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
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

Patent Pending
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

Slider

Shock Sensor

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

![Diagram](image)

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>Shock Level (g)</th>
<th>Deflection (μm)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>500</td>
<td>-50</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.5</td>
<td>1000</td>
<td>50</td>
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</table>

Patent Pending
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
Initial Shock Testing

- Using a linear shock table

<table>
<thead>
<tr>
<th>Sensor Design</th>
<th>Average Latch Level (g)</th>
<th>Range</th>
<th>Number Tested</th>
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<tbody>
<tr>
<td>1</td>
<td>199</td>
<td>± 1%</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>390</td>
<td>± 3%</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>527</td>
<td>± 2%</td>
<td>5</td>
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<tr>
<td>4</td>
<td>712</td>
<td>± 4%</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>1064</td>
<td>± 2%</td>
<td>2</td>
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</table>
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

Patent Pending
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
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

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<table>
<thead>
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<tr>
<td>1,450</td>
<td>9,230</td>
<td>26,240</td>
</tr>
<tr>
<td>1,470</td>
<td>14,140</td>
<td>27,210</td>
</tr>
<tr>
<td>6,380</td>
<td>14,700</td>
<td>28,110</td>
</tr>
<tr>
<td>6,840</td>
<td>14,800</td>
<td>29,900</td>
</tr>
<tr>
<td>8,340</td>
<td>15,390</td>
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</tbody>
</table>

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

Patent Pending
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

Before

After

1 mm
Advanced Sensor Designs

Releasable

Multi-Level

Patent Pending
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

Patent Pending
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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- DARPA
- NSWC Indian Head Team