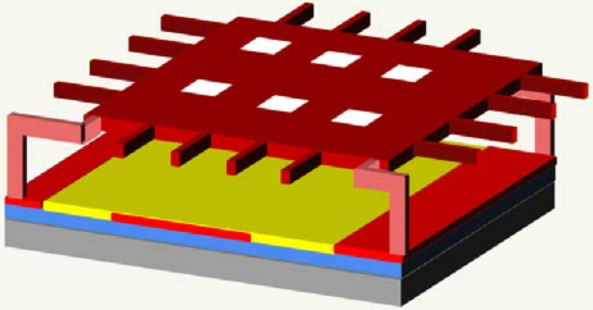
Design and Fabrication of a Three-Axis Capacitive Accelerometer

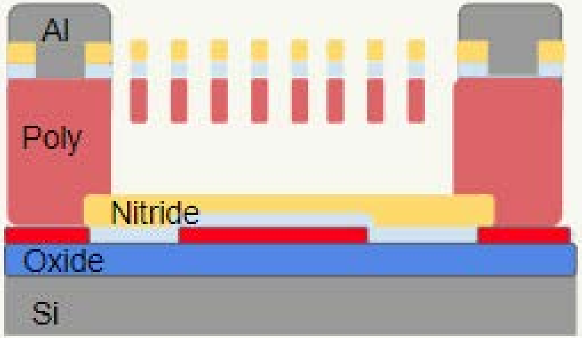


By: Eddie Huang

Advisor: Dr.Fuller

Senior Design Project

Microelectronics Engineering

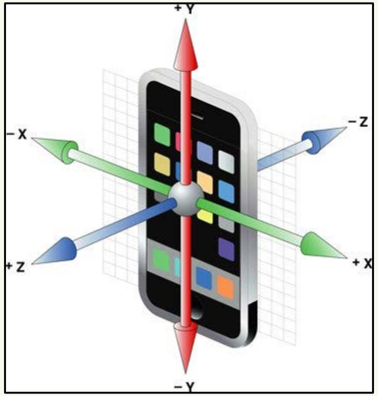


Outline

- Introduction
  - MEMS Applications
  - Project Motivations and Goals
- Theory and Design
  - Capacitive Comb Finger
  - Mask Design
  - Three-Axis Accelerometer Parameters
  - Simulation Results
- Process Flow
- Defects
- Conclusion and Future Work

What Are MEMS and their Applications?

- Microelectromechanical Systems (MEMs) are microdevices that have mechanical and electrical properties and are created using microfabrication processes.
- The MEMs industry has been implemented in many of our devices today such as our phones, game consoles, car airbags, and pedometers.



Ravado, R. "10 Free Accelerometer Apps for iPhone and iPod Touch"

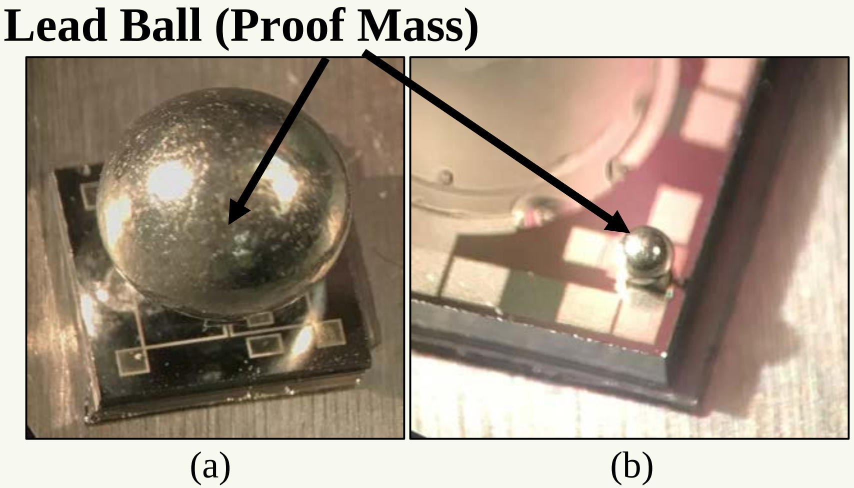
Wii Remote Controller by Nintendo of America

Melissa, Car Airbag Safety – What You Need to Know"

fitbit.com/store

Project Motivations and Goals

- Design and Fabrication of a working 3-Axis Accelerometer in the Semiconductor & Microsystems Fabrication Laboratory (SMFL).
  - Design of Single and Dual Axis accelerometers.
- Testing the capabilities of our SMFL processes to make **working comb-drives** to sense acceleration.
- Three-Axis accelerometer allows for detection of acceleration from the x,y, and z-axis and measure forces up to **±10G**.



Examples of a **Bulk (a)** MEMS pressure sensor and **Surface (b)** MEMS tilt sensor. Both fabricated in Dr.Fuller's MEMS Fabrication Course.

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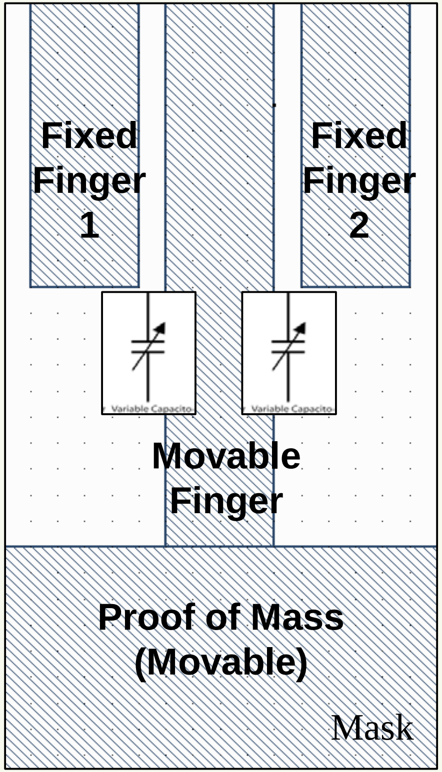
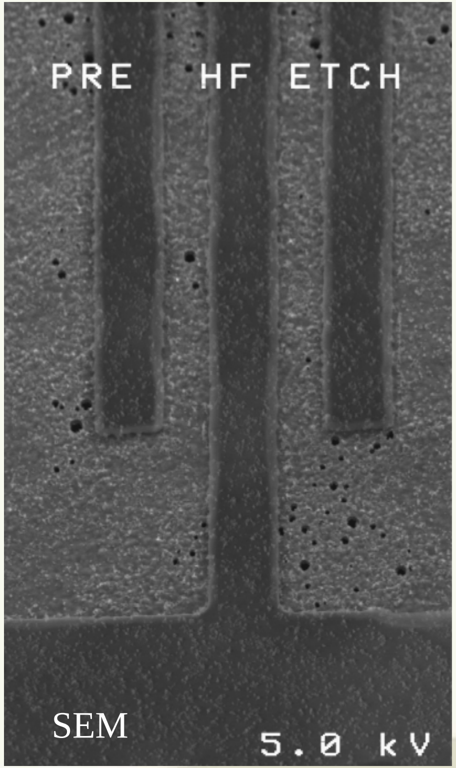
Capacitive Comb Fingers





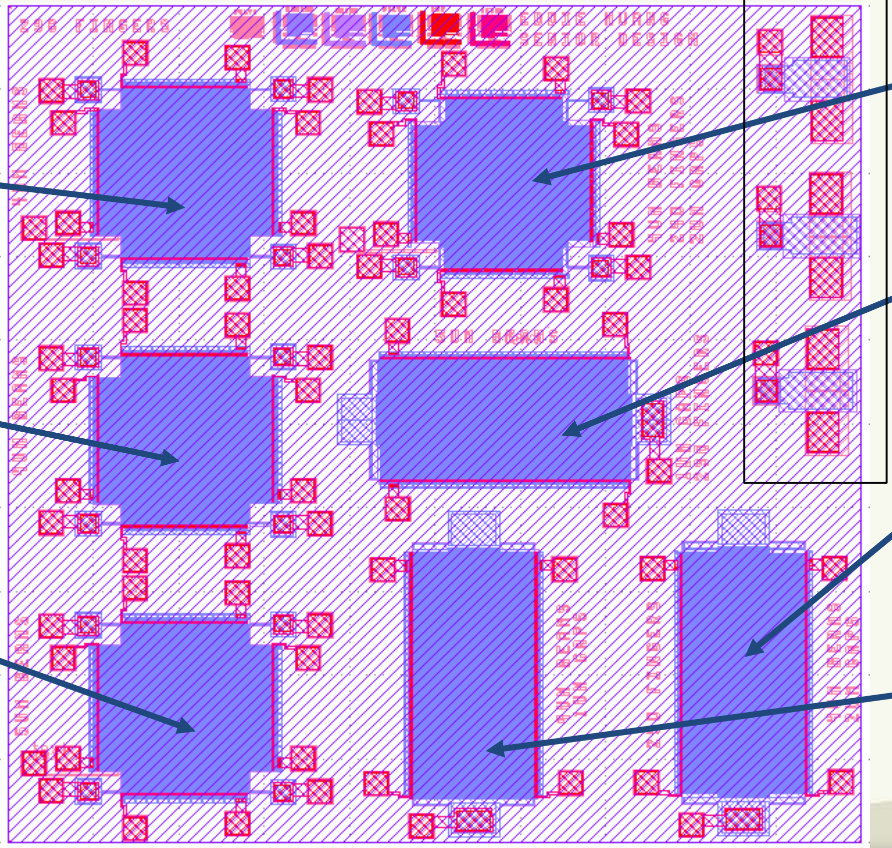
$$C(fingers) = (\frac{\epsilon_o \epsilon_r N_s L_s H_s}{d_o}) * (\frac{1 + d_x}{d_o})$$

Relative Permittivity	ϵo
Permittivity of Air	ϵr
Height of Fingers	Hs
Number of Fingers	Ns
Length of Fingers	Ls
Width of Fingers	Ws
Finger Gap	do
Displacement by Force	dx

Mask Design

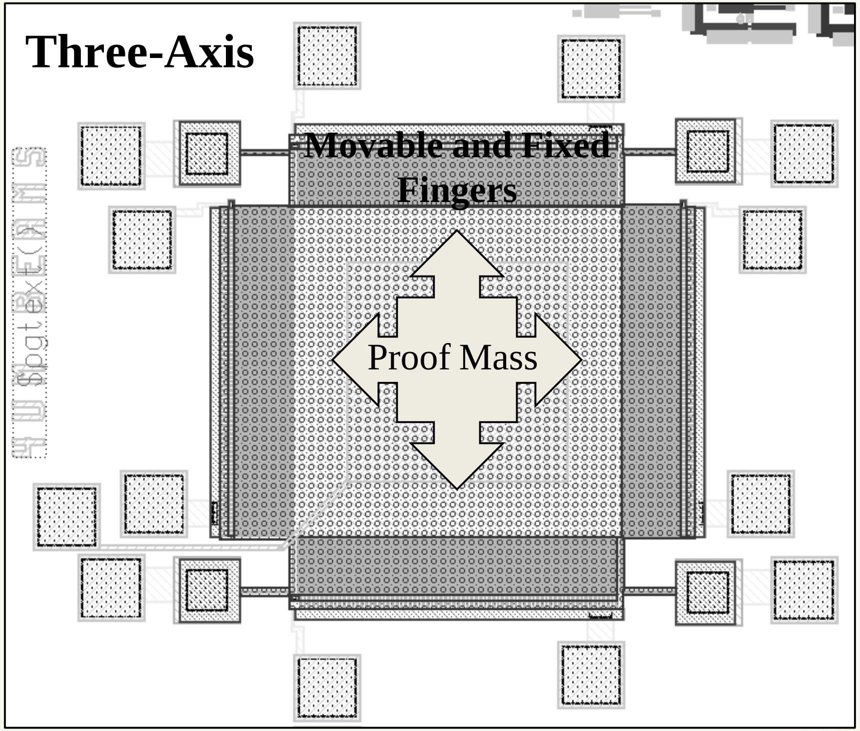
- **Three-Axis**
  - 1um Gaps
  - 4um Beams
  - 296 Fingers
- **Dual-Axis**
  - 1um Gaps
  - 4um Beams
  - 296 Fingers
- **Three-Axis**
  - 1um Gaps
  - 5um Beams
  - 296 Fingers

Cantilever Beams



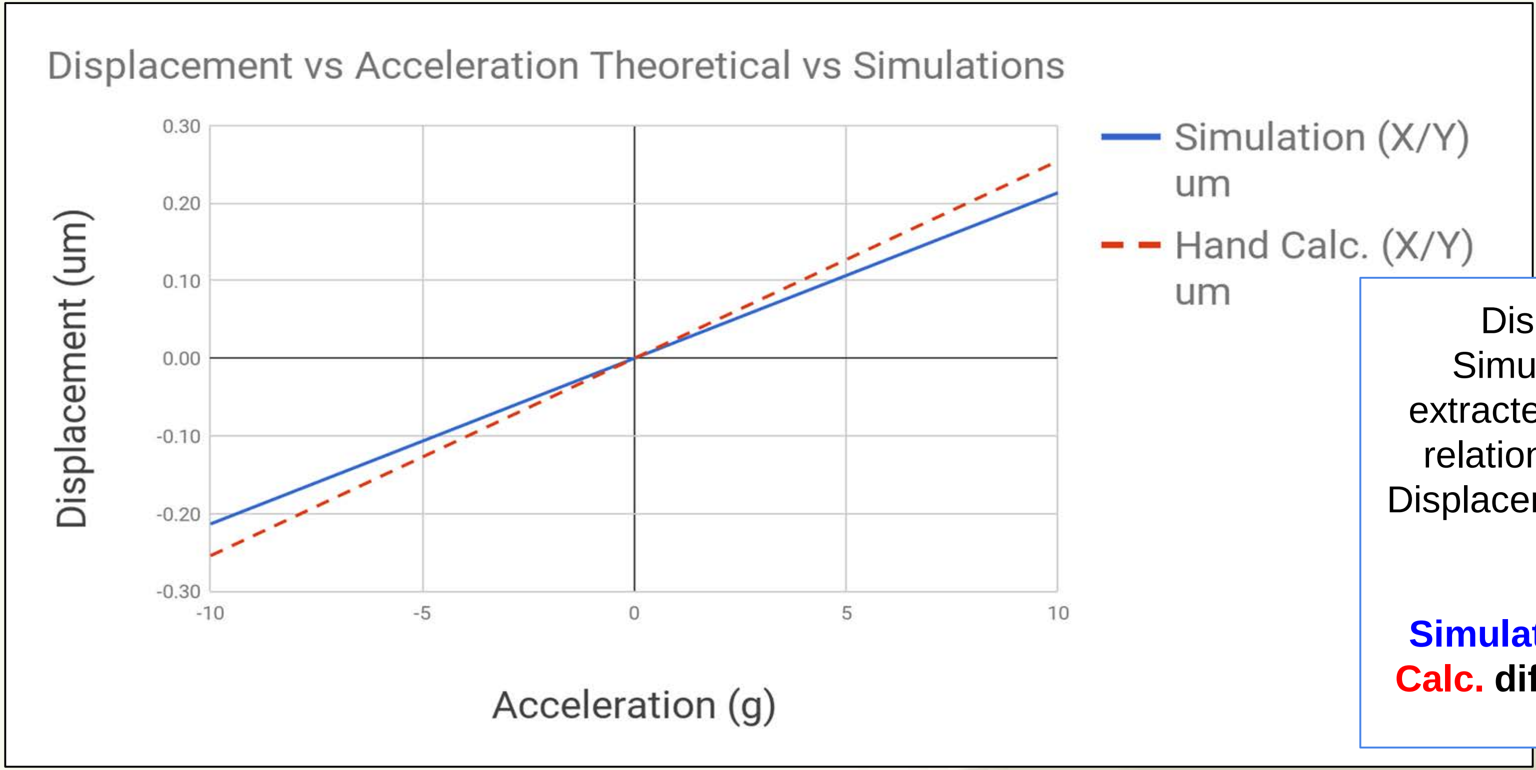
- **Three-Axis**
  - 2um Gaps
  - 4um Beams
  - 240 Fingers
- **1-Axis**
  - 1um Gaps
  - 5um Beams
  - 290 Fingers
- **1-Axis**
  - 2um Gaps
  - 4um Beams
  - 250 Fingers
- **1-Axis**
  - 1um Gap
  - 4um Beams
  - 290 Fingers

Three-Axis Accelerometer Parameters



Parameter	Measurements & Units
Proof Mass Size	1500µm x 1500µm
Proof Mass Thickness	2µm
Proof Mass Weight	9.04µg
Comb Finger Gap	1µm
Comb Finger Length	200µm
Beam Length	250µm x 250µm
Beam Width	4µm

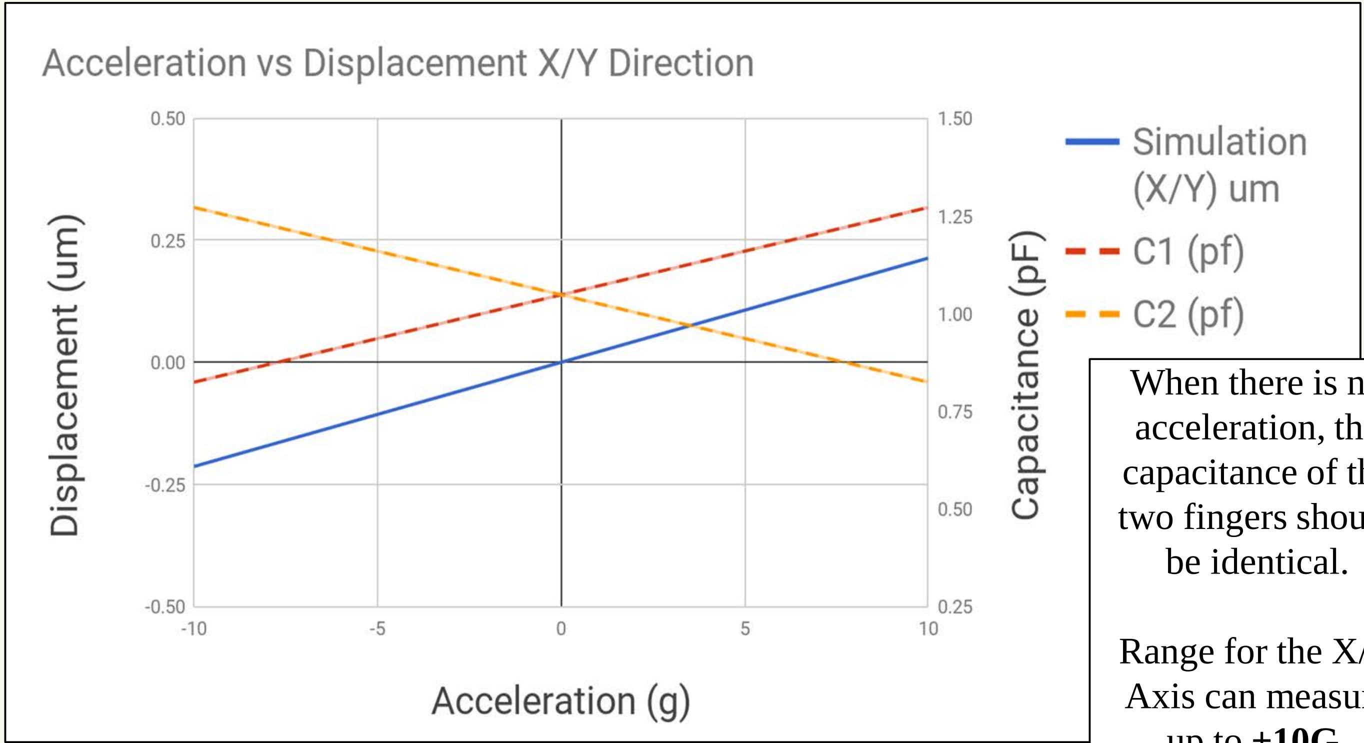
X/Y Axis: Displacement Simulations



Displacement Simulations were extracted from a linear relation of Force and Displacement on ANSYS 18.1.

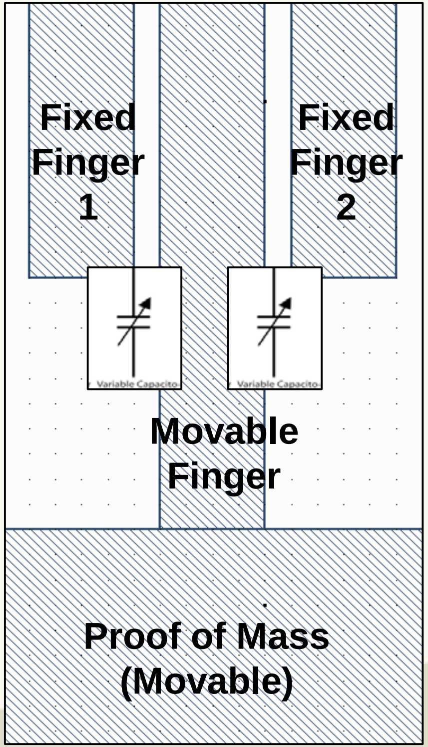
Simulation and Hand Calc. differ about 16%.

X/Y Axis: Capacitive Comb Fingers

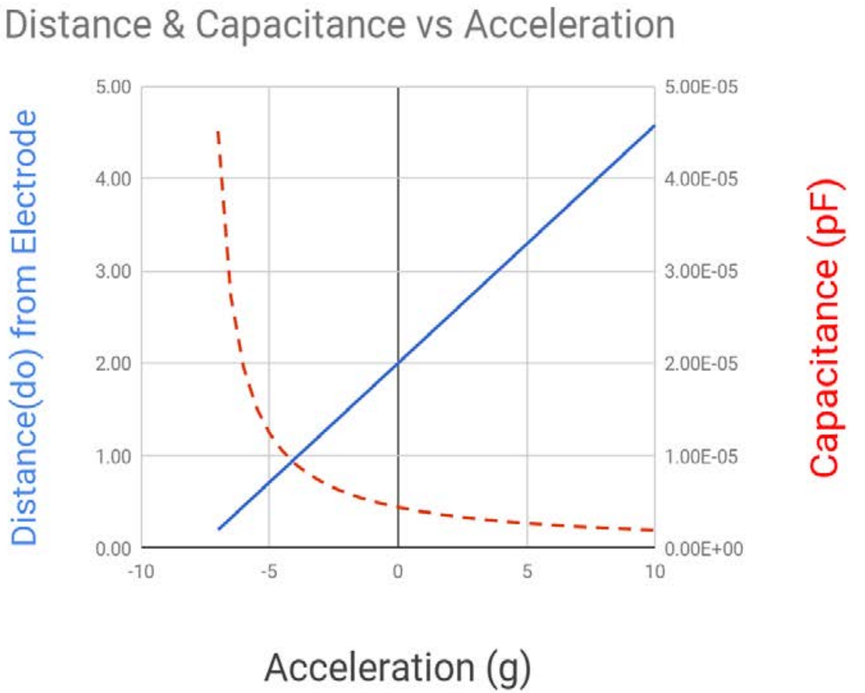


When there is no acceleration, the capacitance of the two fingers should be identical.

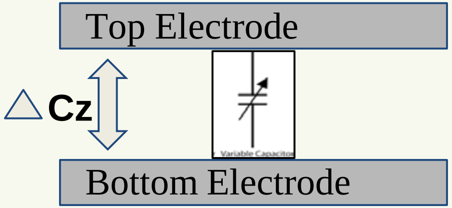
Range for the X/Y Axis can measure up to **±10G.**



Z-Axis Displacement vs Capacitance



$$C_Z = \frac{\epsilon_0 \epsilon_r A}{d_o}$$



The maximum acceleration in the -Z direction only goes up to around -5g, before it hits the bottom electrode.

Therefore, the device will only be operational in the **±5G** range.

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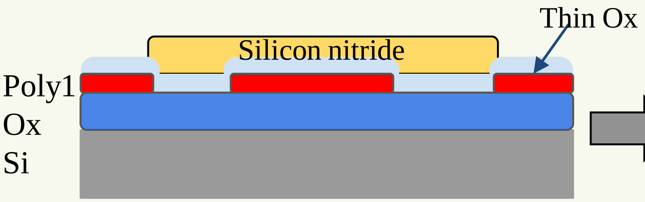
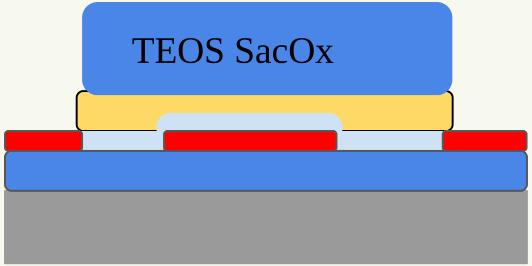
Process Flow

1. Starting wafer
2. Grow 5000Å oxide, Recipe 350
3. PH03 – level 0, Marks
4. ET06 – Wet Etch Alignment Marks
5. ET07- Resist Strip, Recipe FF
6. CL01 – RCA Clean
7. Grow 5000Å oxide, Recipe 350
8. CV01 – LPCVD Poly 5000Å
9. Spin-on-Dopant with P
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 2um
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
26. Spin-on-Dopant with B
27. CL01 – RCA Clean
28. OX05- 500Å pad oxide
29. CV02 – 2000Å nitride
30. PH03 - **level 4** Poly2
31. ET29 – Plasma Etch Nitride
32. ET06 – Wet Etch pad oxide
33. ET68 - STS Etch Poly2
34. ET07 - Resist Strip, Recipe FF
35. PH03 – **level 5** Contact Cut
36. ET29 – Etch Nitride Contact Cut
37. ET06 – Etch Oxide Contact Cut
38. ET07 – Resist Strip, Recipe FF
39. CL01 – RCA Clean two HF
40. ME01 – Metal Deposition - Al
41. PH03 – **level 6** Metal
42. ET55 – Metal Etch - wet
43. ET07 – Resist Strip
44. PH03 – **level 7** – Release
45. SA01 – Saw wafers ½ Thru
46. Special Soap Clean
47. ET66 – Final SacOx Etch
48. Rinse and Dry w Isopropyl Pull
49. TE01 – wafer level testing
50. SEM1 – Pictures
51. Packaging and Testing

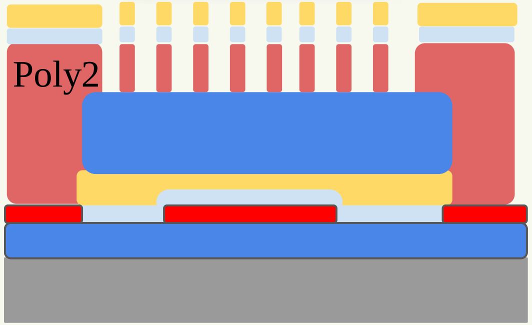
7 Level Process Flow



(a) Level 1+2: Poly1 + Anchor

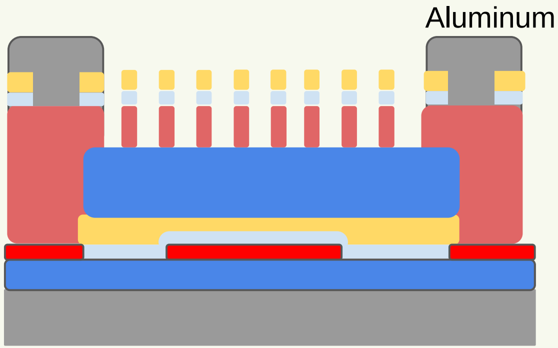


(b) Level 3: SacOx

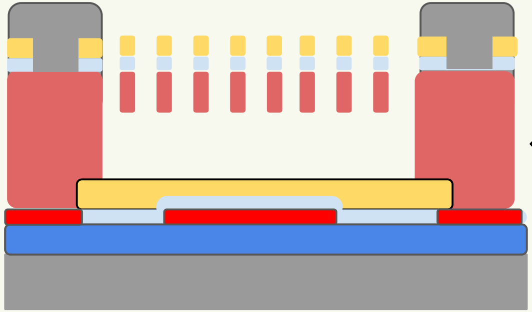


(c) Level 4: Poly2

- Poly2 was meant to be doped using the ion implanter.



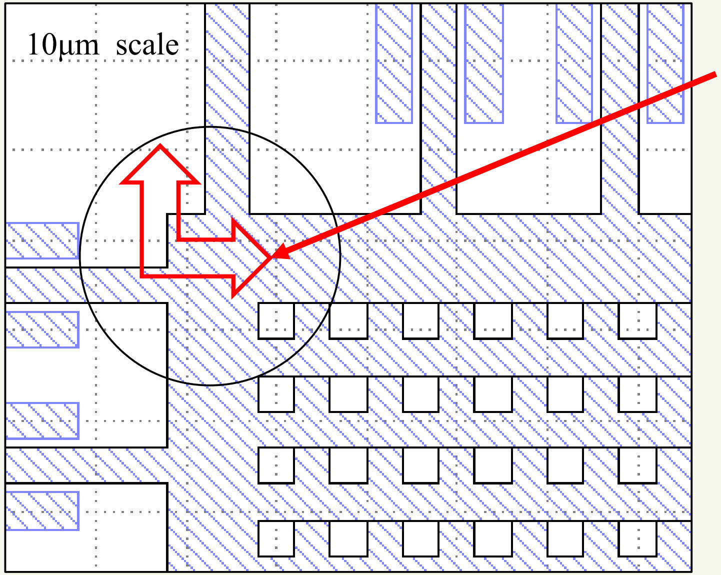
(d) Level 5+6: Contact Cuts +Metal



(e) Level 7: Release

Release Methods

Release is often the hardest part of MEMS devices. The sacrificial layer, TEOS, was used because of it's higher etch rate in Buffered Oxide Etch (BOE) 5:2:1.



Corner of the proof mass

- There is a **10μmx10μm** distance that needs to be cleared out for proper release.
  - **Reduce this distance in future design**

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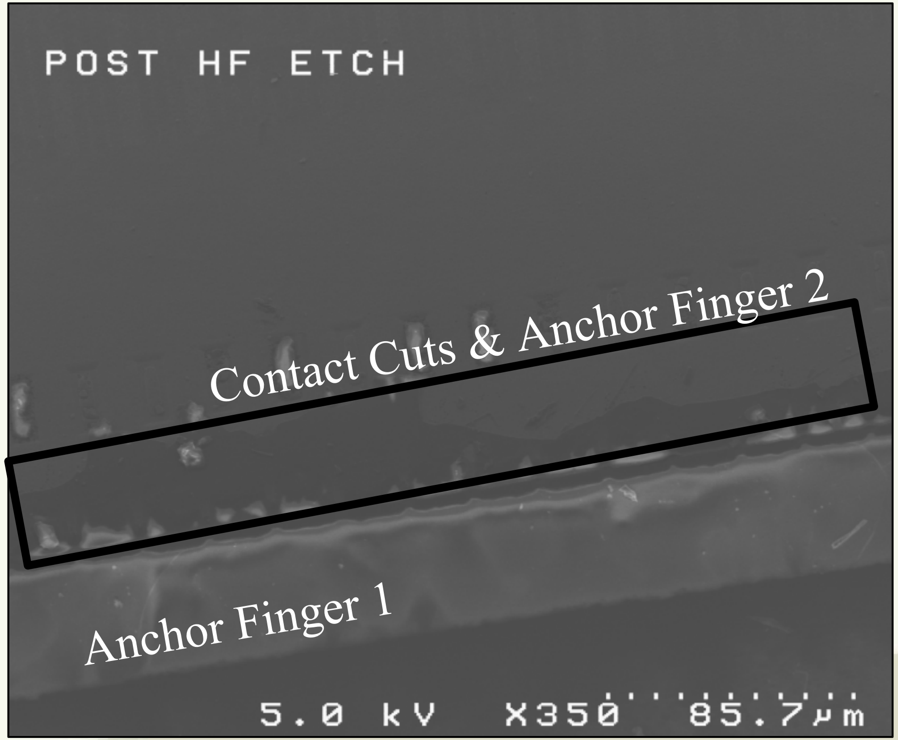
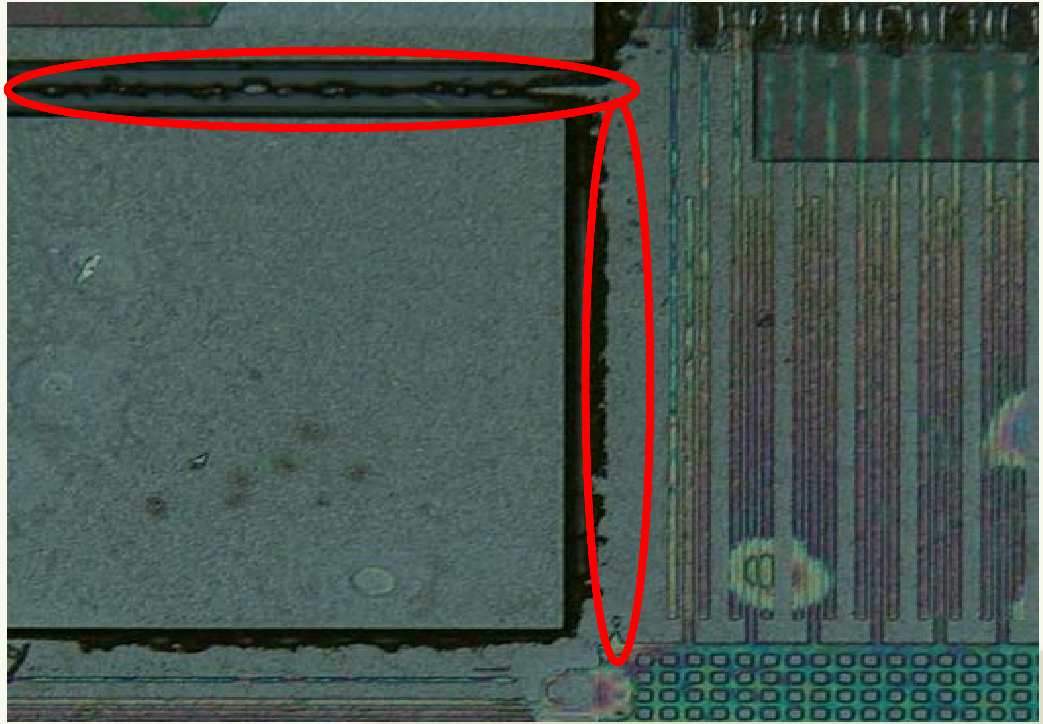
Defects

- Resist peeling due to long HF etch during release and removal of certain features like fixed finger 2 anchors and contact cuts.
  - **Try to reduce etch time and bake resist at higher temperature.**



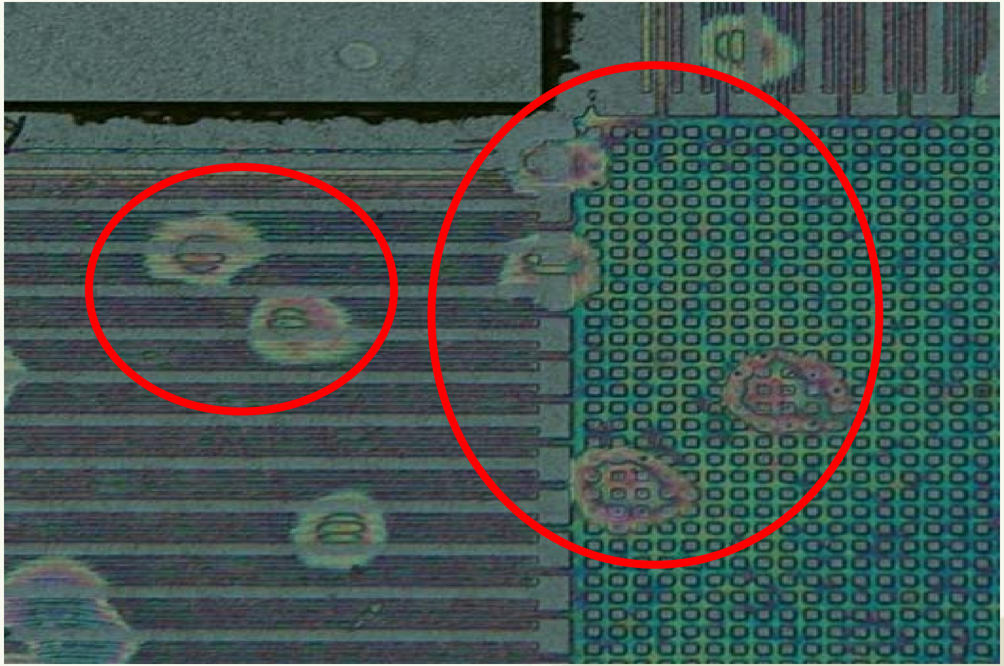
Defects

- Beam Springs were not patterned well on to the poly layer.
  - **Could be overetching during the STS Deep RIE.**
  - **This is a critical defect. Without this, there is no device displacement.**



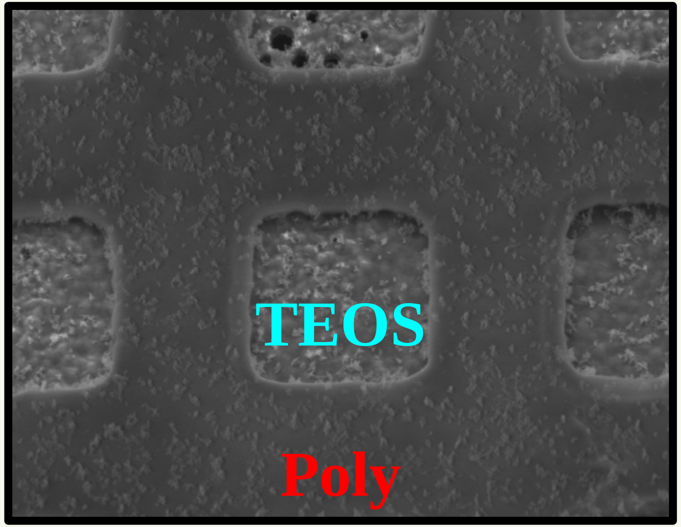
Defects

- Spin-on-dopant spots all over the devices made it difficult to pattern the top poly layer. Topography is critical with top poly.
  - **SOD was not the intended method for the poly. It was only used due to the ion implanter being down.**

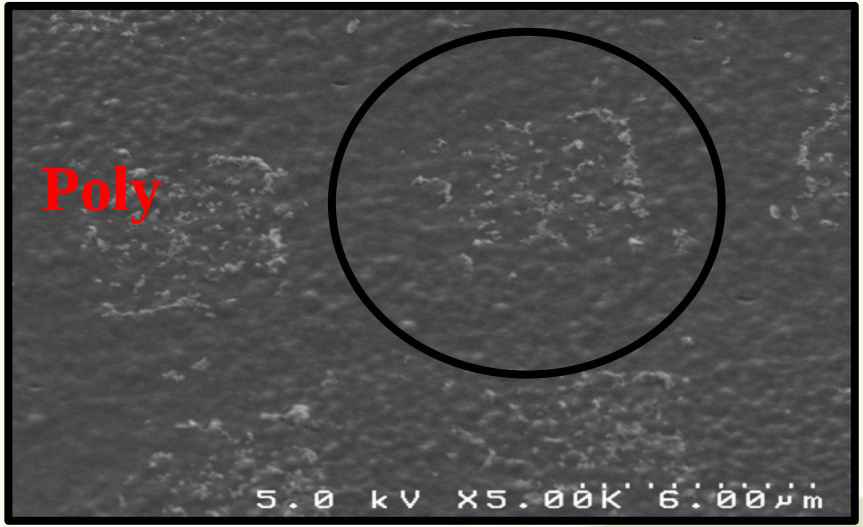


Defects

- Etch holes on the proof mass were **not etched** in the STS, so some devices were unable to be released.
  - **Can be due to pad oxide or nitride not etched enough.**



Etched holes



No etched holes

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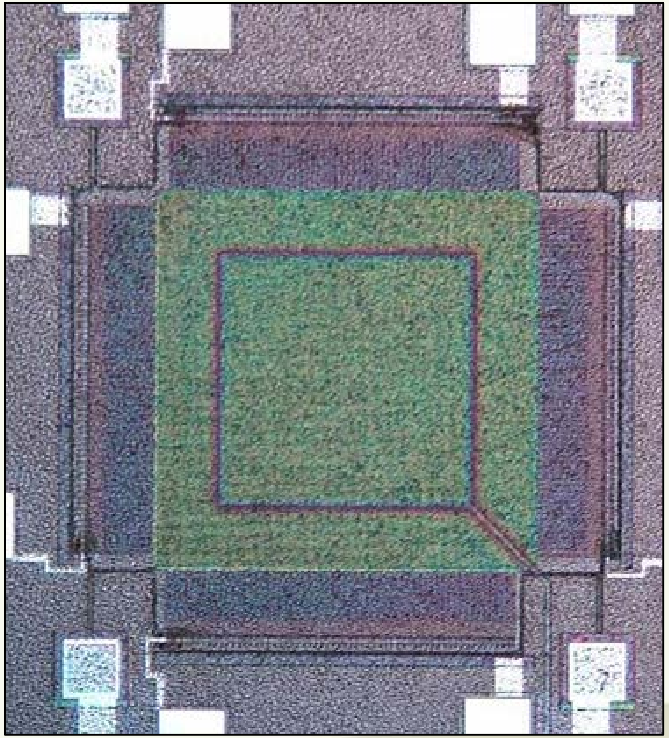
Conclusion

- The Three-Axis Accelerometer was designed to operate up to ±10G.
- The device designed was simulated to observe the change in capacitance of the fixed fingers.
- The design is comprised of a 7 level process flow.
- Results of the fabricated design had defects that were critical to some of the mechanical and electrical properties.



Final Device

Future Design Works

- **Process Improvements.**
  - LPCVD Poly process characterization.
  - Poly Etch characterization (Photo, Nitride, Oxide Etching, and DRIE)
    - Include etch measurements in the design to improve etc control.
  - Different Material for Release.
  - Release Wet Etch characterization
  - Resist Adhesion on Release Layer at different etch times.
    - Use thicker resist and vary hard bake temperatures.
  - **Every Process Step was recorded for future references.**
- **Design Improvements/Iterations**
  - Beam spring width variations to observe process capabilities.
  - Include one fixed finger designs.

Acknowledgements

- Dr. Fuller
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- Dr. Pearson
- SMFL Staff
- MicroE Students of 2018