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Key Considerations to Probe Cu Pillars in High Volume Production

GLOBALFOUNDRIES
FORMFACTOR INC.

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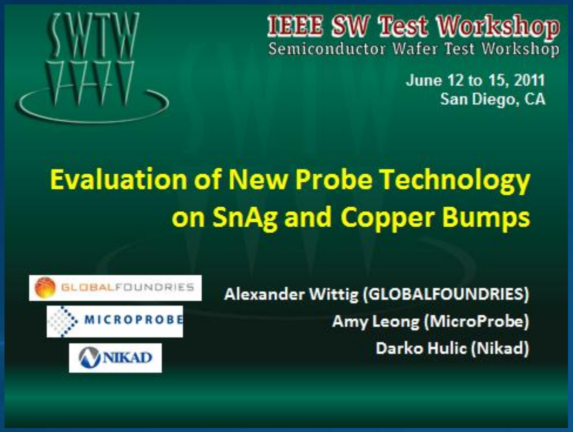
Overview

- **Key Industry Trends**
- **Applying Lessons Learned from 100um Pitch CuP Production Probing to Optimize 80um Solution**
  - 3D Low-force (vertical & lateral probe force)
  - Alignment Control
  - Current Carrying Capability
  - Probe Assembly Throughput
- **Summary**

Chapter 4 of Cu Pillar Probing Study

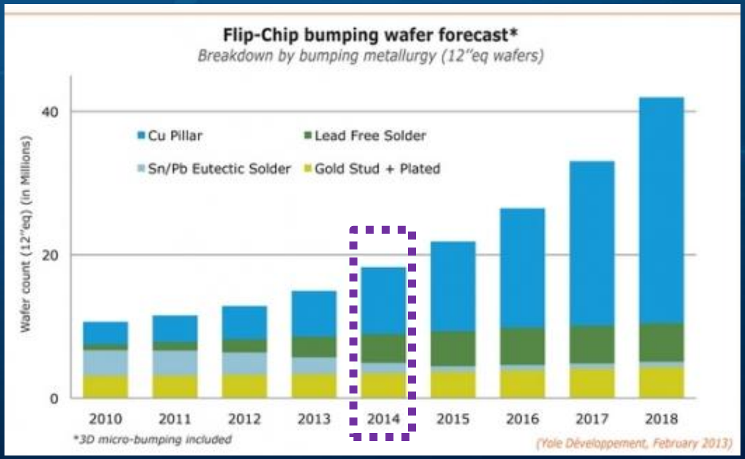


2011: 150um Pitch Cu Pillar Probing

2012: 120um Pitch Cu Pillar Probing

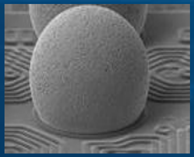
2013: 100um Pitch Cu Pillar Probing

- **In 2014, Cu Pillar is becoming the mainstream flip-chip packaging technology (Source: Yole)**
- **Key issue is "How to best prepare for fine-pitch Cu Pillar probing in high volume production?"**

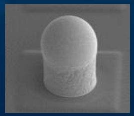


Applying Lessons Learned from 100um Pitch CuP Production Probing to Optimize 80um Solution

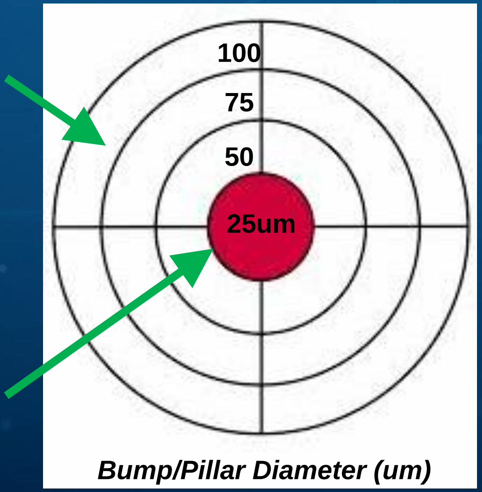
- **Standard Cobra probes are vanishing for leading edge Cu Pillar (CuP) probing**
- **FormFactor has shipped >3000 units of CuP MEMS probe cards used in high volume production, hundreds of custom designs**
  - CuP pitch ranges from 130um to 100um today, rapidly moving into 80um
  - CuP diameter shrinks accordingly from 70um to sub-30um
  - A typical probe card has 5,000 to 25,000 probes
- **Many factors, which seem to be trivial for 150um pitch solder probing, need to be carefully considered when probing sub-100um pitch CuP in high volume production**



150um Pitch Solder Bump



Sub-80um Pitch Cu Pillars



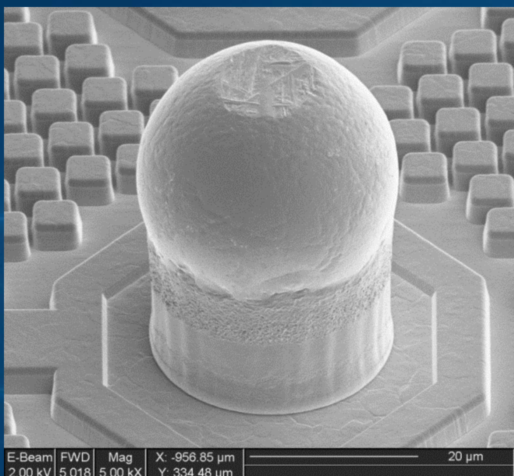
<u>Aiming Accuracy for 80um Grid-array Pitch CuP Probing in HVM</u>

Hit The Bull's Eye
100% Success Rate
20,000+ Arrows Simultaneously

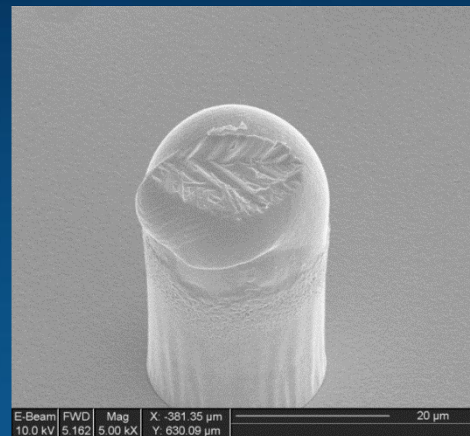
HVM CuP Probing Essentials
Key Differences Between Solder and CuP Probing

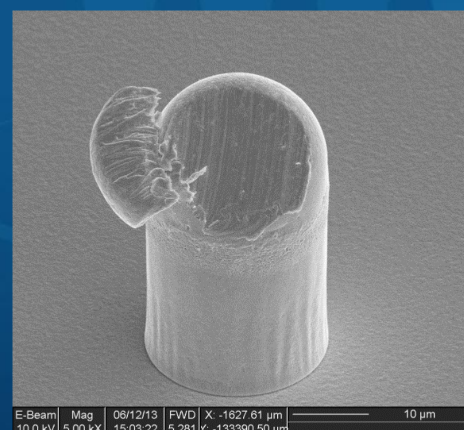
- **3D low-force probing and impact on probe marks**
  - z-force and x/y shear force
- **Probe-tip to Cu Pillar alignment**
  - What x/y alignment target is good enough?
  - Probe card x/y alignment, throughout the product life time
  - Operational optimization (Prober setup, cleaning, etc)
- **Current Carrying Capability @ Fine-Pitch**
- **Probe Assembly Throughput**

Cu Pillar Probe Mark Photo Gallery

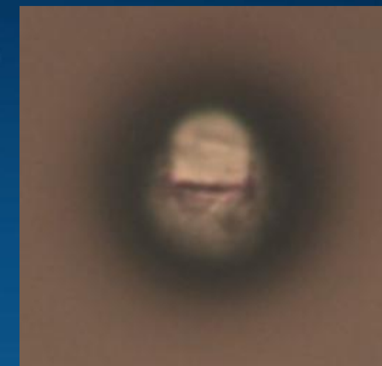


Pass
Good Probe Mark on 30um Cu Pillar

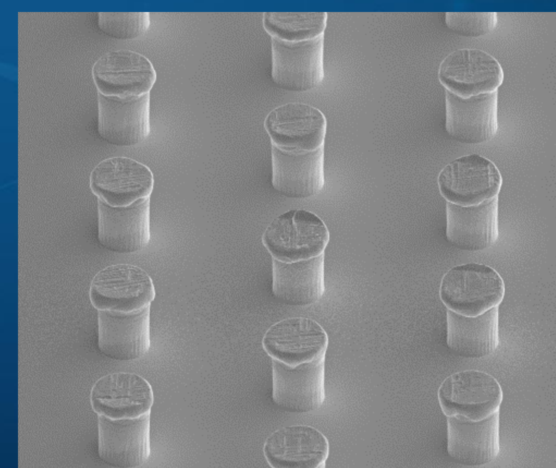




No Pass
Cu Pillars with Sheared Solder Cap



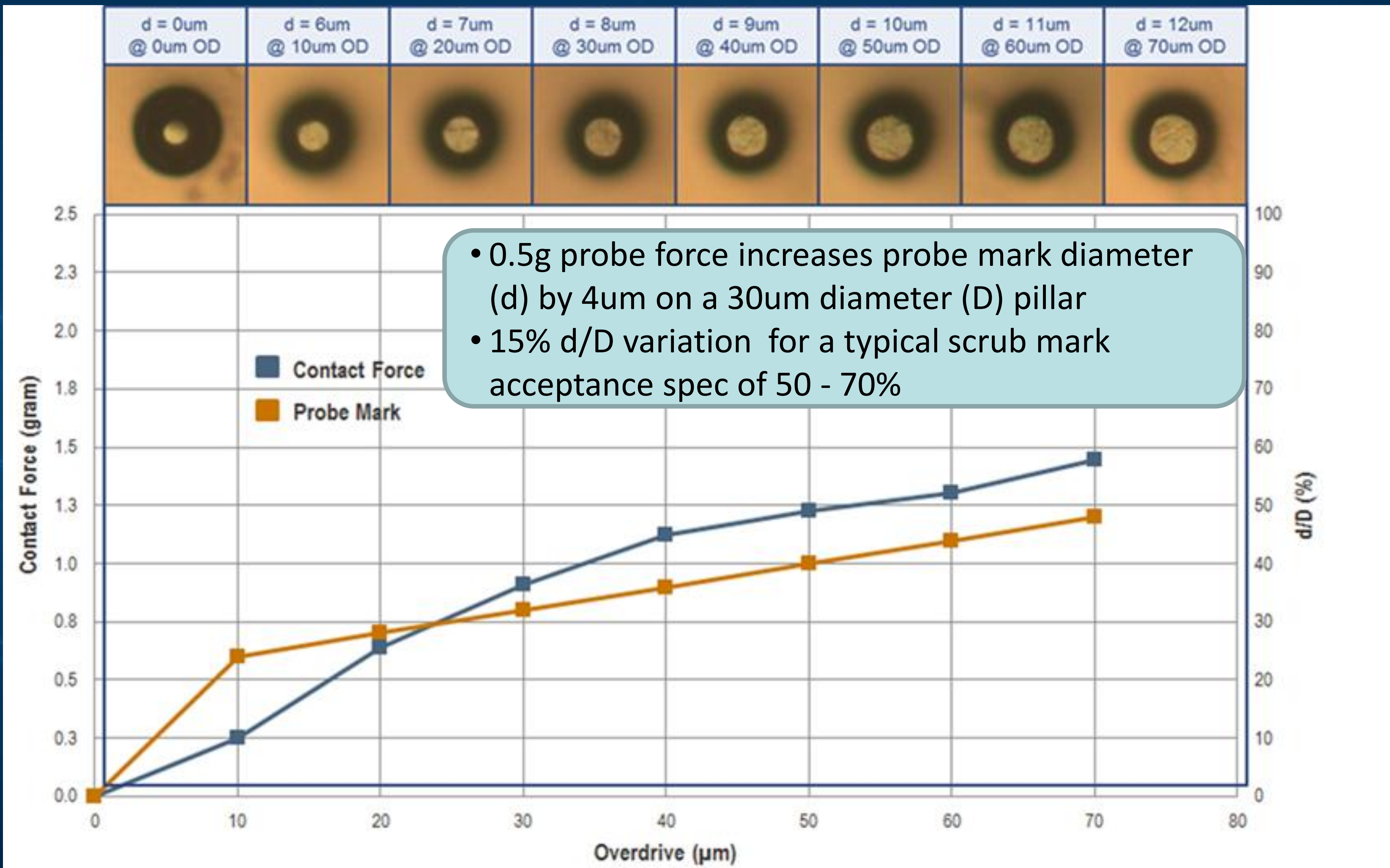
No Pass
Misaligned Probe Tip



No Pass
Probe force too high

Impact of Z-force on Scrub Mark Size

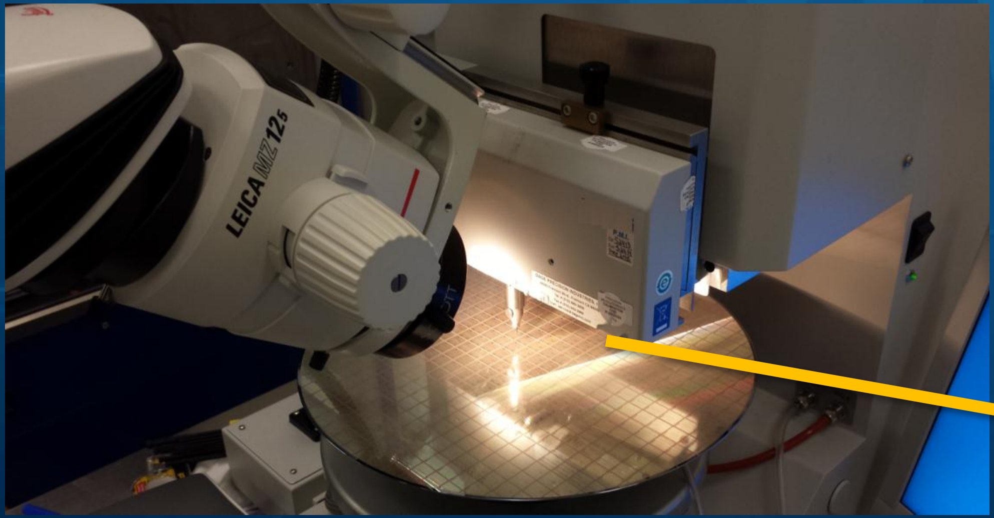
Probe mark size is more sensitive to z-force @ 80um pitch



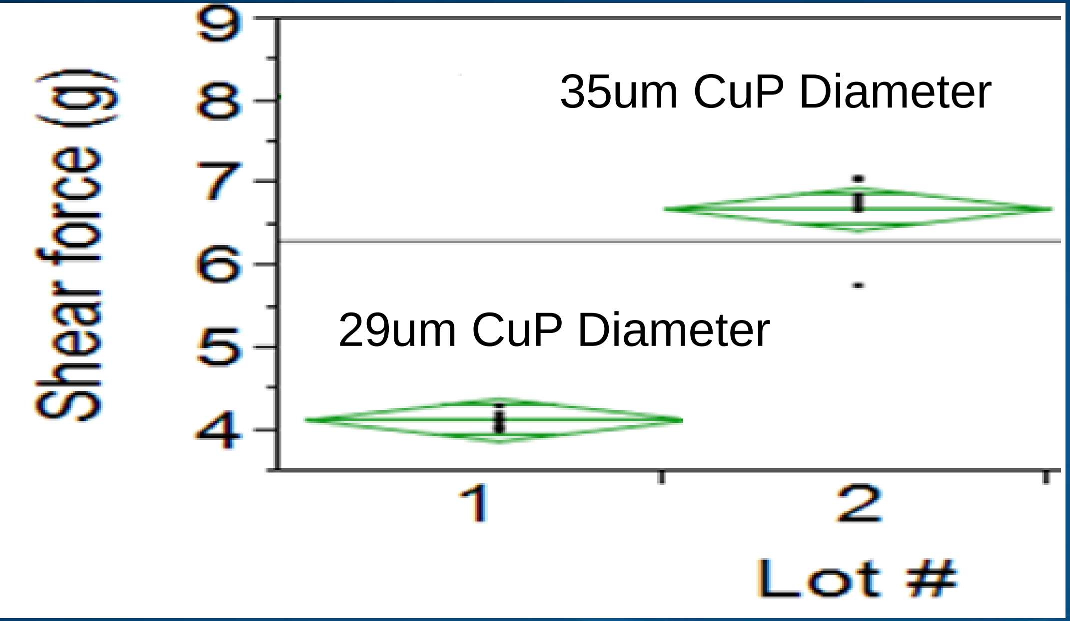
- 0.5g probe force increases probe mark diameter (d) by 4um on a 30um diameter (D) pillar
- 15% d/D variation for a typical scrub mark acceptance spec of 50 - 70%

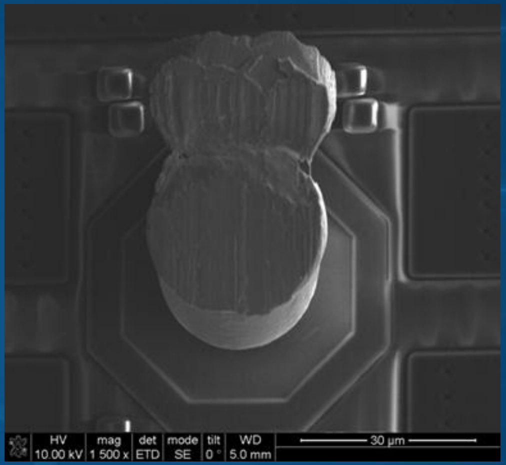
FFI Shear Force Tool for CuP Wafer Characterization

- FFI shear force measurement tool with ultra-fine stylus
- Stylus moves horizontally to push solder materials
- Shear force is measured as solder cap being displaced



Solder Cap Destructive Shear Test Results
Less solder volume, Easier to shear off the Cap

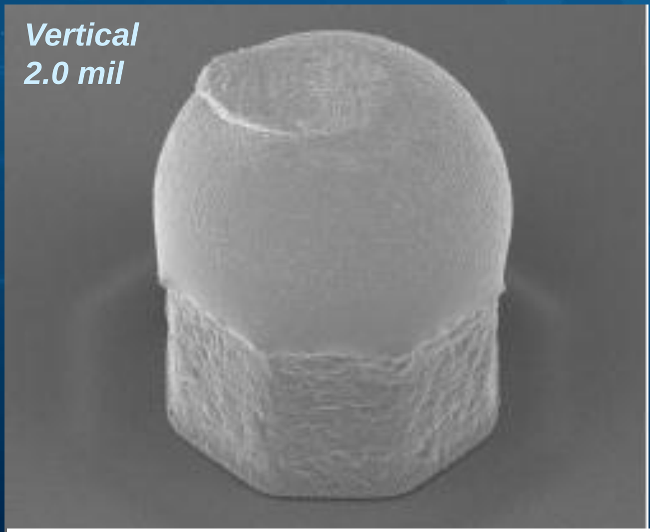


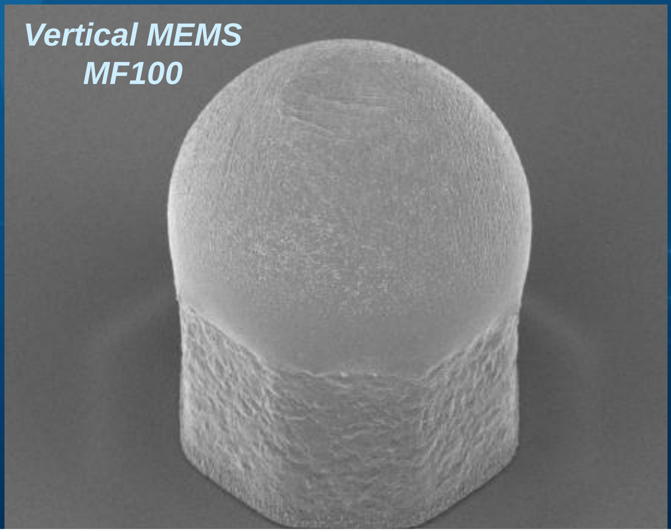


- **Shear height = 26µm, Shear velocity = 50µm/s**
- **17% reduction in CuP diameter leads to ~ 40% more fragile solder cap to lateral shear force**

Low Vertical & Lateral Probe Force is Essential
To Probe 80um Pitch CuP in HVM to Ensure Packaging Reliability

- **Pictures below illustrate that 2 mil probe, with similar z-force but higher lateral force, induce more solder cap disturbance compared to a low-impact vertical MEMS probe (FormFactor's MF100)**
- **Benefit of low-impact probing**
  - Minimizes solder material displacement on the solder surface
  - Eliminate the need for additional reflow post wafer probing (due to solder damage)
  - More even force at pillar footing for better packaging reliability

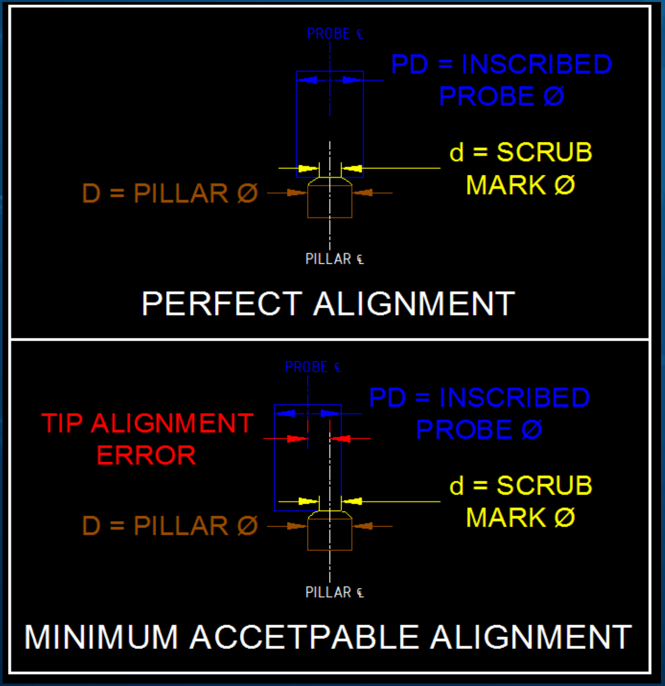




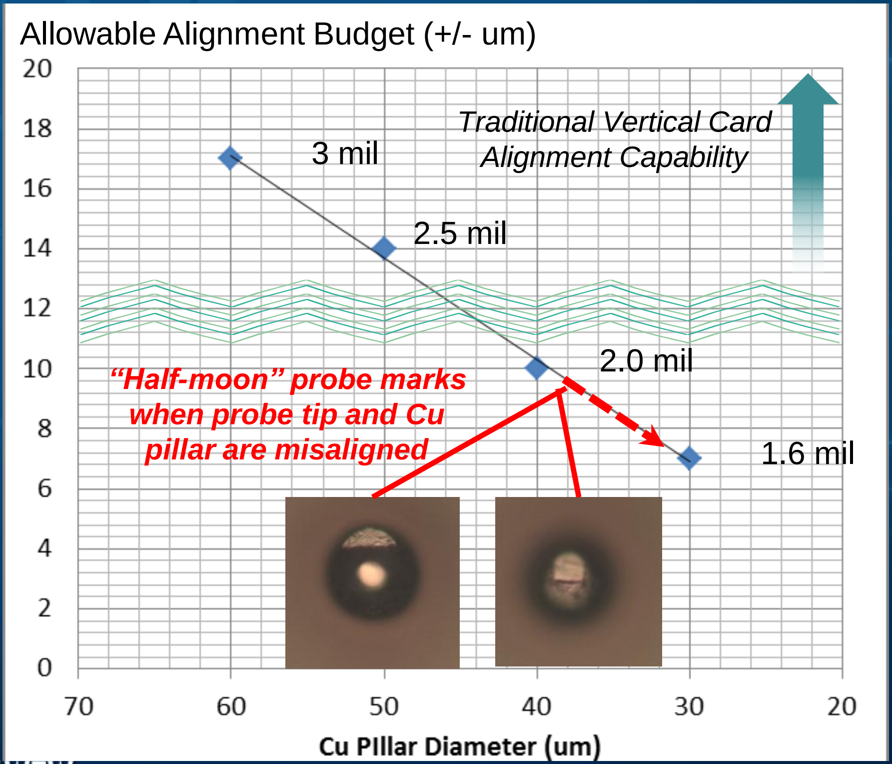
Probe Mark Comparison of Vertical MEMS MF100 vs. Vertical 2.0mil

What is the allowable Probe tip-to-Cu Pillar Alignment Tolerance for CuP Probing in HVM?

- **Really depends – Probe tip geometry relative to Cu Pillar diameter**
- **But for sure --- Allowable alignment budget between probe tip and Cu Pillar decreases as pitch and pillar diameter shrink**

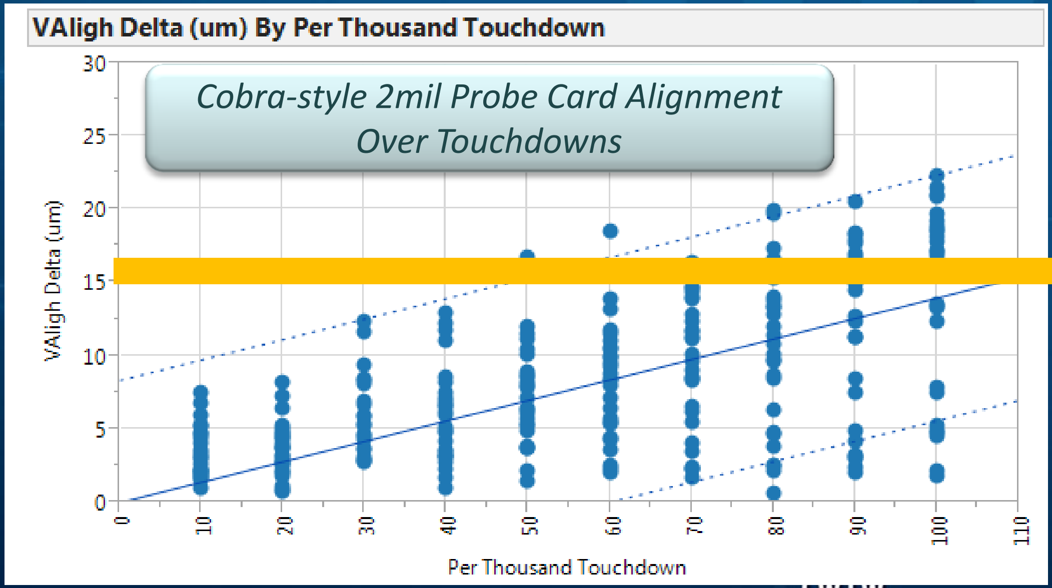


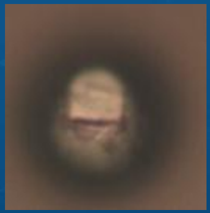
Source: SWTW 2013 Wittig



Good Probe Tip-to-Cu Pillar Alignment is Crucial
Not Just At The Beginning, But Also At the End of Life

- **Cobra-style vertical probe cards are good enough for larger pitch solder flip-chip probing**
  - Don't have to be super accurate to hit the "Dart Board"
- **For CuP production, probe tip-to-CuP alignment stability is crucial**
  - Aiming accuracy must be excellent to hit the "Bulls Eye"
- **Alignment maintenance challenges associated with cobra-style 2mil on 80um pitch CuP**
  - Cobra-style 2mil probe alignment was optimized initially to meet alignment requirement
  - After 40,000 touchdowns, probe tip x/y position began to drift outside the CuP alignment tolerance window
  - Frequent probe tip adjustment (tester down-time) or costly reflow would be needed





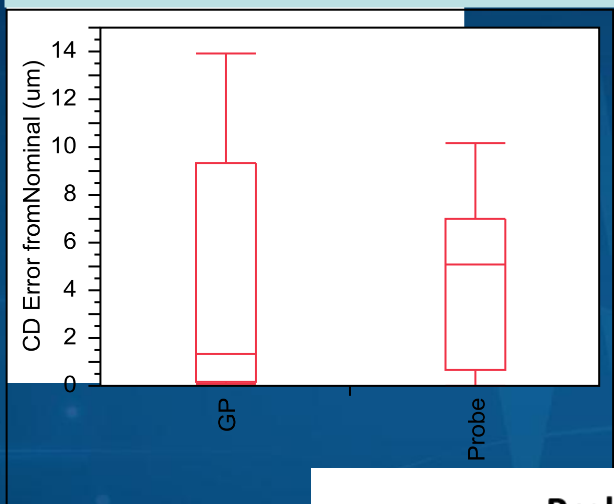
No Pass

Alignment accuracy needed to ensure acceptable scrub mark

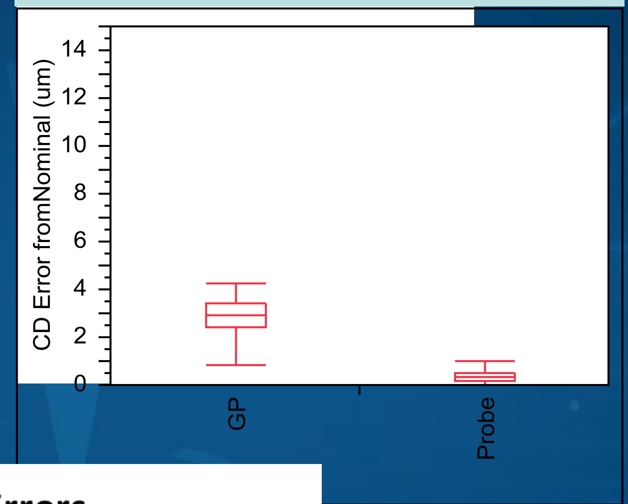
Pass

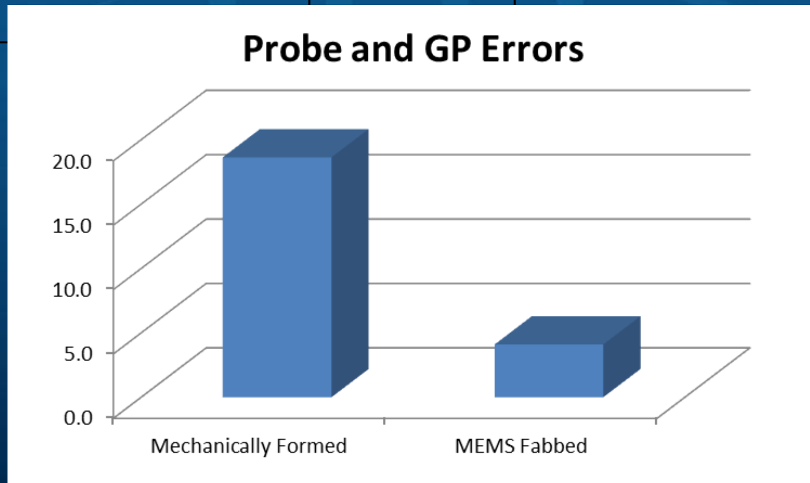
Dimensional Control Improved With MEMS-Based Fabrication Processes

Mechanically Formed



MEMS Fabbed





- Raw “as-fabbed” distributions
- Indicative of natural process capability

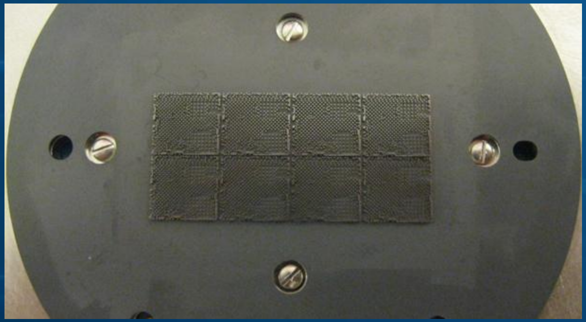
Source: SWTW 2013 Slessor

Essential Factors to Improve Alignment for 80um Pitch CuP Probing in HVM

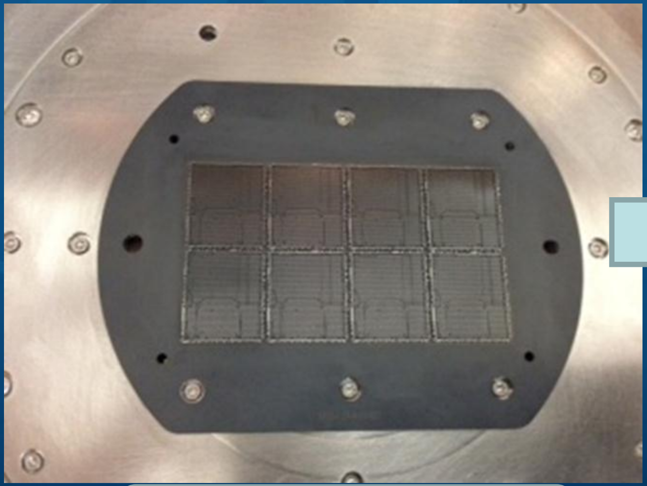
- **Factors to Consider to Maximize Production Uptime**
  - **Prober Setup Optimization**: general algorithm for solder bump probing doesn't work any more
    - Fine-tune the probe-tip recognition alignment recipe to the specific probe type
    - Recognition of the bump needs to be tuned and developed, since the geometry of the Cu pillars are near the limit of the prober optics
    - Maximum allowable probe card planarity needs to be tightened
  - **Probe Tip cleaning:** tip clean with minimal side movement
    - More gentle cleaning materials, i.e. 1um lapping film, as opposed to 3um
  - **Probe Tip X/Y Positioning**: Well maintained x/y spec throughout lifetime
    - MEMS Probes with dimensional control ~5x improved over mechanical formed
    - MEMS formed guide-plates with position ~3X improved accuracy
    - Design and material selections of MEMS probes & guide-plates to minimize x/y positioning drift over life-time

80um Pitch CuP Alignment Scalability
For Multi-sites and Wider Temperature Testing

- **Multi-sites testing will continue to drive up pin counts and probing active area**
- **Dual temperature probing, -40 to 90C**



100um Pitch, 6k Pins
30mm Diagonal Active Area

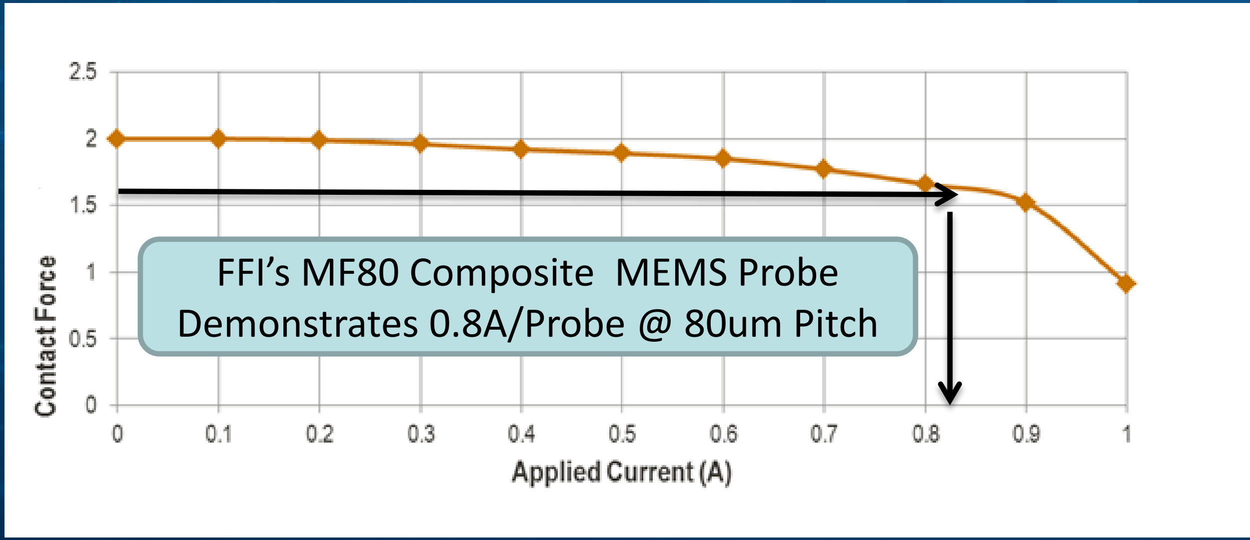


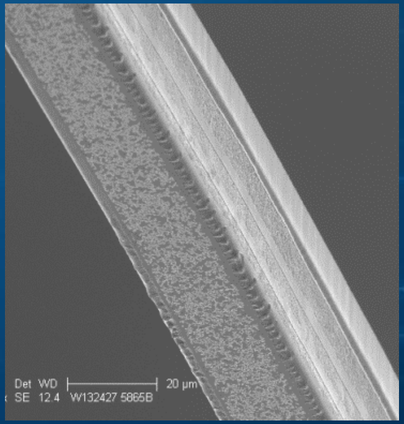
100um Pitch, 25k Pins,
50mm Diagonal

80um Pitch, 30k Pins
>60mm Diagonal

Composite Material MEMS Probes Enables High Current-Carrying-Capability @ 80um Pitch

- Carrying more current through a smaller cross-Section @ 80um CuP pitch is challenging compared to larger probes @150um pitch
- Transient currents can be significantly higher than 0.5A/probe in HVM
- High CCC probe is essential to prevent probes degrade and get plastically deformed in the event of high transient current





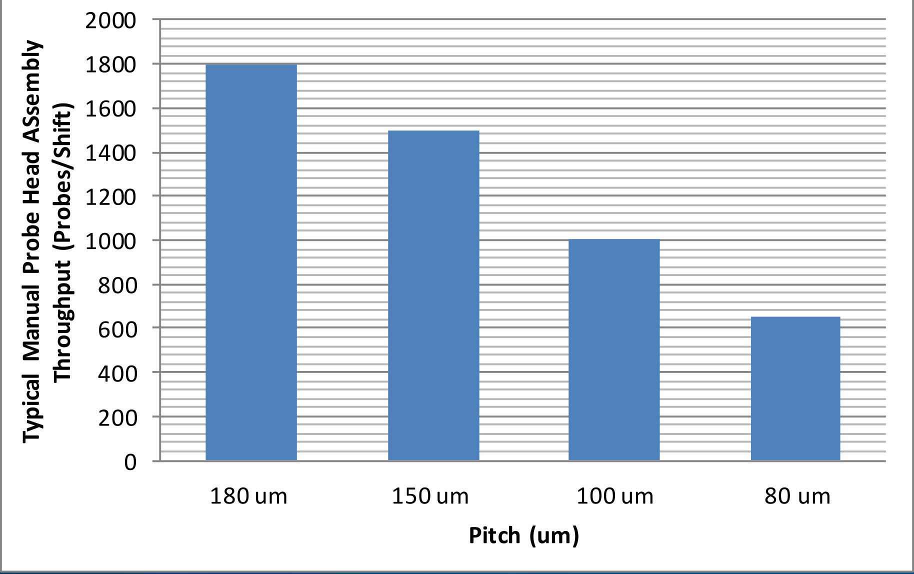
Composite MF80 MEMS Probe with different materials, in different locations, with micron-level precision

Mechanically Formed Vertical Probes Give Way to MEMs Probes Below 100um Pitch

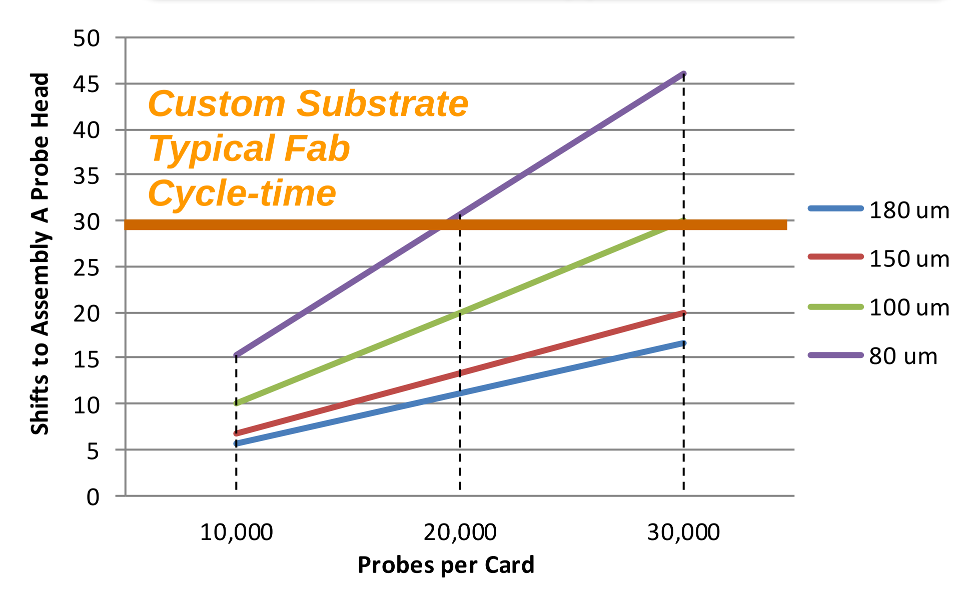
- Mechanical Tolerances for Stamped probes are inferior to MEMs structures
- Guide Plate Mechanical Drilling is Inferior to MEMs Guide Plate Formation Technology
- Tip Geometries are Poorly Controlled by Stamping and Forming Versus MEMs fabrication
- Contact Materials are Limited to Bulk Alloys for Mechanical Probes but are By Design for MEMs probes.
- Stable Contact at Low Probe Forces is Enabled by MEMs contact Design.

Probe Assembly Throughput Is Becoming An Issue for Probe Card Cycle-time @ 80um CuP Pitch

Vertical Probe Assembly Throughput Decreases with Slimmer Probes



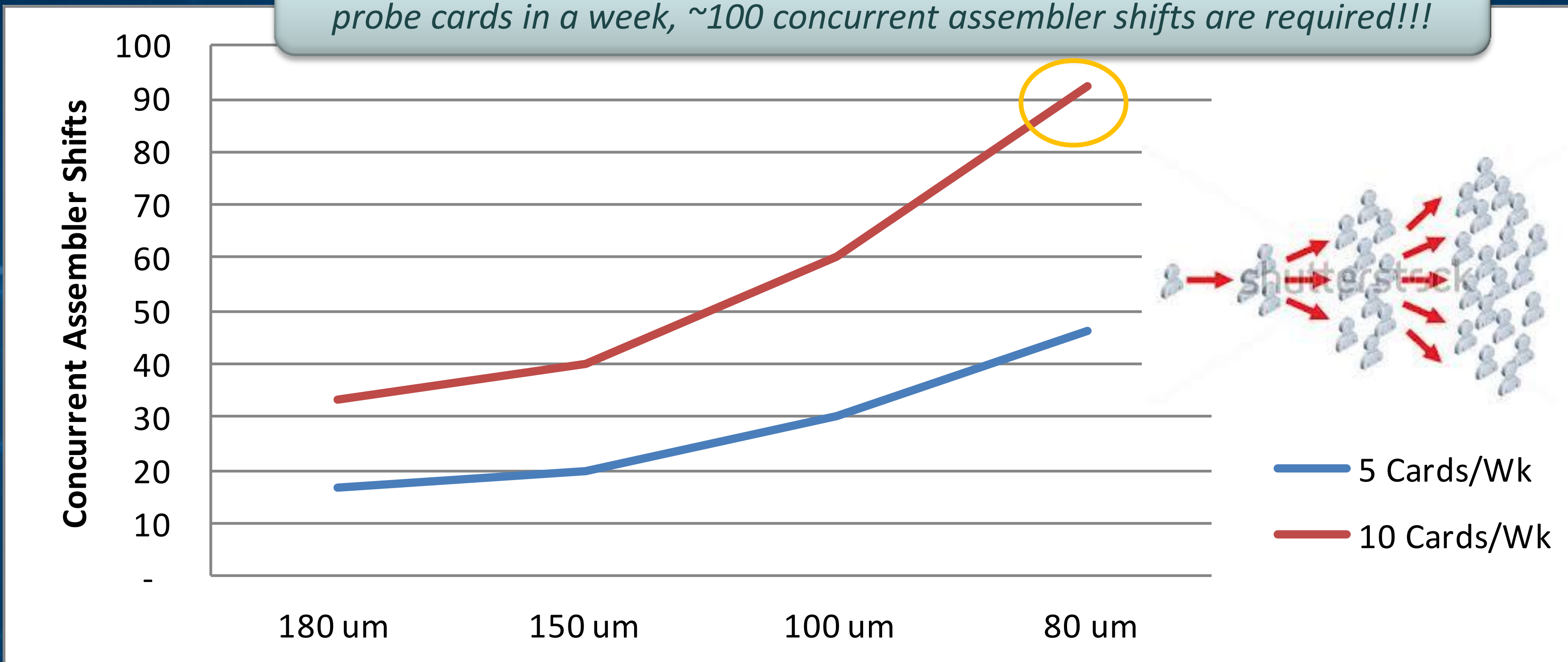
Probe Head Assembly Is Becoming the Critical Path to Probe Card Cycle-time As Pin Counts/Probe Card Approaches 20k Pins

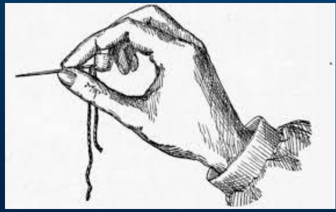


Time-to-Volume Ramp-up @ 80um CuP Pitch

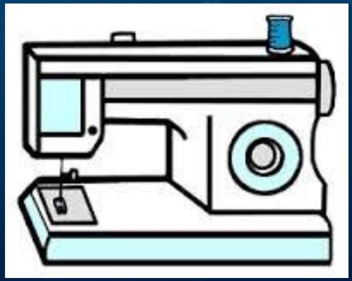
What if 5 or 10 cards are needed in a week to address peak demand?

With manual probe head assembly, to ship 10 units of 30k-pins 80um-pitch probe cards in a week, ~100 concurrent assembler shifts are required!!!





"Hand to Machine" Conversion
Begins @ 80um Grid-array CuP Pitch



Summary

- **Static trend of grid-array packaging pitch is turning into rapid reduction with Cu Pillar Technology**
  - 150um -> 130um -> 100 -> 80um -> sub-50um
- **Conventional technology can't keep up with the current trend**
  - 3D Low-force, Alignment, Current Carrying Capability, Assembly Method
- **MEMS probe contact technology is required to keep up with the rapid pitch reduction, while keeping sanity and peace in HVM**
  - Many HVM wisdoms for probing solder bumps no longer work for CuP
  - Close collaboration among users, test cell and probe card suppliers is essential
- **"Hand to Machine" probe assembly conversion begins at 80um grid-array pitch CuP HVM**