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MEMS Reliability

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TCG XIV

Goal: Develop a mechanistic understanding of the reliability of MEMS devices that can be used to *design accelerated aging protocols* and *qualification specifications*.

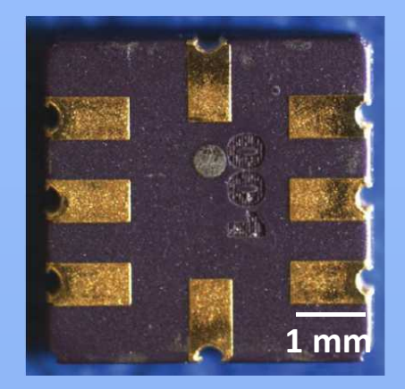
Objectives:

- Identify and model critical failure modes/mechanisms in MEMS Devices.
- Generate data and information useful for the development of aging and reliability models.
- Update specifications and accelerated aging protocols specific to MEMS devices.

MEMS Device Reliability

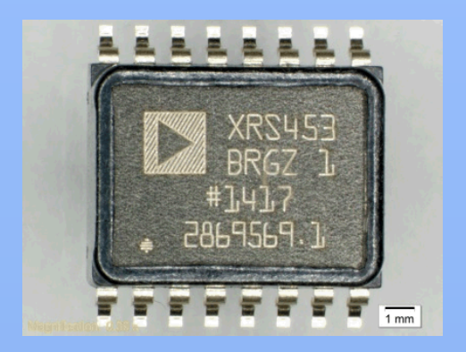
Select Devices

ADXL193 Single Axis, High-g, MEMS Accelerometer



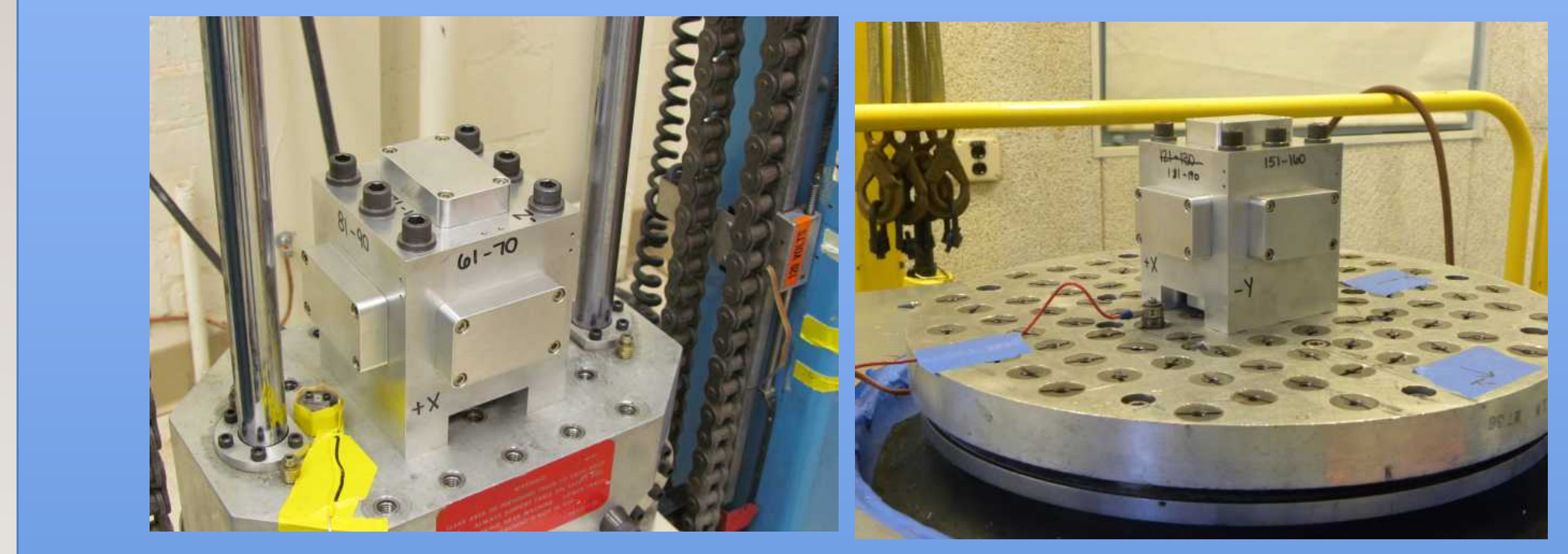
A Ceramic Leadless Chip Carrier

ADXRS453 High Performance, Digital Output Gyroscope



A Plastic Leaded Package (SOIC -package)

Perform 'Margin' Reliability Experiments



Mechanical Reliability Experiments:

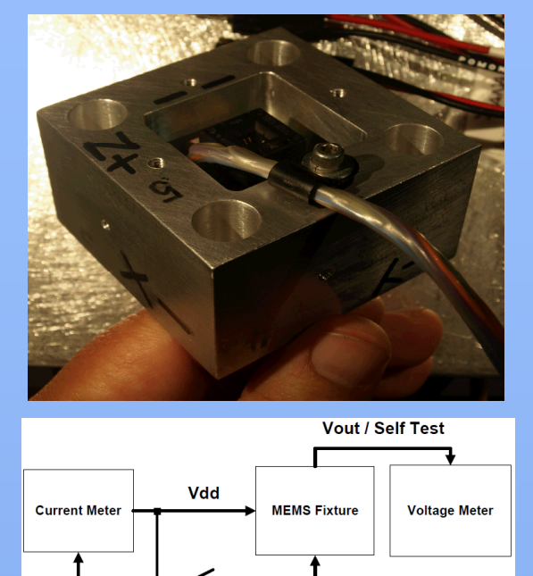
- Drop Test: simulate a 1 meter drop *-Pulse shape: 2000g / 250ms* (ref: MIL STD 810 Method 516.5F)
- Shock Reliability Tests, repeated mechanical shock pulse with same profile. *Pulse shape: 3000g / 0.3ms* (ref: MIL STD 883G Method 2002.4)
- Cycling Reliability Tests, repeated mechanical shock pulse with increasing pulse amplitude, i.e. 1000g, 2000g, 3000g, 4000g…. 10,000g / ~0.2-0.5 ms (ref: MIL STD 810 Method 515.5F)
- Variable Frequency Vibration Experiment (ref: Mil-Std 883 2007.3)

Coupled Thermal + Mechanical Reliability Experiments:

- Combine Cycling Reliability Experiment (1000g, 2000g, 3000g, etc…) with Thermal Cycling
- Combine Variable Frequency Vibration Experiment with Thermal Cycling
- Experimental Procedure: Mechanical cycle(s), test for device functionality, thermal cycles, test for device functionality, etc….

Test for Device Functionality

For the ADXL193 - accelerometer



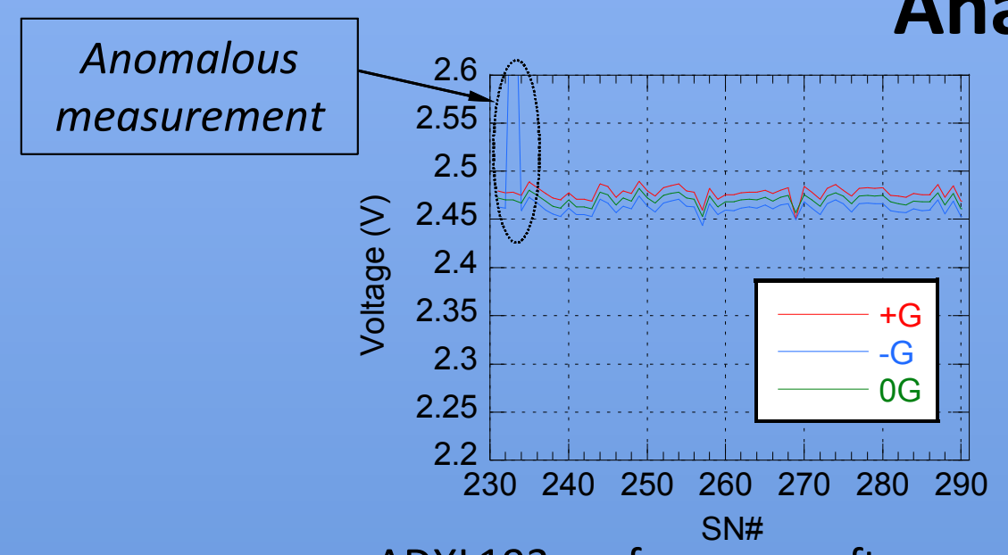
Electrical Test Fixture with device and schematic of test circuit

For the ADXRS453 gyroscope

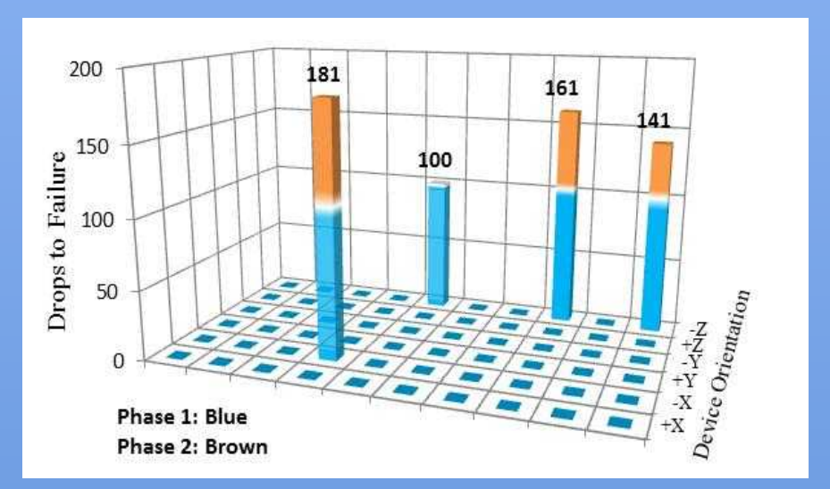
Test board- allows for simultaneous measurement of 10 chips

3-axis turntable which covers a ±300°/sec range

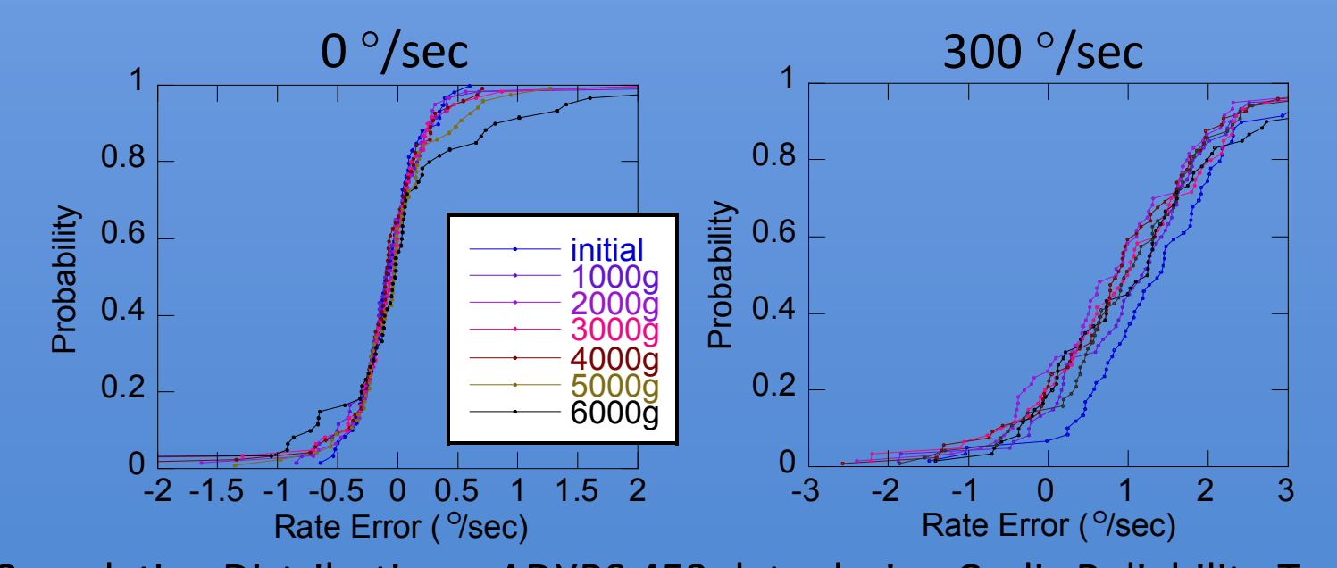
Analyze Data



ADXL193 performance after coupled thermal+ cyclic reliability experiments

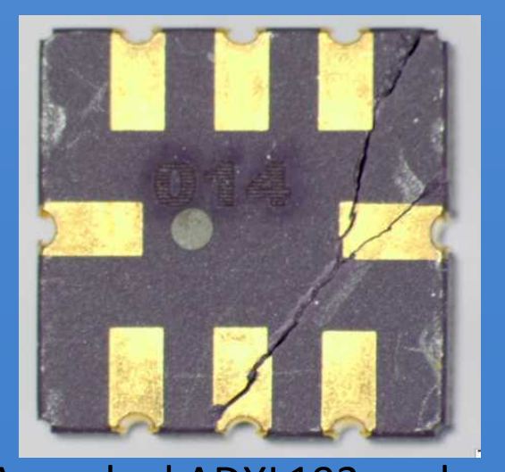


Observed Failures in ADXL193 Drop Test experiments. Failures seem to occur randomly.

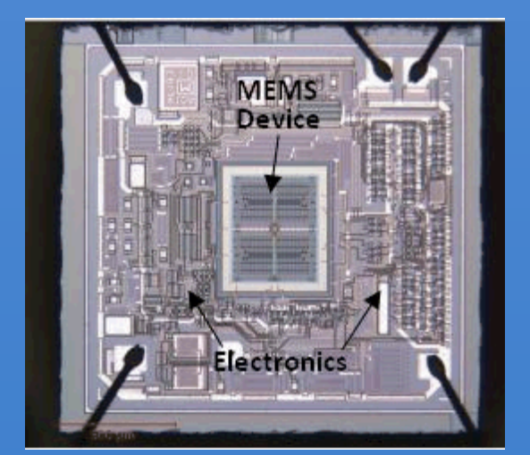


Cumulative Distributions -ADXRS 453 data during Cyclic Reliability Testing

Perform Analysis on Failed Devices



A cracked ADXL193 package



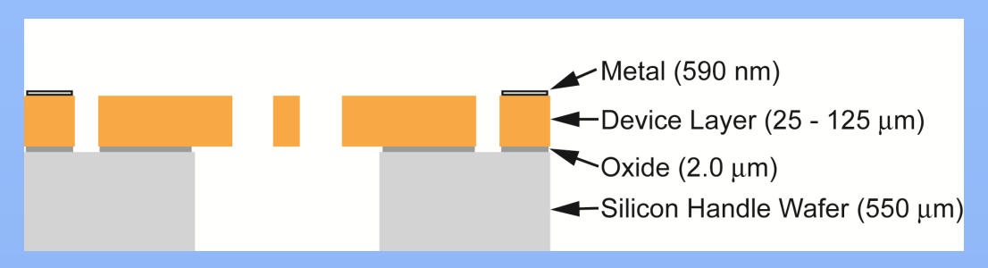
Failure Analysis on a de-lidded ADXL193

often, devices remained functional even after package had cracked

MEMS Structure Reliability

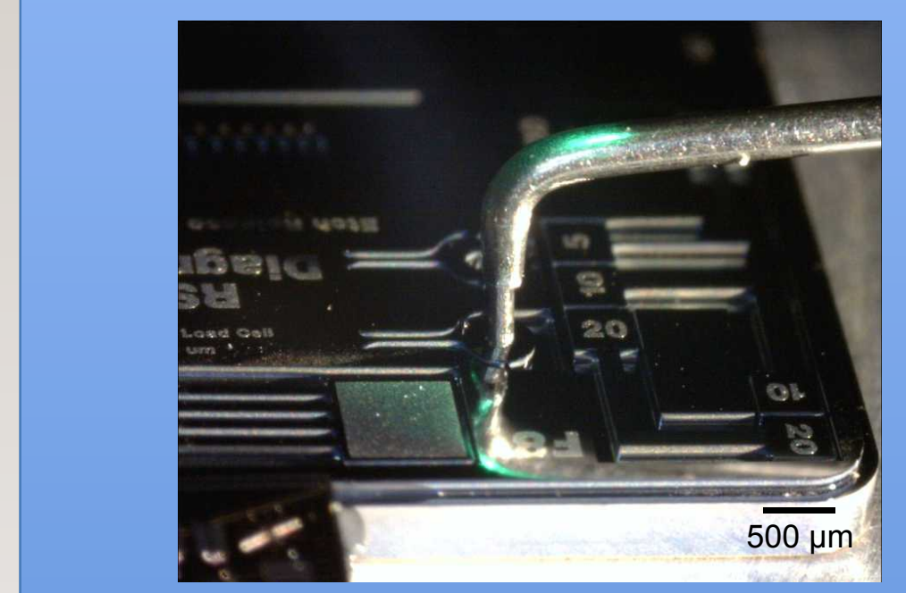
SIDEWALL ROUGHNESS EFFECTS ON SILICON-ON-INSULATOR (SOI) MEMS FRACTURE STRENGTH

'Silicon-on-Insulator' Process

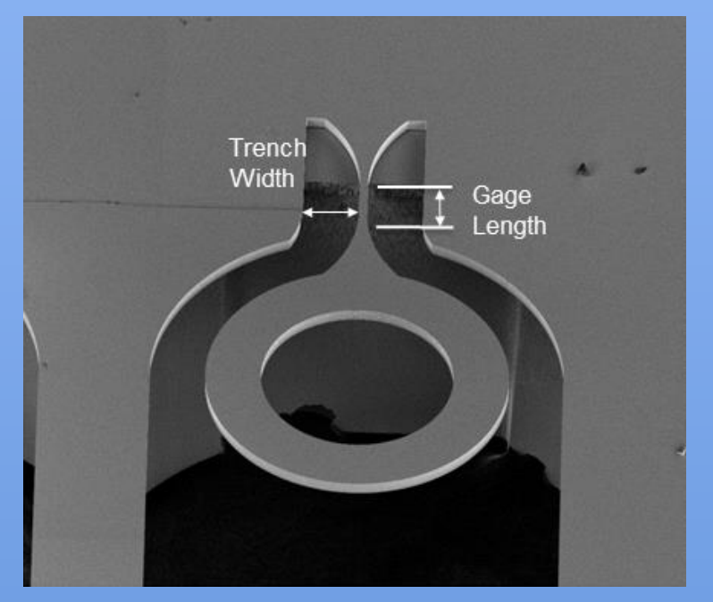


- SOI MEMS Structures fabricated from Device Layer

Develop a test structure and method to characterize the strength of SOI MEMS Materials

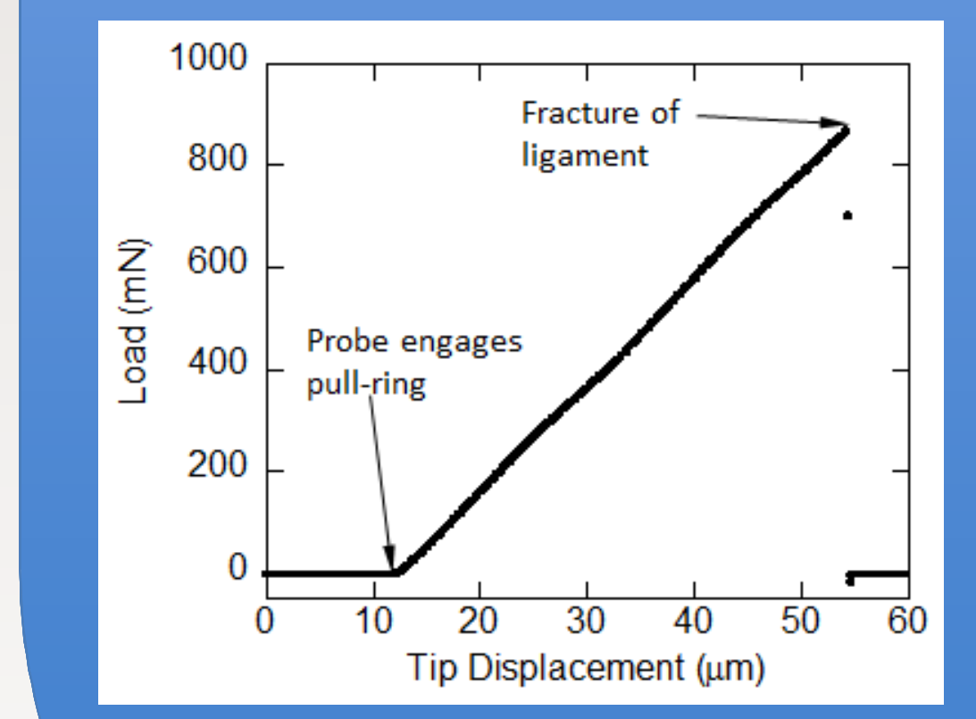


Mechanical Test Platform



'Pull-tab' strength test specimen

Perform Measurements



Typical Response of a pull-tab specimen

25 μm thick device layer

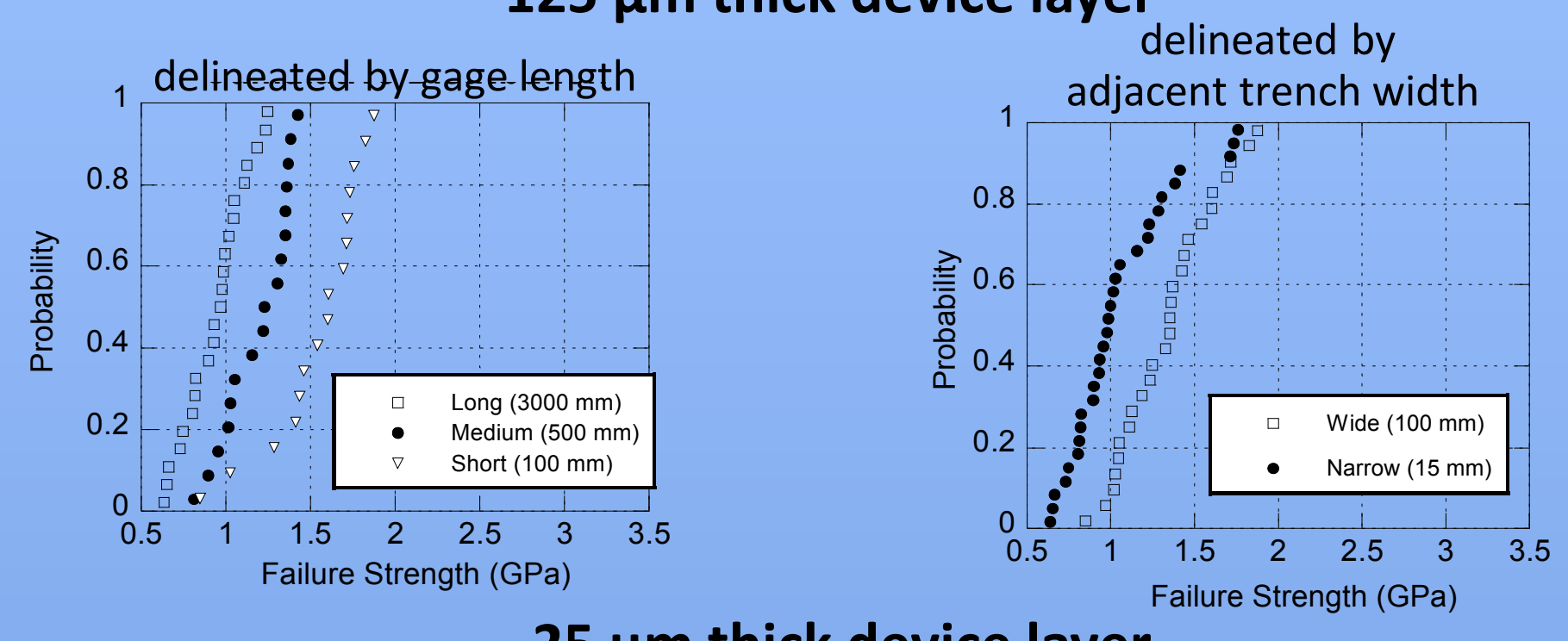
Specimen Designation	Length (μm)	Trench Width (μm)	Aspect Ratio	No. of Tests
short-narrow	100	15	1.667	9
medium-narrow	500			9
long-narrow	3000			3
short-wide	100	100	4	9
medium-wide	500			6
long-wide	3000			6

125 μm thick device layer

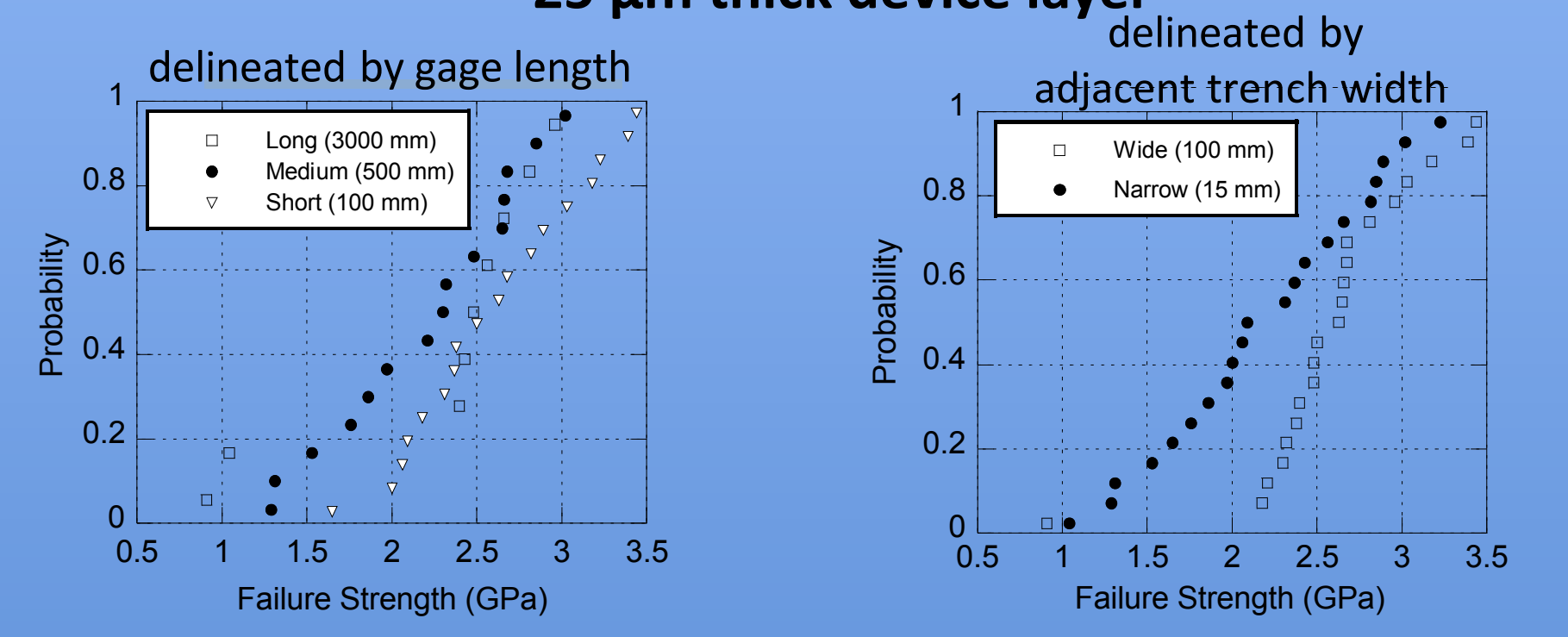
Specimen Designation	Length (μm)	Trench Width (μm)	Aspect Ratio	No. of Tests (W1/W2)
short-narrow	100	15	8.333	5
medium-narrow	500			11
long-narrow	3000			14
short-wide	100	100	1.25	11/8
medium-wide	500			6/8
long-wide	3000			9/8

Results: Cumulative Distribution of Fracture Strengths

125 µm thick device layer

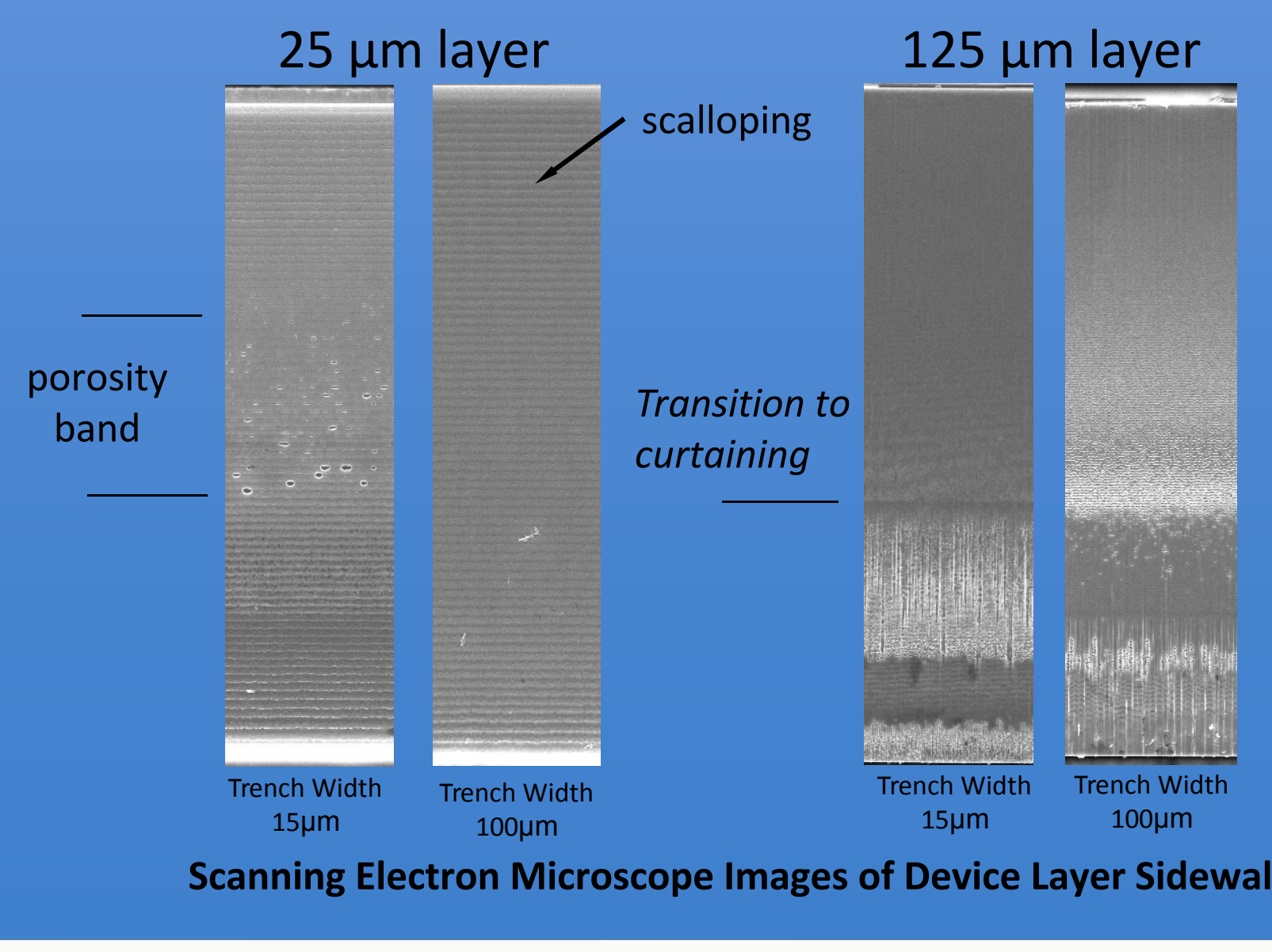


25 µm thick device layer



- Distributions separate by gage length in the 125 um device layer and adjacent trench width in the 25 um device layer thickness.

How Sidewall roughness impacts strength distributions



Scanning Electron Microscope Images of Device Layer Sidewalls

- Significantly increased roughness in curtaining layer attributed to lower strength distributions in 125 µm layer.
- Strength scales with surface area in brittle materials when failure is governed by a spatial distribution of critical surface flaws.

$$\left(\frac{\sigma_1}{\sigma_2}\right) = \left(\frac{A_2}{A_1}\right)^{1/m}$$

- Results suggest that flaws are not spatially distributed in 25 µm ligaments.
- Porosity Band lowered strength distribution in 25 um thick 15 um trench width samples

Observations:

- Silicon MEMS structures within devices are robust, with ligament strengths often exceeding 1 GPa in SOI fabricated structures.
- MEMS device failure often associated with package failure leading to wirebond failure and die cracking. In many cases, a device would remain functional even after package cracks were observed. Thus, the actual MEMS structure is not regarded as the weak link in a MEMS Device design.
- So far, observed failures from margin testing do not follow a trend. Failures tend to occur randomly suggesting a distribution of reliability in a lot of MEMS devices, with the less reliable devices failing earliest.
- Device functionality testing has occasionally revealed anomalies in device output signals, often self-corrected after the next iteration of reliability testing. These anomalies tend to be observed when thermal cycling is part of the reliability or functionality experiments.

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