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Packaging of a MEMS Optical Switch For Developmental Testing

Ceramic Interconnect and Ceramic Microsystem Technologies (CICMT 2009)

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Outline

- Motivation
- Description of our MEMS (micro electro-mechanical system)-based optical switch
- Package requirements for concept testing
- Issues in design and assembly of packages
- A ceramist's solution to stiction
- Conclusions

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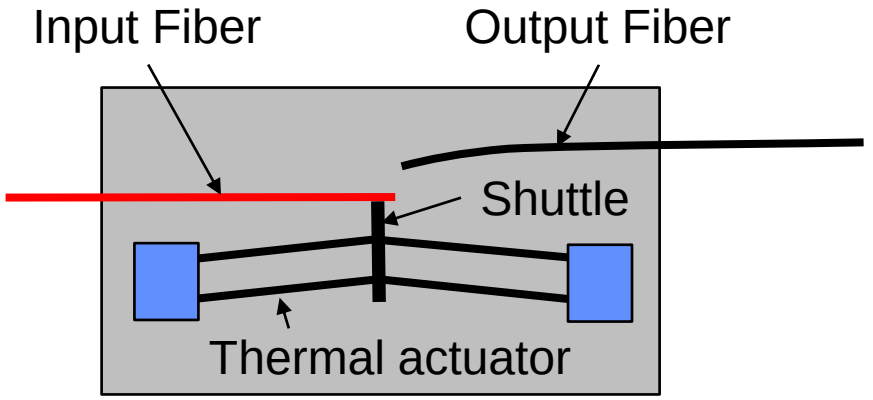
Motivation

- **Microelectronic systems – Concept often proven using a probe station at the wafer scale or with bare die**
- **MEMS – Due to required mechanical, fluidic, or optical interaction, must often be tested in a package to prove concept**

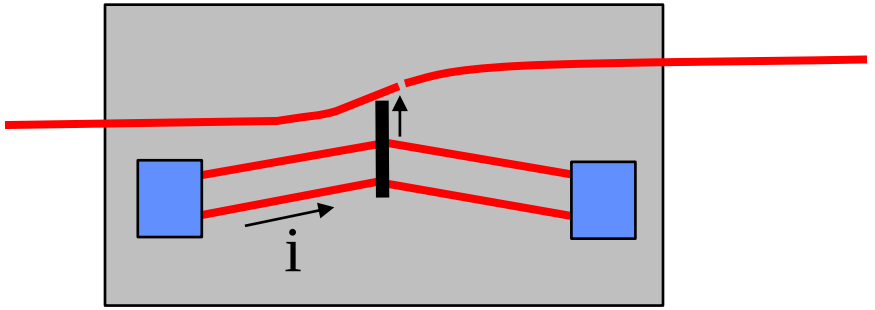
We discuss the prototype packaging of MEMS-based optical fiber switch for developmental testing

MEMS Optical Switch Concept

1. **Current flowing through actuator causes localized Joule heating**
2. **Shallow-angle chevron-shaped actuator expands between fixed anchors**
3. **Small expansion of beam length relative to anchor spacing causes large displacement of shuttle**
4. **Shuttle on actuator moves a fibers into alignment, closing switch**
5. **Latch (not shown) keeps fibers in alignment until reset**



Switch Open (shunting)



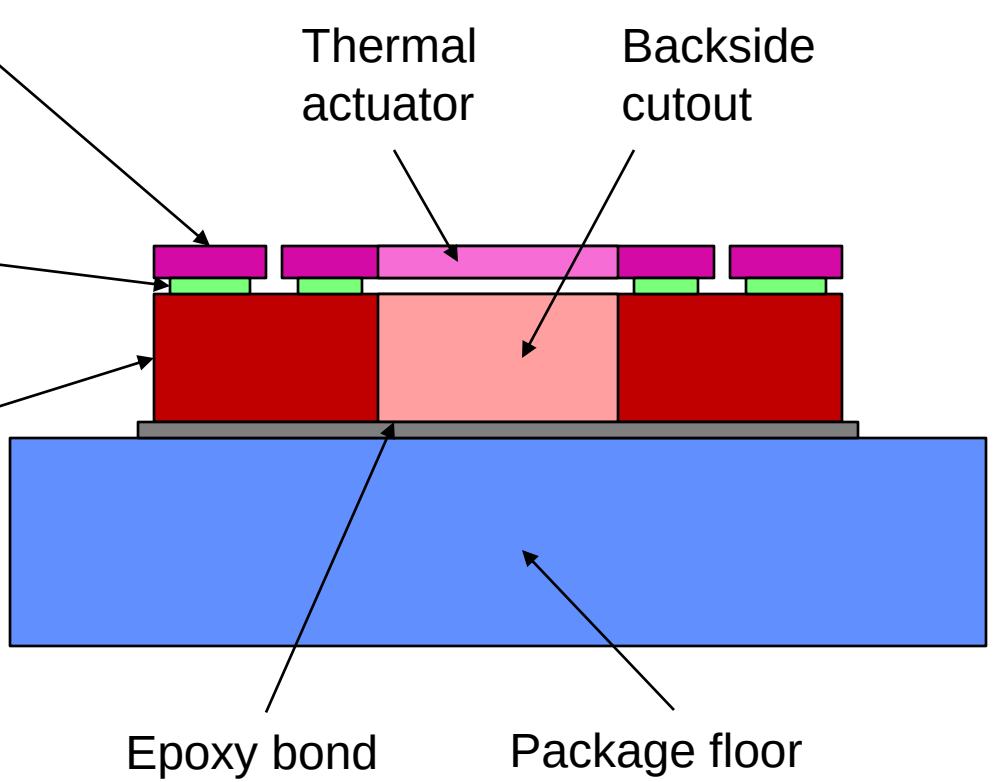
Switch Closed (transmitting)

Layers in MEMS Device

SOI (silicon on insulator)

- **125 µm device layer that includes thermal actuators and other movable elements**
- **2 µm buried oxide (BOX) provides mechanical connection and electrical isolation between layers, removed under movable elements**
- **500 µm handle layer with backside cutouts to minimize heat loss**

Features are deep reactive ion etched (DRIE) from both front and back with BOX doubling as etch stop



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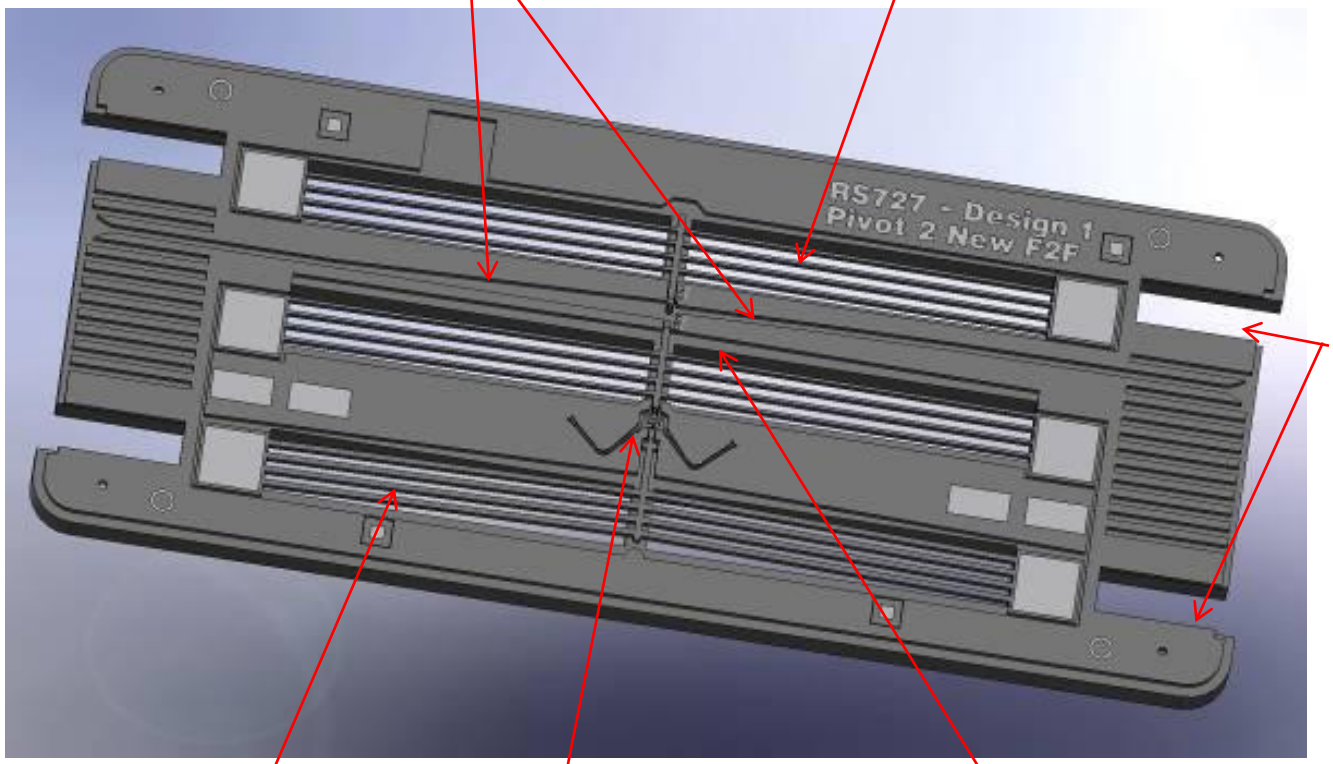
Layout of MEMS Device



Fiber grooves

Intent actuator

Cutouts for MT connector pins

Reset actuator

Latch

Fiber actuator

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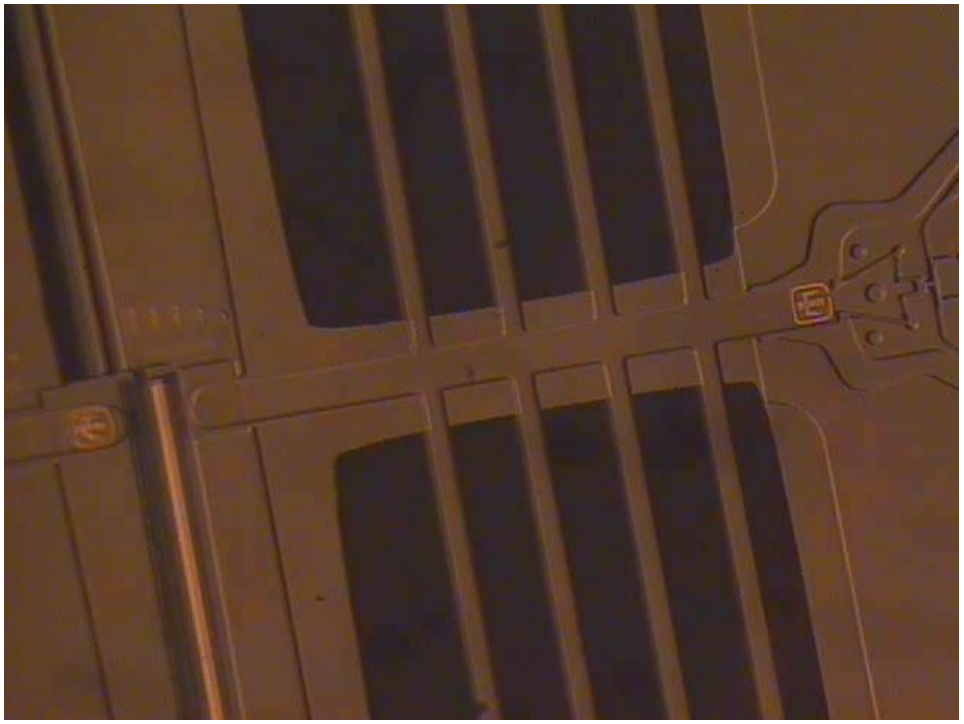
Device in Operation

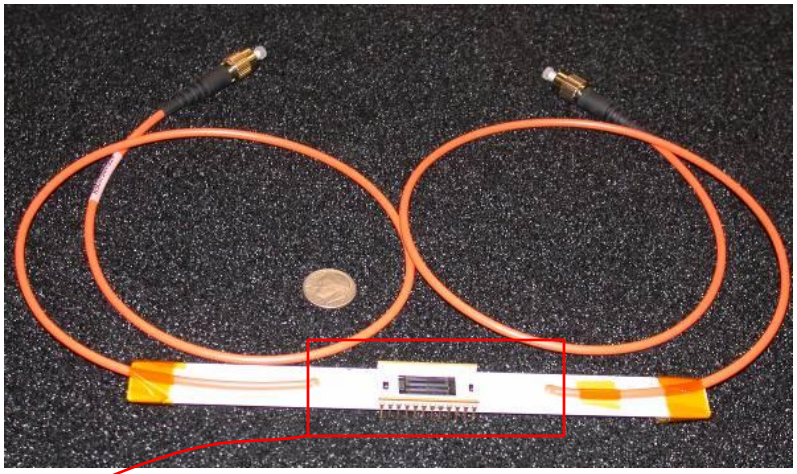


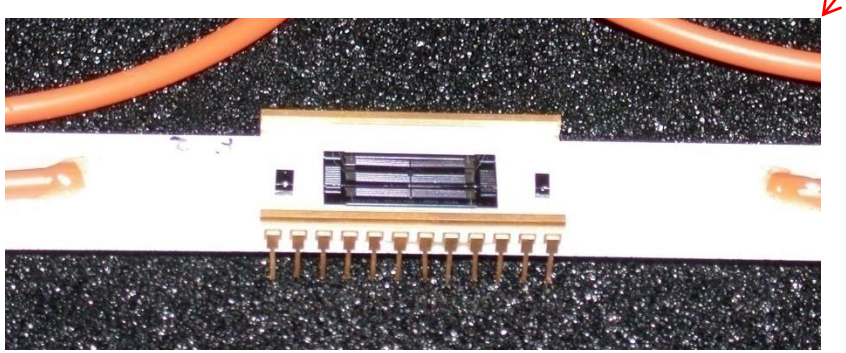
- **Scene 1: whole switch**
- **Scene 2: fiber actuator, optical fiber and latch**
- **Scene 3: optical fiber switching and transmitting light**

Package For Bench Testing

Requirements:

- Electrical connectivity to MEMS die
- Support for optical fibers
- Avoid residual stress in die that could cause actuator displacement





Solution:

- HTCC “bathtub” DIP (dual in-line package) with ends sawed off, on alumina substrate for fiber support
- Room temperature epoxy die attachment

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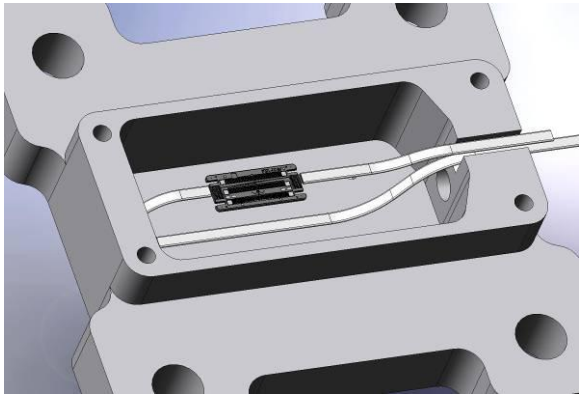
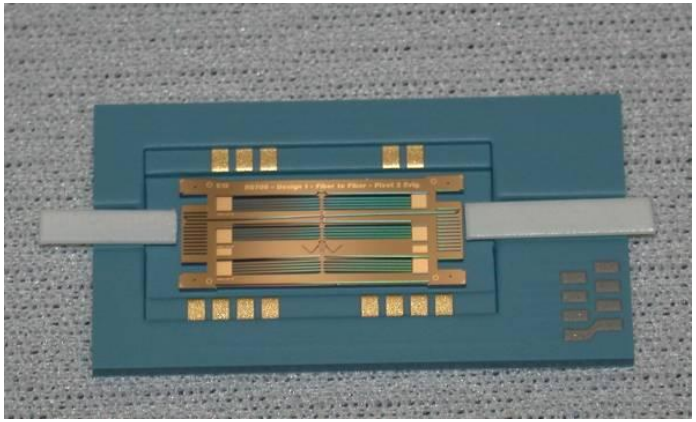
Package For Vibration Testing

Further requirements:

- Small form factor
- Ruggedized fiber attachment
- Withstand potting pressures
- Observation window





Solution:

- Custom LTCC package and lid
- Ribbon fiber with unused fiber stubs epoxied into grooves in MEMS die
- Solder pads for direct connection to wiring harness

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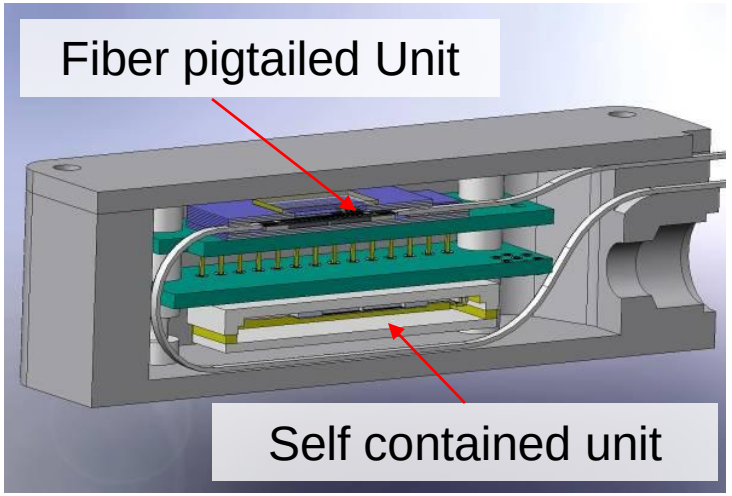
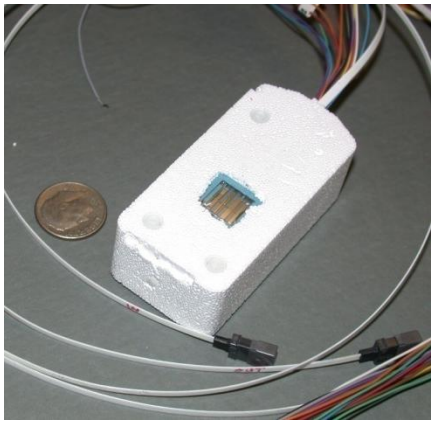
System Design for Test

Due to importance of showing success of MEMS concept, two devices were put into test bed

- **LTCC package with optical fiber pigtails terminated with MT connectors for external optical testing**
- **Bathtub DIP consisting LED, switch, photo-detector, and stub fibers for self-contained optical testing**

Units were mounted on PCBs, held in cavity using plastic pins, and potted in place using expanded polystyrene beads





Potted assembly removed from cavity with window exposed

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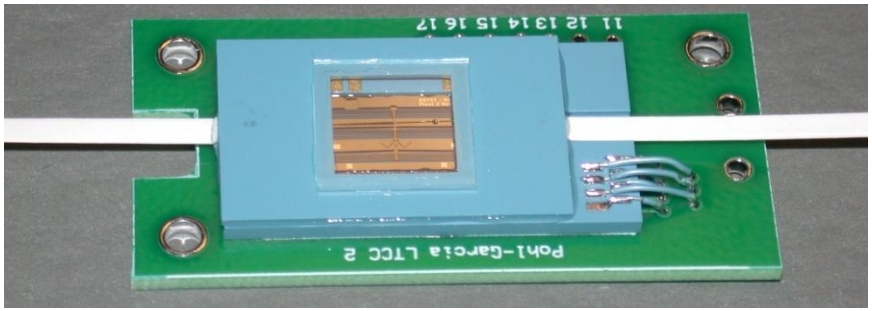
Package Concerns for Fiber-Pigtailed Unit



- **Protection of MEMS die during mechanical environments testing**
- **Survivability of package under potting pressure**
- **Thermal stresses on MEMS die from die attachment**
- **Preparation of optical fibers**
- **Complexity of device assembly**
- **Bonding of optical fiber to die / package**
- **Survivability of device under potting temperature**

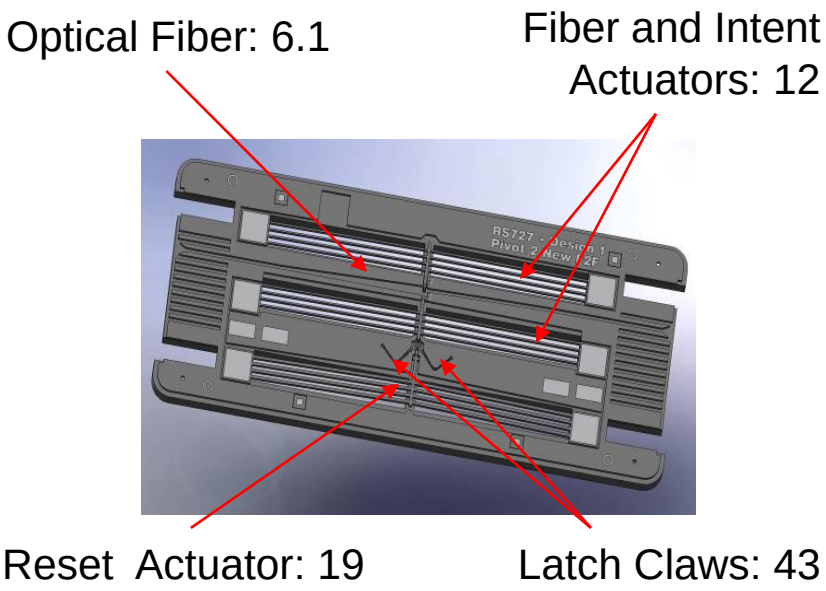
Mechanical Protection of MEMS Die

Considered including mechanical stops to protect movable elements in MEMS

- **FEA modeling indicates that under inertial loading, the movable elements are**
  - **stiff – all vibrational modes above 4000 Hz)**
  - **strong – all factors of safety (FOS) above 6 for 1000g static loading**
- **Response to shock loading still unknown**

Decided to forego mechanical stops based on promising FEA results

Factors of Safety under 1000g static loading



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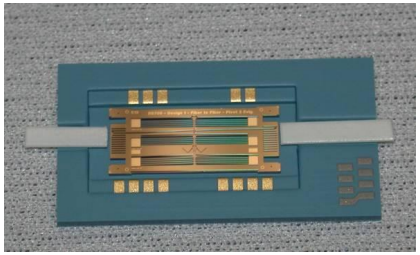
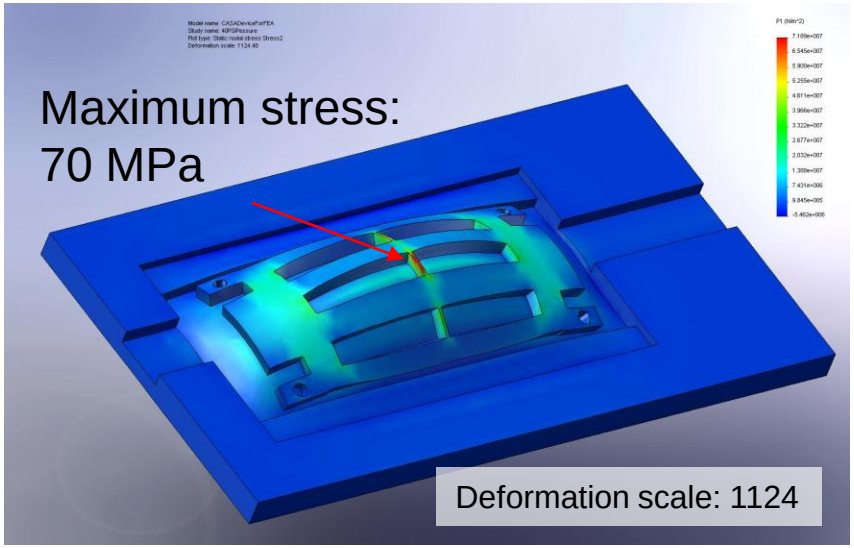
Analysis of Potting Stresses on Package

- **In potting, it was assumed that the pressure could reach 275 kPa (40 psi)**
- **Modeling predicts package safe, but cavity floor flexure could cause die failure**
- **Modeling predictions prompted us to strongly bond the LTCC package to the PCB to provide extra backside rigidity**





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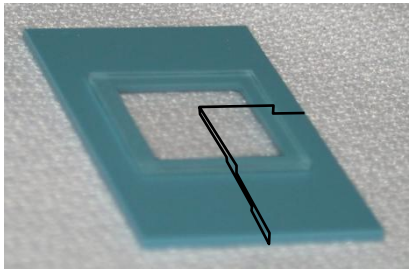
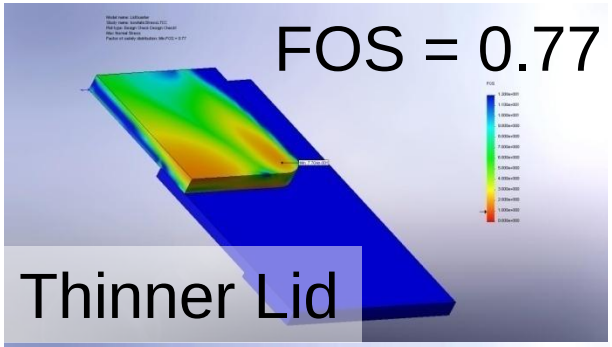
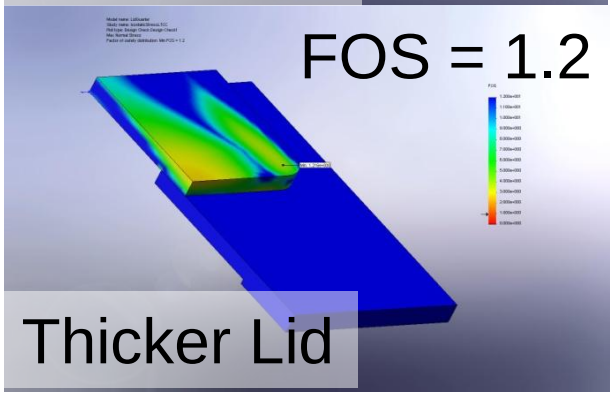
Analysis of Potting Stresses on Lid

- **Under same 275 kPa potting pressure**
- **Modeling predicts LTCC safe, but glass close to slow crack growth threshold**
- **Increasing LTCC thickness to reduce flexure of frame had larger impact than increasing glass thickness**
- **Made the lid thicker in response**







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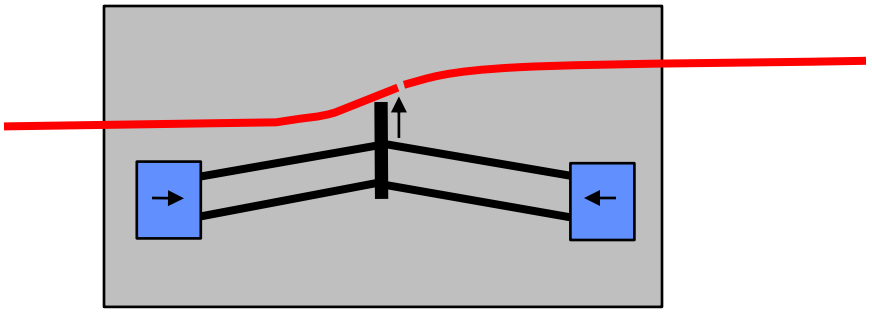
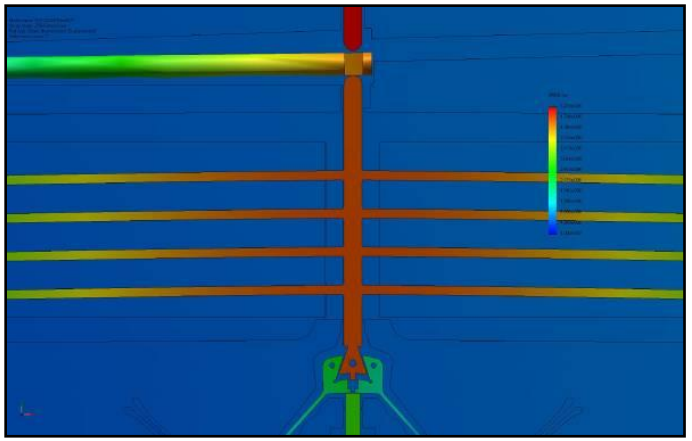
Need to Avoid Die Attach Thermal Stresses

- **Thermal stresses from high-temperature die attachment can result in deflection of actuators with no applied current**
- **Small contraction of anchor spacing relative to actuator beam length causes large displacement of shuttle**
- **Used a room-temperature-curable epoxy to avoid problem**



Partial Actuation Due to Compressive Thermal Stresses in Die



Model of die on alumina with stress-free temperature of 102 C. Shuttle displacement from nominal (indicated by red color) is 43µm.

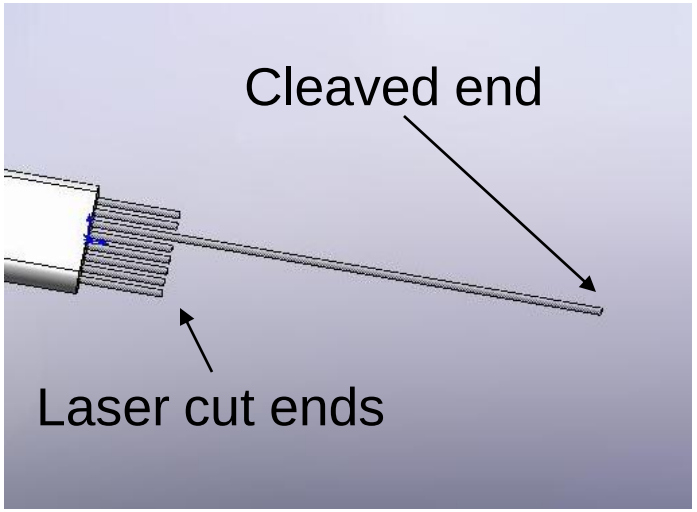
Preparing Ribbon Fiber For Insertion

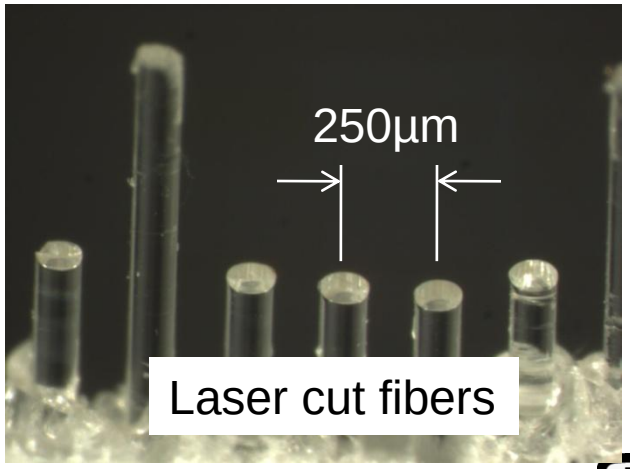
Approach is to use multi-fiber ribbon and use passive fibers for mechanical support

- **Active fibers must have pristine cleaved ends**
- **Passive fibers must be cut shorter without damaging active fiber**

Process

- **Strip jacket**
- **Mechanically cleave all fibers with multifiber cleaver**
- **Cut passive fibers to length with CO_2 laser**





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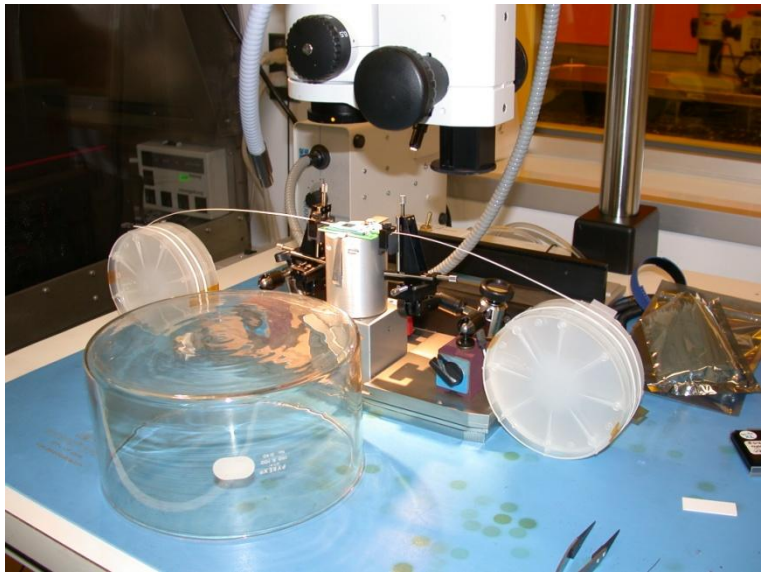
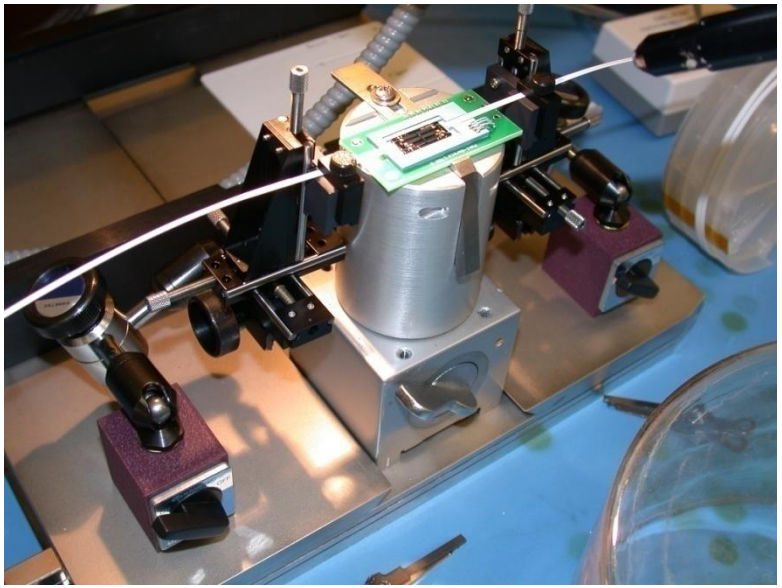
Assembly of Fibers Into MEMS Die

- Tools are two x-y-z rotationally adjustable micromanipulators, a workholder, and a boom mounted microscope

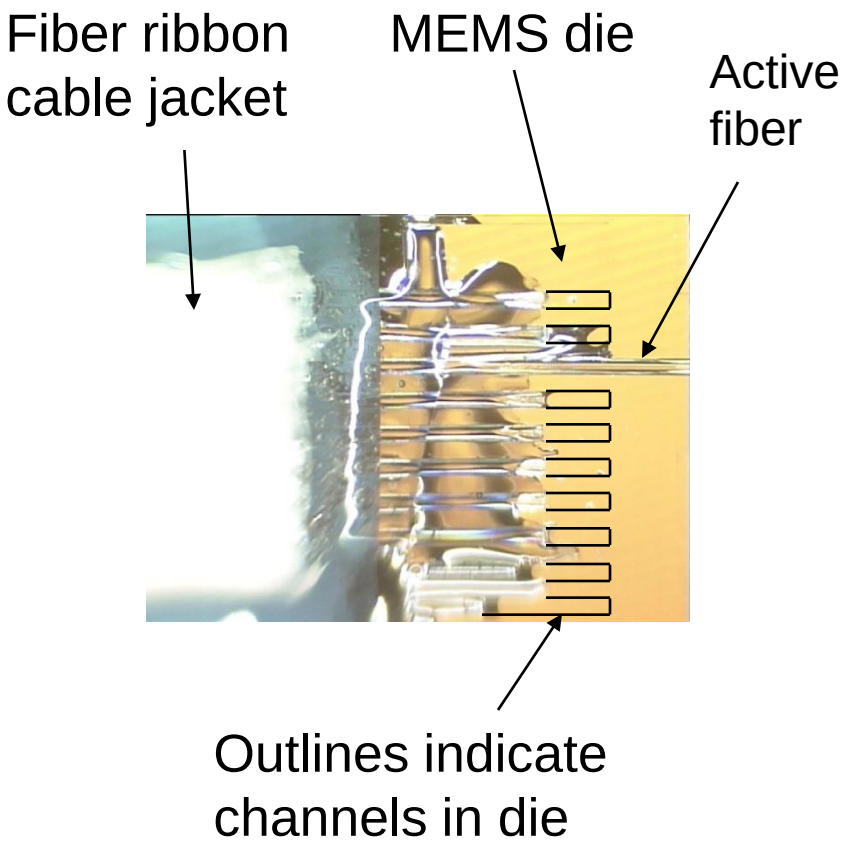




- Use micromanipulators to feed fibers into grooves in die
- Epoxy fiber into place by hand

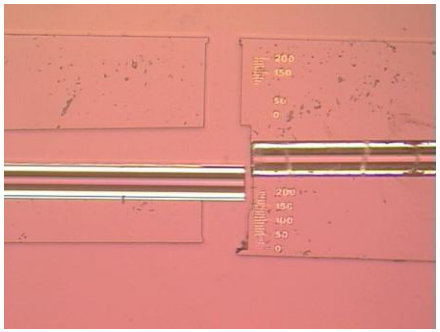
Bonding Fibers to Die

- **Robust bond is created by epoxying fibers into channels on die over about 1 mm of length**
- **Epoxy extends over edge of die to prevent unprotected fiber from rubbing on die edge**
- **No appreciable bonding to fiber jacket**
- **Package lid prevents fiber from peeling up**

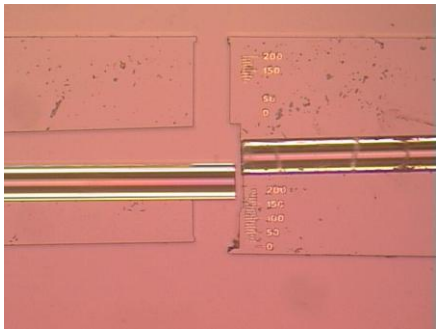


Testing the Fiber Bond Strength

- **Pigtailed packaged devices were non-destructively tested on a pull tester with a maximum load of 50 N (11.2 lbs)**
- **No movement of fiber was detected**



Pre-test picture



After pull tests up to 50 N

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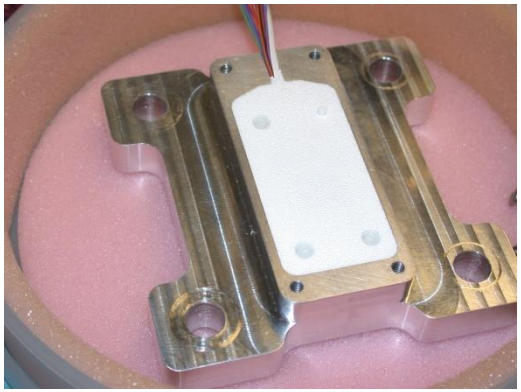
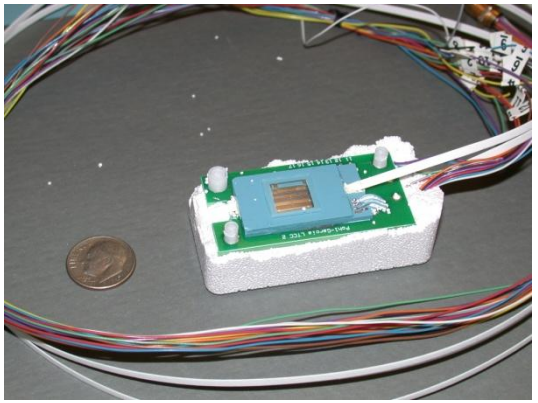
Potting Process

- **Expand polystyrene beads in closed cavity containing device**
- **Temperature up to 100°C, pressure estimated at up to 275 kPa (40 psi)**

Putting beads into housing



Fused beads with lid removed



Post-test tear-down

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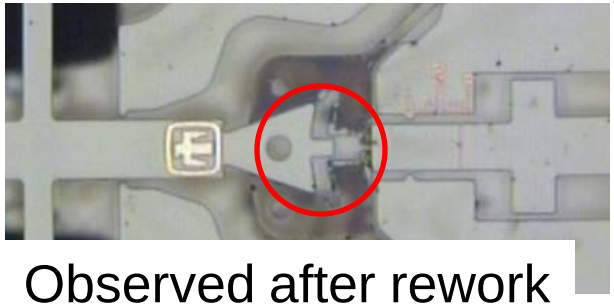
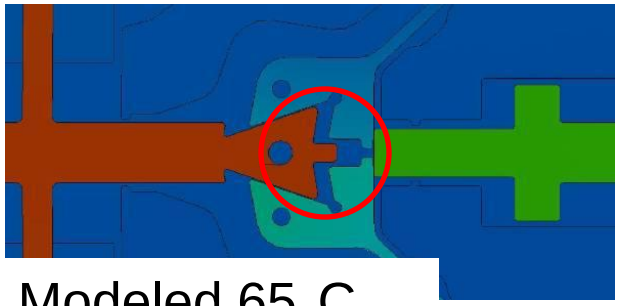
Thermal Stresses from Post-Cure Thermal Excursion

- **A self-contained unit (MEMS in an HTCC bathtub DIP) was reworked, requiring heating to ~180°C**
- **Observe fiber actuator displacement at room temperature commensurate with a 65°C stress free temperature (assuming no compliance in epoxy bond)**
- **Similar effects are observed after potting**
- **Will have to address in next version of package**

Stress Free



Observed after rework



Modeled 65 C stress free temp

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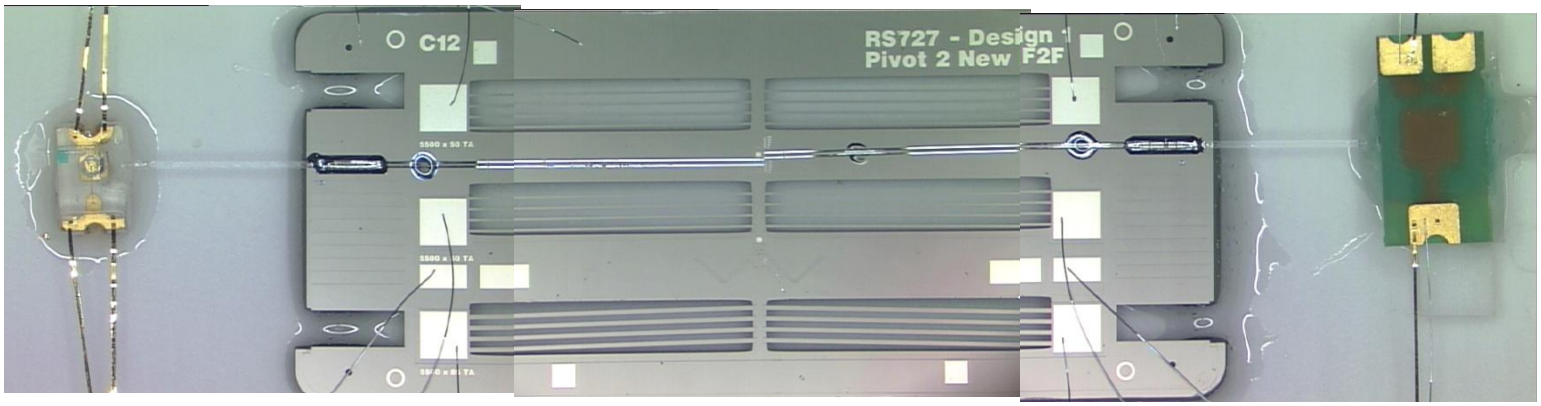
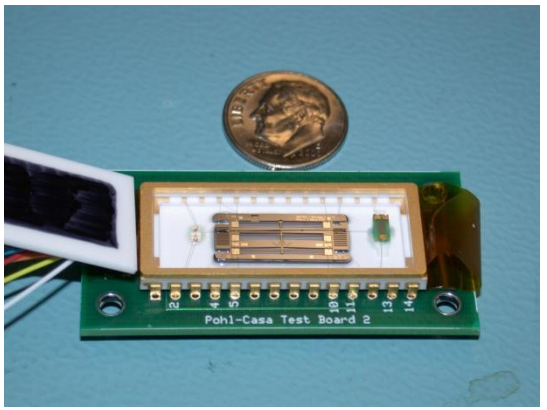
Self Contained Unit



LED MEMS Switch Photodiode

- **Much simpler because we don't have to worry about external loads on fiber, aligning end of long fiber**



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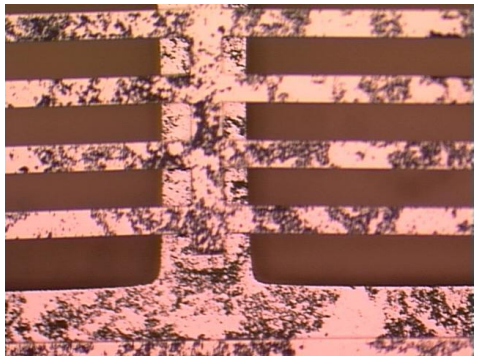
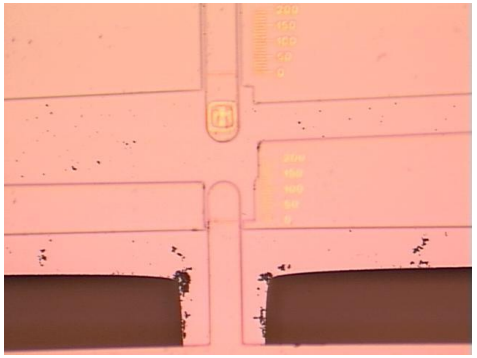
Solving Stiction Problems

Are particles in MEMS devices always bad?

- **Large area, smooth, clean surfaces separated by 2μm gap between device and handle layers would stick if brought into contact.**
- **Used 1μm alumina particles delivered in water / isopropanal suspension to ensure separation of surfaces**
- **Approach effective even though process not perfected. Ideally, use few particles that get drawn into small gaps where needed.**



Too many particles, but device worked



Fewer particles, but still effective

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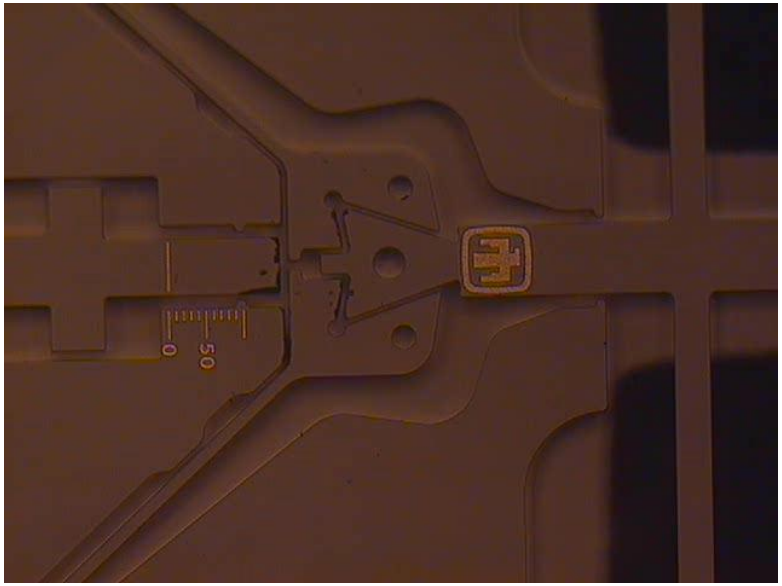
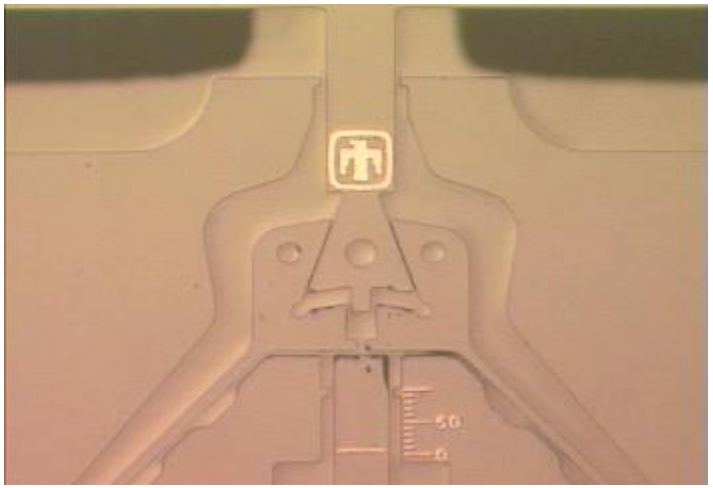
Results

- **Device survived testing**
- **Stresses from thermal excursion during potting caused displacement of actuators**



Pre-test movie



Post-test movie

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Future Package

- Will have to be hermetic
- Avoid use of organics
- Need to solve CTE mismatch issues
- Manufacturability will have to be improved

Conclusions

- LTCC technology allows for rapid fabrication (2 weeks for us) of prototype packages for MEMS development for environmental testing of MEMS devices
- FEA design tools are valuable in analyzing the likely response of the packaged system before fabrication and test

Acknowledgements

- **Dennis De Smet - LTCC fabrication, device assembly, and testing**
- **Gayle Schwartz – Assembly**
- **Howard Arris – Potting**

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