MEMS Electrostatically Actuated Resonator

By: Daniel Shyer
Advisor: Dr. Fuller
Microelectronic Engineering, BS
Rochester Institute of Technology
MCEE-495 Senior Design

Rochester Institute of Technology
Microelectronic Engineering

Abstract

The goal of this project is to design, simulate, fabricate and test MEMS electrostatically actuated resonators.

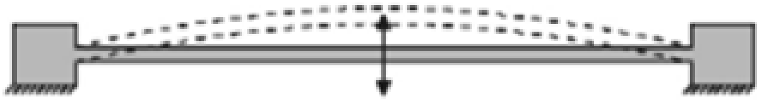
The resonator uses a cantilever beam that will oscillate at a resonant frequency which can be used for signal filtering or as integrated timing within semiconductor circuits.

MEMS resonators are used instead of traditional LC filters or quartz resonators because of their small size, low power consumption, high q factor, improved reliability, performance and being able to integrate into a CMOS process.

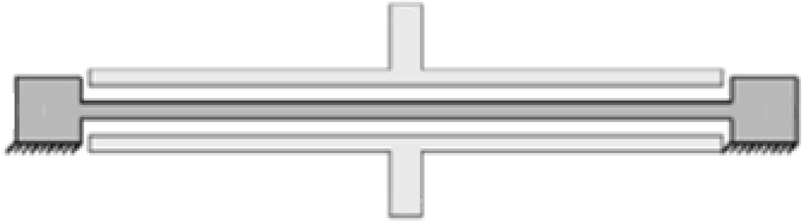
The design of the MEMS resonators included a few variations of a fixed-fixed and a fixed-free cantilever design. Finite element analysis of the resonator was performed using Solidworks. Fabrication of the MEMS devices was done using a surface micromachining process. Testing of the devices show cantilever actuation with increasing capacitance versus increasing actuation voltage. Resonant testing is ongoing.

Equations used for Design [1] [3]

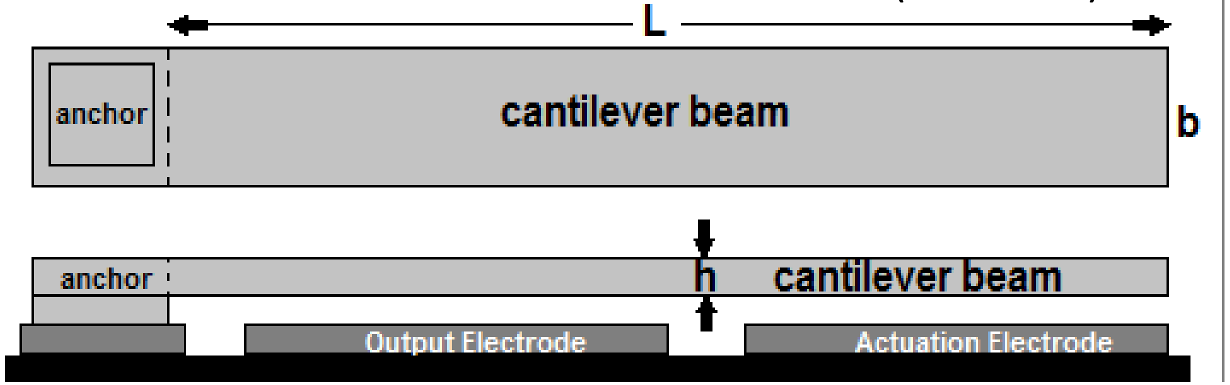
- $C = \varepsilon_o * \varepsilon_r * A/d$
- Moment of Inertia $= bh^3/12$
  - (b) beam width
  - (h) beam height
- Resonant Frequency(fixed-free) = $(^1/_{2\pi})(^{3.5156}/_{L^2})\sqrt{(^{EI}/_{\rho})}$
  - (ρ) mass density
  - (L) Beam length
  - (E) Youngs Modulus for Si = 1.9E11 N/m2
  - (I) Moment of Inertia
- Cantilever Deflection Ymax = $(FL^3)/(48EI)$
  - (E) Youngs Modulus for Si = 1.9E11 N/m2
  - (I) Moment of inertia
  - (L) Beam length
  - (F) Electrostatic force applied
- Electrostatic Force = $(\varepsilon_o * \varepsilon_r * A * V^2)/(2 * d^2)$
  - ε_o permittivity of free space(8.85e-14 V/cm)
  - ε_r is the relative permittivity of air (1.0)
  - (A) Area of the plate
  - (V) Volts applied
  - (d) Distance between the plates



Fixed-Fixed Cantilever beam (top view)

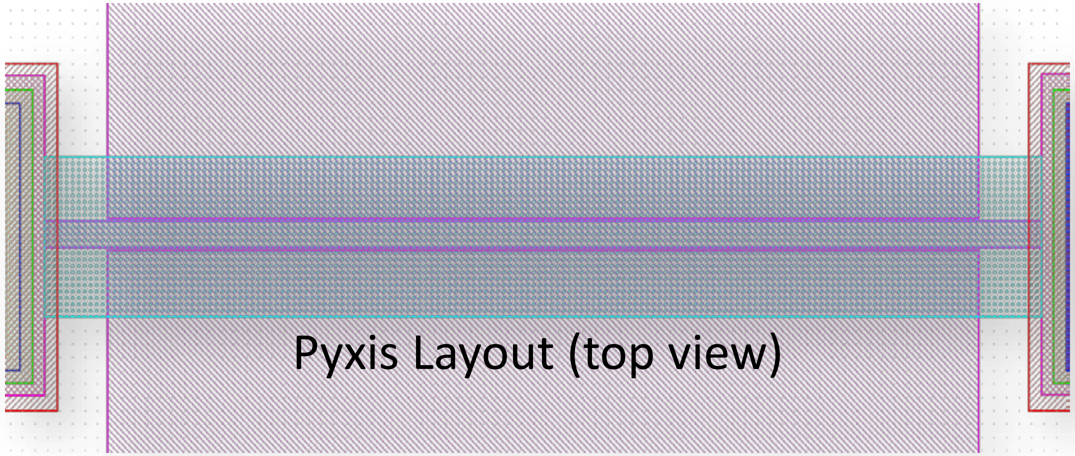


Fixed-Free Cantilever beam (side view)

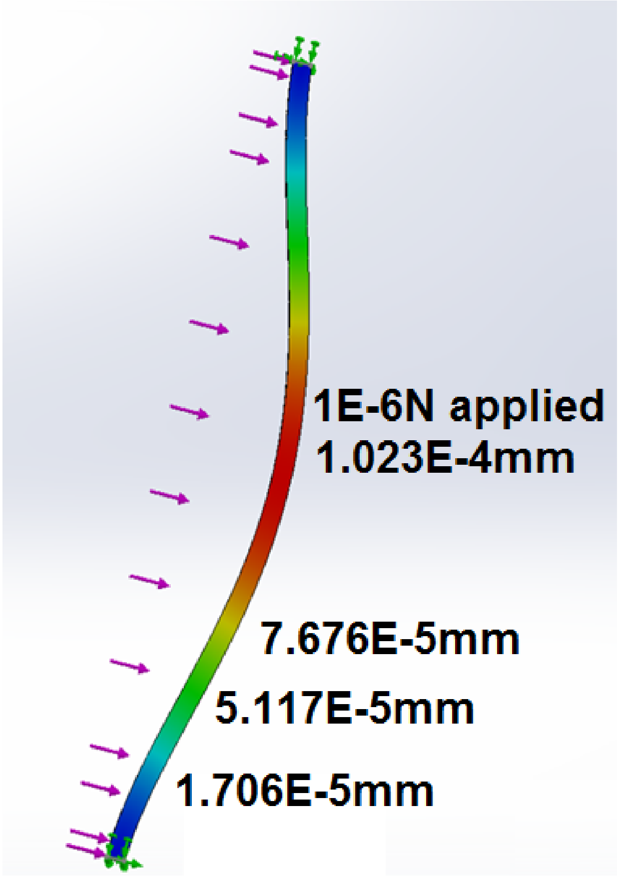


Resonator design and simulation

Fixed-Fixed Resonator[4]



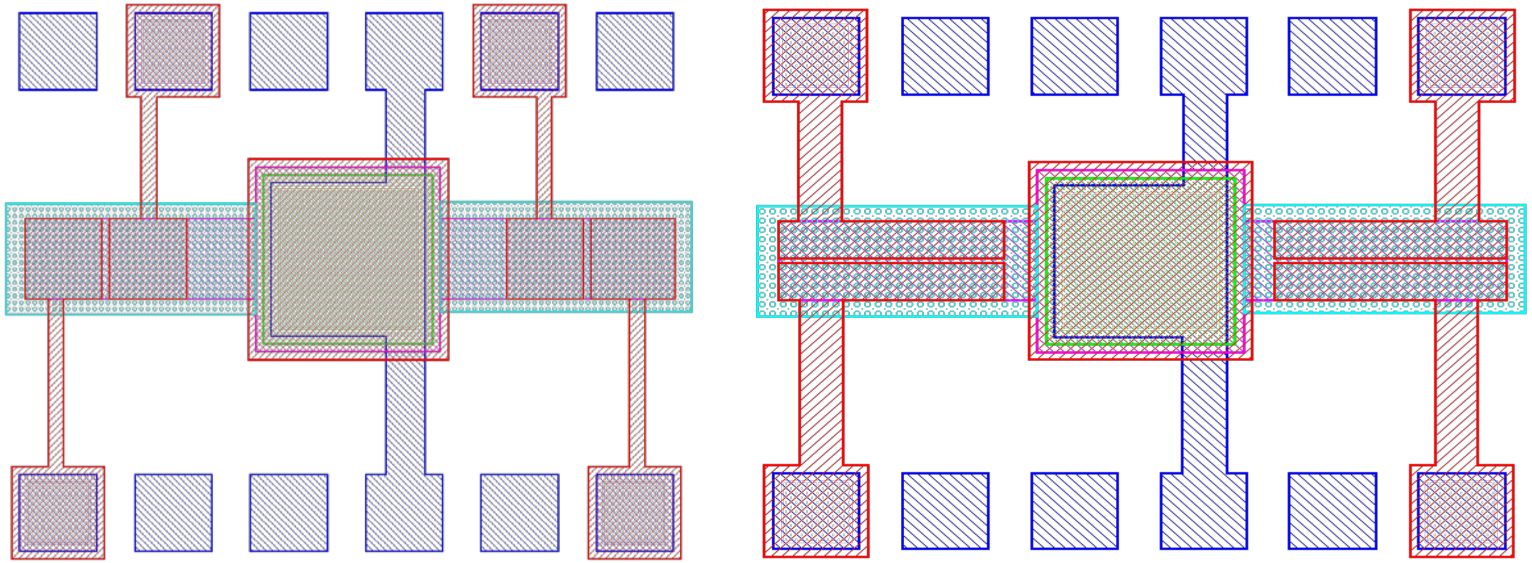
-1000um x 20um x 2um beam (18.7KHz)
-1e-6N(~23V) applied to beam via electrostatic pad
- 0.1um simulated displacement
- Calculations predicted 0.87um displacement



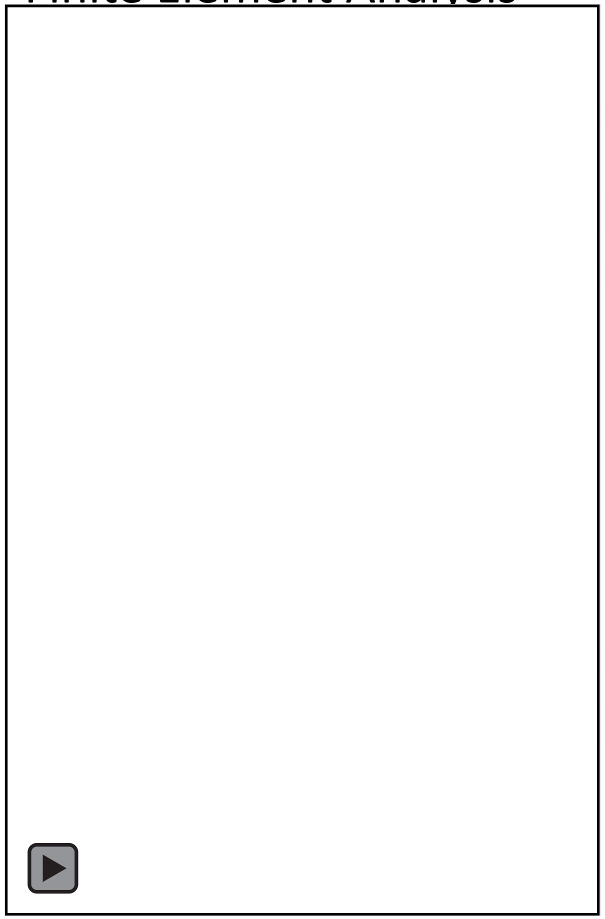
Finite Element Analysis

Resonator design and simulation

Pyxis layout of a Fixed-Free Resonator[1]



Finite Element Analysis



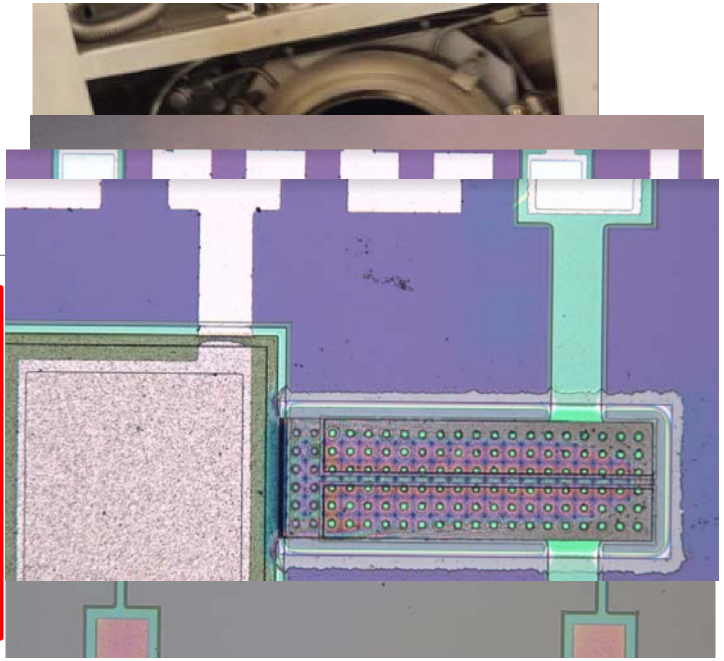
-300um x 100um x 2um beam (32.6kHz)
-1e-6N (~10V) applied to beam via electrostatic pad
- 0.43um simulated displacement
- 0.76um calculated displacement

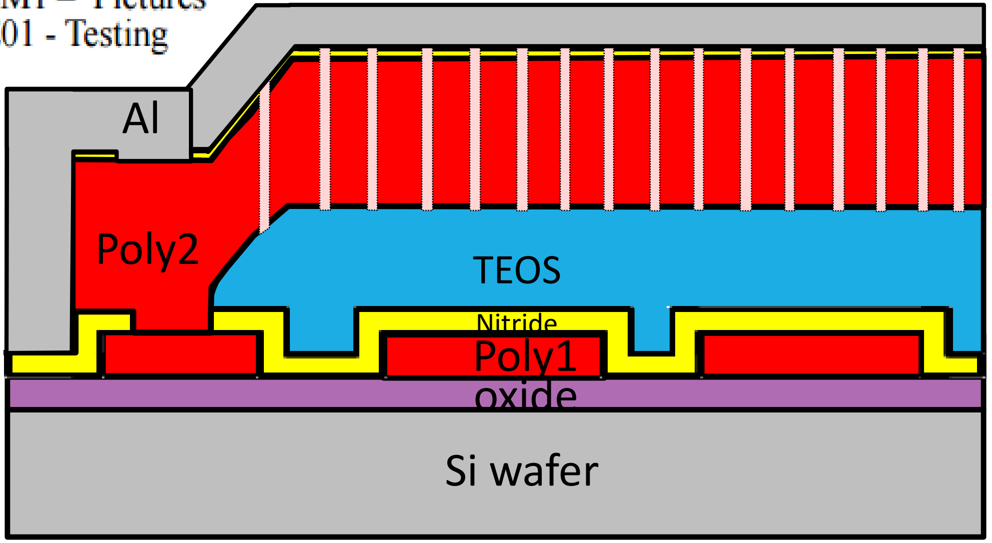
Fabrication

RIT Surface MEMS 2016 Process [2]

1. Starting wafer
2. PH03 – **level 0**, Marks
3. ET29 – Zero Etch
4. ID01-Scribe Wafer ID, D1…
5. ET07 – Resist Strip, Recipe FF
6. CL01 – RCA clean
7. OX04 – 6500Å Oxide Tube 1
8. CV01 – LPCVD Poly 5000Å
9. IM01 – Implant P31, 2E16, 60KeV
10. PH03 – **level 1** Poly-1
11. ET08 – Poly Etch
12. ET07 – Resist Strip, Recipe FF
13. CL01- RCA Clean
14. OX05 – 700Å Dry Oxide
15. CV02- LPCVD Nitride 4000Å
16. PH03 – **level 2** Anchor
17. ET29 – Etch Nitride
18. ET07 - Resist Strip, Recipe FF
19. CL01 – RCA Clean
20. CV03-TEOS SacOx Dep 1.75um
21. PH03 – **level 3** SacOx Define
22. ET06 - wet etch SacOx Define Etch
23. ET07- Resist Strip, Recipe FF
24. CL01 – RCA Clean
25. CV01-LPCVD Poly 2um, 140 min
26. PH03 - **level 4** No Implant
27. IM01-P31 2E16 100KeV
28. ET07 Resist Strip, Recipe FF
29. CL01 – RCA Clean
30. OX05- 500Å pad oxide
31. CV02 – 2000Å nitride
32. PH03 - **level 5** Poly2
33. ET29 – Plasma Etch Nitride
34. ET06 – Wet Etch pad oxide
35. ET68 - STS Etch Poly2
36. ET07 - Resist Strip, Recipe FF
37. PH03 – **level 6** Contact Cut
38. ET29 – Etch Nitride Contact Cut
39. ET06 – Etch Oxide Contact Cut
40. ET07 – Resist Strip, Recipe FF
41. CL01 – RCA Clean two HF
42. ME01 – Metal Deposition - Al
43. PH03 – **level 7** Metal
44. ET55 – Metal Etch - wet
45. ET07 – Resist Strip
46. PH03 – **level 8** – Release
47. SA01 – Saw wafers ½ Thru
48. ET66 – Final SacOx Etch
49. ET07 - Resist Strip, Recipe FF
50. SEM1 – Pictures
51. TE01 - Testing

https://people.rit.edu/lffeee/SurfaceMEMsFabricationDetails.pdf

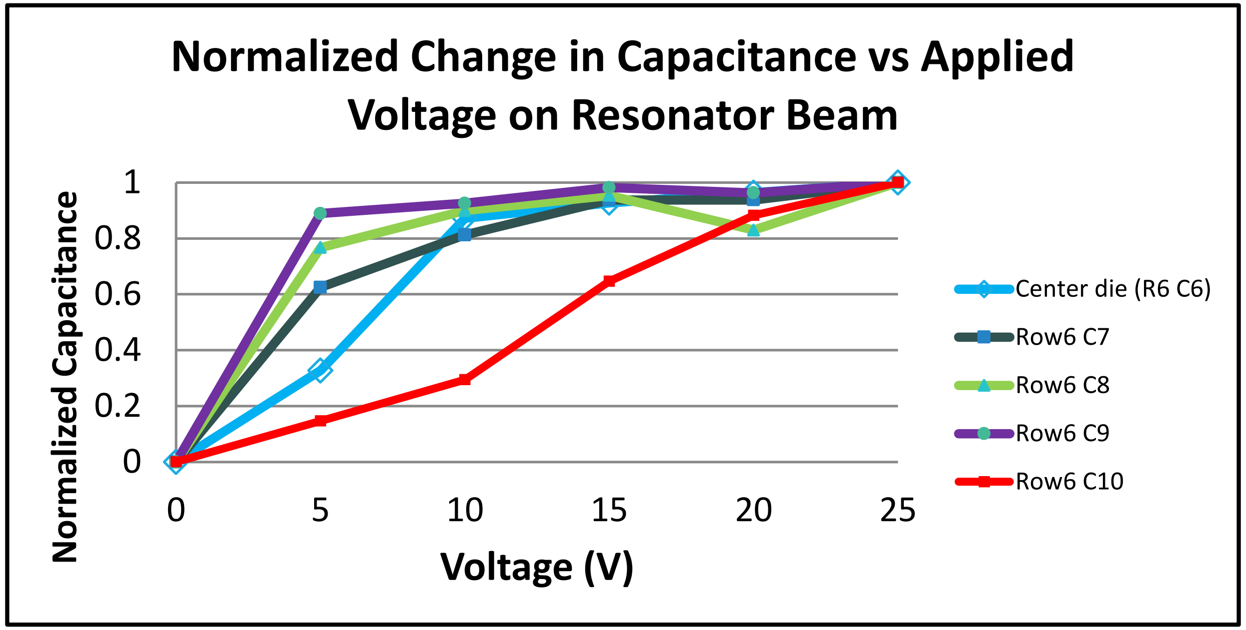


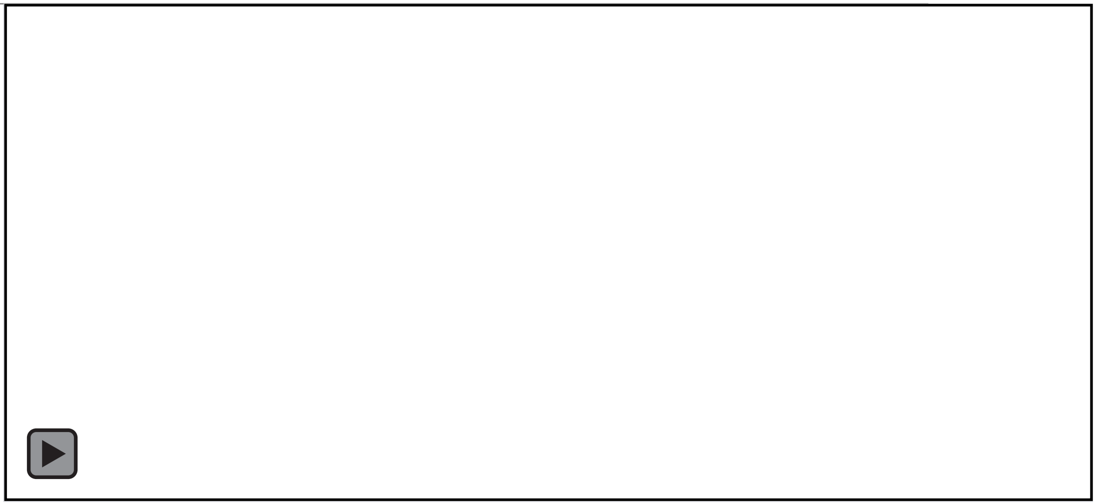


Results

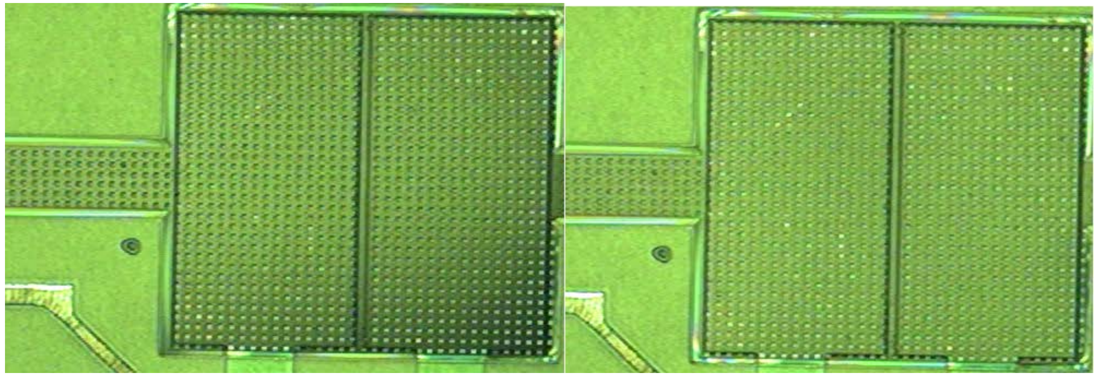
Release of the Fixed-Free cantilever

- Release of cantilever beams was verified
  - Measured change in capacitance with increasing actuation voltage
  - Observed deflection under the microscope
- Resonance testing has not been successfully completed





No cantilever deflection full cantilever deflection

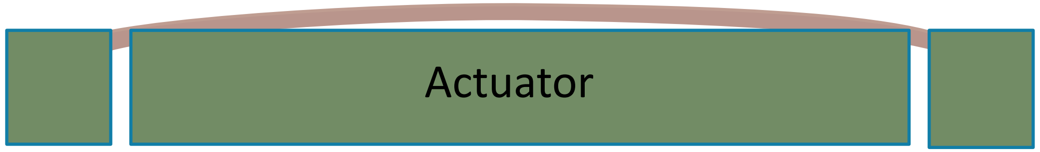


Results (continued)

Release of the Fixed-Fixed cantilever

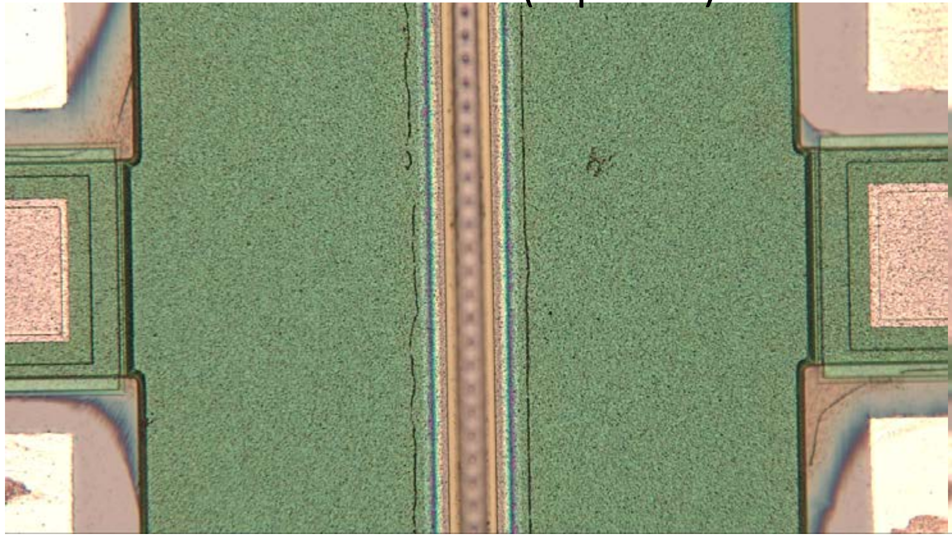
- Compressive stress discovered from poly2 deposition
- No successful actuation of fixed-fixed cantilever beam
- Need to develop a stress free poly2 deposition process and/or redesign beam with springs to reduce stresses

cantilever beam

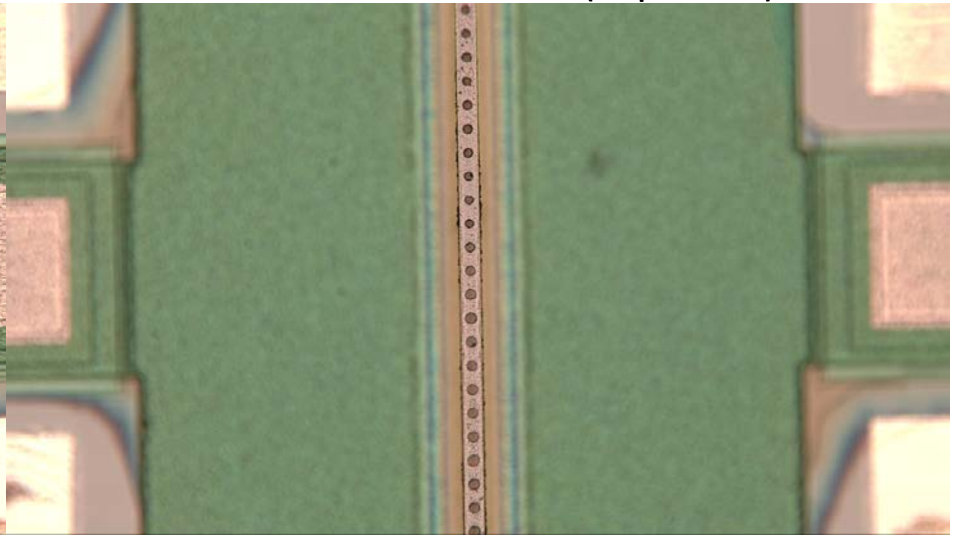


Side view of compressive stress

Actuator in focus (top view)



cantilever in focus (top view)



Conclusion

- MEMS electrostatically actuated resonators were designed, simulated, fabricated and tested in this project.

- The design of the resonators included various dimensions with variations of a fixed-fixed and fixed-free cantilevers.

- Simulations confirmed the calculations used for design within an order of magnitude.

- Fabrication of the devices was done using a surface micromachining process.

- Testing of the devices showed actuation of the released cantilevers with increasing capacitance with an increasing voltage.

- Some new considerations were proposed for the MEMS fabrication process and design.

Acknowledgements & References

Thanks to Dr Fuller, Dr Pearson, Dr. Ewbank, the SMFL staff, Adam Wardas, Jackson Anderson and Stephanie Bolster for their assistance in this project.

[1] "L. Fuller." (2016): *MEMS_Mechanical_Fundamentals*. RIT, 10 Oct. 2016. Web.

[2] "L. Fuller." (2016): *SurfaceMEMSFabricationDetails*. RIT, 1 Nov. 2016. Web.

[3] Irvine, Tom. "Bending Frequencies of Beams, Rods, and Pipes."*Http://www.vibrationdata.com/*. N.p., n.d. Web. 8 Nov. 2016.

[4] R. M. C. Mestrom, R. H. B. Fey, J. T. M. van Beek, K. L. Phan, and H. Nijmeijer, "Modelling the dynamics of a MEMS resonator: Simulations and experiments," Sensors and Actuators a-Physical, vol. 142, pp. 306-315, Mar 2008.