Survivability and Reliability of Silicon MEMS Components

Presented to:
NDIA 2019 Fuze Conference
Presentation 21868

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- 15 May 2019 -

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MEMS Safe and Arm

- Micro-electro Mechanical System (MEMS) Safe and Arm Devices (S&A) offer the potential for small volume, low cost, and low energy consumption.
- NSWC IHEODTD has nearly two decades of silicon/silicon on insulator (SOI) MEMS design, fabrication, and packaging experience.
- Safety locks: integrated mechanical structures used for command actuated locking architectures.
- Arming: design and fabrication of environmentally derived and command architectures.
- All non-explosive components fabricated on SOI wafers using established semiconductor processes.
MEMS Fuzing Applications

Gun Launched Projectiles

Underwater Systems

Mortars
MEMS Reliability Description

**Technology Goal:** Assess the reliability of a microdetonator-based MEMS S&A by exposing multiple, packaged devices to simulated life cycle environments and performing subsequent failure identification and analysis in order to determine if it is capable of being utilized in a fuzing system that must meet a 99% reliability requirement.

**Approach:** Design, model, fabricate, and package MEMS S&A chips, expose the packages to environments determined by Mil-Std 331 and JOTP-052 that represent a fuze life cycle, assess any failures, and determine cause.

- Following work primarily funded under the Joint Fuze Technology Program
# Test Matrix

<table>
<thead>
<tr>
<th>Testing Purpose</th>
<th>Test</th>
<th>Results</th>
<th>Next Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance and Safety</td>
<td>T &amp; H</td>
<td>Passed- No visual or electrical changes</td>
<td>Complete</td>
</tr>
<tr>
<td>Performance and Safety</td>
<td>Vibration</td>
<td>Passed- No visual or electrical changes</td>
<td>Complete</td>
</tr>
<tr>
<td>Safety</td>
<td>5 Foot Drop</td>
<td>On-going</td>
<td>Design and fabrication process refinements to improve subverted safety integrity</td>
</tr>
<tr>
<td>Performance</td>
<td>VHG</td>
<td>On-going</td>
<td>Inert and Live testing, final VHG tests will include the electronics board</td>
</tr>
</tbody>
</table>
**Test Article Configuration**

- 9 X 9 mm silicon MEMS S&A chip
  - Two of the three chips have a subverted lock (only one lock engaged)
- Wire bonded into a chip carrier (allowing for electrical interfaces through the electronics board below) for testing/functioning chip pre- and post-test
- Epoxy mixture with glass micro-balloons for shock absorption and clear mixture to allow visual inspection
- Aluminum housing fixture- represents a generic fuze housing
Temperature and Humidity Testing

- Temperature/Humidity testing: Mil-Std 331-C appendix C, -54°C to 71°C and 95% humidity, cycling over 28 days
- Visually inspected MEMS and performed resistance checks pre- and post-tests
- Interesting note: unfilled epoxy (used in these tests for visual inspection) show cracks post test, while tactical micro-balloon filled epoxy seemed to be unaffected
- Johns Hopkins Applied Physics Laboratory: T&H Test Facility

Passed T&H Testing with No Adverse Effects to the MEMS
Vibration Testing

- Military tracked vehicle vibration determined to be harshest environment on MEMS S&A: Tests consisted of five phases ranging test levels from ~4-6 Grms
- Tested all five phases in X-, Y-, and Z- orientations with visual inspection and resistance checks pre- and post- testing
- Prior to test, locks were thickened to increase lock-slider interference which proved successful during these subverted tests
- Johns Hopkins Applied Physics Laboratory: Shaker Table

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Five Foot Drop Testing

- Pass criteria: Lock re-engages post-drop so slider is kept in safe position
- Previously passed dual-lock engagement drop tests, subverted chip testing to come
- Orientation where set-back lock latches out is highest risk orientation

- Johns Hopkins Applied Physics Laboratory: Drop Apparatus

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High-G Testing

- Testing is on-going with efforts to minimize limitations and maximize the effectiveness of the tests
- Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division (NSWC IHEODTD): Very High-G (VHG) Machine
Comparison of Shock Impulses

Shock Level: Acceleration vs Time

Zoomed in Shock Level Acceleration vs Time

- VHG
- IB Model
- Gun Launch

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High-G Testing

- Primary damage mechanism under inertial loading is from micro structure impact
- High ramp rate from VHG results in high relative velocities between micro-structures (over-test for slider)
  - Small clearance between guides (distance= key design parameter in decreasing impact velocities)
  - High ramp rate leads to high velocity impact
  - Lower ramp rate: gap is closed before peak acceleration is reached

<table>
<thead>
<tr>
<th>Distance, d (µm)</th>
<th>VHG Energy (µJ)</th>
<th>Gun Launch Energy (µJ)</th>
<th>IB Model Energy (µJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>8.06</td>
<td>0.54</td>
<td>0.04</td>
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<tr>
<td>10</td>
<td>20.76</td>
<td>1.51</td>
<td>0.11</td>
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<tr>
<td>25</td>
<td>57.91</td>
<td>3.41</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Slider Energy at Wall Impact
Upcoming Efforts

Drop Testing Efforts
• Conduct drop tests in various orientations with subverted chips

VHG Testing Efforts
• Refine the etching method for the slider bumpers to reduce the gap between bumpers from 30 µm to 10 µm to minimize slider impact damage.
  • Test chips with different gap sizes for comparison and theory validation.
• Refine VHG test methods to replicate damage modes of tactical shots
• Conduct VHG tests with inert and live MEMS S&A with updated testing procedures
Conclusions

- Indian Head has been successful in T&H testing for MEMS S&A
- MEMS S&A chips have passed harsh vibration testing (tracked vehicle profiles)
- Tests are being conducted to prove MEMS S&A survivability for five foot drop
- Methods to more closely replicate gun launch shock profiles using VHG are being developed with upcoming inert and live tests to determine MEMS S&A high-G survivability
Questions?