SWTW 2-0-1-7

SW Test Workshop

Semiconductor Wafer Test Workshop

FeinProbe® Solution for WLCSP Applications

FEINMETALL
Contact Technologies

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Overview

- Motivation
- WLCSP Market Drivers
- WLCSP Application Requirements
- Stages of FeinProbe® Internal Qualification and Testing
- Summary and Conclusion

Motivation

- **Diversification of semiconductor products:**
  - Smartphones/Tablets
  - Internet of Things/Wearables
  - Virtual Reality
  - Artificial Intelligence
  - 5G Connectivity
  - Automotive and much more others like Medical, Industrial, Military…
- **Increasing WLP (Fan-in and Fan-out) without substrates or interposer for IC chips**
- **Increasing final tests at wafer level**

WLCSP Market Drivers

- Good electrical performance
- Good thermal performance
- Smaller and lower profile
- High power
- High system integration
- High I/O density
- Low cost

General WLCSP Requirements

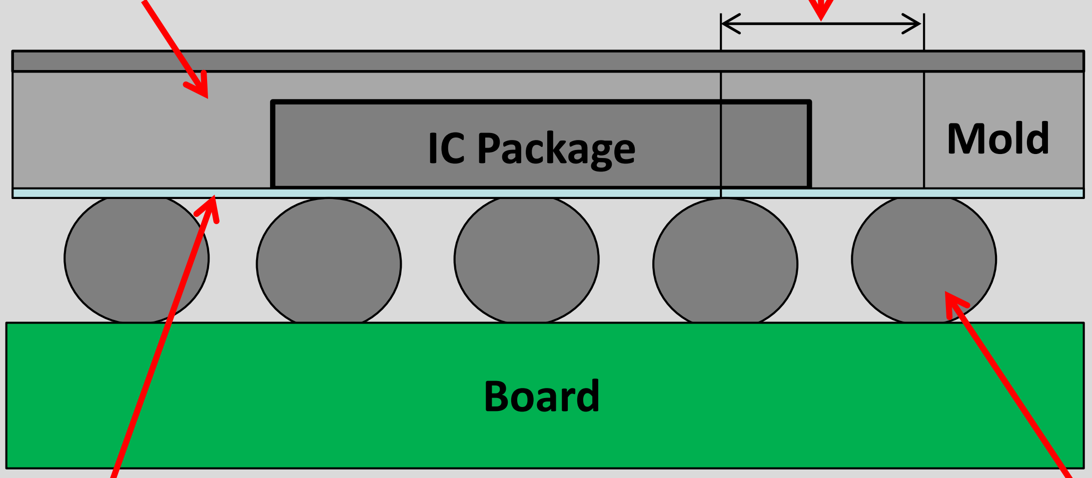
Electrical

- Low resistance for DC measurements
- High bandwidth for functional tests or AC tests
- Low path inductance to reduce the noise on the DUT power and ground at its switching frequency
- High current capacity for power delivery and DC parametric tests
- Kelvin probes for analog and mixed signal

Mechanical

- High contact force
- Short probe length for electrical parameters
- Large plunger compliance for reliable contacts
- Longer lifetime
- Effective cleaning method

Fan-out WLP Connection to PCB



Die Size
< 100 sq mm

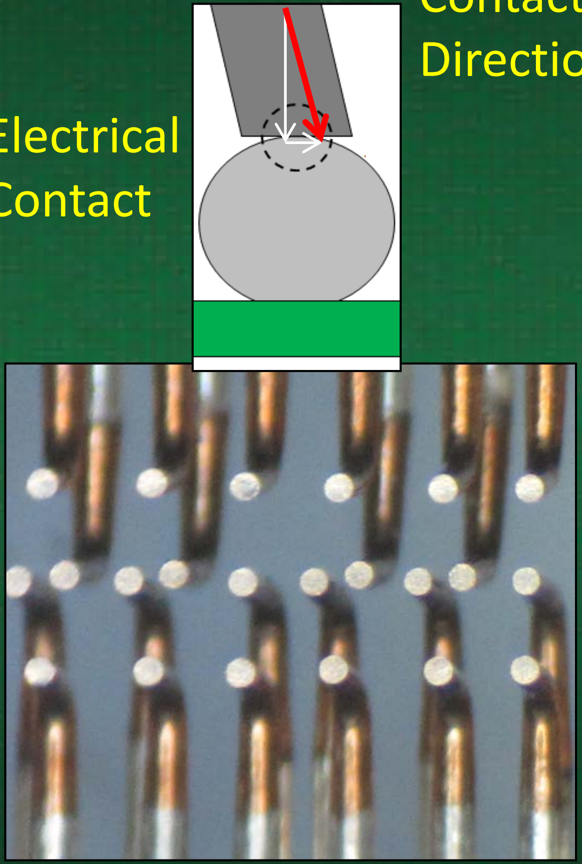
Bump Pitch
> = 300 µm

RDL Thin Film

No IC Underfill and no IC
Substrate or Interposer

Low I/O Count
< 500 Pin Count

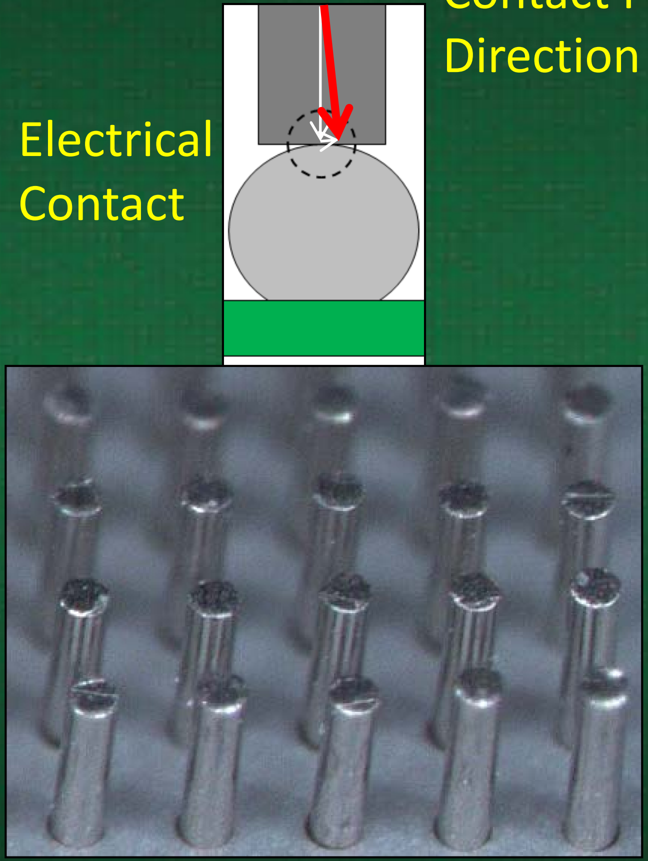
Probe Card Technology for WLCSP Testing



Contact Force Direction

Electrical Contact

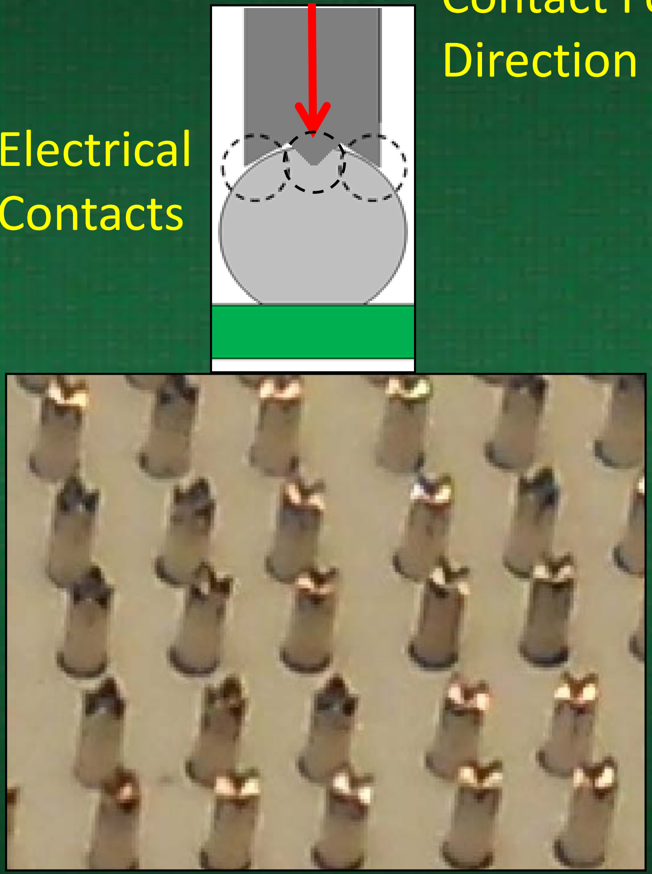
Cantilever Technology



Contact Force Direction

Electrical Contact

Buckling Beam/Hybrid BB Technology



Contact Force Direction

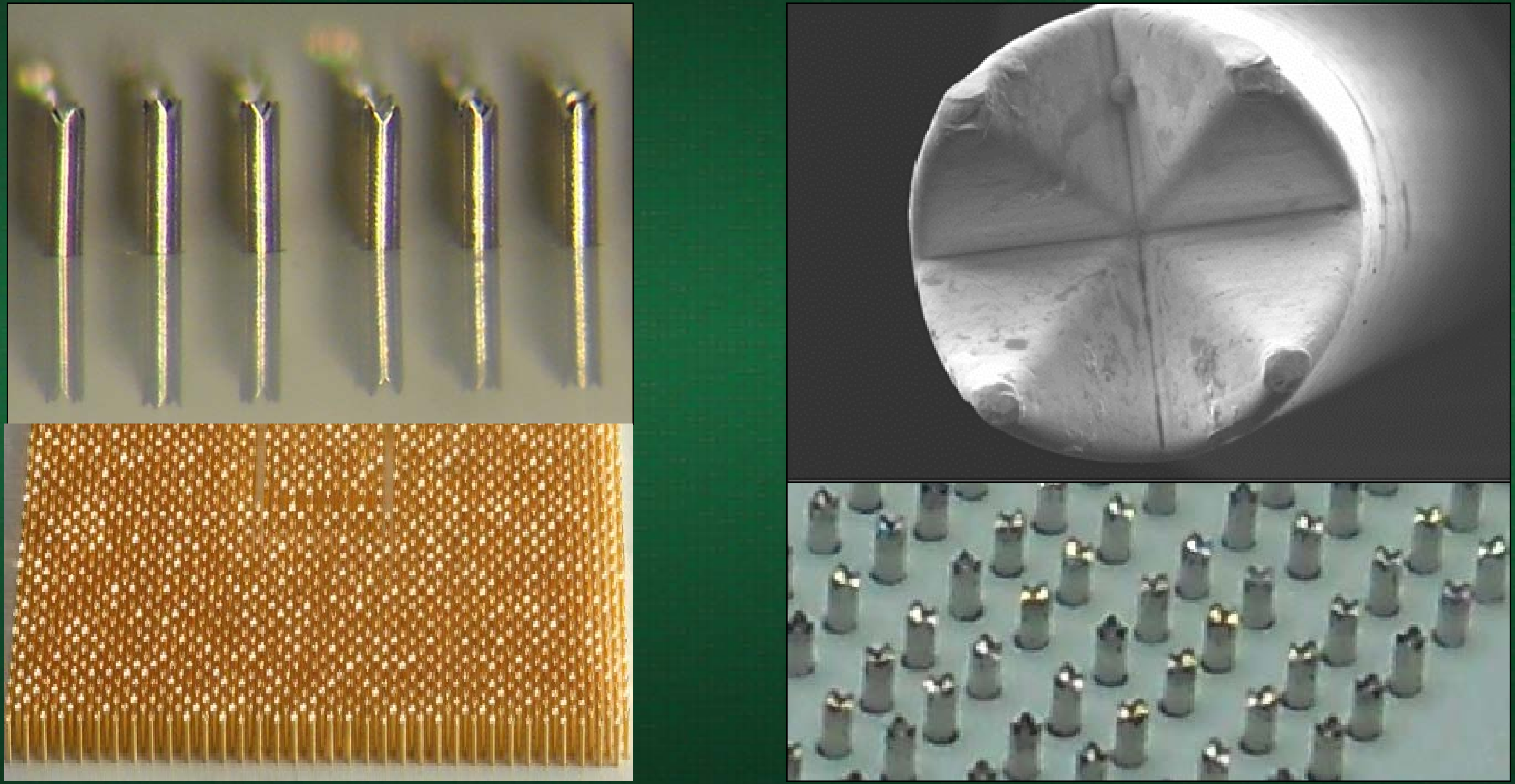
Electrical Contacts

Spring Probe Technology

FeinProbe® Spring Contact Advantage

- ☐ Stable and consistent contact resistance
- ☐ Self-aligning plunger tip
- ☐ High bandwidth
- ☐ High Current Carrying Capability (CCC)
- ☐ Large spring range force
- ☐ Large plunger tip compliant
- ☐ Low bump damage
- ☐ No probe coating required

Crown Plungers of FeinProbe® Head

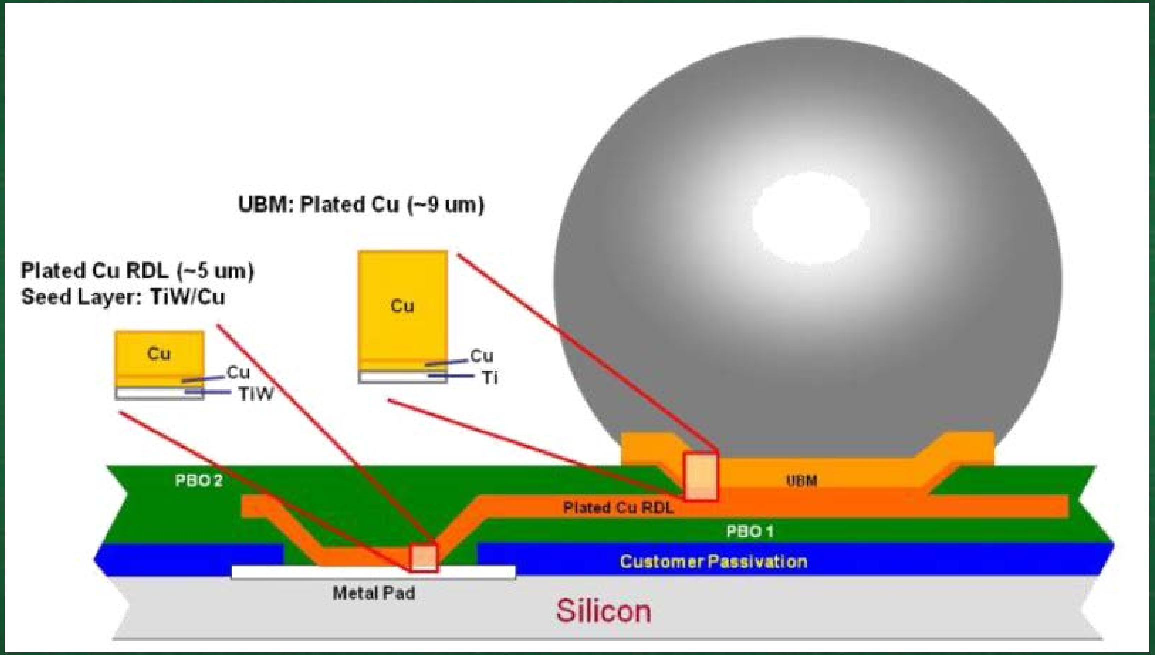


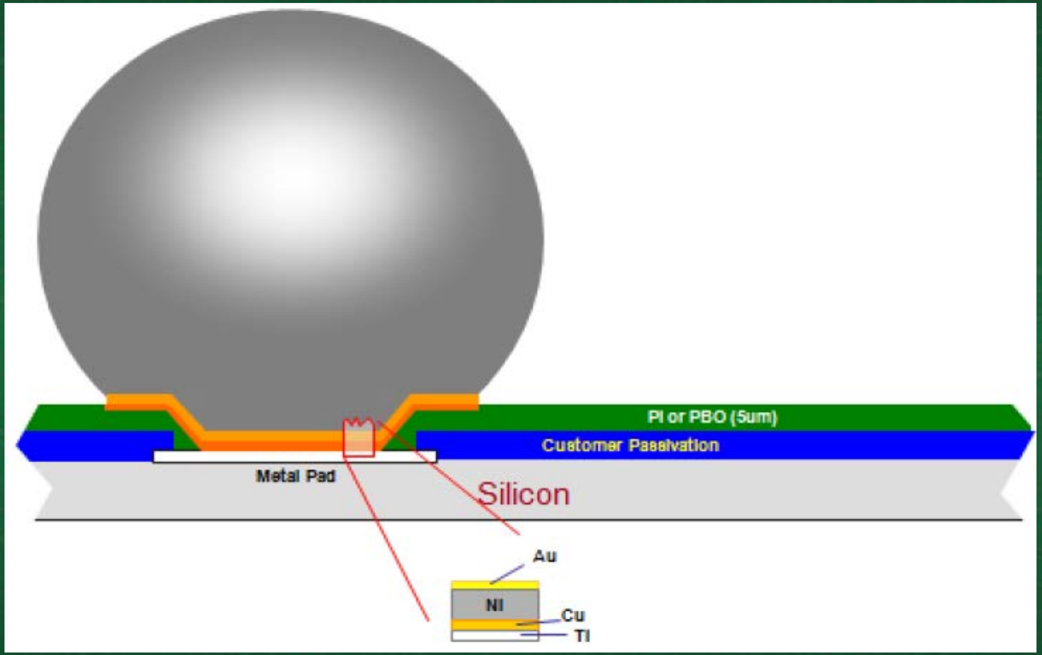
Stages of FeinProbe® Qualification and Testing

- ☐ Finite Element of Solder Bump-Crown Tip Plunger Model
- ☐ Contact Force Test of Probe Head
- ☐ Path Resistance on Bumped Wafer
- ☐ Vector Network Analyzer Probe Test
- ☐ Probe Current Carrying Capability Method

Why Finite Element Bump-Probe Contact Study?

Current WLCSP Technology Options





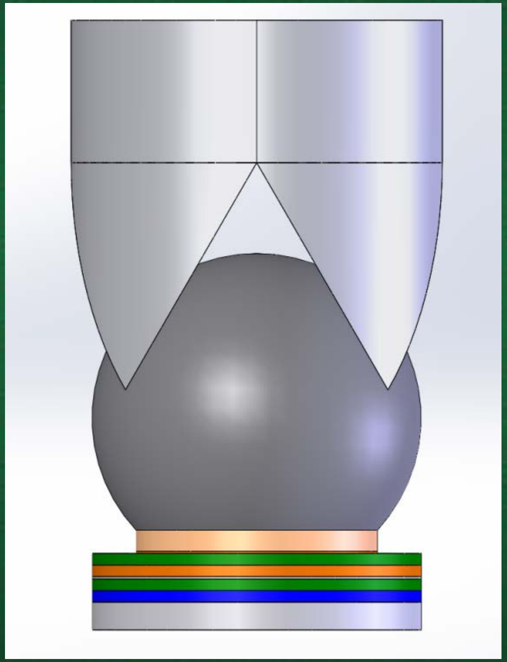
CSP with RDL:
- 4 mask
- 9 um UBM Cu/Ti

Low cost solution:
- No RDL
- 2 mask
- 5 um UBM Au/Ni/Cu/Ti

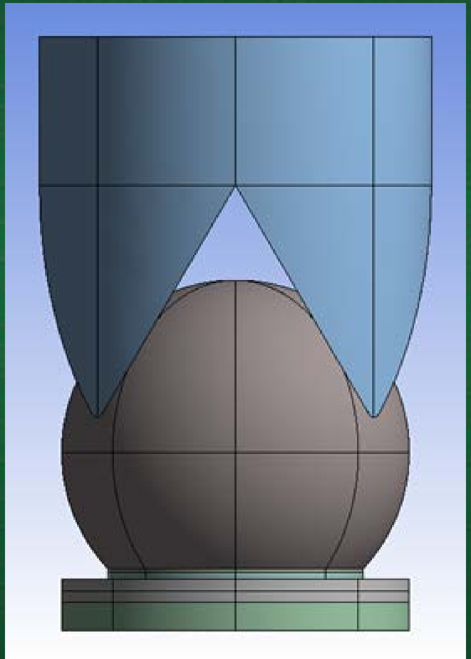
Source: C.Lee Amkor

Finite Element Probe-Bump Models

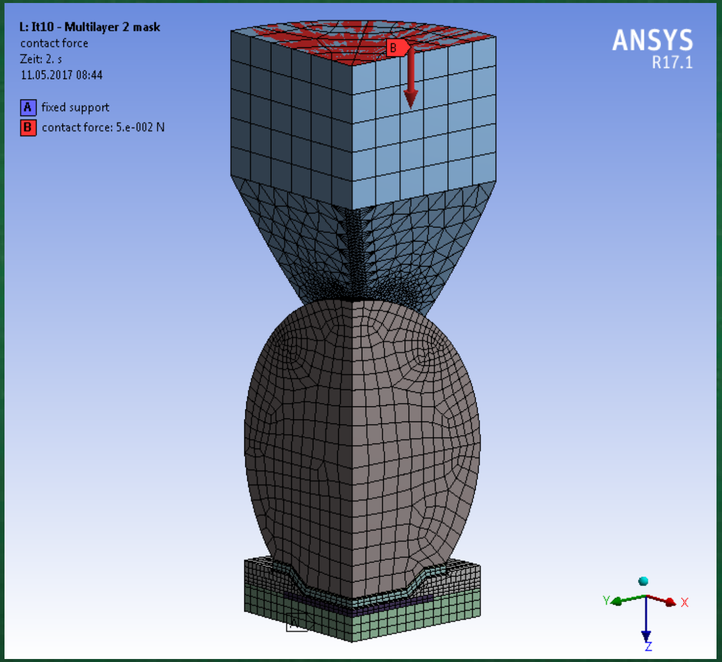
FE Model w/ 4 mask



FE Model w/ 2 mask



Boundary Conditions



FE model – Quarter

- Lead-free bump diameter 142um
- Crown plunger diameter 160um
- Plunger force F=20gf

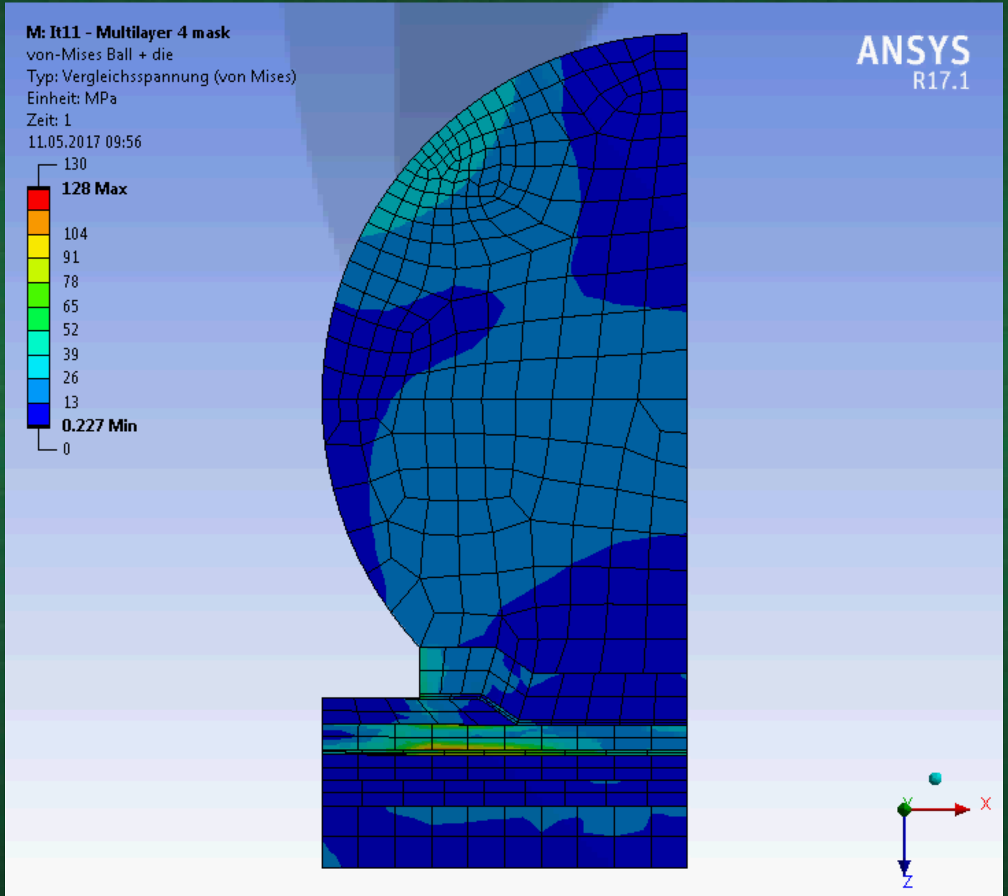
Model Material Properties Table

Model part	Material	Young's Modulus E (GPa)	Poisson's Ratio (-)	Yield Point (MPa)	CTE (ppm/C)
Crown plunger	Pd alloy	110	0.35	930	11.7
Solder ball	Sn/Ag	50	0.36	34.2	25
Cu	Cu	117	0.34	62	16.8
PBO 1	PI	2.3	0.3	69	35
PBO 2	PI	2.3	0.3	69	35
Custom Passivation	PI	3.5	0.35	69	35
Silicon	Si	131	0.26	UTS 7000	2.54
Gold	Au	79	0.4	205	14.2
Nickel	Ni	207	0.31	138	13.3
Titanium	Ti	116	0.32	379	8.5

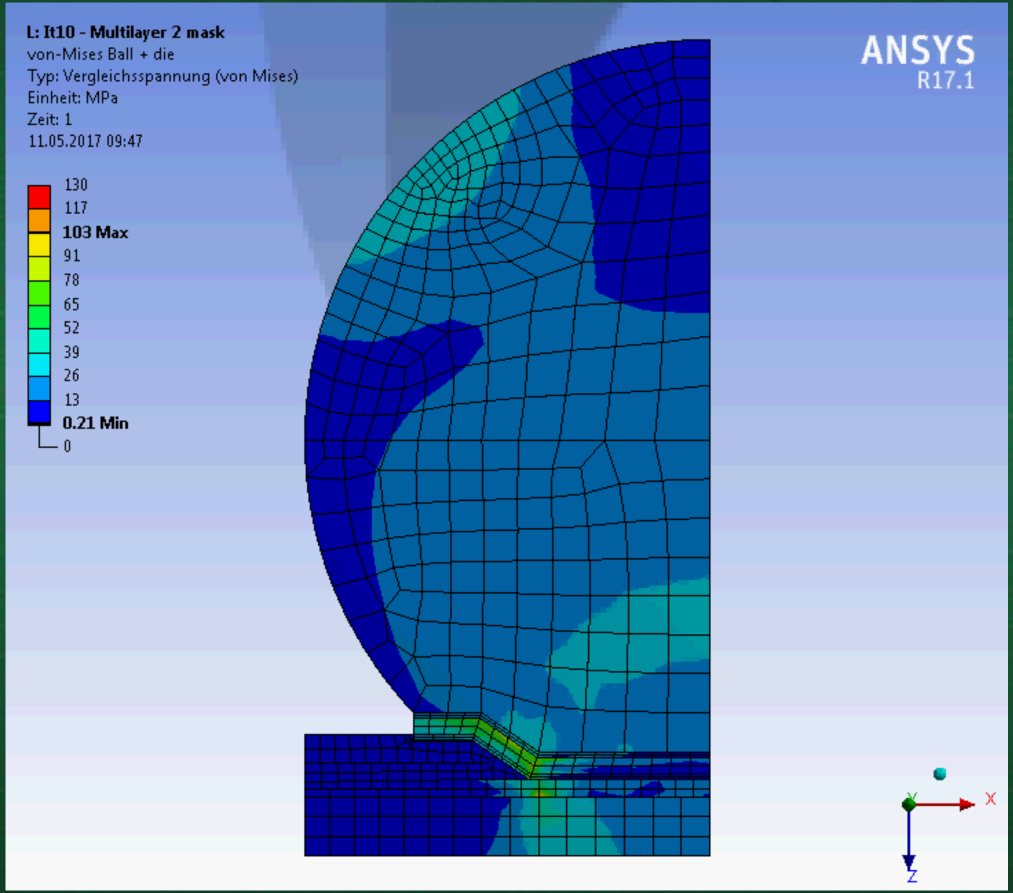
Source: Amkor, NIST, STATS ChipPAC, Japan Institute of Metals

Model Stress Simulation

FE Model w/ 4 mask

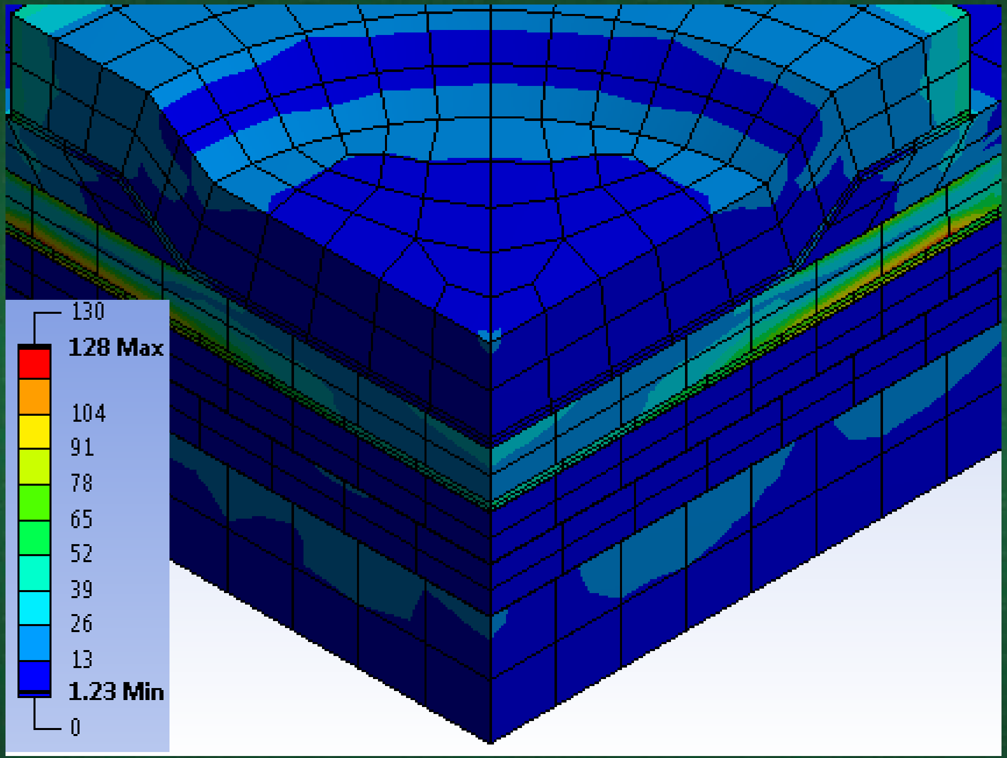


FE Model w/ 2 mask



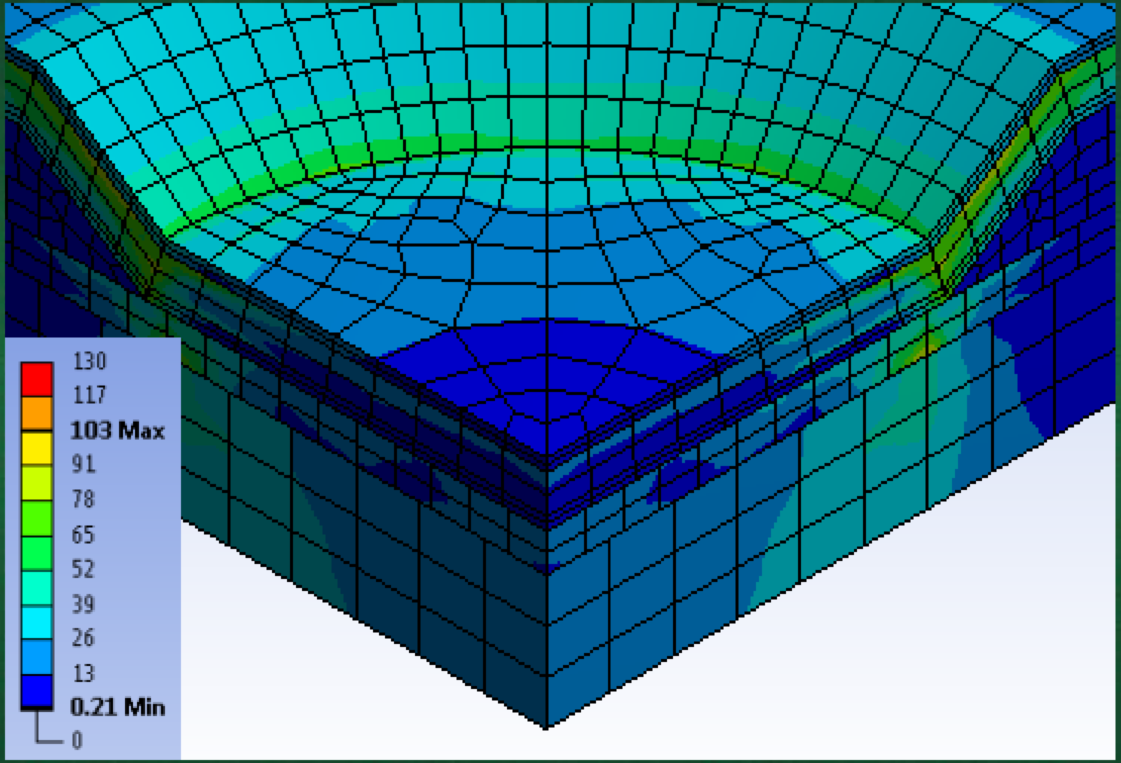
Stress Calculation in the UBM

FE Model w/ 4 mask



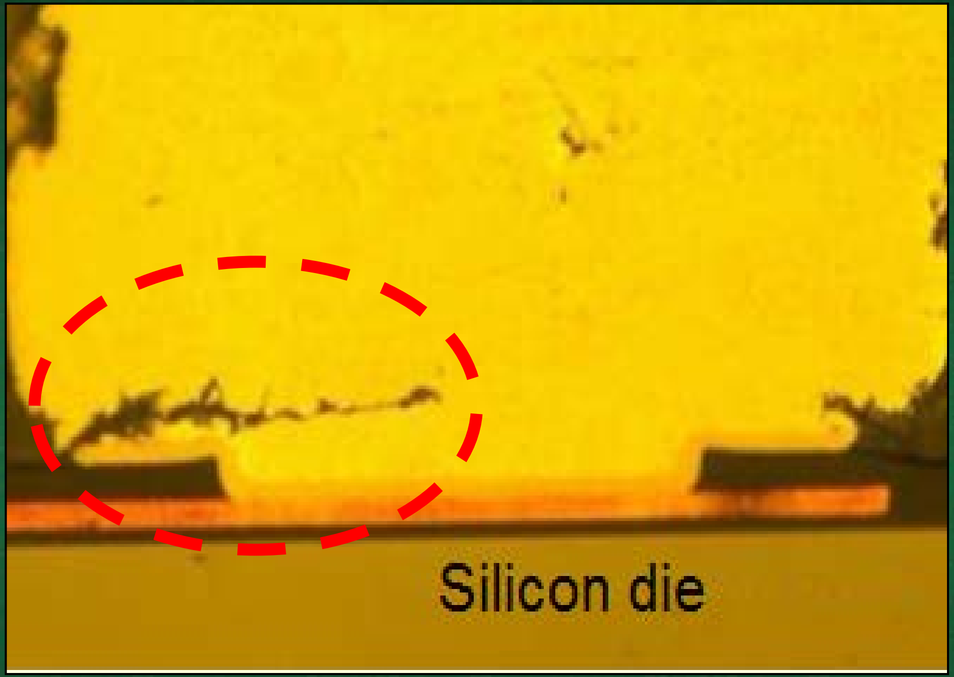
High stresses at the bottom of UBM and on the edge

FE Model w/ 2 mask

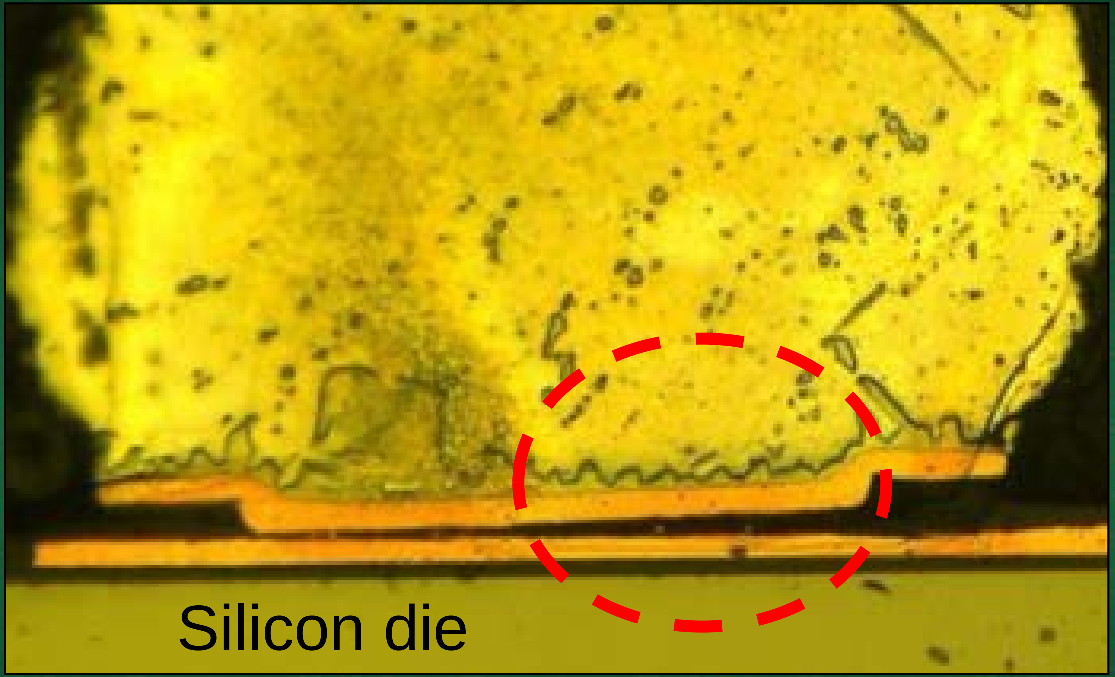


High stresses underneath of solder bump

Potential Bump Failures



Crack from UBM edge

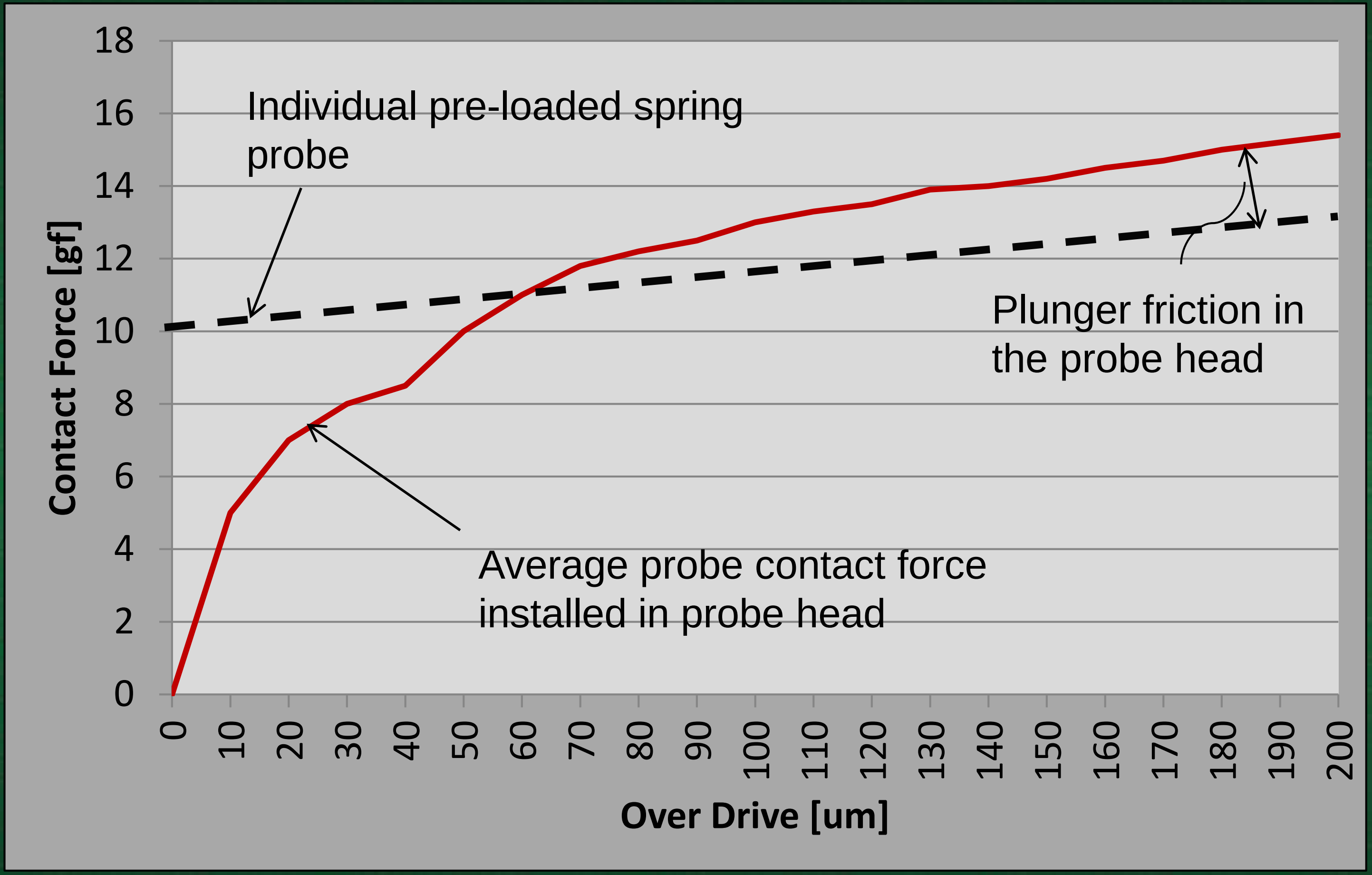


UBM and RDL detachment

The failure causes are related to high range of temperature and possible high stress concentrations in the UBM

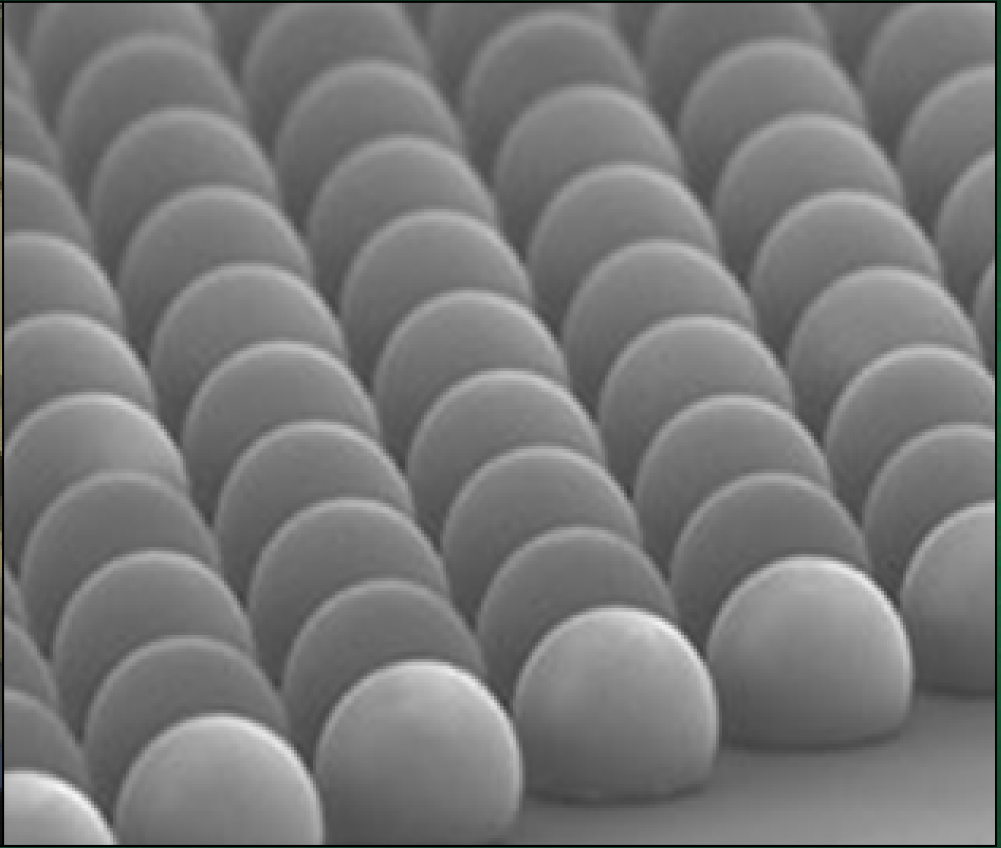
Source: *Journal of Electronic Packaging, 2015*

Contact Force Test - Full Probe Head



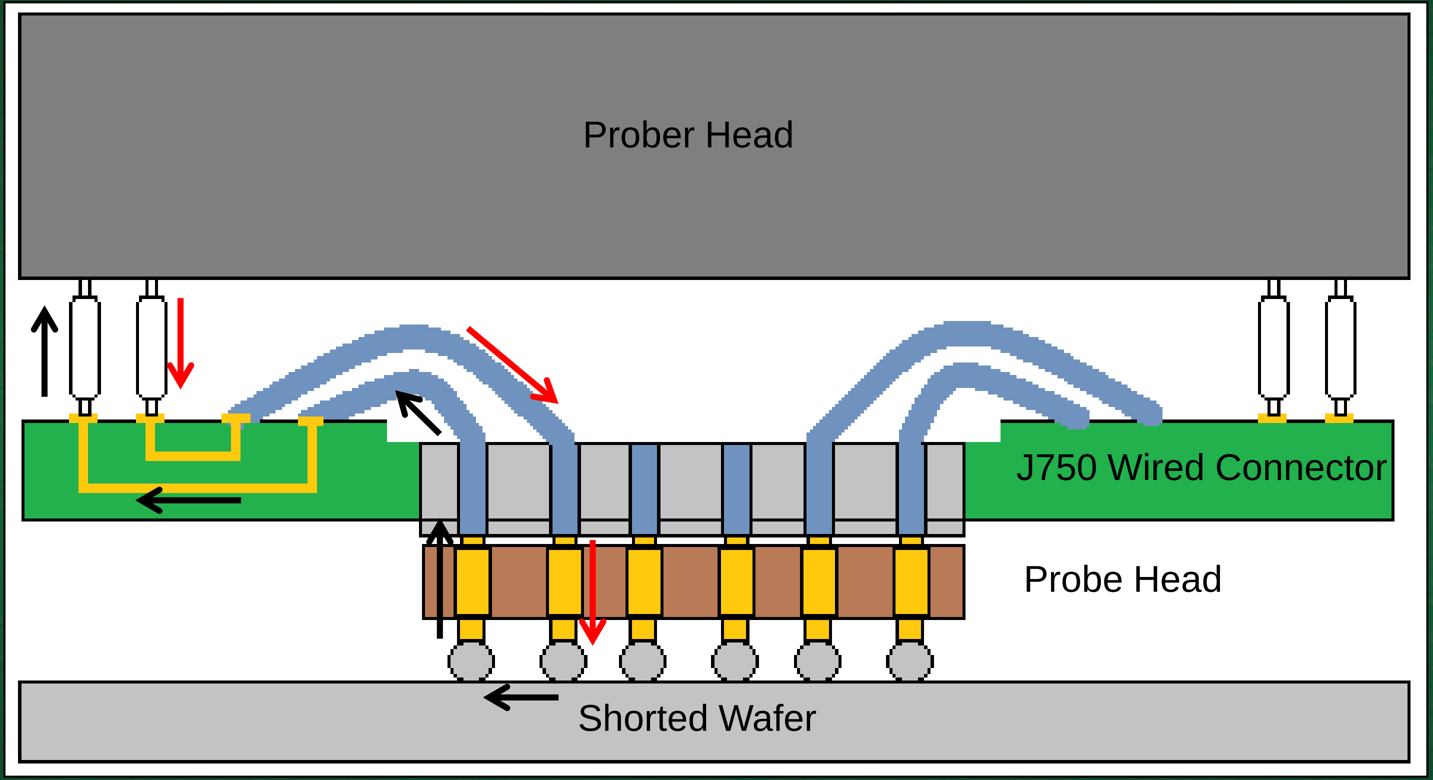
The contact force of test probe head measured by EAP500 system at RT

Path Resistance Test



The bumped wafer SAC305: pitch 250um, bump size 142um
The test over drive 175um

Path Resistance Illustration



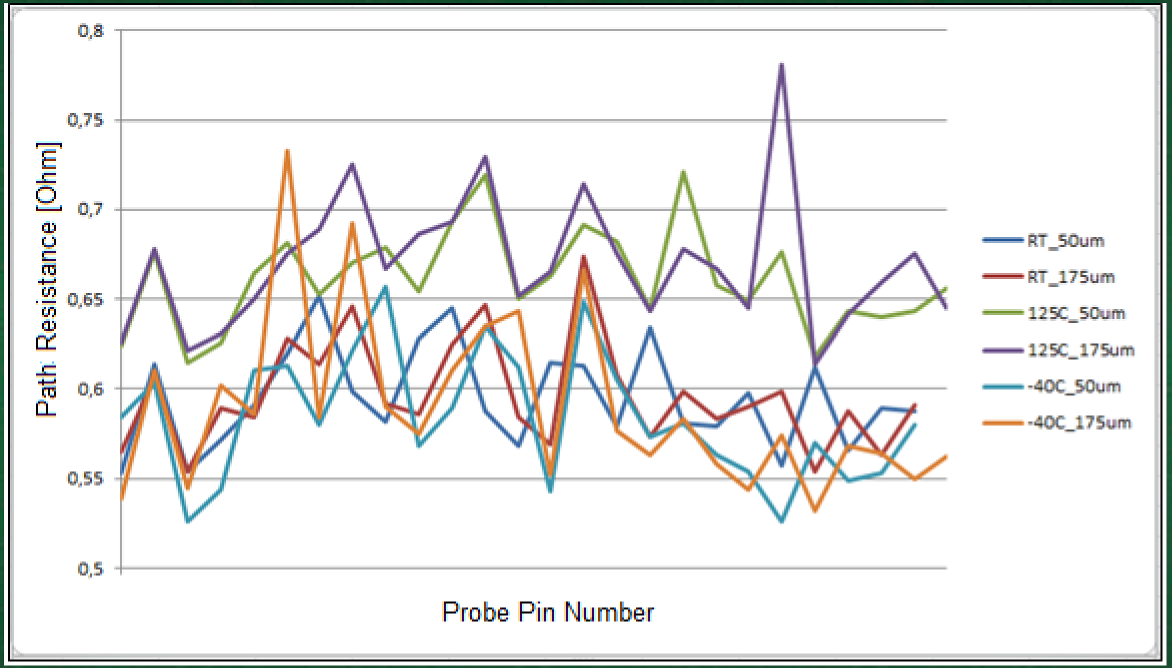
→ Signal Path

→ Return Path

The path contact resistance contains material resistivity of wafer, solder bump, probe, connector wire, PCB solder, PCB trace and prober head pogo, and contact resistances of probe to bump, probe to wired connector, pogo to PCB and pogo to probe head

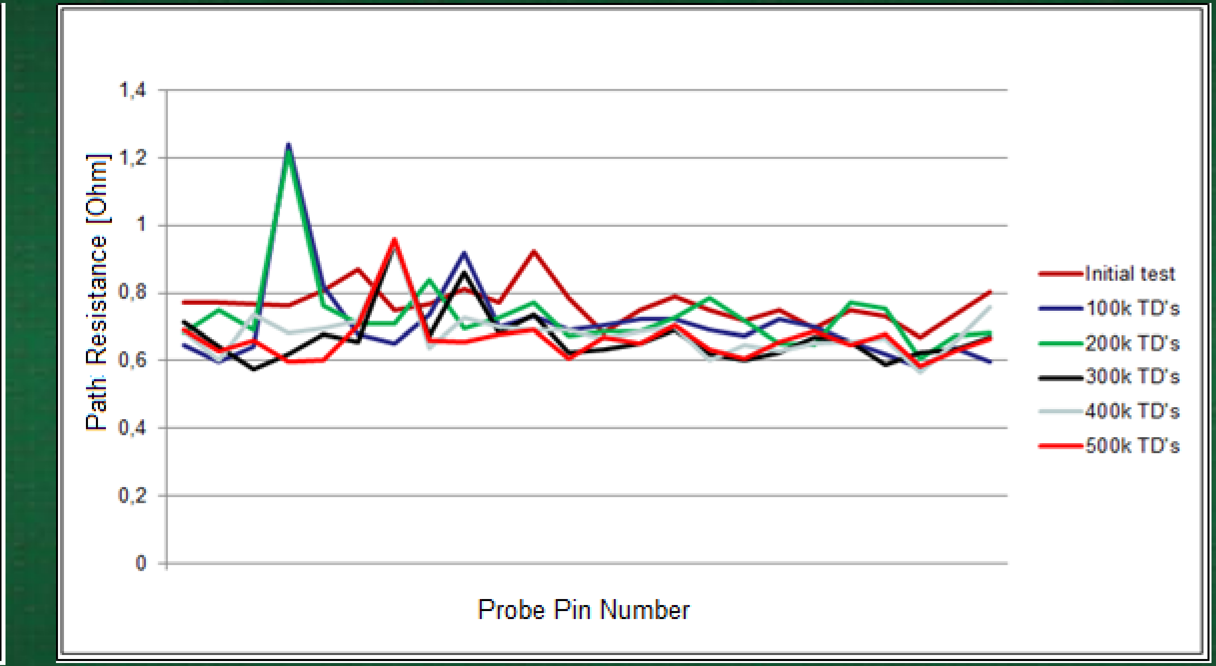
Path Resistance and Life Test Charts

At Varied Temperature and OD



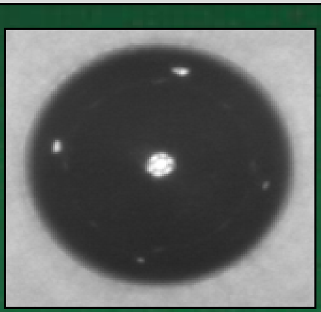
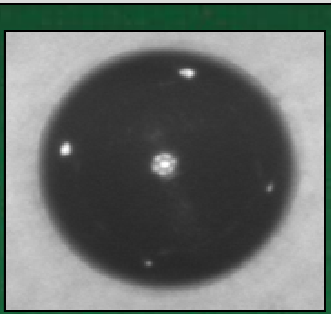
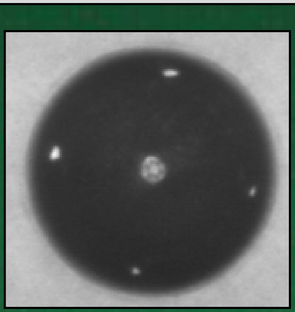
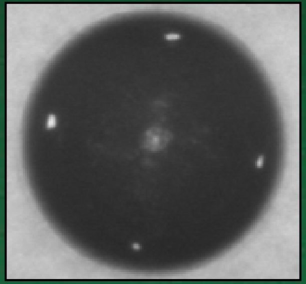
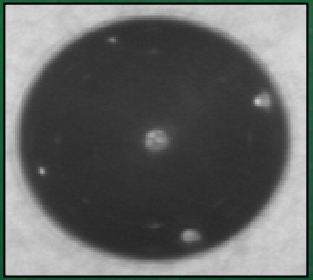
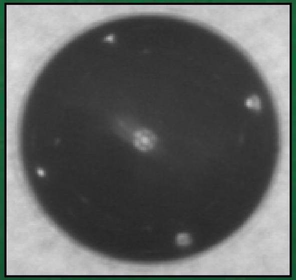
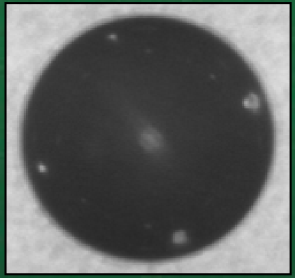
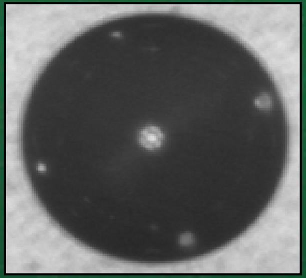
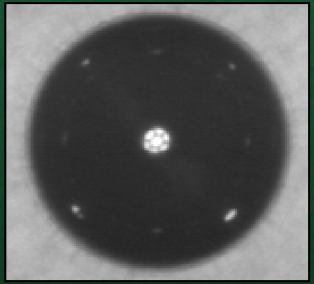
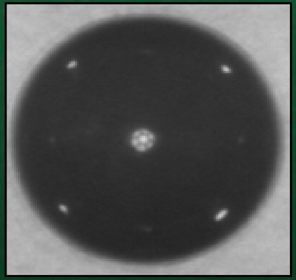
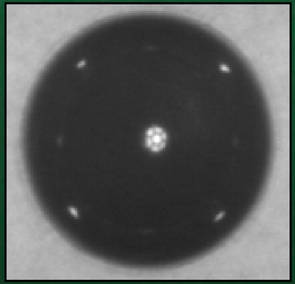
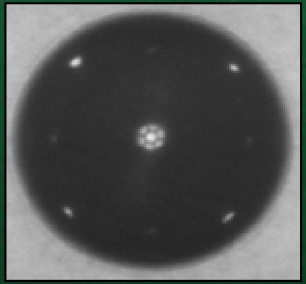
Path resistance at 125C is slightly higher (0.2 Ohm) than at RT and -40C

Life Test at 175um OD



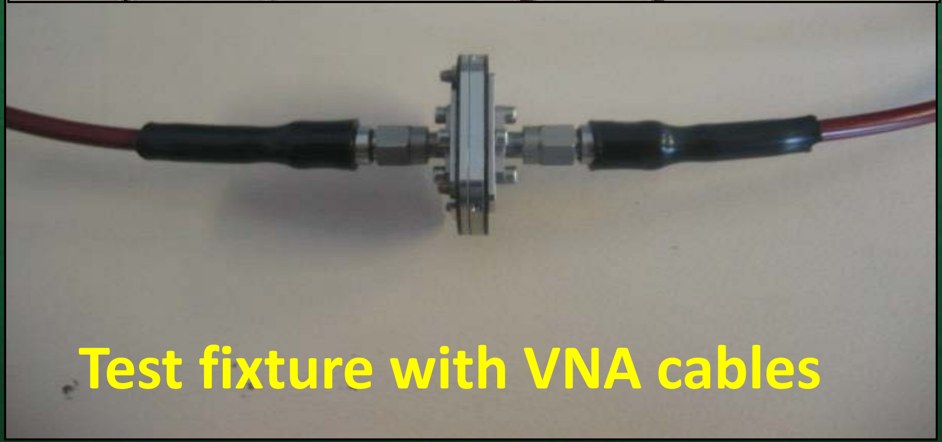
Path resistance at 175um OD shows a quite uniform and consistent profile up to 500k TD’s

Wafer Bump Scrub Marks

Over Drive	50μm	100μm	150μm	175μm
Wafer Bump Image at RT				
Wafer Bump Image at 125C				
Wafer Bump Image at -40C				

Vector Network Analyzer Test

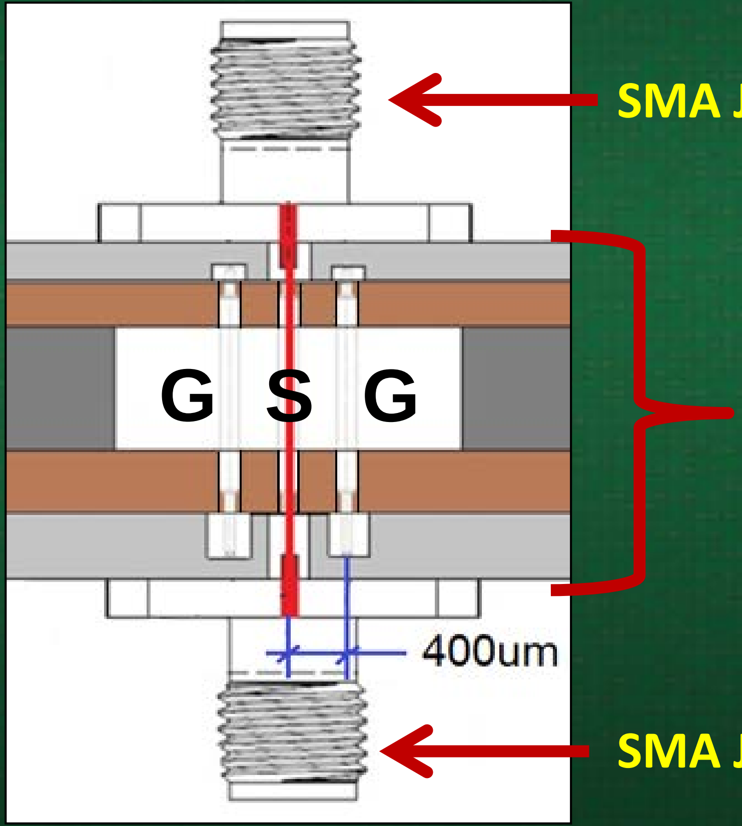
ENA 5071C



Test fixture with VNA cables

Configuration: G-S-G

Probe pitch: 400um

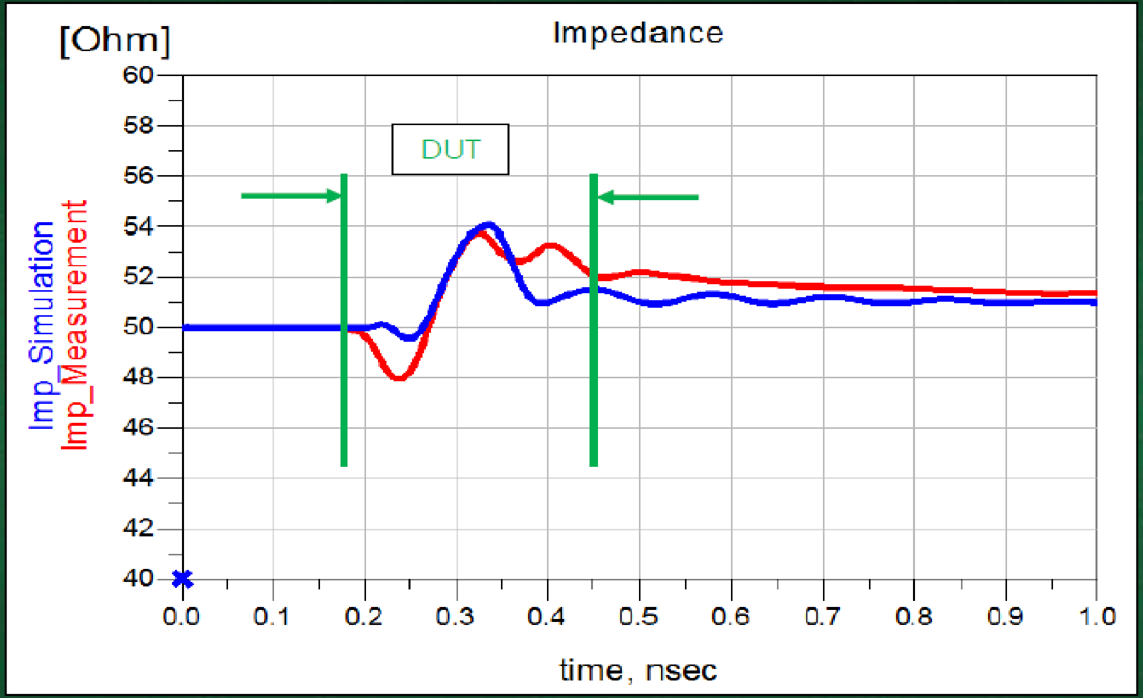


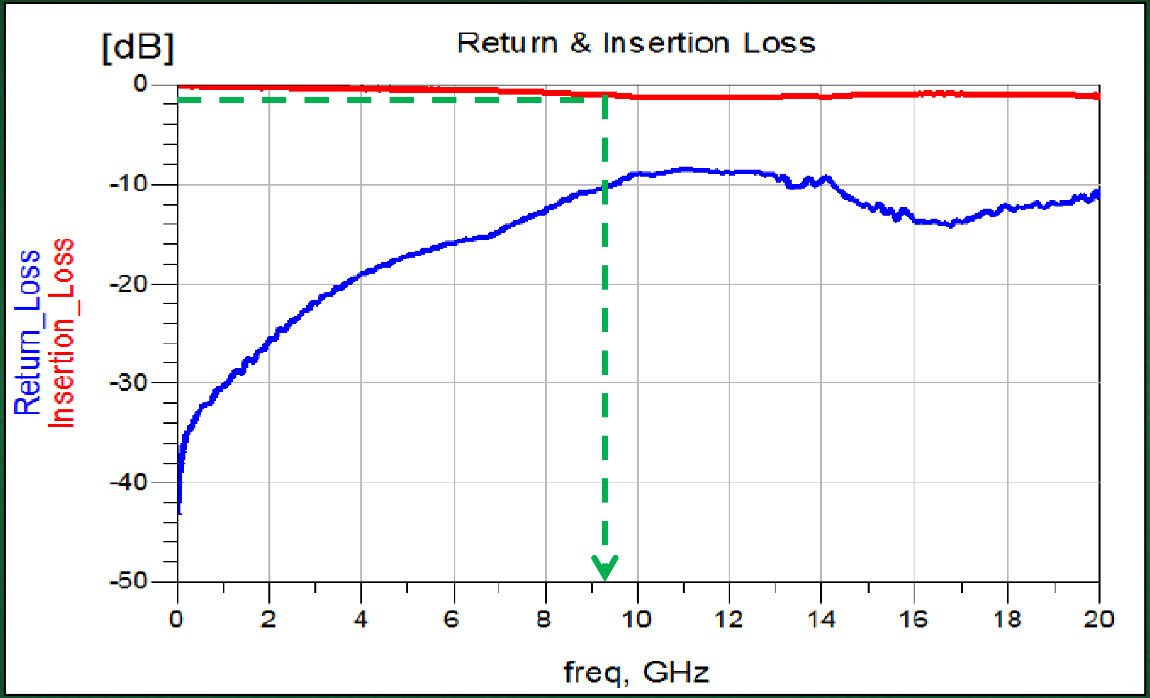
SMA JACK, 50 Ohm, 27GHz

Test Fixture

SMA JACK, 50 Ohm, 27GHz

Impedance and s-Parameters Measurements



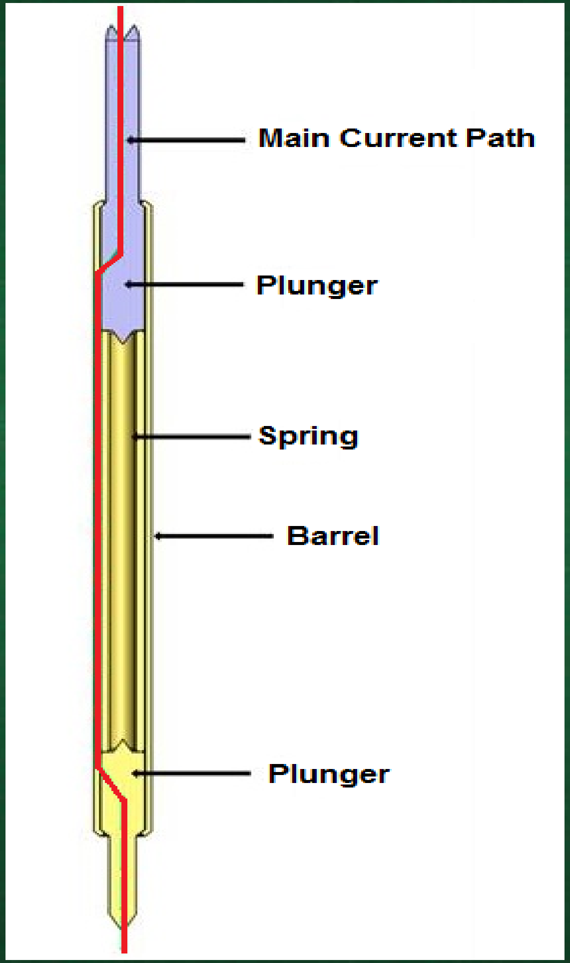


The impedance characteristic was obtained by applying a signal with rise time 50ps (20-80%)

S21- Insertion Loss: 9.3GHz @ -1dB

S11 – Return Loss: 9.5 GHz @-10dB

Probe Current Carrying Capability - Method

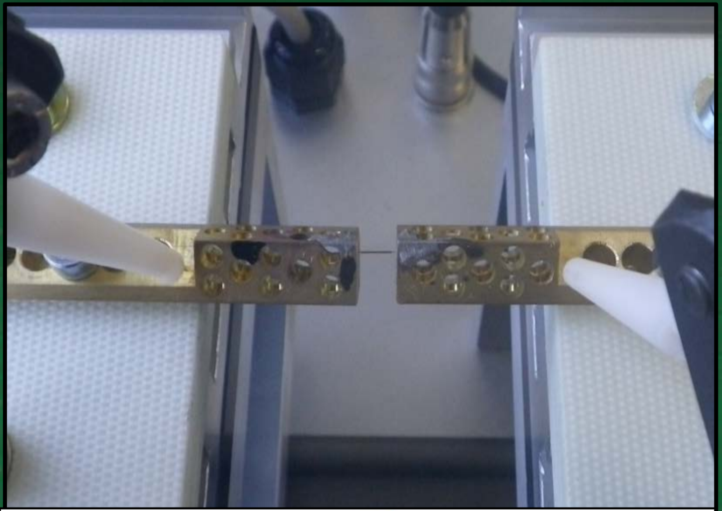


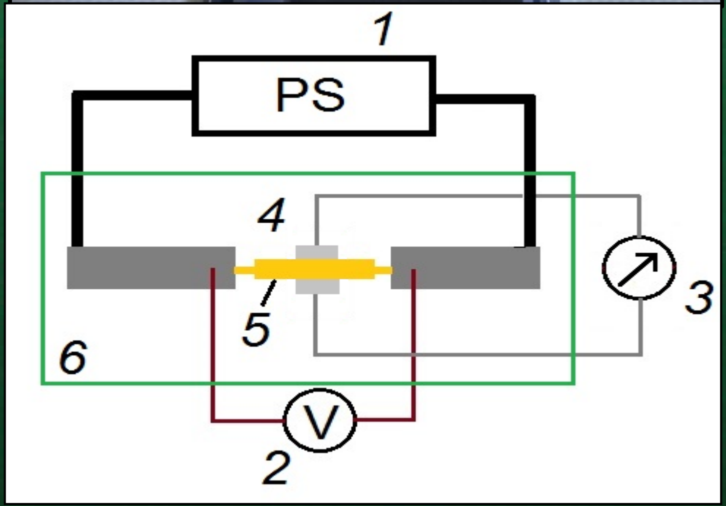
The standard procedure of International Sematech Manufacturing Initiative (ISMI 2009) describing the probe current carrying capability test methods has not mentioned anything about a method how to define the CCC for spring probe.

Therefore based on our internal empirical researches and tests, the maximum continuous current has been defined as a maximum tolerable probe warming temperature during the current lab test.
In case of FeinProbe®, the temperature change of probes under the current has been defined for 20 degree (K) measured by thermocouples

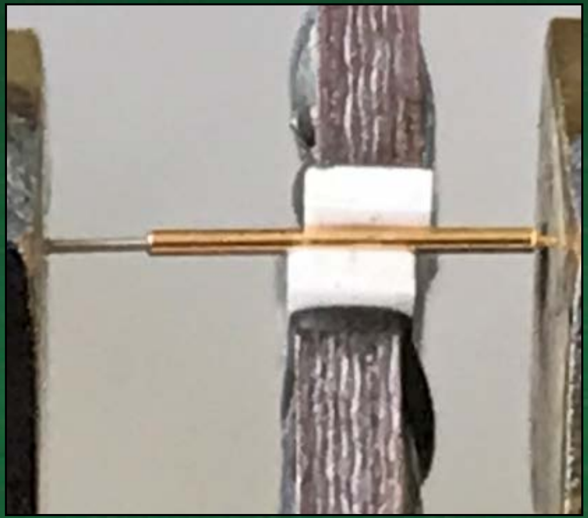
$Tp = K + Te$
Tp – probe surface temperature
K – probe temperature change measured by thermocouples
Te – environment temperature (RT)

Probe Current Measurement Cases



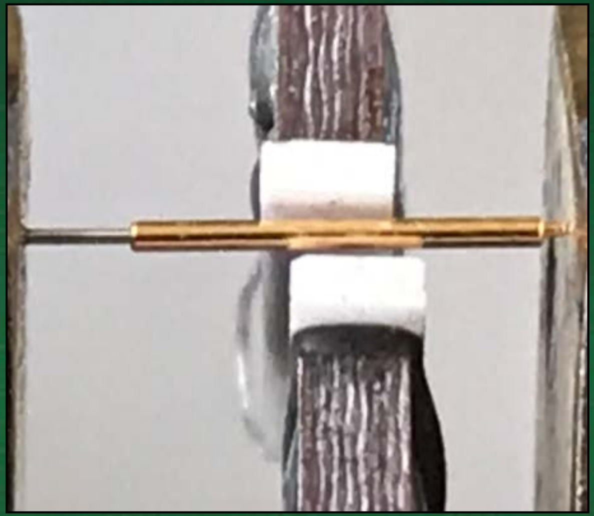


Case 1



Thermocouples touching the test probe

Case 2

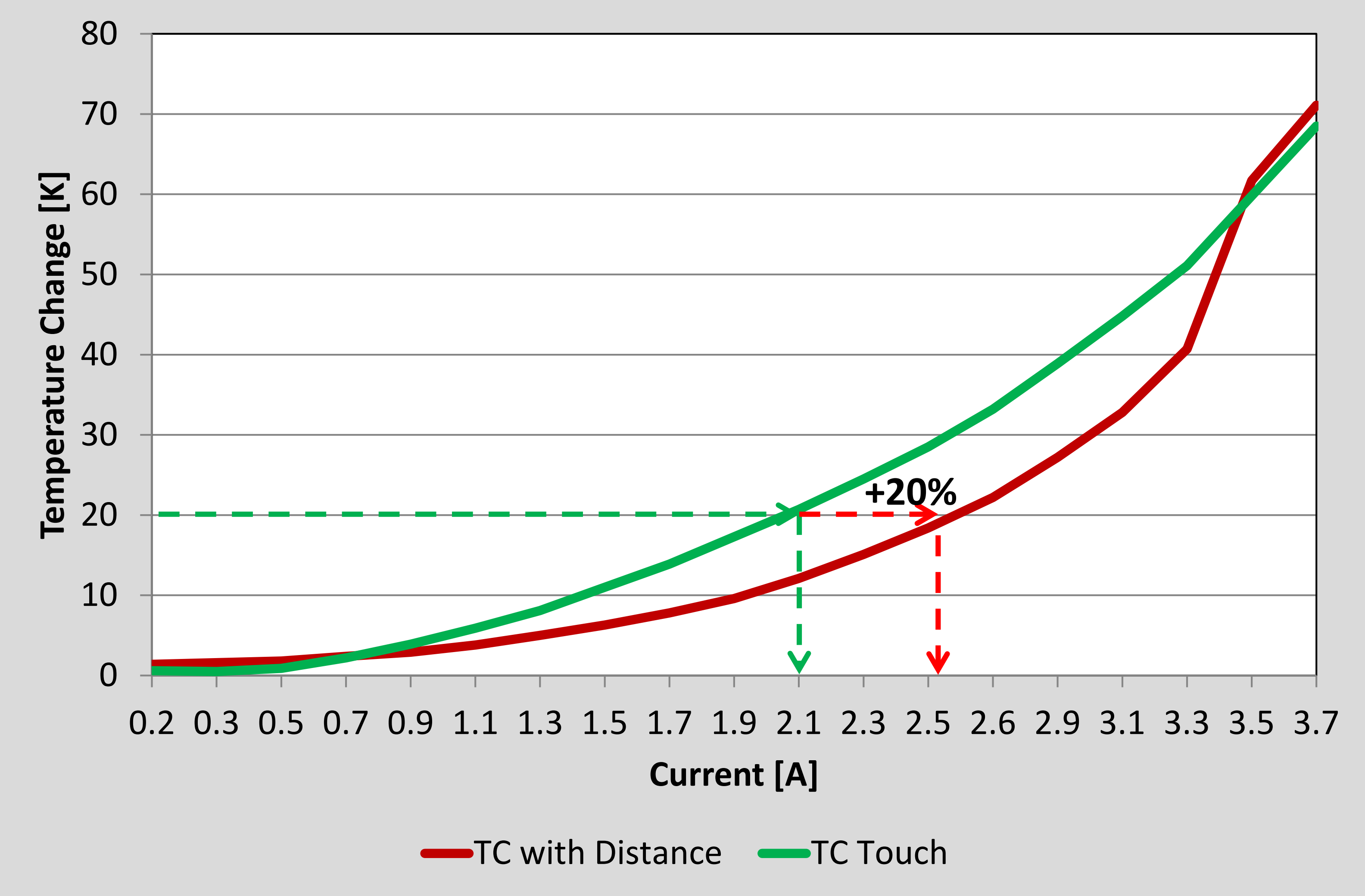


Thermocouples with distance to the test probe

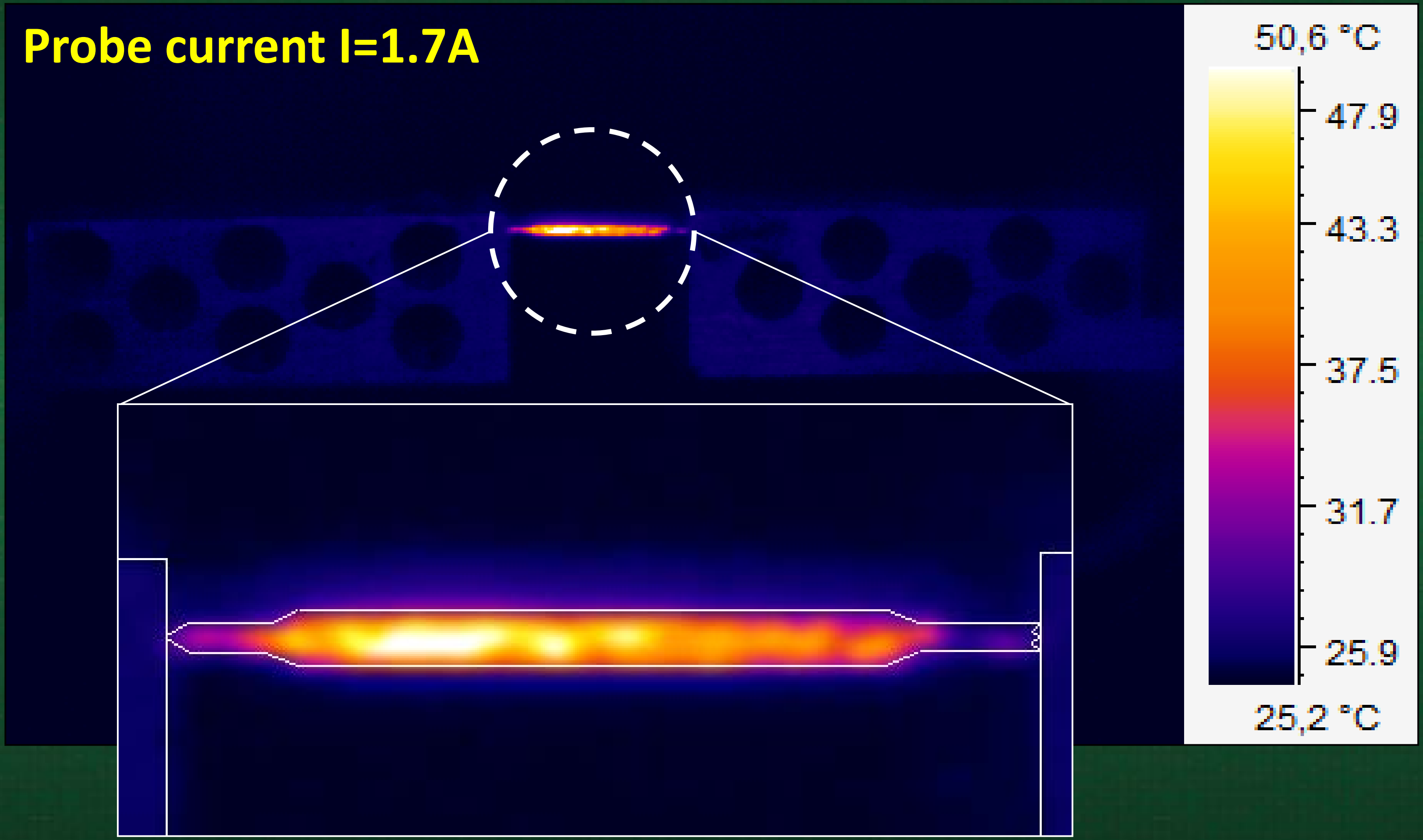
Schematic Diagram Description

1 - power supply
2 – digital voltmeter
3 – thermocouple meter
4 - thermocouples
5 - spring probe
6 - probe station

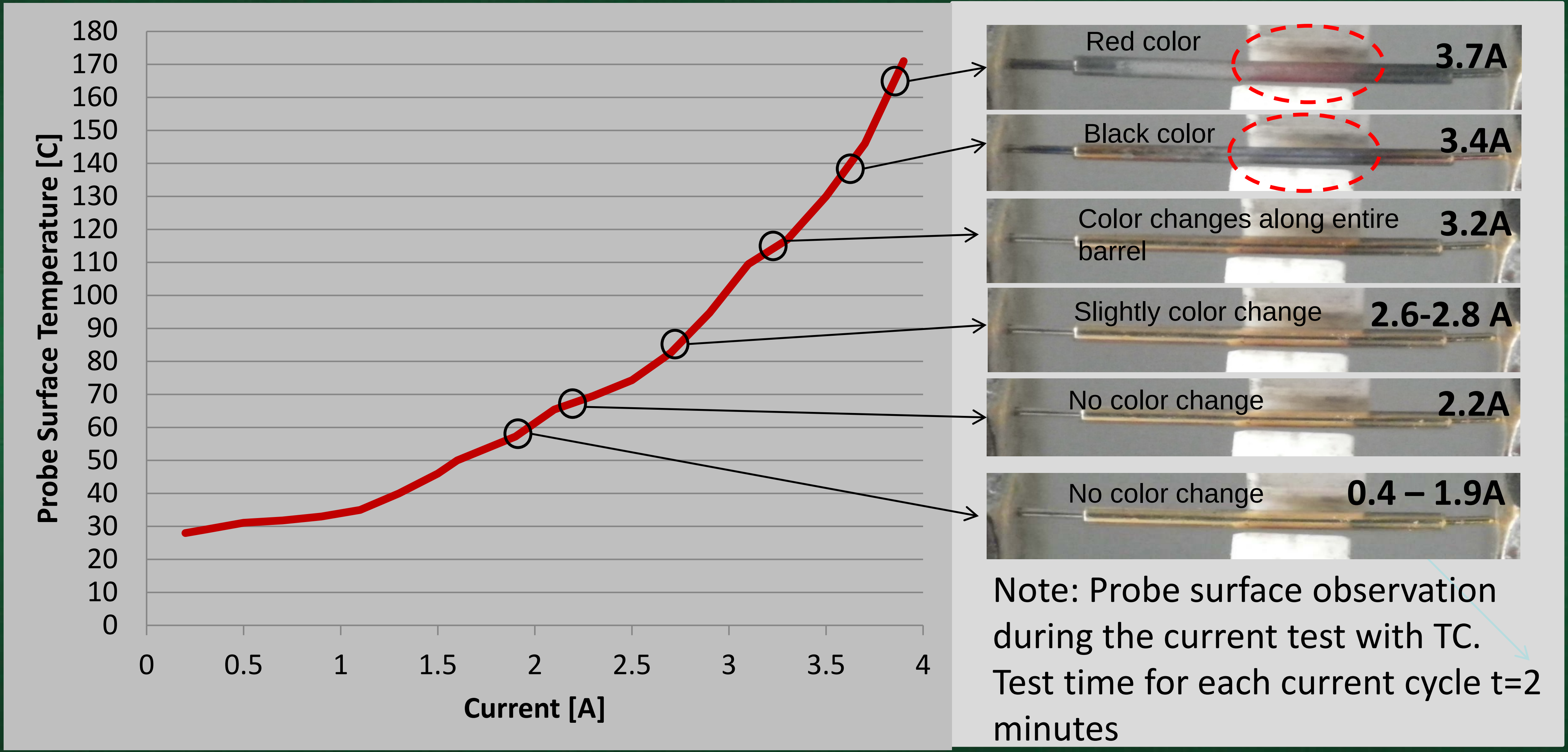
Probe Temperature Change Chart



Probe Image in the Eye of Infrared Camera

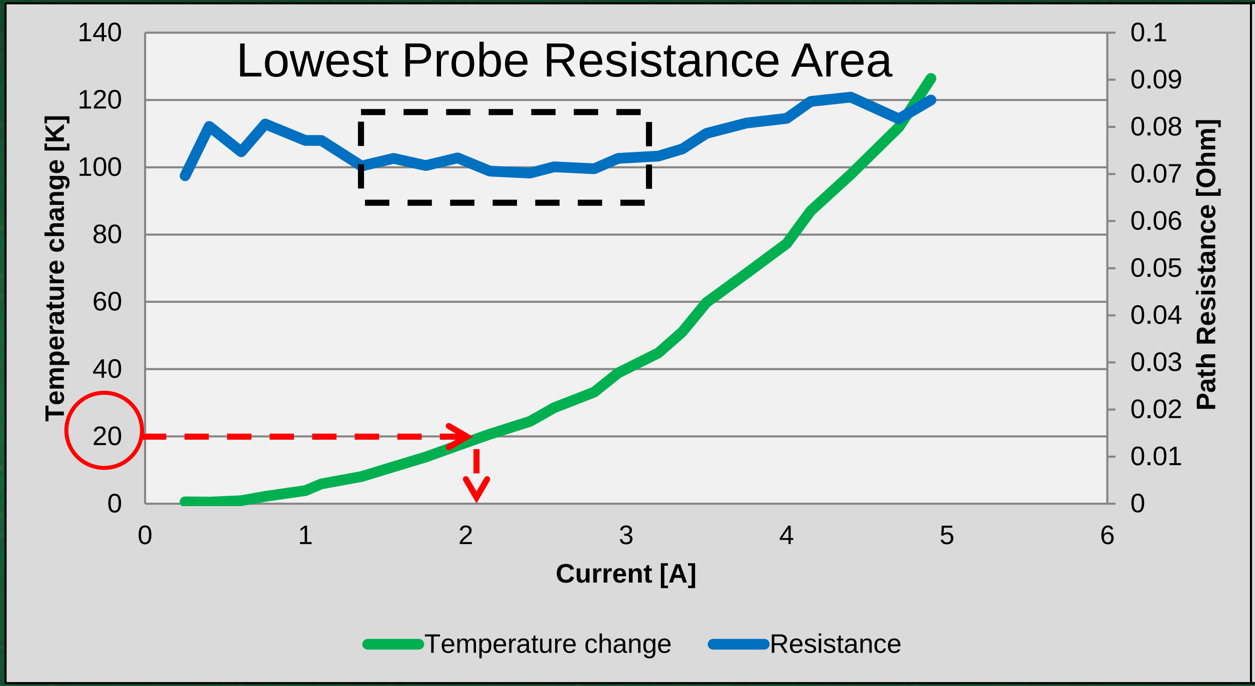


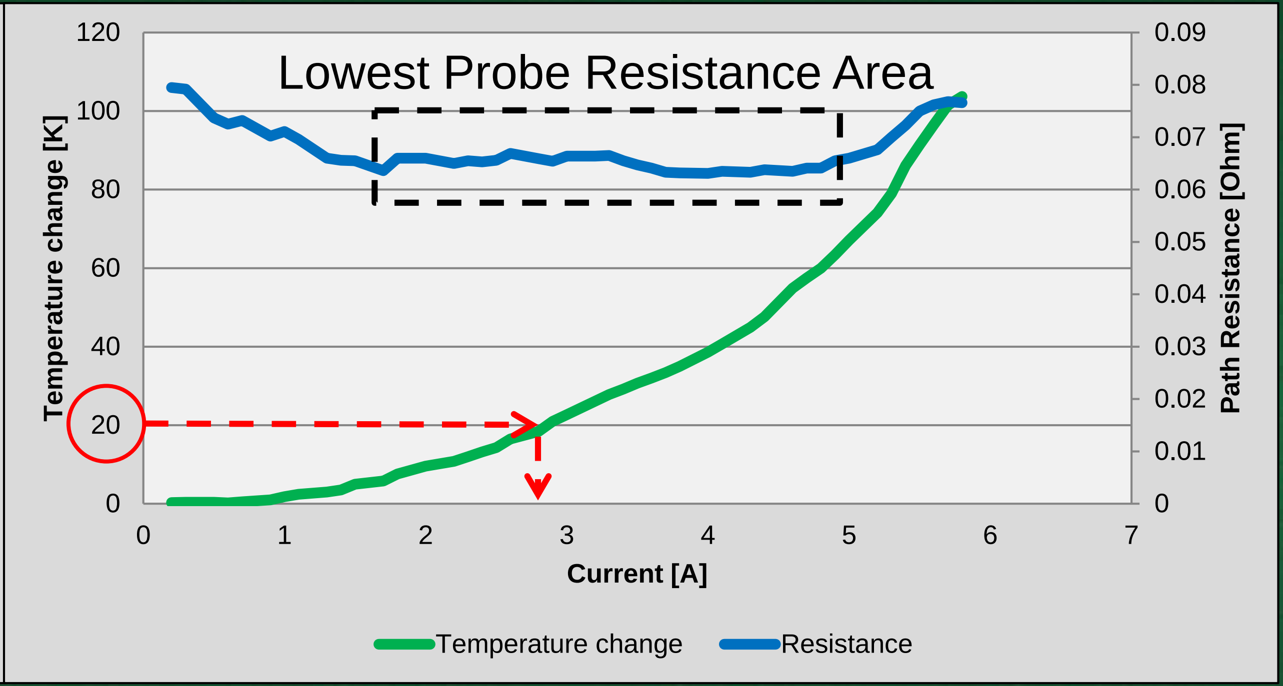
Probe Surface Temp Measured by IC



Note: Probe surface observation during the current test with TC. Test time for each current cycle t=2 minutes

FeinProbe® Current CC and Resistance Graphs





Probe length L= 8.6mm
Continuous CCC= 2.1 A
Path resistance = 70 mOhm

Probe length L=3.2mm
Continuous CCC= 2.8 A
Path resistance = 65 mOhm

Summary and Conclusions

- The advanced package technology exploring the 3D, complex and high pin count of FOCSP requires a reliable test solution and the presented five stages of qualification methodology can be a good approach to guarantee an appropriate contact solution
- The thinner and smaller UBM may cause a cracking or delamination issues of the under bump metallization during the wafer test

Summary and Conclusions

- The update of ISMI procedure is needed to standardize the CCC measurement method for the spring probes. The presented approach is a suggestion for an alternative method

Follow-on Work

- Study of the low spring force probe
- Study of the spring probe at high temperature

Acknowledgments

I would like to thank colleagues at Feinmetall for their help in preparation of this presentation. Many thanks to Jörg Behr, Gunnar Volkmann and Jörg Burgold.

Thank You