A Piezoresistive Buckled-Beam MEMS Memory Device

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Memory Device Development

<u>Goal:</u> A bistable, non-volatile MEMS memory device

<u>Previous designs:</u> [1]

(a) Symmetrical-base cantilever

(b) Asymmetrical-base cantilever

<u>Problems:</u> Non-volatile, low piezoresistivity

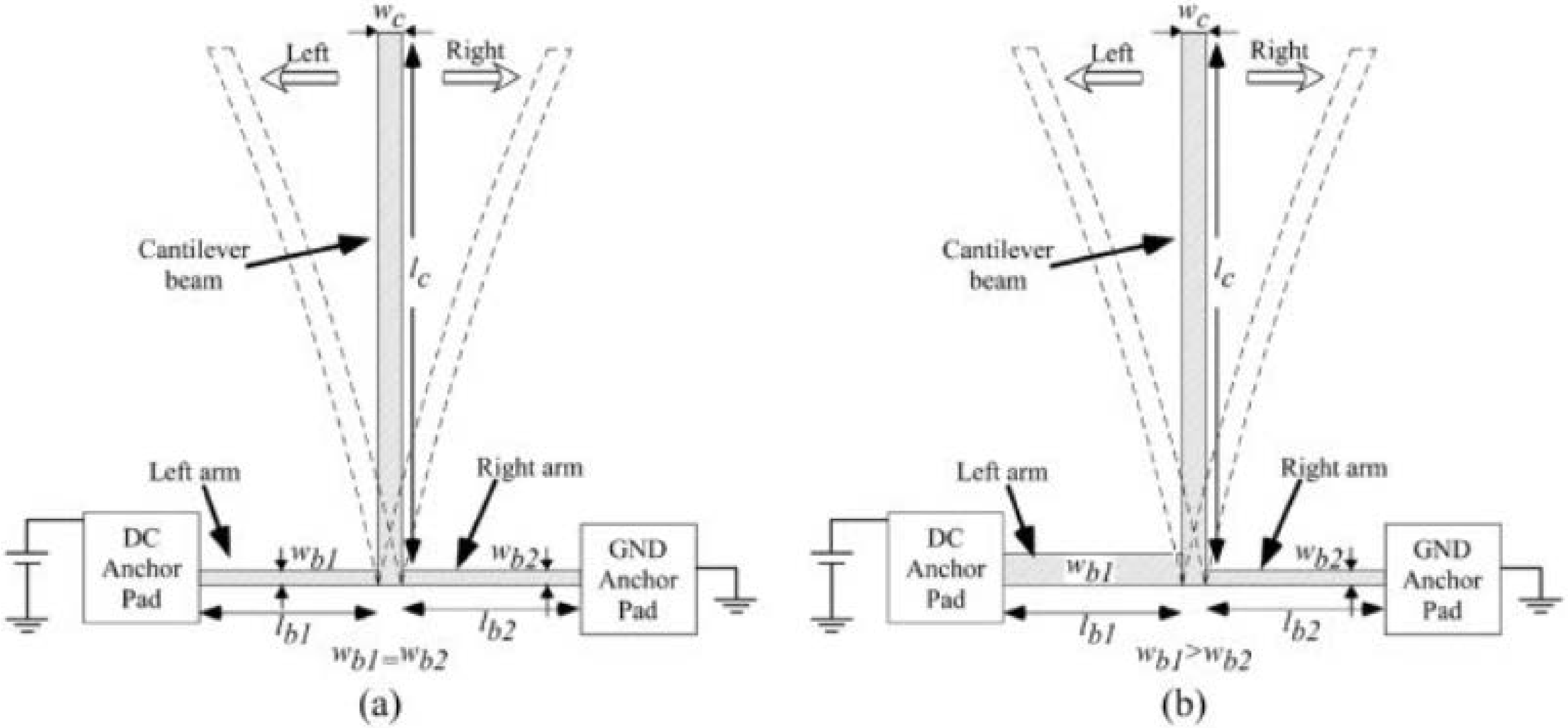
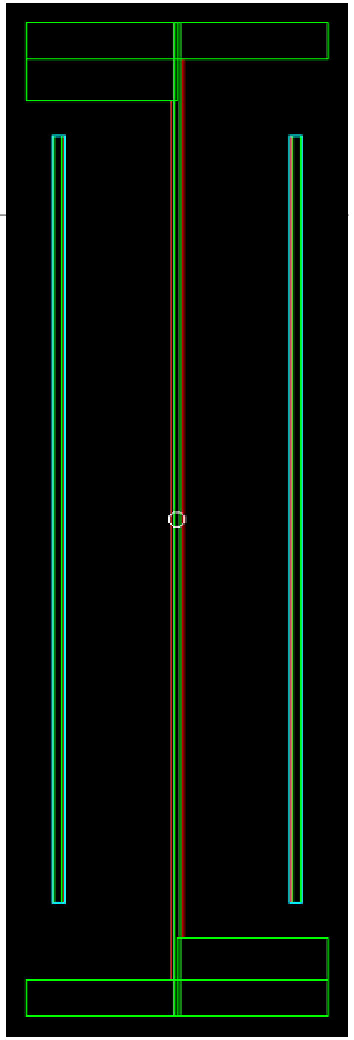


Figure 1. Cantilever beam design. Courtesy of Pranoy Deb Shuvra.

Development (continued)



Solution: “Fixed-fixed” buckled beam

- Growing oxide on non-buckled beam causes it to buckle [2]
- Beam must be >28um long to buckle according to Euler’s buckling criteria

Features: Inherently bistable and non-volatile

- Two possible buckling states: left and right
- Asymmetrical anchors at ends of beam will deform and cause dissimilar changes in device resistance when beam buckles left and right
- Electrodes on either side of beam cause beam to switch states when sufficient voltage applied

Problem: Small, hard-to-detect signal

- Need to see if signal can be maximized based on geometry and materials
- How to detect signal

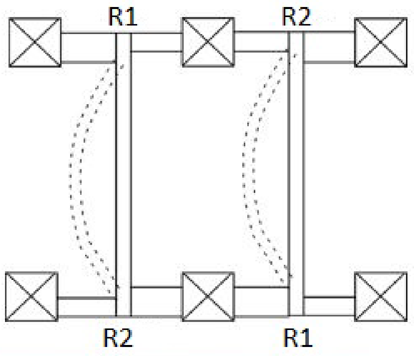
Optimization Criteria

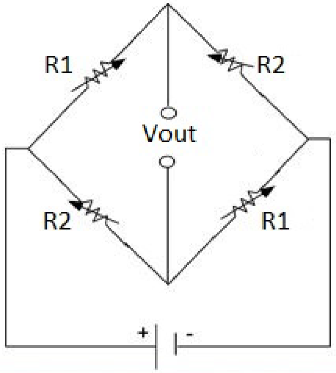
1. Signal strength – Voltage difference between “0” and “1” state (want >10uV)
   - Wheatstone bridge to detect signal
   - Voltage polarity across bridge terminals may also be used

2. Switching voltage – Voltage to switch buckling state (want <200V)

3. Pull-in voltage – Voltage that causes beam to “snap” to electrodes
   - Prevent pull-in instability in the operating voltage range: Vpull > Vsw + 50V

4. Center displacement – Maximum displacement of buckled beam at its center with no force applied



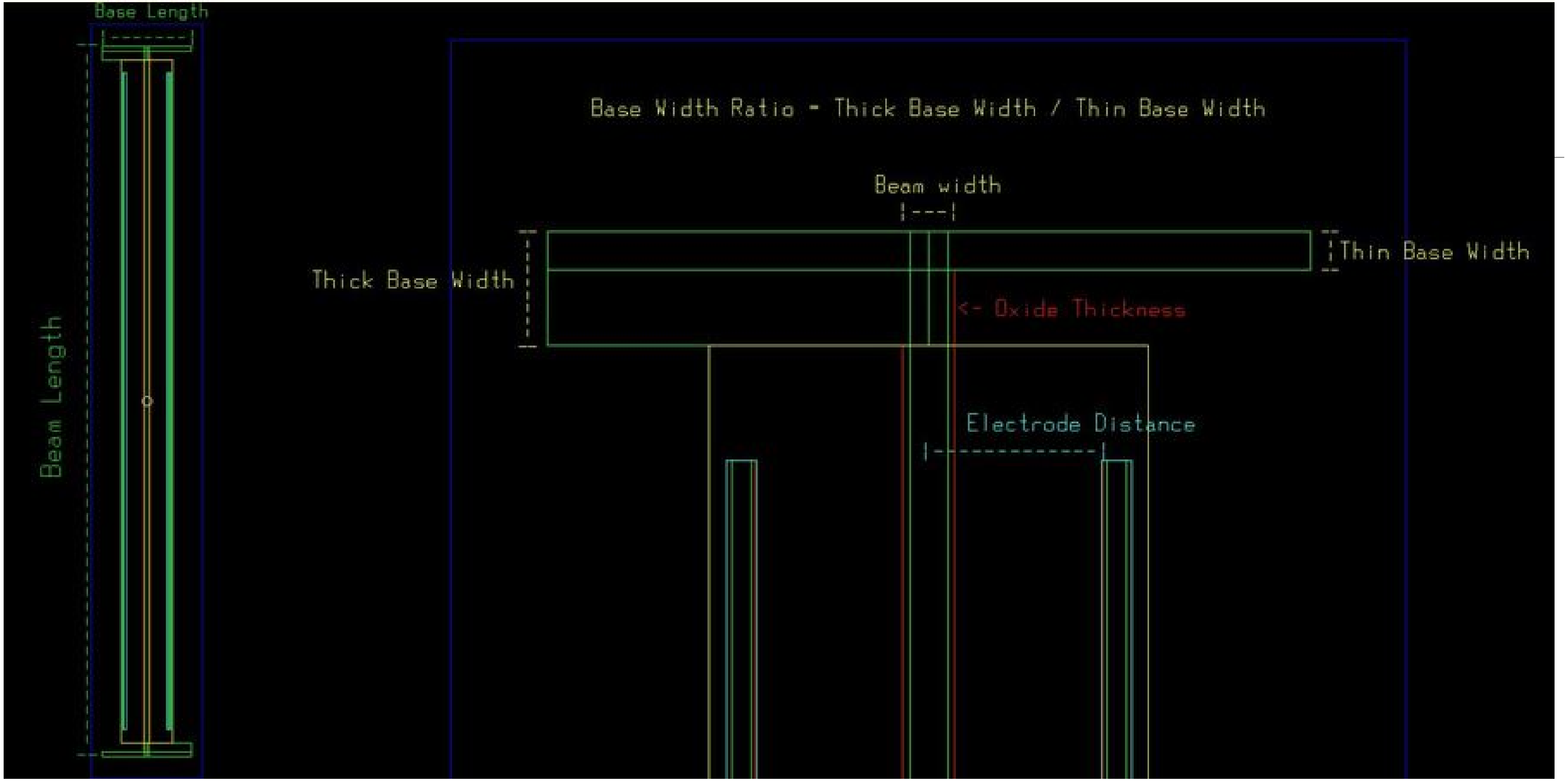


<u>Process:</u> Use MEMS simulation software CoventorWare (finite-element modeling) to produce initial theoretical results, then fabricate and test if time permits

Optimization Methodology

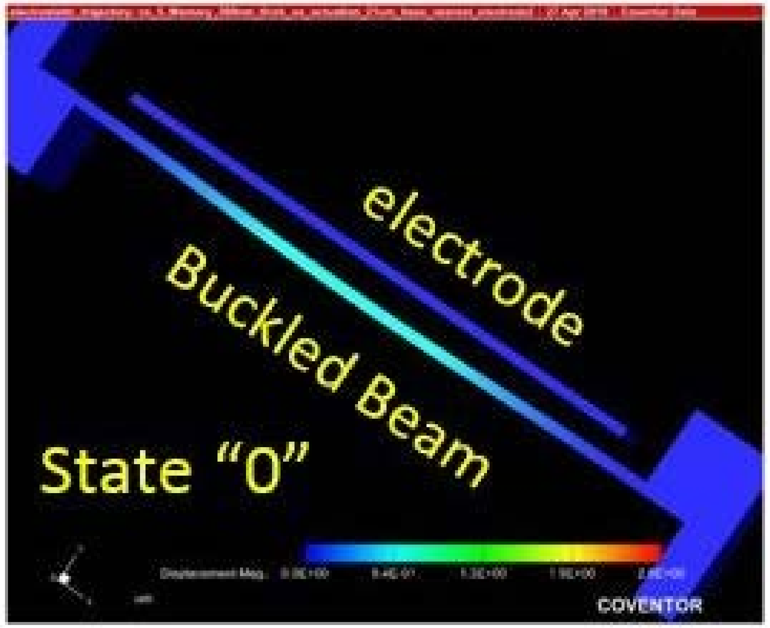
1. Rank output parameters in order of importance.
2. Rank input parameters in order of importance (preferably in pairs).
3. Optimize the most important output parameter, then the next most important, etc.
4. Change order and/or add input parameters if data suggest.

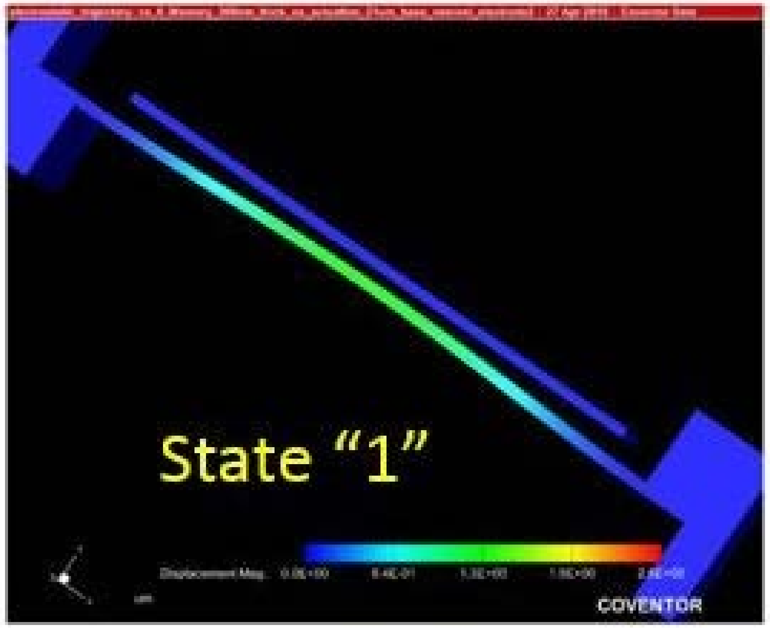
Definition of input parameters on next slide…


Base Length
Beam Length
Base Width Ratio = Thick Base Width / Thin Base Width
Beam width
Thick Base Width
Thin Base Width
<- Oxide Thickness
Electrode Distance

Simulation Process

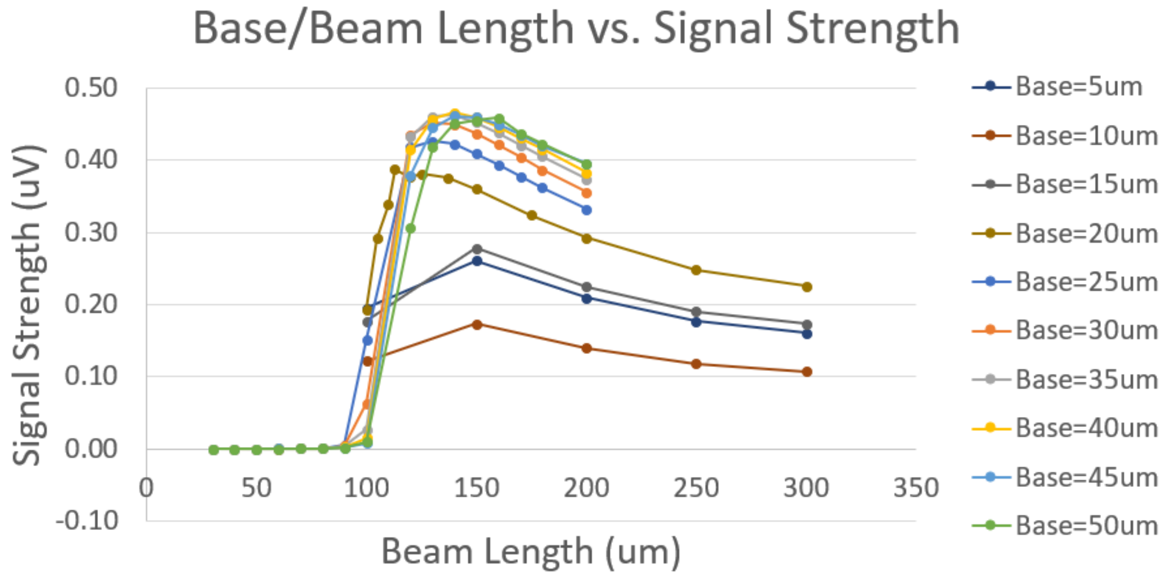
- Signal strength was measured by “pushing” beam into both states, then measuring resistances of the anchors
- Switching and pull-in voltage was measured separately by “pushing” beam into the right state, then applying a voltage to the left electrode to cause it to switch and pull in

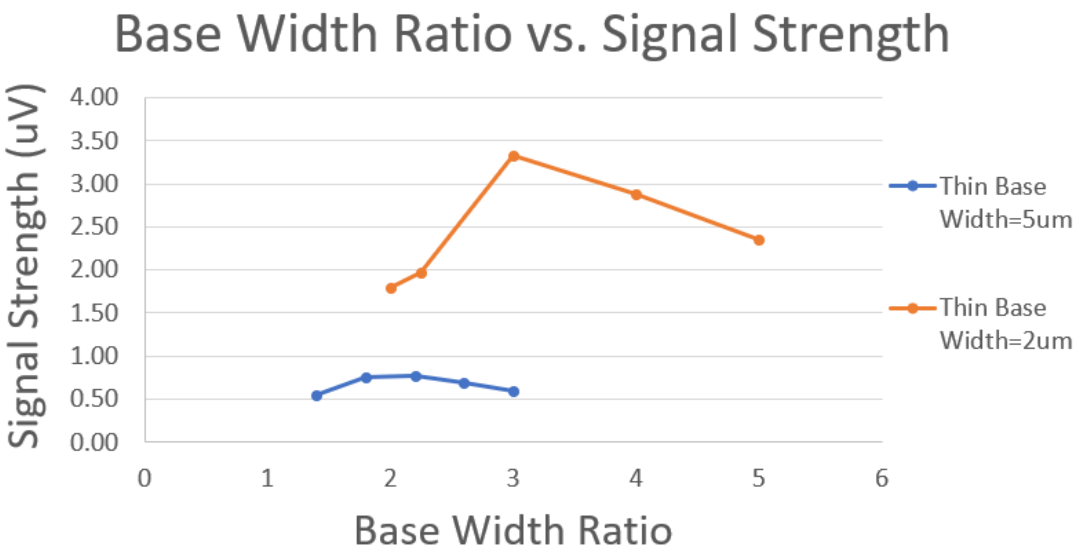




Results

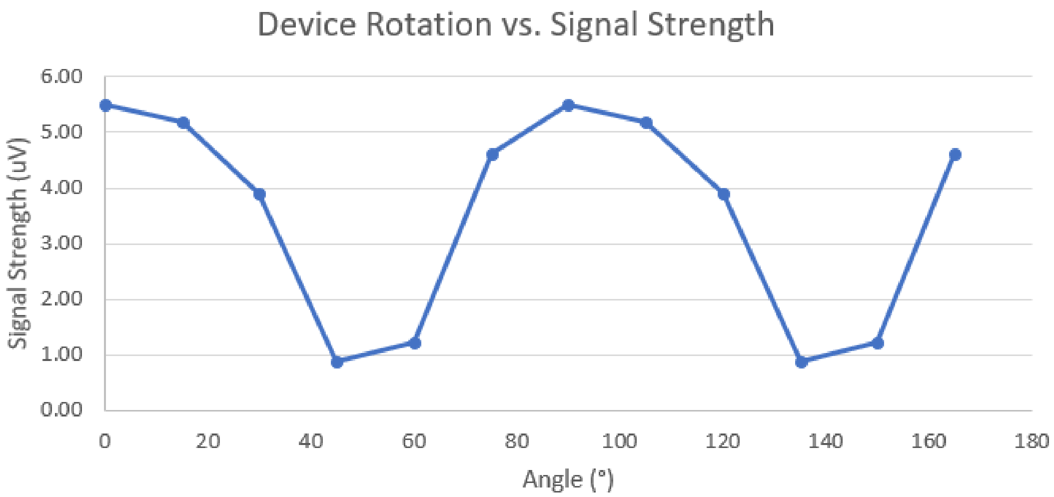
- Longer bases up to 50um yield larger signals. Signal strength peaks at beam lengths between 100-150um for 1um wide beams.
- A thinner thin base increases signal strength. There is a thick base width that corresponds to a peak in signal strength and depends on the thin base.

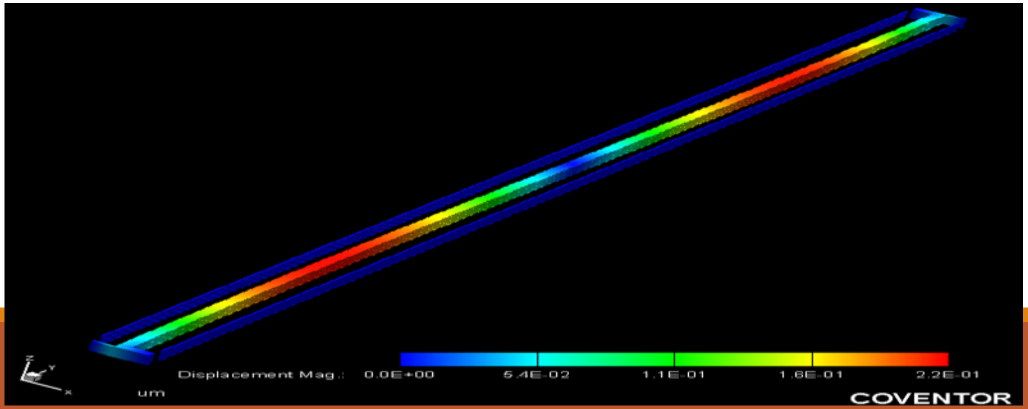




Results (continued)

- Rotating the device (to simulate different planar orientations of silicon) decreases the signal.





- A thicker beam significantly increases the signal given an appropriate length and electrode distance (to control switching voltage).
  - Electrode distance is generally (center displacement) + (2-5um)

BUT

- Beam may buckle into 2^{nd} mode if too thick and too short (bottom-left image).
  - Possible explanation: Beam acts as two cantilevers
  - Due to stiffness and symmetry of beams, net force (larger than oxide stress) at center is zero. Oxide stress causes buckling at cantilever midpoints.
  - CoventorWare mechanical and electromechanical analysis results begin to have large discrepancies at beam widths >3um

Final Model

Original model had a signal strength of 0.2uV– optimization yielded 28x increase in signal

Discrepancies in CoventorWare simulations prevented definitive signal strength calculations on “better” models (largest viable signal observed was 23.5uV)

Input parameters	Design
Base length	40 um
Beam length	260 um
Thin base width	2 um
Thick base width	6 um
Beam width (including oxide)	2.7 um
Oxide thickness	350 nm
Electrode distance from center	9 um

Output parameters	Design
Signal strength	5.5 uV
Switching voltage	100 V
Pull-in voltage	387.5-400 V
Center displacement	2.1 um
Voltage level “0”	-4.35 uV
Voltage level “1”	1.15 uV

*Vin = 2.5 V

Conclusion

MEMS memory device can yield signals up to 23.5uV, but more practically around 3-5uV.

- Optimization led to detectable signal – can use comparator or other detection methods
- Device is radiation-hard, low-power

Limitations:

- Model does not assume oxide on anchors – may cause decrease in piezoresistance
- Model is rather large for practical/industrial use
- No experimental data (yet)

Future directions:

- Fabrication and testing
- Certain Si-Ge alloys have been shown to have higher PZR/strain gage coefficients, which may help with scalability [3]

References

[1] Shuvra, P. D., McNamara, S., Lin, J., Alphenaar, B., Walsh, K., and Davidson, J. 2016. Axial asymmetry for improved sensitivity in MEMS piezoresistors. *Journal of Micromechanics and Microengineering* **26** 095014.

[2] Vangbo, M. and Backlund, Y. 1998. A lateral symmetrically bistable buckled beam. *Journal of Micromechanics and Microengineering* **8** 29-32.

[3] Richter, J., Hansen, O.,Nylandsted Larsen, A., Lundsgaard Hansen, J., Erickson, G. F., and Thomsen, E. V. 2005. Piezoresistance of silicon and strained Si0.9Ge0.1. *Sensors and Actuators A: Physical* **123-124** 388-396.

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