Shock Testing of Surface Micromachined MEMS Devices

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Project Background

• Goals:
  – What level and direction of shock causes a Surface Micro Machined MEMS device to fail?
  – Are actuators operational after shock tests?
  – What are the failure mechanisms due to shock?
  – Is survivability process dependent, SUMMiT™ vs. Cronos MUMPs®?
  – What is the effect of a combined temperature and shock environment?
  – Are modeling tools available to predict failure?

• Plan:
  – Shock test MEMs die containing actuators and simple structures, with inspections before and after shock tests
    • Simple structures used to correlate modeling results
    • Actuators from ‘Standard Component Library’
      • Microengines, Torsional Ratcheting Actuator (TRA), Thermal Actuator (TA)
Test structures – Test setup

- Beams designed with differing layers, lengths and anchor sizes
- Die bonded to Al fixture and shocked using Hopkinson bar
SUMMiT™ Die Layout

47th Annual Fuze Conference  April 8-10 New Orleans, LA

Beams  TA  TRA  Microengine
Post-shock Inspection Results - SUMMiT™

• **SUMMiT™ fabricated die**
  
  – **Compression part I:** (21 die, 5K to 200K g’s)
    • No beams failures
    • No pre-shock operation of actuators for comparison
  
  – **Compression part II:** (4 die, 100K to 200K g’s)
    • No beams failures
    • All actuators intact, but few function properly
  
  – **Tension:** (5 die, 50K to 200K g’s)
    • Long beams (> 400 microns) broken between 50K and 150K g’s
    • Microengines broken at all levels tested
    • Most TA’s and TRA’s intact, but none function properly
  
  – **Shear:** (3 die, 60K g’s)
    • No beam failures
    • Microengines’ gear fails, 50% of TRA’s function, all TA’s function
Post-shock Images - SUMMiT™

- Typical failure of a microengine after shock in tension

- After 210K g shock in tension, 300 micron beams with small anchors and all longer beams are broken
Post-shock Images - SUMMiT™

- Failure due to fracture of polysilicon material, not de-lamination of layers

S.E.M. image by M.B. Ritchey
Cronos Die Layout

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Cantilever Beams

Thermal Actuator

Resonator
Post-shock Inspection Results - Cronos

- Cronos MUMPs® fabricated die
  - Compression: (6 die, 100K to 200K g’s)
    - Very few beam failures
      - Only beams with 2 micron anchor size failed
    - All actuators were intact, and most function properly
      - Exception: Thermal actuators do not function after 106 K and 215 K g’s
  - Tension: (9 die, 50K to 200K g’s)
    - 3 die detached from fixture
    - Increasing beam failures with increasing shock levels
      - Some damage at low shock levels may be due to larger parts coming loose and sliding across die
    - Most actuators intact and function properly
      - Exception: Resonators missing after 153K g’s
  - Shear: (2 die, 60K g’s)
    - Very few beam failures
      - Only beams with 2 or 3 micron anchor size failed
    - All actuators were intact, and all function properly
Post-shock Images - Cronos

- Typical failure of resonator
- Typical Poly 2 beam failures
  - Function of anchor size
Post-shock Images - Cronos

- Poly 2 beams after 124K g’s tension shock
- De-lamination of anchors smaller than 3 microns

- Poly 1 beams after 124K g’s tension shock
- De-lamination of anchors smaller than 4 microns
Design for High-g Shock Survivability

- How to apply what we learn to future designs?
  - Mechanical stops
  - Minimize stress concentrations, develop MEMS Design Guide
  - Orient MEMs device in application to minimize shock effect
Conclusions

• Surface Micromachined (SMM) MEMS devices are very sensitive to the direction of shock inputs
• Failures of SMM MEMS actuators seen at levels as low as 50K g’s
• Most common failure mechanism is fracture of polysilicon material

• Current work in progress
  – Run shock tests at temperatures ranging from –65°F to 165°F
  – Test g-hardened designs: mechanical stops, etc
  – Run shock tests of MEMS in vacuum

• Extensions to this work
  – Study survivability of wire bonds
  – Expand testing to include DRIE and LIGA parts
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• Questions?