Wafer probe challenges for the automotive market

ON Semiconductor®

Luc Van Cauwenberghe

ON Semiconductor

SWTW

IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

June 10 - 13, 2012 | San Diego, California

Overview

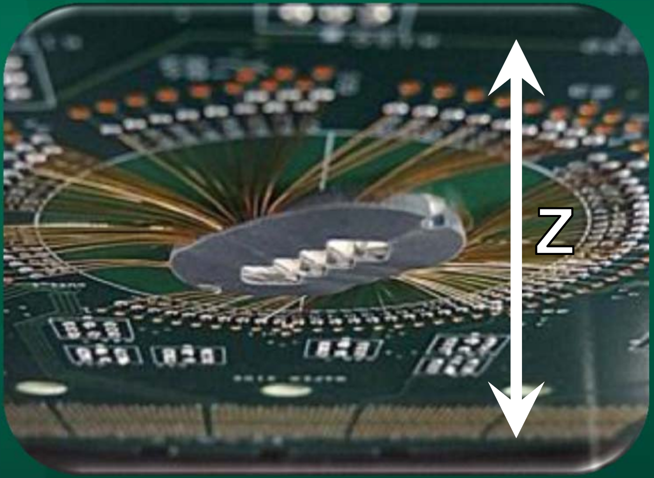
- Automotive wafer probe requirements
- Results of experiments
- Summary
- Follow-on Work
- Acknowledgements

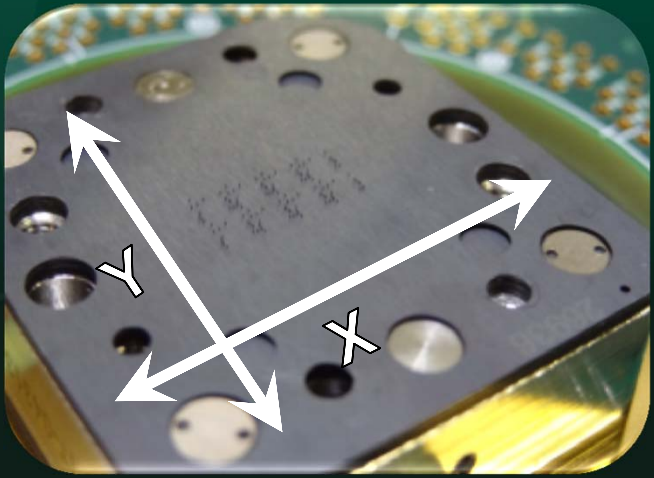
Automotive wafer probe requirements

- **Temperature**
  - -55ºC up to 200ºC
  - Probed die deliveries: Full test coverage at probe
  - Dual and tri-temp probe
- **Disturbed area on bond pad**
  - Multiple probe insertions
  - Bond pad size reduction → smaller Si area
  - Bond wire diameter in Multi Chip Modules

Impact of temperature on probe card

- PCB temperature profile
- Z movement of probes
- X-Y movement of probes



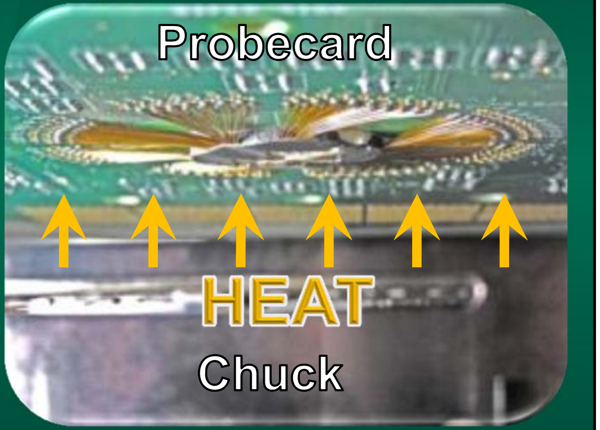


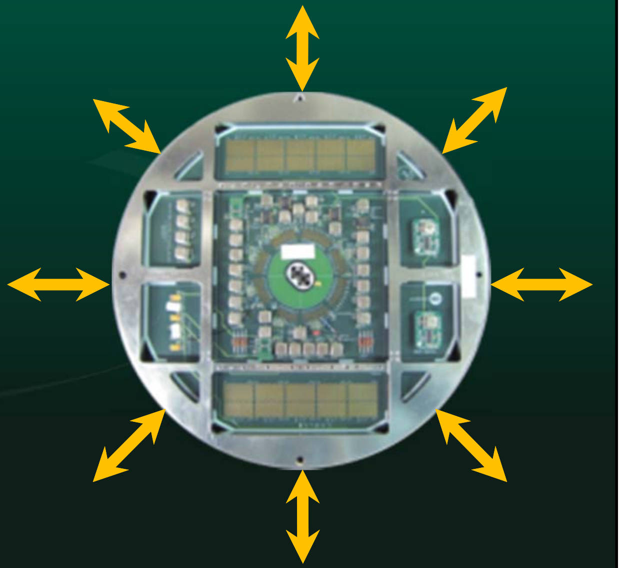
PCB temperature

- **Radient heat transfer**
- **Thermal expansion of the PCB dominates the mechanical behavior of the complete probe card assembly**

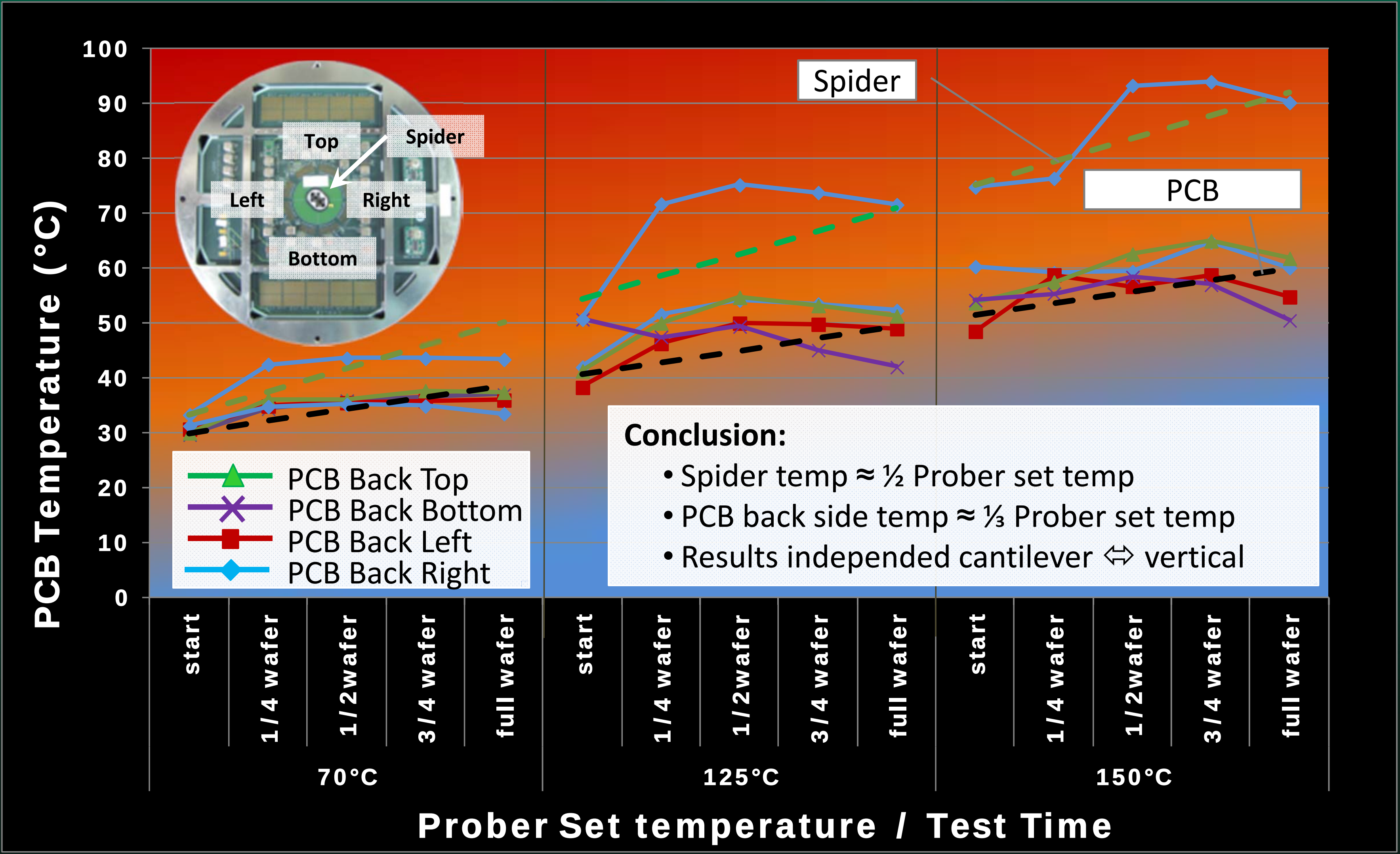
	CTE XY (ppm/°C)	CTE Z (ppm/°C)
FR4	``	140 to 220
Rogers	11 to 16	46 to 50
N7000	10 to 12	2,5%
N8000	11 to 13	70 to 375

- **Temperature limitation active and passive components**
  - Relays: typical maximum 85ºC or 125ºC
  - Active components: typical maximum up to 125ºC
  - Passive components: typical maximum 125ºC to 150ºC





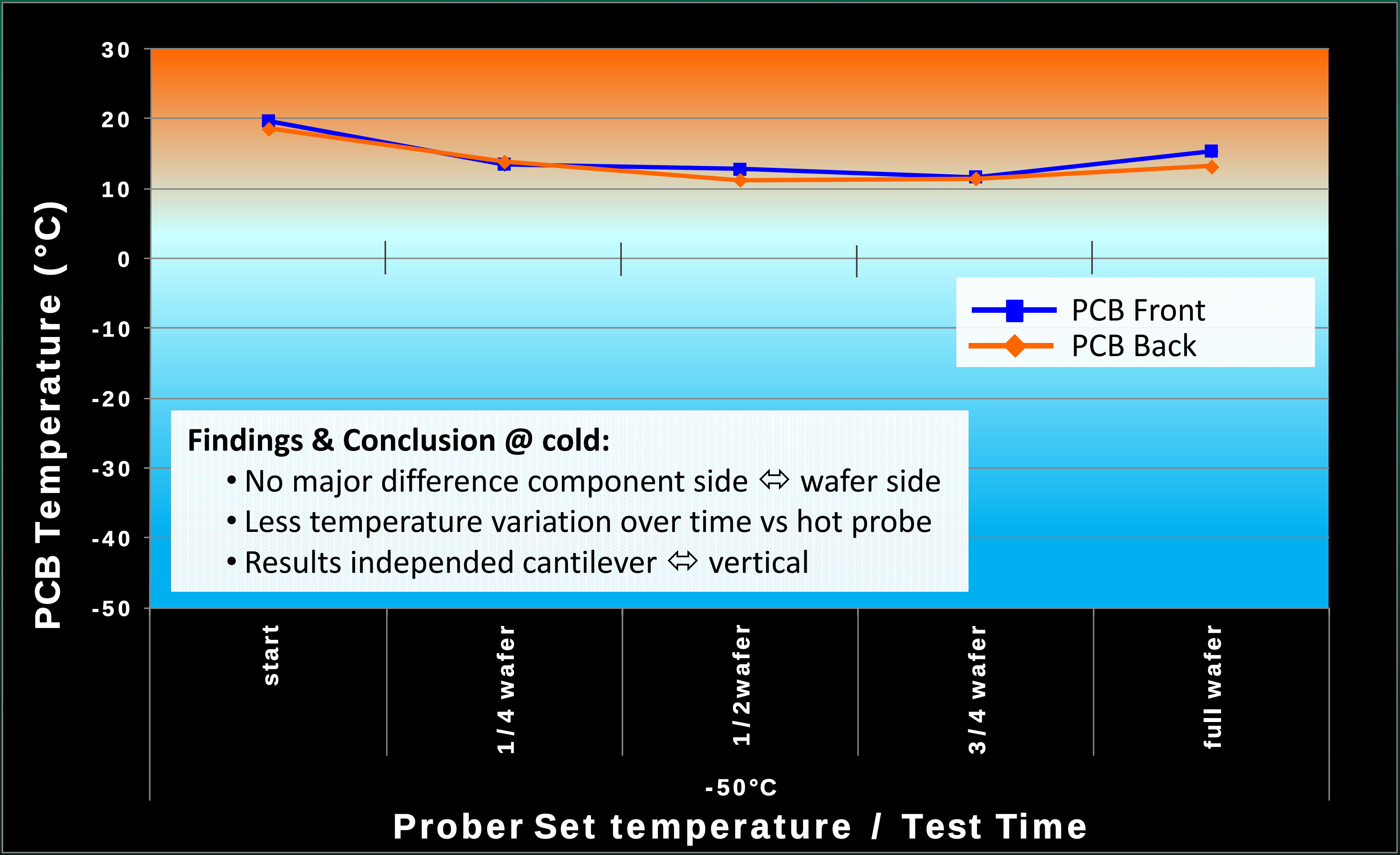
PCB temperature evolution at hot



Conclusion:

- Spider temp ≈ ½ Prober set temp
- PCB back side temp ≈ ⅓ Prober set temp
- Results independed cantilever ⇔ vertical

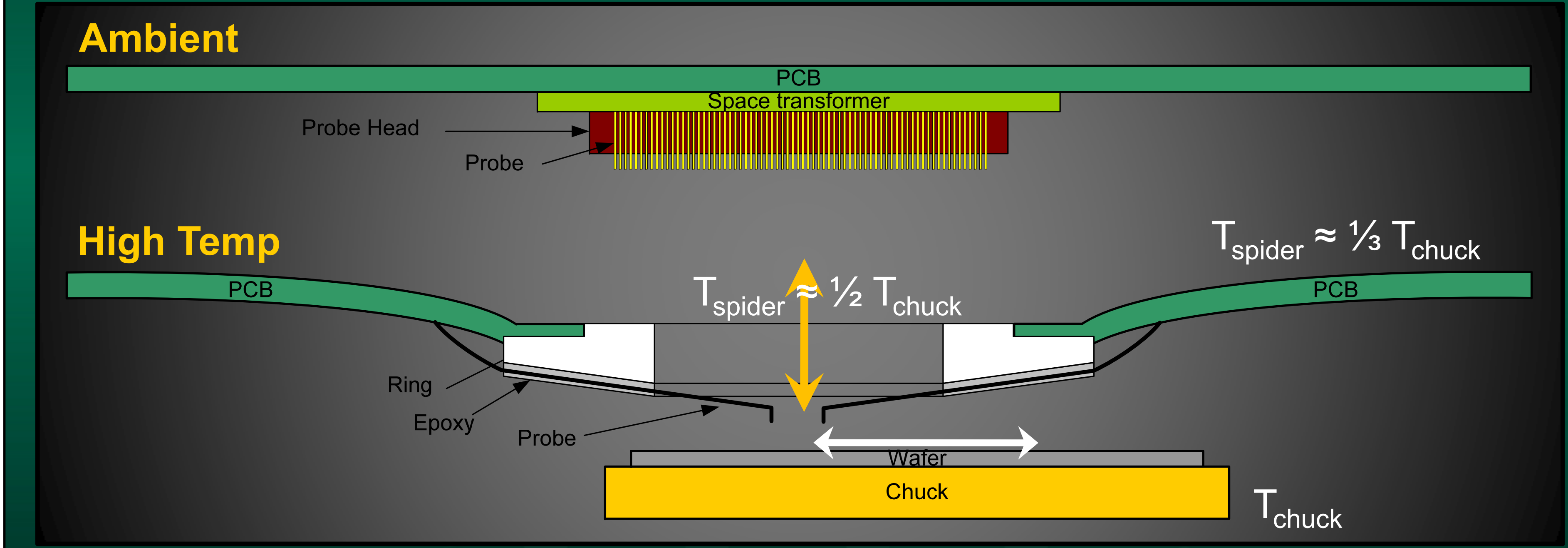
PCB temperature evolution at cold



Findings & Conclusion @ cold:

- No major difference component side ⇔ wafer side
- Less temperature variation over time vs hot probe
- Results independed cantilever ⇔ vertical

Z movement of probes

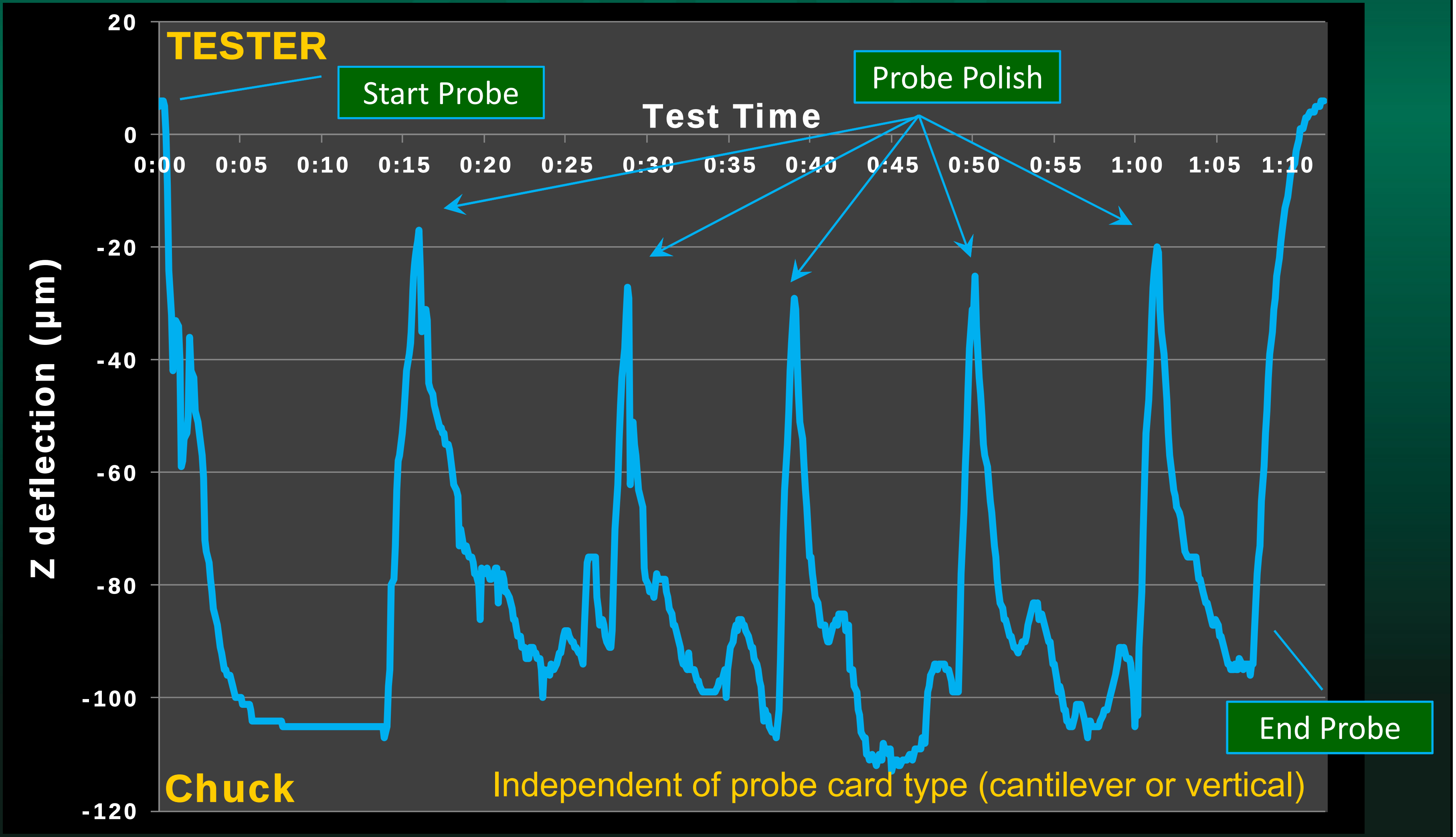


- **Root cause**
  - Continuous moving heat source (chuck)
  - Thermal behavior probe card assembly
  - Build quality of the spider / probe head
  - Independent of probe card type

Z deflection experiment: Initial conditions

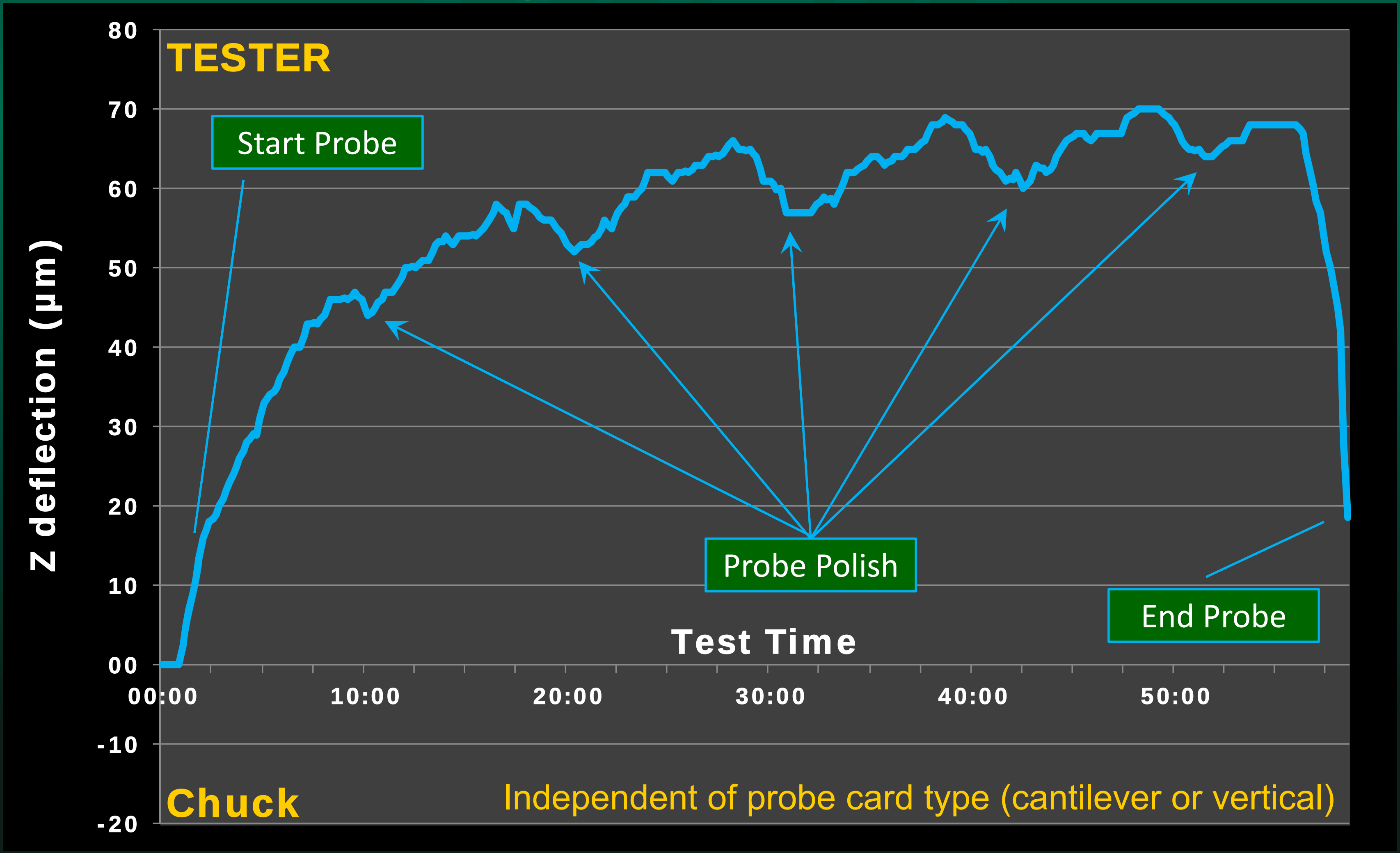
- **Soak prior to measurements**
  - Prober soak: 2hrs after reaching set temp
  - Probe card soak: 10 min
    - After prober soak
    - Chuck centered under the probe card
    - No contact
- **Zero-level = needle position after soak**
- **Process settings**
  - Test time per wafer: 1hr 10min
  - Probe polish interval: every 100 die
  - Probe polish recipe: 25 touch downs, 20µm overdrive

Z deflection: standard probe card at 175ºC



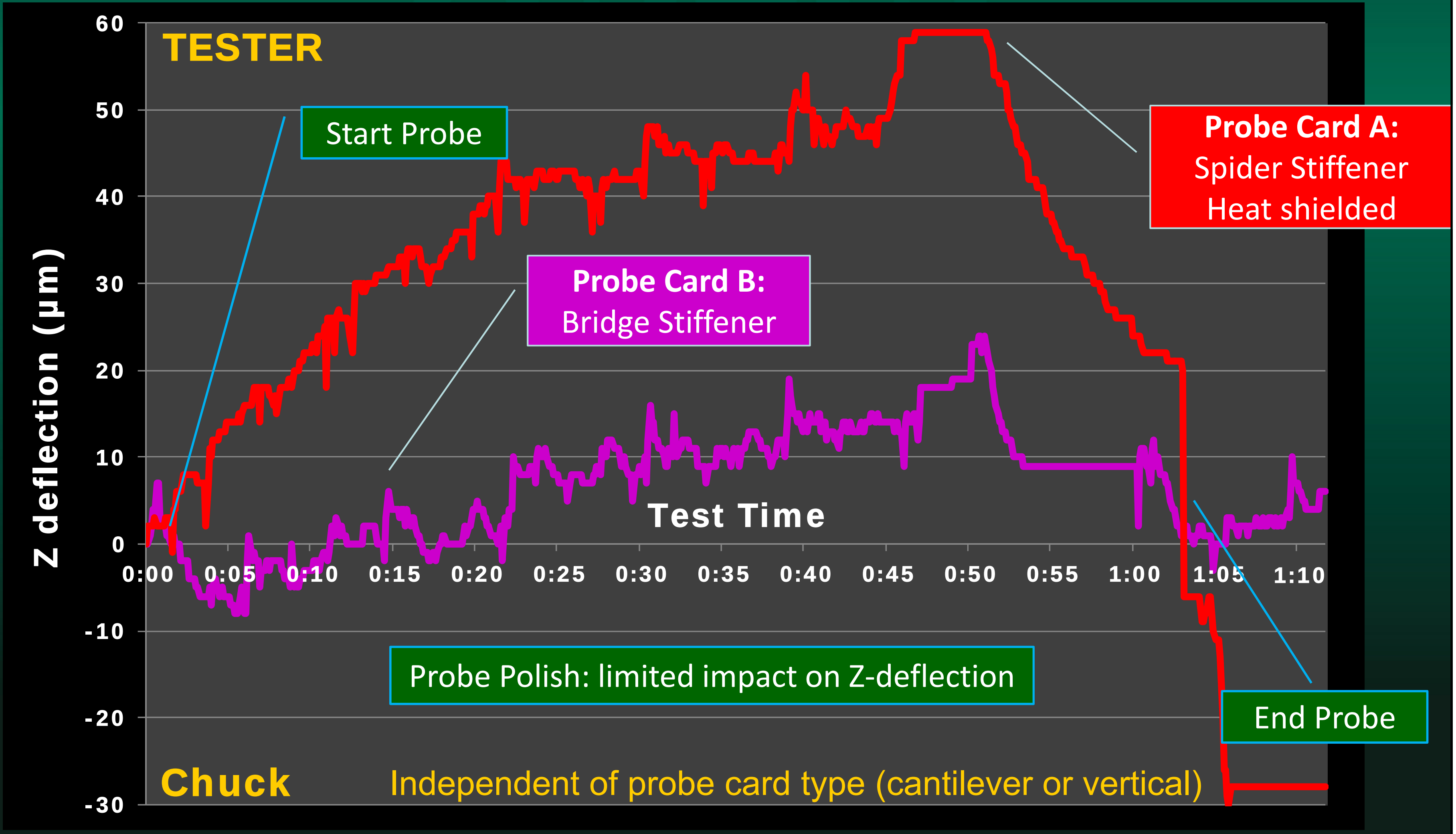
Independent of probe card type (cantilever or vertical)

Z deflection: standard probe card at -50ºC



Independent of probe card type (cantilever or vertical)

Z deflection: High Temp probe cards at 175ºC



Start Probe

Probe Card A:
Spider Stiffener
Heat shielded

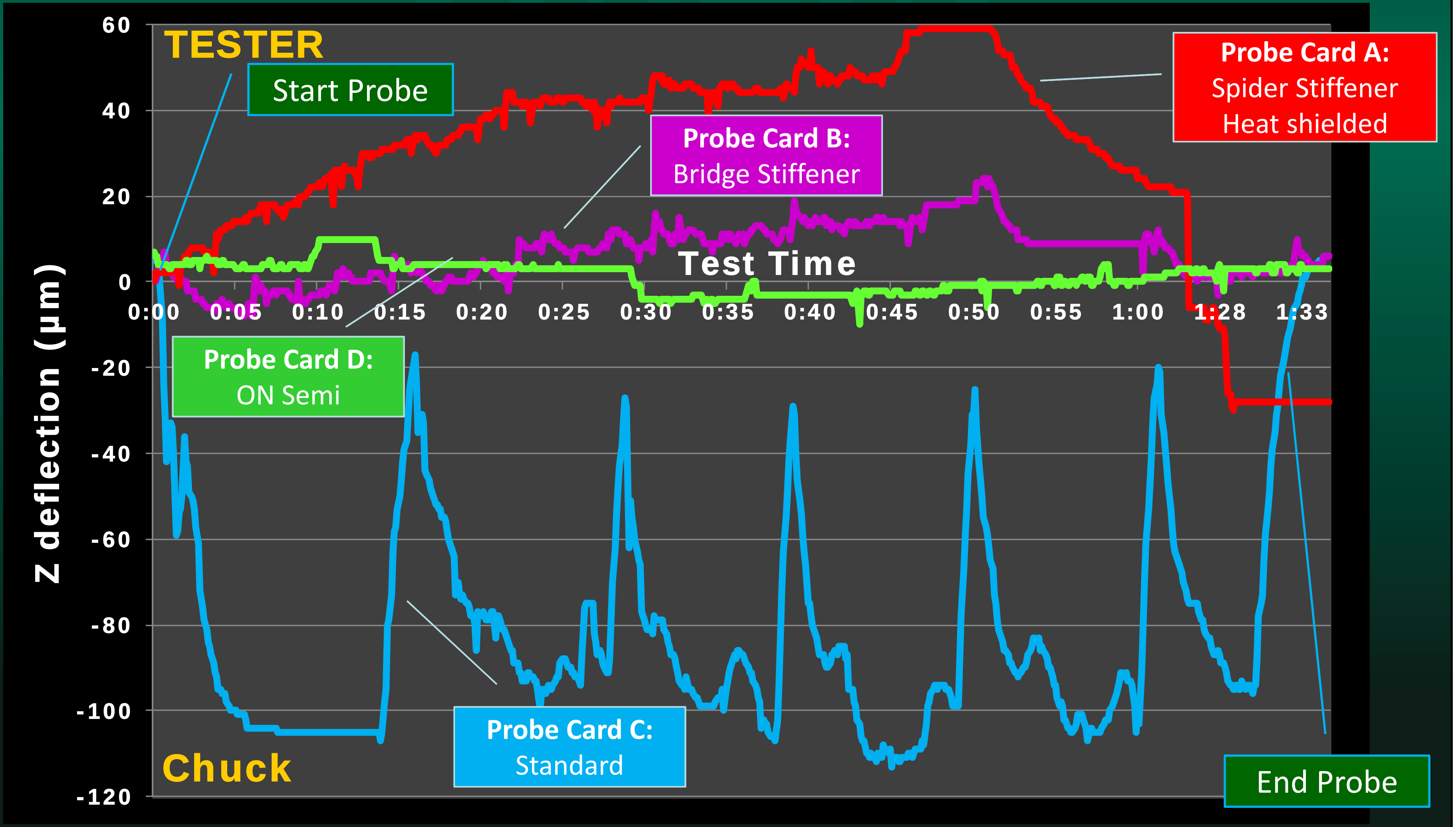
Probe Card B:
Bridge Stiffener

Probe Polish: limited impact on Z-deflection

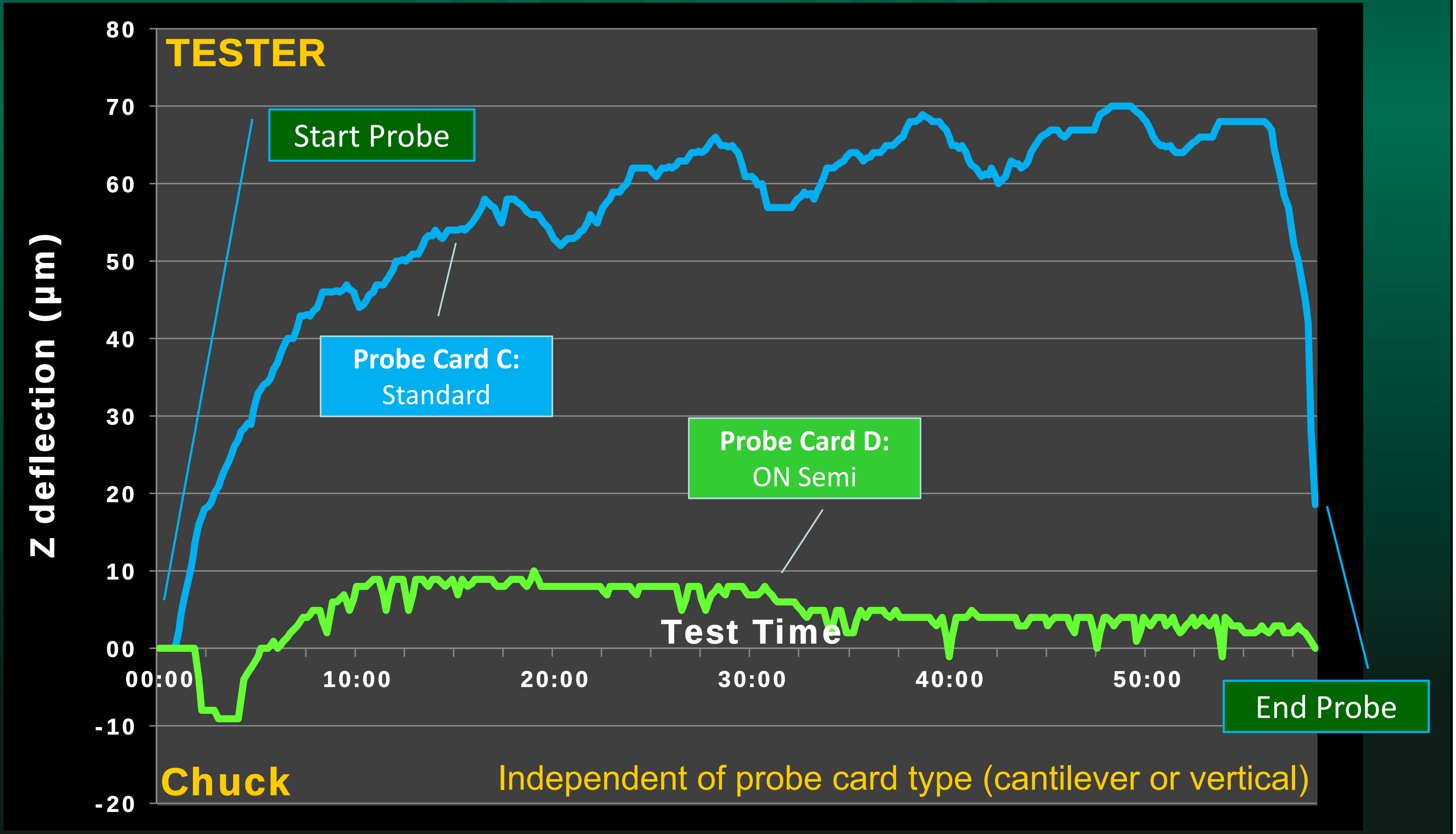
End Probe

Independent of probe card type (cantilever or vertical)

Z deflection:
ON Semi High Temp probe cards at 175ºC



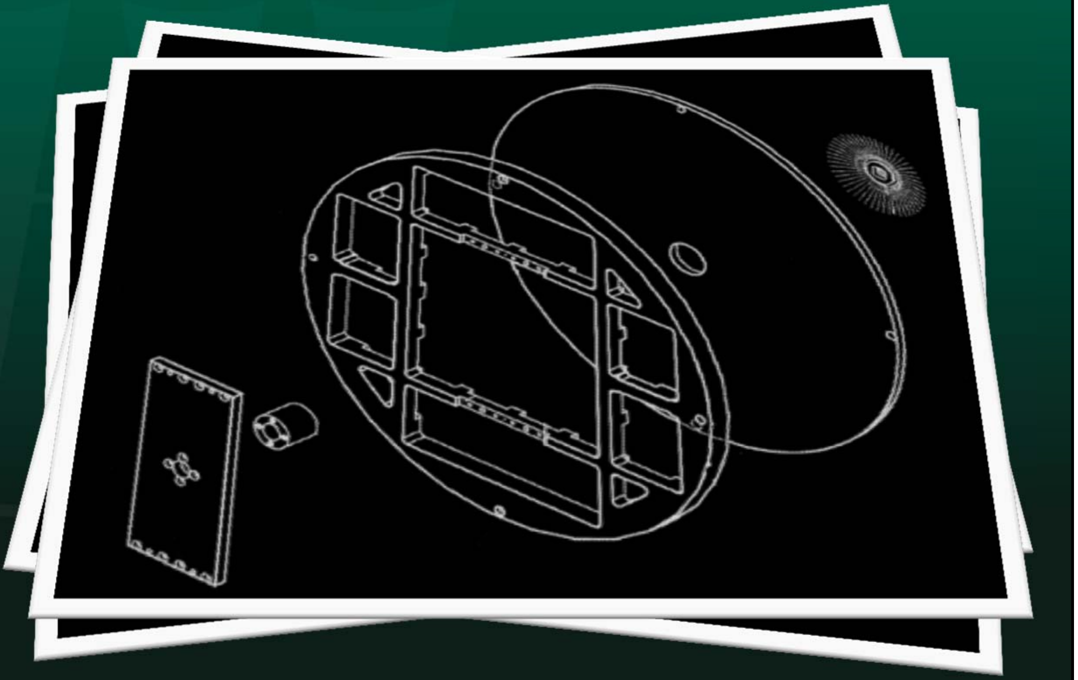
Z deflection: ON Semi High Temp probe cards at -50ºC



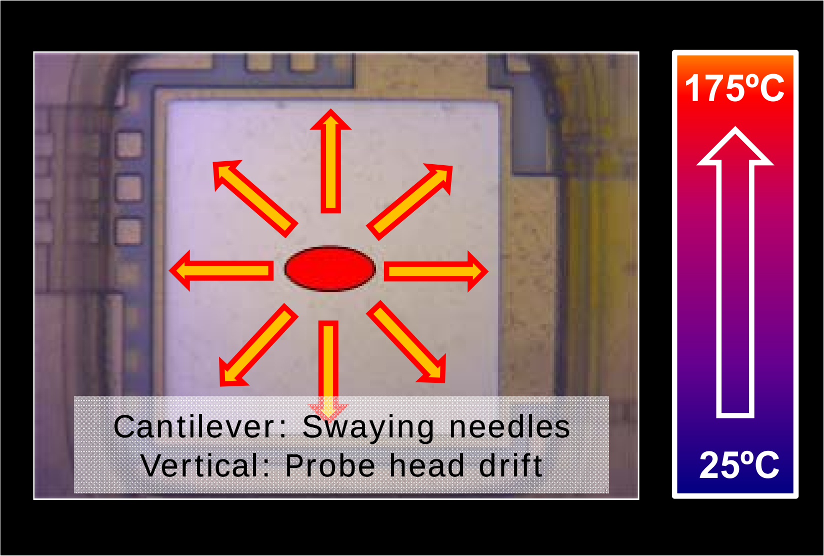
Independent of probe card type (cantilever or vertical)

ON Semi High Temp probe cards

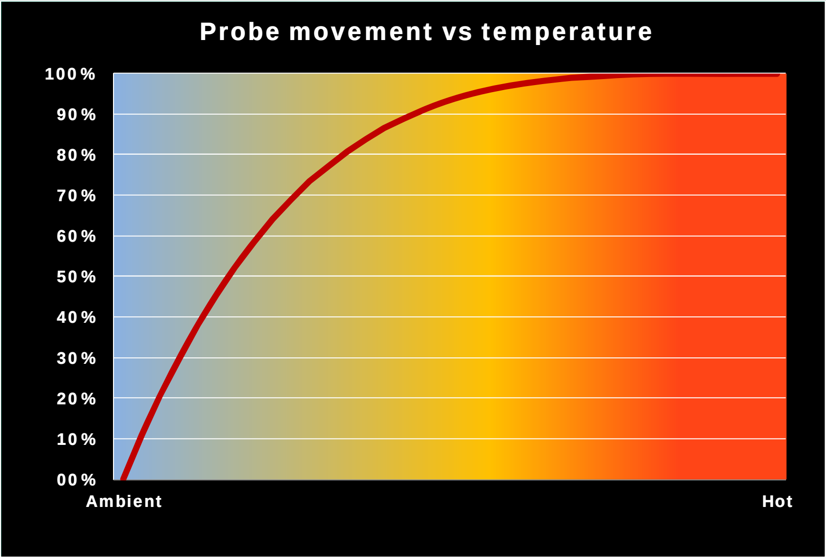
- **Patented design: US 7,816,930**
- **Bridge stiffener concept**
- **Allows PCB expansion without Z deflection**
- **Implemented on:**
  - Teradyne uFLEX
  - Teradyne Catalyst
  - SZ M3650 & Falcon
  - Credence ASL1000



X-Y movement of probes

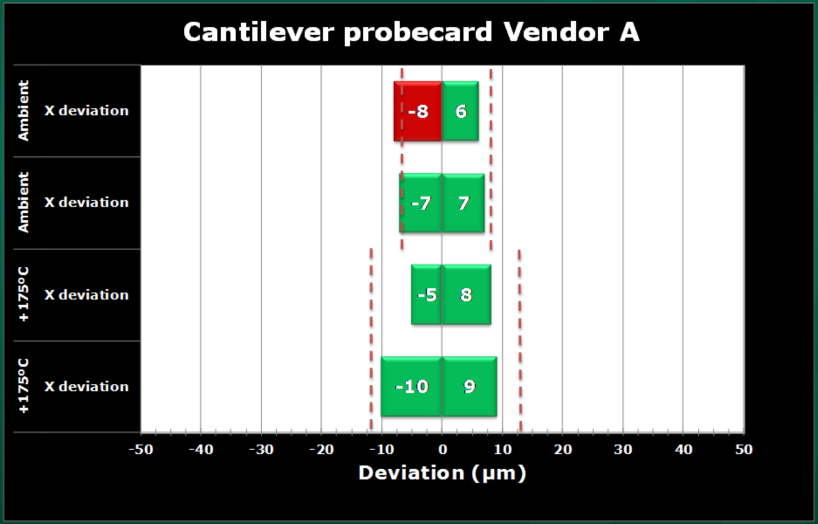


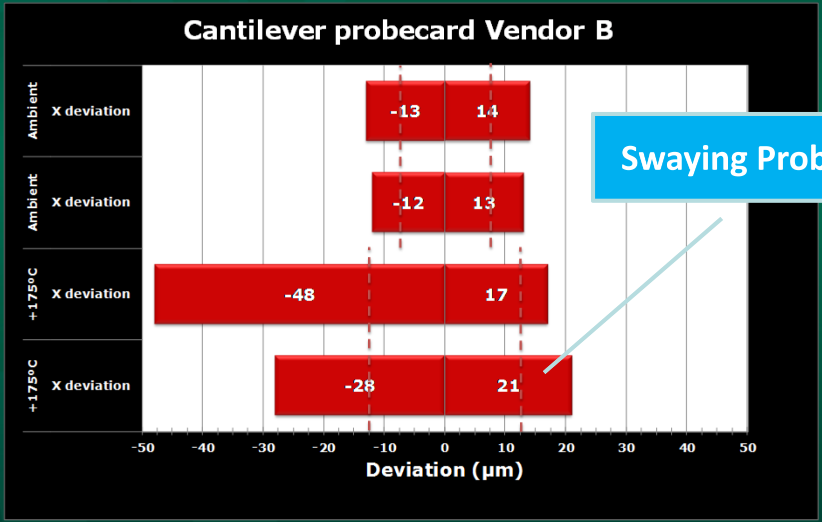
Cantilever: Swaying needles
Vertical: Probe head drift



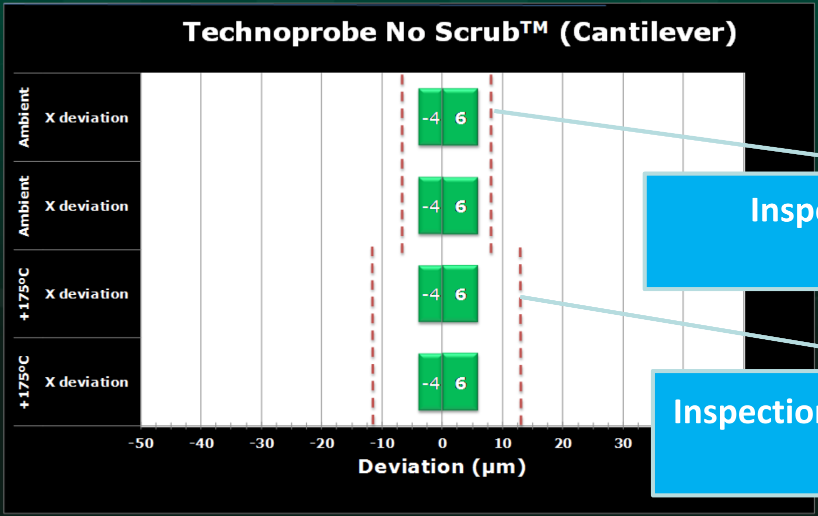
- **Root cause**
  - Build quality of the spider (cantilever)
  - Build quality of entire probe card assembly
  - Memory effect of the probes (cantilever)
  - Thermal behavior probe card assembly

Experiment: X/Y movement
Cantilever probe cards





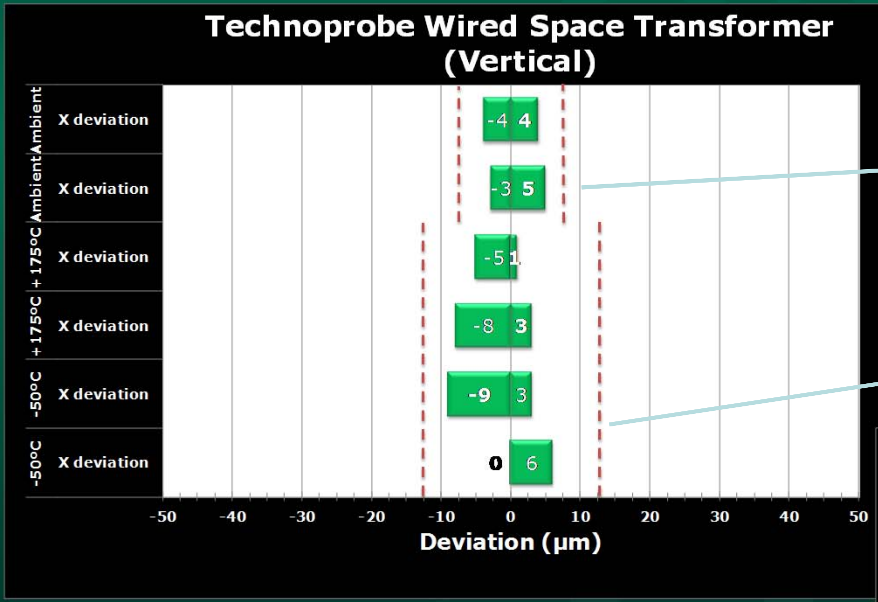
Swaying Probes



Inspection limits 25 ºC:
+/- 7.5µm

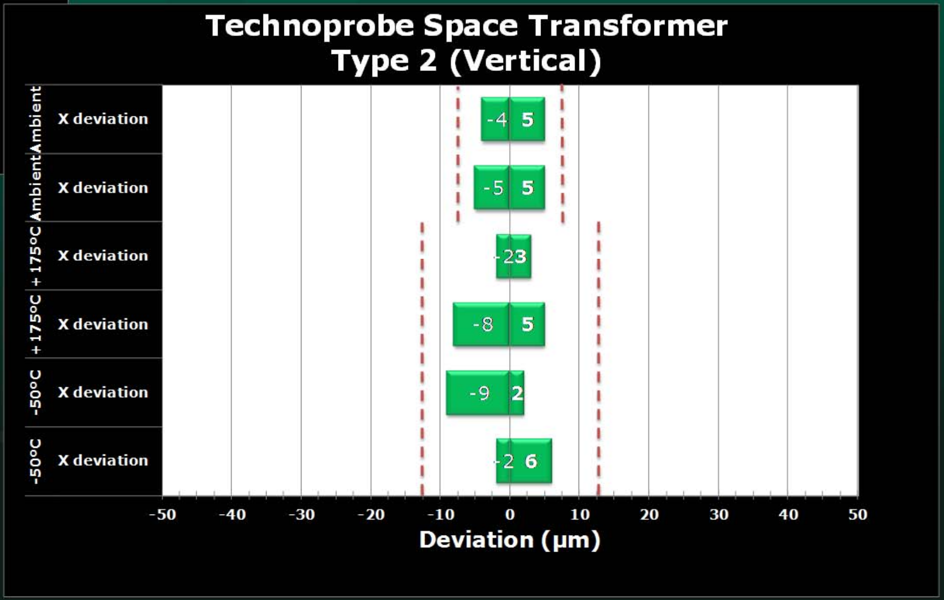
Inspection limits High temp + Cold:
+/- 12.5µm

Experiment: X/Y movement Vertical probe cards



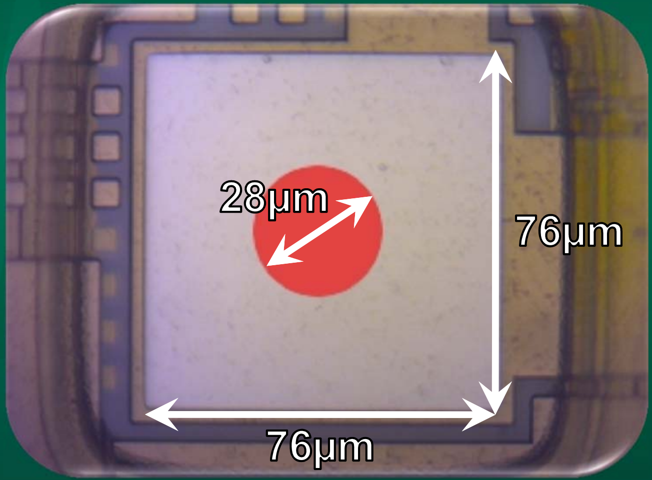
Inspection limits 25 ºC:
+/- 7.5µm

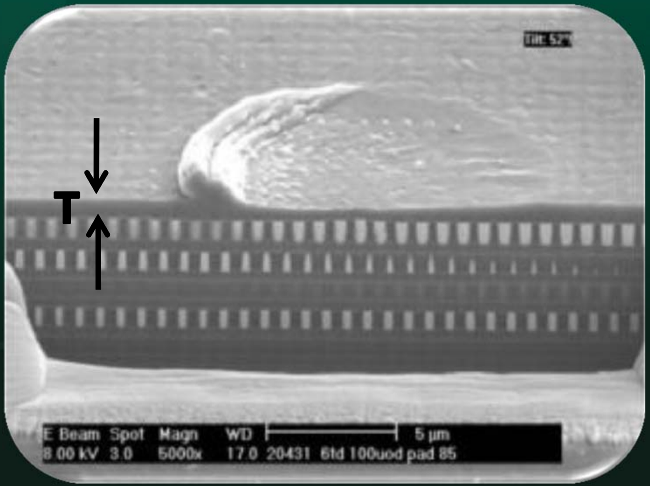
Inspection limits High temp + Cold:
+/- 12.5µm



Bond pad damage

- **Key for probed die deliveries**
- **Max disturbed area**
  - Diameter of entire probe mark area ≤ 28µm (≤615µm2)
- **Probe depth**
  - Maximum half of the thickness of top layer (T) of pad metallization
  - Maximum ≤ 500nm
- **Number of probe marks**
  - Number of probe insertions + 1



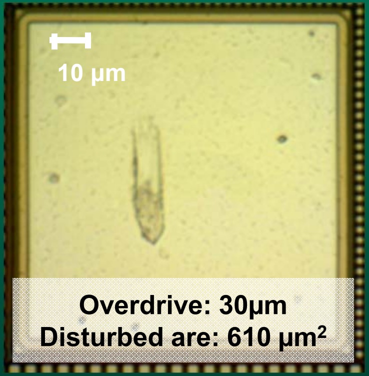
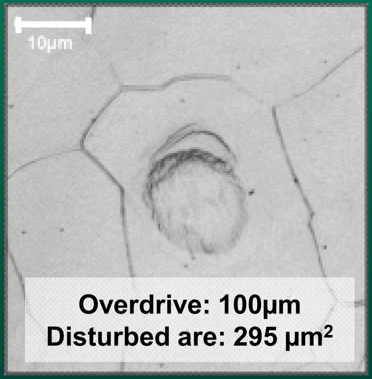
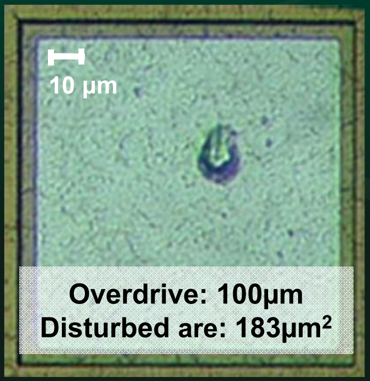
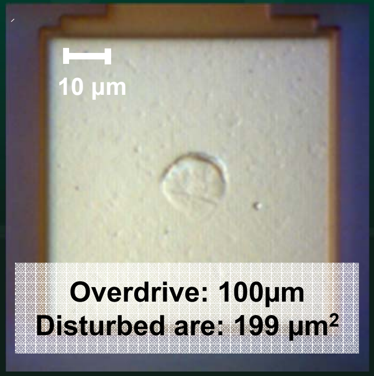
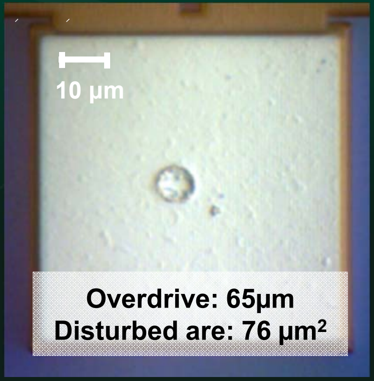


Experiment: Bond pad disturbance

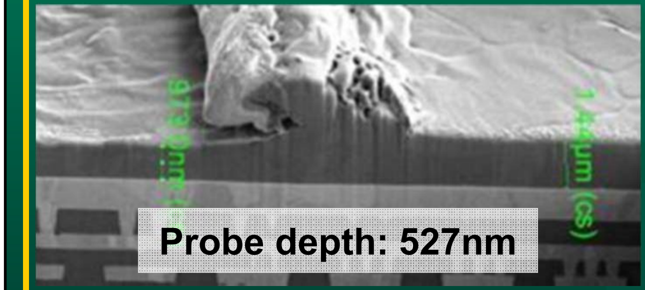
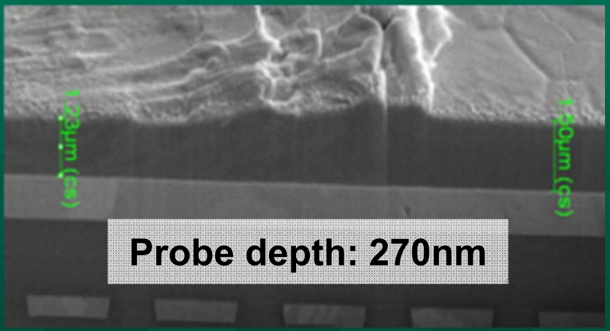
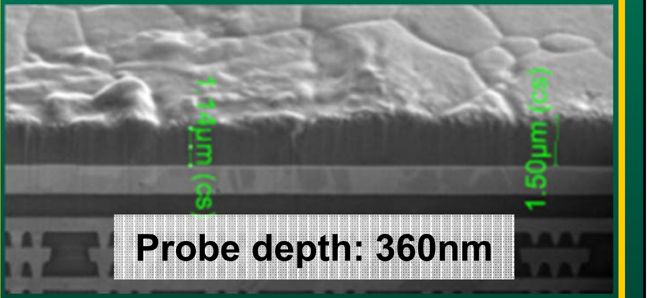
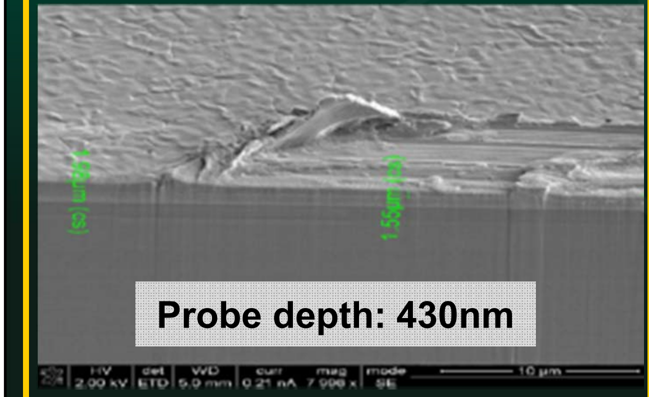
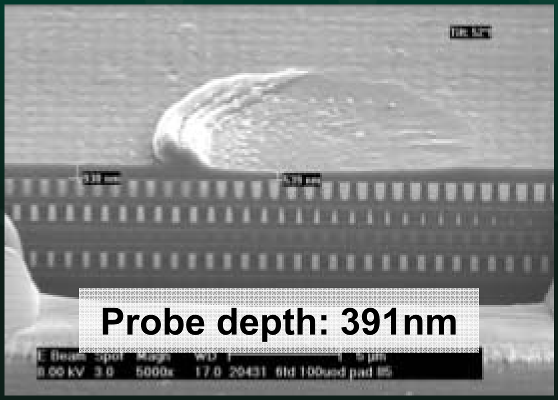
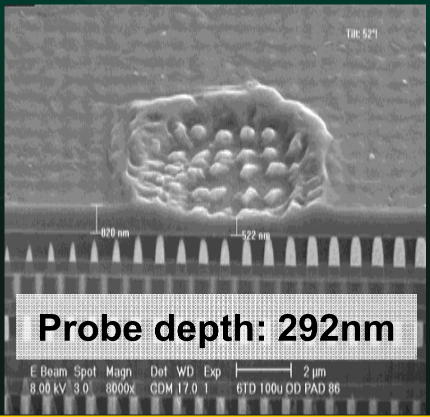
- **Evaluation disturbed area and probe depth**

- **Test conditions**
  - Temperature: 25ºC
  - Touch count: 1
  - Overdrive Cantilever: Typical production setting
  - Overdrive Vertical: Max allowed overdrive

Max disturbed area (≤615µm2)

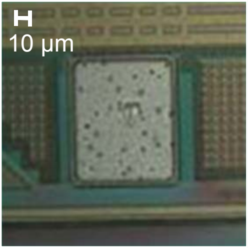
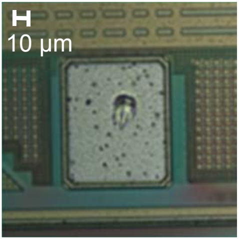
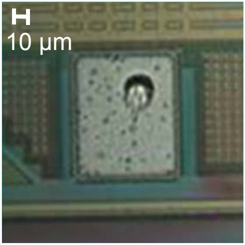
Cantilever (25 µm tip)	Cantilever Technoprobe - No Scrub^{TM} (25 µm tip)	Vertical Technoprobe - Route 60 (13 µm tip)
 Overdrive: 30µm Disturbed are: 610 μm^2	 Overdrive: 30µm Disturbed are: 200 μm^2	 Overdrive: 100µm Disturbed are: 295 μm^2
Vertical Buckling beam Vendor A (10 µm tip)	Vertical Buckling beam Vendor B (12 µm tip)	Vertical Buckling beam Vendor C (7 µm tip)
 Overdrive: 100µm Disturbed are: 183μm^2	 Overdrive: 100µm Disturbed are: 199 μm^2	 Overdrive: 65µm Disturbed are: 76 μm^2

Probe depth
(≤500nm or ½ top metal thickness)

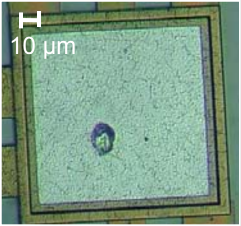
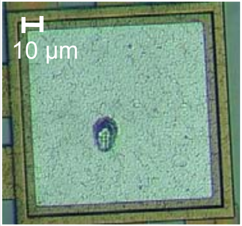
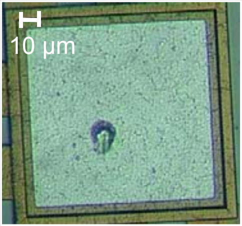
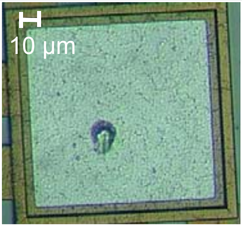
Cantilever (25 µm tip)	Cantilever Technoprobe - No Scrub™ (25 µm tip)	Vertical Technoprobe - Route 60 (25 µm tip)
 Probe depth: 527nm	 Probe depth: 270nm	 Probe depth: 360nm
Vertical Buckling beam Vendor A (10 µm tip)	Vertical Buckling beam Vendor B (12 µm tip)	Vertical Buckling beam Vendor C (7 µm tip)
 Probe depth: 430nm	 Probe depth: 391nm	 Probe depth: 292nm

Overdrive vs disturbed area

- **Cantilever (25µm tip diameter)**

Overdrive = 15 µm	Overdrive = 30 µm	Overdrive = 60 µm
		
130µm^2	270µm^2	527µm^2

- **Vertical (10µm tip diameter)**

Overdrive = 25 µm	Overdrive = 50 µm	Overdrive = 75 µm	Overdrive = 100 µm
			
174µm^2	182µm^2	183µm^2	183µm^2

Number of probe marks

- **Probe mark ≠ Touch count**
  - Probe mark: Individual visible imprint of a probe
    - ≤ Number of probe insertions + 1
  - Touch count: Number of touch downs on the bond pad
    - Top metal thickness ≤5500Å: max touch count =3
    - Top metal thickness >5500Å: max touch count =5
- **Impact: Increased disturbed area**
- **Why multiple probe marks?**
  - Dual or tri-temp probe
  - Multi DUT probe and re-probe
  - Data retention bake → pre and post bake probe

Probe card technology vs number of probe marks and disturbed area

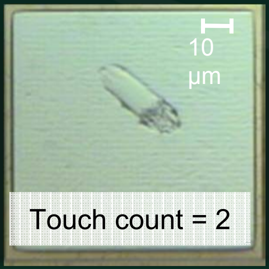
1 Probe mark	2 Probe marks	3 Probe marks	≥4 Probe marks
			
Cantilever probe cards (25µm tip) Vertical probe cards No Scrub™ (25µm tip)	Vertical probe cards (≤25µm tip) No Scrub™ (25µm tip)	Vertical probe cards (12µm tip) No Scrub™ (25µm tip)	Vertical probe cards (<12µm tip)

- **Multiple DUT probe with multiple probe insertions is only possible with advance probe card technologies**
- **The probe tip diameter selection is critical to comply with the max disturbed area requirement**

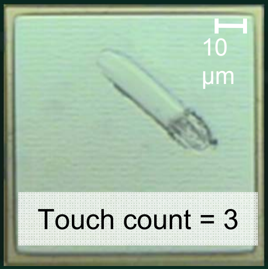
Impact of touch count

- **Experiment on cantilever touch count**
  - Overdrive = 75µm (worst case)
  - Increment touch count 1 to 7
  - Thin top metal: thickness ≤5500Å
- **Conclusion:**
  - Cantilever:
    - Impact on probe depth and disurbed area (scrub)
    - Aluminum build up at end of scrub
  - Vertical: main impact on probe depth
  - Touch count ≥ 5 : Exposed Metal Oxide (EMO)

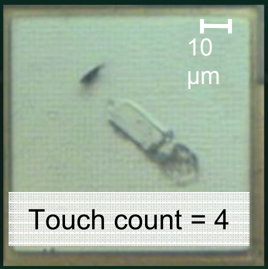
Touch count = 1



Touch count = 2

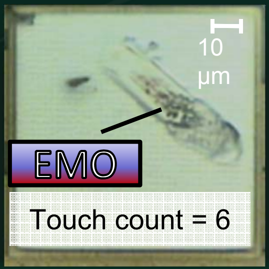


Touch count = 3



Touch count = 4

Touch count = 5

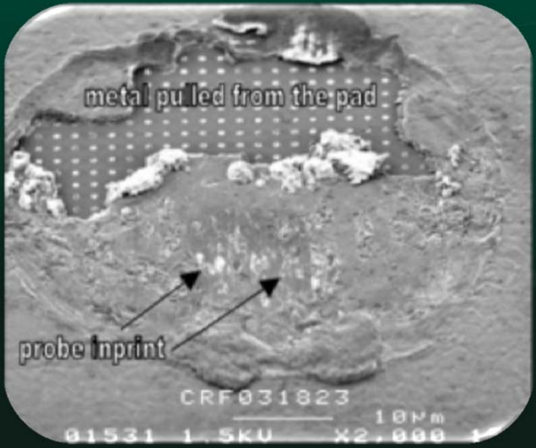


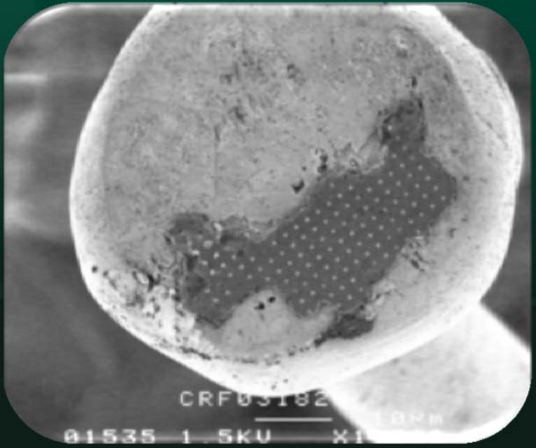
Touch count = 6

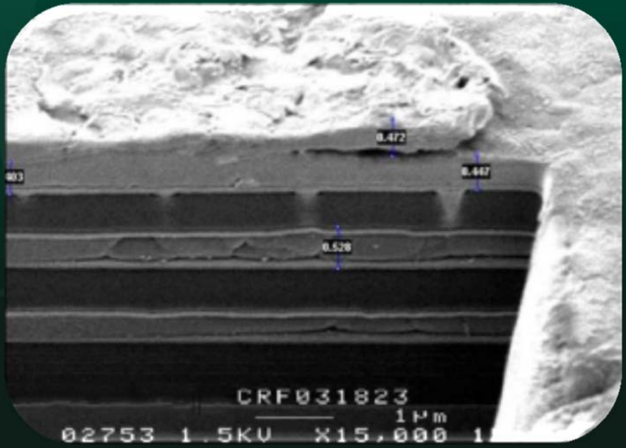
Touch count = 7

Cantilever probe impacts bond process

- **Aluminum build up at end of probe mark**
  - Build up amount driven by overdrive and touch count
  - Random height
- **Intermetallics only formed at part of the bond area**
- **Potential risk: Bond ball lift at temperature**







Summary: Temperature impact

- **Z deflection**
  - Dominated by PCB thermal behavior
  - Best result at 175ºC: 15µm
  - Best result at -50ºC: 10µm
- **XY movement of probes**
  - Cantilever :
    - Large differences depending on spider build quality
    - Difference between individual probes → Swaying probes
  - Vertical :
    - Determined by probe head design
    - All probes show similar movement → Probe head drift
  - Best result at 175ºC: 6µm

Summary: Bond pad damage

- **Automotive requirements and multi DUT probe require more advanced probe card technologies**
- **Standard Cantilever probe cards**
  - Disturbed area is very dependent on applied overdrive
  - Difficult to comply with automotive requirements
  - No Scrub™ (Technoprobe) is a potential alternative
- **Vertical probe cards**
  - Probe tip diameter drives the disturbed area
  - Disturbed area is less dependent on applied overdrive
  - ON Semiconductor uses ROUTE 60 ™ LL (Technoprobe) for high temp
    - Combined with ON Semiconductor patented concept for high temp cards
    - High current carrying capability: 850 mA
    - Low pad damage
    - Life time (tip length)

Future work

- **Wafer probe at 200ºC**
- **Optimize Multi DUT probe recipes to reduce number of probe marks and touch count**
  - Ongoing evaluation on impact of the probe card configuration
  - Ongoing evaluation of Multi DUT probe stepping pattern
- **Analyze the influence of temperature on Contact Resistance (Cres)**
- **Analyze behavior of probe on Over Pad Metalization (OPM)**

Acknowledgements

- **Frank De Ruyck**
  - Equipment Engineer, ON Semiconductor
- **Wim Dobbelaere**
  - Director Test & Product Engineering Automotive Mixed Signal, ON Semiconductor
- **Riccardo Vettori**
  - R&D and Process Engineer , Technoprobe
- **Riccardo Liberini**
  - Mechanical Design Manager , Technoprobe
- **Marco Di Egidio**
  - Process Engineer , Technoprobe

ON Semiconductor®

TECHNOPROBE
Wafer Probing Technologies