SWTEST 2026 CONFERENCE

35th ANNIVERSARY

The Dual Action MEMS Solution: Cleaning Innovation Meets Cost Reduction

Presenters :

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Entegris: Dr. Kenneth Boblak

Collaborator:

FormFactor, Inc.

Outline

Section 1 – TI Problem Statement

- Introduction to Halo Debris on FFI T11 MEMS Springs
- History of Cleaning MEMS Springs at TI

Section 2 – Entegris Material Design

- Introduction to Dual Action MEMS Media
- Cleaning Efficacy
- Probe Wear Data

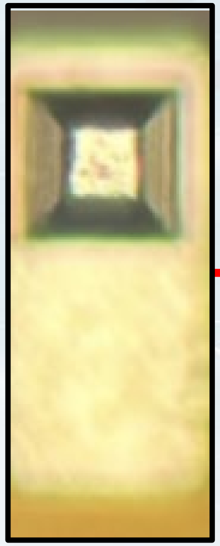
Section 3 – TI Evaluation

- Dual Action MEMS Evaluation
- Wear Study
- Contact Resistance Data
- Probe and Inspect Yield Analysis
- Probe Card Related Fail Trend
- Reduction in Cost of Test

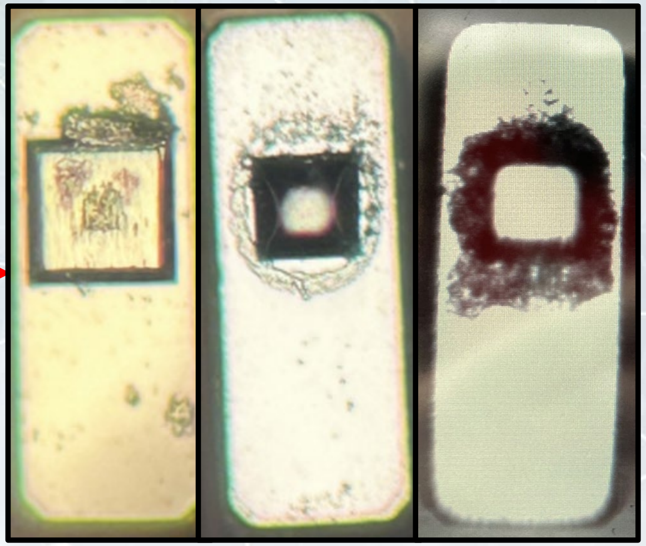
FFI-T3/T11 MEMS Springs Debris

- **Halo Debris**
  - Debris slowly builds up at the base after contacting the bond pads
  - Covers the square base of the pyramid shaped probe tip
  - Causes unstable contact resistance
- **Contact Resistance (CRES)**
  - Occurs when the probe tip and bond pad make contact
  - Influenced by debris, oxidation, probe force, and roughness, etc.

Clean Probe:



Halo Debris:



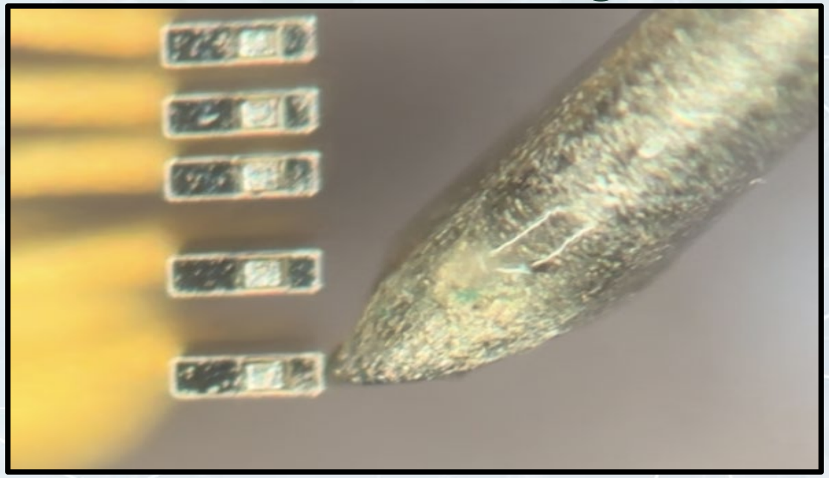
The Cost of Debris and CRES

- **Production Losses and Downtime:**
  - In-line lapping must occur often once build up has occurred to recover CRES
  - Unstable CRES leads to yield loss and yield recovery efforts
  - Debris can cause prober needle alignment failures
  - Eventually offline cleaning is required (push tool, brush, aggressive lapping film)

Push Tool Cleaning:

>500

Needle alignment fails due to debris in the past year



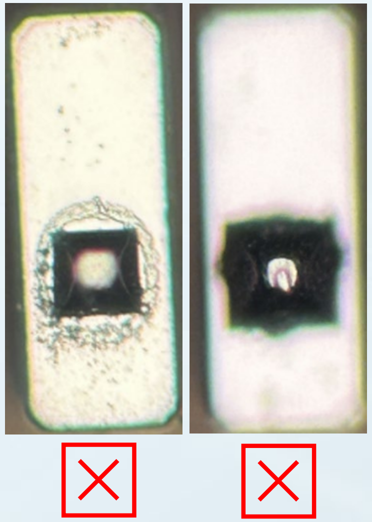
>4,000 hours

Downtime cleaning probes offline in the past year

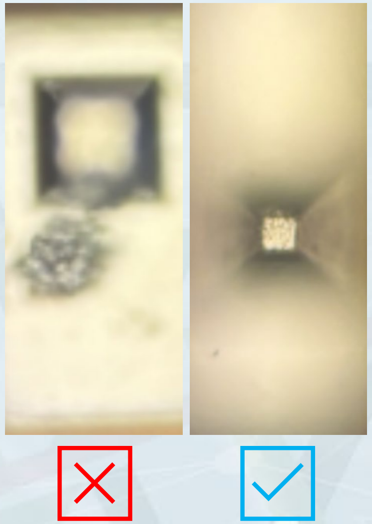
History of Cleaning MEMS Springs at TI

35th ANNIVERSARY

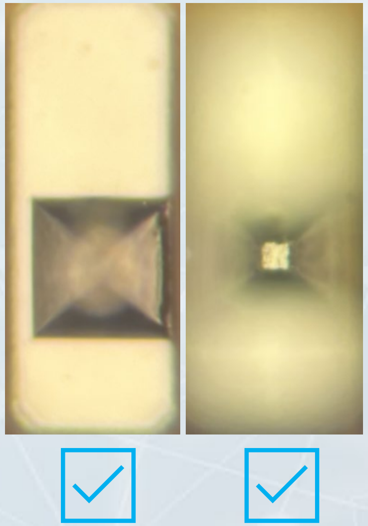
Polymers:



Lapping Films:



Dual Action:



Old Cleaning Solution

- X Probe pierces media where some Halo debris is removed
- X Not abrasive enough for tougher tip debris
- ✓ Good for probe card lifetime

Recent Cleaning Solution

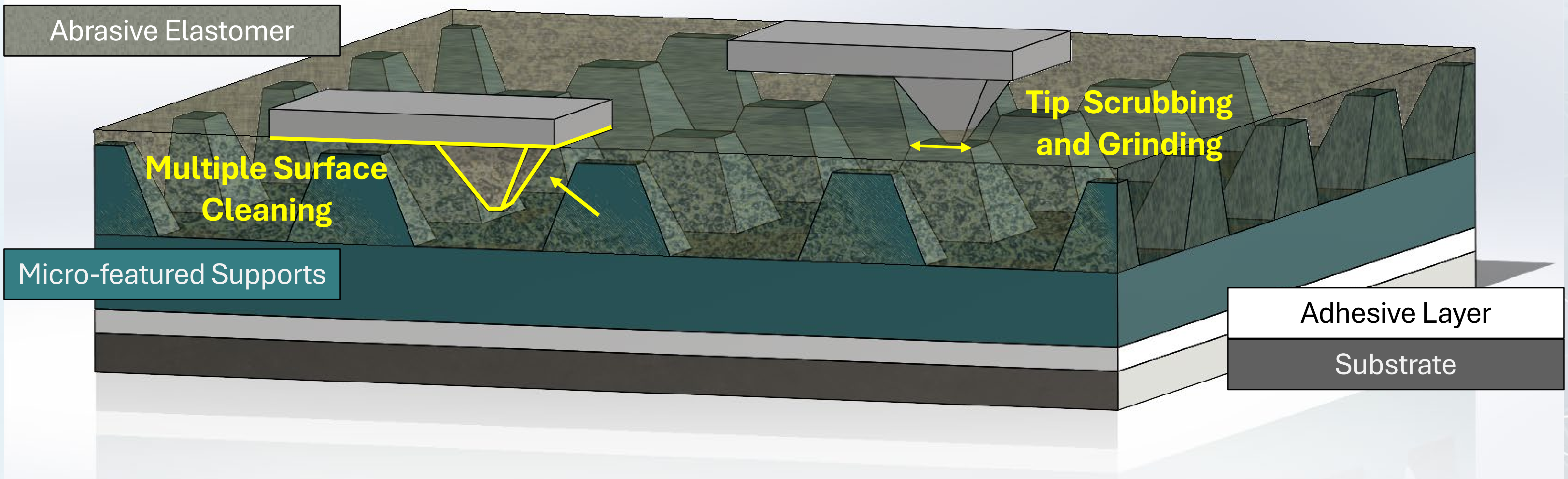
- ✓ Probe “slides” across surface lapping off tougher tip debris
- X Ineffective for Halo debris build up
- X More abrasive than Polymers

Qualification of Dual Action

- ✓ Localized tip lapping for tougher debris
- ✓ Effective at removing Halo debris build up
- ✓ Middle ground for probe card lifetime

Introduction to Dual Action MEMS

Action 1: Localized Wear
Action 2: 3-Dimensional Cleaning



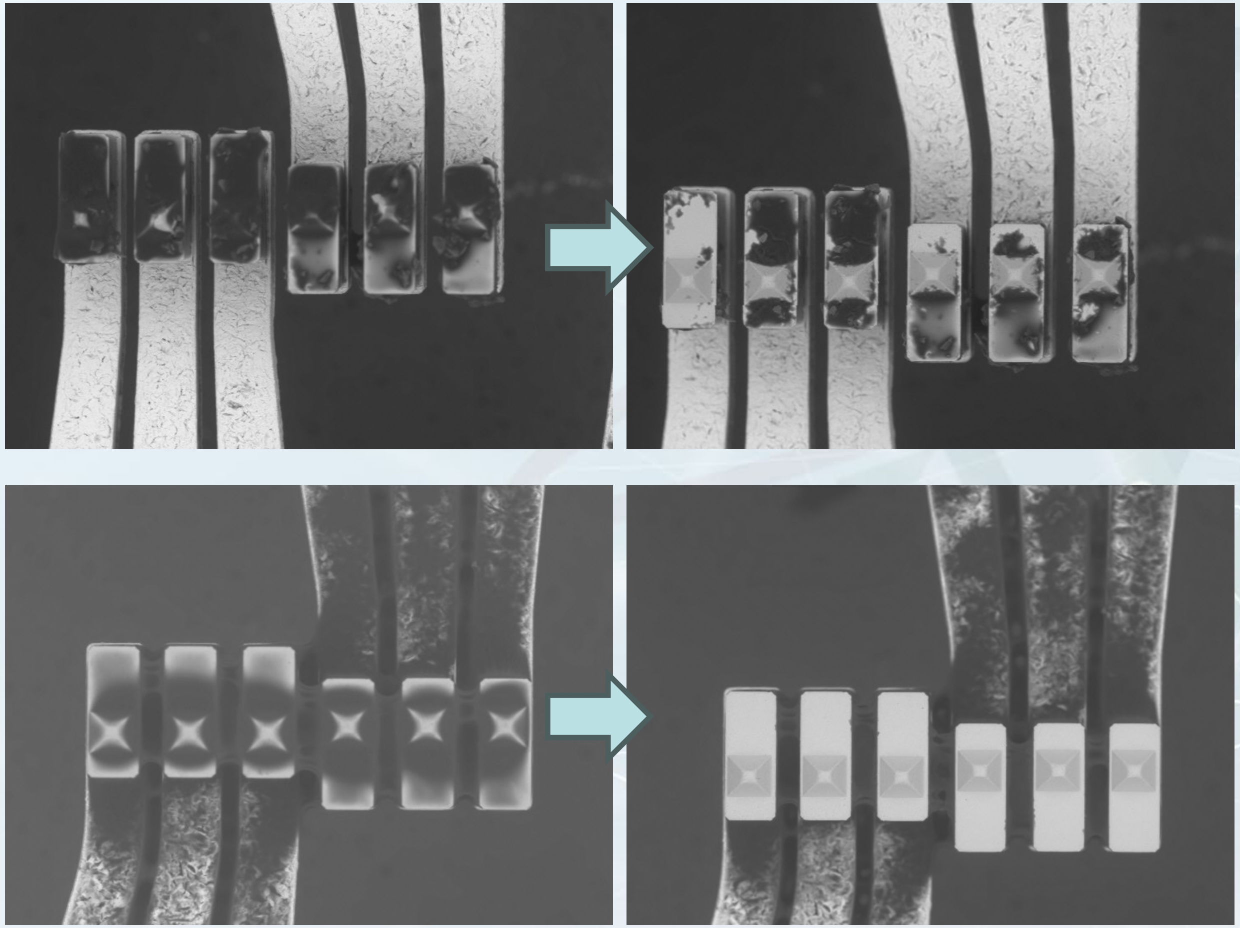
U.S. Patent Application US20250242388A1 (Entegris, Inc., published July 2025).

Proof of Concept

Initial Final

Hard Contamination

Soft Contamination

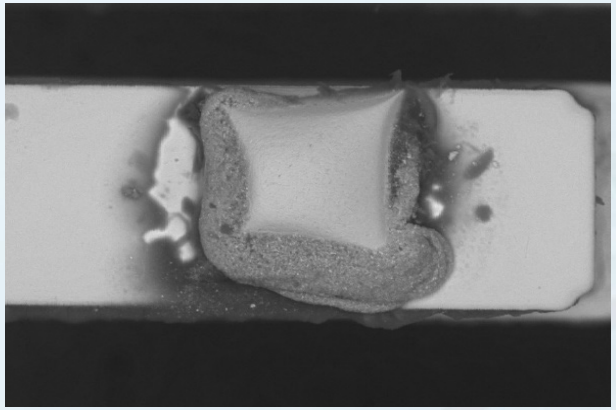


ACTION ONE: Localized Wear
- Simulates tough debris
- Contamination removed at the tip and edge of pyramid

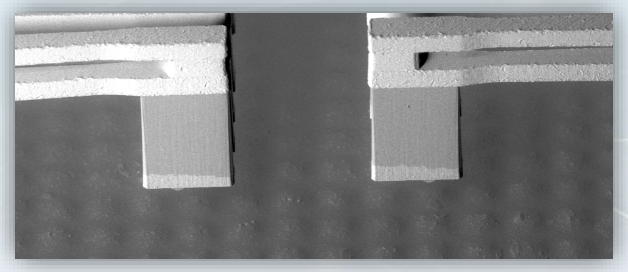
ACTION TWO: 3D Cleaning
- Simulates loose debris removal
- Helped to visualize media contact areas

Dual Action Cleaning Efficacy

Experimental Conditions



Contaminated T11 Spring
from FormFactor, Inc.



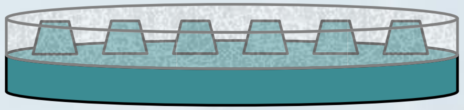
- **Equipment**
  - LTU: In-house mini prober
  - SEM imaging
- **Cleaning Materials**
  - PP150-03, HP WFL4.0, Dual Action MEMS
- **Conditions:**
  - Indexing step size: 90 µm
  - Indexing pattern: Spiral
  - Temperature: 25°C
  - Overtravel: 2.4 g/spring, ~75 µm overtravel

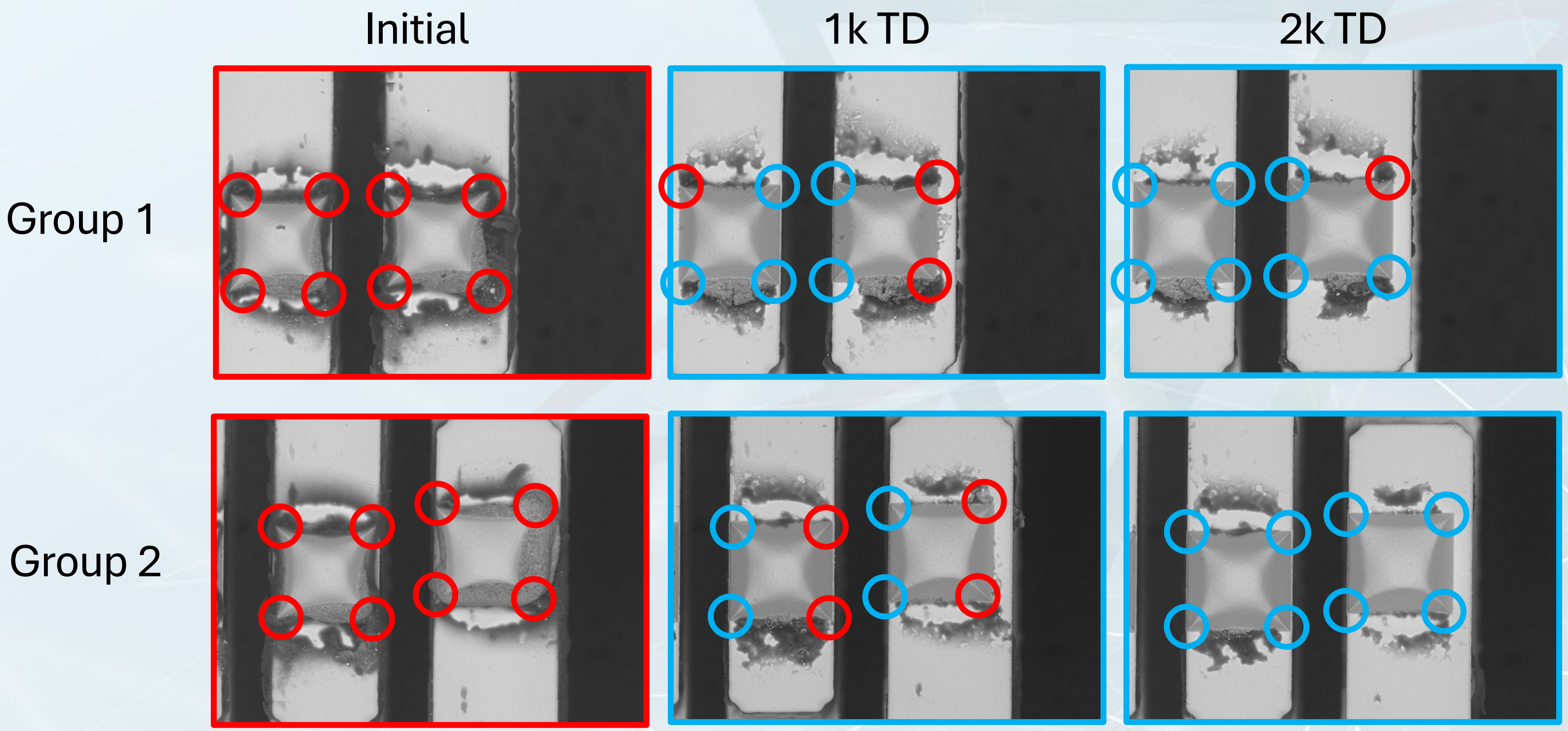
*Unless otherwise defined

Cleaning Real Halo Debris

Dual Action MEMS Cleaning Optimization

Criteria: Two Visible Corners for Prober Alignment





	Initial	1k TD	2k TD
Corner Pass Rate:	0%	66.7%	95.8%
Spring Pass Rate:	0%	100%	100%

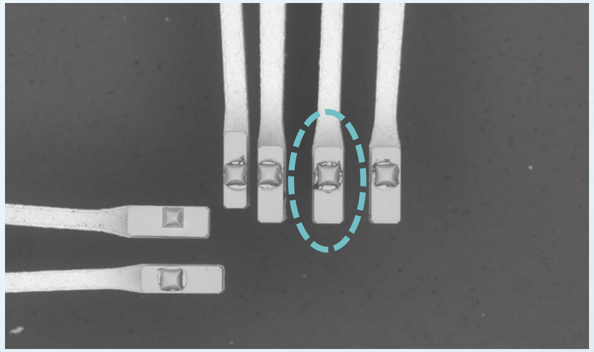
Observations:

- >95% total cleaning efficacy after 2k TD
- Significant debris removal and recovery at 1k TD
- No other material removes halo debris this quickly!

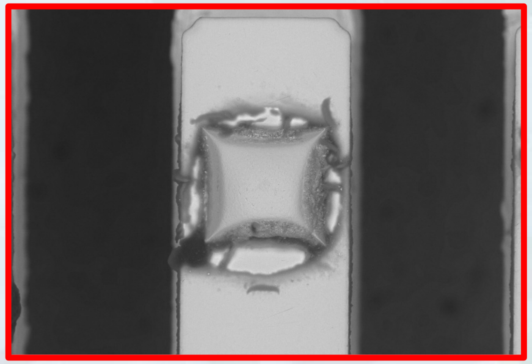
Cleaning Real Halo Debris

Isotropic PP150-03 Evaluation

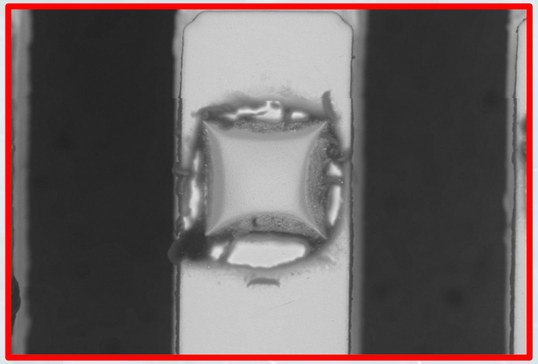
Initial Condition



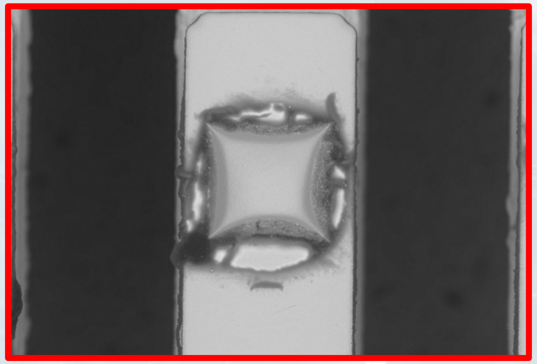
Initial



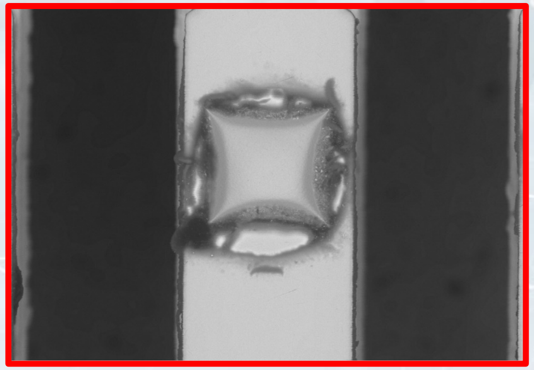
10k TD



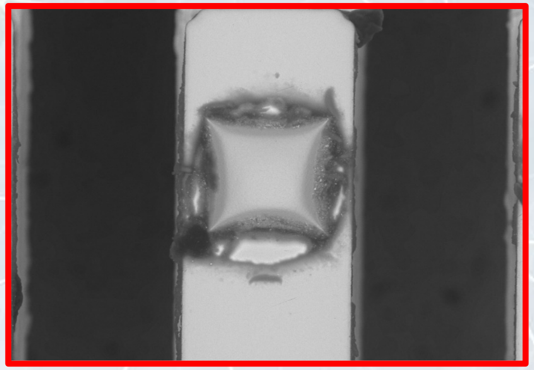
25k TD



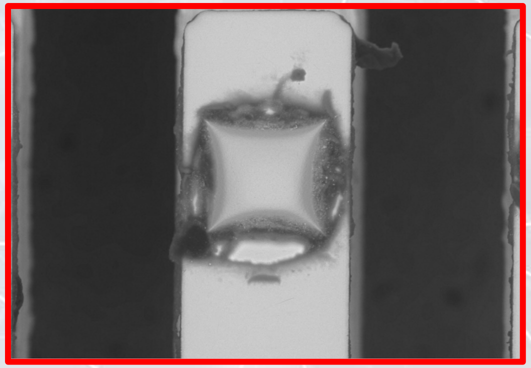
50k TD



75k TD



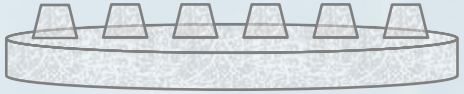
Final: 100k TD



Observations:

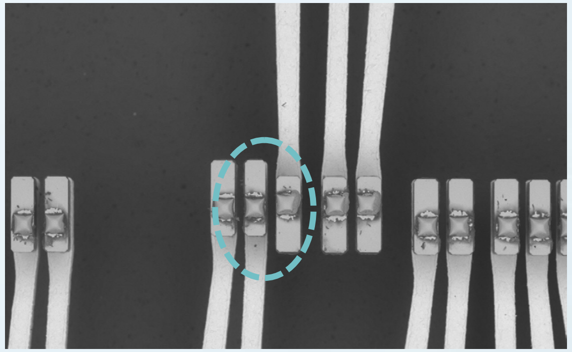
- No halo debris removal
- Slight increase in debris

Cleaning Real Halo Debris

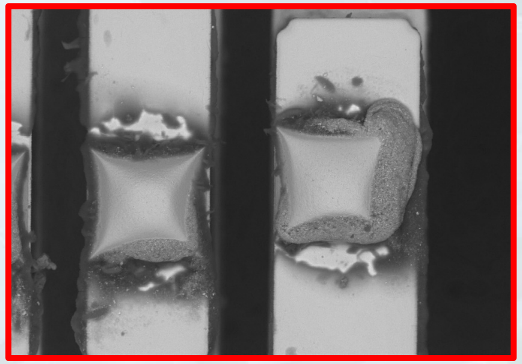


HP WFL4.0 Evaluation

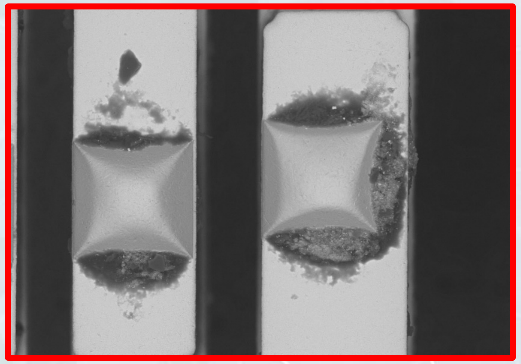
Initial Condition



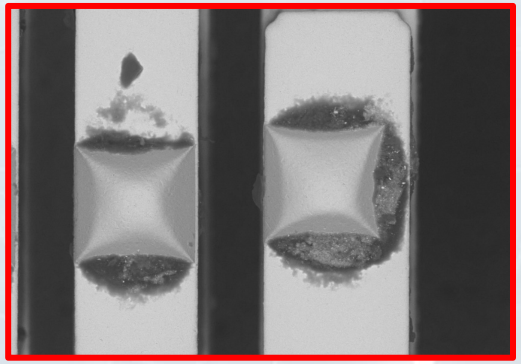
Initial



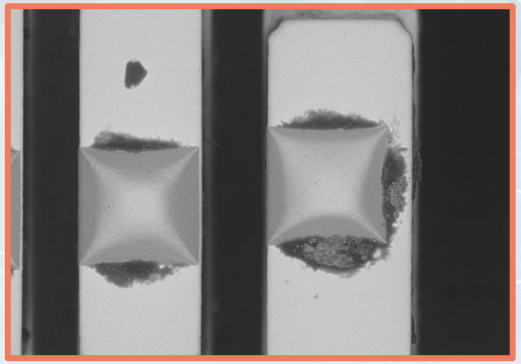
10k TD



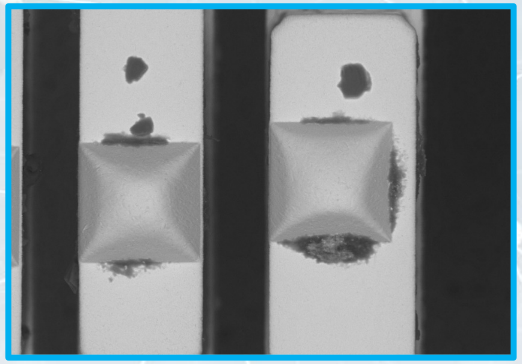
25k TD



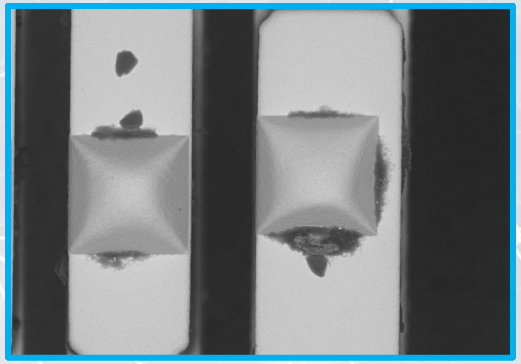
50k TD



75k TD



Final: 100k TD

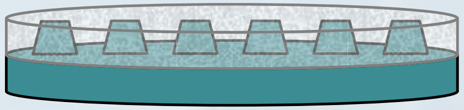


Observations:

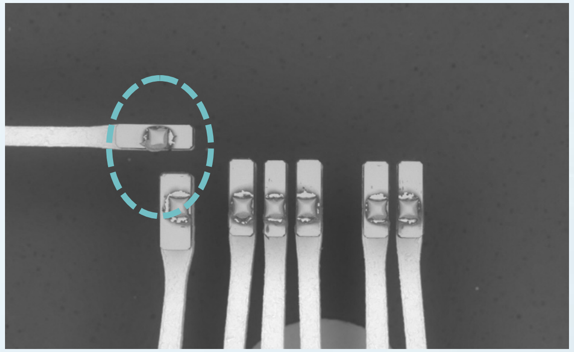
- Major halo debris removed
- Acceptable recovery at >50k touchdowns

Cleaning Real Halo Debris

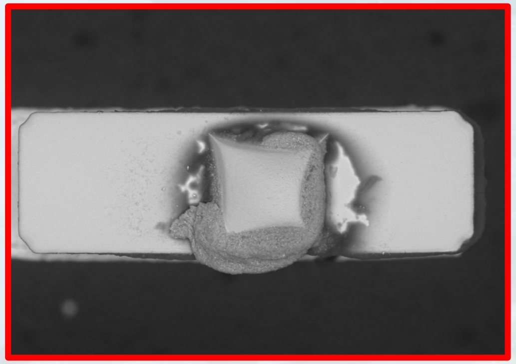
Dual Action MEMS Evaluation



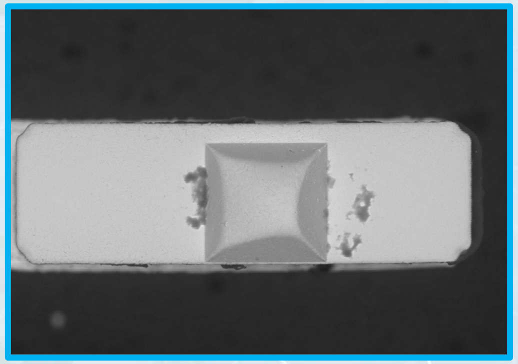
Initial Condition



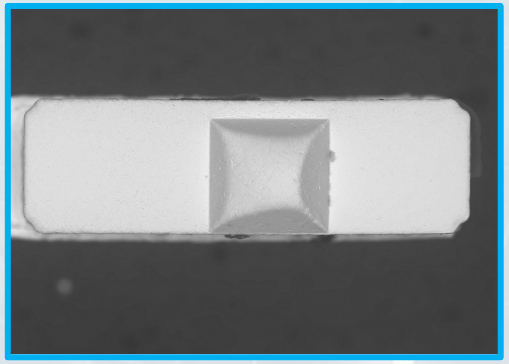
Initial



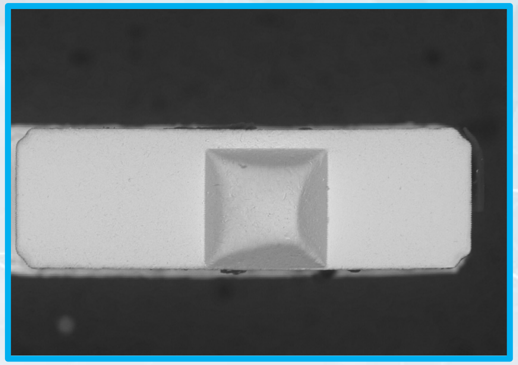
10k TD



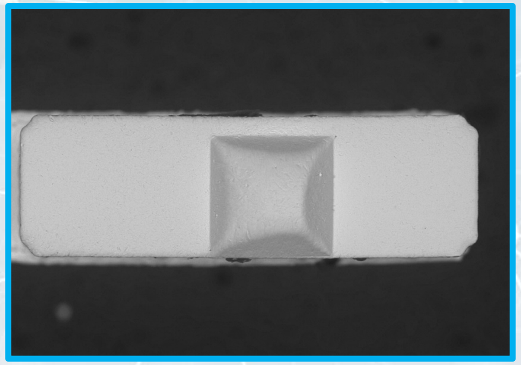
25k TD



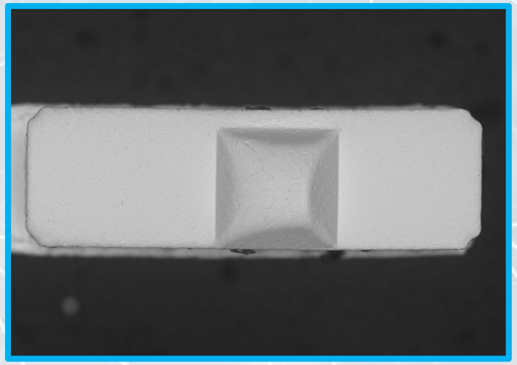
50k TD



75k TD



Final: 100k TD



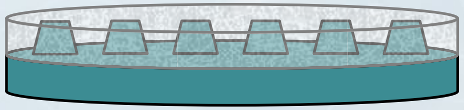
Observations:

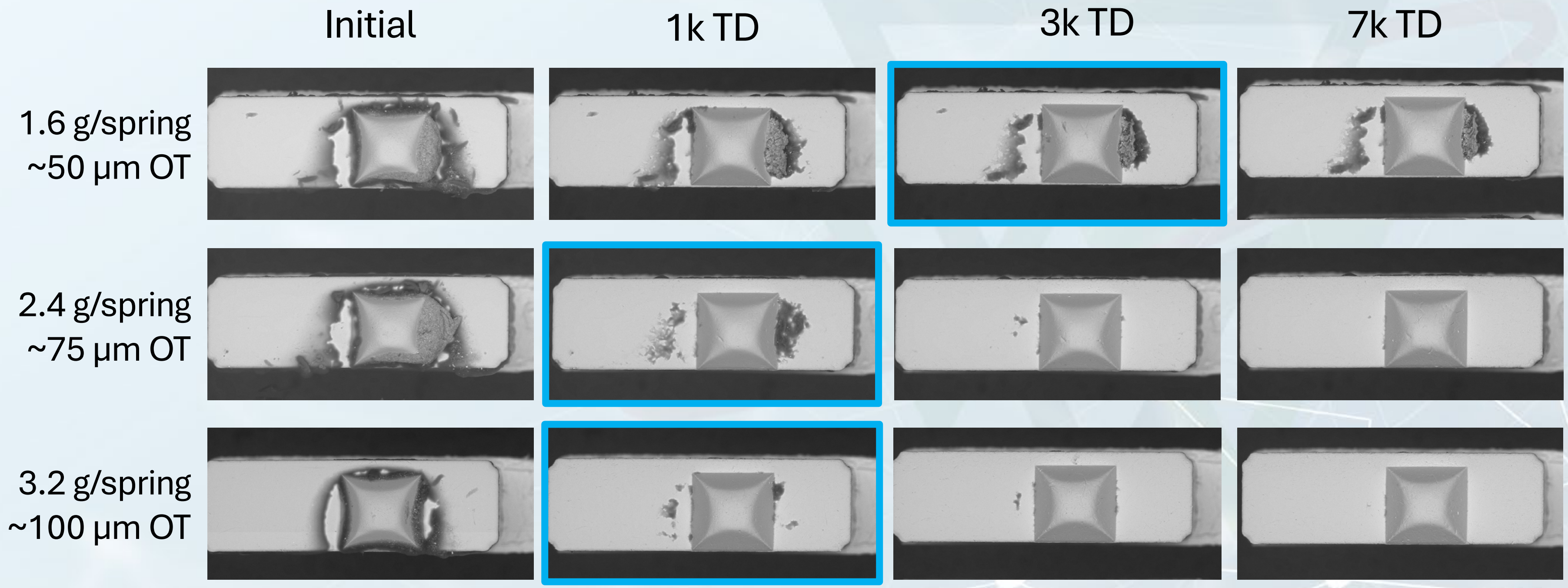
- Acceptable debris removal at 10k TDs
- No new debris formation

Cleaning Real Halo Debris

Dual Action MEMS Effect of Overtravel on Cleaning

Criteria: Two Visible Corners



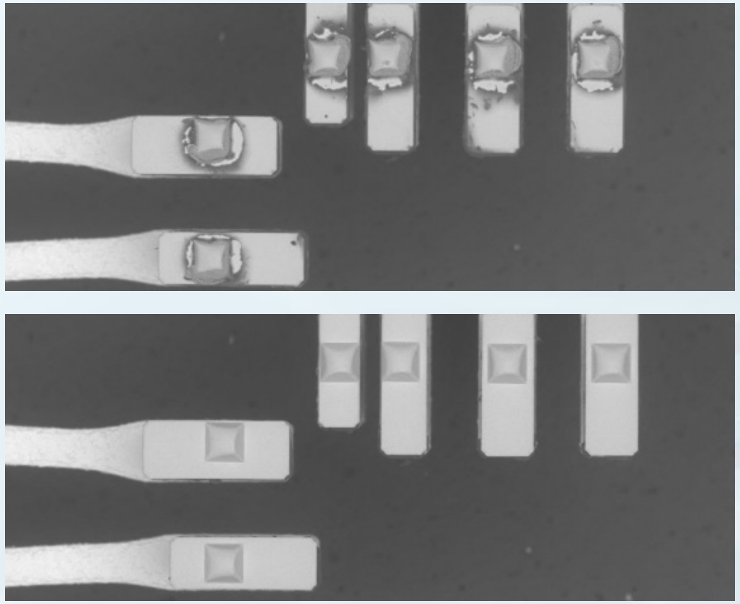


Observations:

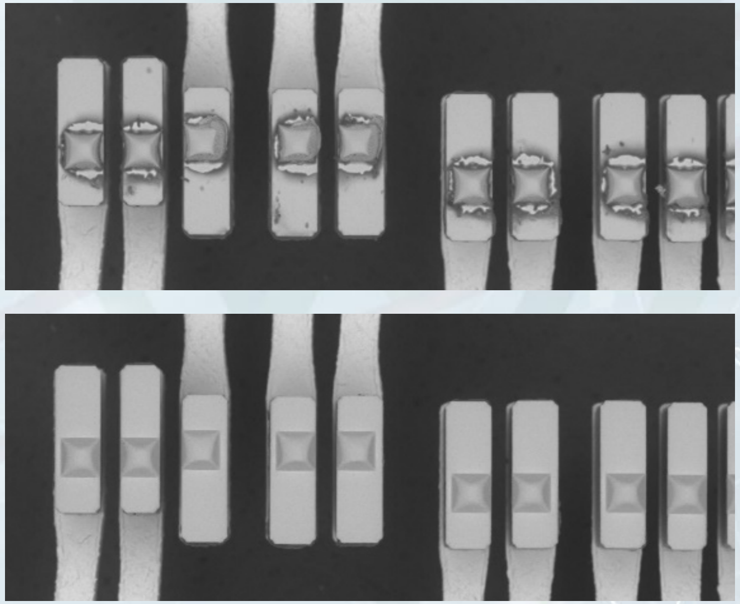
- Cleaning rate is dependent on force per spring
- Even at low force, cleaning is superior to legacy cleaning media
- Higher force exhibits nearly 100% spring recovery in less than 7k TDs

Cleaning Real Halo Debris

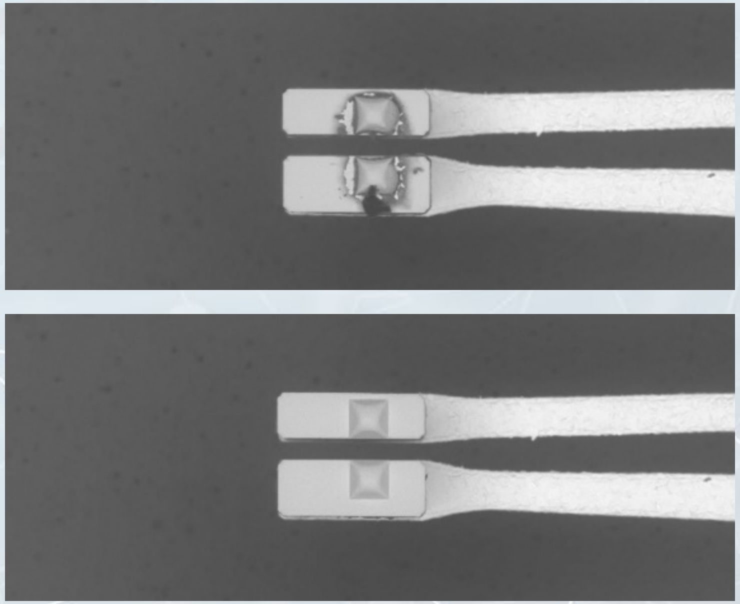
Dual Action MEMS Orientation Check



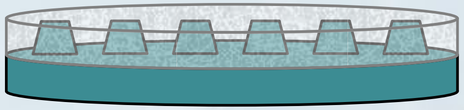
Location 1



Location 2



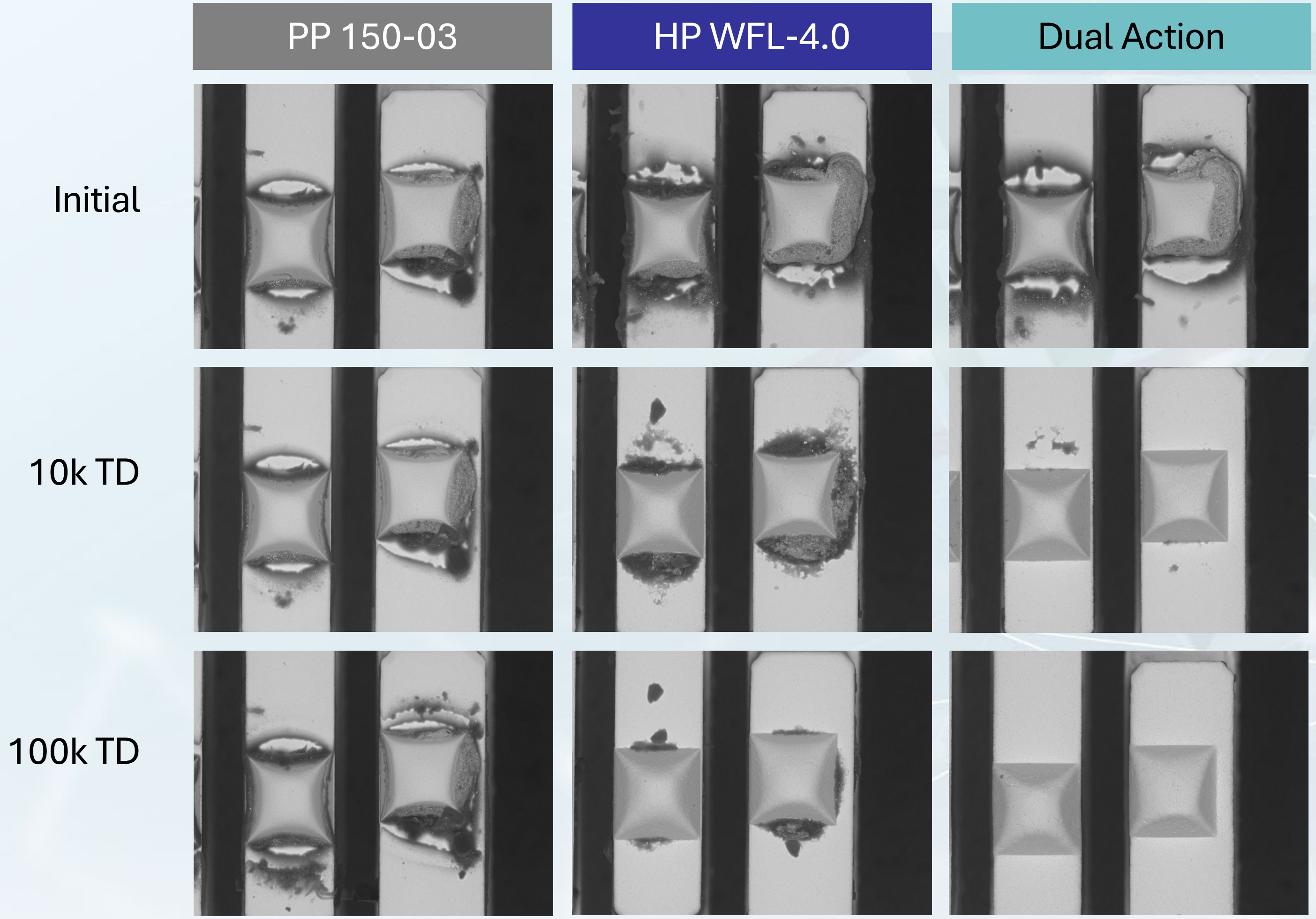
Location 3



Observations:

- Orientation has no effect on cleaning efficacy
- No misalignment after 100k TDs

Cleaning Material Summary



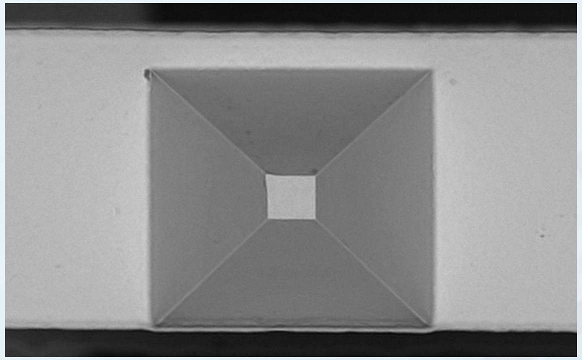
Dual Action MEMS is Superior

- Removes halo debris to a satisfactory level in 1k TD or less
- Completely removes all halo debris and recovers spring tip
- Does not generate new debris
- Orientation of spring does not matter

S	Dual Action MEMS
A	HP WFL-4.0
B	Isotropic Control
C	Original PP150-03

Wear Profile Analysis

Experimental Conditions



Fresh T11 Spring
from FormFactor, Inc.

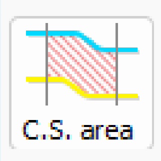
- **Equipment**
  - LTU: In-house mini prober
  - SEM and Keyence imaging
- **Entegris Cleaning Materials**
  - 0.5 um Probe Lap Yellow, Dual Action MEMS
- **Conditions**
  - Indexing step size: 90 μm
  - Indexing pattern: spiral
  - Temperature: 25°C
  - Overtravel: 2.4 g/spring, (~75 μm)

*Unless otherwise defined

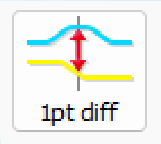
Keyence Image Analysis

Cross-Section Area Wear, Vertical Wear, and X,Y Planarity

Three Metrics



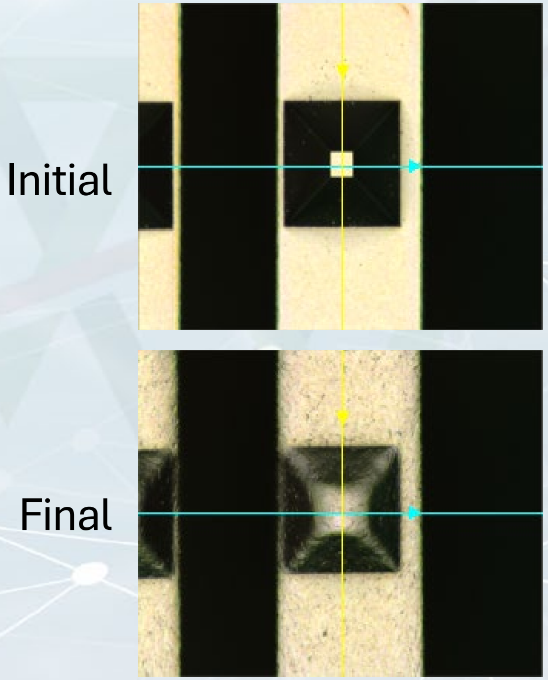
Cross-sectional area:
1. Two images aligned
2. Used “compare” tool to calculate area

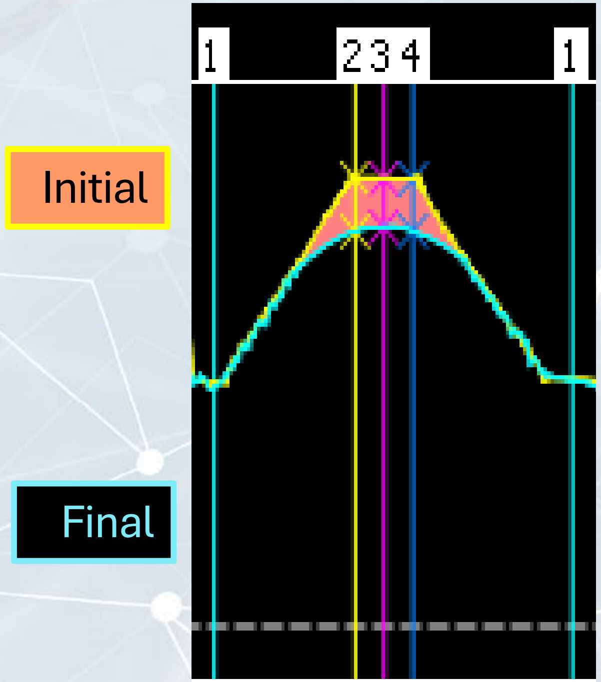


Vertical wear:
- Average change of points 2, 3, and 4

X,Y planarity profile:
- Sloping = Point 2 - Point 4

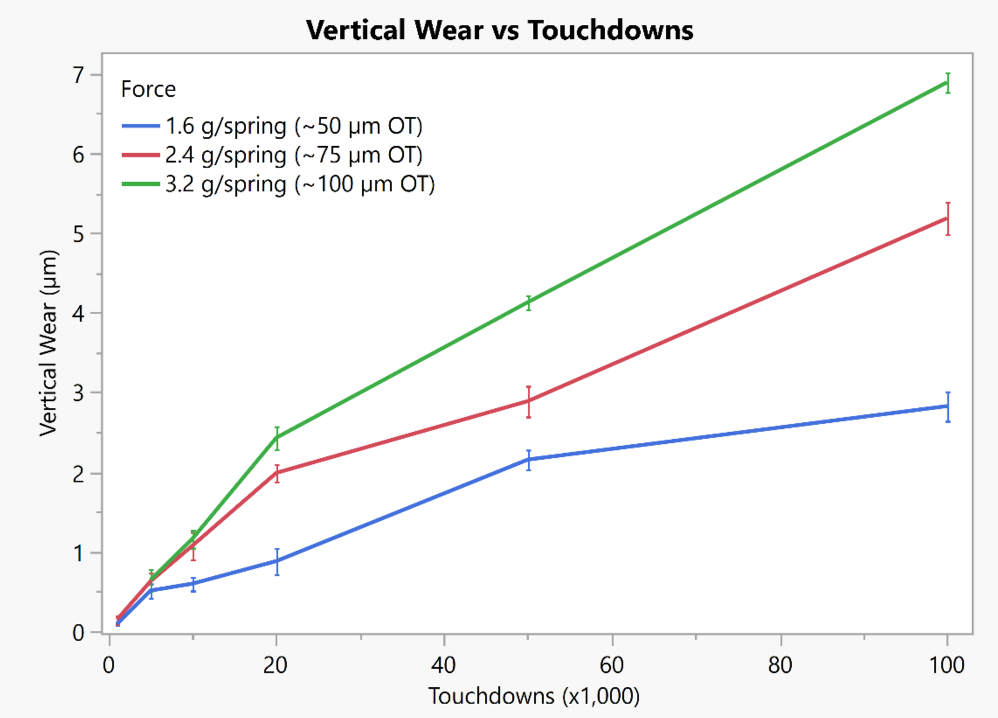
Measurement Method Example

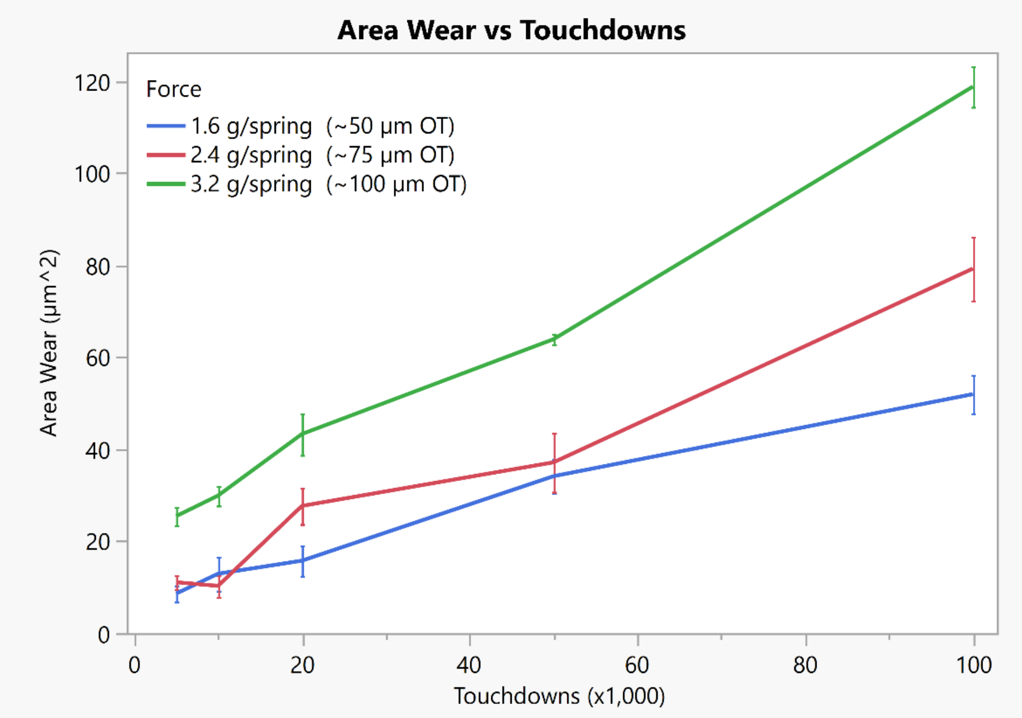




Keyence Wear Profile Analysis

Vertical and Cross-Section Area



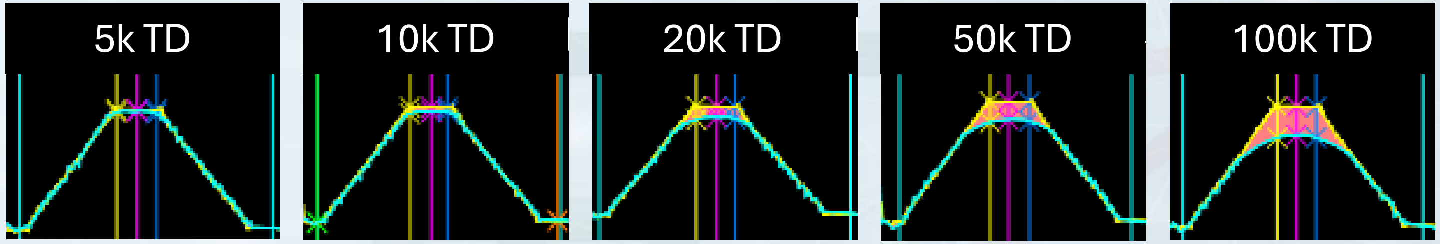


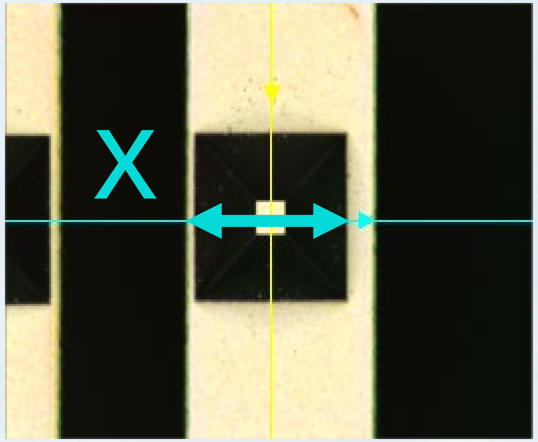
Observations:

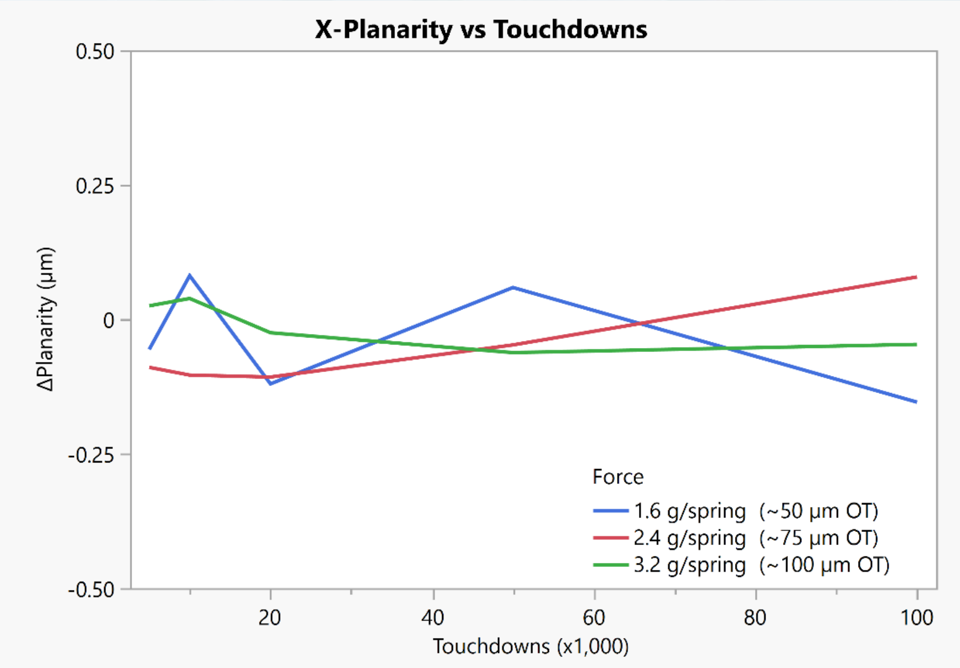
- Vertical wear and area wear directly correlate with force
- Spring count is important for calculating overdrive

Keyence Wear Profile Analysis

X-Dimension Tip Planarity





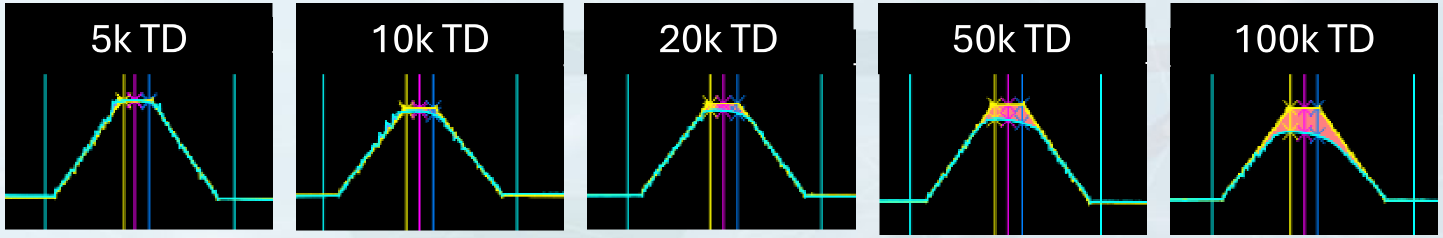


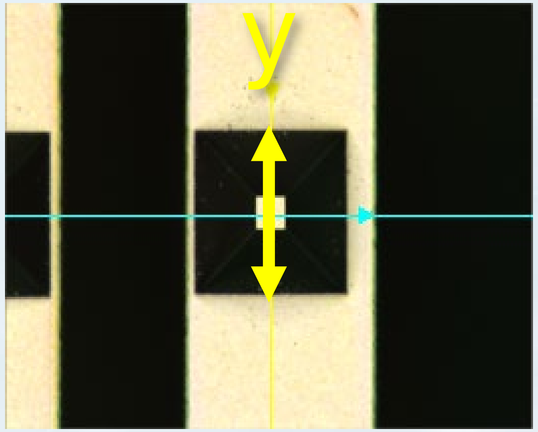
Observations:

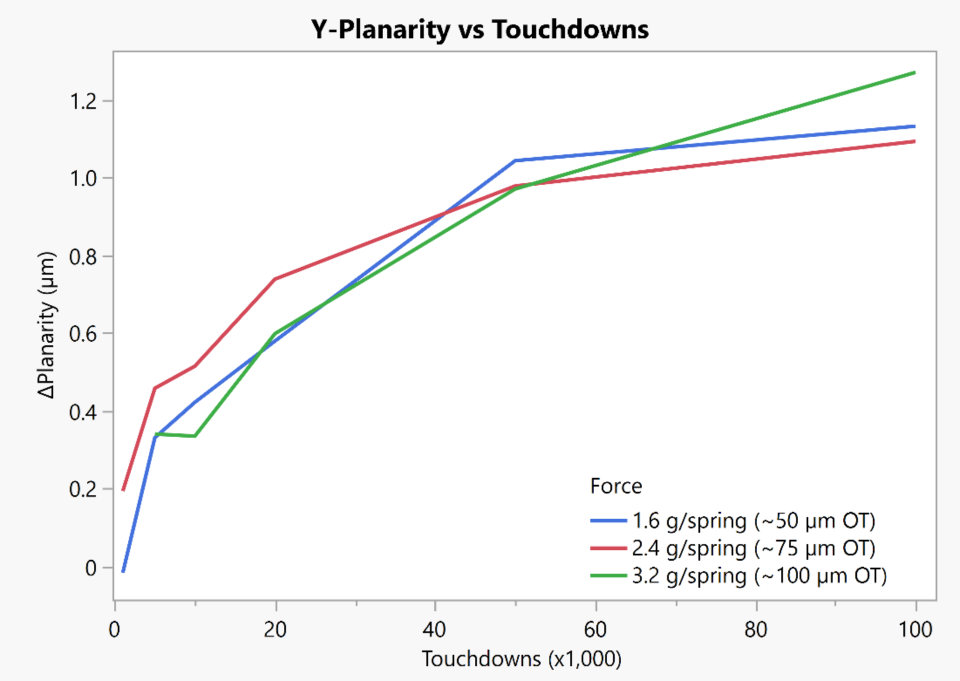
- Slight rounding after 20k TDs
- Change in planarity is negligible
- Higher force does not affect planarity in the X-dimension

Keyence Wear Profile Analysis

Y-Dimension Tip Planarity

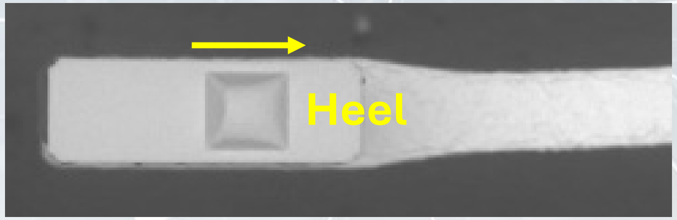






Observations:

- Y-plane sloping is significant
- Not dependent on force
- Direction is always toward the heel of the spring



*Recovered T11 Spring

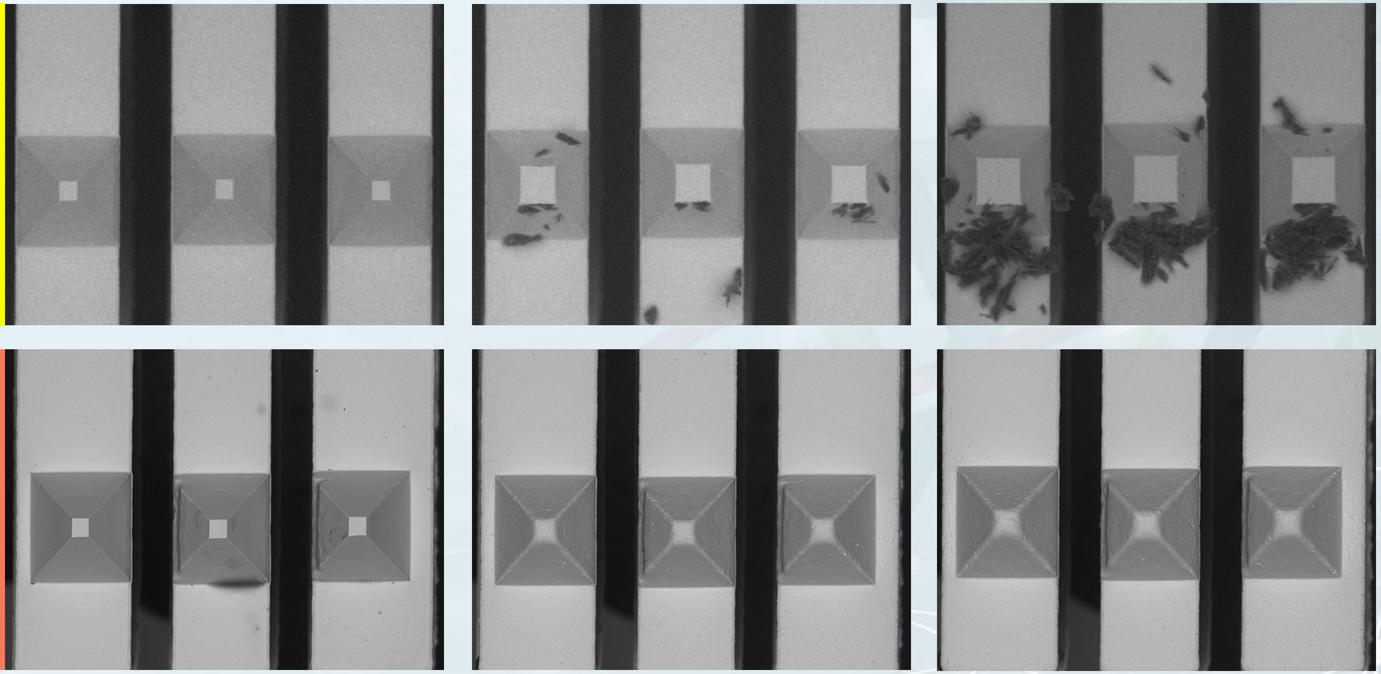
Wear Rate Comparison

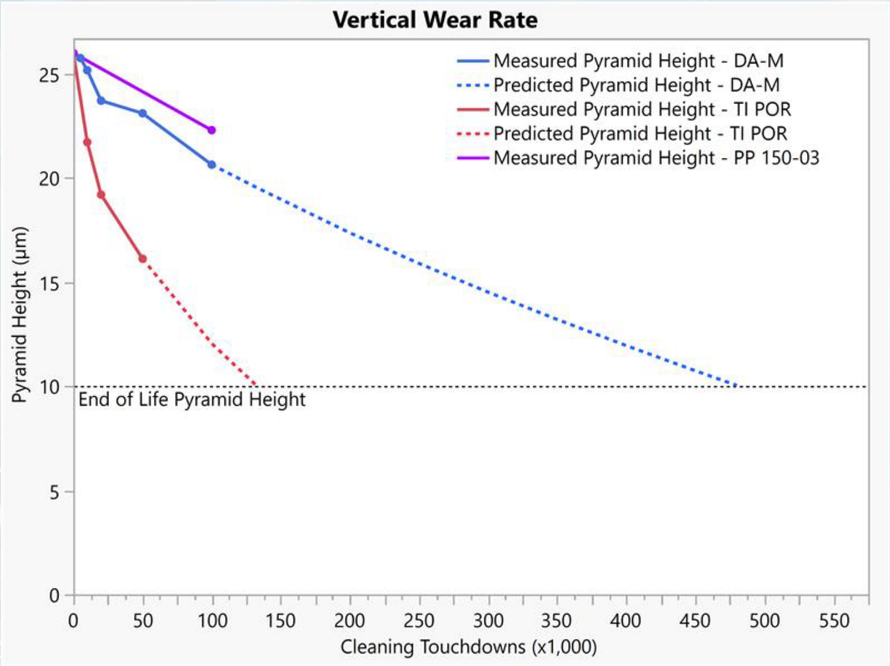
Absolute Cleaning Wear Rate

Initial | 10k TD | 20k TD

TI POR PL

Dual Action MEMS





Observations:

- Aggressiveness: PL >> Dual Action > Probe Polish
- 350k more cleaning touchdowns to EOL compared to PL
- Zero debris accumulation or material transfer

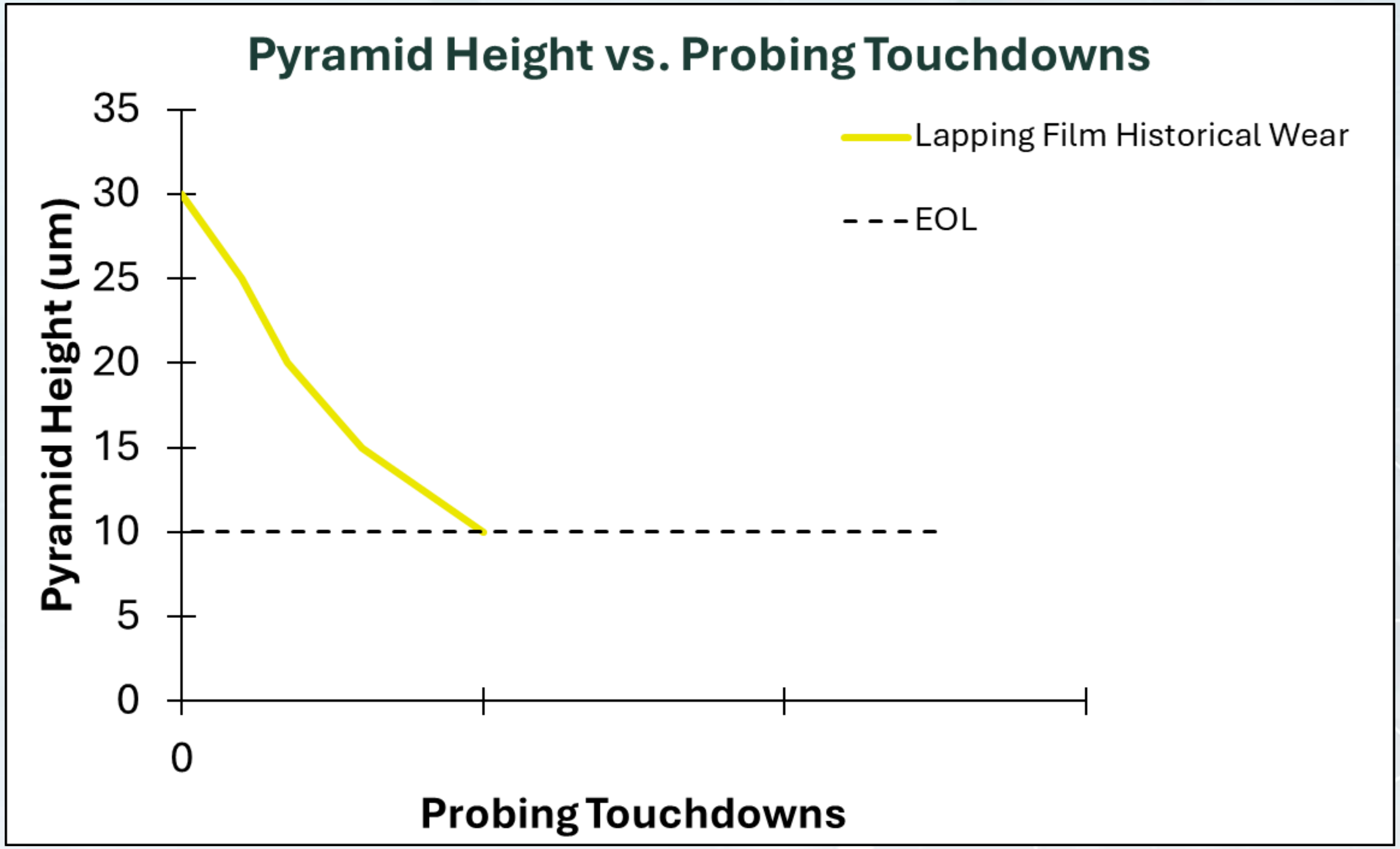
Dual Action MEMS Evaluation

The following will use an earlier lapping film process as a baseline for comparison

- Wear Study
- CRES Data
- Probe and Inspect Yield Analysis
- Probe Card Related Failure Trend
- Overall Reduction in Cost of Test

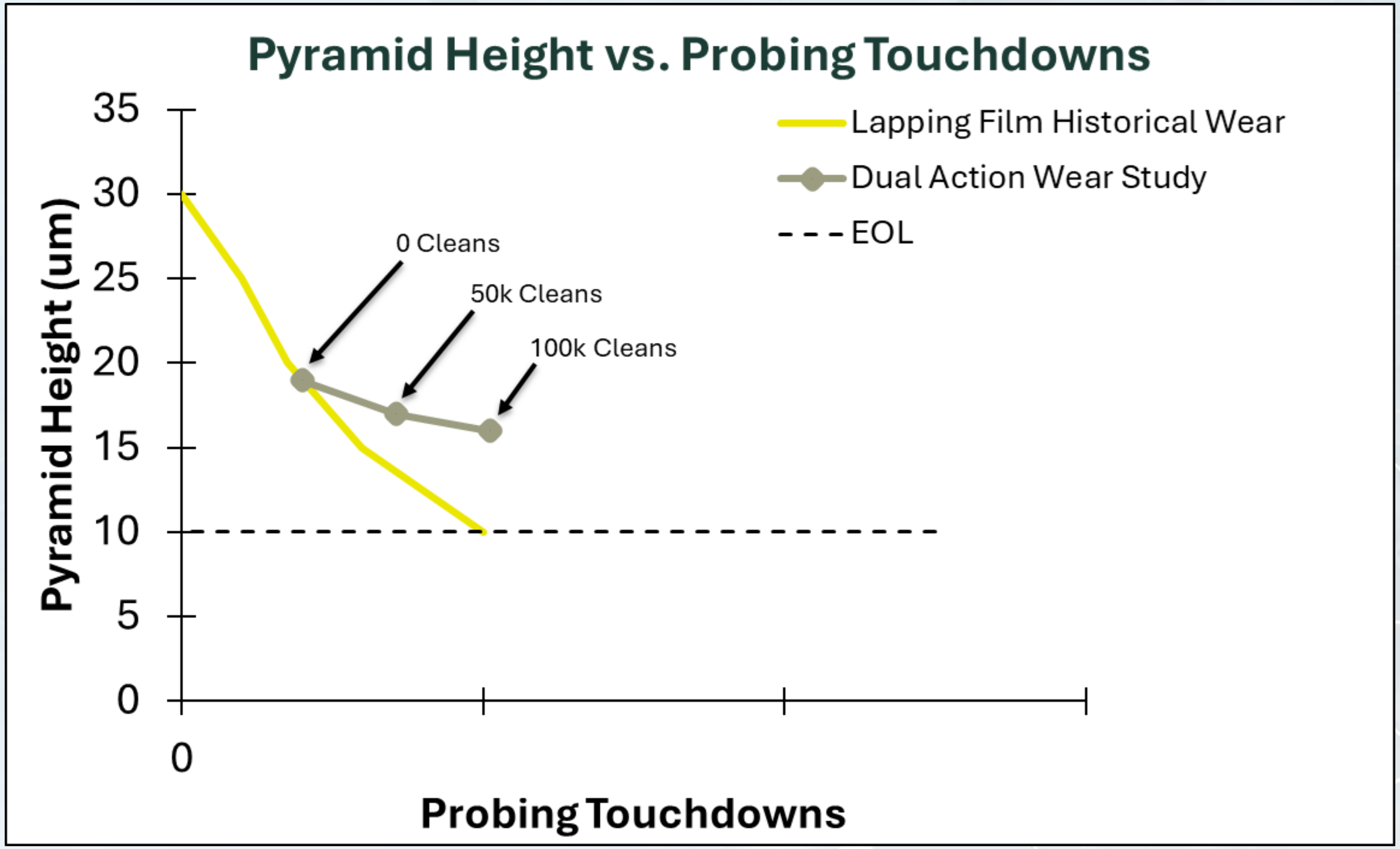
Wear Study

- Historical wear of production MEMS springs represented below
- New probe pyramid height is ~30 µm
- A height of ~10 µm was used for this study's end of life (EOL)



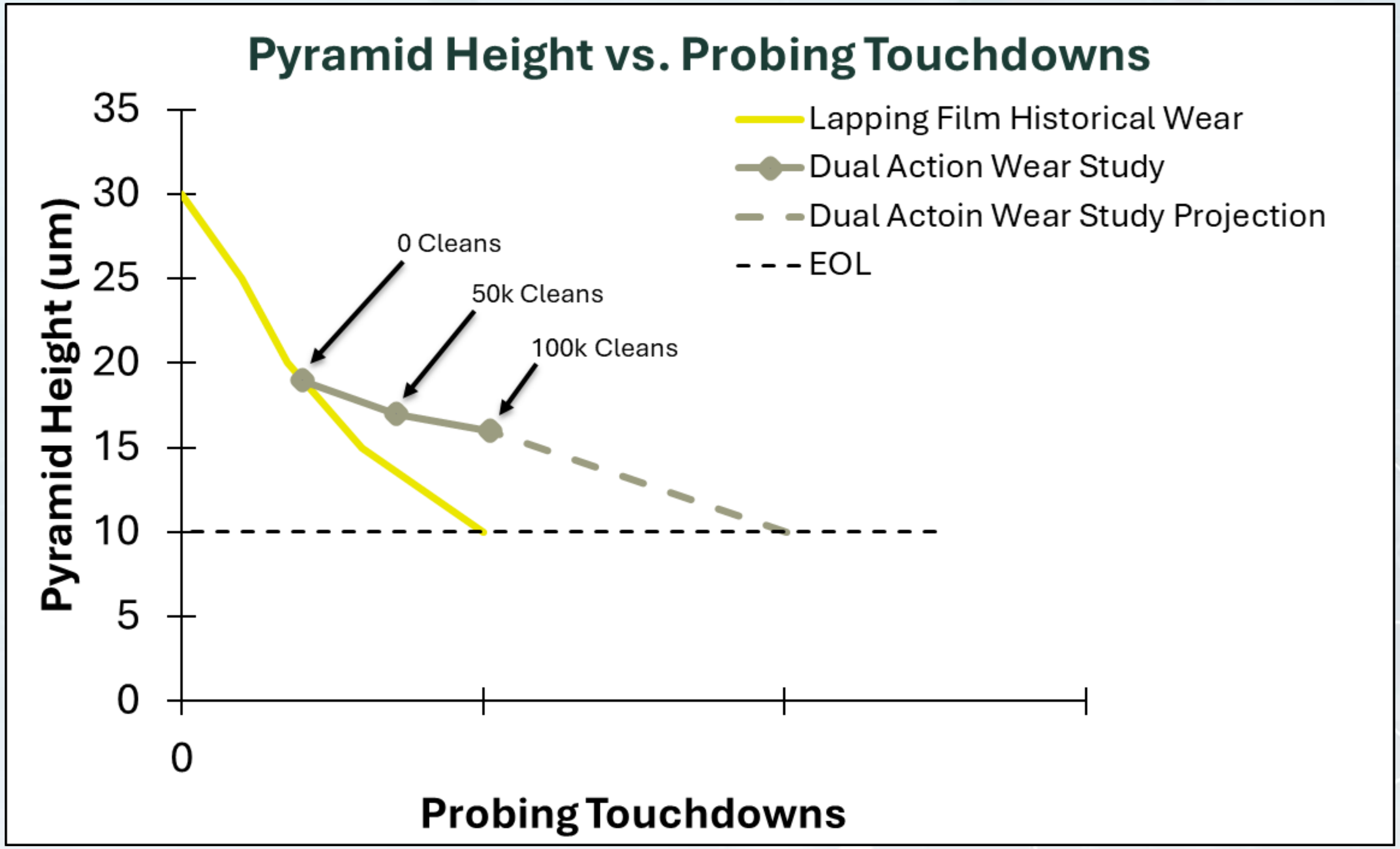
Wear Study

- A probe card with an average pyramid height of 19 µm was used for a wear study
- Pyramid height was measured after 50k and 100k cleaning touchdowns on Dual Action
- Same cleaning routine between baseline lapping film and Dual Action



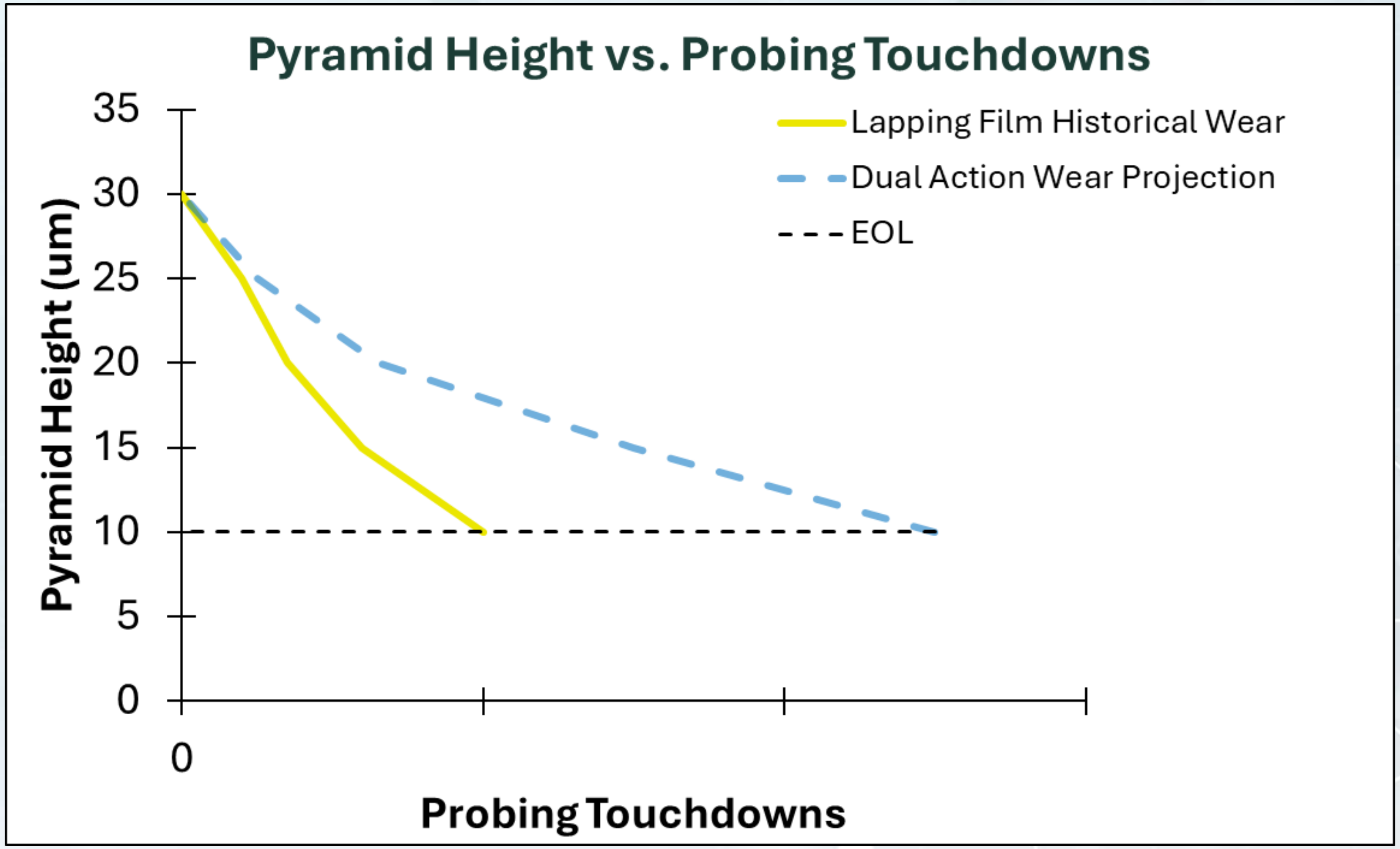
Wear Study

- **Wear rate was calculated and used to project when end of life would occur when starting from a pyramid height of ~19 µm (in a production environment)**



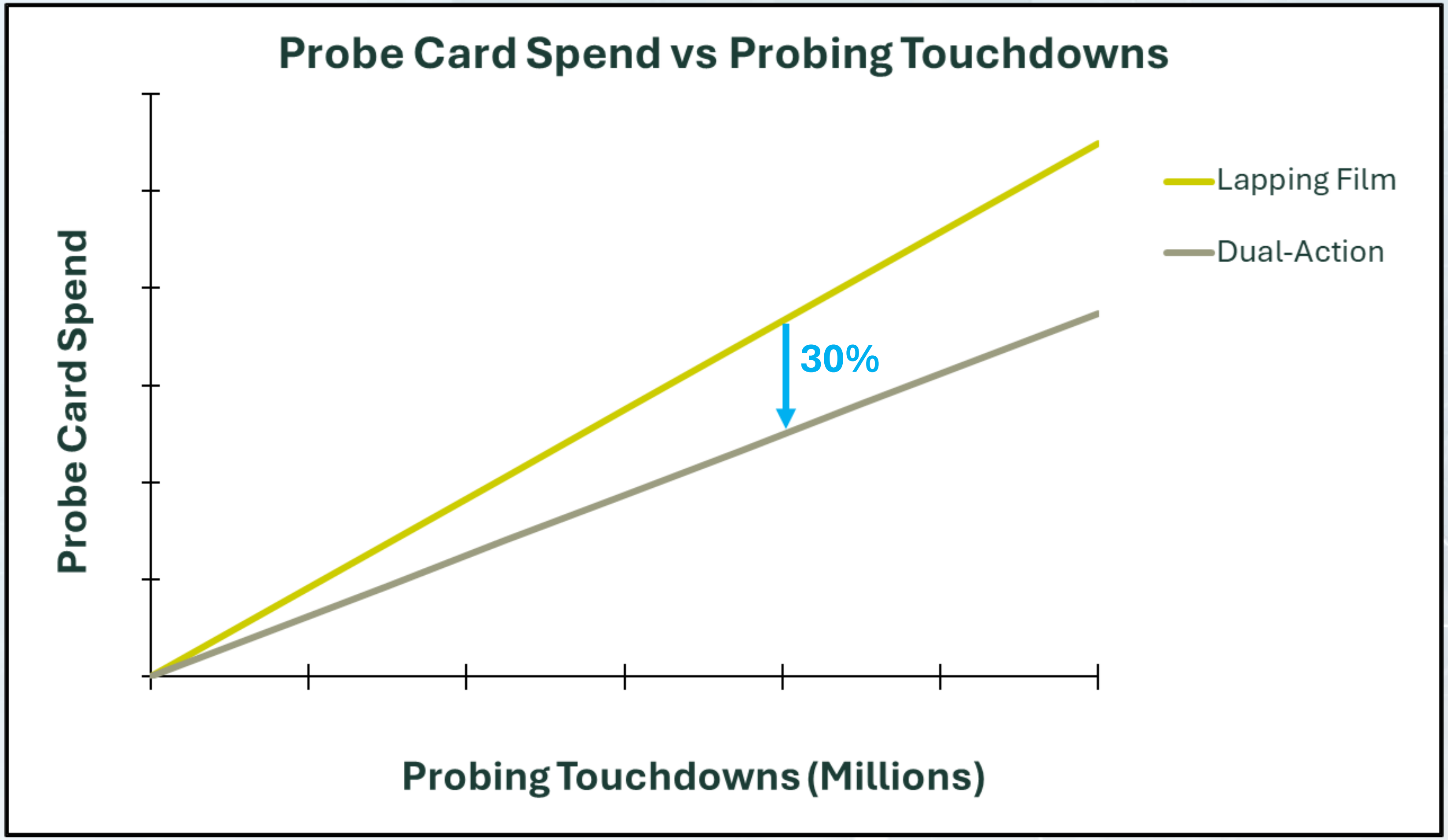
Wear Study

- New probes starting at ~30 µm are projected to last over twice as long!
- Entegris projects similar wear rate



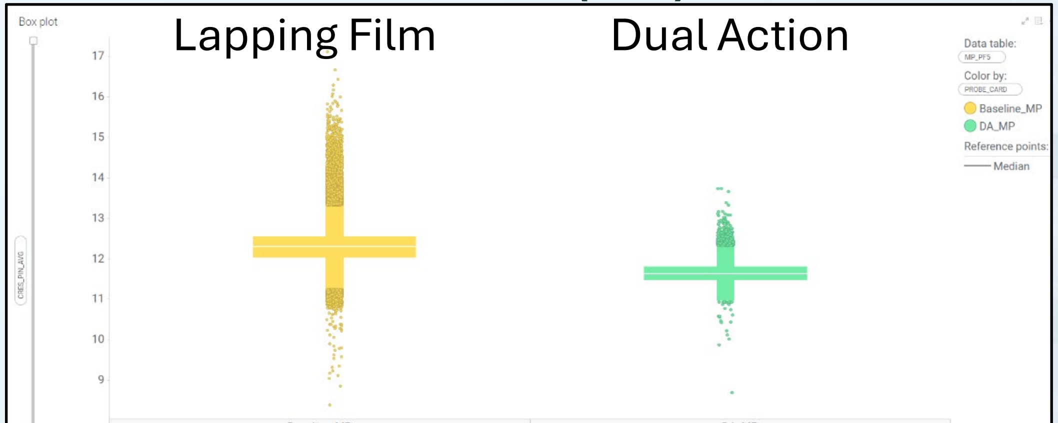
Estimated Probe Card Savings

- **Probe card spend is estimated to reduce by 30% when using Dual Action under similar test conditions as lapping films**



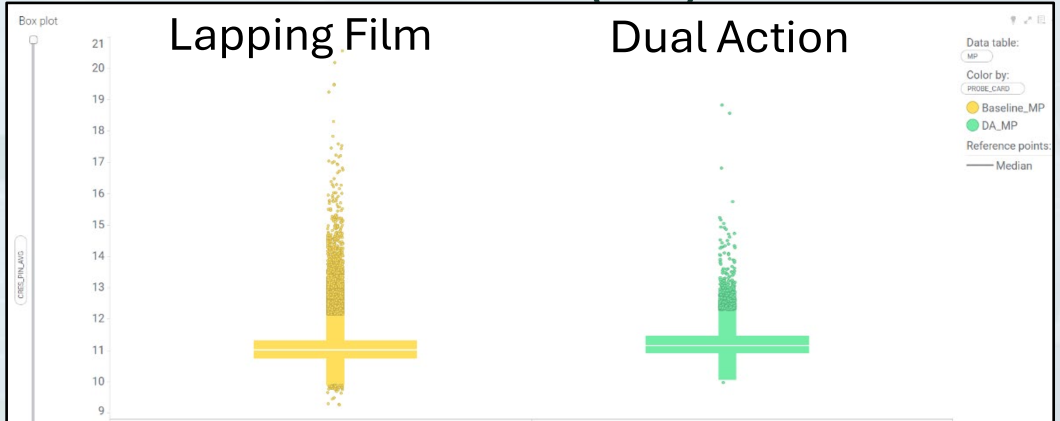
CRES Data

- **Device A (30C)**



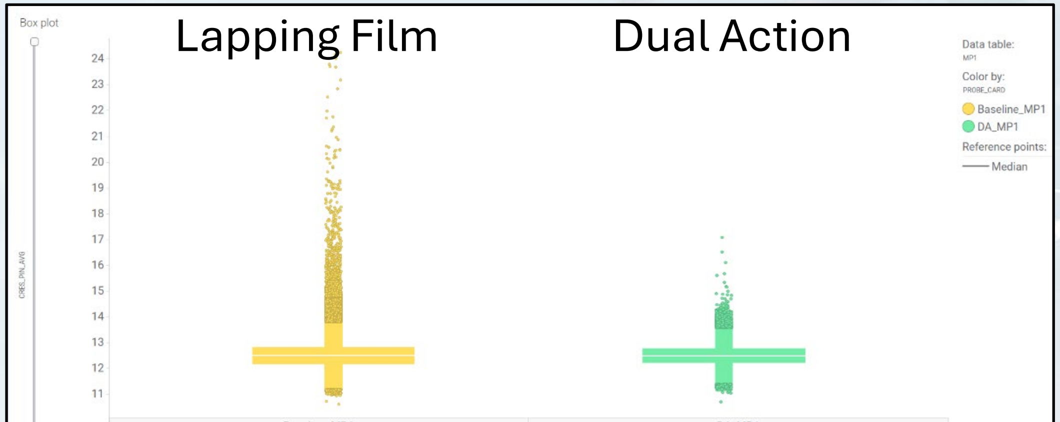
	Baseline_MP	DA_MP
Avg	12.299	11.6465
Median	12.2991	11.637
StdDev	0.486788	0.256294
StdErr	0.001056	0.00111078
Var	0.236962	0.0656864
Outliers	9174	486

- **Device B (30C)**



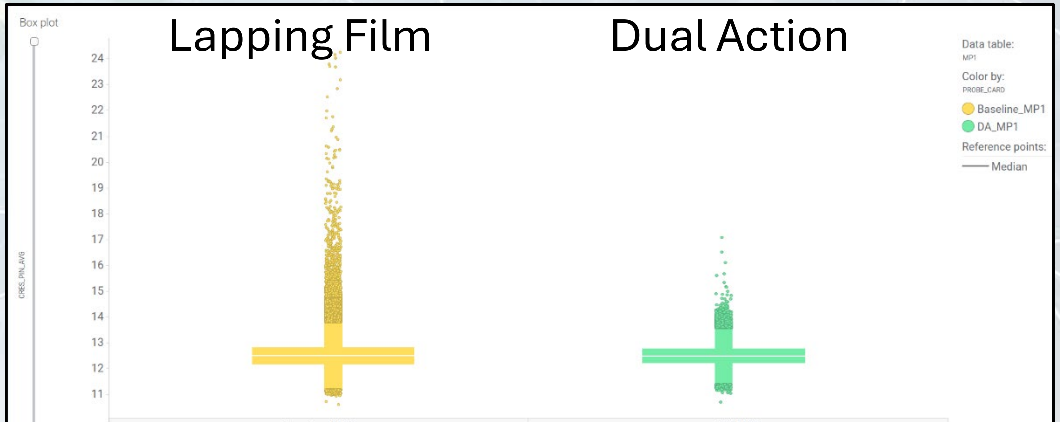
	Baseline_MP	DA_MP
Avg	11.0483	11.2019
Median	11.0071	11.1463
StdDev	0.439898	0.452722
StdErr	0.000440394	0.00206604
Var	0.193511	0.204957
Outliers	15727	831

- **Device A (125C)**



	Baseline_MP1	DA_MP1
Avg	12.5187	12.4986
Median	12.4914	12.4744
StdDev	0.530554	0.41846
StdErr	0.000562593	0.00106137
Var	0.281488	0.175109
Count	889346	155445

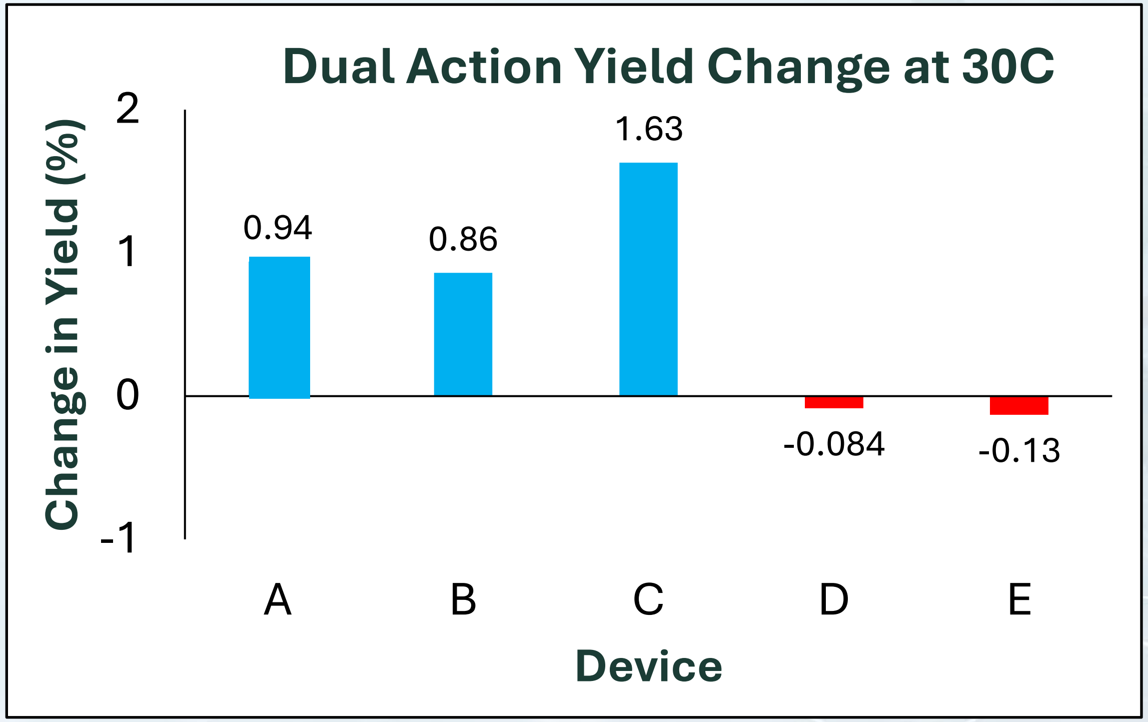
- **Device B (125C)**

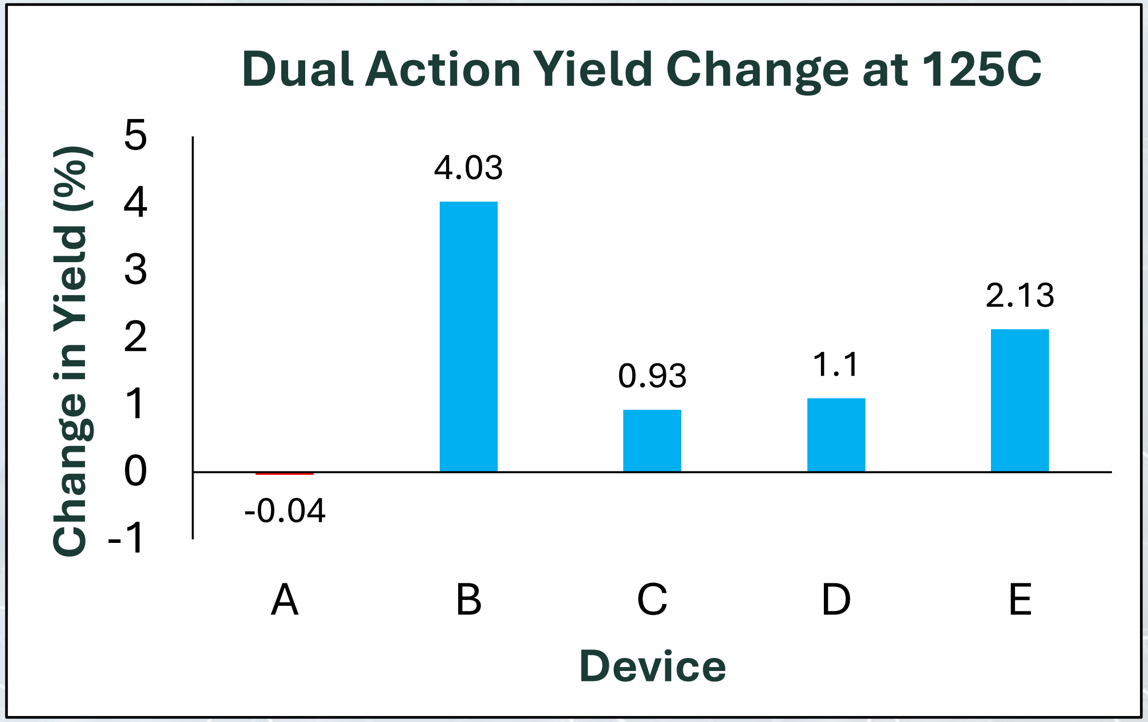


	Baseline_MP1	DA_MP1
Avg	12.5187	12.4986
Median	12.4914	12.4744
StdDev	0.530554	0.41846
StdErr	0.000562593	0.00106137
Var	0.281488	0.175109
Count	889346	155445

% Yield Analysis - Different Devices

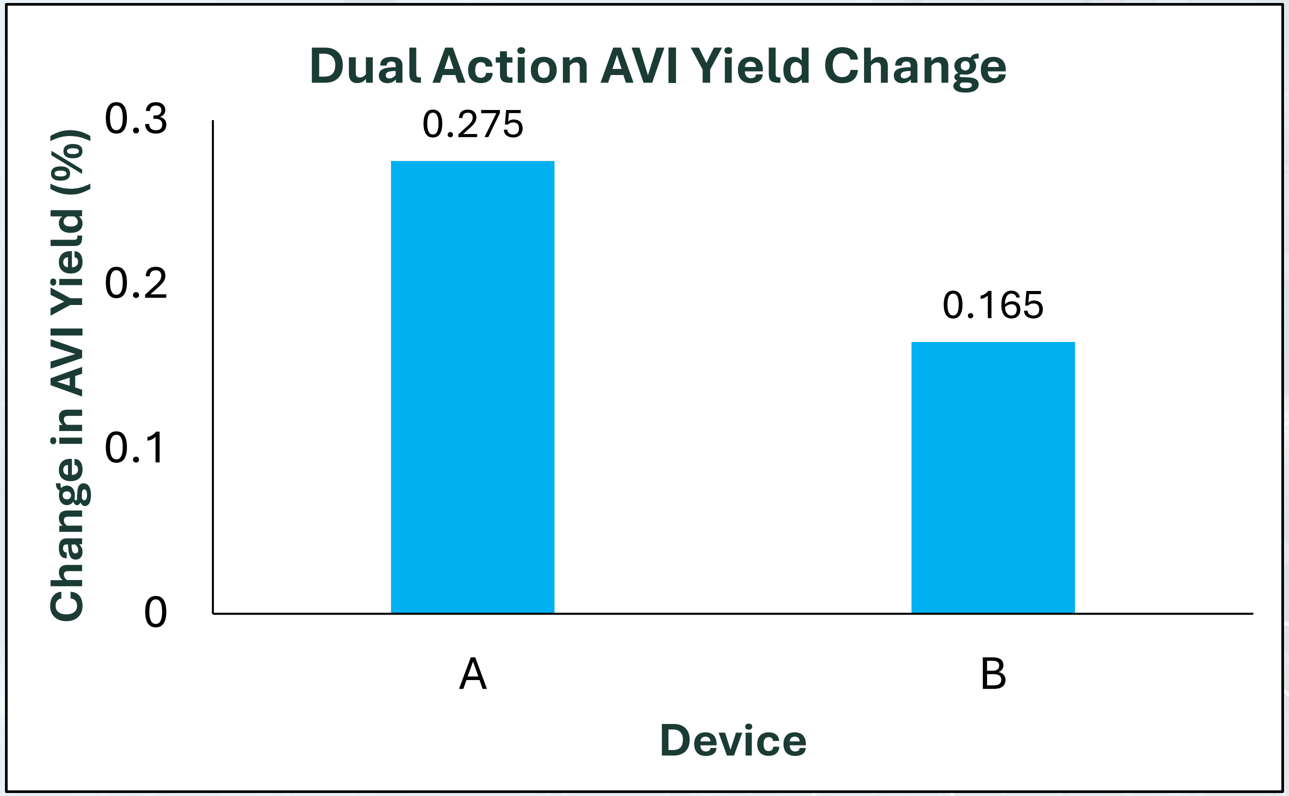
- Yield data suggest cleaning with Dual Action has potential for increased probe yield, particularly at hot temperatures, when compared to cleaning with lapping films



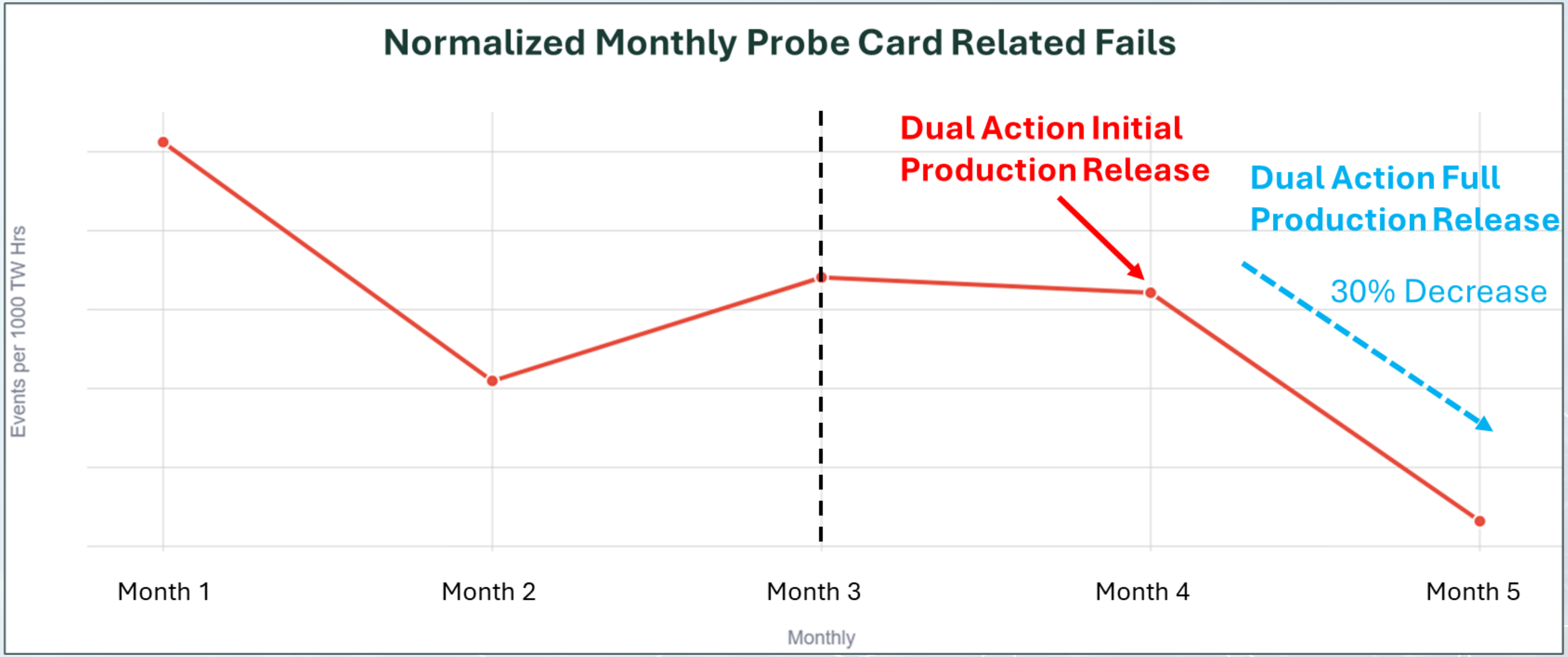


AVI Yield - Two Different Devices

- Automated visual inspection (AVI) yield data for Dual Action vs. lapping films shows signs of less debris depositing onto the wafers
- Less Debris = Less Scrapped Material



Probe Card Related Failure Trend

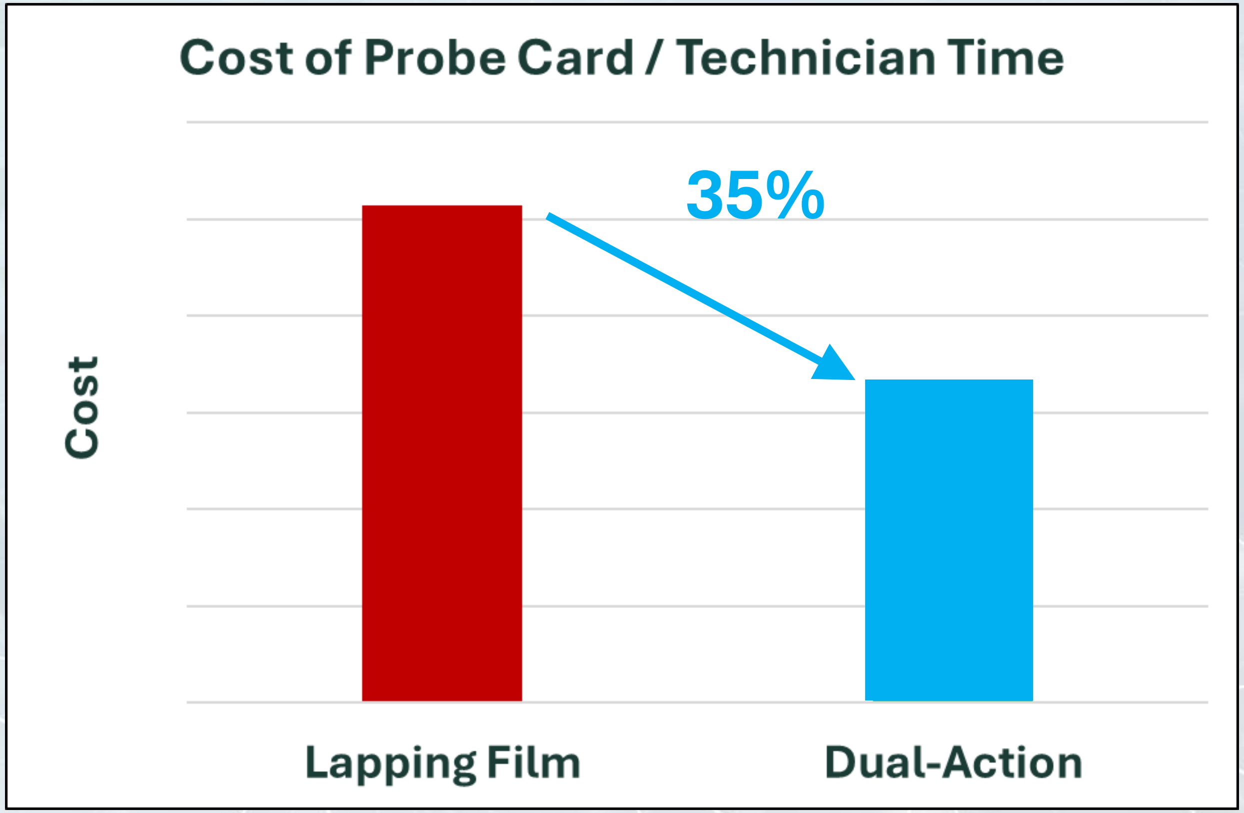


- **Fails are down 30% on average after the implementation of Dual Action vs. previous months**
  - Includes prober down events for yield loss, probe alignment, probe card repair, and offline manual cleaning

Reduction in Cost of Test

- **Dual Action MEMS Qualification Summary and Projected Benefits**
  - ✓ 30% Reduction in Probe Card Downtime
  - ✓ Potential Yield Gain of ~1%
  - ✓ Improved CRES Stability
  - ✓ Longer Probe Card Lifetime
  - ✓ Potential for >1,000 Annual Technician Hours Saved Manually Cleaning

- **Overall Cost Savings**
  - ✓ **35% Reduction in Probe Card Re-order Spend and Technician Labor**
  - ✓ **Yield Gains**
  - ✓ **Improved Test Cell Uptime**
  - ✓ **12% Decrease in Total Cost of Test**



Executive Summary

Qualification of Dual Action MEMS

- **Delivers complete recovery from halo debris**
  - Never achieved to this level or at this speed
- **Prevents debris accumulation and halo formation**
  - Reduces alignment issues and offline cleaning
  - Reduces debris transfer to the wafer
    - **True inline maintenance solution**
    - **Increased product throughput**
    - **Increase yield and revenue**
- **Significantly reduces probe tip wear**
- **35% reduction in probe card spend and technician labor**
  - 12% decrease in total cost of test
- **Qualified by Texas Instruments and approved by FormFactor, Inc.**

Acknowledgements

Texas Instruments: Official Qualification and Adaptation of Dual Action MEMS

- Imran Ahmed – Qualification Support
- Thomas Vaughan – Automation Support

Entegris: Advanced Cleaning Materials Dual Action MEMS Design

- Dr. Brian Green, Stevon Scott, and Mark Stark – Co-inventors
- Alex Baglione, Dustin Clapshaw, and Gwendolyn Church – NPD Team

FormFactor, Inc.: Dual Action MEMS Approved Cleaning Material for T11 Technology

- Mike Stadt, David Lacy, Patrick Rhodes – Evaluation and Recommendation
- Cameron Harker, Patrick Chen – Project Presentation Collaboration

Northwest Test Solutions

- OEM and Customer Engagement

Semiconductor Wafer Test Committee

Thank you!