TPEG™: a new vertical MEMS solution for high current, low pitch applications

TECHNOPROBE
Wafer Probing Technologies

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Outline

- Background
- Technoprobe at a glance
- TPEG™ MEMS process overview
- Objectives
- Development steps
- Results
- Conclusions
- Follow-On Work

Background

- Today ICs testing applications are more and more demanding in terms of requested enhanced fine pitch capability with reduced pad damage risk and increased Current Carrying Capability (CCC) even at high testing temperature.

- Best trade-off has to be found to address stringent and conflicting technical requirements while progressing towards a reduction in the cost of ownership of the probe cards and of the overall cost of testing.

Technoprobe at a glance

- **Who we are**
  - Founded in 1993 and privately owned, with > 350 employees worldwide and serving top semiconductor manufacturers
  - Headquartered in Europe and with a global infrastructure to offer prompt local support and fast probe cards availability
  - Ranked among the top 5 Probe Cards manufacturers worldwide

- **Knowledge and Progress**
  - Broad product portfolio
    - Cantilever, Vertical and MEMS
  - Highly customized products
  - Relentless investments in technology

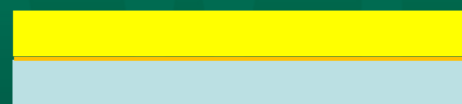
Technoprobe heading into future

- **TP recognized the necessity to offer the advantage of needles capable of combining different features in a resulting unprecedented performance**
- **To this purpose, TP developed the in-house capability of a new proprietary manufacturing process for MEMS needles, TPEG™**
- **TPEG™ process allows**
  - Complete tailoring of needles design and features (min pitch, tip shape & length, forces, CCC, temperature) to Customers' requirements
    - New alloy materials for high current and high testing T
  - Extension of advanced testing to a broad application portfolio
    - High current applications, high operating temp, low pad damage …
  - Extension of the inherent advantage of vertical probe card high parallelism with the result of a reduction of the overall cost of testing
  - Fast needle developments, reduced time to market

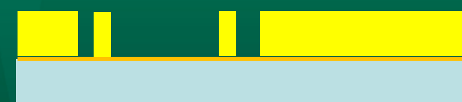
TPEG™ MEMS process overview

- **TPEG™ proprietary MEMS process**
  - TechnoProbe Etching and Galvanic

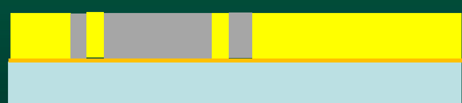
Metallized Si substrate



Thick PR spinning

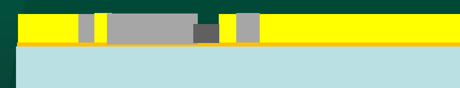


Litho and PR devpt.

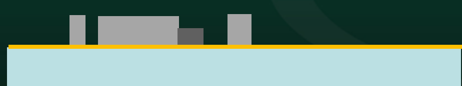


Alloy deposition

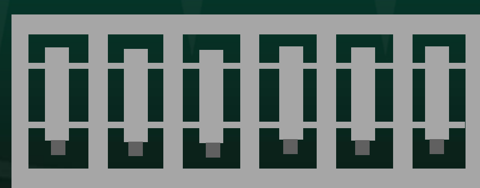
Thinning and planarization



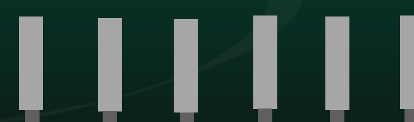
Tip etching



PR removal/ substrate etching



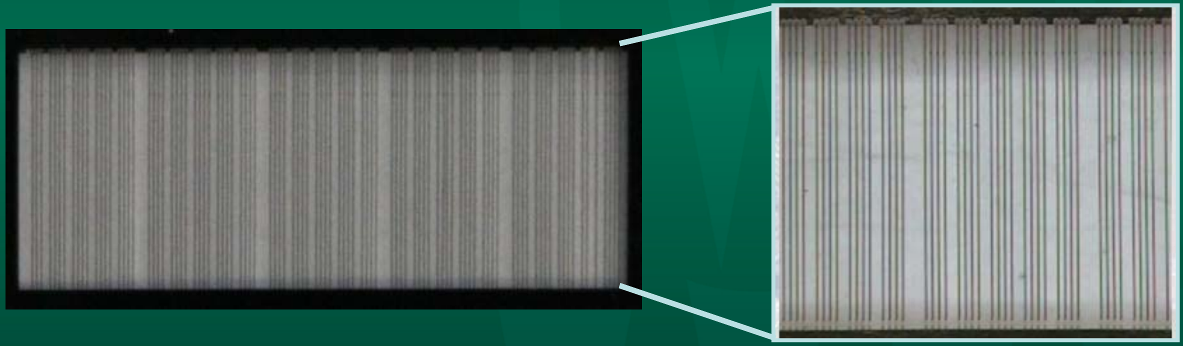
Needle strips removal from substrate



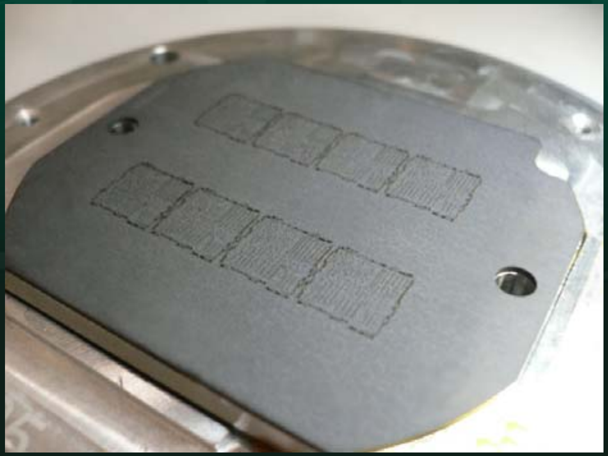
Needles ready for assy

TPEG™ MEMS process overview

- **MEMS TPEG™ T1 and T4 needles**



- **6K needles //8 MEMS TPEG™ T1 probe head**



Objectives

- **TPEG™ MEMS development - target performances:**
  - Min pitch:
    - Down to 40 um in Full Array (FA) configuration
  - Low force probe:
    - Down to 2 – 2.5 g for pad damage on WB pads
    - Down to 5 g for high pin count (>20K needles) on Cu Pillar and/or on bumps
  - Current Carrying Capability (CCC):
    - up to 1.5A per probe at 70 um linear pitch
  - Testing Temperature
    - from -55°C up to +200°C

Development steps

Material characterization
- Mechanical
  - Young Modulus
  - Tensile Yield Strength
  - Ultimate Tensile strength
  - Elongation %
- Electrical
  - Resistivity
- Thermal
  - CTE
  - Resistivity (T)
  - Young Modulus (T)

Market trend & Customer roadmap
- Min pitch
- Parallelism
- Testing Temp
- Current per probe
- Probe force

Simplified FE models
- Mechanical PH model
- Electro - thermal model

Full FE models
- Mechanical model
- Electro-thermal model
- El. – Thermo – Mech. model

PH design
- Alloy definition
- Needle design
- PH mechanical design

External MEMS process:
> 13 WKs learning cycle

Continuous fine tuning and optimization

In-house MEMS process:
< 4 WKs learning cycle

PH testing – lifetest
- Mechanical cycling
- Interference test
- Scrub mark analysis

PH testing
- Probe force
- CCC and C_RES
- Mechanical cycles

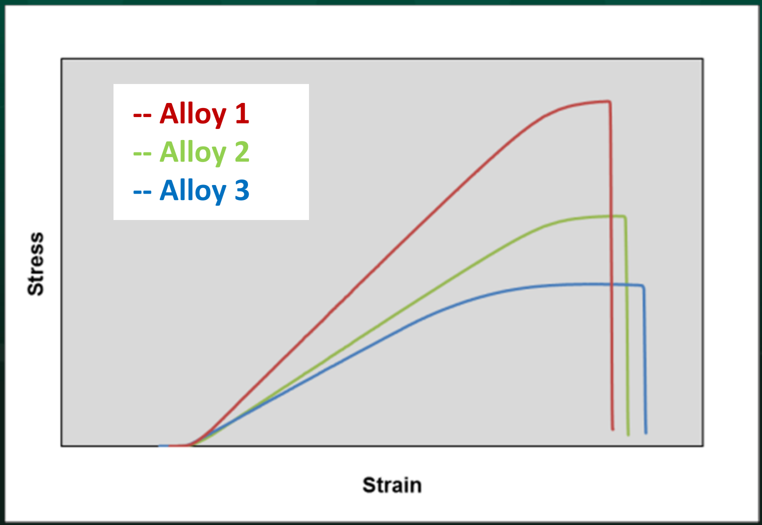
Improved PH design and process

Base alloys characterization and selection

- **Evaluated alloys**
  - Three alloys evaluated with different mechanical and electrical properties
- **Mechanical characterization**
  - Stress-strain tests
- **Electrical characterization**
  - Resistivity
- **Thermal characterization**
  - CTE
  - Resistivity (T)
  - Young Modulus (T)

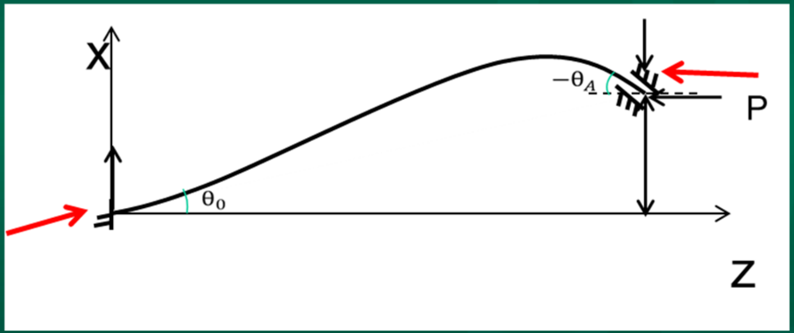
Stress – strain tests

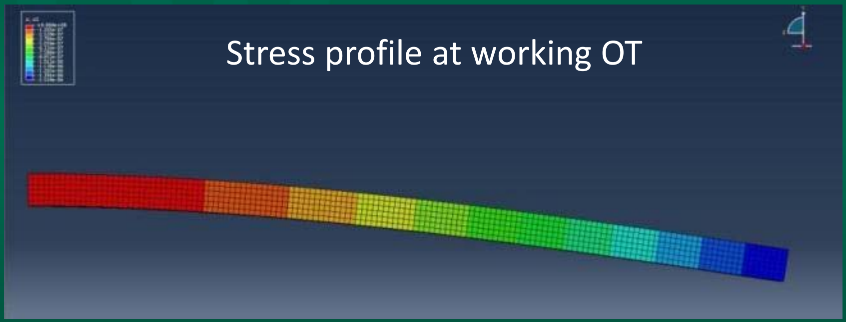
- **A specimen has been specifically designed**
  - No standard is today available
- **Typical parameters extracted from the curve**
  - Young Modulus, Tensile Yield strength, Ultimate Tensile Strength



Mechanical Model

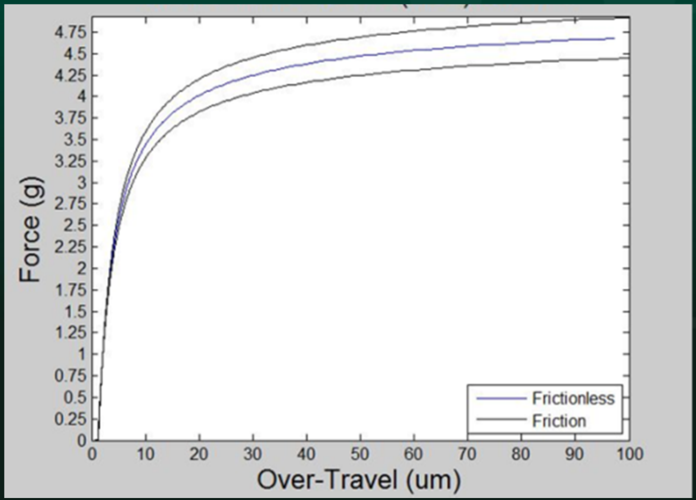
- **FE model – single needle:**



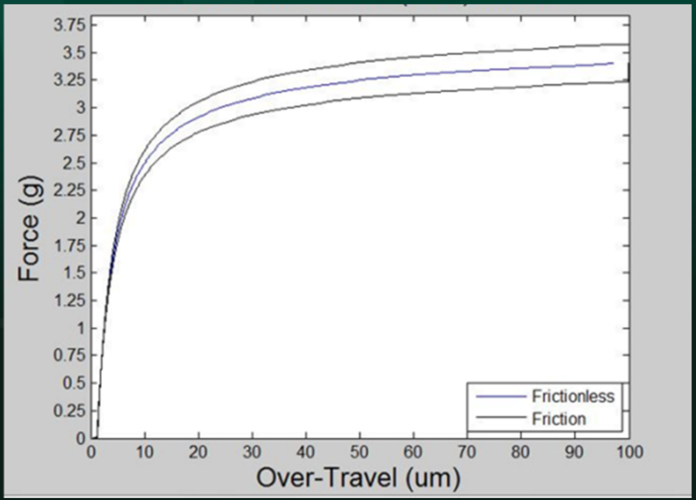


- **Force – OT: simulations**

Design A

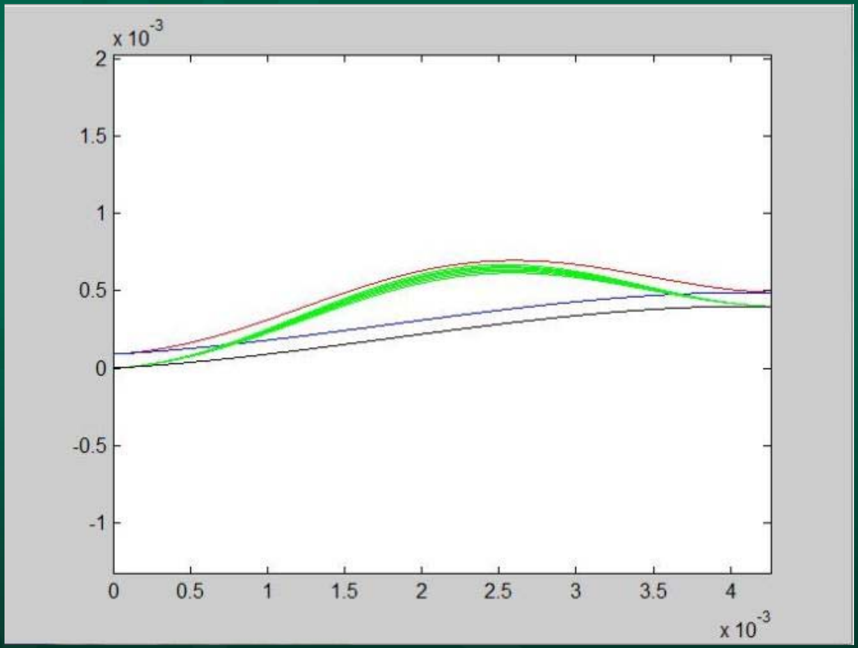


Design B



Mechanical interference model

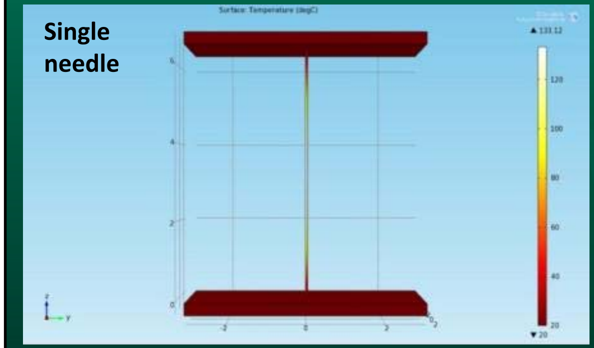
- **Simplified FE model has been used to predict possible mechanical interference between adjacent needles**
  – A pair of needles is considered
  – A defined working OT is applied to both
  – Increasing planarity bias is imposed to one of the two needles

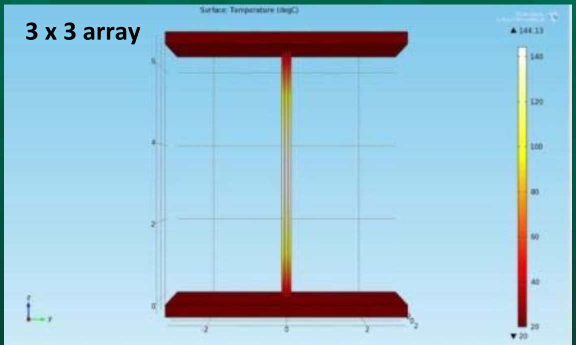


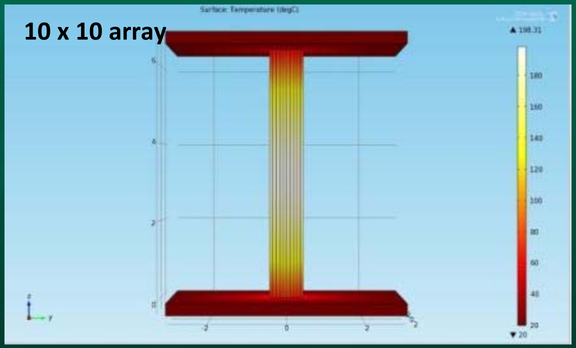
– **Black and blue lines:**
  - **Adjacent needles 1 and 2 at 0 μm OT**
– **Red and green lines:**
  - **Same needles at working OT**
  - **Green lines: needle 2 at increasing planarity bias**

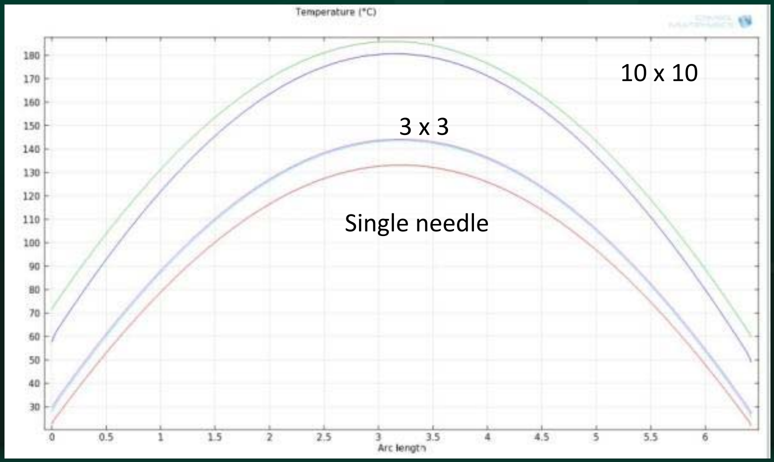
Electro-thermal model

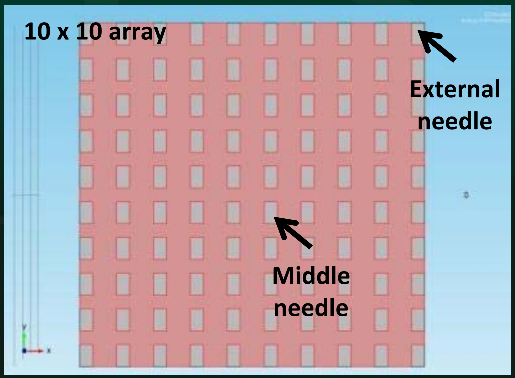
- **Simplified FE multiphysics model**
  - Al pad on needle tip side; Au pad on needle head side





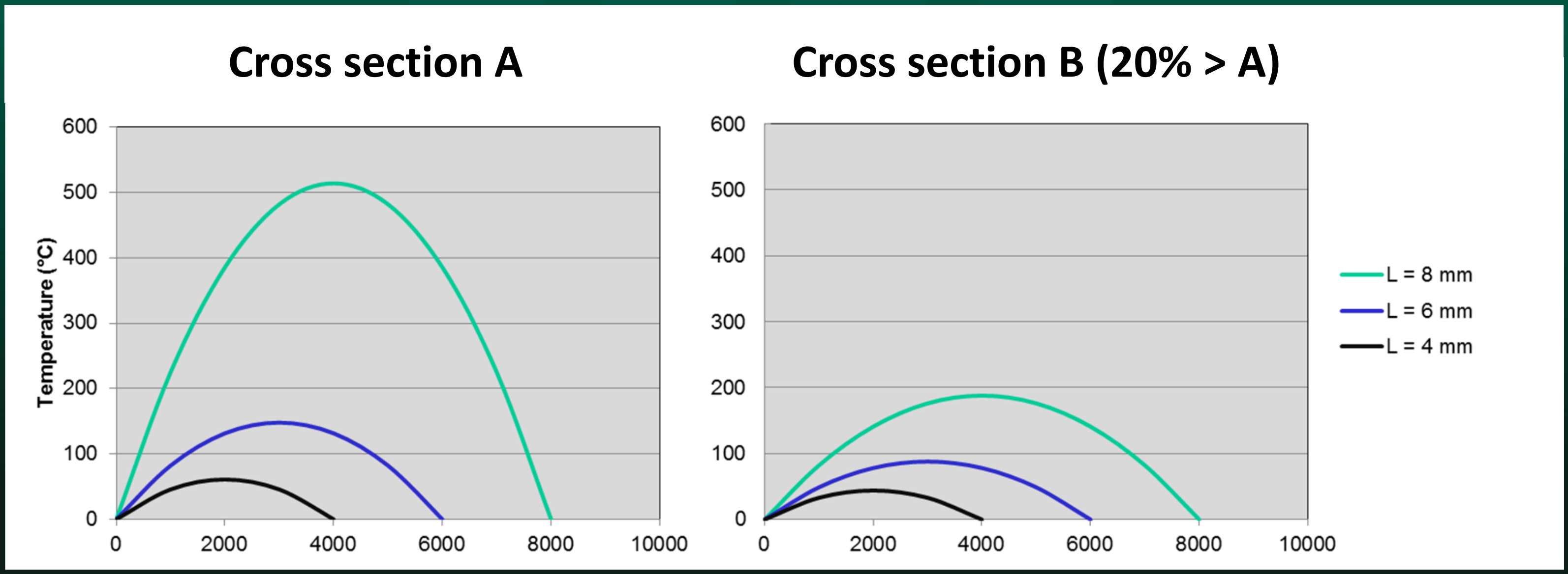






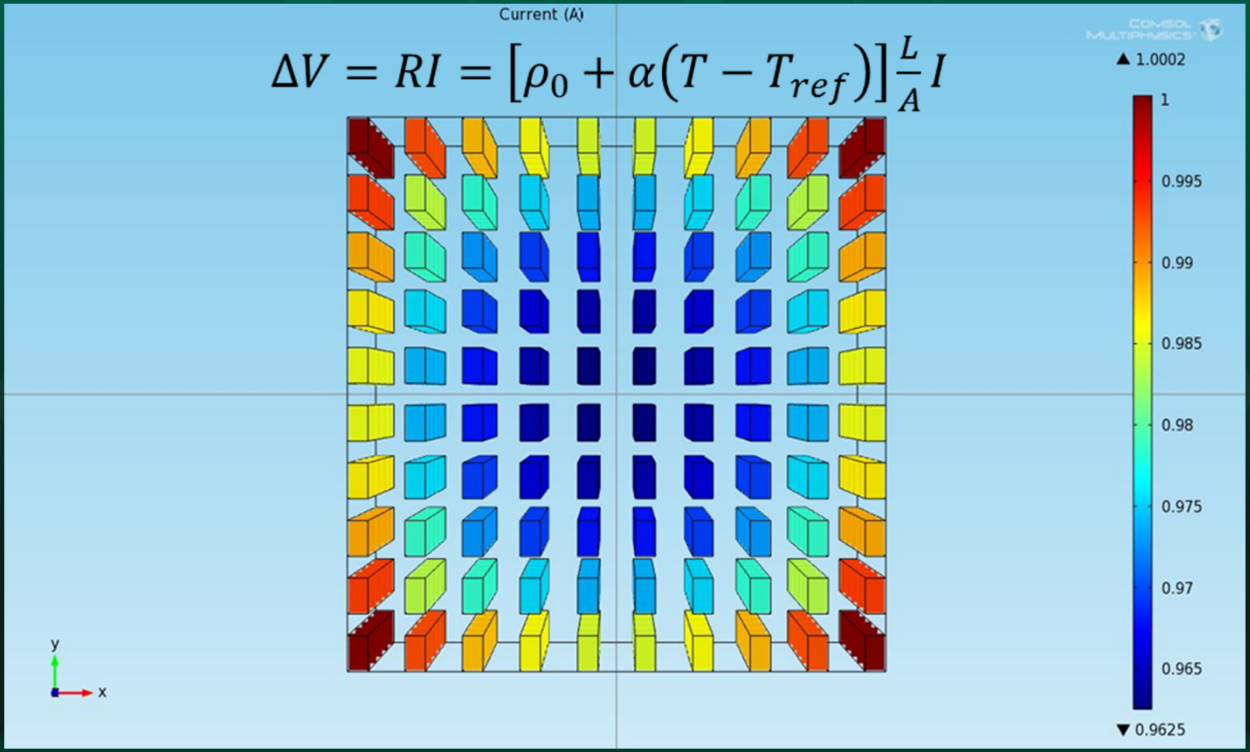
Electro-thermal model

- **Temperature distribution in the needle with 1A current flowing by varying:**
  - Needle length
  - Needle cross section



Electro-thermal model

- **Another typical effect**
  - Force 1 V to all probes, model the I per probe
  - Current is lower in the center of the array, where T is higher as per Ohm's law



Thermal, electrical & mechanical model

- **FE model under development**
  - Mechanical behavior dependent on geometry, derived from simplified mechanical FE model
  - Temperature profiles imported from thermo- electrical FE model
- **Mathematical code ready**
- **Next Steps**
  - Alignment with experimental data
  - Simplified model to predict needle behavior under thermo-electro-mechanical load fatigue stress

New TPEG™ MEMS probes

Distinctive features

Benefits to Customer

- **TPEG™ MEMS T1**
  - Min. Pitch 60/55 µm linear
  - CCC up to 820 mA
  - Force 2 - 2.5 g

❖ Reduction of min pitch and force with simultaneous increase of CCC to enable testing of advanced SoC
❖ Customizable tip length to increase lifetime and reduce overall testing cost

- **TPEG™ MEMS T3**
  - Min. Pitch 90 µm Full Array
  - CCC up to 1200 mA;
  - Force 4 - 5.5 g

❖ Reduced force to allow for testing on next generation bumps and to increase probe count to > 20.000
❖ CCC performance at the forefront of the market for probing on bumps

- **TPEG™ MEMS T4**
  - Min. Pitch 70 µm
  - CCC up to 1500 mA
  - Force 3 - 3.5g

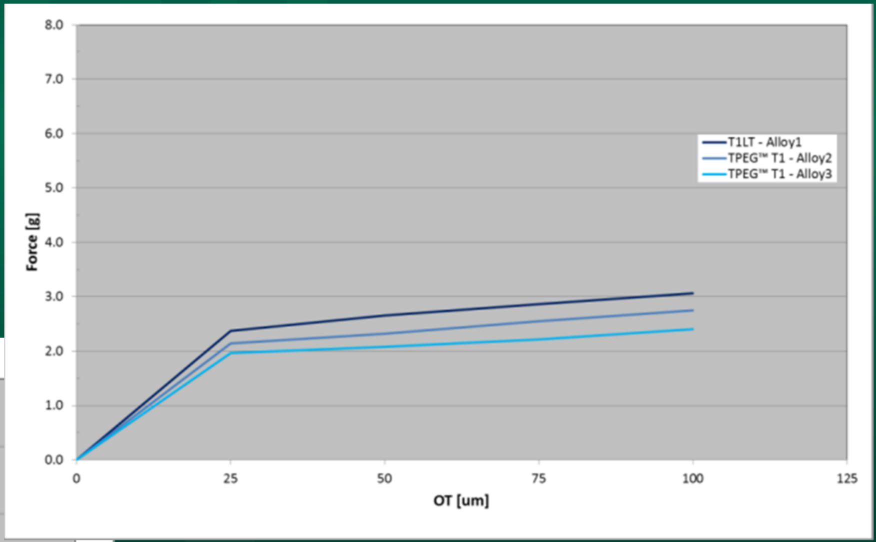
❖ Increased CCC and reduced force to advance testing of high current applications (automotive)
❖ Customizable tip length to increase lifetime and reduce overall testing cost

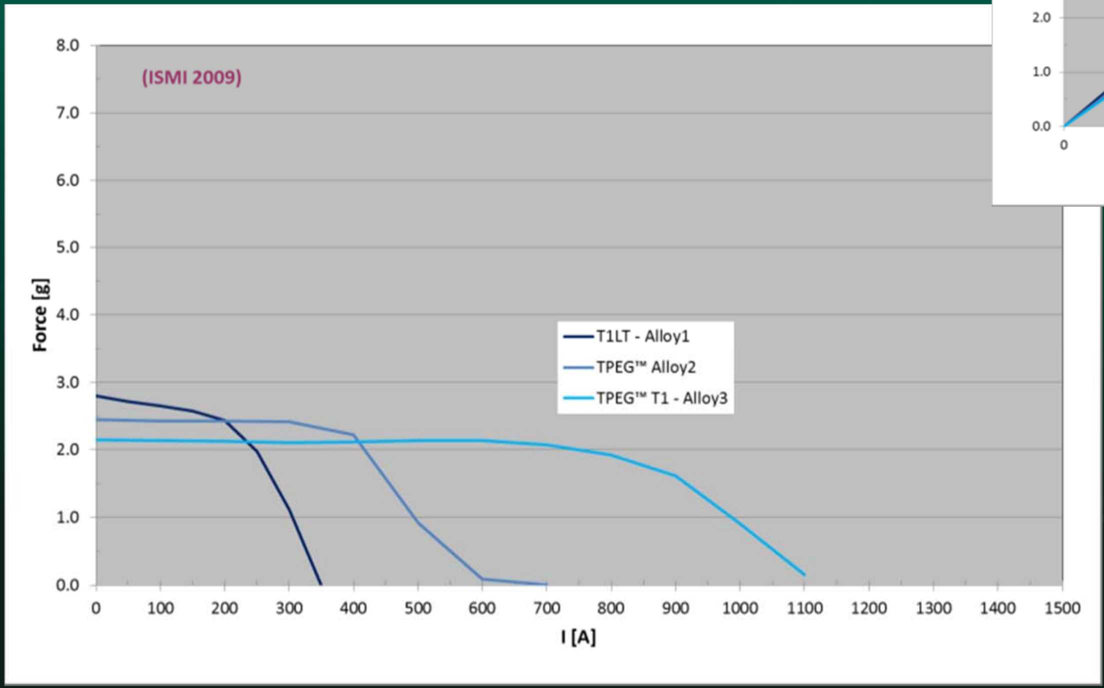
- **TPEG™ MEMS T0 (Q4 '12)**
  - Min. Pitch 40 µm (linear and FA)
  - Target CCC: > 250 mA
  - Target force: ~ 1.5 g

❖ Ultra fine pitch capability at the forefront of the market and allowing testing on leading edge microprocessors and SoC

TPEG™ MEMS T1: force and CCC

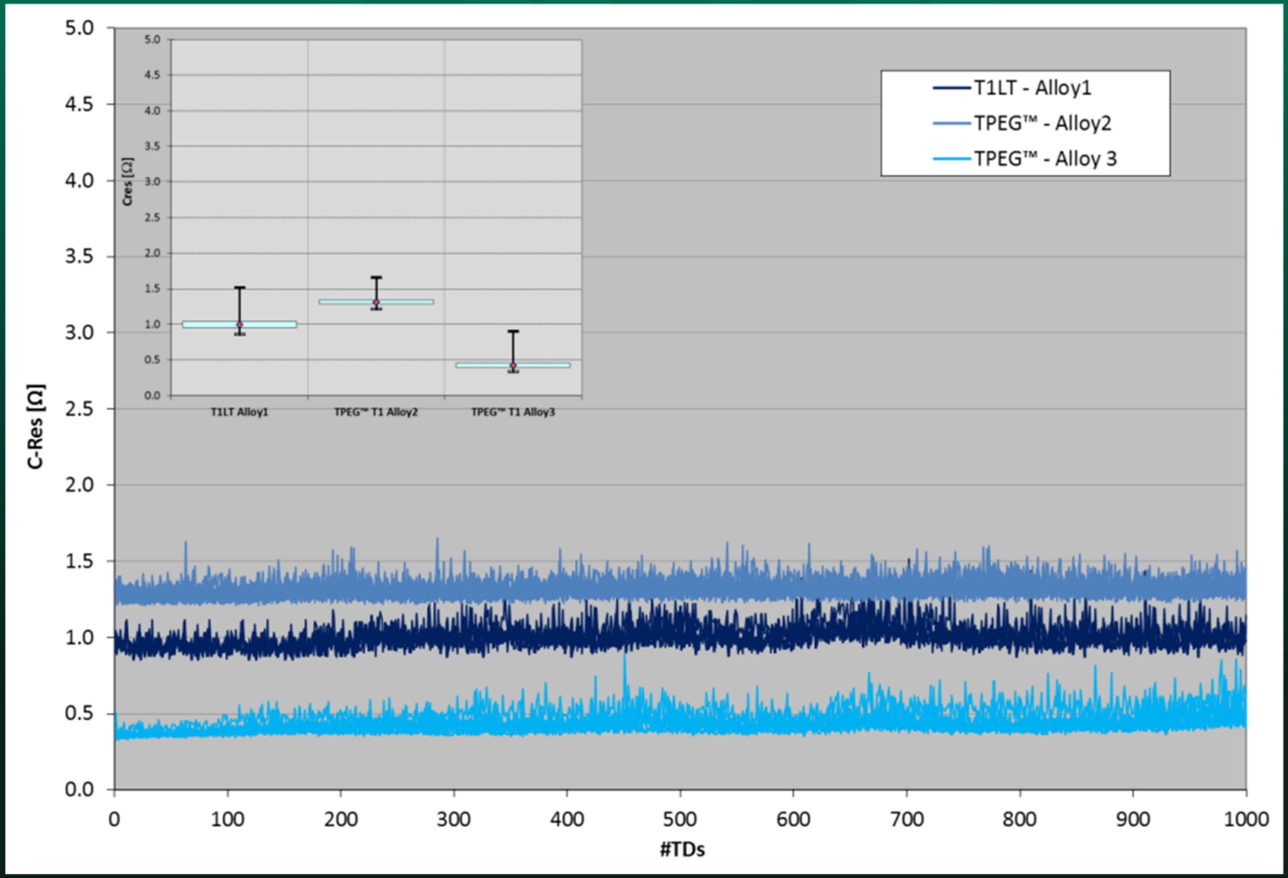
	T1LT Alloy type 1	TPEG™ T1 Alloy type 2	TPEG™ T1 Alloy type 3
CCC – ISMI'09 [mA]	220	410	820
Force @ 75 µm OT[g]	2.8	2.5	2.1





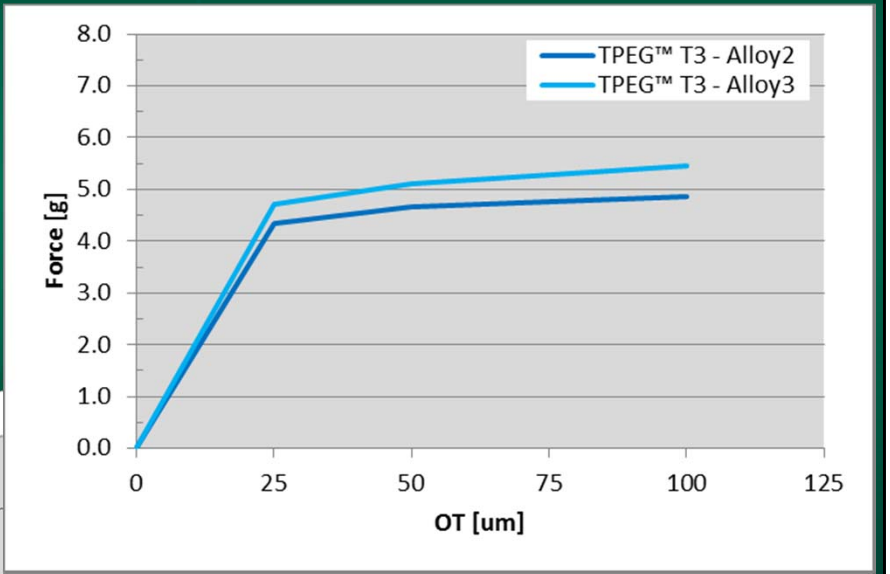
TPEG™ MEMS T1: C_RES

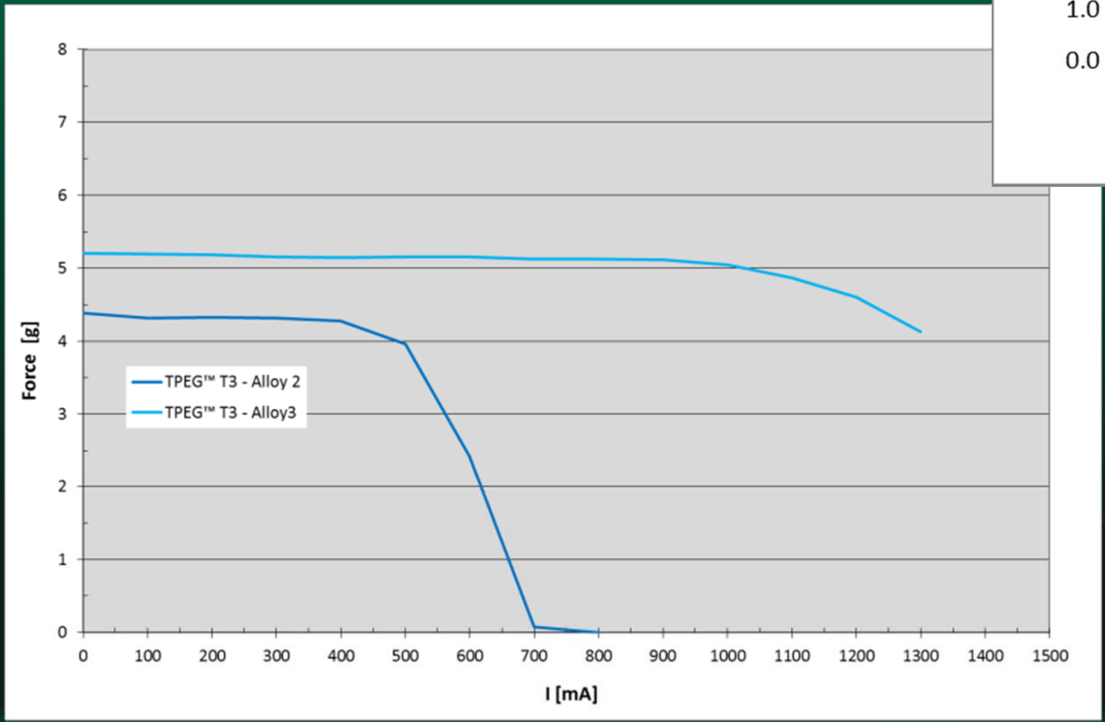
- **Contact resistance on Al blank wafer @ 75 µm OT**
  - 1K consecutive TDs without on-line cleaning @ Room Temp



TPEG™ MEMS T3: force and CCC

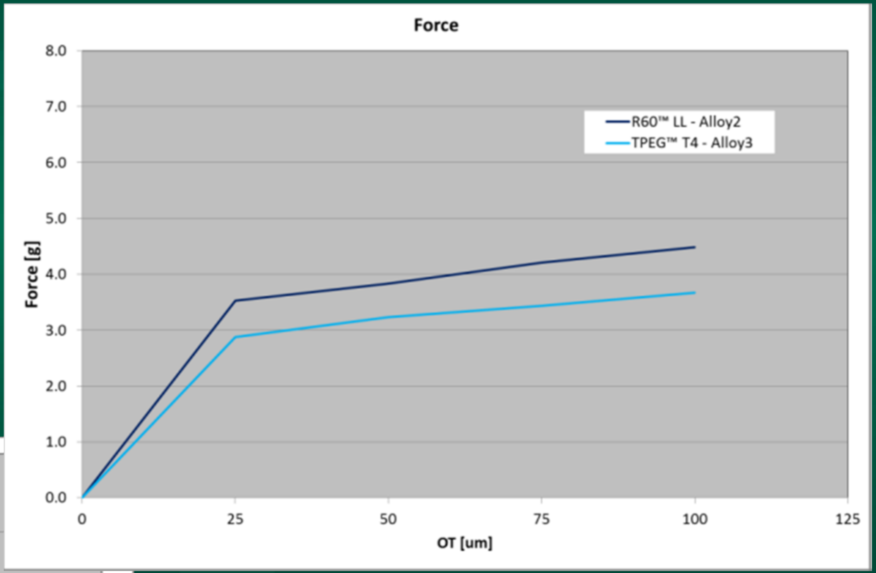
	TPEG™ T3 Alloy type 2	TPEG™ T3 Alloy type 3
CCC – ISMI’09 [mA]	520	1240
Force @ 75 µm OT [g]	4.5	5.2

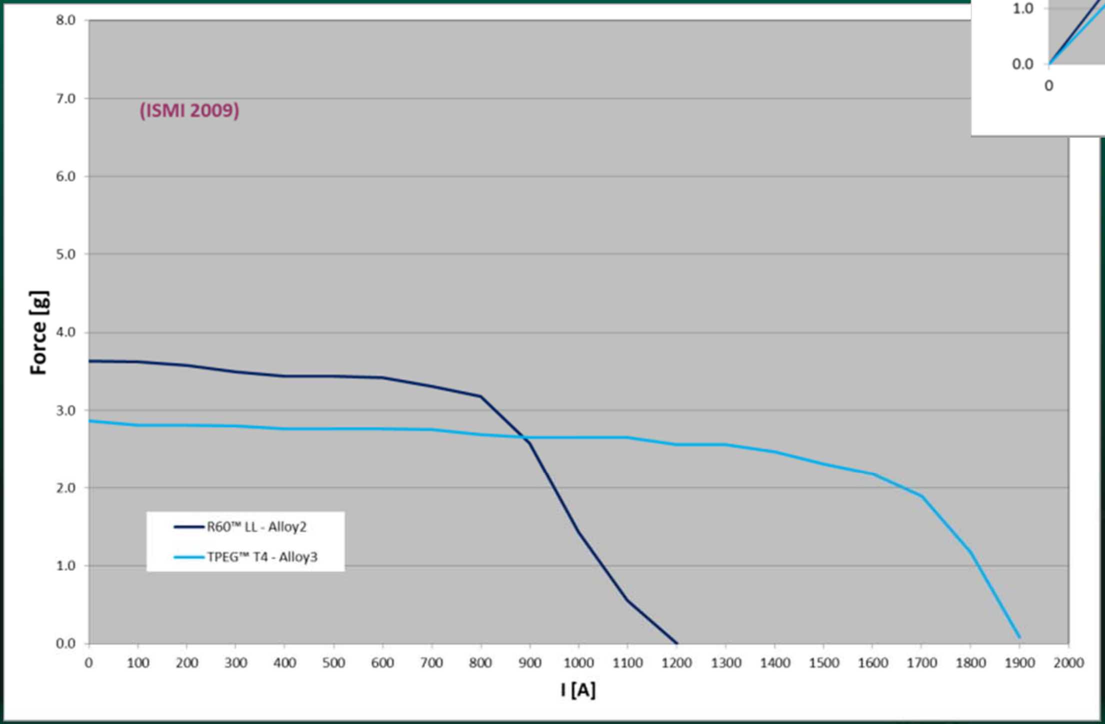




TPEG™ MEMS T4: force and CCC

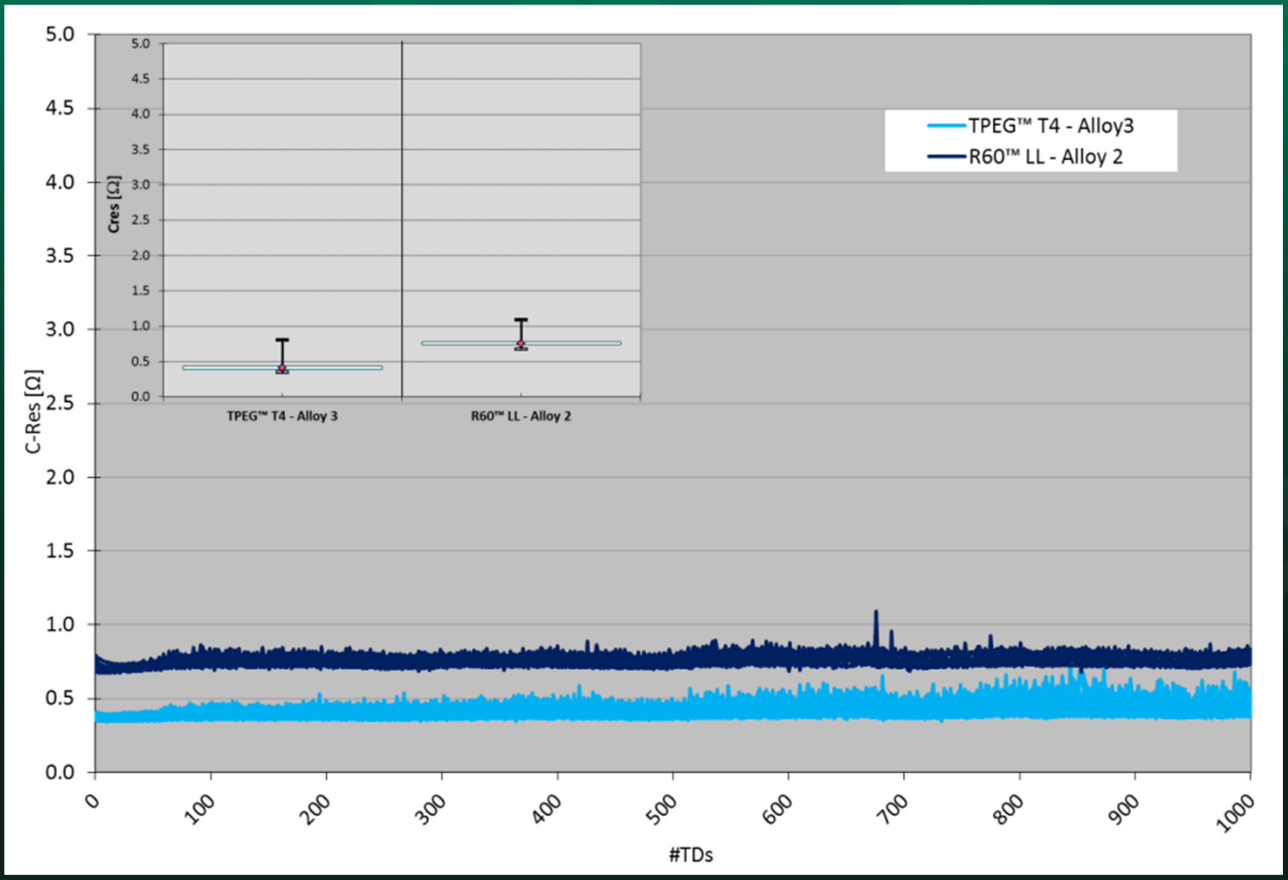
	R60™ LL Alloy type 2	TPEG™ T4 Alloy type 3
CCC – ISMI'09 [mA]	850	1.500
Force @ 75 µm OT [g]	3.5	3.0





TPEG™ MEMS T4: C_RES

- **Contact resistance on Al blank wafer @ 75 μm OT**
  - 1K consecutive TDs without on-line cleaning @ Room Temp

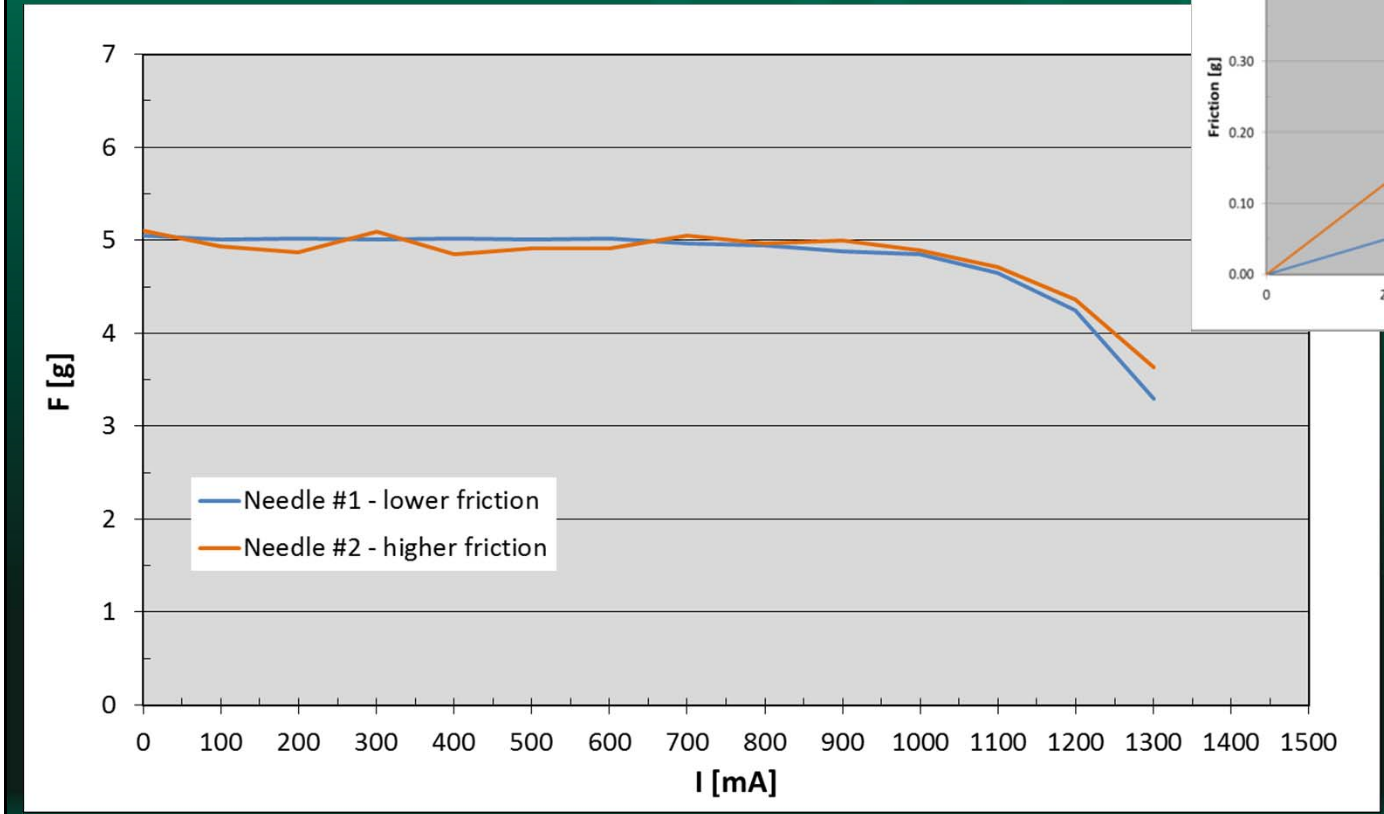


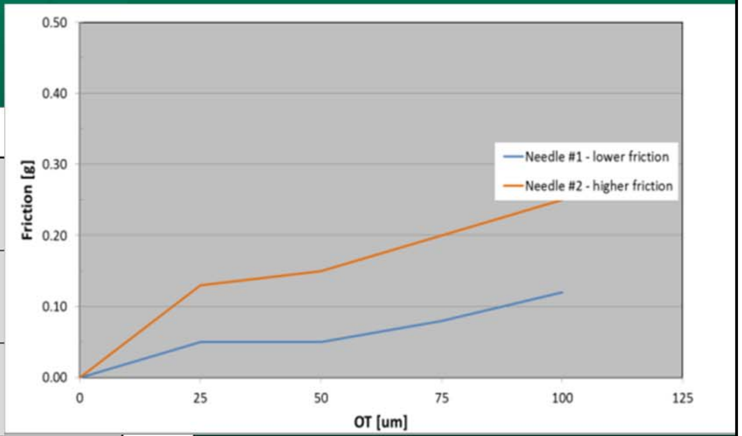
Effects of friction and C_RES on CCC

- **Mechanical friction**
  - Mechanical friction between needles and guiding plates is playing a major role on CCC curve stability
    - The highest the friction, the less stable the CCC curve before typical current degradation phenomena occur
  - Friction phenomena have to be addressed at all design levels
    - Needle metal surface optimization
    - Needle design optimization
    - Needle/PH mechanics design optimization
- **Contact Resistance (C_RES)**
  - C_RES is playing a major role on CCC performances
    - C_RES has to be kept as low as possible at both tip and head side

Effects of friction on CCC

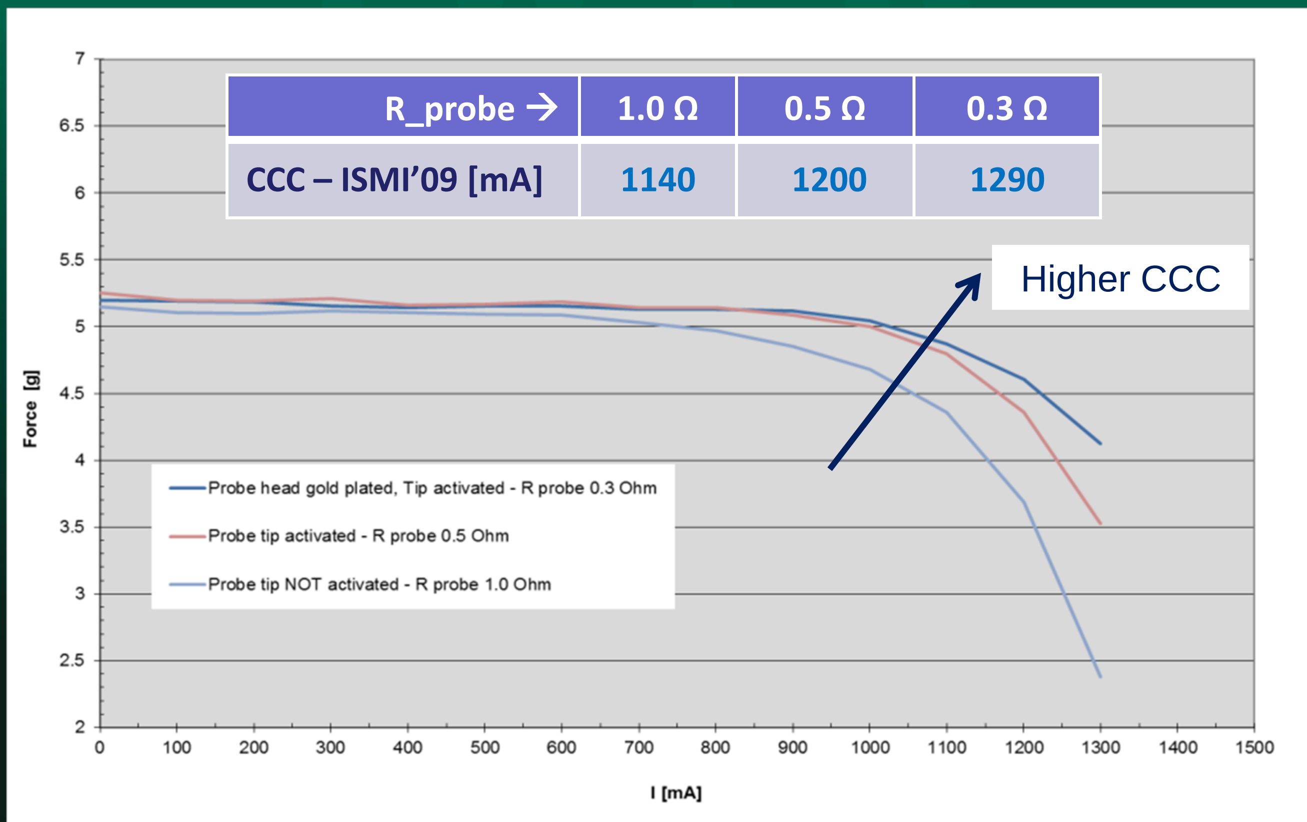
- **Higher friction is leading to less stable CCC curve**
  - Same CCC @ 100 μm OT (> 1.2A per needle in this case)
  - Mechanical instability due to friction





Effects of C_RES on CCC

- **Reducing C_RES has a direct influence on CCC**
  - C_RES to be controlled at both Tip and head side, where most of heat dissipation occurs



R_probe →	1.0 Ω	0.5 Ω	0.3 Ω
CCC – ISMI'09 [mA]	1140	1200	1290

TPEG ™ MEMS Development

Solutions summary

	Minimum pitch [µm]	Force @ 75 µm OT [g]	CCC ISMI'09 [mA]	Suited for
TPEG™ MEMS T1 Alloy type 2	60/55 linear	2.5	410	Advanced SoC Microprocessors
TPEG™ MEMS T1 Alloy type 3	60/55 linear	2.1	820	
TPEG™ MEMS T3 Alloy type 2	90 full array	4.5	520	Flip Chip applications Next Generation Cu pillar/ bumps
TPEG™ MEMS T3 Alloy type 3	90 full array	5.2	1240	
TPEG™ MEMS T4 Alloy type 3	70 linear	3.0	1500	High Current Automotive Applications

- **TPEG™ MEMS probe geometries and PH mechanics can be customized to get the desired pitch, force and CCC ranges**

Conclusions

- **Technoprobe found a way to overcome needle conflicting features to realize next generation probe cards fully tailored to Customer demanding requirements**
- **The degree of freedom offered by our proprietary TPEG™ process allows to address:**
  - Different pad structures and materials
  - High current at low pitch with minimized pad damage applications

Follow-on work

- **TPEG™ process optimization for full release to mass production**

- **Implementation of the electro thermo-mechanical numerical modeling**
  - Static
  - Dynamic (fatigue stress simulation)

Thank you!

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