Fabrication of MEMS Electrostatically Actuated Switch

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MEMS for Low-Power Logic

- MEMS – <u>M</u>icro<u>e</u>lectro<u>m</u>echanical <u>S</u>ystems
- MEMS switches have potential for low-power applications [1]
  - Virtually no leakage current
  - Little resistance across switch
- Low-power required for devices using scavenged energy
  - Piezo-, thermo-, and photo-electric energy sources
  - "Internet of Things" devices

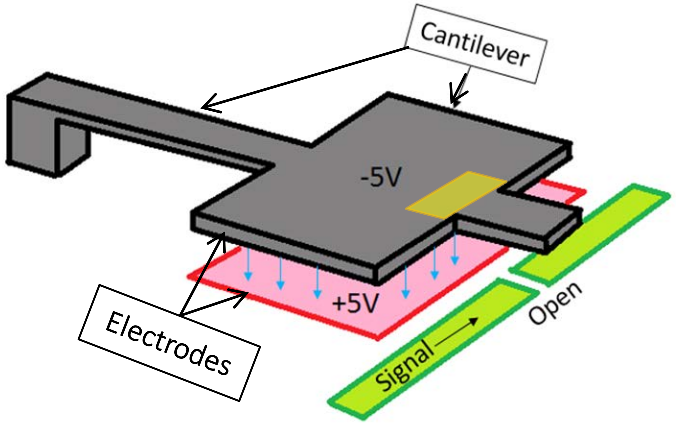


Fig. 1 – One arm MEMS switch

MEMS Switch Operation

- Uses electrostatic force to rectify an open circuit with flexible, conductive polysilicon
  - Physical relay vs. static MOSFET
- Improved device properties compared to MOSFETs:
  - Lower insertion loss
  - Higher isolation
  - Lower power consumption
- Several designs created to analyze operation of devices
  - Observe effect on "pull-in" voltage

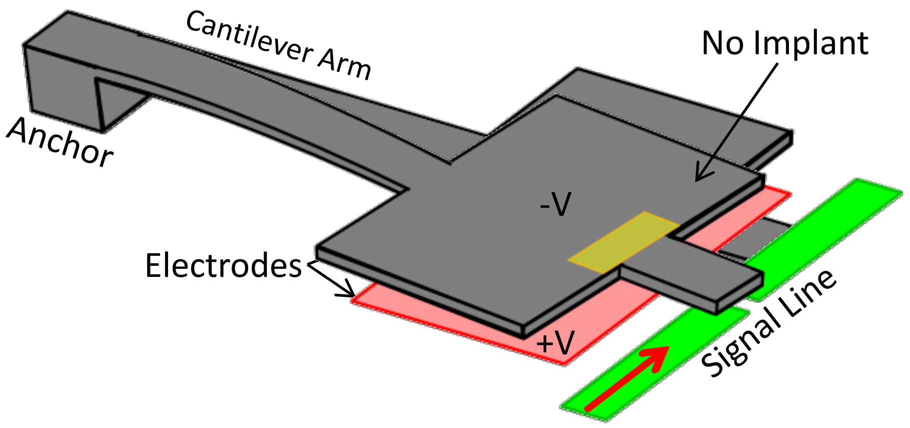


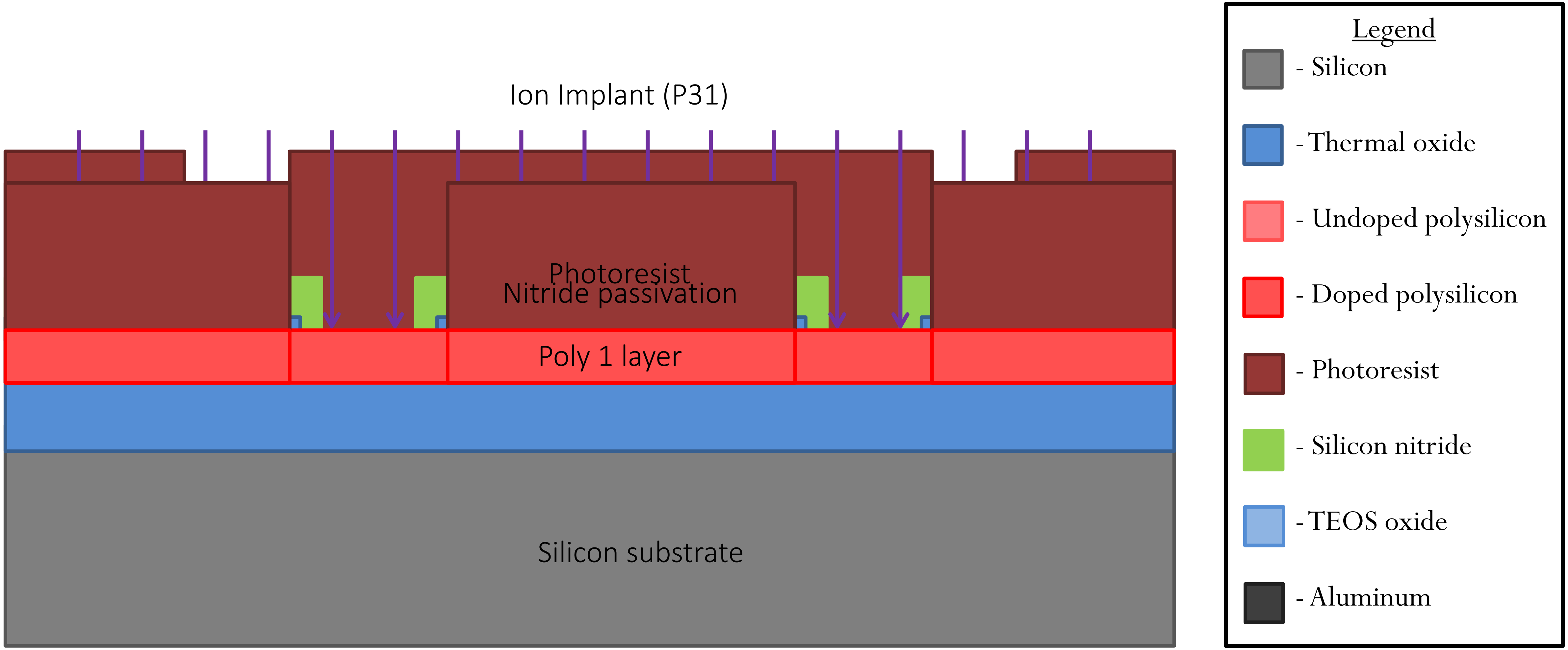
Fig. 2 – One arm MEMS switch operation

Project Objectives

- Analyze effect of device dimensions
  - Length, width, electrode area of actuating arm
  - Calculate for "pull-in" voltage
- Analyze different types of switches
  - One-arm, two-arm, and four-arm switches
- Help Dr. Fuller and Adam Wardas develop a more robust MEMS fabrication process [3]
  - Surface MEMS fabrication process still in development (less than 2 years old)
  - Provide more perspective for fabricating switches

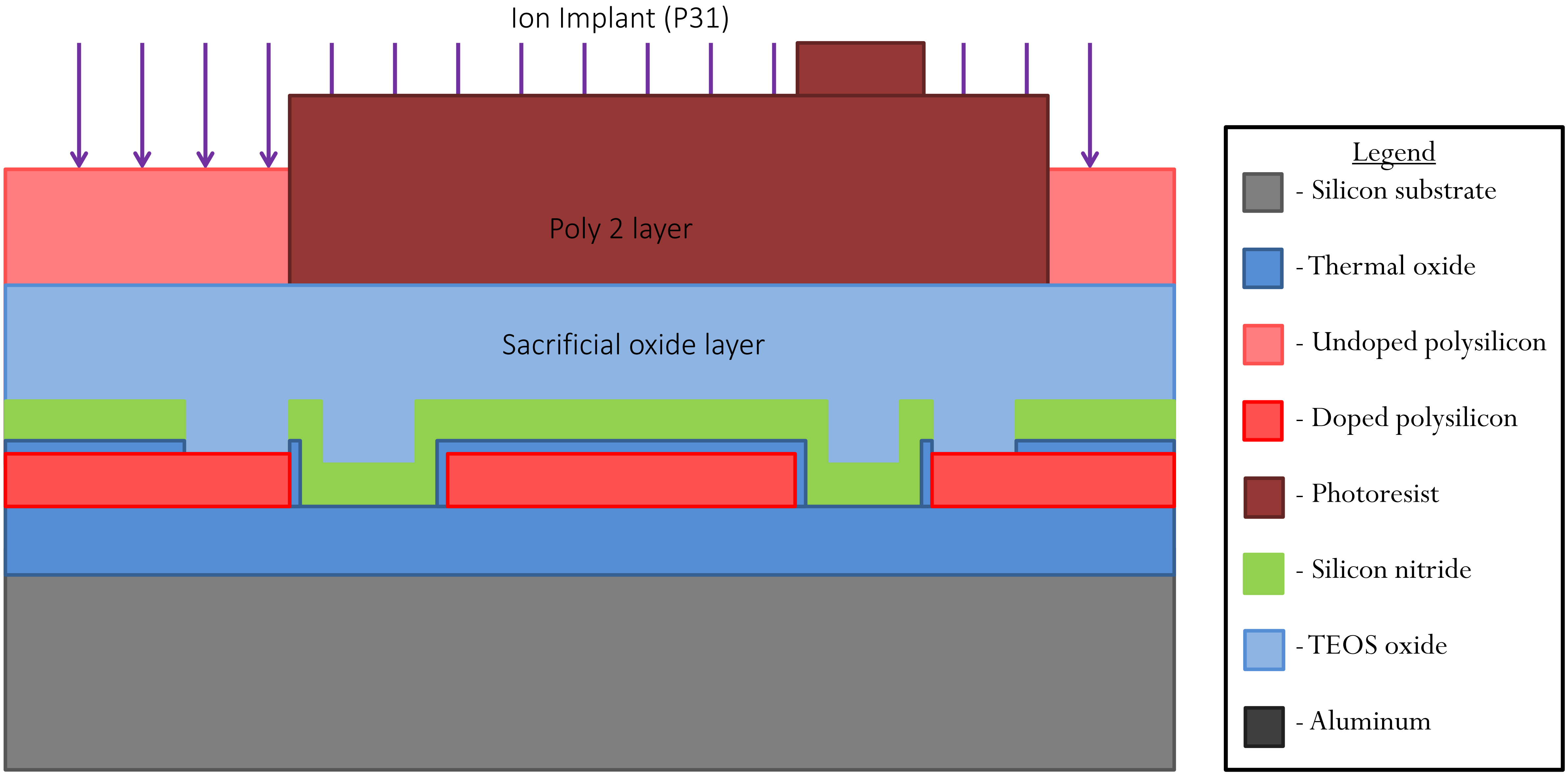
Fabrication Process

- Processing partner: Adam Banees, fellow μE senior
- Eight mask levels, about 50 processing steps [3]:
  1. Polysilicon 1 – interconnect poly and passivation
  2. Anchor – etch openings through poly passivation
  3. Sacrificial Oxide – deposit and etch sac. ox.
  4. No Implant – deposit poly 2; mask regions of poly 2 from implant; passivate poly 2
  5. Polysilicon 2 – mechanical poly and passivation
  6. Contact Cut – etch contact holes through poly 2 passivation
  7. Metal – deposit and etch aluminum
  8. Release – etch away sacrificial oxide (most difficult level)

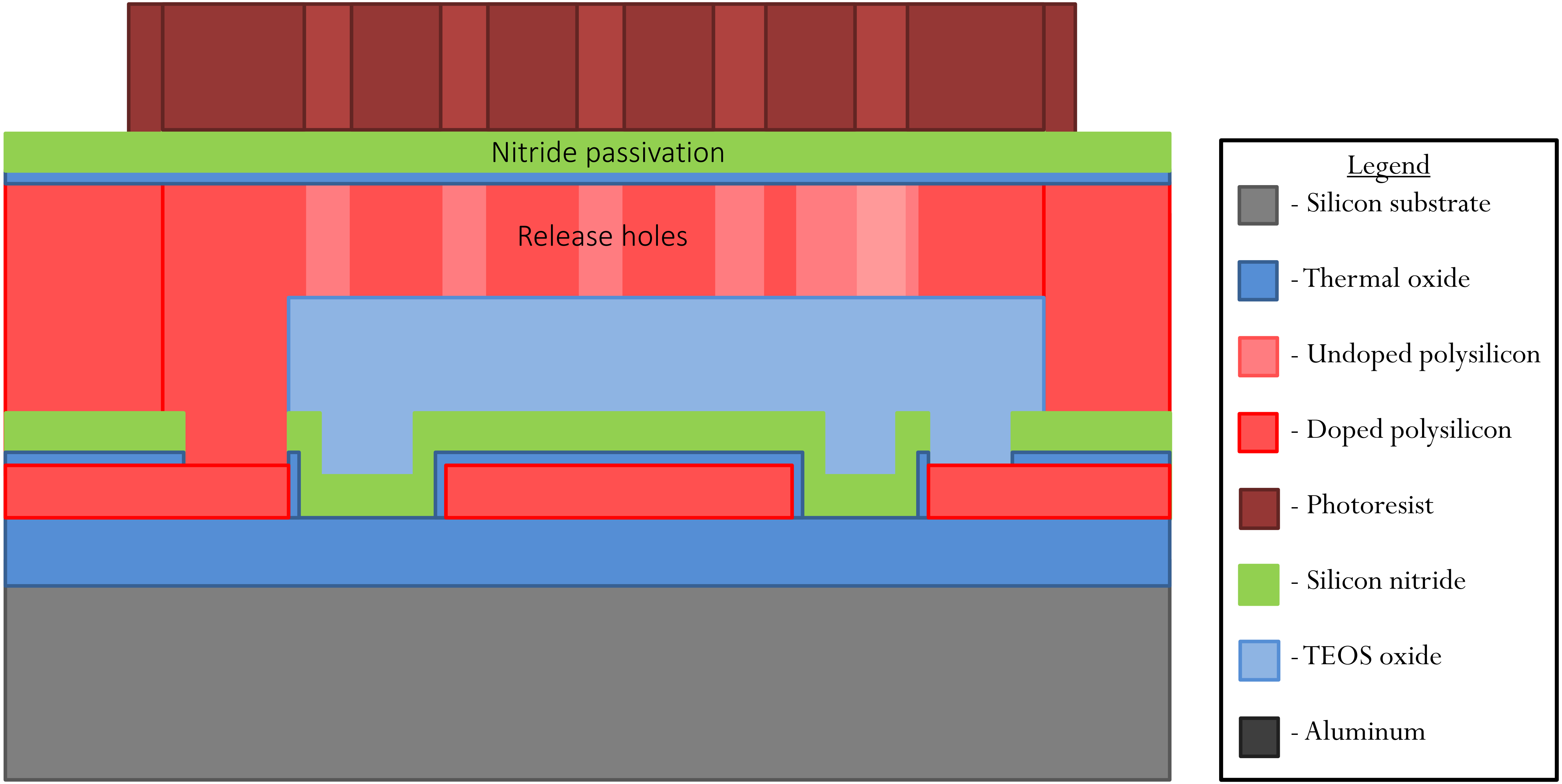


Level 1 – Anchor etch

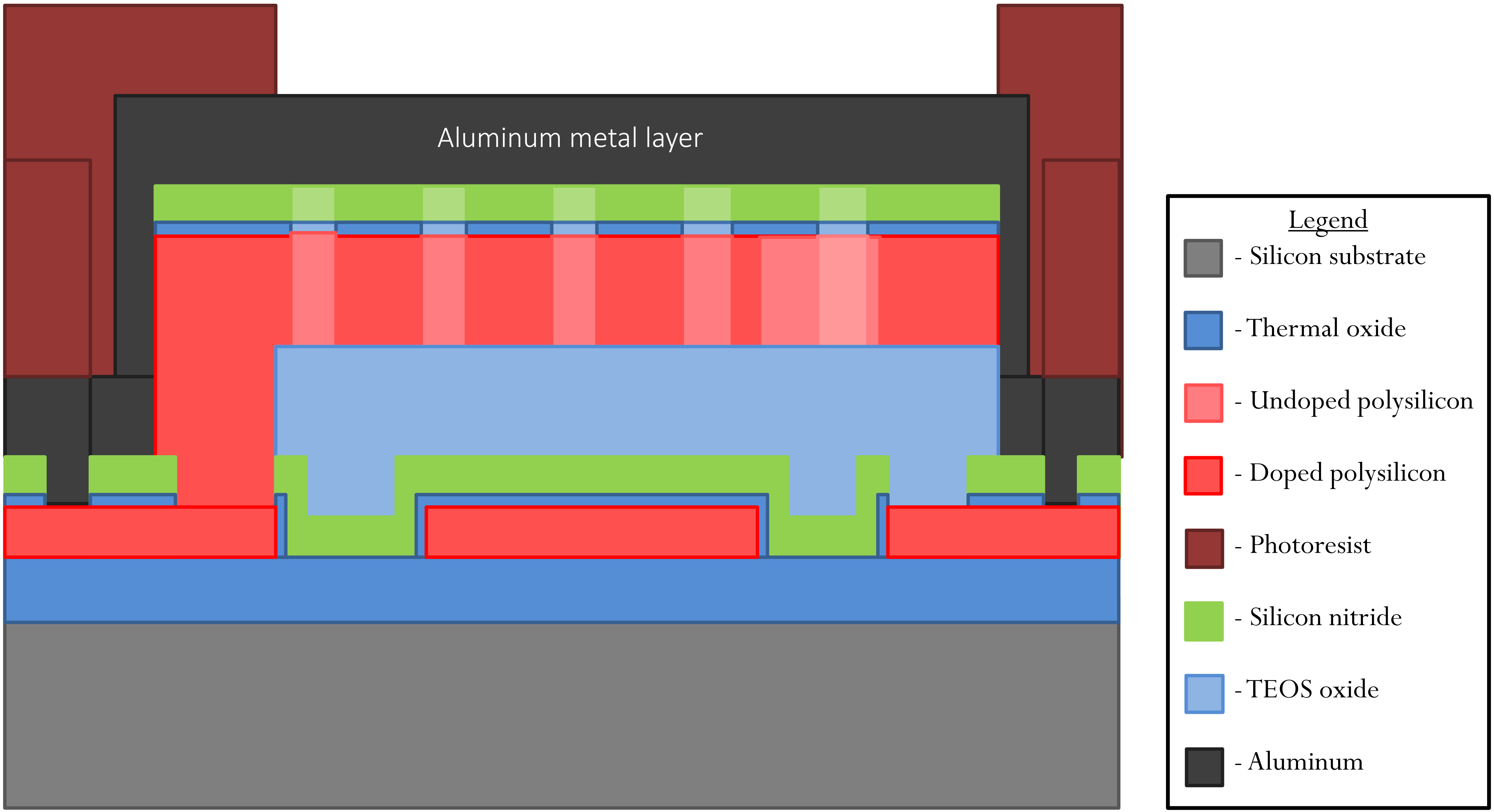
Level 2 – Interconnect poly



Level 4 – Sacrificial oxide etch



Level 5 – Contact cut
Level 6 – Mechanical poly



Level 7 – Aluminum metal

Level 8 – Release etch

Device Designs

- Three distinct types of devices: one-arm, two-arm, and four-arm
- Full factorial on dimension variables
  - Length (L [μm])
  - Width (b [μm])
  - Electrode area (A [μm^2])
  - Number of meanders (four-arm only)
- Two sets of devices in fabrication:
  - First set (Fall 2015): proof of concept
  - Second set (Spring 2016): device parameter investigation

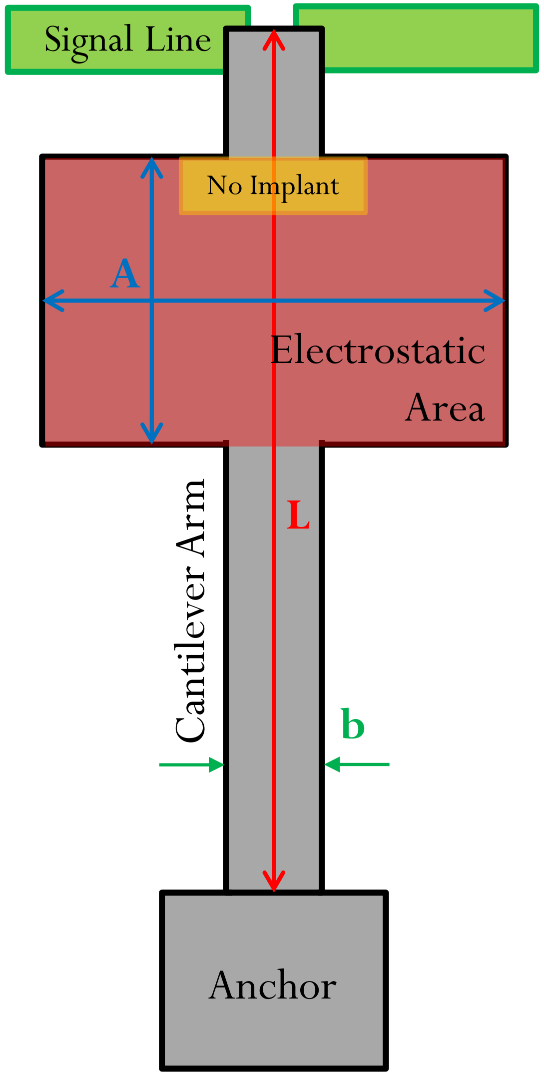


Fig. 3 – Design parameters for one arm MEMS switch

Device Designs (cont.)

- Four arm device based on design by Artur Nigmatulin (2011)

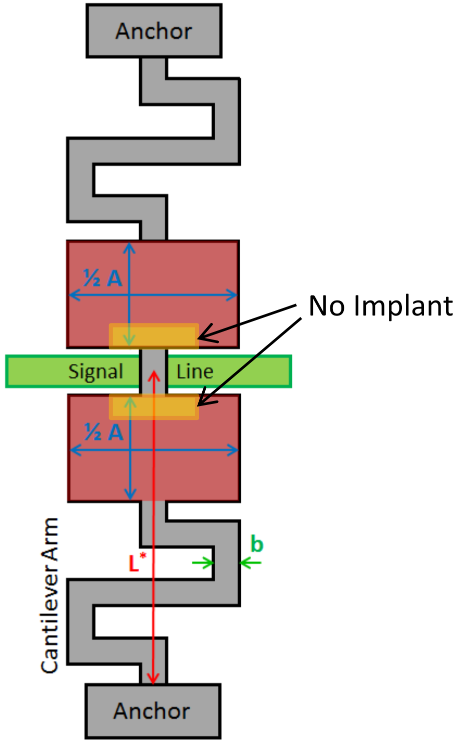


Fig. 4 – Design parameters for two arm MEMS switch

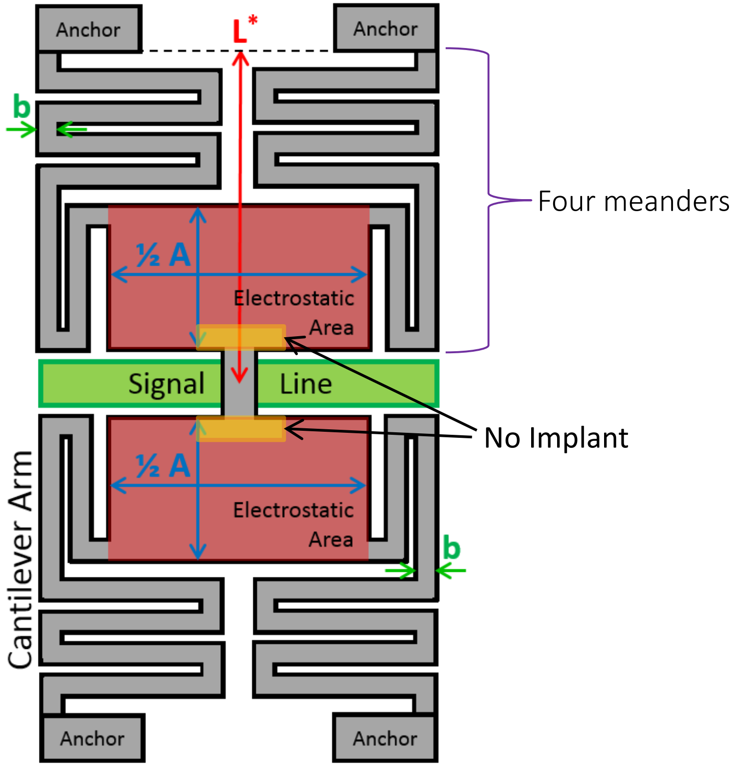


Fig. 5 – Design parameters for four arm MEMS switch

Experimental Design

- Total number of unique devices:
  - 18 one-arm designs
  - 18 two-arm designs
  - 16 four-arm designs
- L^* - effective length

One Arm Parameters			
L [μm]	240	290	N/A
b [μm]	6	10	20
A [$μm^2$]	2000	5000	8000

Two Arm Parameters			
L^* [μm]	280	340	N/A
b [μm]	4	6	8
A [$μm^2$]	6600	7700	9300

Four Arm Parameters		
L^* [μm]	300	320
b [μm]	5	7
A [$μm^2$]	21200	22600
M [#]	3	4

Calculations for Electrostatic Force

- Single arm equations [2]: $F_{emf} = \frac{\varepsilon_o \varepsilon_r V^2 A}{2d^2}$; $F_{cant.} = \frac{Y_{max} 3Ebh^3}{12L^3}$

- Dual arm equations [2]: $F_{emf} = \frac{\varepsilon_o \varepsilon_r V^2 A}{2d^2}$; $F_{cant.} = \frac{Y_{max} 4Ebh^3}{L^3}$
- Green: design variables; Red: calculated variables

	A	B	C	D	E	F
1	Single Cantilever Equations					
2					meters	microns
3	Ymax=	2.00E-006	m	A=	8.00E-010	800
4	h=	2.00E-006	m	b=	2.00E-005	20
5	E=	1.90E+011	N/m^2	L=	2.00E-004	200
6	d=	2.00E-006	m	Vth=	15	V
7	e0=	8.85E-012	F/m			
8	er=	11.7		Max stress=	7.00E+010	dyne/cm^2
9						
10						
11	F(Deflection)=	1.90E-006	N			
12	F(Electrostatic)=	1.96E-006	N			
13	Stress=	2.94E+007	dyne/cm^2			
14						

Fig. 6 – Example calculations from excel

Current Device Status

- First set of devices at release layer; work still being done
  - Release layer is most difficult process
- Second set of devices at metal
  - Issues seen with metal etch

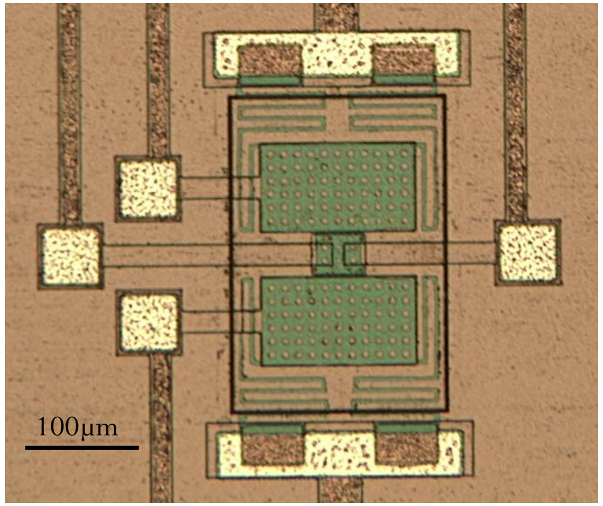


Fig. 7 – Four arm device from first set (pre-release)

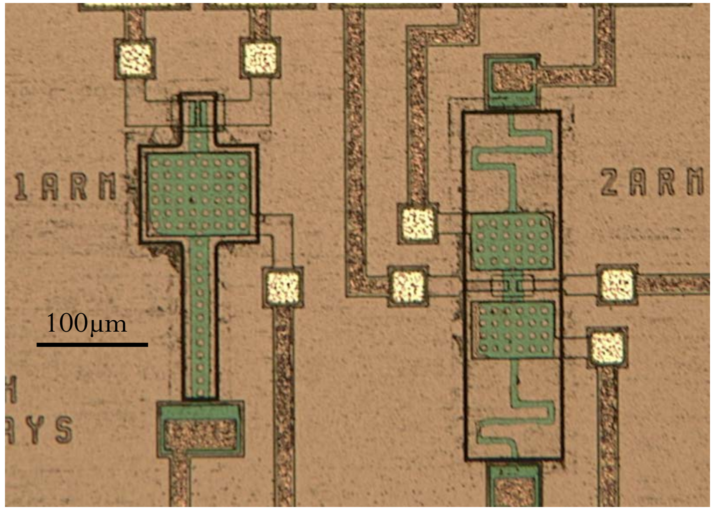


Fig. 8 – One and two arm devices from first set (pre-release)

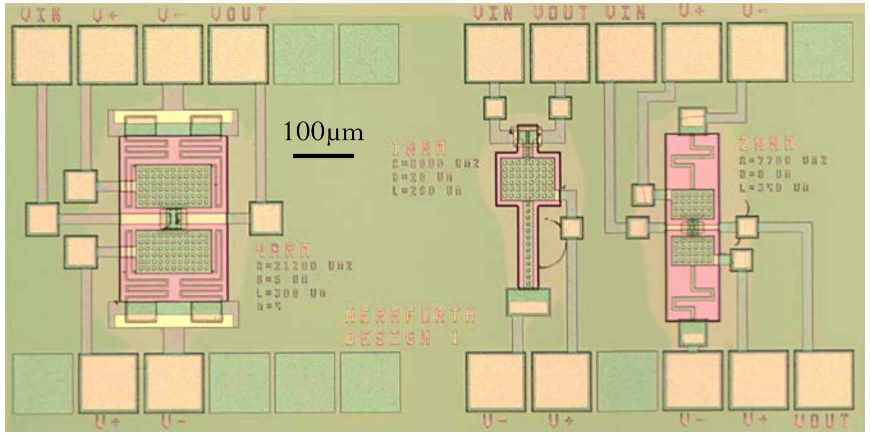


Fig. 9 – Design 1 devices from second set (pre-metal)

Project Issues

- Anchor level litho not processed correctly; weeks spent trying to recover
- Found design error during Spring; had to reorder Poly 2 mask
  - New design rule created as a result
- Aluminum metal is not fully etching
  - Need to determine source of issue

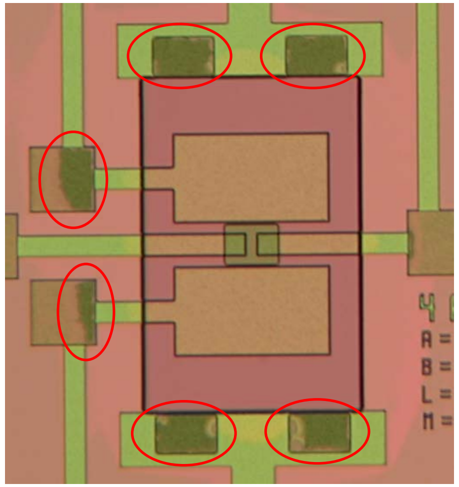


Fig. 10 – Films left over from bad anchor litho/etch

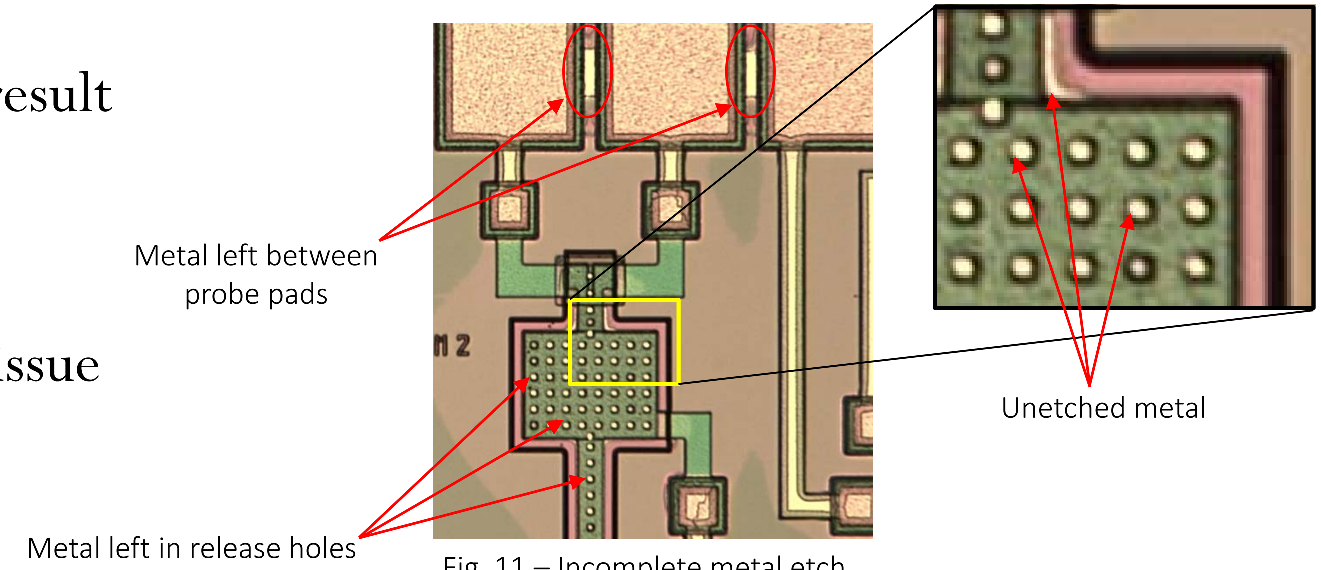


Fig. 11 – Incomplete metal etch

Results

- New design rule developed:
  - Anchor level over Poly 1 must be covered by Sac. Ox. or Poly 2
  - Otherwise, Poly1 is etched when etching Poly 2
- More experimentation done with exposure process
  - Poly 2 level litho very sensitive; provided more data for exposure dose and focus

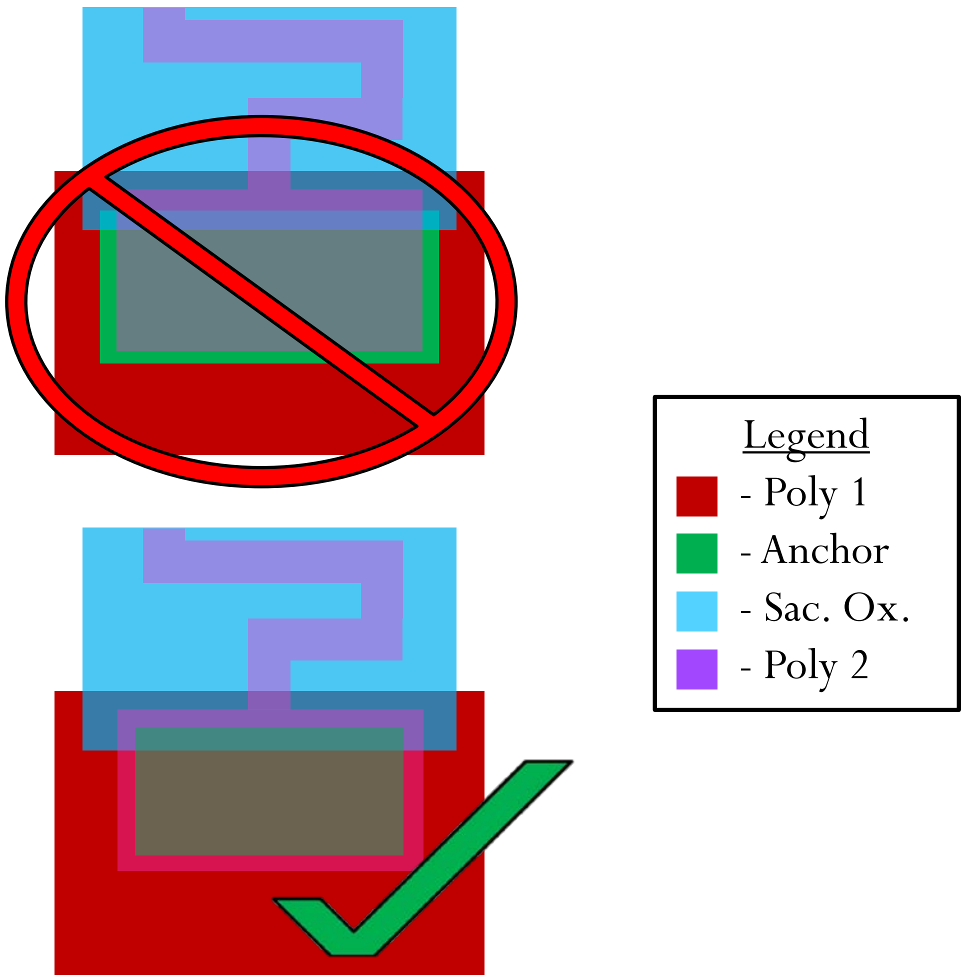


Fig. 11 – Layout view of implementing new design rule

Results (cont.)

- More processing data obtained for development
- Design for DC MEMS switch; previous switches are AC
  - Include Anchor cut at switch to allow Poly 2 to contact Poly 1
- Experiments done to improve metal etch
  - May need to change from wet etch to plasma

Acknowledgements

- Thanks to Dr. Fuller and Adam Wardas for their work developing the MEMS fabrication process
- Thanks to Dr. Puchades for giving me the idea for this project and material to study it
- Thanks to Adam Banees, Adam Wardas, Chris O'Connell, and the SMFL staff for help with processing
- Thanks to Drs. Pearson and Ewbank for aiding in developing this project

References

[1] MEMS Switch for Low-Power Logic, T. K. Liu

[2] MEMS Mechanical Fundamentals, L. Fuller

[3] Surface MEMS Fabrication Details, L. Fuller