Fabrication of Electrostatically Actuated MEMS Switch

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I. Project Objectives

Goal: To fabricate an electrostatically actuated MEMS switch.

- Analyze effects of device dimensions on performance
- Help develop a more robust MEMS fabrication process
- Observe logical operations using MEMS switches

II. Motivation

- MEMS switches have potential in low-power applications [1]
  - Low insertion loss
  - High isolation; virtually no leakage
- Ideal for "Internet of Things" applications [1]
  - Can operate with scavenged energy
  - Device speed and size not crucial
- Help to create a more robust MEMS fabrication process [3]
  - Find and report new considerations of process
  - Attempt to fabricate DC contact MEMS switch; analyze process feasibility

III. Electrostatic Actuation Theory

- Vertical actuation using electrostatic force
- Three types of devices:
  - One armed
  - Two armed
  - Four armed
- Calculations made for one and two arm devices
- Electrostatic force (F_{emf}) needs to be greater than force required for deflection ($F_{x\text{-}arm}$)
- Actuating arm comes into contact and connects both ends of signal line
- Figures of merit:
  - V_p – Pull-in voltage

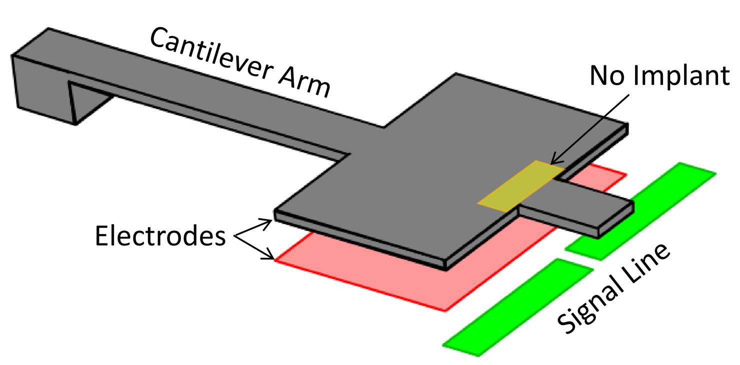

Fig. 1: One arm switch (open)

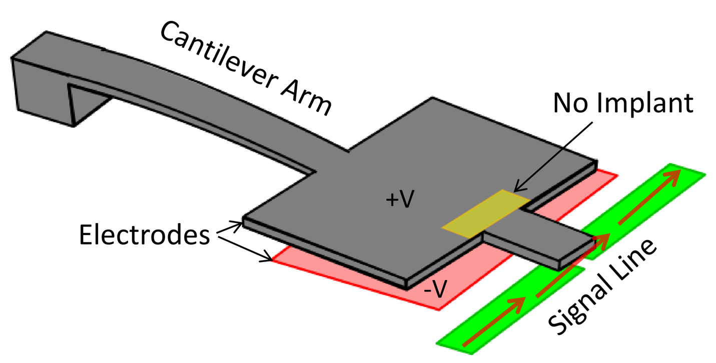

Fig. 2: One arm switch (closed)

$$F_{1-arm} = \frac{Y_{max} 3 E b h^3}{12 L^3} \quad [2]$$

$$F_{2-arm} = \frac{Y_{max} 4 E b h^3}{L^3} \quad [2]$$

$$F_{emf} = \frac{\varepsilon_0 \varepsilon_r A V_p^2}{2 d^2} \quad [2]$$

IV. Experimental Setup

- Two sets of devices fabricated:
  - First set (Fall 2015): proof of concept
  - Second set (Spring 2016): device parameter investigation
- Investigation into the parameters affecting device performance:
  - Length of arm (including meanders) (L [μm])
  - Width of arm (b [μm])
  - Electrode area (A [μm²])
  - Number of meanders in four arm device (M [#])
- Performed a full factorial on these parameters
- Total number of individual devices:
  - 54 parameter investigation devices
  - 4 logic gates (Inverter, 2NAND, 2NOR, 3NAND)
- Fabrication process [3]:
  - 8 mask levels
  - 51 processing steps

One Arm Parameters			
L [μm]	240	290	N/A
b [μm]	6	10	20
A [μm²]	2000	5000	8000

Fig. 2: One arm full factorial

Two Arm Parameters			
L* [μm]	280	340	N/A
b [μm]	4	6	8
A [μm²]	6600	7700	9300

Fig. 3: Two arm full factorial

Four Arm Parameters		
L* [μm]	300	320
b [μm]	5	7
A [μm²]	21200	22600
M [#]	3	4

Fig. 4: Four arm full factorial

* These lengths are not the values used in calculating deflection force; rather L* is used to more simply represent the device dimensions

V. Device Design

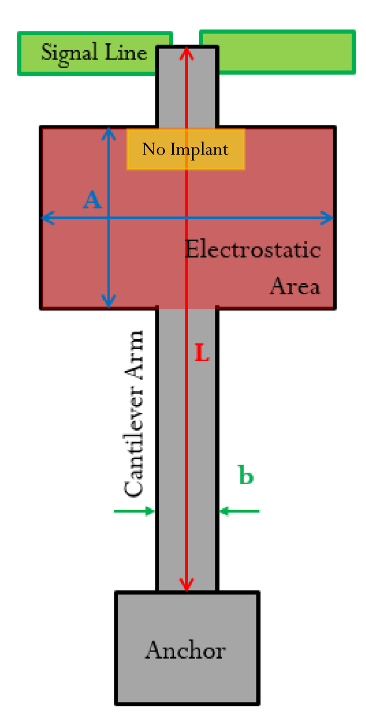

Fig. 5: One arm device design

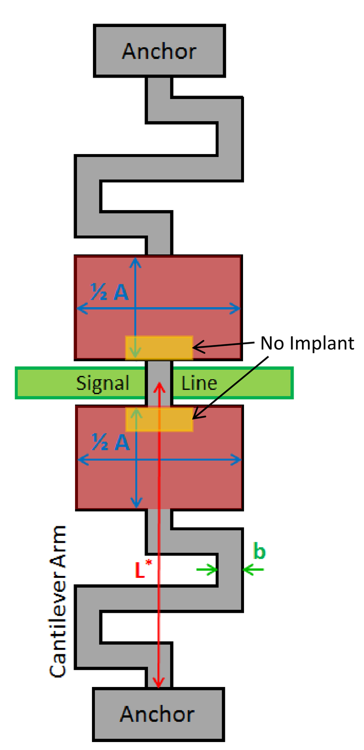

Fig. 6: Two arm device design

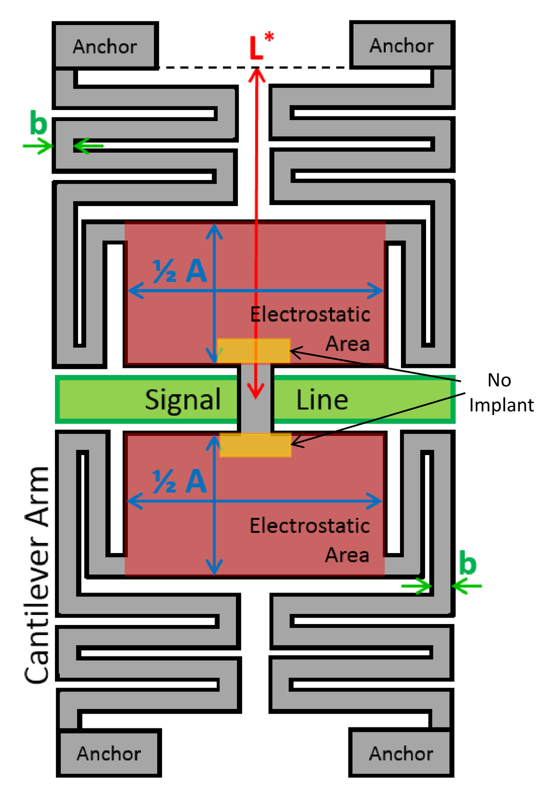

Fig. 7: Four arm device design

VI. Discussion of Results

- Determined a new design rule for MEMS layout:
  - Anchor level over first polysilicon must be covered by second polysilicon or sacrificial oxide
- Provided more data/perspective for developing more robust MEMS fabrication process
- Devices not completed fabrication; first set at release (most difficult step) and second set at metal

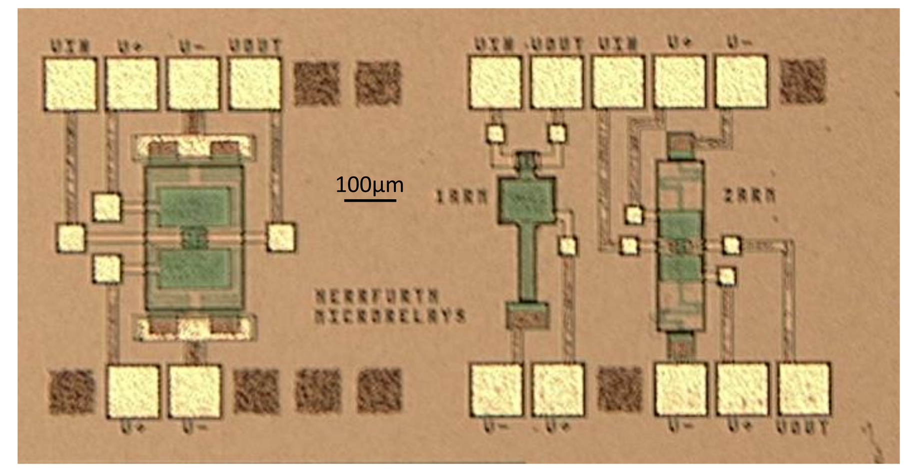

Fig. 8: First set of devices (pre-release)

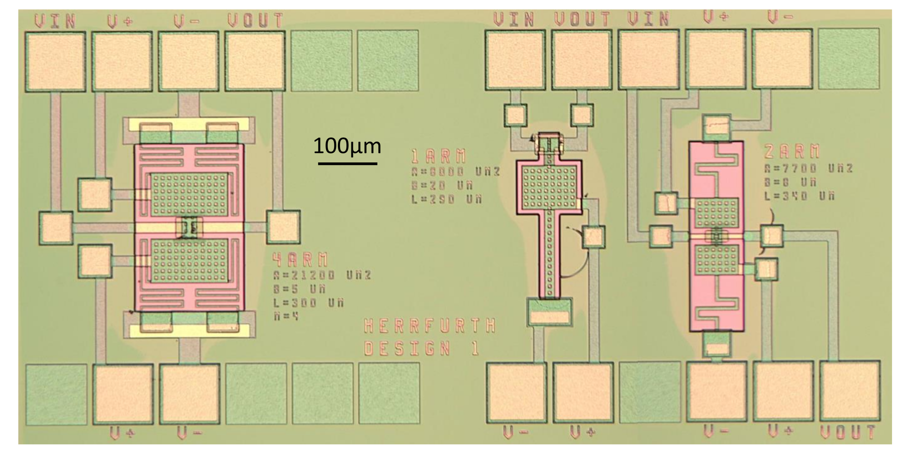

Fig. 8: Second set of devices (Design 1; pre-metal)

VII. Conclusions

The MEMS fabrication process is still being developed and debugged. Considerations for how this process would treat electrostatically actuated switches were investigated in this project. New design rules and more data was collected for analyzation of the process in relation to switches.

Future Work

As the MEMS fabrication process is developed more, it will be possible to attempt fabrication of these devices with the hope of more successful iterations.

References

[1] MEMS Switch for Low-Power Logic, T. K. Liu
[2] MEMS Mechanical Fundamentals, L. Fuller
[3] Surface MEMS Fabrication Details, L. Fuller

Acknowledgements

- Dr. Lynn Fuller, Dr. Ivan Puchades
- Adam Wardas, Adam Banees, Chris O'Connell
- Dr. Pearson, Dr. Ewbank
- SMFL Staff

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