stability of the device.
- The residual intensities at neighboring **qubit** locations represented here by the frequency values to the right and left of the peak were measured to be below the peak output intensity (around 11000 Hz here) consistent with the Gaussian beam directions.

References

Caleb Knoernschild, Changsoon Kim, Bin Liu, Felix P. Lu, and Jungsang Kim.
Mems-based optical beam steering system for quantum information processing in two-dimensional atomic systems.
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URL https://opg.optica.org/ol/abstract.cfm?URI=ol-33-3-273.

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doi: https://doi.org/10.1016/S0924-4247(98)00178-2.
URL https://www.sciencedirect.com/science/article/pii/S0924424798001782.

Thank You