C01-06

MEMS Sensors and Carrier-Level Reliability

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Objective: *Develop necessary metrology techniques and perform environmental testing to identify and document the dominant defects, failure mechanisms, failure modes, and failure sites in hermetic and non-hermetic MEMS-based systems consisting of sensors, actuators, chip-to-chip bonded parts, and electro-optical interfaces.*

Motivation

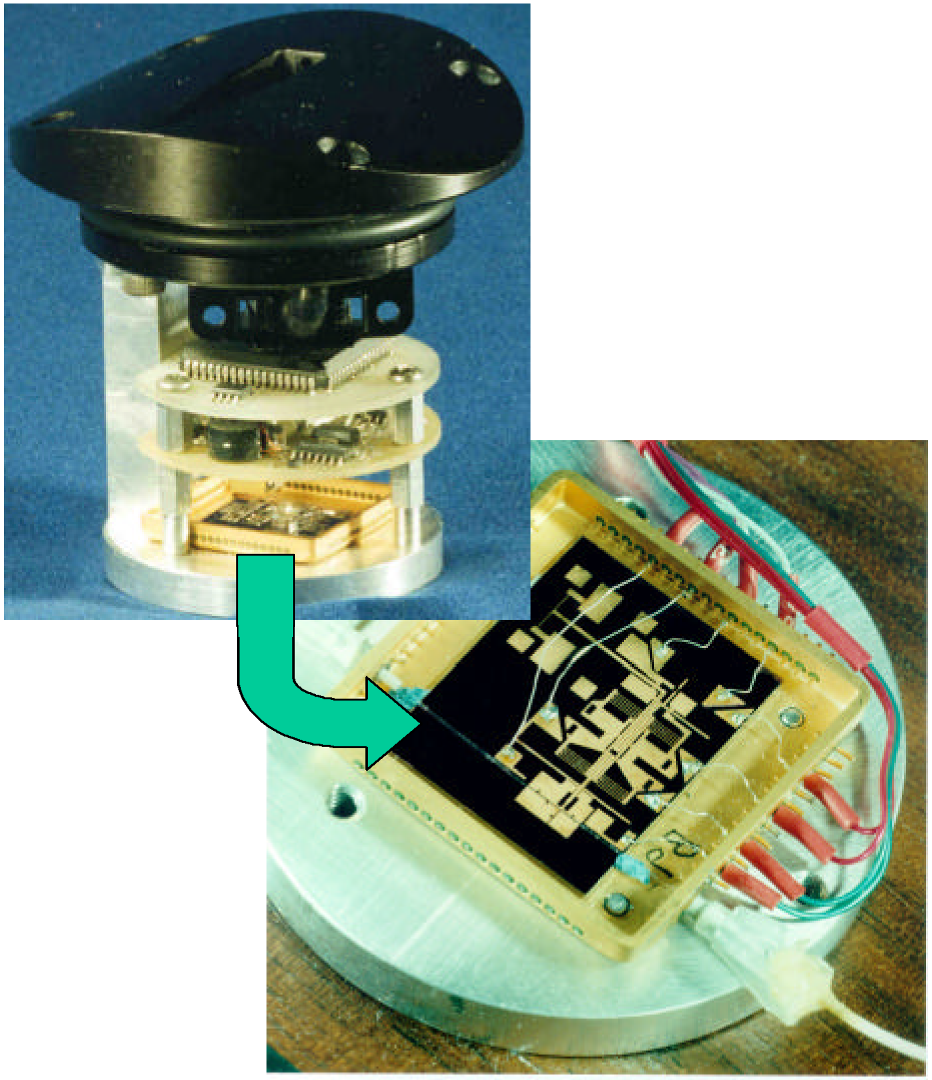
In recent years, microelectromechanical systems (MEMS) have gone from laboratory curiosities to commercial devices. While the basic principles of silicon micromachining are well understood, there is still much work to be done in ensuring long term reliability of packaged MEMS.

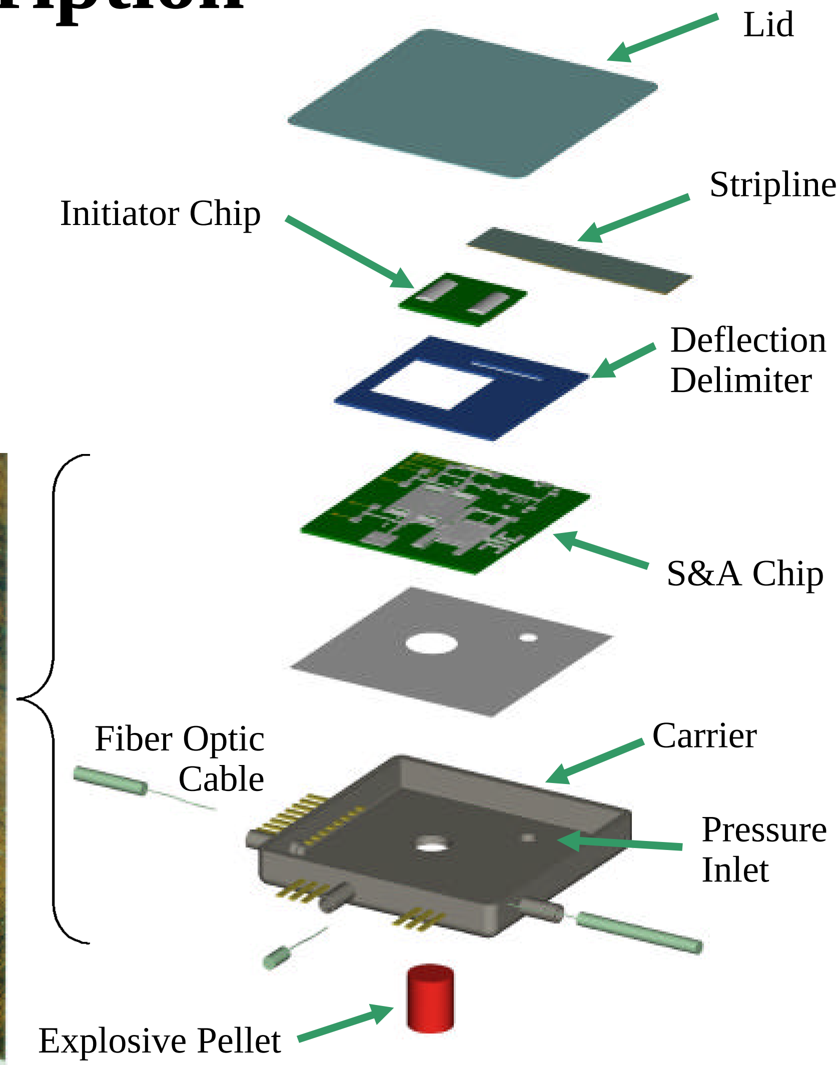
- In this project we are assessing two attributes of the MEMS packaging challenge:
  - Chip-to-chip bonding (initiated in C99-52, C00-45)
  - Reliability of carrier-level MEMS part (initiated in C00-45)
- The specific vehicle driving this research is a MEMS based Safety and Arming (S&A) device for Naval Surface Warfare Center.

MEMS Projects at CALCE

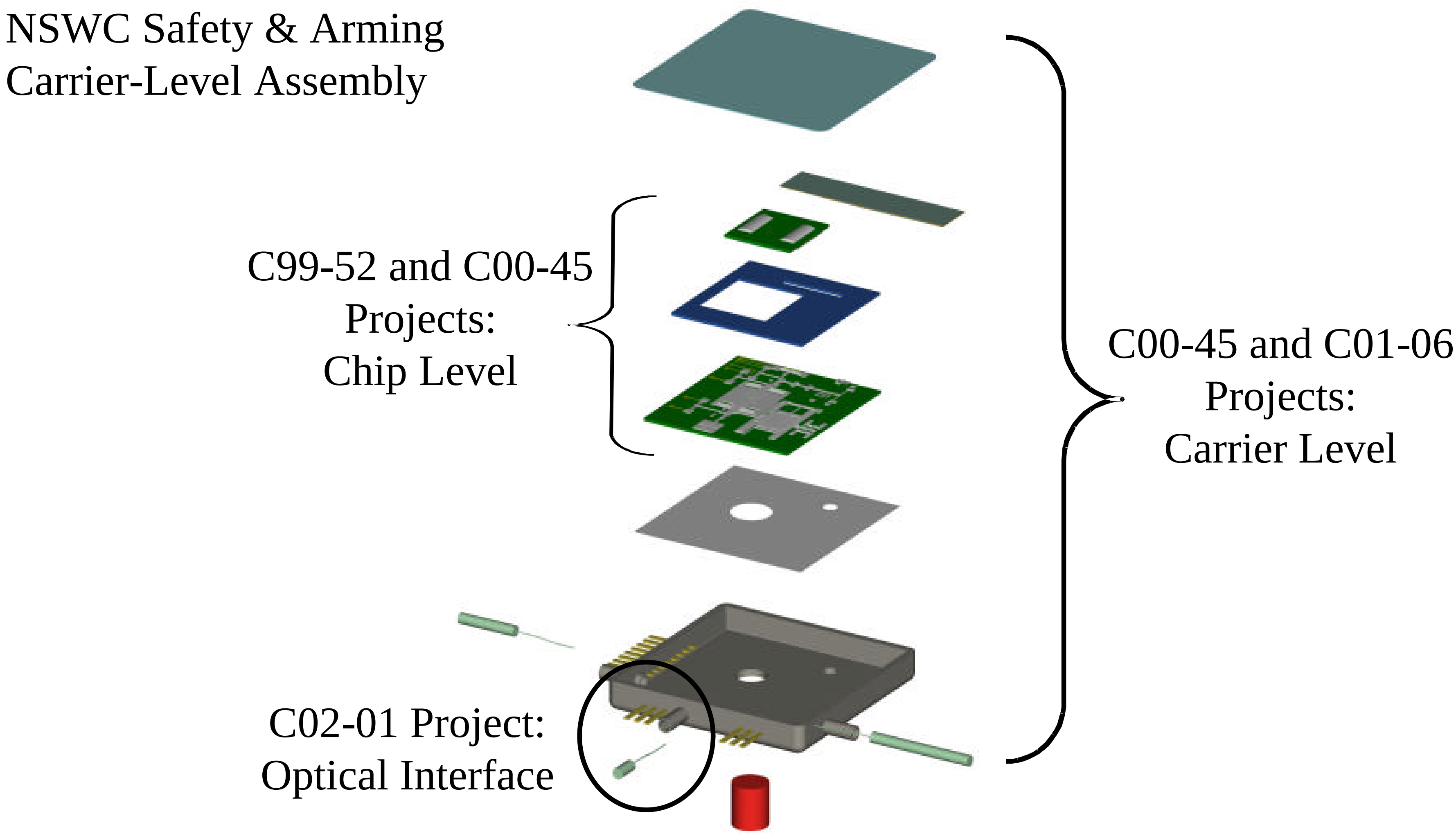
1999	C99-52 MEMS Packaging and Reliability Assessment • Accelerated testing of chip-to-chip bonding
2000	C00-45 MEMS Carrier-Level Reliability • Accelerated testing of chip-to-chip bonding • Accelerated testing of packaged MEMS LIGA switches
2001	C01-06 MEMS Sensors and Carrier-Level Reliability • Accelerated testing of packaged MEMS LIGA switches • Failure analysis of packaged MEMS LIGA switches • Simulation of chip-to-chip bonding die shear
2002	C02-01 Reliability of Optical Interfaces to MEMS • Reliability of metalized optical fiber interfaces to chip-level MEMS packages • Reliability of glass tape seal for hermetic optical waveguide MEMS packages C02-10 PoF Approach to Life Consumption Monitoring

Safety & Arming (S&A) Package Description





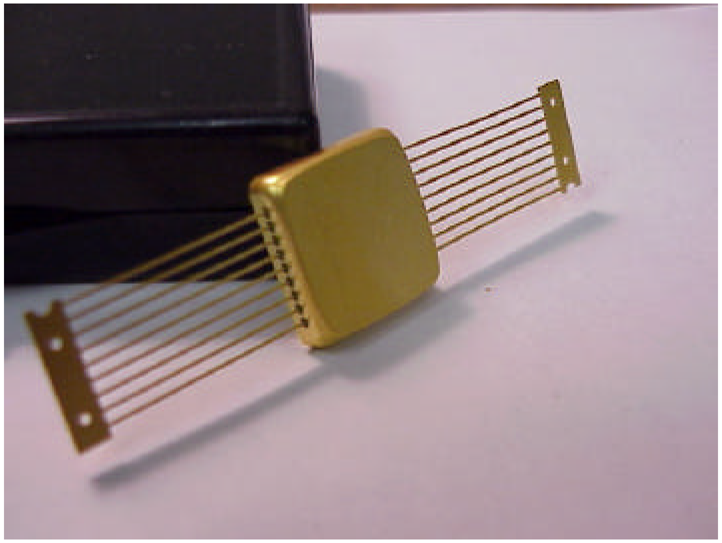
MEMS Test Vehicle

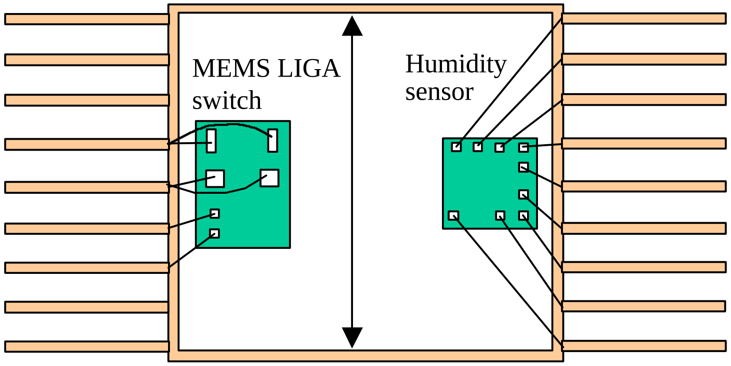


Carrier-Level Reliability Testing

This Kovar carrier containing a MEMS LIGA switch and humidity sensor, was used to study the long-term effects of moisture on the operation of a MEMS device.

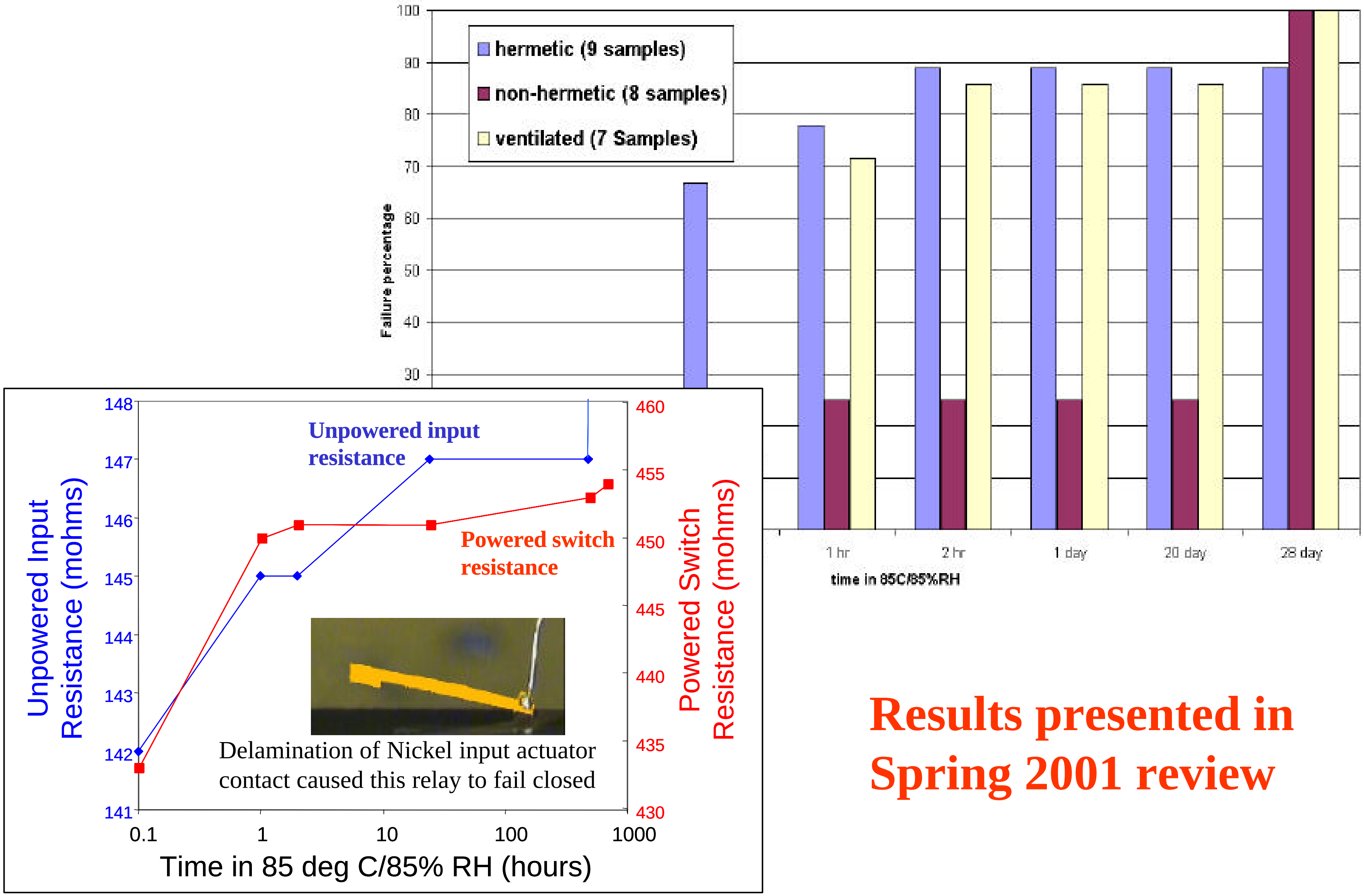
- Preconditioning (16 hours at 125 C)
- Lid attach (hermetic, non-hermetic, ventalated)
- Performance characterization
- 28 days 85% RH, 85 C
- Thermal shock (-55 C to 70 C)





Kovar Chip Carrier

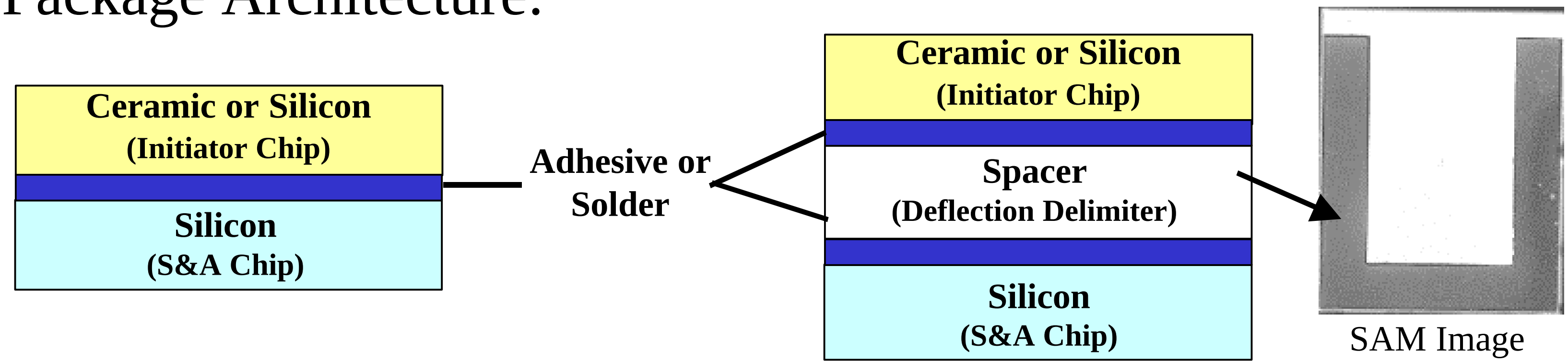
Carrier-Level Reliability Testing



Results presented in Spring 2001 review

Chip-to-Chip Bonding Review

Package Architecture:



SAM Image

Design Specification:

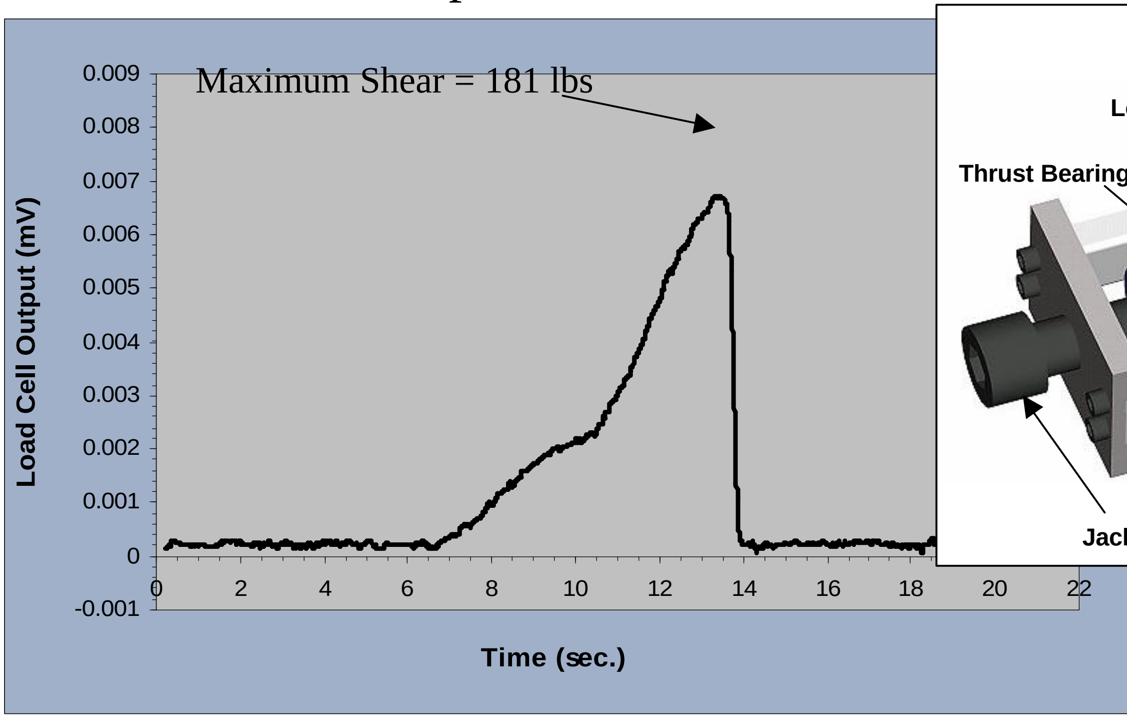
Design No.	Bond Material	Bottom Substrate	Top Substrate	Spacer	Bond Thickness (mm)
1	Thermoplastic Paste	Silicon	Ceramic	Alloy 42	0.051
2	Thermoplastic Film	Silicon	Ceramic	-	0.178
3	Epoxy Film	Silicon	Ceramic	-	0.178
4	Thermoplastic Film	Silicon	Silicon	-	0.178
5	Epoxy Film	Silicon	Ceramic	Alloy 42	0.051
6	Thermoplastic Film	Silicon	Ceramic	Alloy 42	0.051
7	Indium Solder	Silicon	Ceramic	Alloy 42	0.005

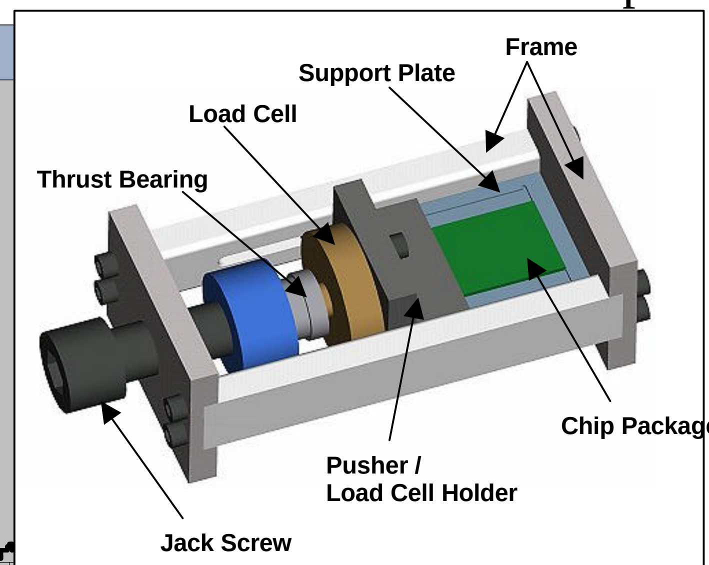
- Accelerated testing
- Thermal cycling
- Mechanical shock
- Die shear

http://www.calce.umd.edu/members/projects/2001/C01-06/paper1.PDF

Die Shear Experiment

- Verification of delamination measurement methodology developed in previous projects.
- Determine the strength of the bonds for varying degrees of delamination by assessing the effect of the delamination on bond strength through die-shear testing.
- Problem – the experimental die shear results looked like a scatter of points





Die Shear Results for Ceramic – Design 1

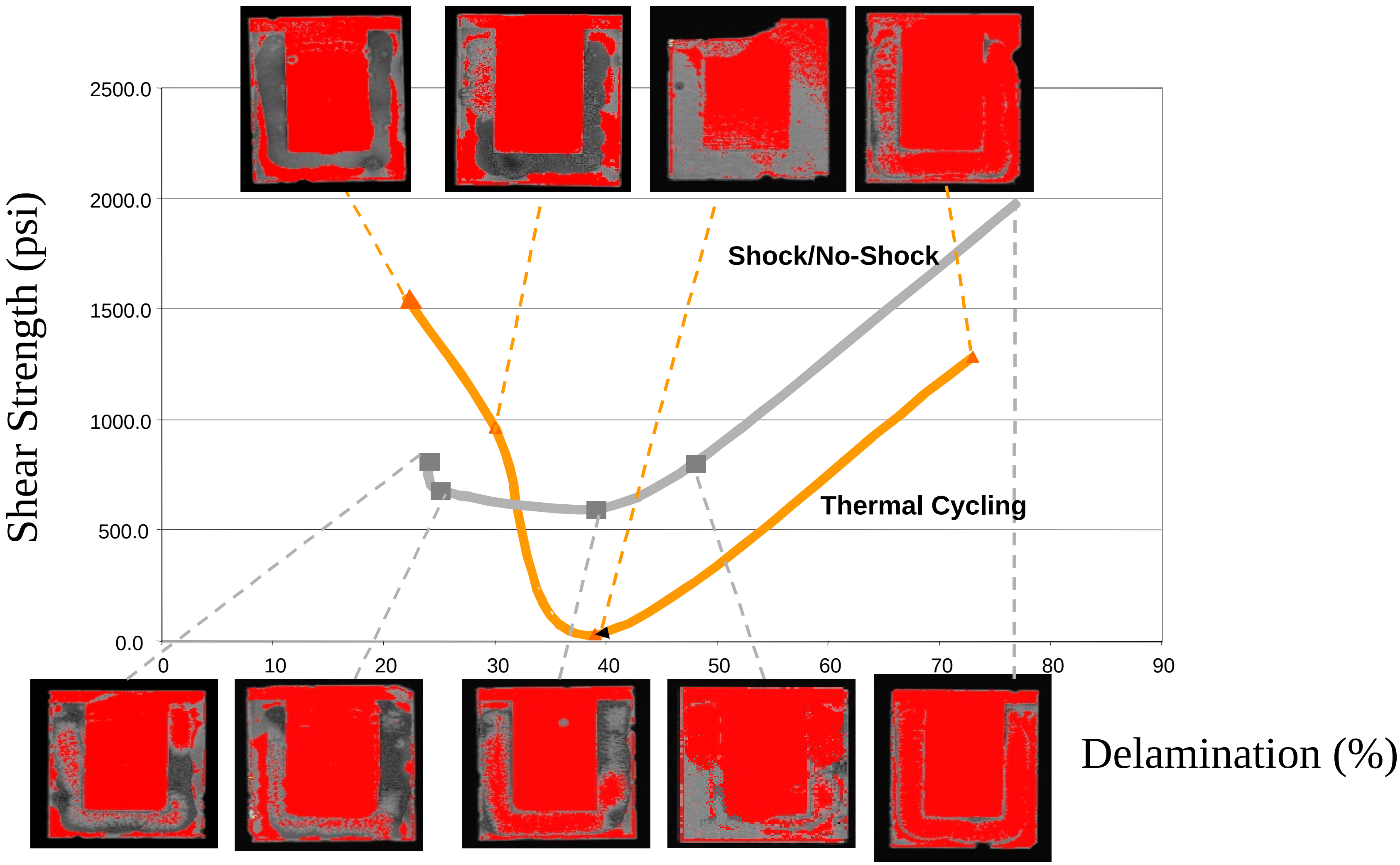
(Thermoplastic Adhesive-Alloy 42 Spacer-Silicon)

	Enviro.	Failure	Initial Delam. %	Final Delam. %	Actual Bond Area	Shear Load		Ult. Shear Strength (psi)	
Package	**Test**	**Interface**	**@ Failure Int.**	**@ Failure Int.**	**(in^2)**	**mV**	**lbs**	**Design Area**	**Actual Area**
1-1	TC	Si	64	73	0.041	2.3	64.1	418.7	1550.9
1-3	TC	Si	30	30	0.107	3.7	103.1	673.6	962.3
1-9	TC	Cer	52	52	0.073	4.5	125.3	819.3	1706.8
1-14	TC	Si	39	39	0.093	0.1	2.8	18.2	29.8
1-8	TC	Si	21	22	0.119	5.5	153.2	1001.3	1283.8
1-10	S	Si	39	39	0.093	2	55.7	364.1	596.9
1-15	S	Cer	66	66	0.052	2.4	66.9	436.9	1285.1
1-7	S	Si	25	25	0.115	2.8	78.0	509.8	679.7
1-11	NS	Si	77	77	0.035	2.5	69.6	455.1	1978.9
1-5	NS	Si	48	48	0.080	2.3	64.1	418.7	805.3
1-6	NS	Si	24	24	0.116	3.4	94.7	619.0	814.5
1-13	A	Si	77	100	0.000	0	0.0	0.0	0.0
1-2	A	Si	56	100	0.000	0	0.0	0.0	0.0
1-4	A	Si	20	100	0.000	0	0.0	0.0	0.0
1-12	A	Cer	43	100	0.000	0	0.0	0.0	0.0
Expected					0.153		306	2000	2000
Mean				60	0.062		58	382	780
S. D.*				29	0.045		48	312	657

*Standard Deviation

Die Shear Strength Plots

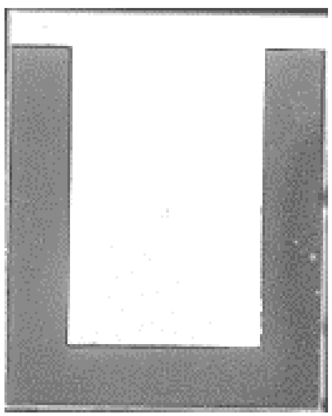
(Thermoplastic Adhesive-Alloy 42 Spacer-Silicon)



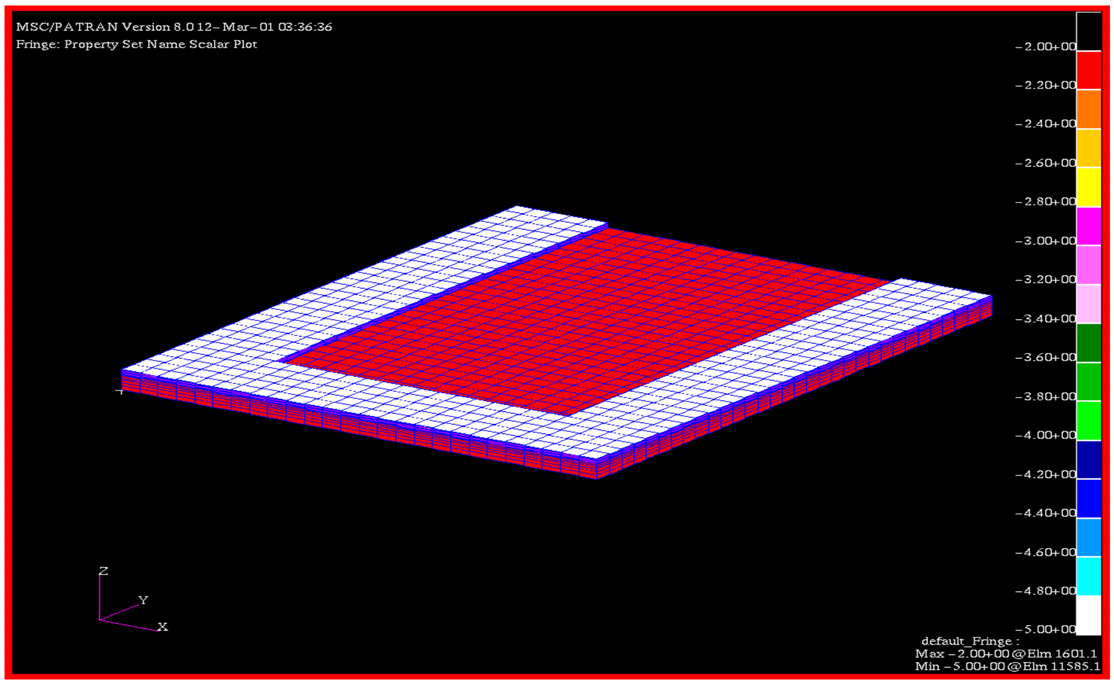
FEM Model and Mesh Analysis

Features of the model:

- 3D model
- Eight-noded isoparametric brick element
- 11984 elements in the model

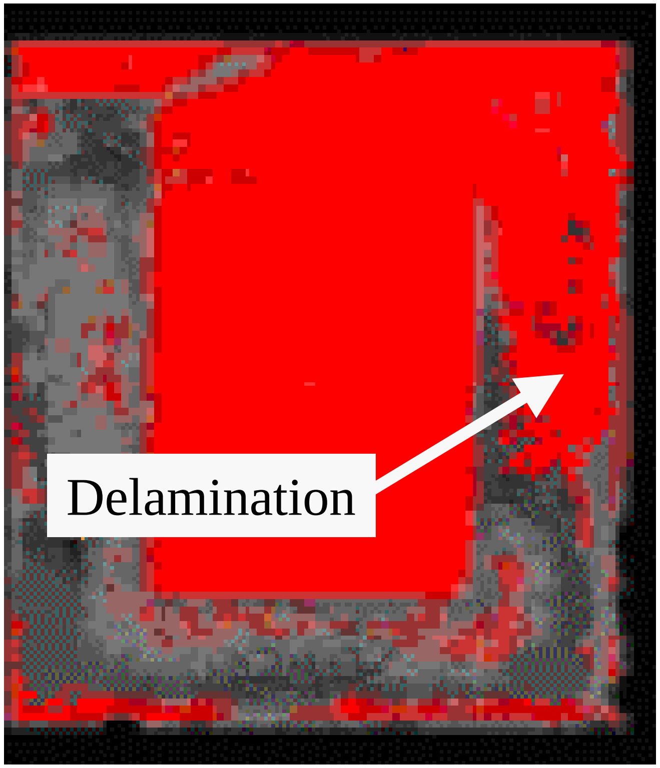


"U" shaped deflection delimiter

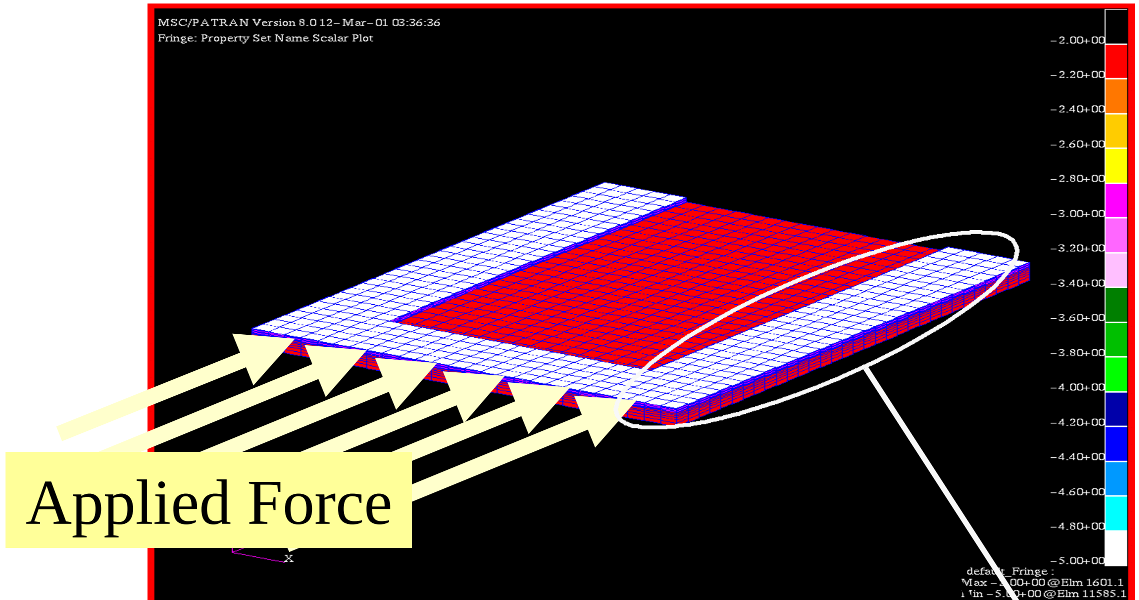


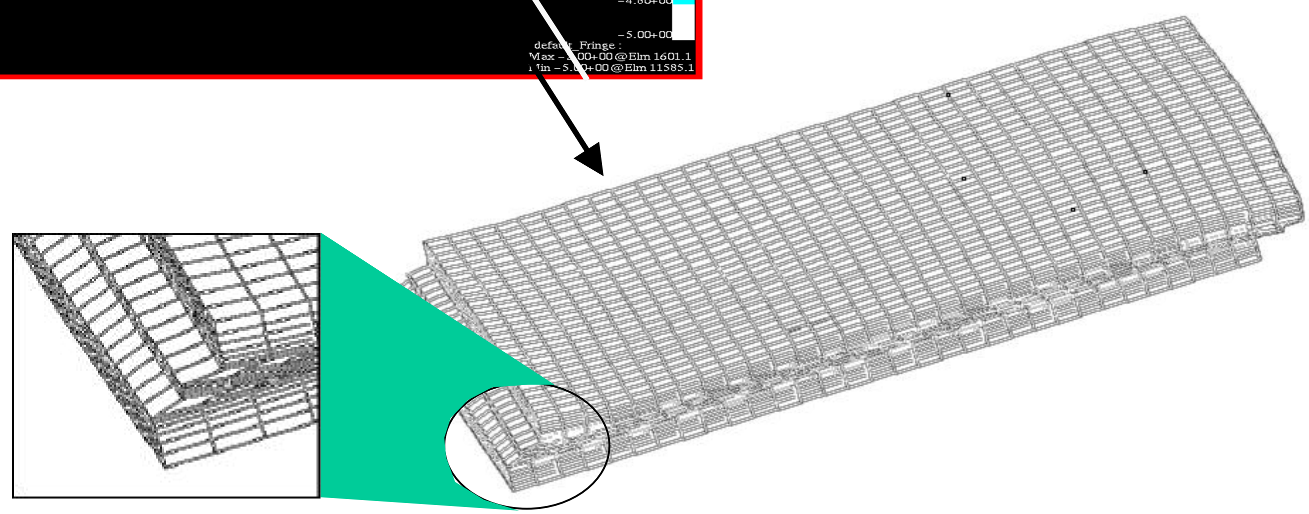
Modeling Process

1. Map delamination observed in SAM pictures to the FEM model.
2. The deflection delimiter in the FEM model is uniformly loaded.
3. The sample is deemed to have failed when shear stress at any point reaches the maximum strength of adhesive material.



Analysis

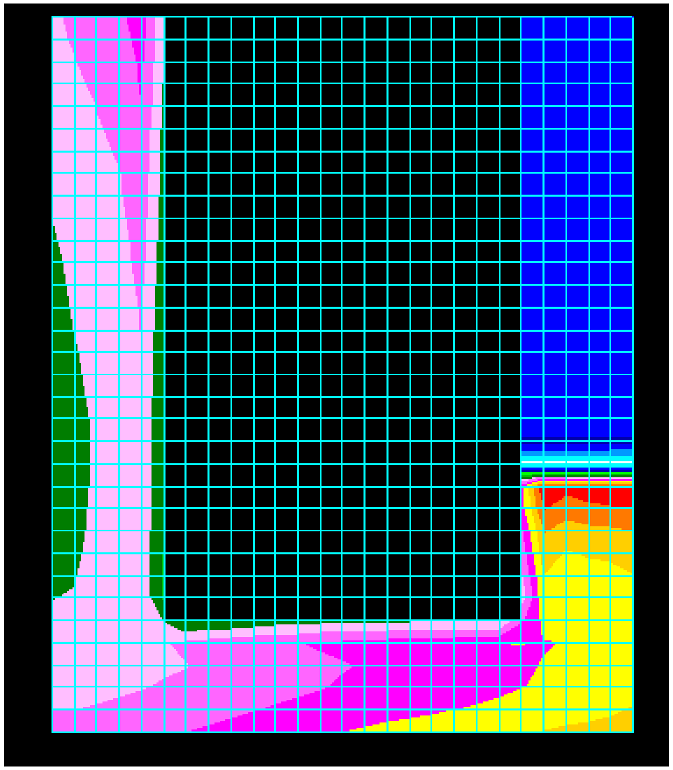




Shearing of the
U-shaped
adhesive

Example Delaminated Model

SAM phase inversion image used to map delamination profile into the FEM model

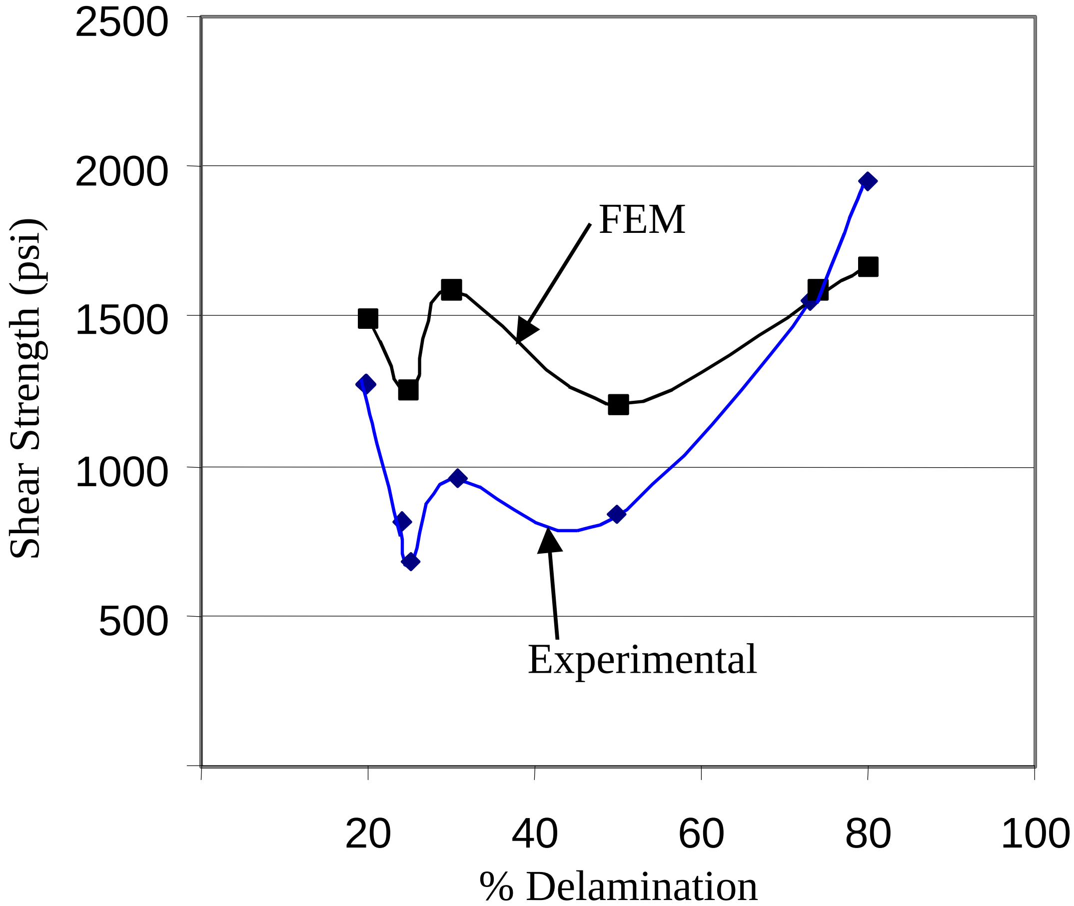


FEM model predicted stress distribution in the silicon at the silicon-adhesive interface

(Sample 3 of Design 1)

Comparison of Experimental and FEM Predicted Shear Strength for Samples in Design 1

(Thermoplastic Adhesive-Alloy 42 Spacer-Silicon)

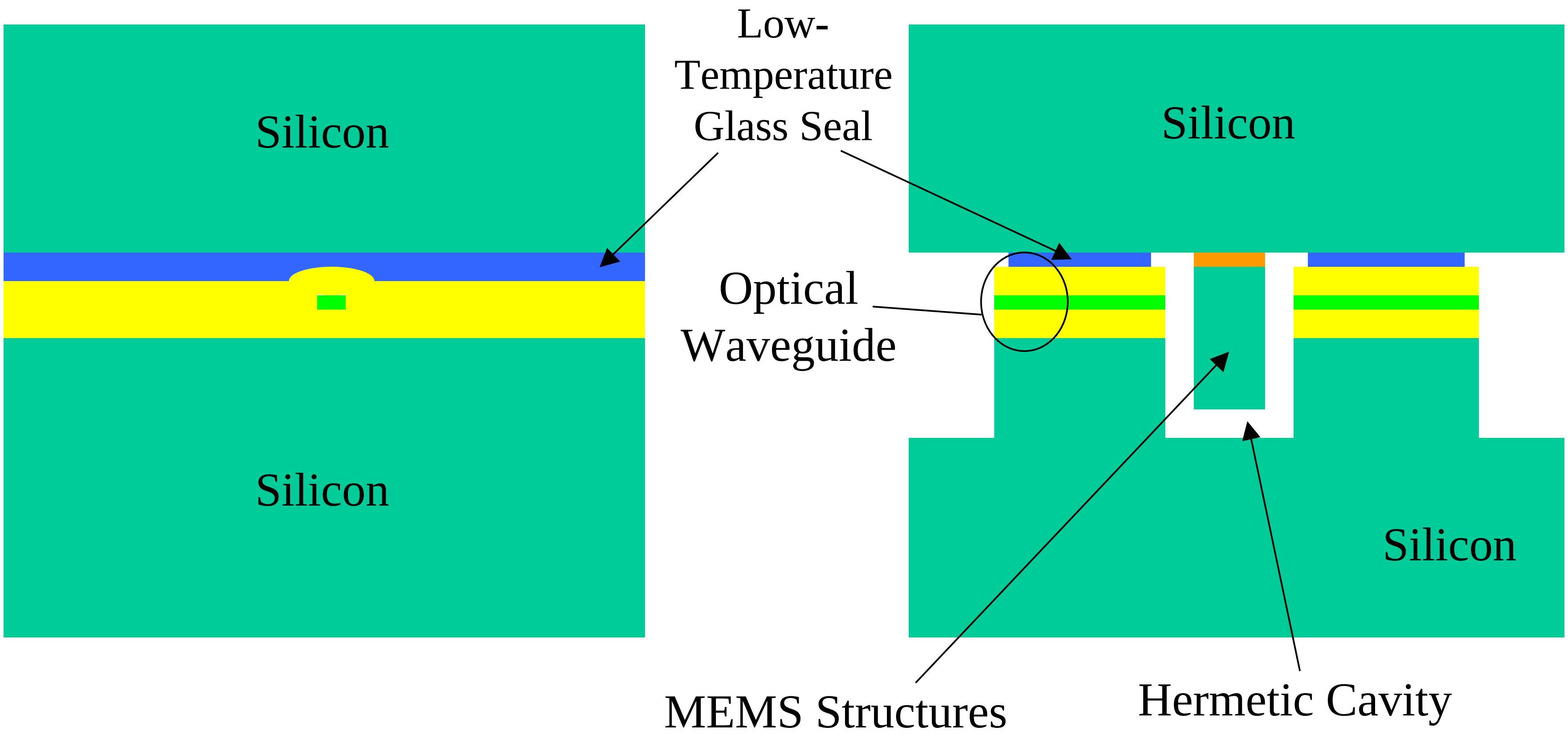


Progress on Reliability of Optical Interfaces to MEMS

Two MEMS are being prepared for environmental testing at this time:

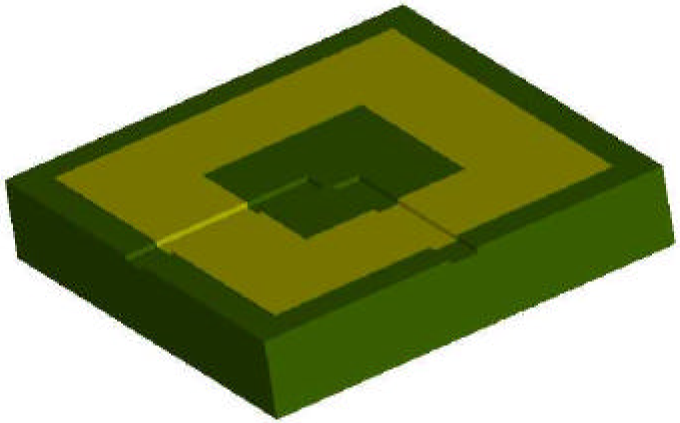
1) Hermetic optical waveguide structure (MOEMS) developed by Don DeVoe (University of Maryland) for NSWC.
    - Silicon wafers bonded using glass tape
    - Sample structures being used to assess ability to observe state of glass seal with the SAM
2) Metalized optical fiber connected to a chip-level hermetic MEMS package
    - Device chip and cap designed, assembly process identified
    - Evaporation of indium onto gold plated silicon completed
    - Reflowed indium solder in an inert environment on aligner-bonder

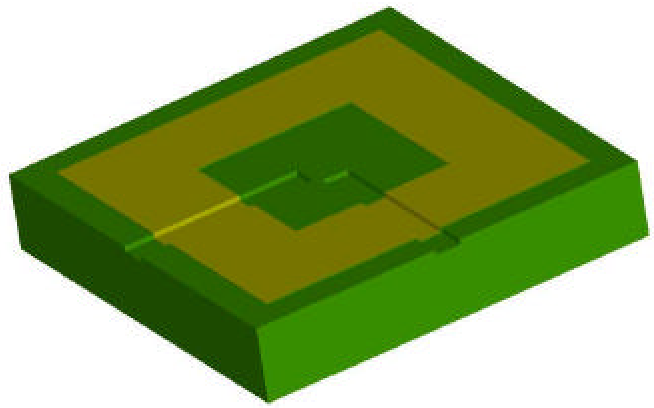
MOEMS - Hermetic Optical Waveguide Structure

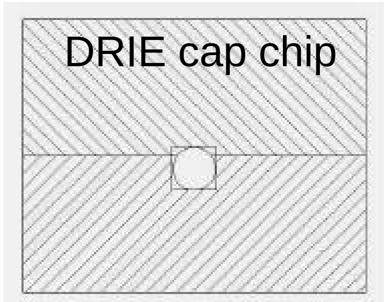


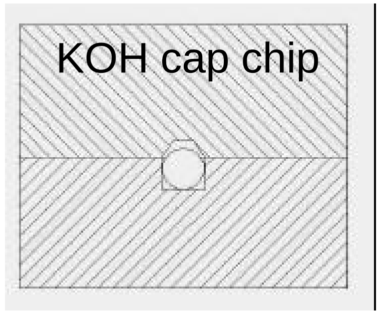
(Maryland MEMS Laboratory, D. DeVoe)

MOEMS – Fiber Connection, Chip and Cap Design









Device Chip

- **Silicon-on-insulator (SOI)**
- **DRIE process similar to S&A fabrication**
- **Deposition of metal into optical grooves**
- **Deposition of solder**
- **Solder mask design**

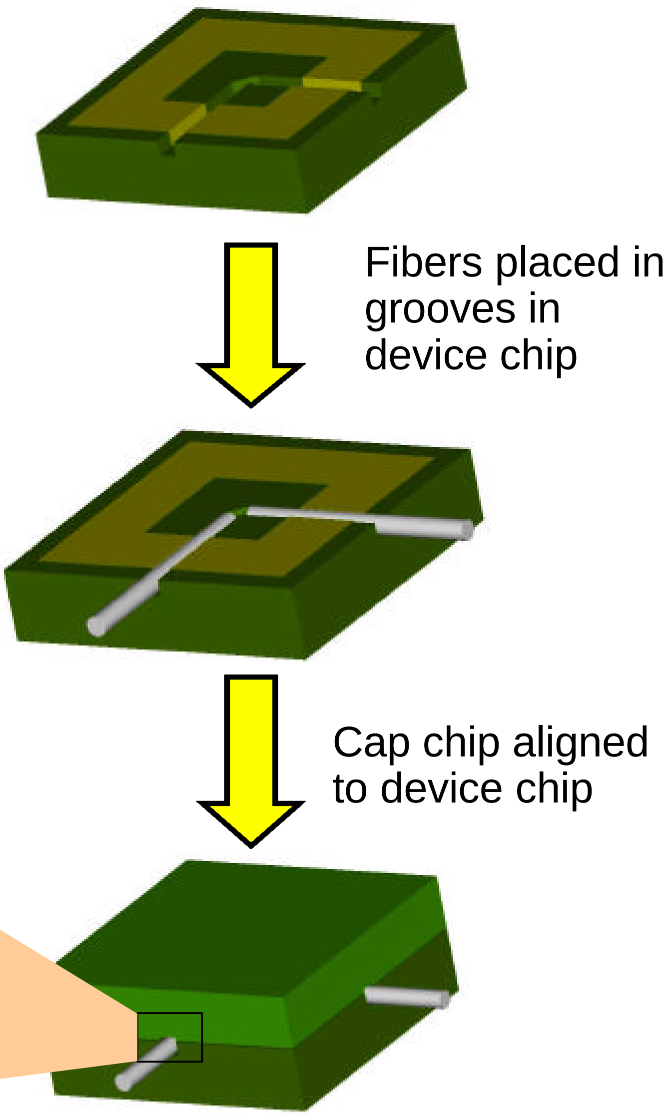
Cap Chip

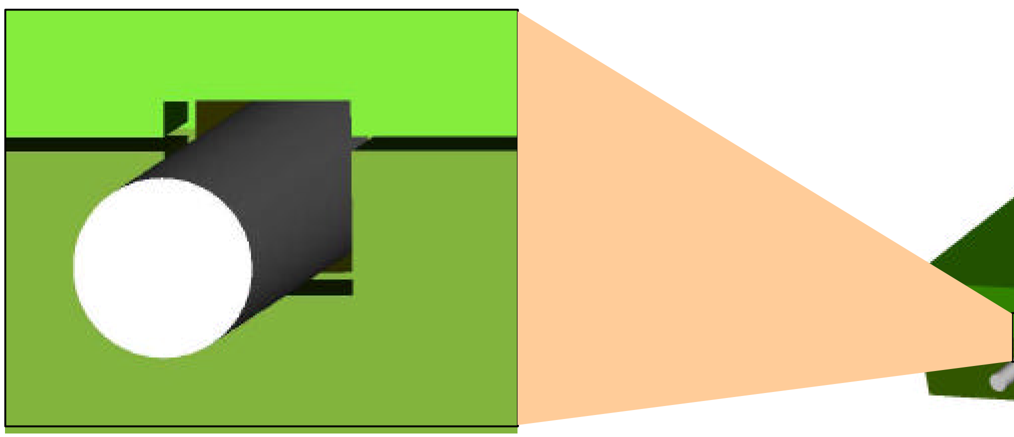
- **Silicon**
- **DRIE or KOH etch**
- **Deposition of metal into optical grooves**
- **Deposition of solder**
- **Solder mask design**

MOEMS – Fiber Connection, Assembly

Issues:

- Alignment techniques
  - Forced
  - Solder surface tension
- Voids
- Fiber strain relief





Benefit To Members

- MEMS LIGA switches
  - Characterization
  - Environmental testing
  - Failure analysis

  report being prepared at this time

- Finite element modeling verification of MEMS chip-to-chip bond delamination measurement methodology

  report available at: http://www.calce.umd.edu/members/projects/2001/C01-06/paper1.PDF

- Two MOEMS structures obtained and initial testing and characterization underway

  to be delivered in C02-01 project