Integrated MEMS Mechanical Shock Sensor

NSWC Indian Head

NDIA Fuze
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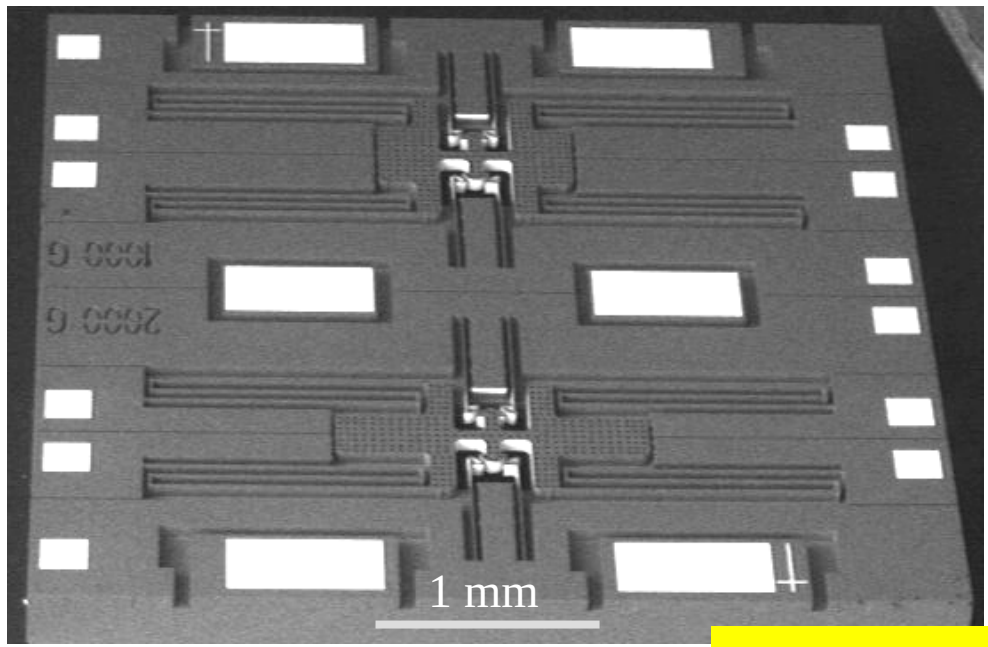
Outline

- Overview
- Applications
  - Integrated shock sensor for S&A
  - Stand alone shock and impact switch
- Modeling
- Packaging
- Testing
- Advanced Designs
- Future Applications



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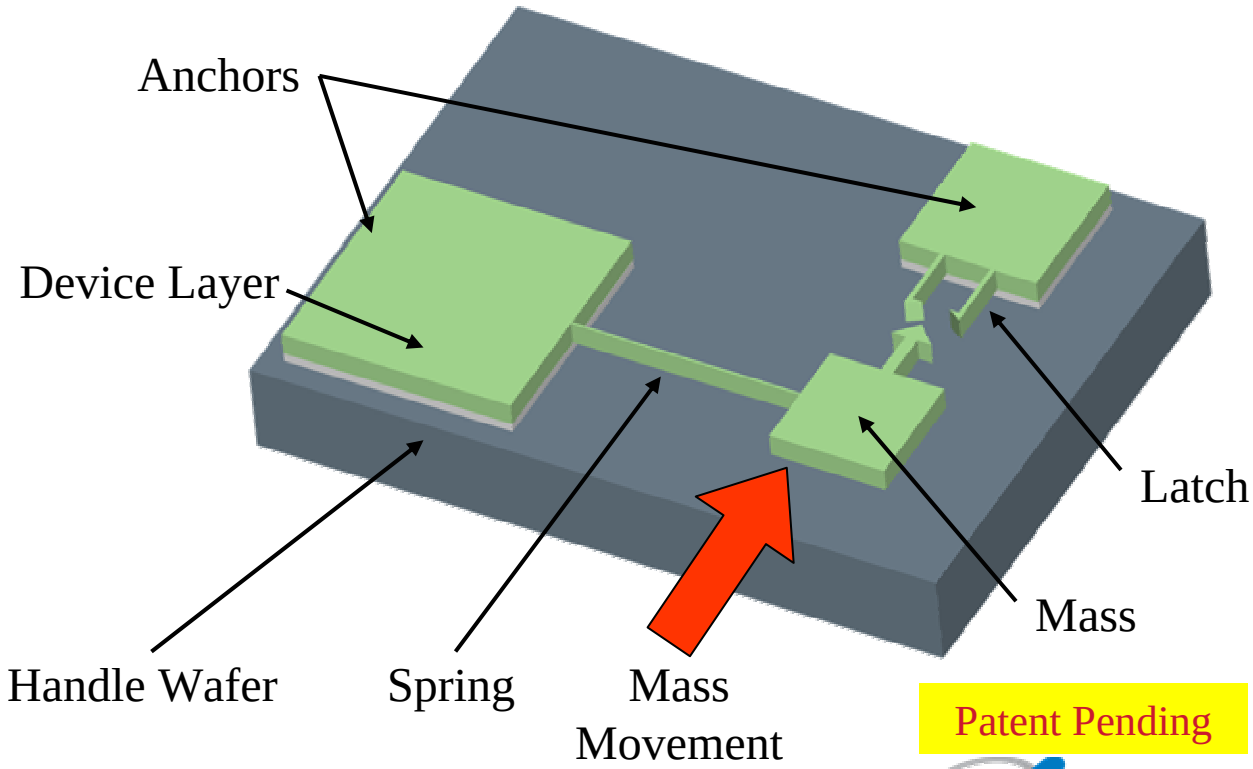
Shock Sensor Overview

- A non-powered shock sensor that latches if the applied shock is above a predetermined threshold

Threshold Sensor:
- Impact and shock
- Mass Moves
- Latch engages



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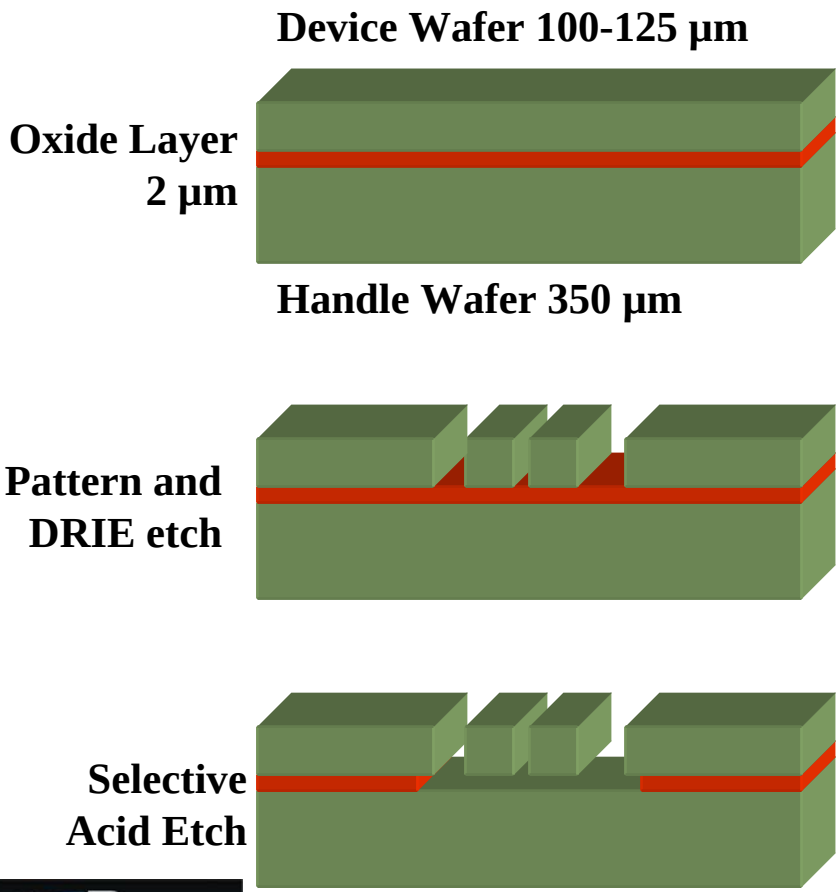
Fabrication: DRIE

- Deep Reactive Ion Etching (DRIE) using Silicon on Insulator (SOI) wafers



Process Flow:

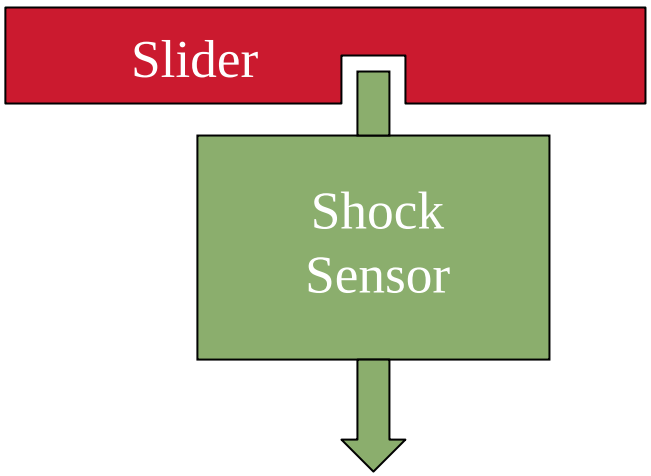
1. Begin with SOI wafer
2. Pattern device wafer
3. DRIE etch to oxide stop
4. Partial release in timed acid etch
   - large structures = anchored
   - small structures = released

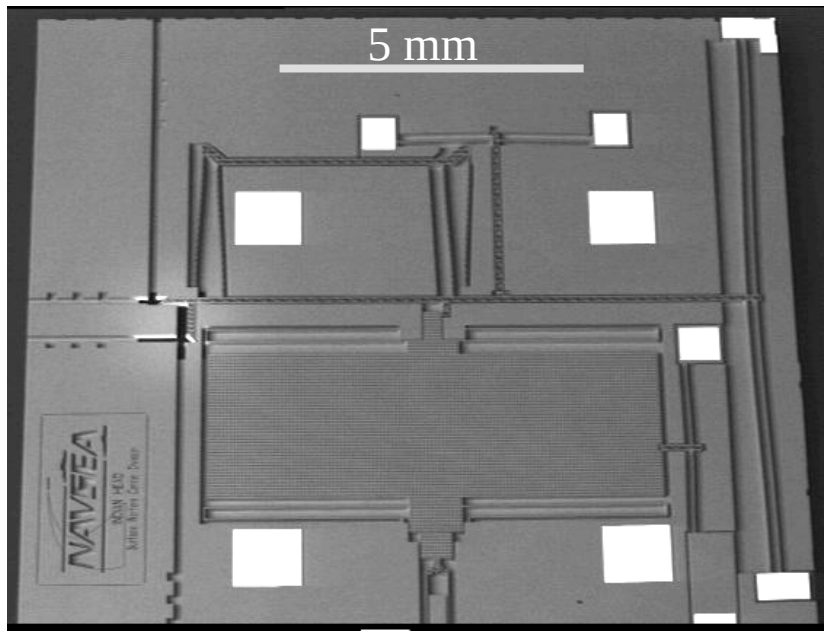
Commercial DRIE:

- Accelerometers, IMUs
- Pressure and Chemical Sensors
- Over 10 commercial and 40 academic foundries

Integrated Shock Sensor for S&A

- Mass locks a slider
- Lock is removed when the shock exceeds the designed threshold
- Used as an environmental sensor on the Canistered Countermeasure Anti-Torpedo (CCAT) S&A

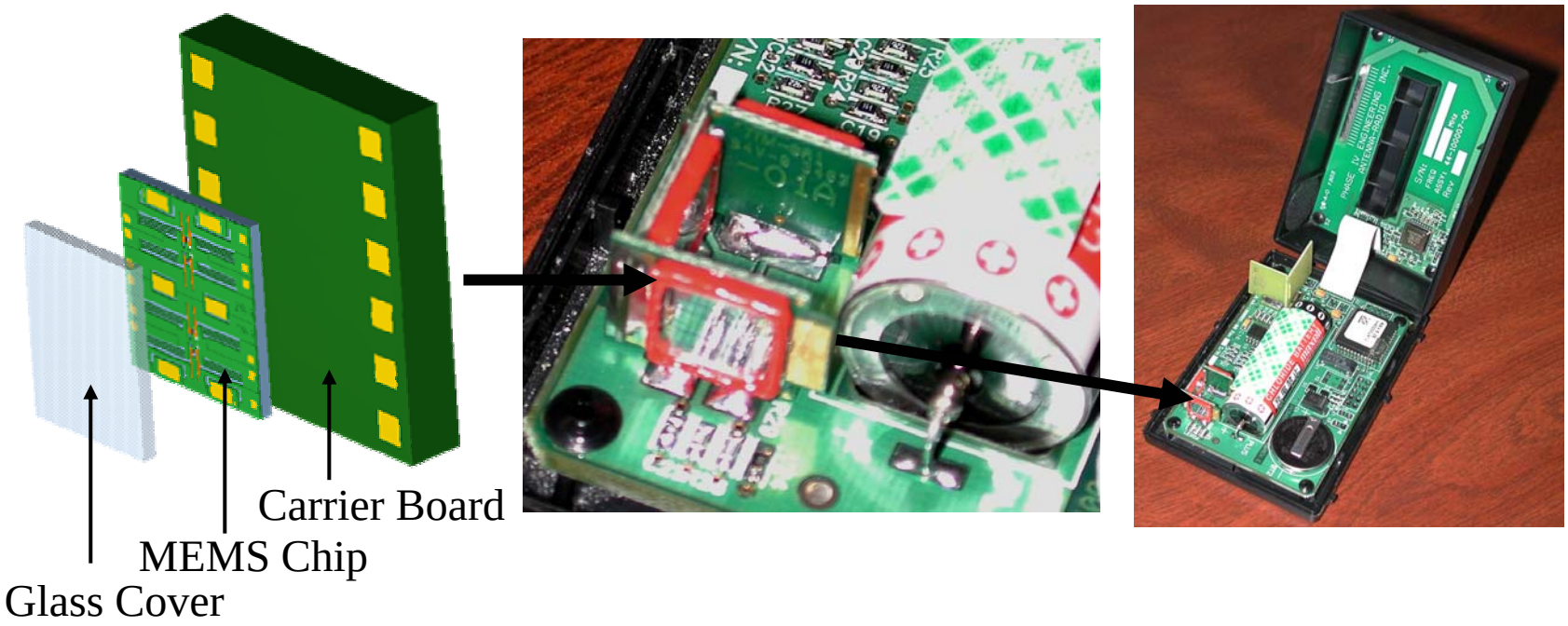




12 by 12 mm CCAT S&A Chip

Stand-Alone Shock and Impact Sensor
ATOS RFID Tag

- Mass closes an electrical switch when the shock threshold is exceeded
- Used in the Advanced Technology Ordnance Surveillance Radio Frequency Identification (ATOS RFID)

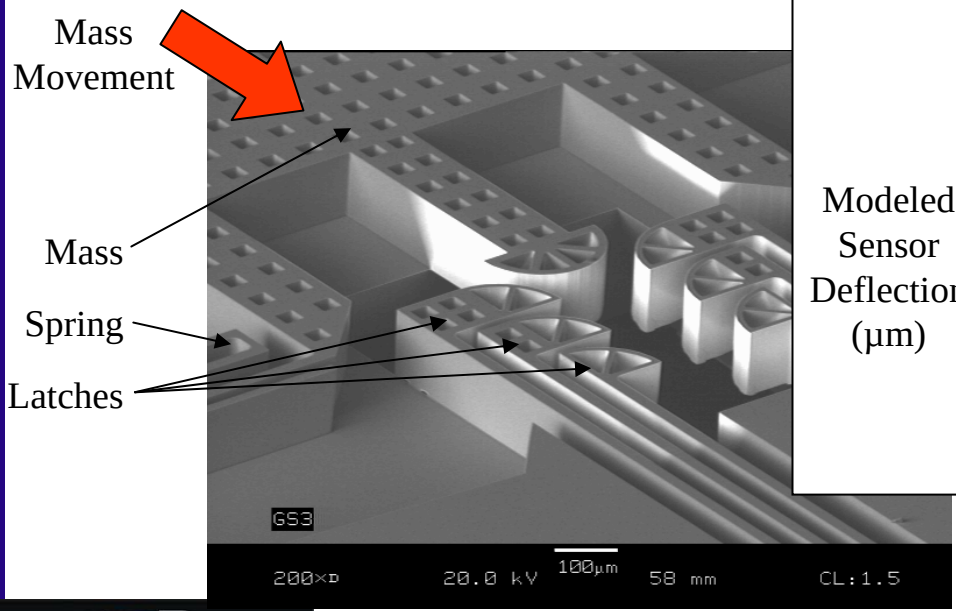


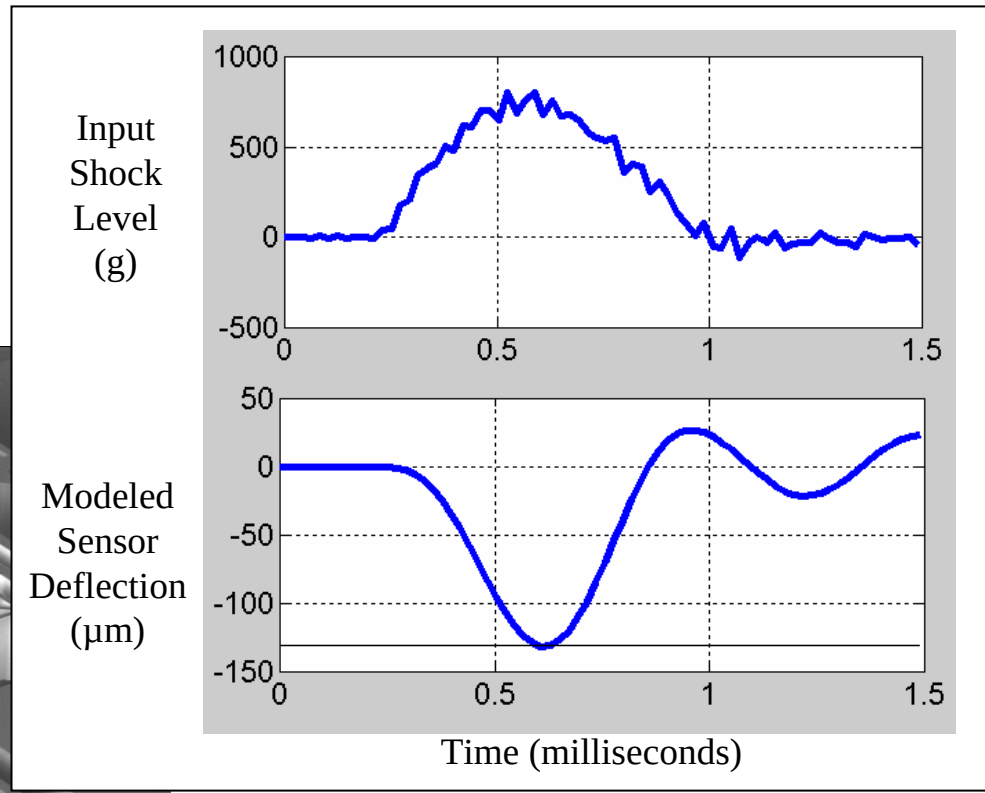
Modeling

- Used to predict latching levels
- Using vibration equation for base excitation:

$$m\ddot{z} + c\dot{z} + kz = -m\ddot{y}$$

- Solved using 2 separate techniques:
  - Duhamel integral
  - Finite difference





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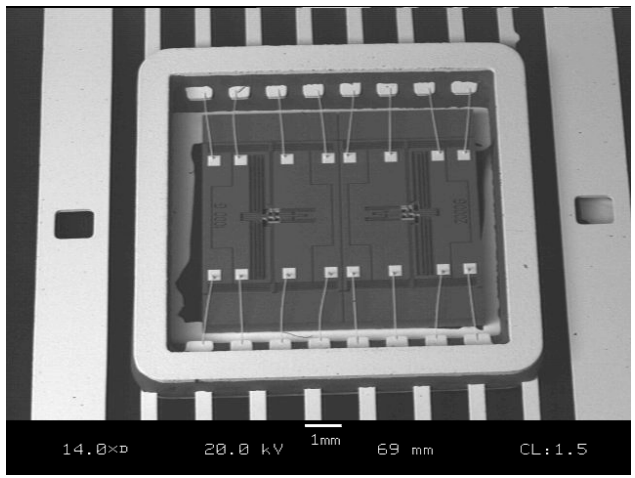
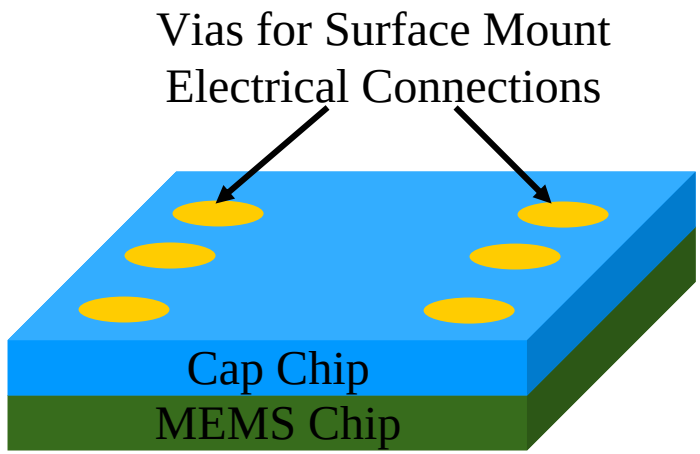
Packaging

- Cap chip to limit out-of-plane deflection
- Hermetic packaging is necessary for long shelf life applications
- Packaging options
  - Hermetic chip carrier: current technology
  - Chip level hermetic seal: future for low cost and high volume



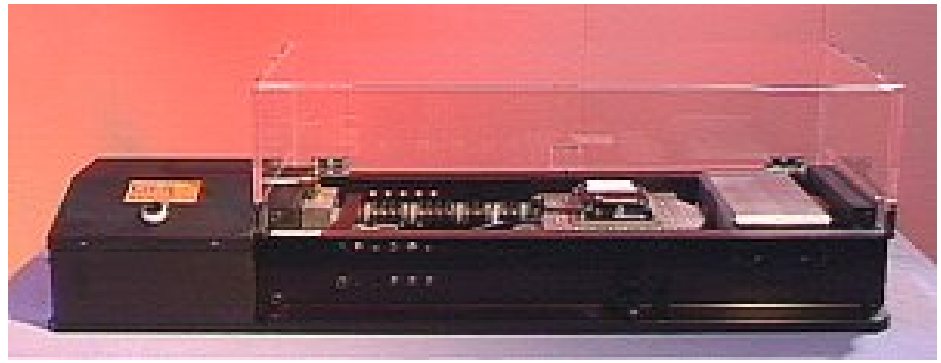
Hermetic Chip Carrier



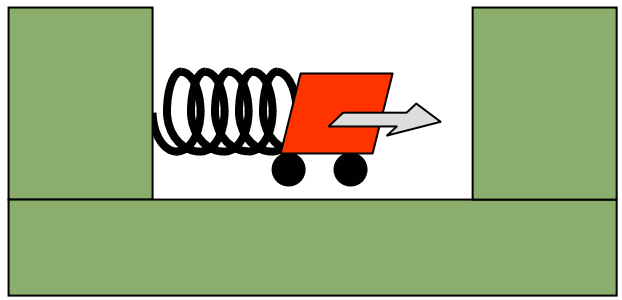
Chip-Level Hermetic Seal

Initial Shock Testing

- Using a linear shock table

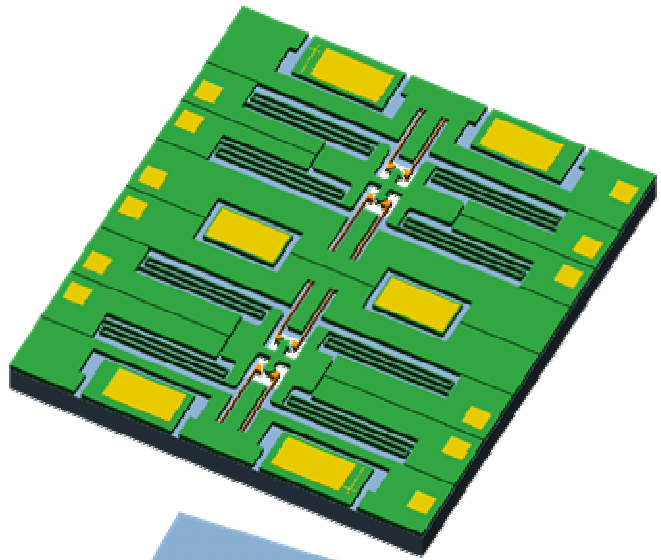


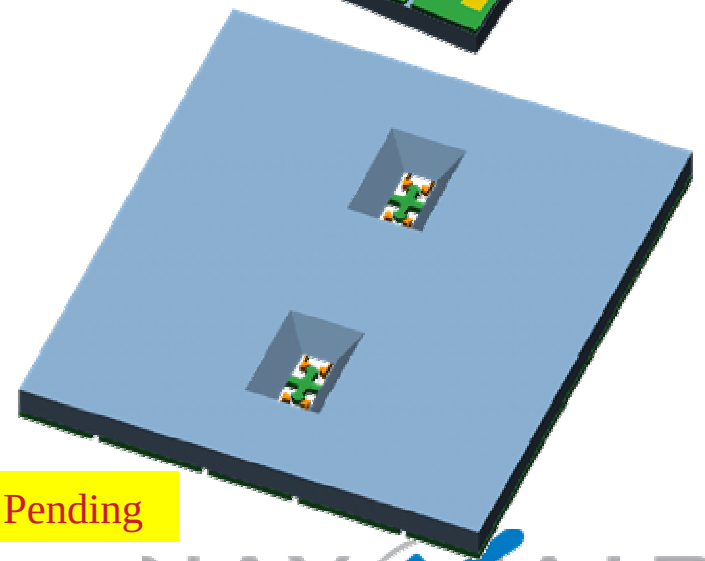
Sensor Design	Average Latch Level (g)	Range	Number Tested
1	199	± 1%	2
2	390	± 3%	5
3	527	± 2%	5
4	712	± 4%	4
5	1064	± 2%	2



5” Airgun High Shock Testing

- Primarily to demonstrate survivability
- Sensors: 6.2 by 6.7 mm
  - Two sensors per chip designed to latch at 360 and 720 G, tested at 30 kG
- Using existing hardware not designed for high shock survivability:
  - Large mass
  - Etched square holes in substrate





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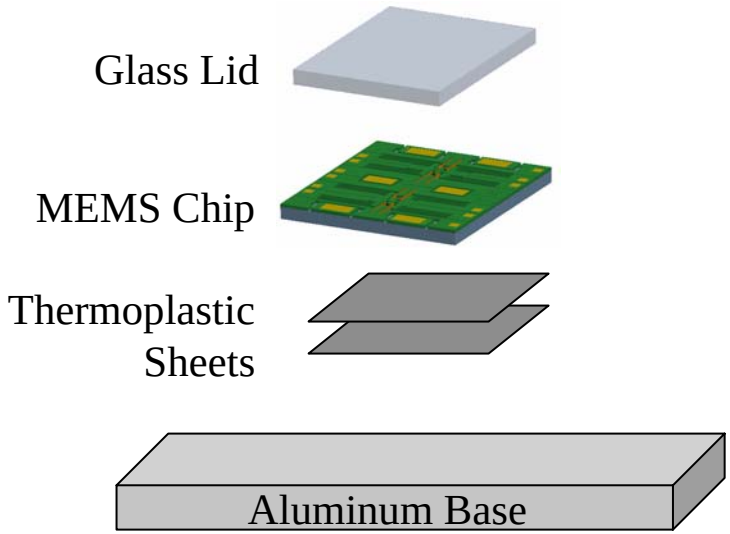
Shock Survivability Packaging

- Glass lid attachment with solder (and flux)
- MEMS chip attachment with two 5 mil thermoplastic sheets
- Epoxy reinforcement of glass lid
- 22 packages were made

0.80 in

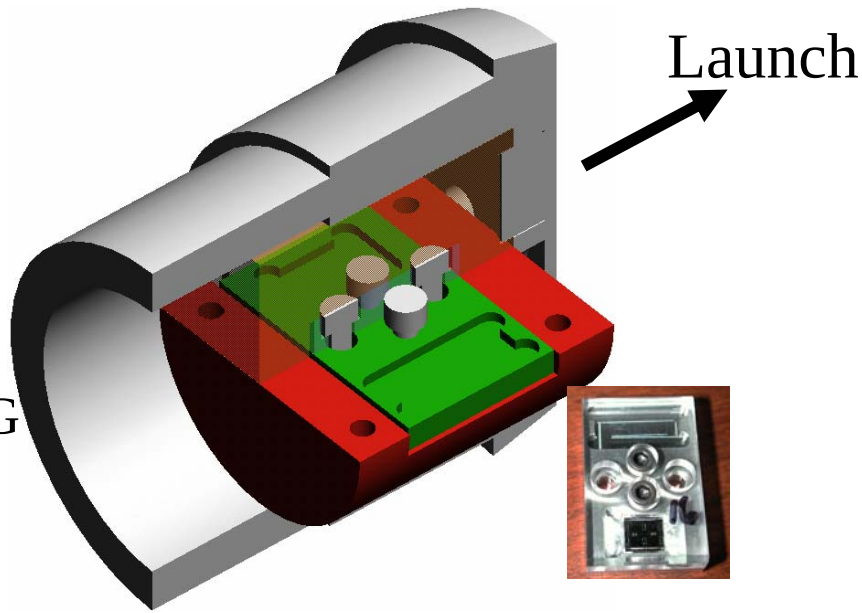


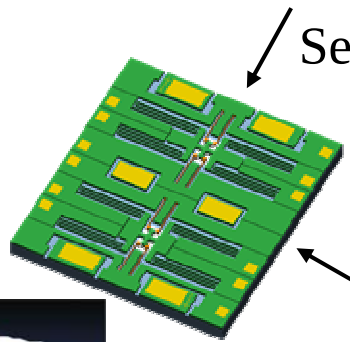
5” Airgun Test Levels

- Setback testing: 14 tests from 1,450 G to 29,900 G
  - Tests conducted using 5” airgun at NSWC Dahlgren
  - One test at each of the following levels

1,450	9,230	26,240
1,470	14,140	27,210
6,380	14,700	28,110
6,840	14,800	29,900
8,340	15,390	

- Cross-axis testing
  - 2 tests at 23,000 G and 28,700 G





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5” Airgun Test Results

- 27 out of 27 sensors functioned as designed (1 no-test, sensor damaged during packaging)
- No observable damage to the substrate
- Below 25,000 G: 1 broken latch out of 96 latches, most likely due to the etch pit under the latch
- Between 25,000 and 30,000 G:
  - 1 broken mass out of 10
  - 5 broken springs out of 40
  - 2 broken latches out of 40

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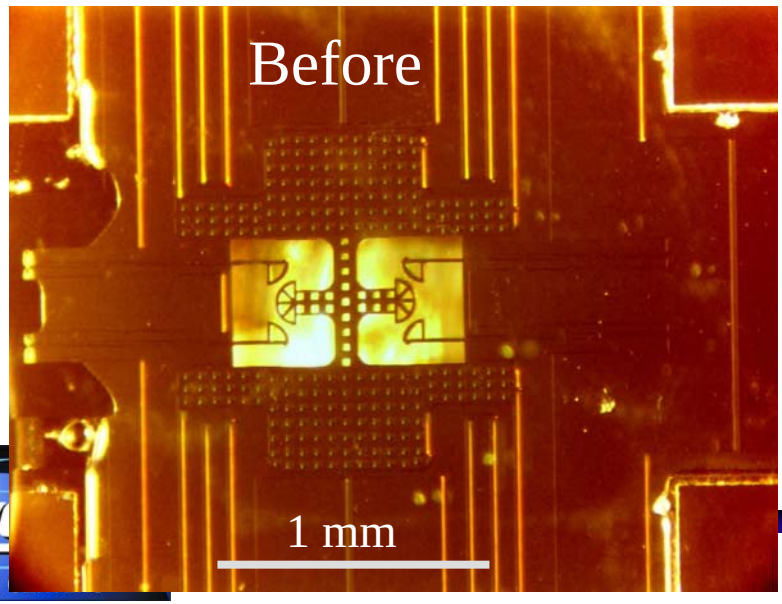
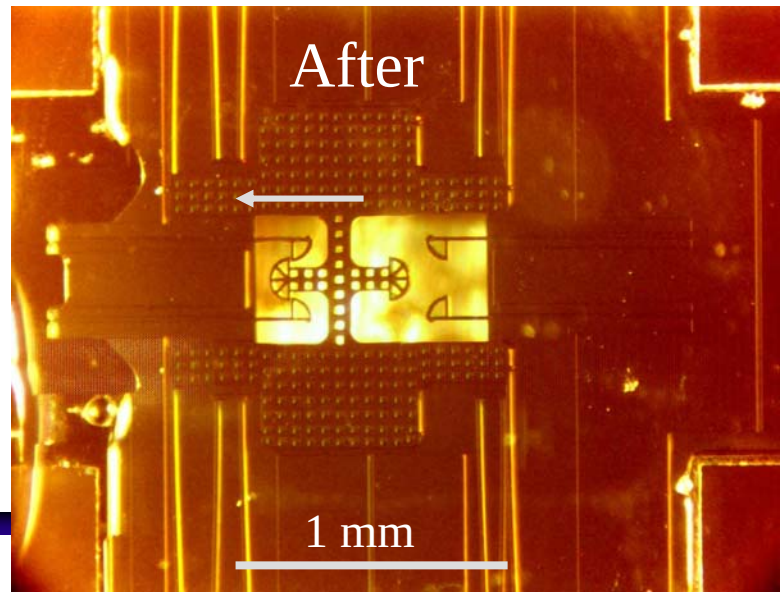
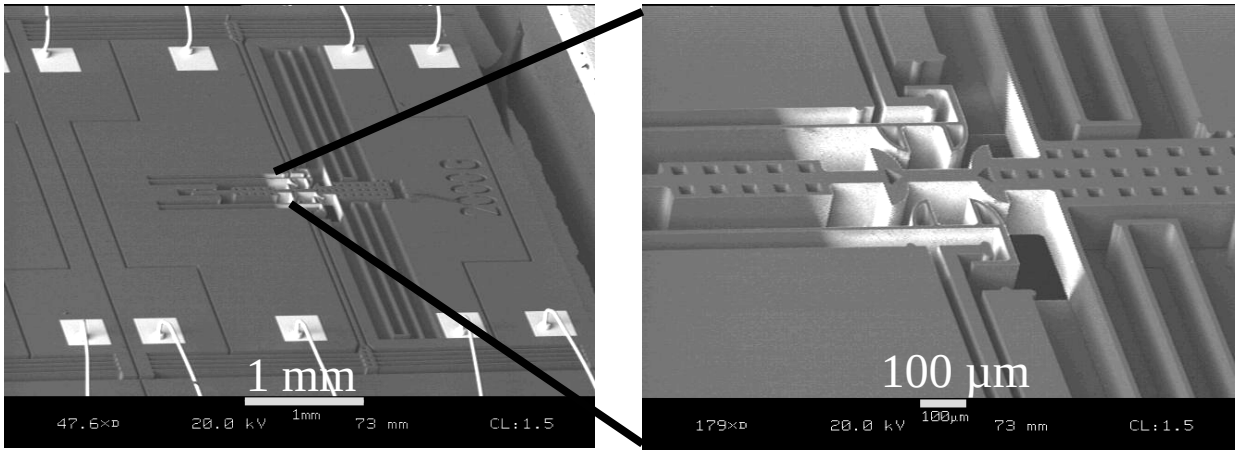
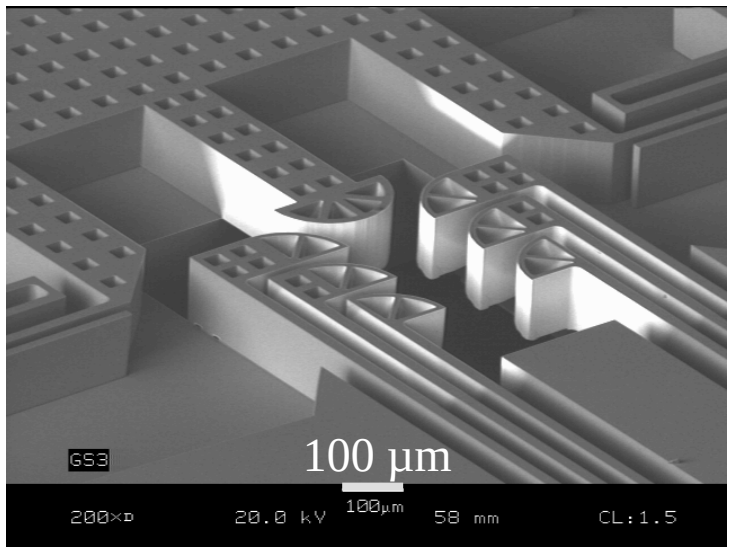




Advanced Sensor Designs



Releasable



Multi-Level

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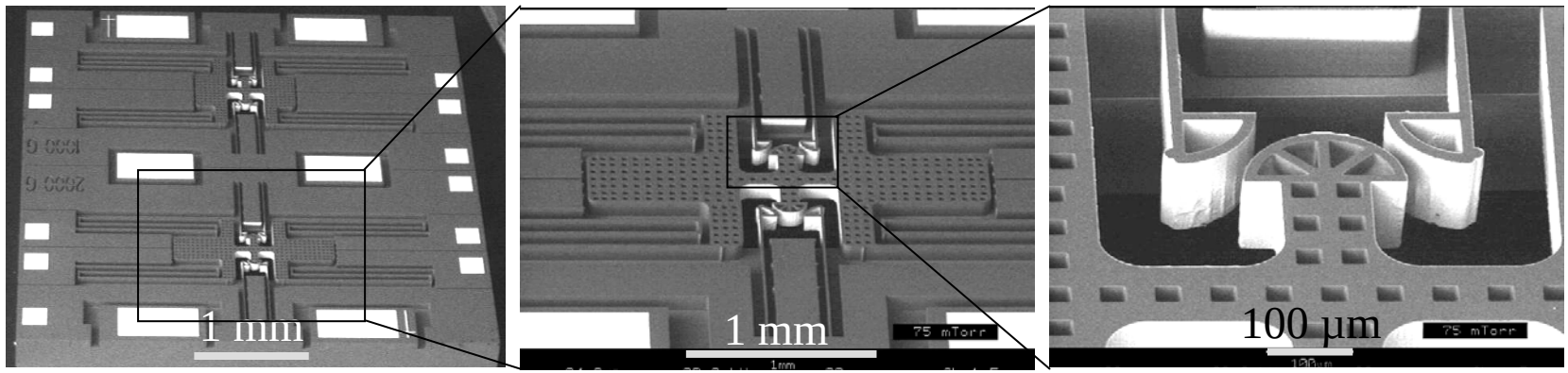
Future Applications

- DRIE silicon MEMS technology is applicable to explosive-on-a-slider for high-g fuze/S&A applications
- Next-generation medium caliber gun launched munitions
- Submunitions



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Conclusion

- Shock Sensor
  - Over 1000 working sensors fabricated to date
  - Accurate sensors fabricated from 30 to 1100 g
  - Shock survivability demonstrated to 30,000 g
- Current applications
  - Integrated into S&A for CCAT
  - Stand alone sensor for ATOS
- Future applications
  - Med. caliber gun-launched munitions
  - Submunitions

Acknowledgements

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