SWTEST 2021 CONFERENCE

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Challenges of Expanding Large Area Arrays for Fine Pitch Vertical Probe Cards

FormFactor™

Cameron Harker (Presenter)
Sr. Director of Marketing
Yohannes Desta, PhD
Dir. of NPI Engineering
FormFactor, Probes BU

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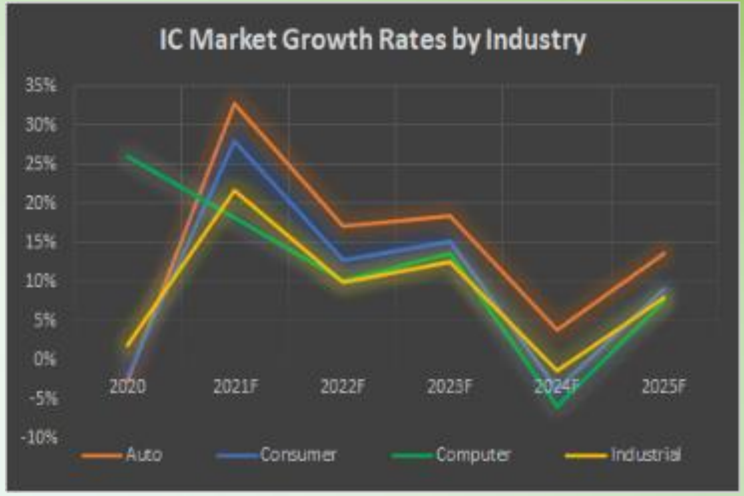
Agenda

- **Motivation of Work**
  - Continued strong growth in the wire bond, automotive IC market
  - Expanding challenges and trends for wire bond probing
- **Development Strategy Overview**
  - Architectural Strategy
  - Product Overview
- **Product Validation Results**
  - Internal Validation Results
  - External Validation Data
- **Summary and Acknowledgements**

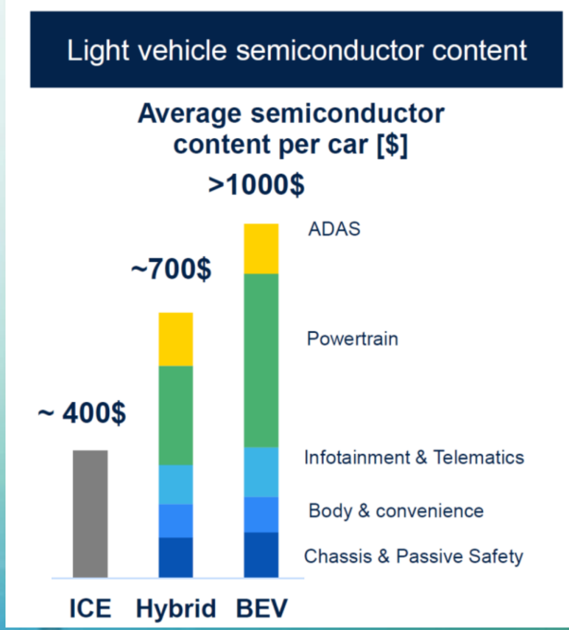
Automotive Semiconductor Market Overview

- **Automotive electronics is a fast-growing market**
  - Automotive IC market forecasted to grow to ~$40B in 2021
  - Forecasted 16.8% CAGR from 2020 to 2025 is the strongest end-use segment *(IC Insights 2021 report, June update)*
  - Value of semiconductors in cars continues to increase with advances in hybrid and electric vehicles



(IC Insights 2021 report, June update)

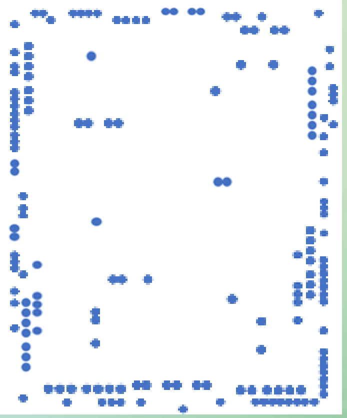
- **Requirements for automotive applications:**
  - *"Unlike semiconductors intended for use in consumer electronics, automotive semiconductors must retain functionality in more extreme environments (colder and hotter temperatures) for longer periods of time"*
    - *The Automotive Semiconductor Market, USITC, May 2019*



(IHS – Automotive semiconductor market tracker – Jun 2020)

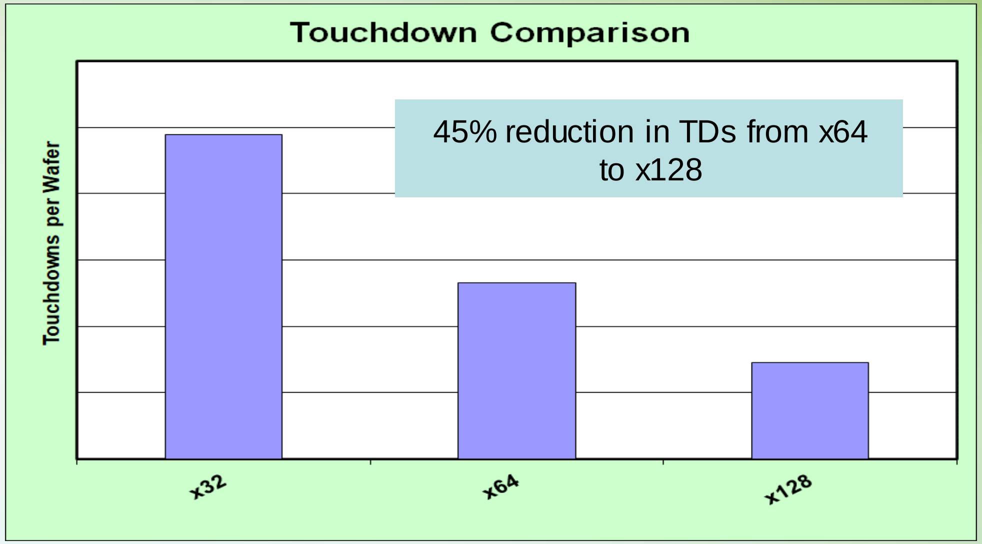
The Impact of Automotive Requirements for Semi Wafer Test

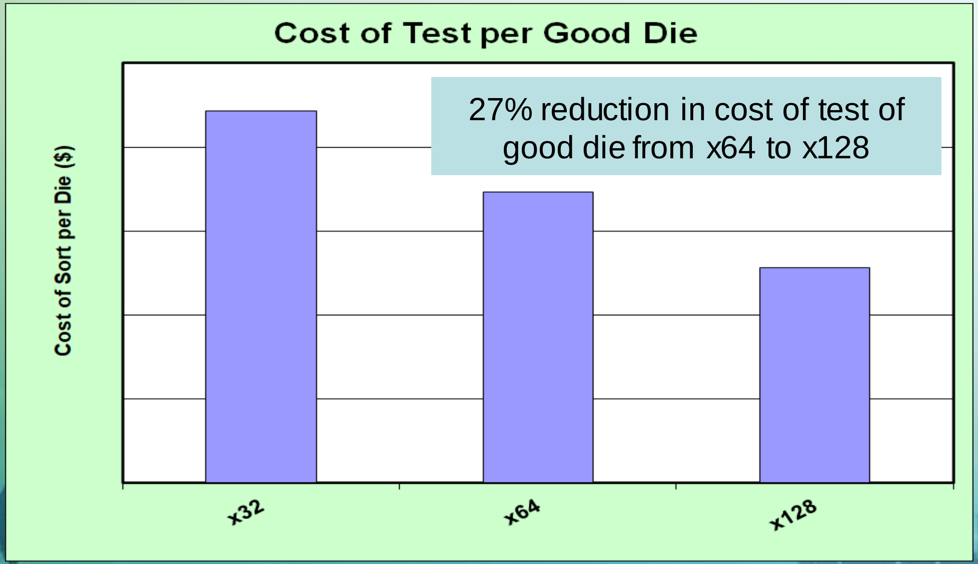
- **Critical requirements for automotive semiconductor test**
  - Test temperature extremes continue to increase
  - Structures are typically peripheral pads for wire bond applications
  - Pad pitch continues to shrink
  - Pad sizes are being reduced to support die size shrinks
  - Dense device circuitry under the pads
  - Devices can be sensitive to CRES and CRES variation
  - Automotive suppliers driving reduced costs

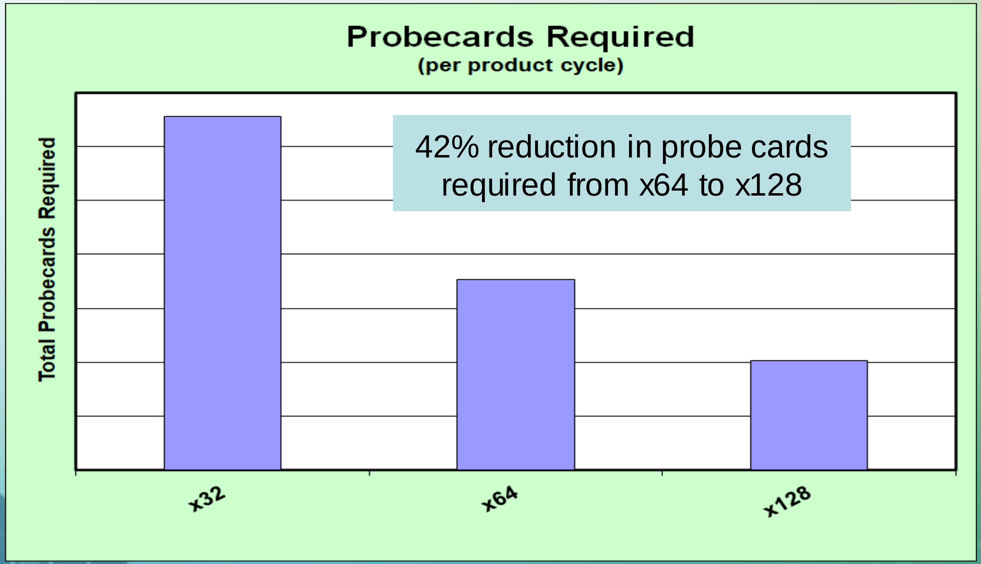


Meeting Cost of Test Reduction Challenges

- **Reduce cost of test with increased parallelism**
  - TCOO analysis
    - Key Assumptions
      - 5.0mm x 5.0mm die size
      - 300mm wafer
      - 30 sec test time

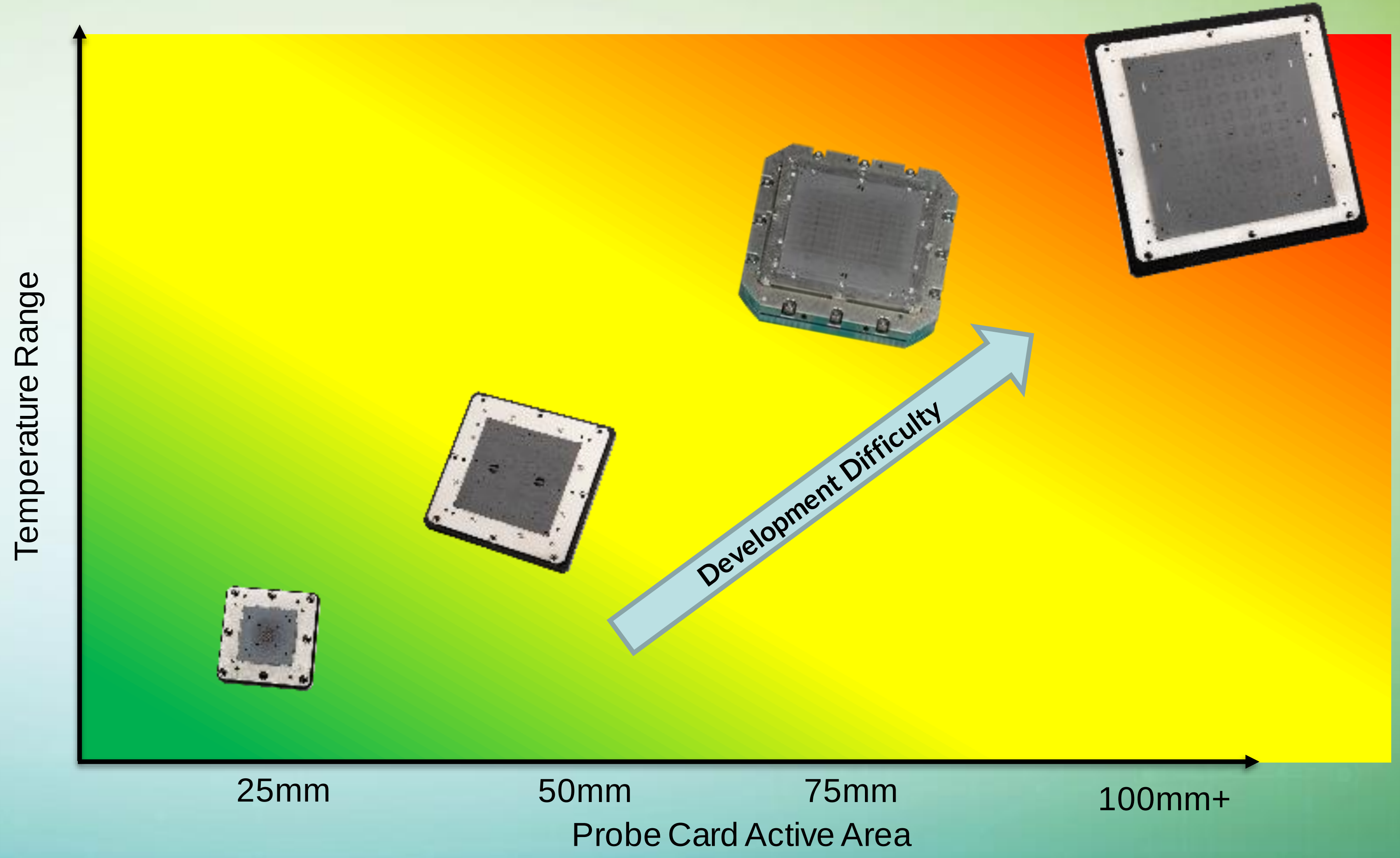






Increasing Probe Card Active Area

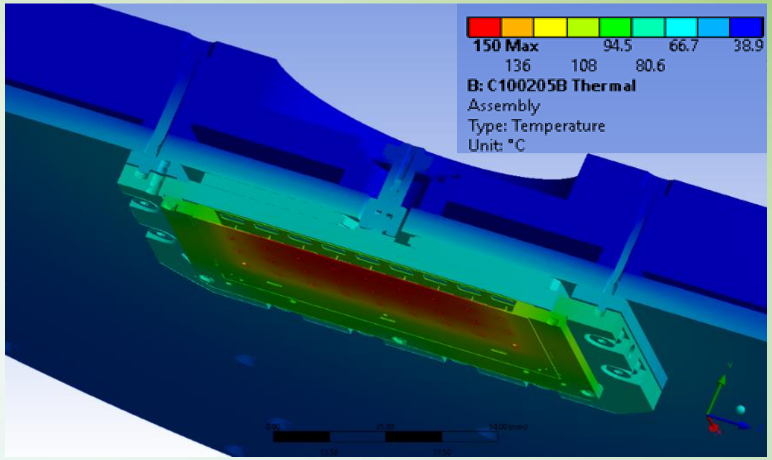
- **Increasing parallelism requires increased probe head active area**
- **Presents significant development challenges to overcome to meet probing requirements**
- **Must consider critical requirements**
  - Thermal effects
  - Device Layouts
  - Pad size/pitch
  - Electrical



As PH sizes and thermal requirements increase, CTE mis-match issues become significant challenge to overcome

Large Active Area Vertical PC Material Selection Strategy

- **Three step process used to optimize the materials of various LAA probe card components:**
  1. **Prediction of thermal gradient** on various components of the probe card by use of FEA simulation for the full temperature range
     → Chuck temperature of 150°C, 100°C temperature delta between the coldest and hottest components
  2. **Optimal material selection:**
     - Use thermal gradient derived from step one as input to thermal-mechanical model
     - Predict misalignment between various components and select best material combinations
  3. **Experimental validation** of optimal material set for the full probe card build



Thermal model of a probe card with prober chuck temperature set at 150°C

Model includes:
1. **Thermal conduction** of all parts of the assembly
2. **Contact conductance** between the different horizontal members
3. **Radiation** between the wafer and probe card
4. **Air conduction** between the wafer and PCBA

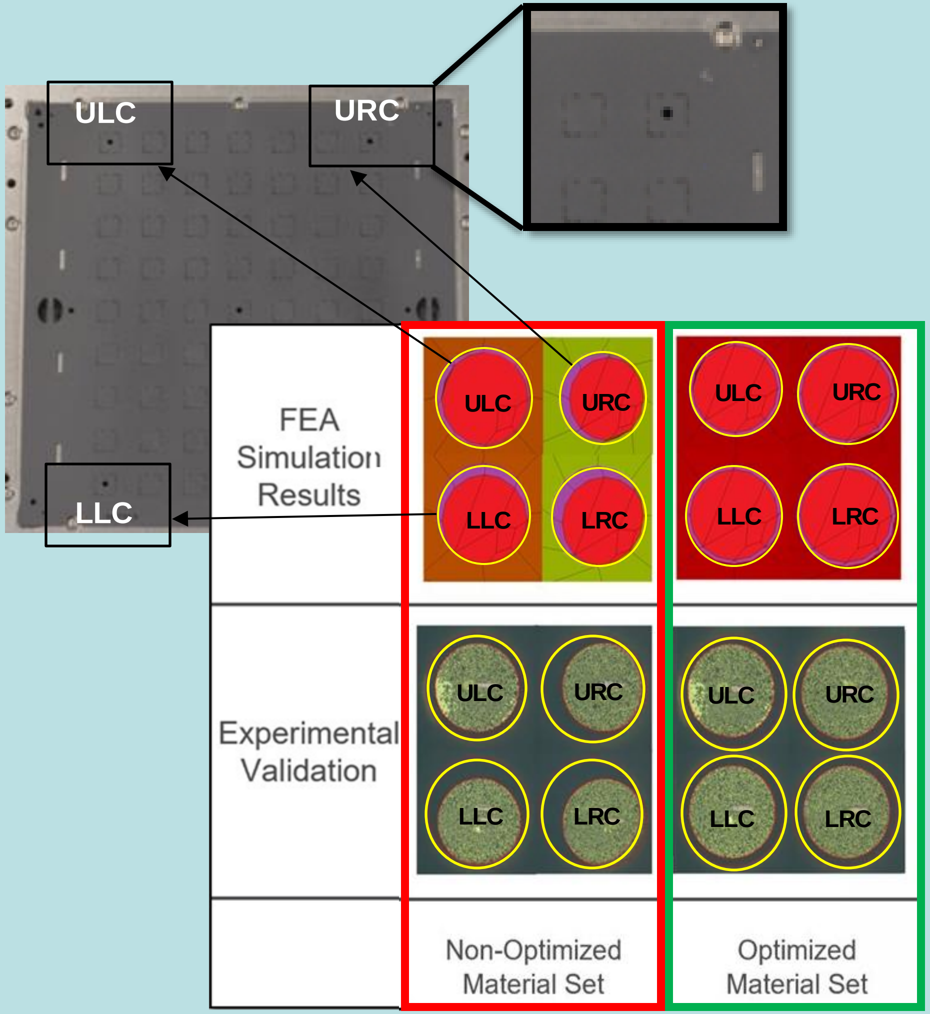
Vertical PC Components Material Selection Challenges

Component	Consideration	Solution
Guide Plates	CTE has direct impact on wafer bond pad size capability	Best match to customer wafer
Space Transformer (ST)	ST to probe misalignment	Best match to guide plate
Mounting Hardware	ST to probe misalignment	Best match to ST

- **Based on requirements of peripheral pad probing, FFI developed a solution based on an Multi-Layer Ceramic (MLC) ST**
  - Advantages include:
    1. Low to moderate levels of CTE of the MLC → stable thermal-mechanical performance
    2. ST flatness → good probe planarity

- **Optimized material set → stable thermal-mechanical performance**

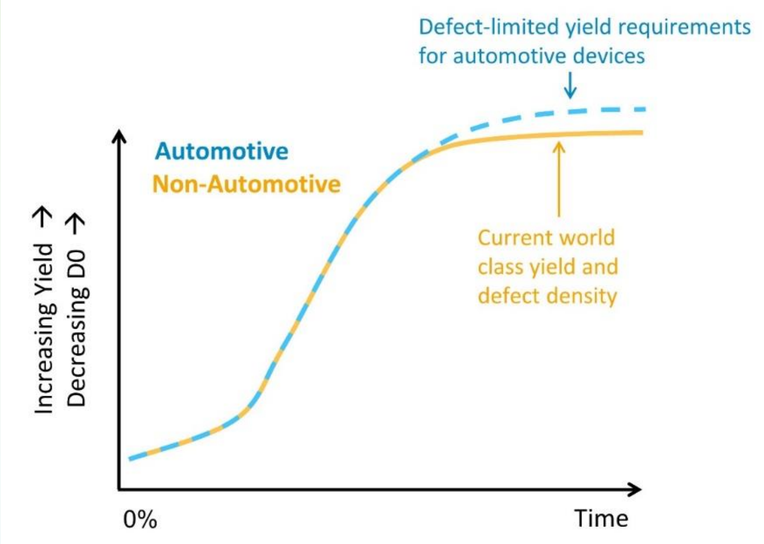
Guide Plate to ST Alignment Analysis



ST to Guide Plate Misalignment at 150°C

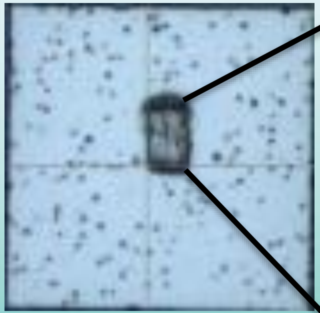
Bond Pad Integrity – Minimize Pad Damage

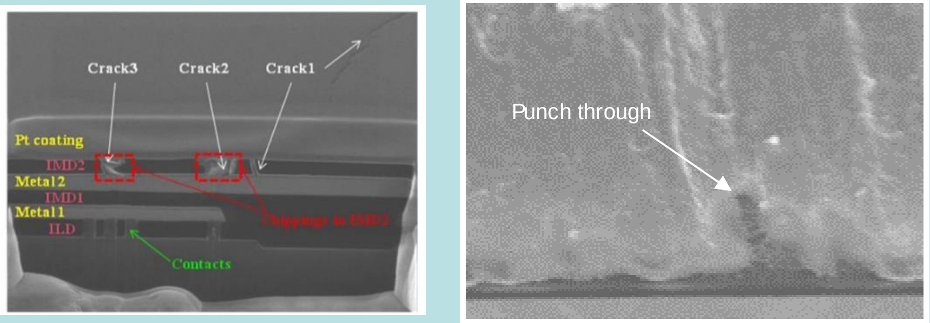
- "Reliability expectations for automotive devices are orders of magnitude higher than consumer devices"
- Bond pad damage must be held to a minimum – both surface area and depth
  - Need clean area for bonding the device
  - Zero tolerance for ILD cracking for UPC damage



Automotive IC Industry Trends – Semiconductor Engineering – Jan. 2018

	Low Force MEMS Springs	Medium/High Force Springs
Spring Force	1.2 – 1.5 grams at production OT to support minimal pad damage	4 - 12 grams at production OT - High force can create excessive pad damage



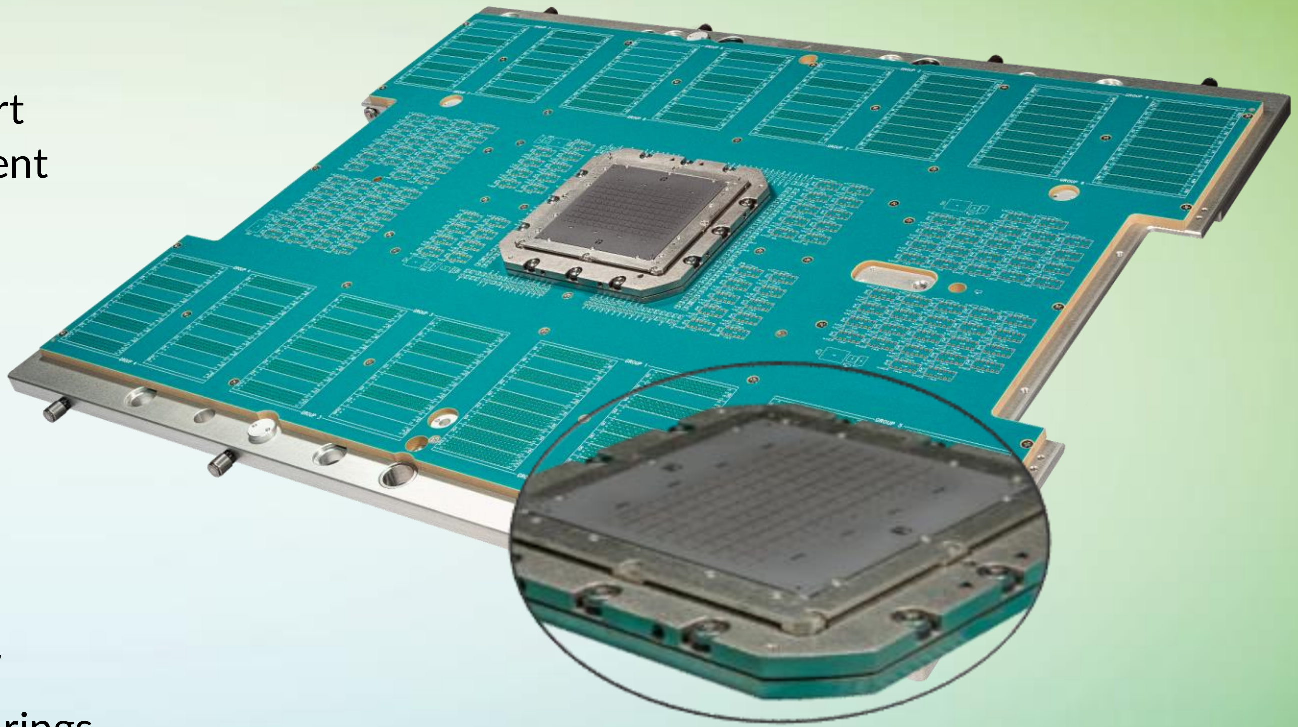


SEM images of pad damage issues causing device failures/issues

Meeting the Challenges of LAA Vertical Probing

- **Requirements:**
  - Thermally stable vertical spring architecture to support wide temperature range of automotive test requirement
  - Tight pad pitch, multiple pad rows, core pads
  - Probe on small pads with minimal pad damage
  - Stable electrical performance – low, stable CRES
  - Increase parallelism to reduce cost of test

- **Kepler™ Vertical Probe Card Features:**
  - Utilizes Multi-Layer Ceramic (MLC) space transformer
  - Proprietary fine pitch, low force vertical 2D MEMS springs
  - Full planarity/tilt adjustment capability
  - Flexible probe head configuration to support various device layouts, array sizes and pad pitch requirements
  - Service friendly architecture – field replaceable springs and components



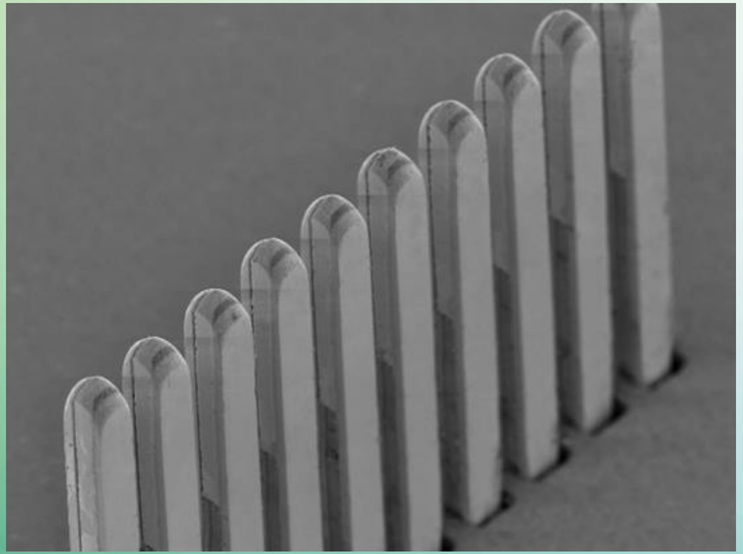
128 site, 60um Pitch, 10K Probes, V93K DD

Experimental and Qualification Results

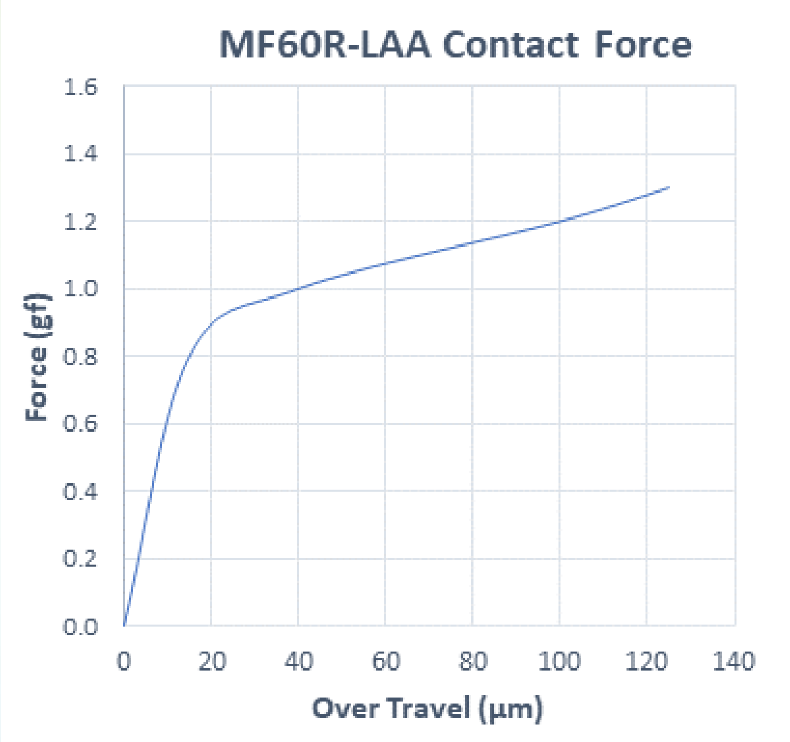
- **Low force spring performance**
  - 60um pad pitch capable
- **Scrub mark results**
  - Minimal pad damage and placement
- **Thermal performance**
  - Scrub mark position at temperature extremes
- **Planarity results**
  - Capability at 75mm active area
- **CRES performance**
  - Stability at temperature
- **Lifetime study**
  - Confirm low wear rate

FFI MF Family Low Force 2D MEMS Spring

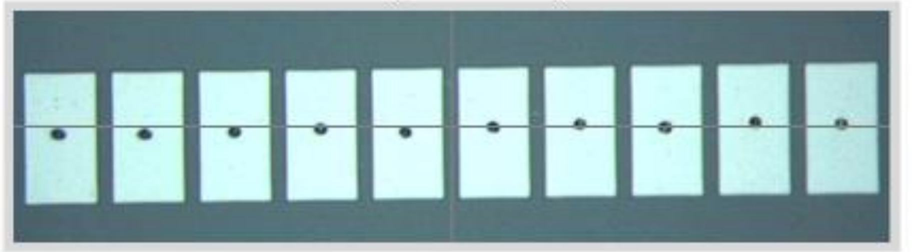
- Utilizing FFI low force 2D MEMS MF spring family, developed a solution for 60um pitch pads applications



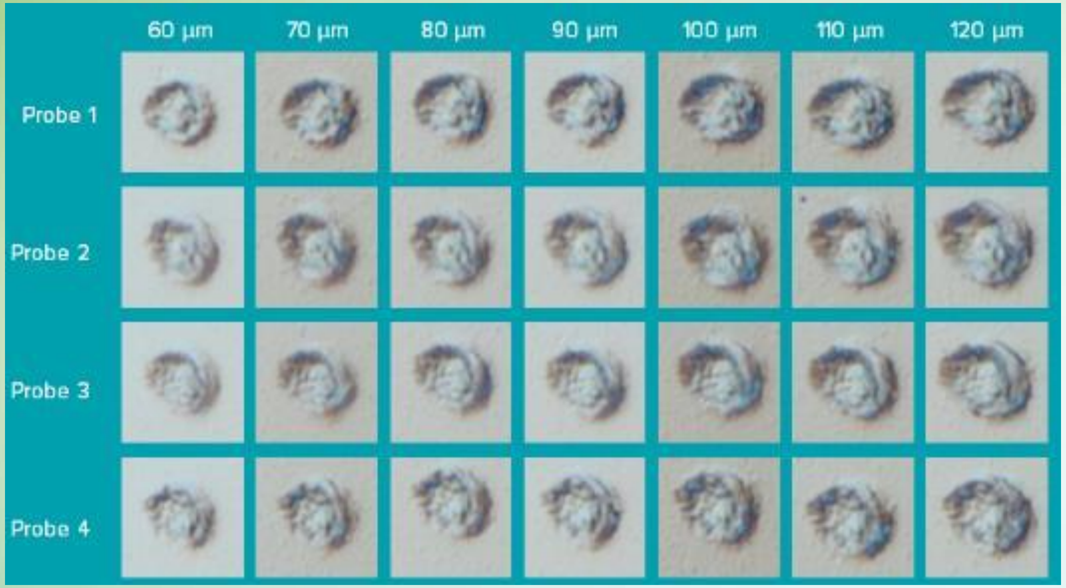
60um pitch SEM and Optical Images



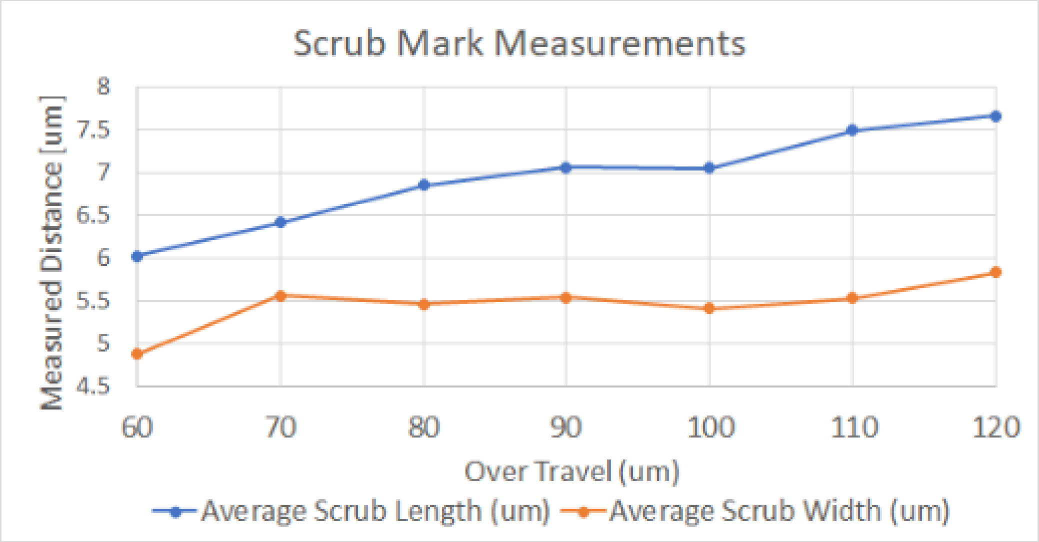
60um pitch probe marks on 55x65um Al pads @ 125C (100um OT)



Scrub Mark Results



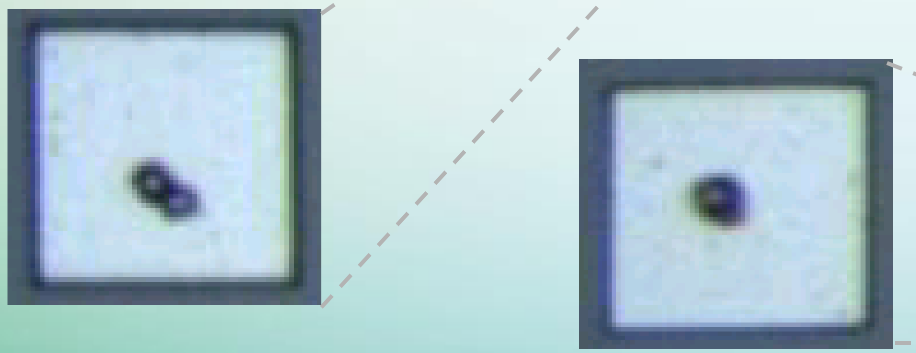
Optical images of scrub marks

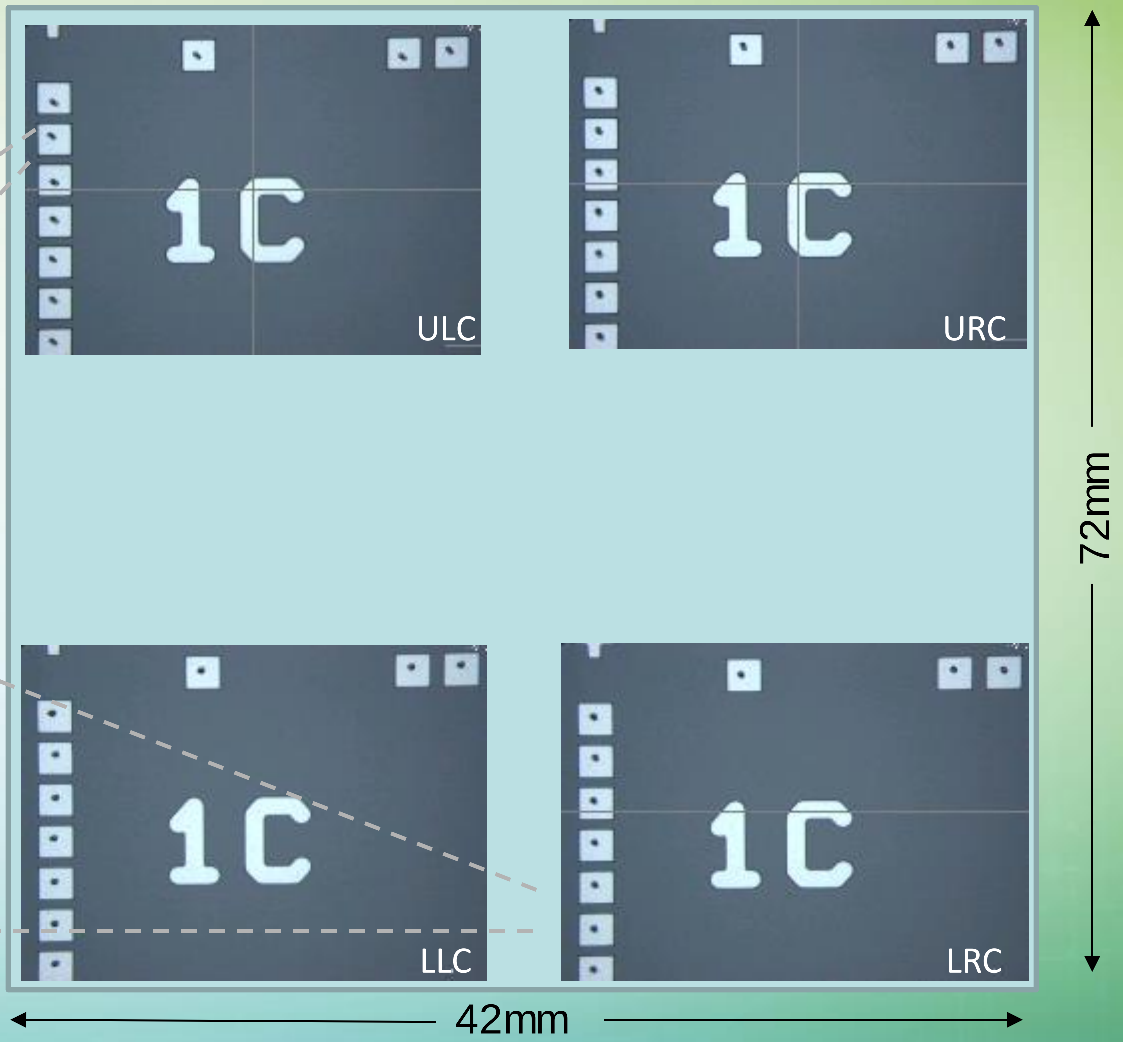


- **MF60R minimizes pad damage**
  - Small scrub mark from low force vertical spring minimizes pad damage area
  - Very low risk of punch through due to small scrub mark with minimal lateral scrub

Kepler™ Thermal-Mechanical Performance

- **Experimental Set-up:**
  - Parallelism: x128
  - Array size: 42mm x 72mm
  - Pad size: 55um x 55um
  - TD data collected at -40°C, 25°C and 150°C
  - Scrub mark images from upper right corner of die from four corners of the array



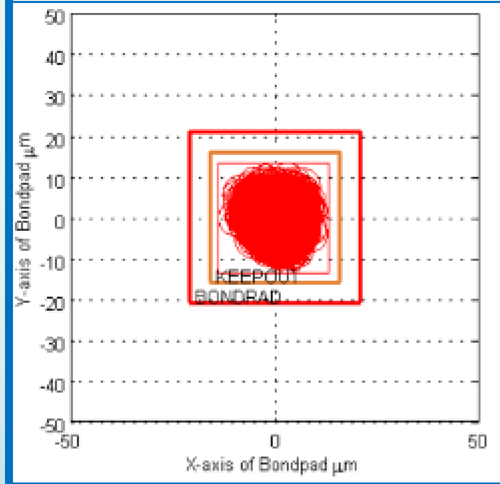


Scrub marks from temp range of 190°C landing in same pad area across the full PH array

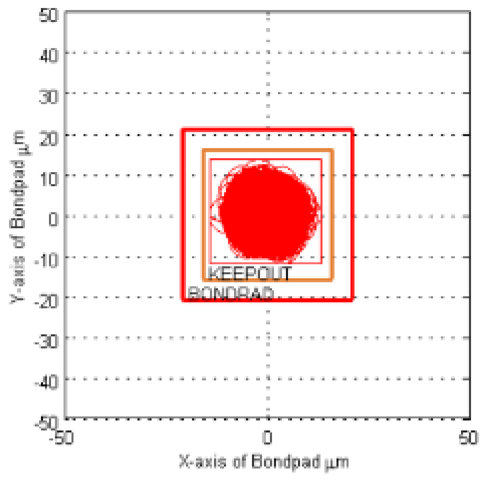
Super Bond Pad Capability at Full Temp Range

- **Super Bond Pad (SBP):**
  - Consolidation of scrub marks superimposed on top of each other to establish a single virtual pad representing all scrub marks
  - SBP calculation removes systematic errors not associated with the probe card capability

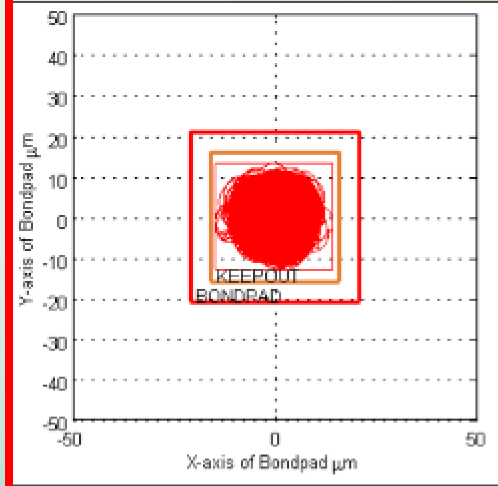
  - Parallelism: x128
  - Array size: 42mm x 72mm
  - Pad size: **42um** x **42um**
  - Keep out: 5um
  - 100% of scrubs in pad area meeting the keep out spec



SBP Size = 27x27um
@ -40C



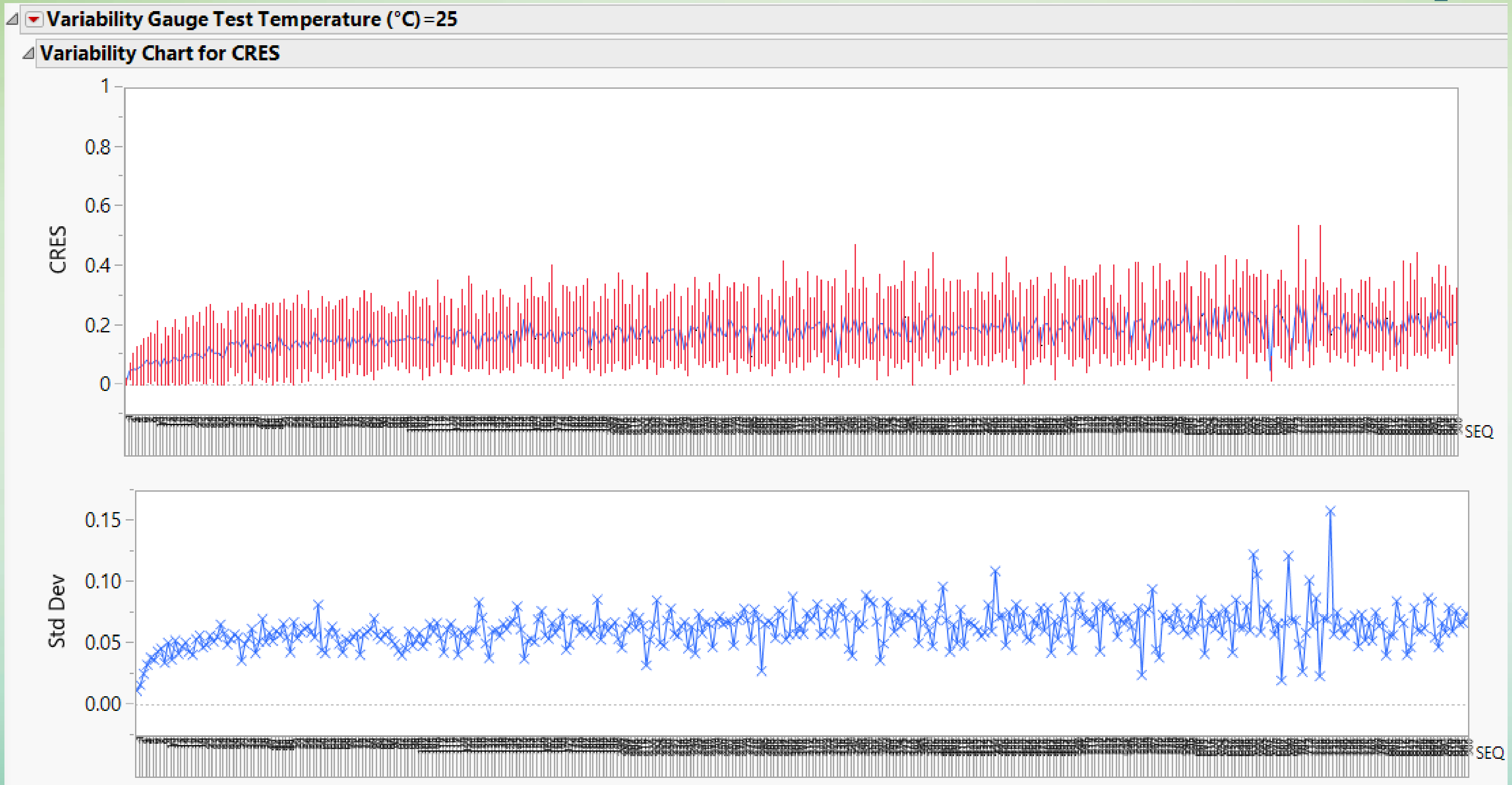
SBP Size = 28x26um
@ 25C



SBP Size = 29x26um
@ 150C

SBP performance <30um per side through entire temperature range

CRES Performance at Room Temperature



Test Conditions: 1000 TD on blank Al wafer at 100um OT

Kepler™ achieves low and stable CRES

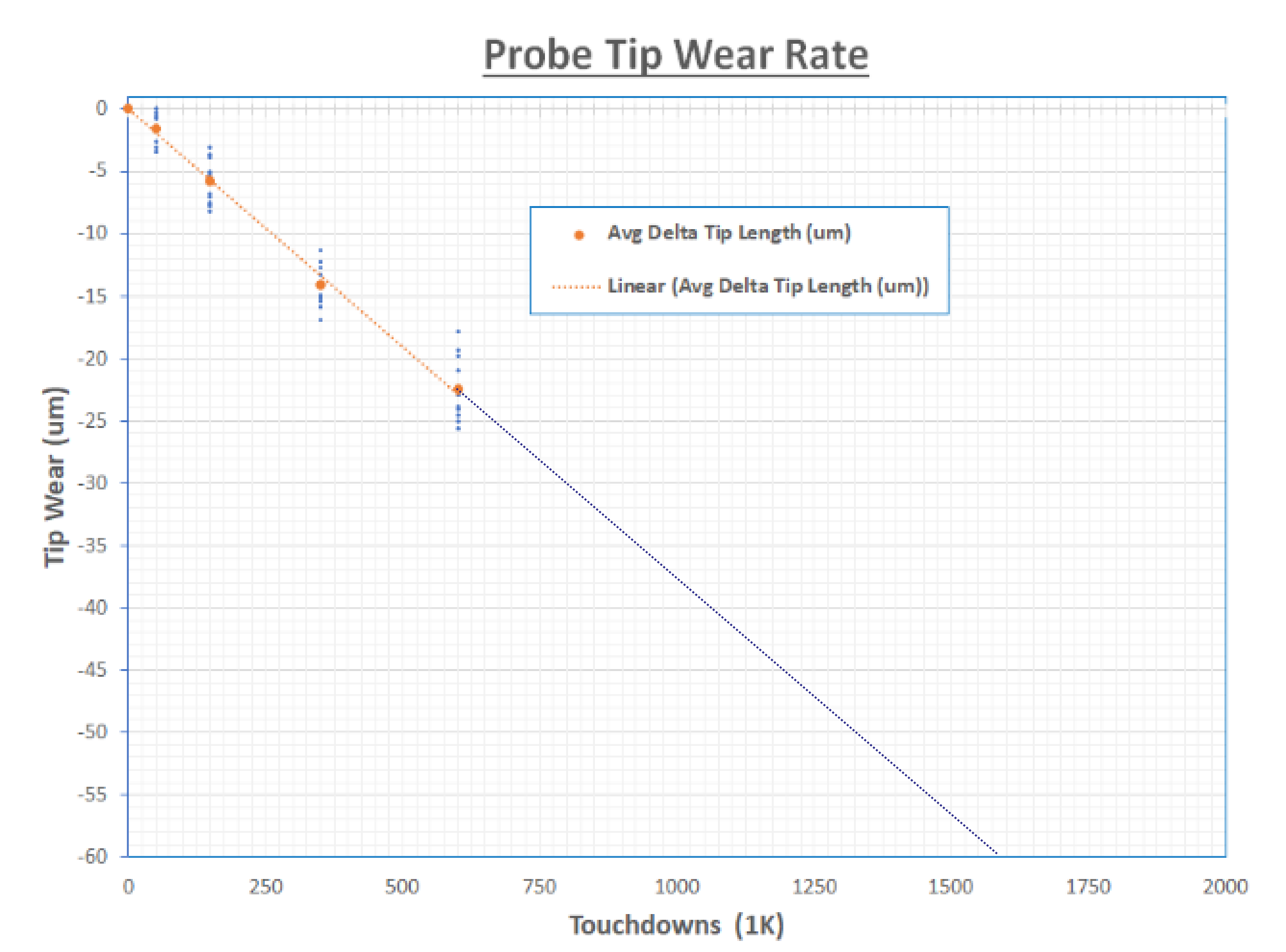
Wear Rate Study Results

Objective:

- Establish probe tip wear rate during production use case

Experiment:

- Accelerated study – 100um OT on Al pads
- Tip length was measured at 50K, 150K, 350K and 600K TDs
- Continue to measure tip length at every 500K TD intervals
- Optimized cleaning recipe with WA6000-SWE

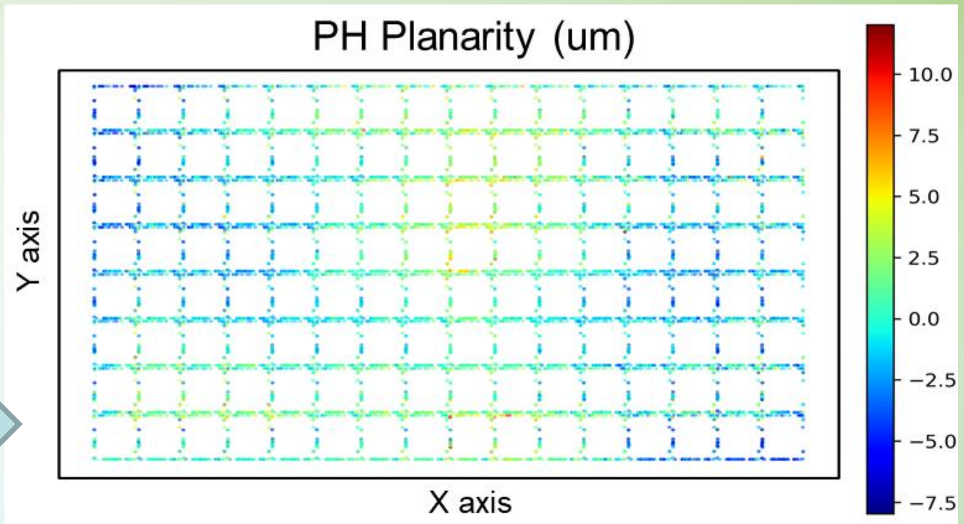


Data projects >1.5M TD lifetime

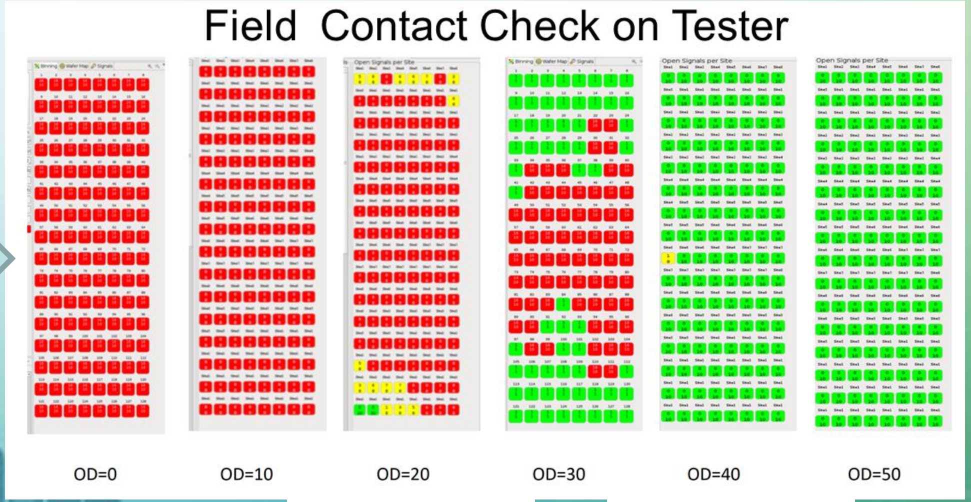
Large Active Area Planarity Performance

- **Planarity measured on PRVX on large active area array:**
  - Array size: 42mm x 72mm
  - Parallelism: x128
- **Measured outgoing planarity <20um on entire array**

Planarity	Min.	Max.
19.9 um	-7.9um	12.0um



  – **Incoming planarity collected with contact check for first to last electrical touch confirmed ~25um planarity across full array**



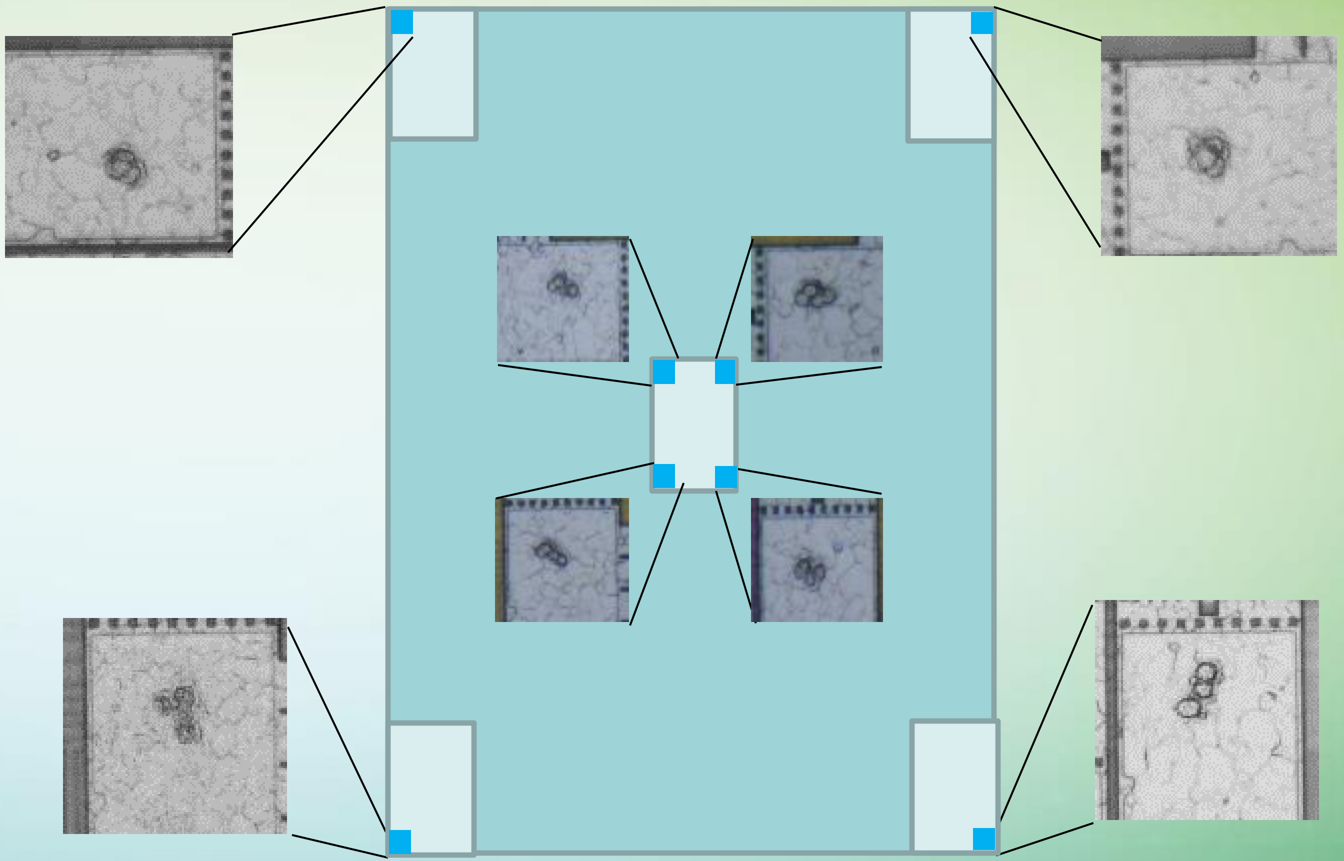
First Touch @ 20um OD

All Touch @ 40um OD

Thermal-Mechanical Performance – Customer Validation

- **Experimental Set-up:**
  - Parallelism: x128
  - Array size: 42mm x 72mm
  - Pad size: **42um** x **42um**
  - TD data collected at 150ºC ,-40ºC, 25ºC and repeated at 150ºC

- **Scrub marks at all edges of the array landing in very small area – minimal pad impact**



Architecture demonstrating very stable scrub mark placement from -40ºC to 150ºC

Summary

- **Strong automotive IC market growth requiring large active area solutions for wire bond applications**

- **FFI has developed a large active area vertical probe card solution**
  - Addressed challenges related to CTE mis-match to meet increasing test requirements
    - Thermal-mechanical stability over wide temperature
    - Tight pad pitch
    - Small pad sizes
    - Tight planarity and scrub mark position
    - Stable and low CRES
    - Long life-time
  - Flexible low force vertical MEMS architecture to reduce cost of test with increasing multi-site capability

Acknowledgements

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  - Doug Ondricek – FormFactor