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MEMS Probe Card Solution to Address Parametric Test Challenges

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Agenda

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- Probe Card Architecture
- Probe Design
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- Scrub Performance
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  - Lifetime Results for different pad metallurgy
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Introduction/Problem Statement

- Test engineers leverage parametric testing to
  - Enhance semiconductor device quality
  - Monitor and control process variations
  - Boost production yield and minimize material waste
  - Help lower overall manufacturing costs
- Parametric probe cards face increasing pressure to deliver ultra-precise, repeatable, low-damage electrical contact with high reliability
- Probe card requirements for parametric testing
  - Ensure ultra-low leakage currents for accurate measurements
  - Utilize robust contact technology to safeguard wafer integrity
  - Deliver high reliability and consistent performance over extended use
  - Support yield enhancement and waste reduction
  - Enable faster time-to-market by reducing lead time for new designs

MEMS Probe Card Requirements

- Smaller Pad size and Pitch
  - <=40μm pitch requires smaller probe cross section
- Low force 2D MEMS springs
  - Reduces risk of pad damage
- Very low scrub ratio < 7%
  - Low scrub marks is critical to achieve smaller pad size
- Low particle generation
  - Tip to beam clearance >250μm is critical
- Works across different pad surfaces
  - Stable low CRES required for variety of pad metallurgies for Al, Cu, Inline and Solder
- Constant probe tip length
  - Tip size needs to be consistent across Beginning of Life (BoL) and End of Life (EoL)

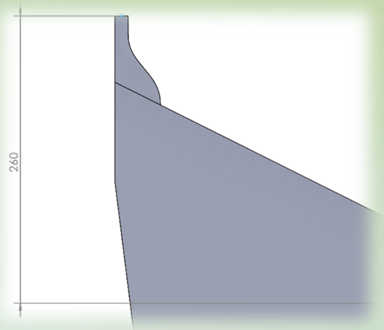

Fig. 1 – Tip to Beam Clearance

Attribute	Value
Pad Size	25x25 μm
Pitch	40 μm
Max OT	150 μm
Operating OT	100 μm
Scrub Length	<15 μm
Leakage	<0.5 pA
Pad Layout	Flexible
Pad Material	Al, Cu, Solder, Cu Pillars, Ti, Nb, etc.

Table 1 – Attribute and Value

Probe Card Architecture

- A novel MEMS probe card architecture was designed and developed to meet the demanding parametric test requirements
- Interchangeable probe heads built with ultra high precision MEMS probes
  - Capable of exchanging different probe head designs on-site using a common PCBA
  - MEMS probes with fine pitch capability, low force, low scrub ratio and stable Contact Resistance (CRES) developed
- Key Benefits
  - Reduced lead-time
  - Flexibility of asset utilization
  - Lower cost
  - Maximizes Total Cost Of Ownership (TCOO)

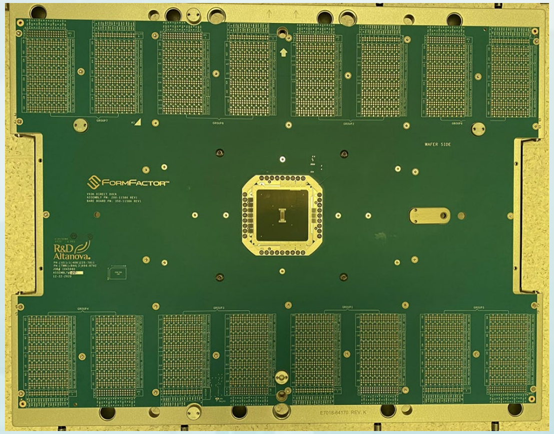

Fig. 2 – MEMS Probe Card

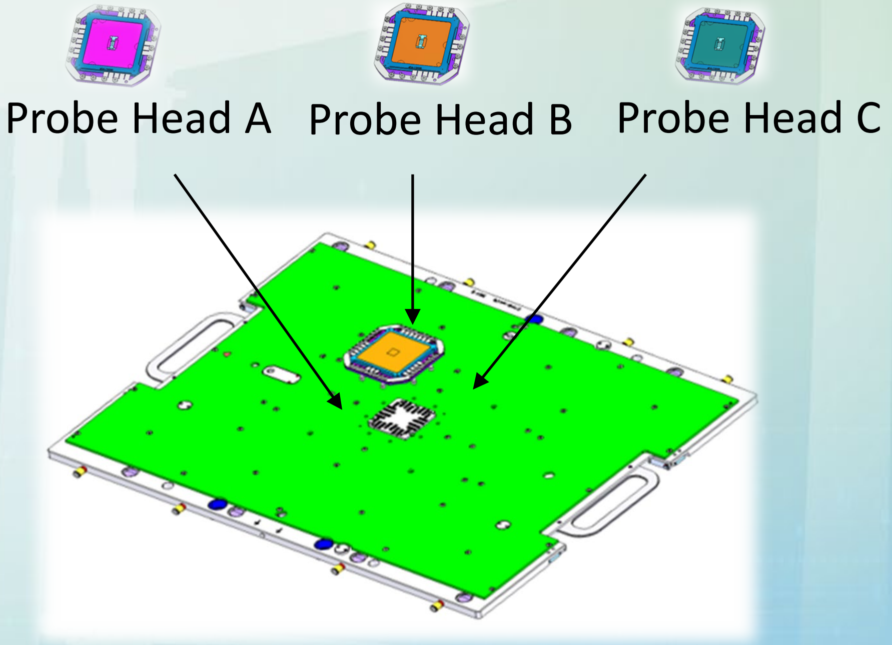

Fig. 3 – MEMS Probe Card with Interchangeable Probe Heads

Probe Design

- Input parameters/ factors to consider
  - Optimal MEMS metallurgy
    - Superior thermo-mechanical properties
    - High yield strength
    - Optimal Young's modulus
  - Dimensions/size of the probe
  - Ease of fabrication
- Output parameters
  - Desired maximum stress at maximum Over-Travel (OT) with sufficient margin
  - Appropriate contact force ~ 2.5-4.5g at operating OT
  - Desired total scrub length ~ 12-15 μm
- All the above parameters determined through FEA
  - Optimized probe design selected from an iterative process
  - Best candidate was down selected for fabrication

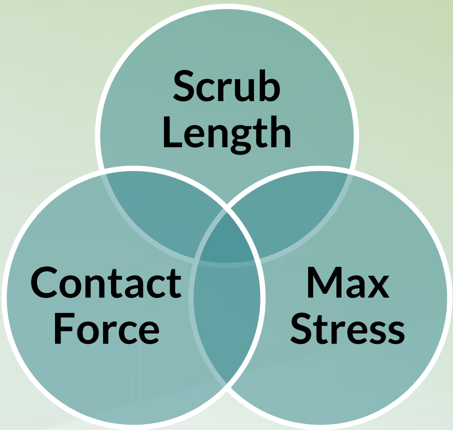

Fig. 4 – Optimum probe design criteria

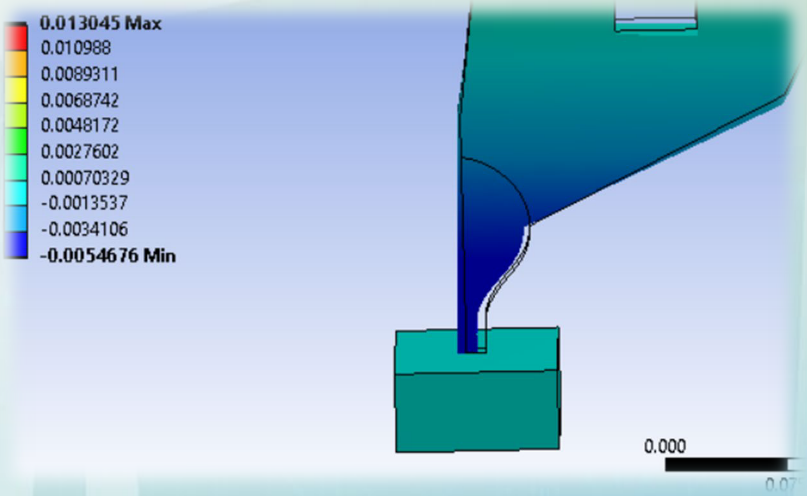

Fig. 5 – Scrub Length as per FEA

Probe Down-Selection

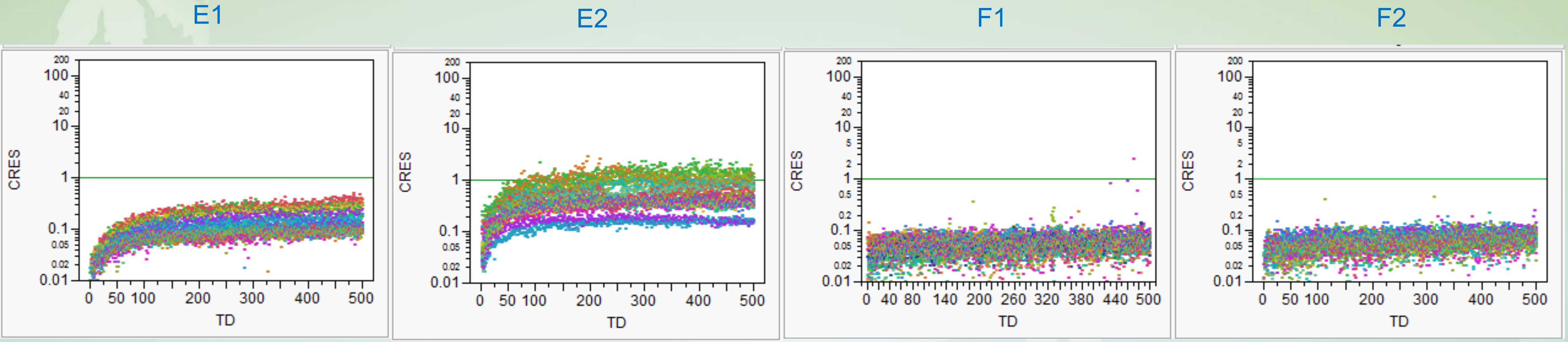

Fig. 6 – CRES data for Probe E1, E2, F1 and F2

- Contact Resistance (CRES) and Scrub mark data was collected for different probe designs at maximum Actual Overtravel (AOT) of 150µm
- Stable CRES was demonstrated for 500 production touchdown (TD) cycles without any cleaning
- Down selected E1 based on CRES and scrub performance
- F1 and F2 had longer scrub length which will not meet customer's small pad size requirement

Probe Down-selection - CRES

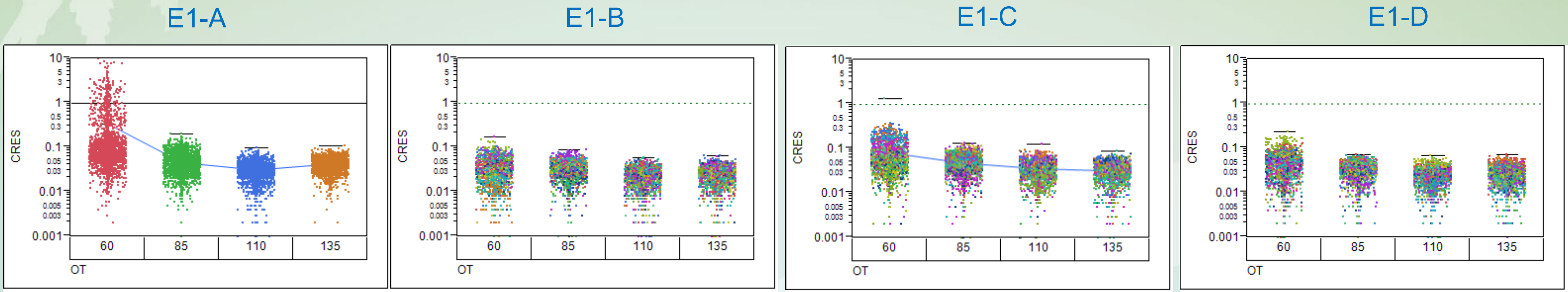

Fig. 7 – CRES data for the variants of probe E1

- Above are the 4 variants of E1
- 3 of the 4 candidates pass CRES even at 60µm OT
- E1-D was down-selected for Cu, Cu Pillar, Solder, Aluminum pads

Contact Force for Stable CRES

- Contact Force needs to be optimized for low pad damage and stable CRES
  - Low contact force would lead to high CRES and hence, undesirable
  - High contact force though would provide a low CRES but could damage the customer pads
  - E1-D probe's contact force was optimized for stable CRES and low scrub ratio using FEA
- Pad material also influences the CRES performance and accordingly the probe design needs to account for the contact force
- For Titanium pad, increase in contact force is critical as shown in Fig. 8 but scrub length is similar ensuring no damage to the pad
  - E1-B was down-selected for Ti pad
- Good correlation between FEA and experimental data as shown in Fig. 9

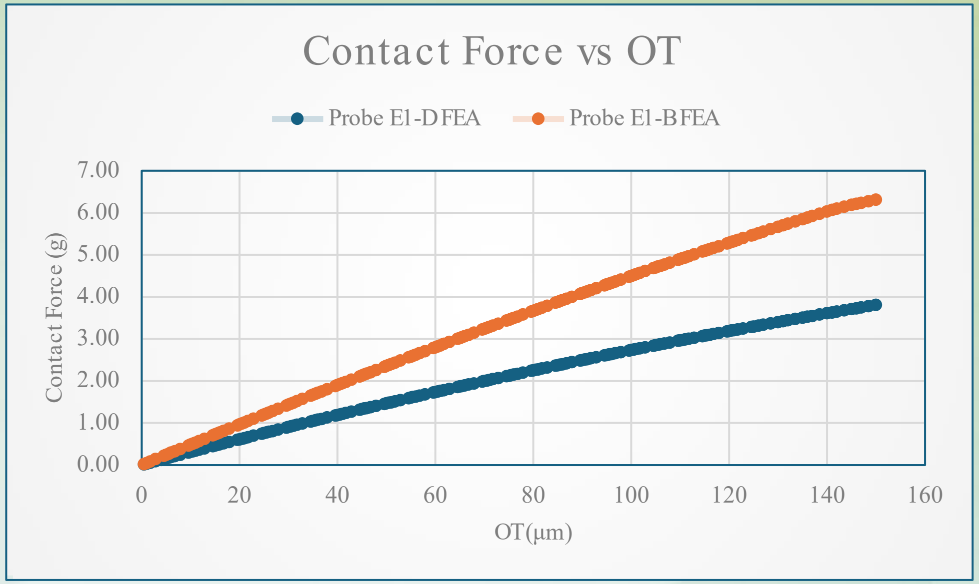

Fig. 8 – Contact Force Vs Overtravel for E1-D and E1-B as per FEA

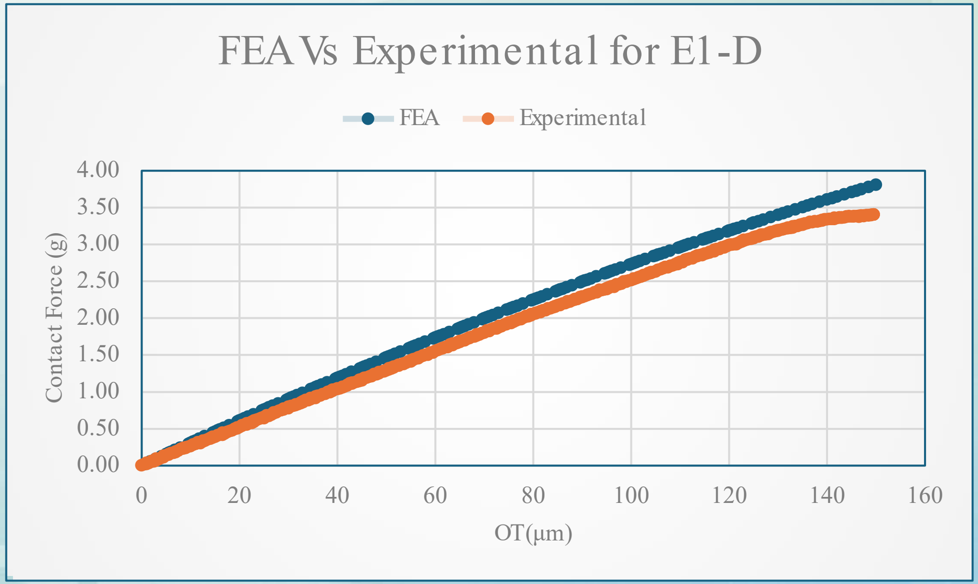

Fig. 9 – Contact Force Vs Overtravel for E1-D, FEA Vs Experimental

Scrub Performance

- Scrub ratio refers to the scrub length with respect to the amount of overtravel
- A consistent predictable scrub ratio is critical for electrical performance
- Scrub ratio: 6.5%
- Scrub depth analysis shows very low punch through on the pad
- Low scrub ratio without pad damage is paramount for very small pad applications

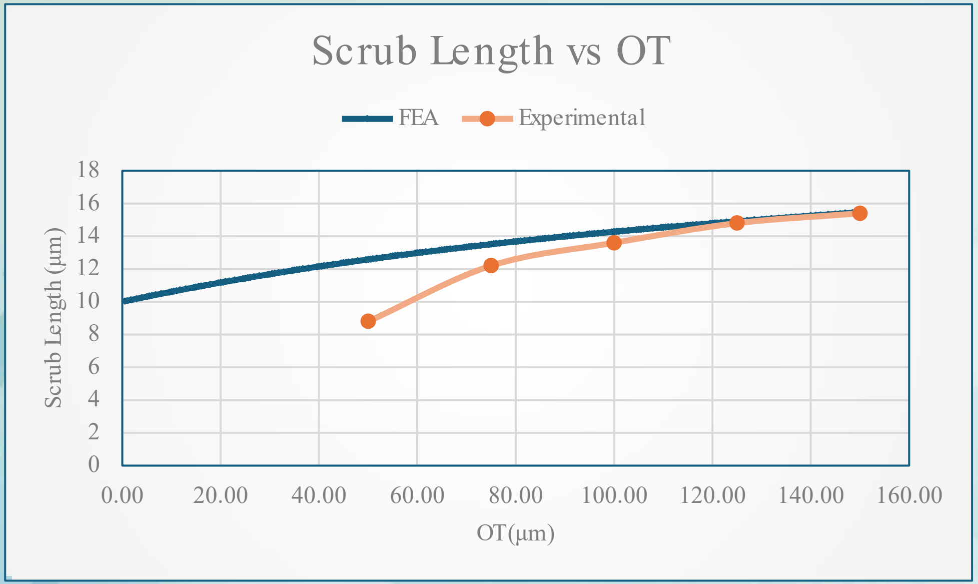

Fig. 10 – Scrub Length Vs OT for E1-D, FEA Vs Experimental

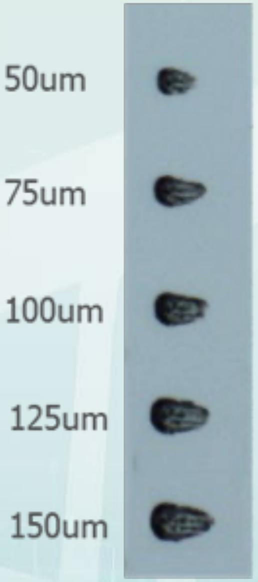

Fig. 11 – Scrub Length Vs OT

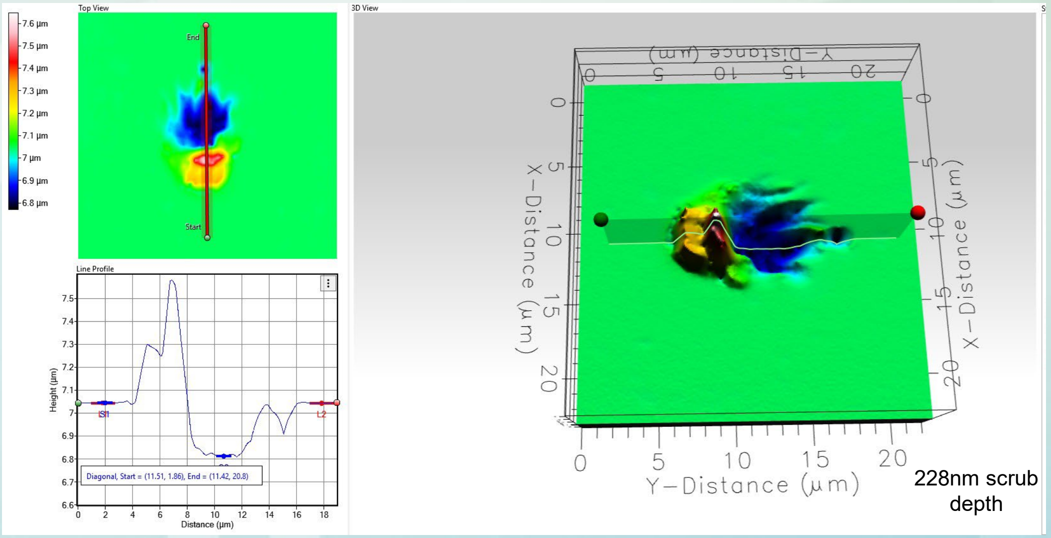

Fig. 12 – Scrub Depth Analysis

Probe Assembly; Pad Size, Layout and Pitch

- MEMS probe assembled using ultra high precision automation tool
- Probe attachment methodology enabling fine pitch solution at 40 µm pitch developed, 20 µm capability in progress
- Pad head to head clearance significantly reduced to 10µm
- Improvement in MEMS probe tip placement accuracy in X,Y and Z
- Flexibility in pad layout and enables high parallelism testing

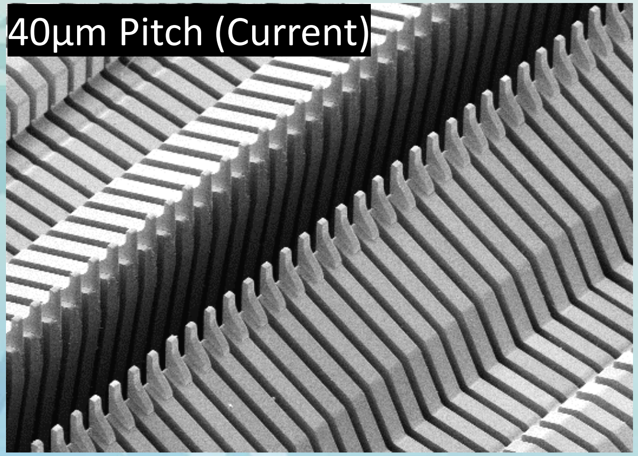

Fig. 13 – Probe Assembly; 40 µm Pitch

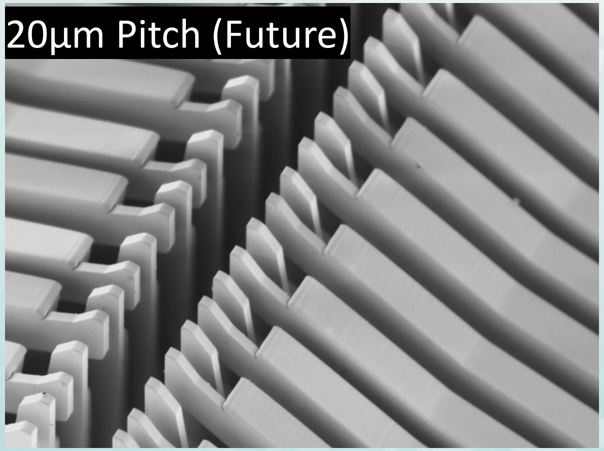

Fig. 14 – Probe Assembly; 20 µm Pitch

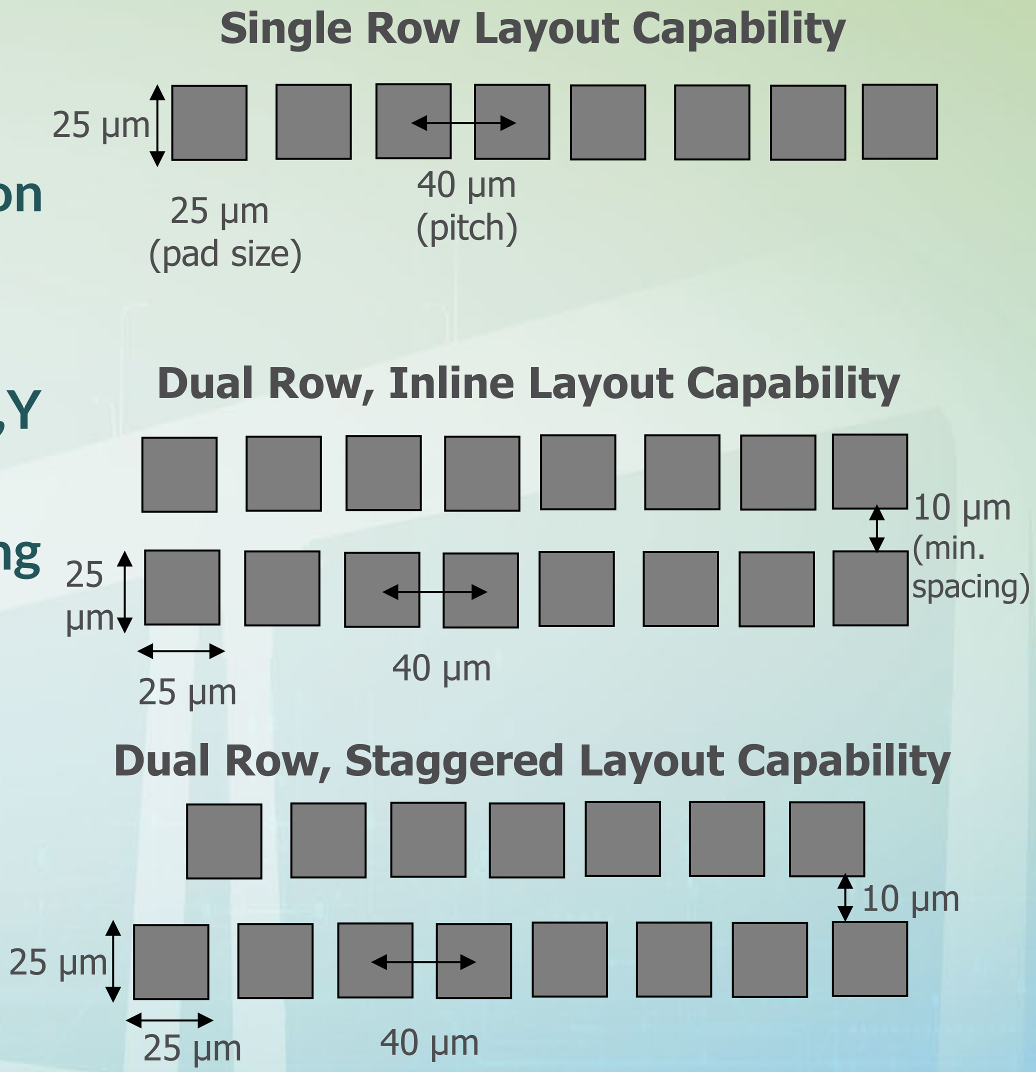

Fig. 15 – Pad size, layout and pitch

Qualification Results - Key Issues/Challenges

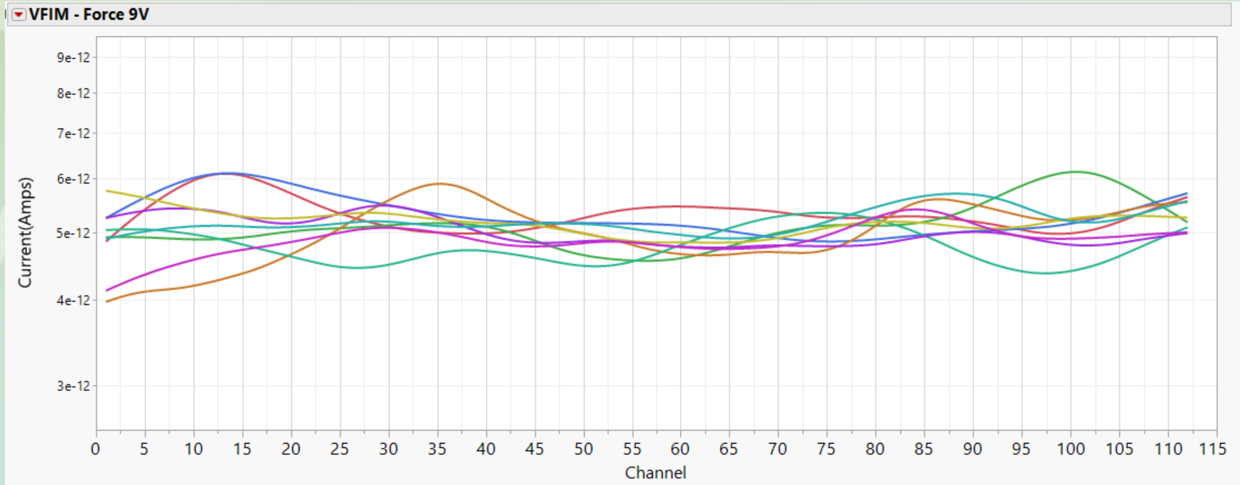

Fig. 16 – Probe Card Ultra low leakage Data

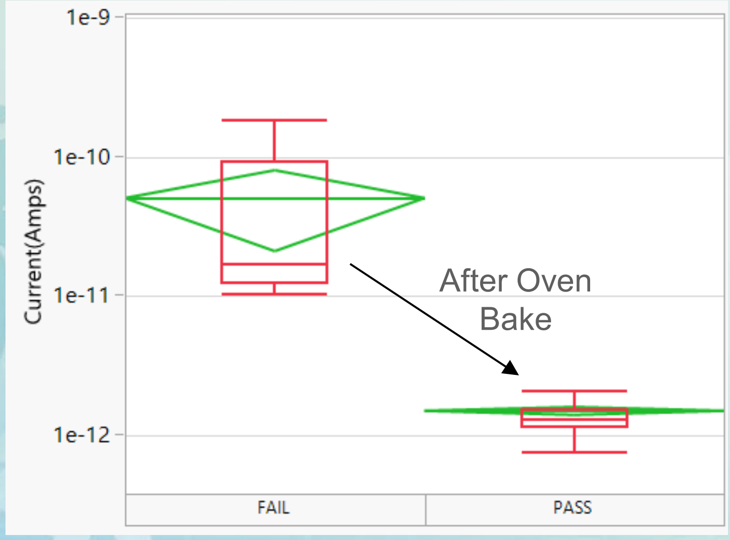

Fig. 17 – Random low leakage failure and fix

Initial evaluation samples passed Intel test requirements

Random Low Leakage Failures

- **Observed few random low leakage failures during qualification and ramp**
- **Low leakage was attributed to moisture build up on PHs**
- **Onsite oven bake on failed PHs showed that the leakage can be reduced**
- **Implemented outgoing bake process on PH as standard practice to reduce leakage failures**
- **Implemented flux-free PH process to further reduce chance of leakage failures**

Qualification Results – Lifetime Data on Copper Pillar

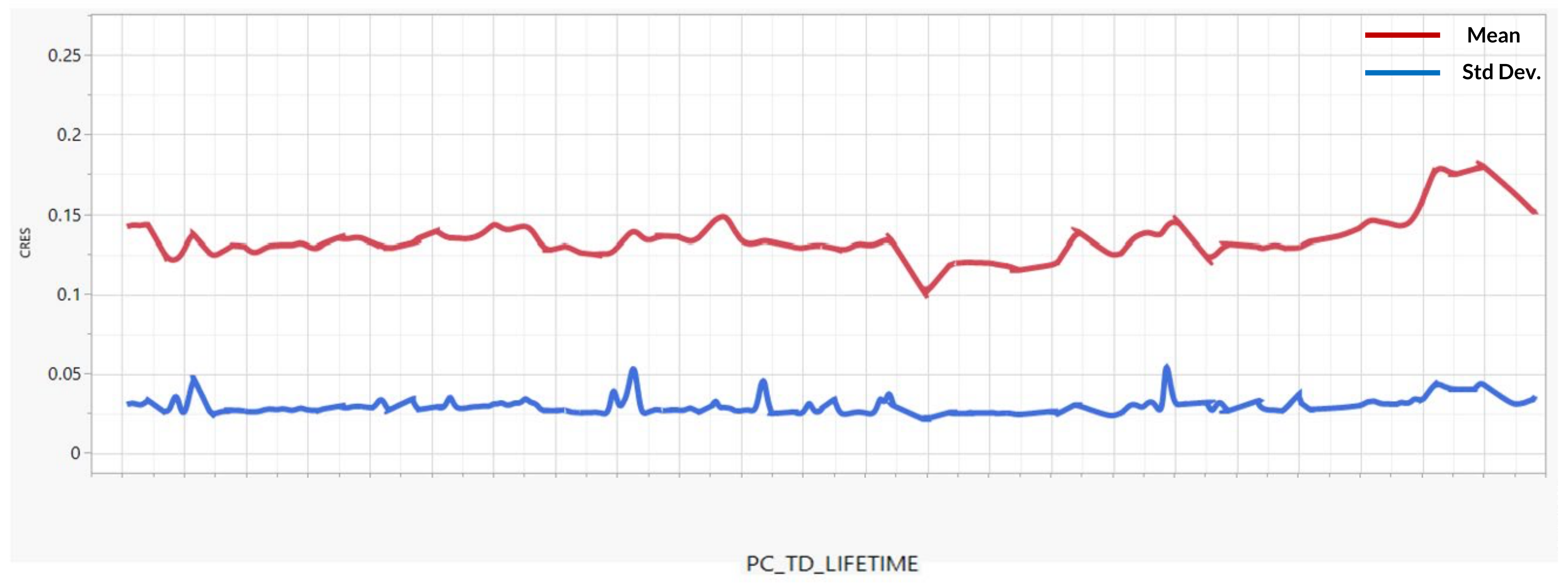

Fig. 18 – CRES and Lifetime Data on Cu Pillar

- **Probing surface - Cu Pillars**
- **Lifetime > 1 million TDs**

Qualification Results – Lifetime Data on Copper Pad

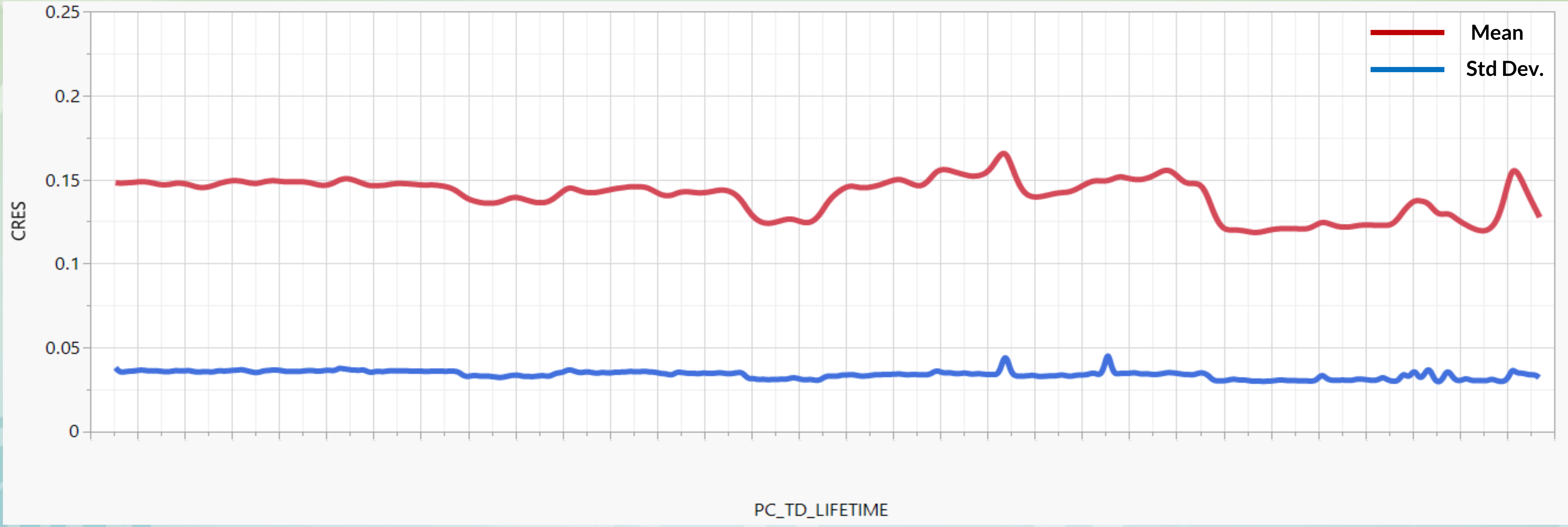

Fig. 19 – CRES and Lifetime Data on Cu Pad

- **Probing surface - Cu Pads**
- **Lifetime > 1 million TDs**

Summary / Conclusion

- Developed an innovative interchangeable MEMS Probe Card architecture that meets Intel's demanding parametric test requirements
- Probe design with desired CRES, contact force and scrub length achieved across different pad surfaces
- MEMS probe fabrication, assembly and capability developed for varying pad sizes, layouts and pitches
- Exceptional CRES and lifetime performance demonstrated
- Future parametric test requirements
  - High temp (180 - 200^{o}C) testing
  - Fine pitch probing <40 μm up to 20 μm
  - Smaller pad size ~ 20x20 μm

Acknowledgements

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  - Jose Gonzalez, Oscar Moreno, Chintan Panchal, Nick Jansen, Xianling Yan, Wilson Kyi, Sudhin Shetty, Jesse Li, Tim Eichenseer, Arvind Sambasivan
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