Shock Testing of Surface Micromachined MEMS Devices

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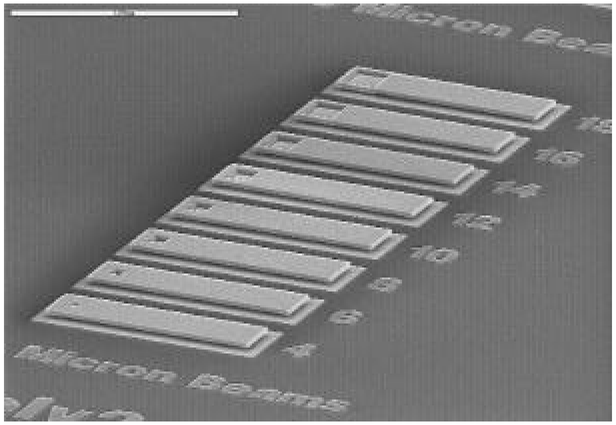
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

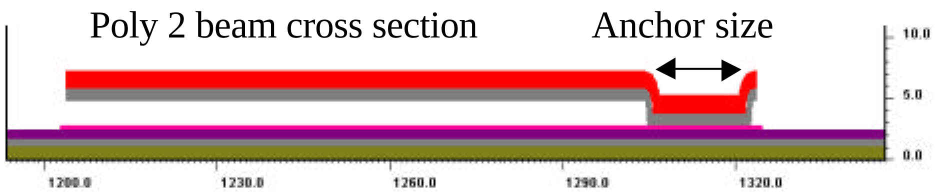
Project Background

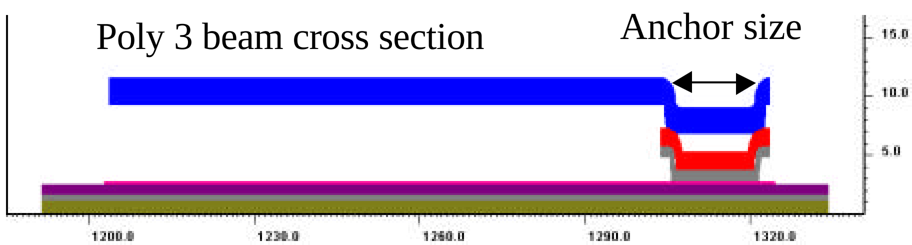
- **Goals:**
  - What level and direction of shock causes a Surface Micro Machined MEMS device to fail?
  - Are actuators operational after shock tests?
  - What are the failure mechanisms due to shock?
  - Is survivability process dependent, SUMMiT™ vs. Cronos MUMPs®?
  - What is the effect of a combined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

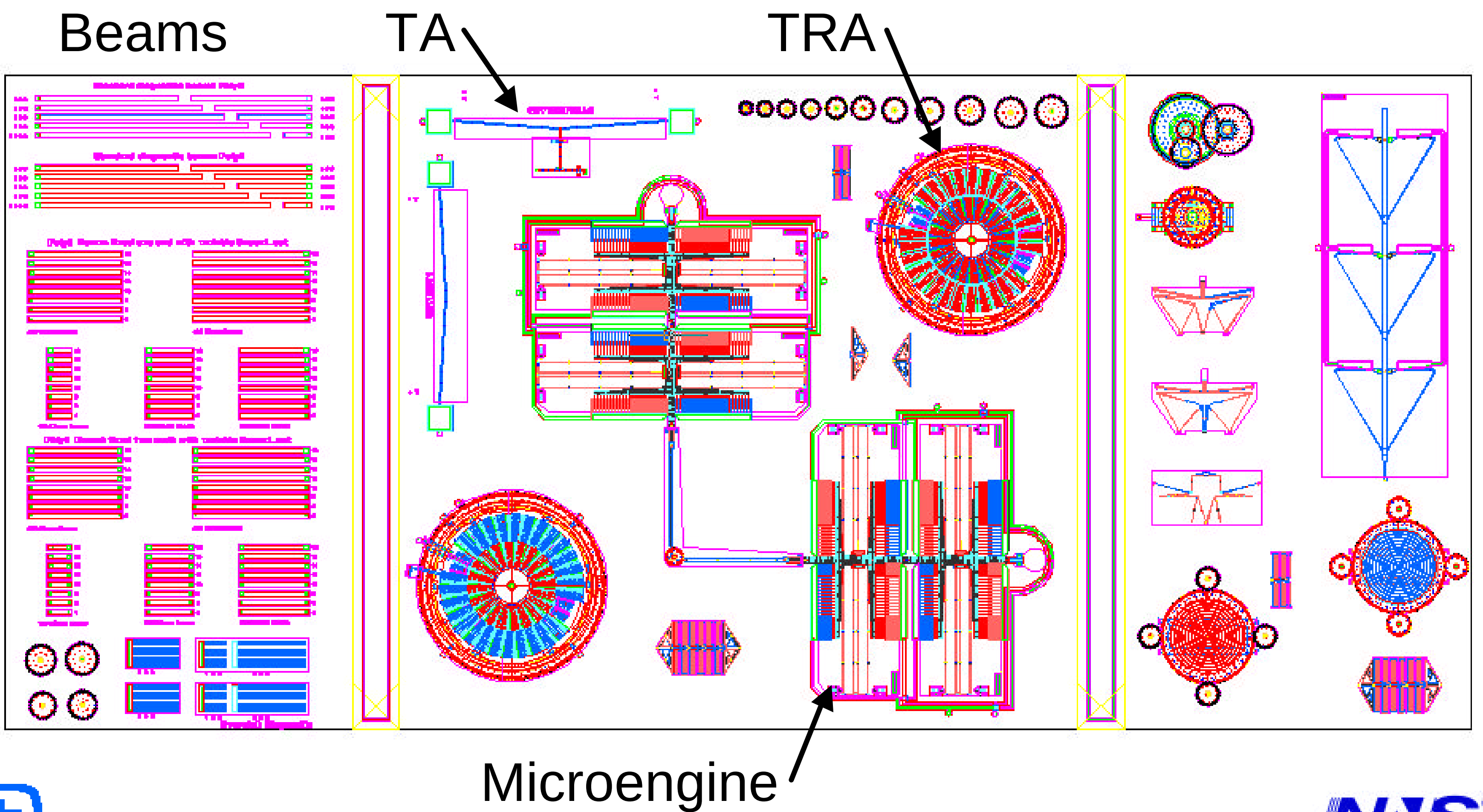


- Beams designed with differing layers, lengths and anchor sizes
- Die bonded to Al fixture and shocked using Hopkinson bar





SUMMiT™ Die Layout



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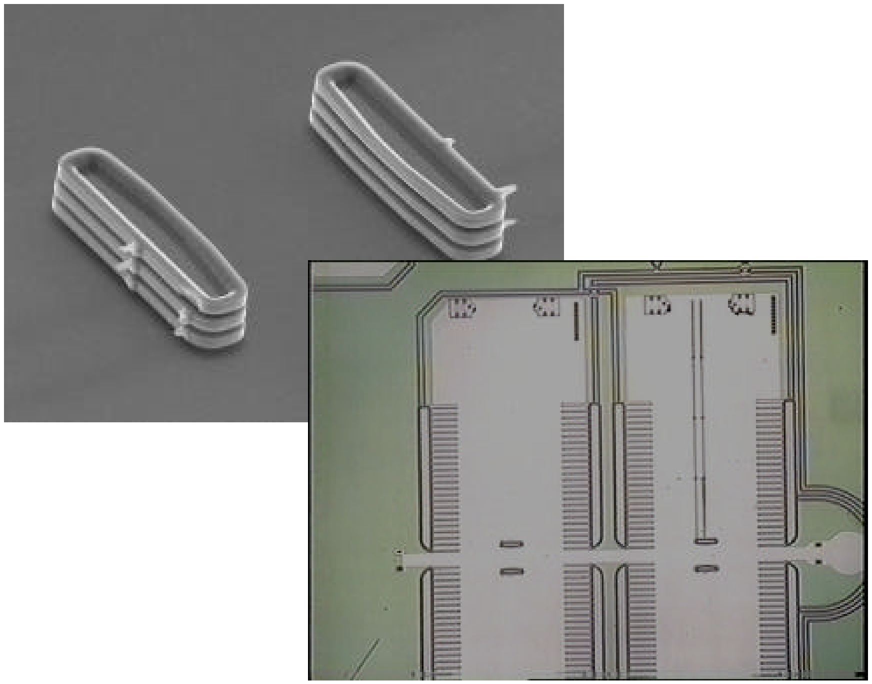
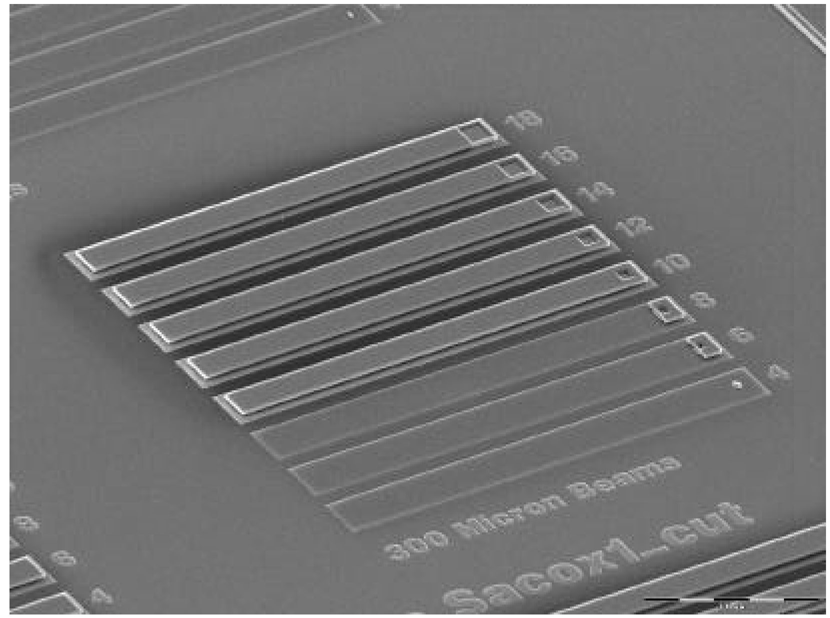
Post-shock Inspection Results - SUMMiT™

- **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™

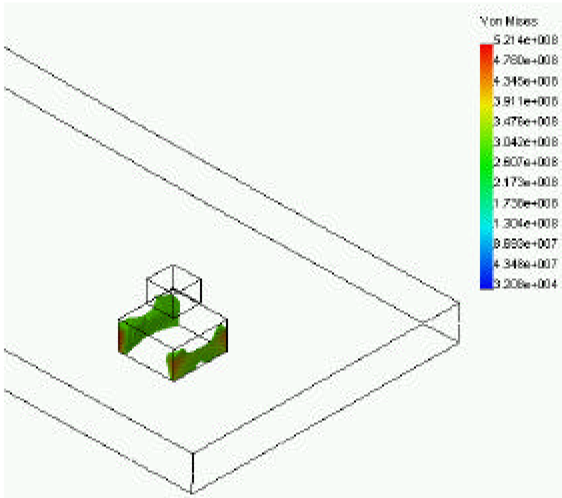


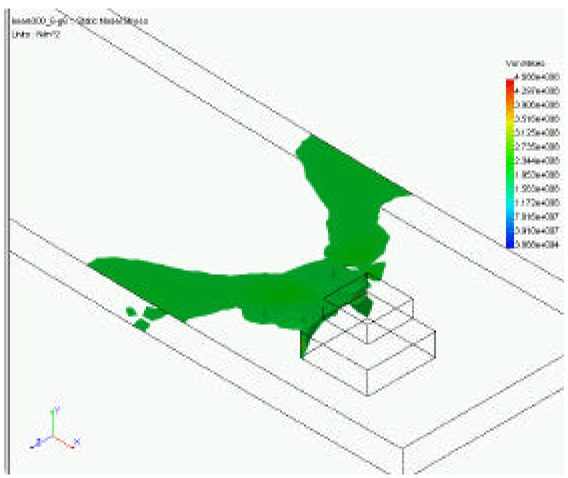


- Typical failure of a microengine after shock in tension

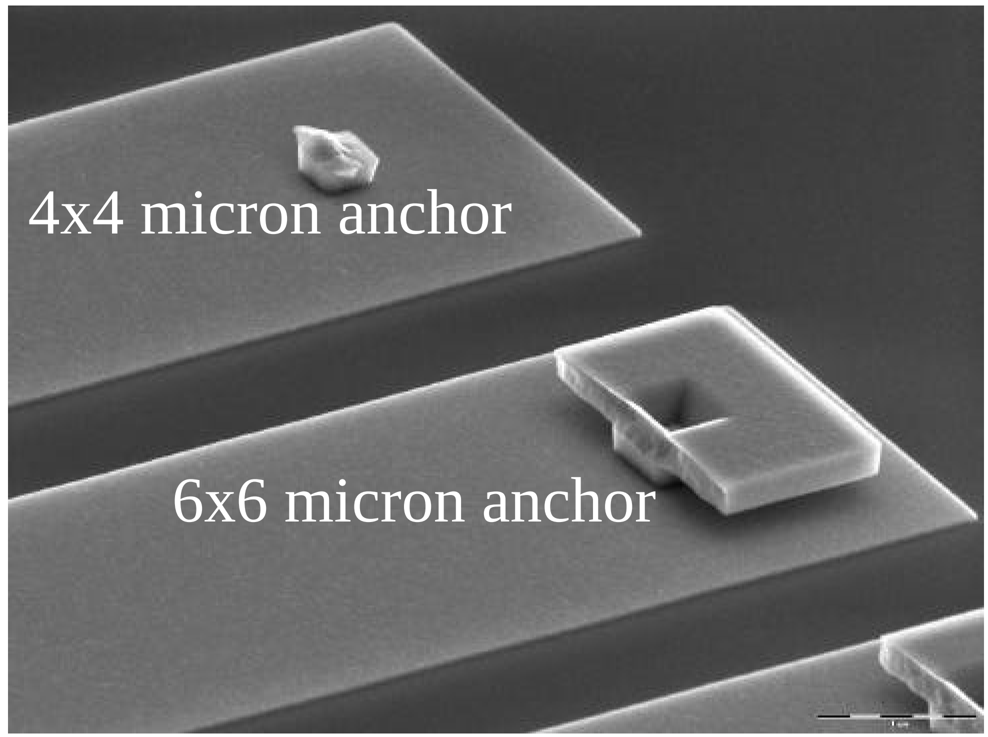
•After 210K g shock in tension, 300 micron beams with small anchors and all longer beams are broken

Post-shock Images - SUMMiT™



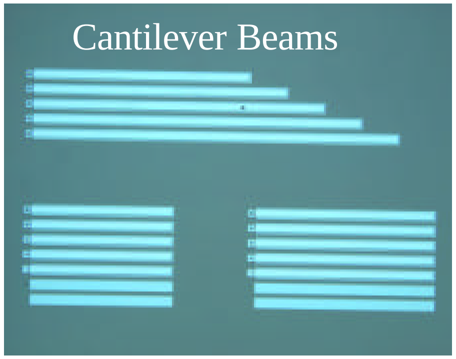


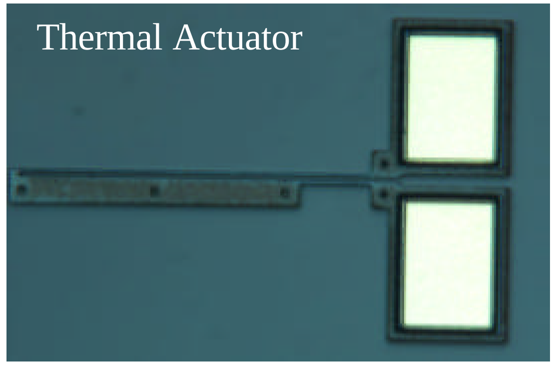
- Failure due to fracture of polysilicon material, not de-lamination of layers

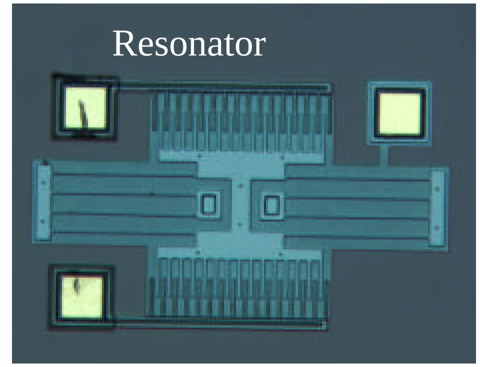


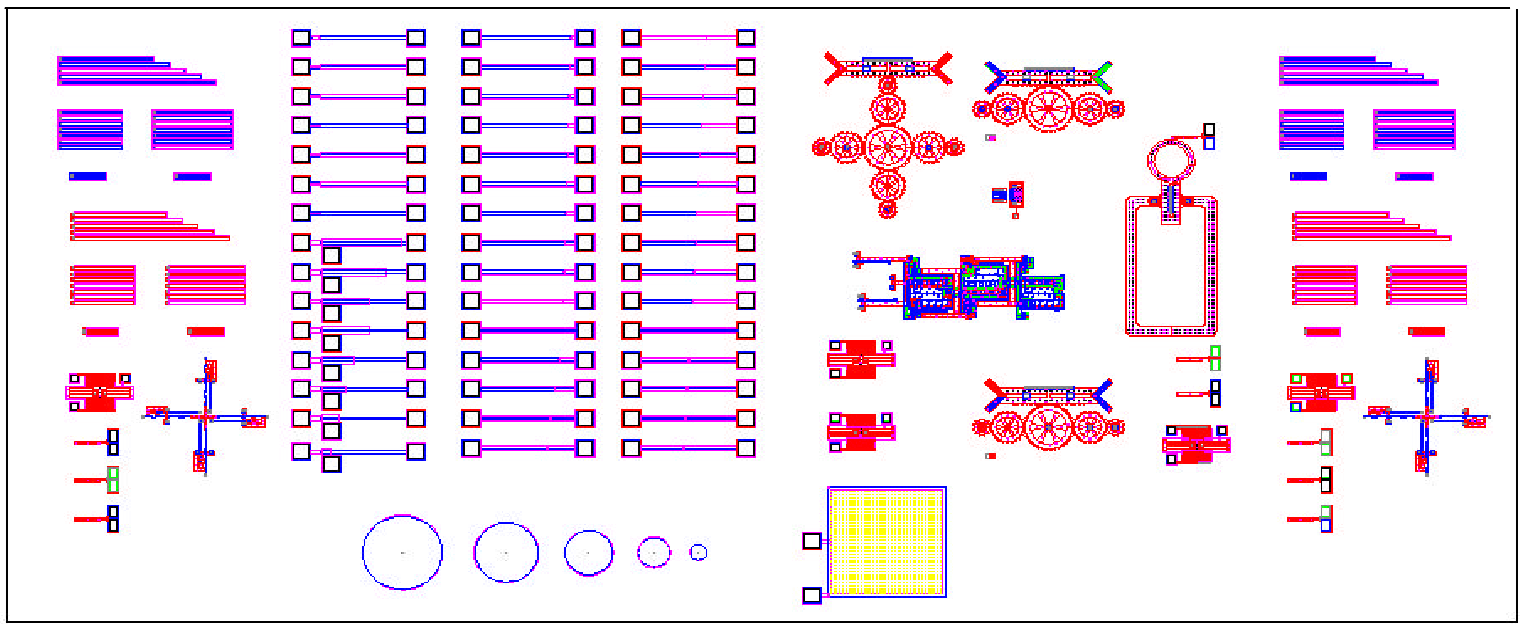
S.E.M. image by M.B. Ritchey

Cronos Die Layout









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

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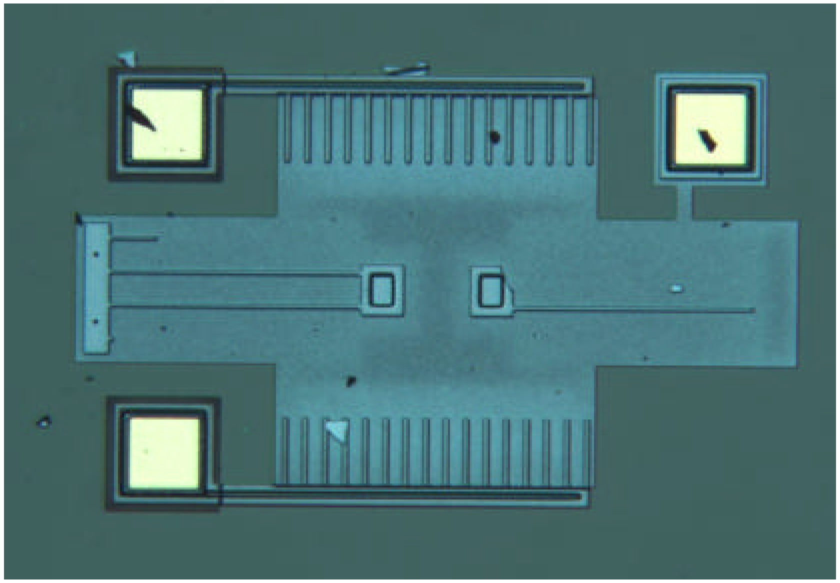
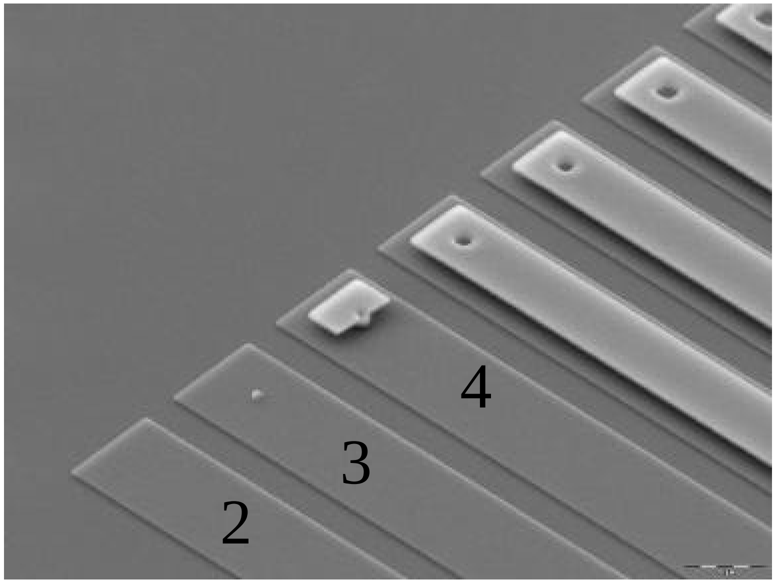
Post-shock Images - Cronos

- Typical failure of resonator
- Typical Poly 2 beam failures
  - Function of anchor size

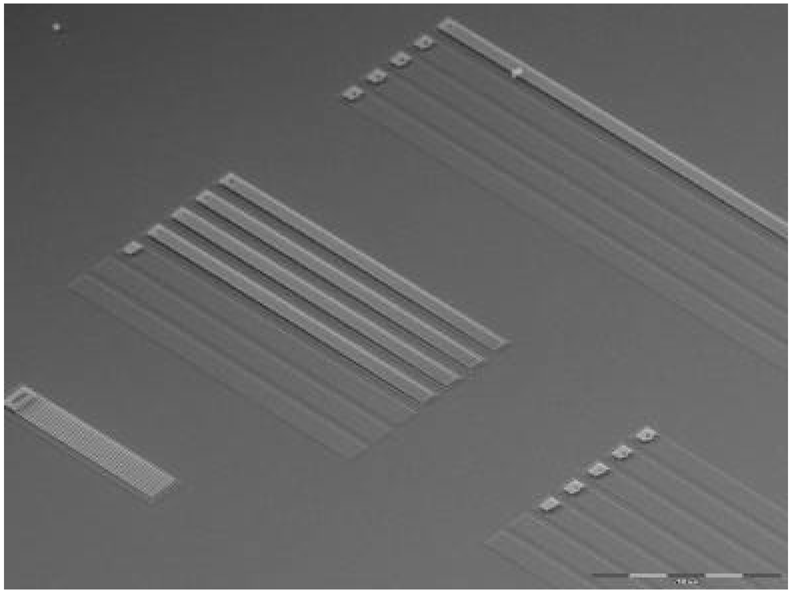


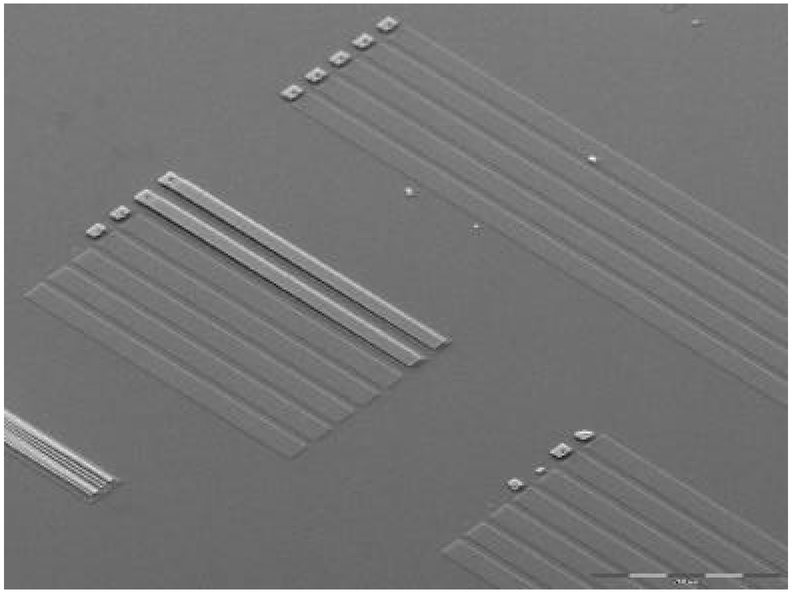


Post-shock Images - Cronos

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

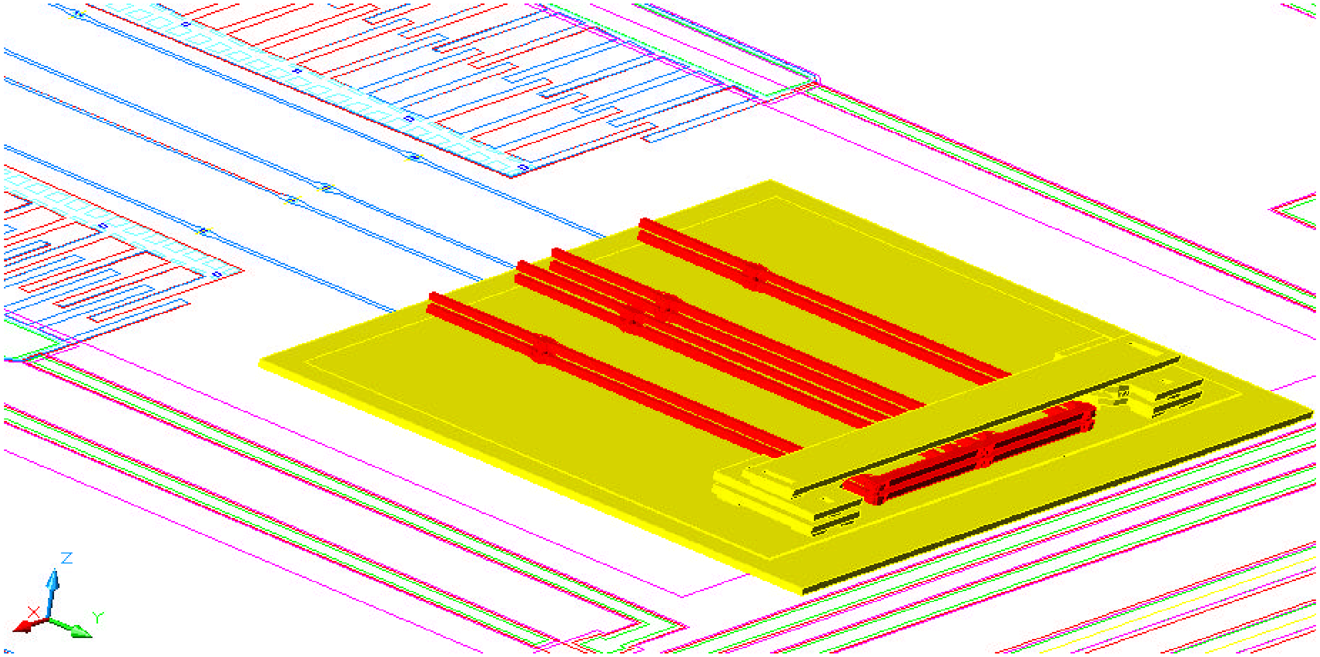
- Poly 1 beams after 124K g's tension shock
- De-lamination of anchors smaller than 4 microns





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

Acknowledgements

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- Questions?