Mr. Gerjan Diepstraten

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Biography:
Gerjan Diepstraten, Ing. Gerjan's engineering experience spans 30 years, with the last 25 years in soldering. Gerjan has a mechanical engineering background and started in 1989 as a mechanical designer at Soltec B.V. From 1998 Gerjan is a member of the Vitronics Soltec Technology Group. The focus was on lead-free soldering for all processes selective, wave and reflow. He joined a Six Sigma Black Belt education at the University of Amsterdam to learn about statistical analysis and techniques to use for internal and customer process optimization. Gerjan joined Cobar Europe B.V./Balver Zinn in 2007 as the Process Support Manager.

Title:
Reflow Soldering Equals Wave Soldering Plus One.

Executive Summary:
Lead-free solder is more than a swap for SnPb and more than simply an alternative alloy. Five years after implementation discussion remains regarding which alloy is the best for which application. Alternative lead-free solders are available with doping of small amounts of elements to improve reliability. This study is compares Sn3,0Ag0,5Cu with low-silver Sn1,0Ag0,7Cu0,05NiGe and Sn0,7Cu0,05NiGe, a modified SnCu alloy.

A design of experiment was done to define the process window of the different alloys. Different flux preheat and solder temperatures were part of the experiment. For each alloy, the preferred parameters were defined to establish a reliable soldering process. The boards were soldered using these settings and reliability levels were tested. The test boards included different pad and barrel dimensions. This returns recommendations for designers to define the optimal pin-to-hole ratio for the different alloys.

For each alloy, the test boards were thermal cycled at -40°C/+125°C (30'/10"/30') and aged at +125°C for 1000 hours. The study included tensile strength measurements, intermetallic thickness growth, cross sections and visual inspection according to IPC standards.

The same alloys were used for reflow soldering. Solder paste with the same flux chemistry was used to perform reliability experiments. The presentation discusses the alloys' performance. It also explains the benefits of adding small elements to an alloy and how to establish a compatible selection for reflow and wave alloys.

BALVER ZINN®
COBAR®

Reflow Soldering Equals Wave Soldering Plus One

Gerjan Diepstraten

Cobar Europe BV/Balver Zinn

Master IPC-A-610 Trainer(MIT) &
Certified J-STD-001 Trainer(CIT)

Content

- Wave soldering alloys and experiments:
  - DoE
  - Solder joint strength
    - Thermal cycling, aging
  - Pin hole recommendations

- Reflow properties lead-free alloys:
  - Wetting
  - Voiding
  - Strength of solder

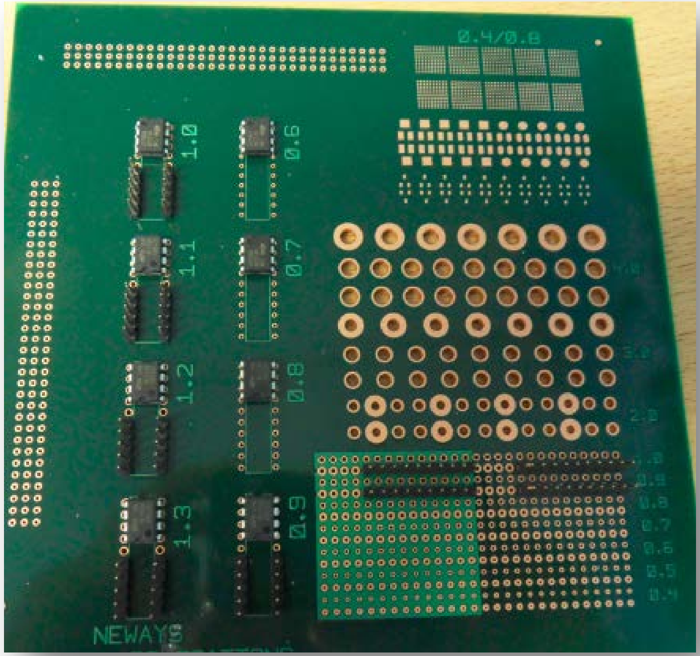
Taguchi - experiment

Define impact of parameters
Define best settings for each alloy
Define what flux type for what alloy

Taguchi Design of Experiment - L9				
Parameter	#	Level 1	Level 2	Level 3
Flux type		Alcohol	Low VOC	VOC - Free
Preheat temp.	°C	100	125	140
Contact time	sec	2	4	8
Solder temp.	°C	255	260	270

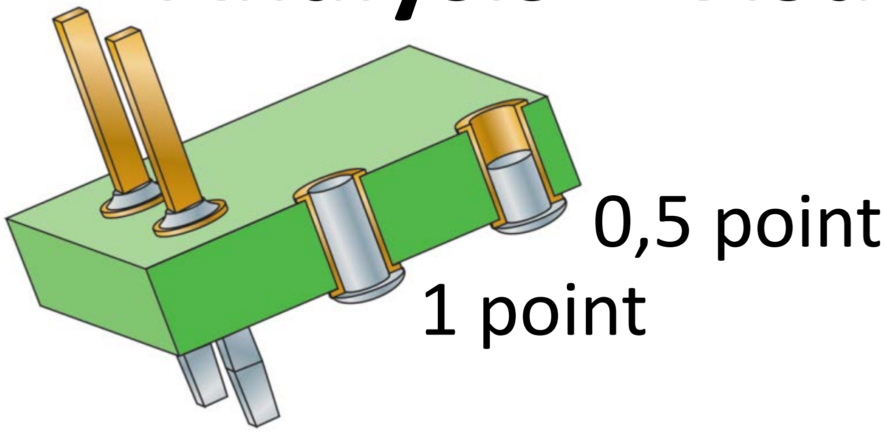
Experiment

Total of 9 runs (2 boards per run)
Define champion: 5 boards – conformation runs



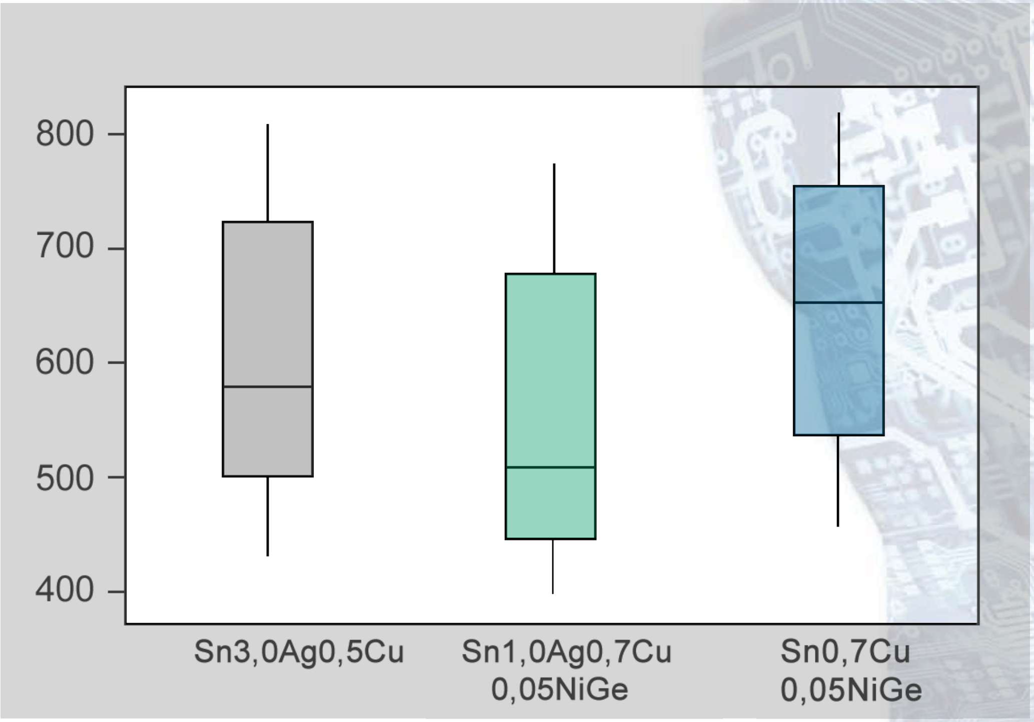
Alloys:
Sn3,0Ag0,5Cu
Sn0,7Cu0,05NiGe
Sn1,0Ag0,7Cu0,05NiGe

Analysis – Visual Inspection



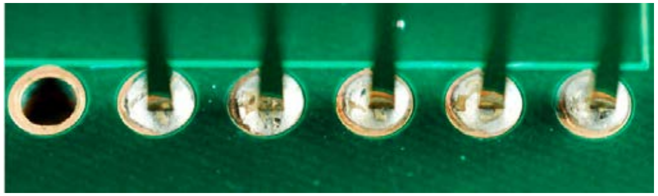
Visual inspection
solder joints/via's

Average score
per board
of all 9 Taguchi runs:

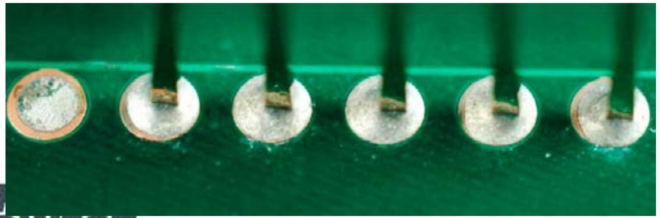


Analysis Sn3,0Ag0,5Cu

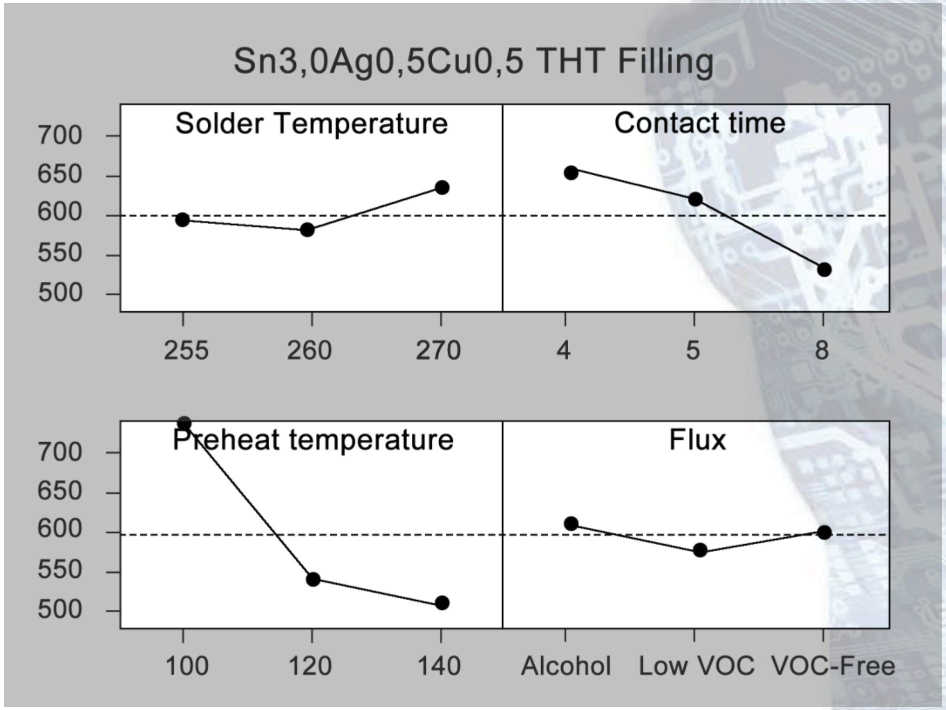
- Preheat temperature is critical. Risk for overheating – no flux activity on wave.
- Short contact time at high solder temperature.



Run 3

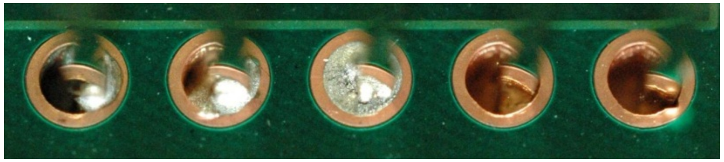


Run 8

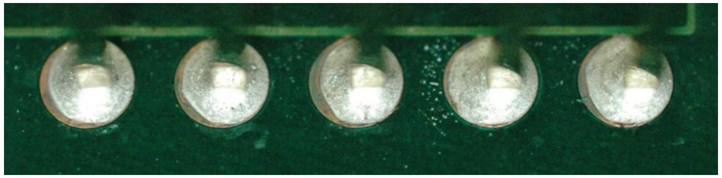


Analysis Sn1,0Ag0,7Cu0,05NiGe

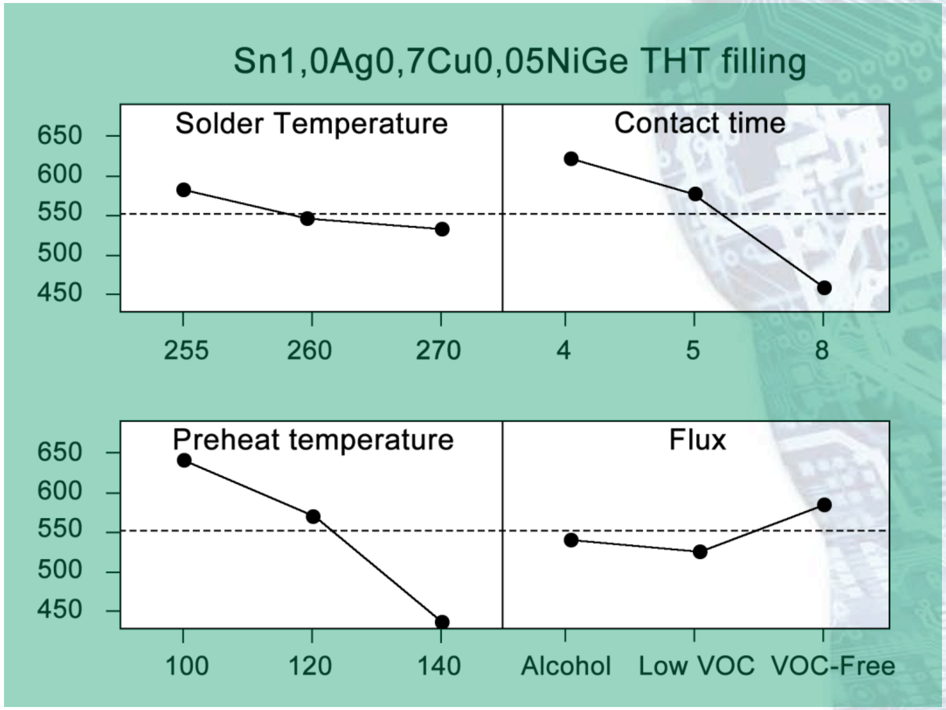
- Preheat temperature is critical. Risk for overheating – no flux activity on wave.
- Short contact time, low solder temperature.
- Water based VOC-free flux



Run 3

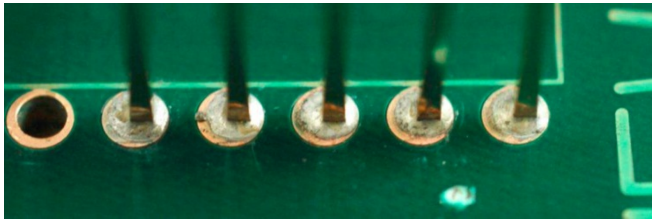


Run 8

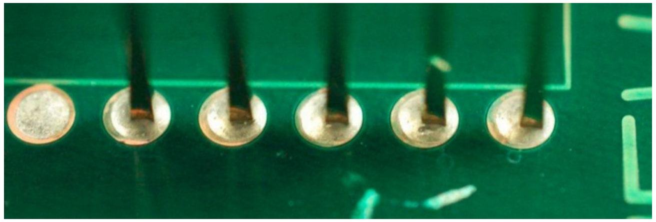


Analysis Sn0,7Cu0,05NiGe

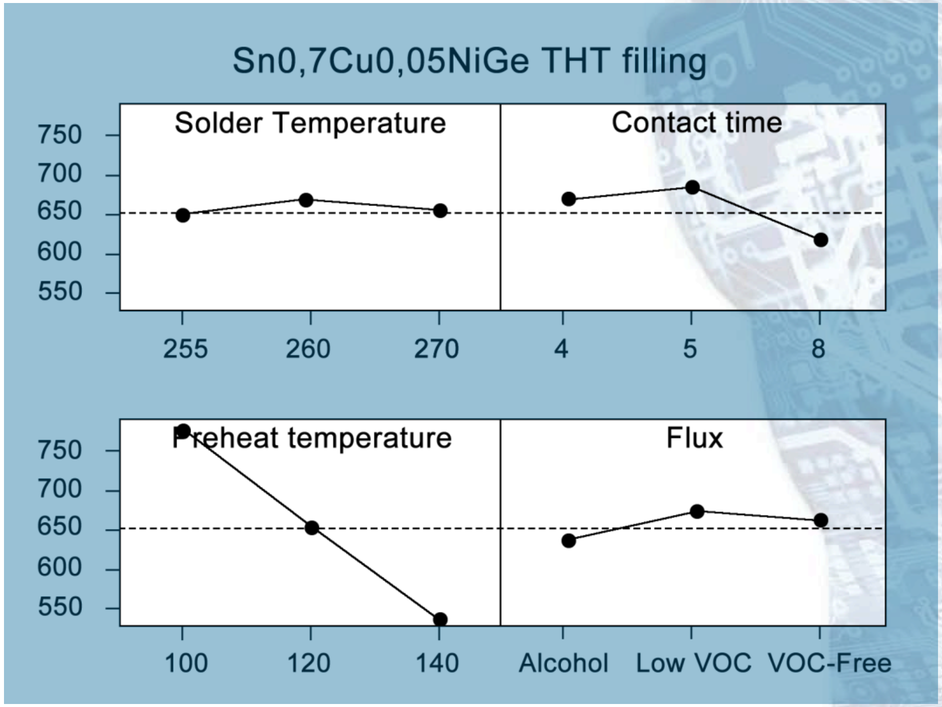
- Preheat temperature is critical. Risk for overheating – no flux activity on wave.
- Contact time, solder temp and flux have no significant impact.



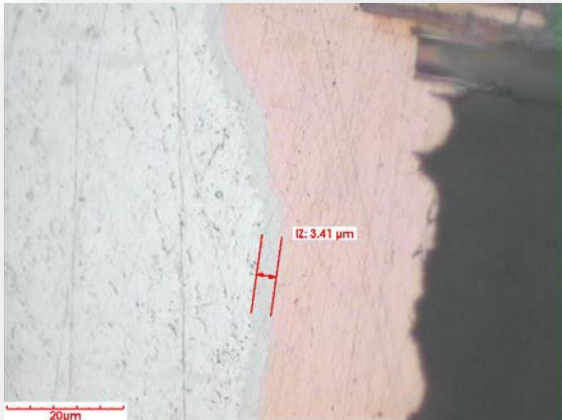
Run 3

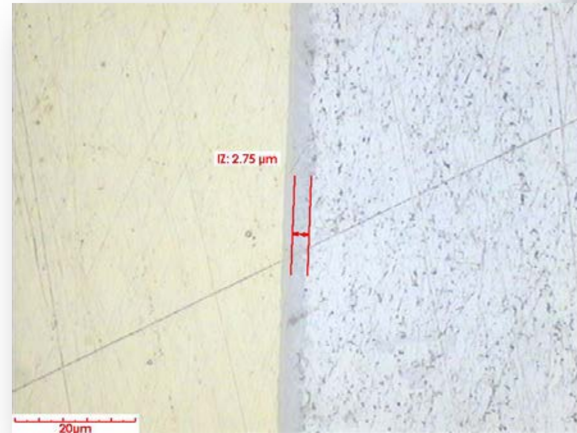


Run 8

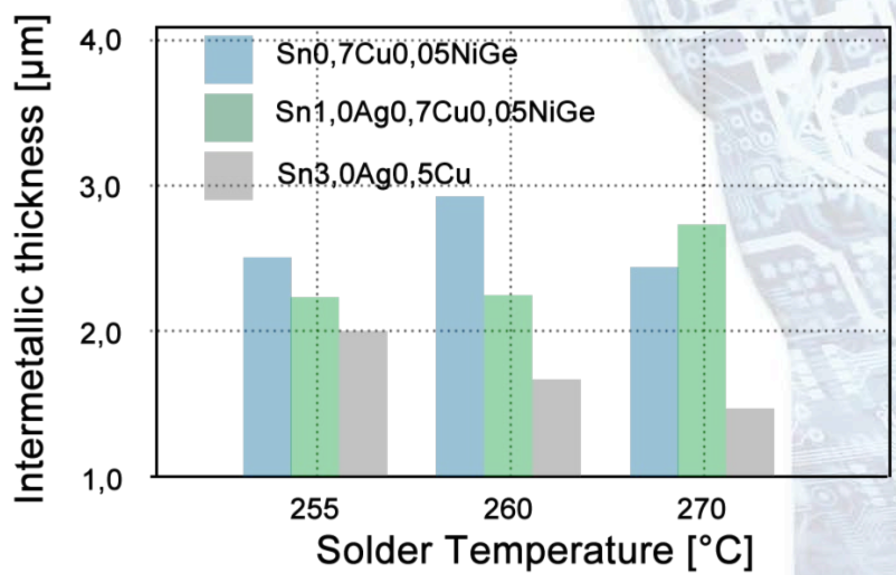


Intermetallic after soldering

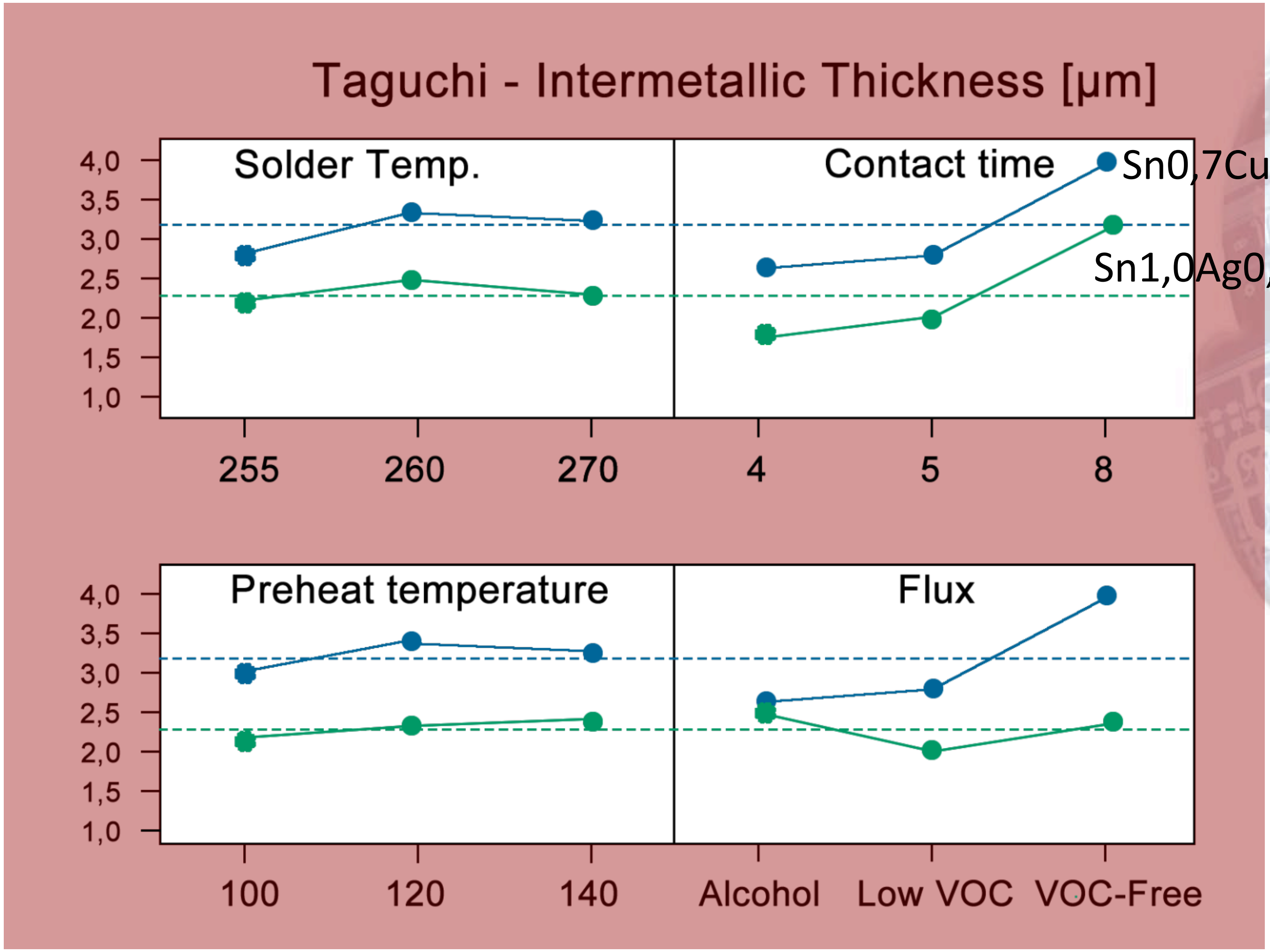




- Initial the Sn0,7Cu0,05NiGe has a thicker intermetallic.
- Historical data shows that Ni is slowing down IMC growth



IMC Thickness DoE

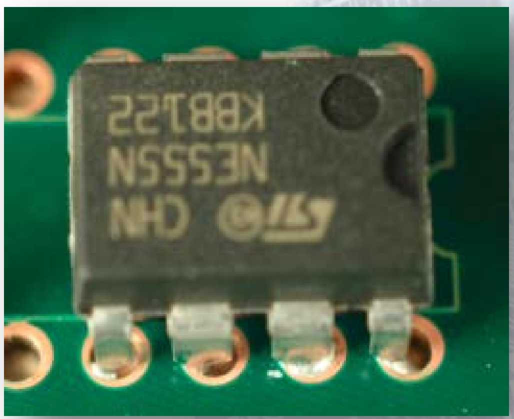


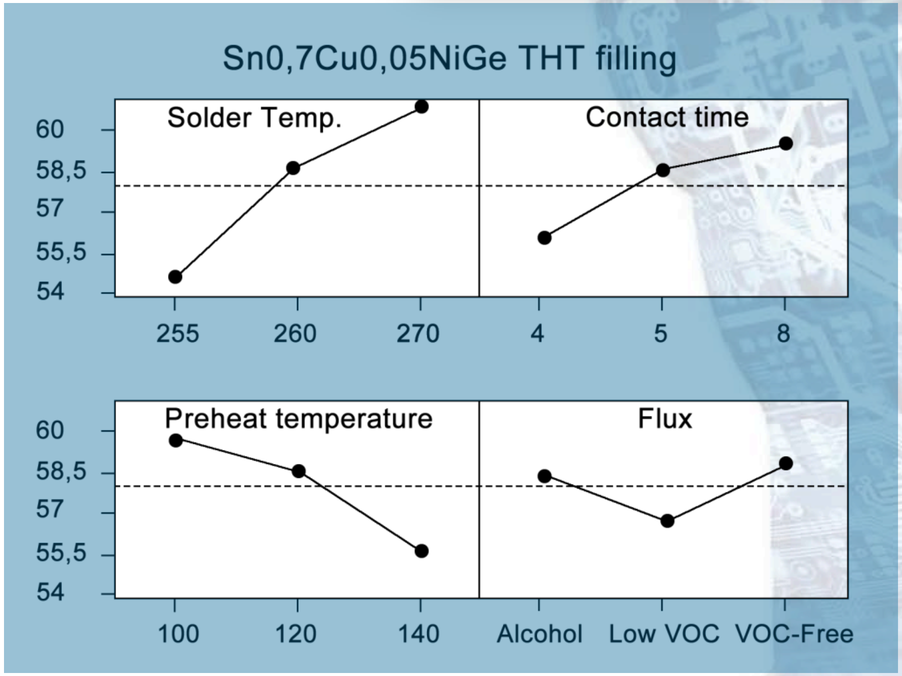
Contact time is the dominant factor

DIL components

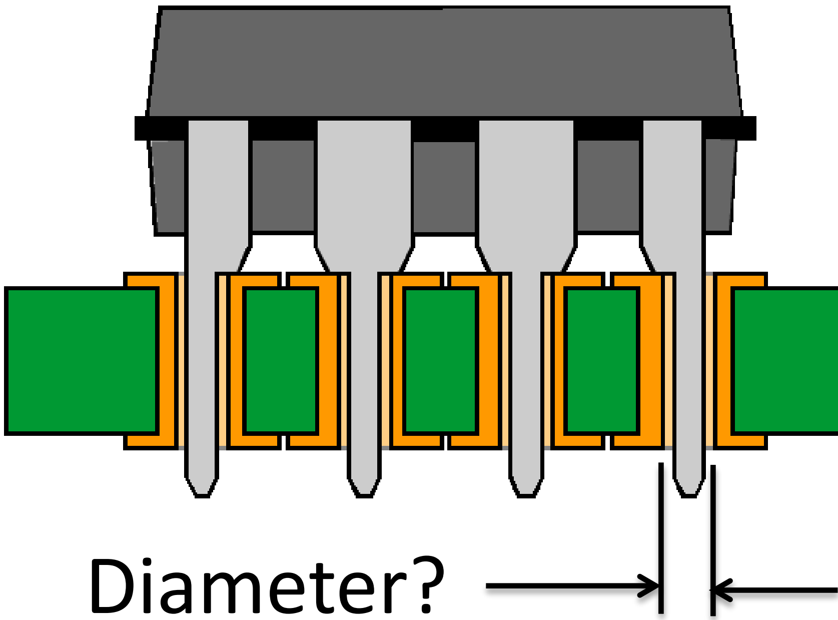
Hole filling DIL components:

1. For all alloys a higher solder temperature is better.
2. Topside preheat temperature of 100 °C.
3. Alcohol or VOC-Free water based flux.

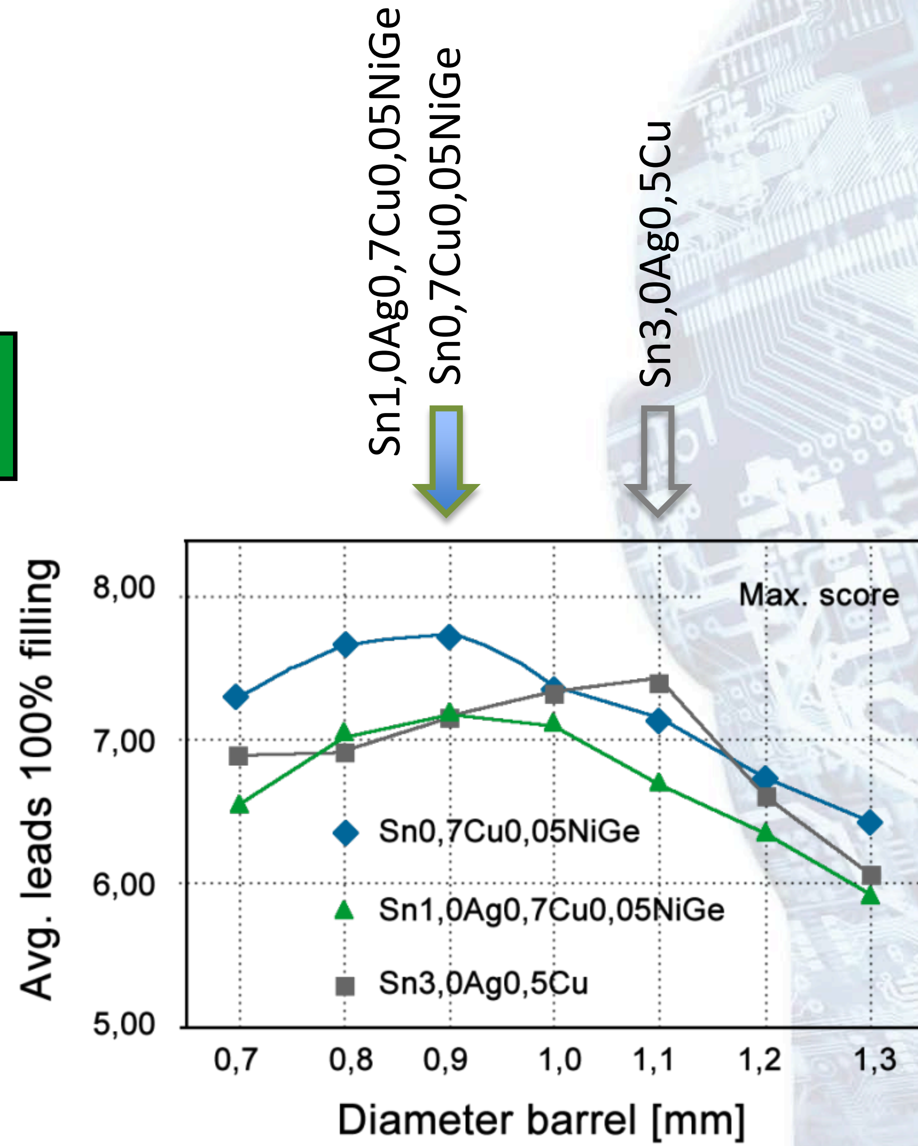




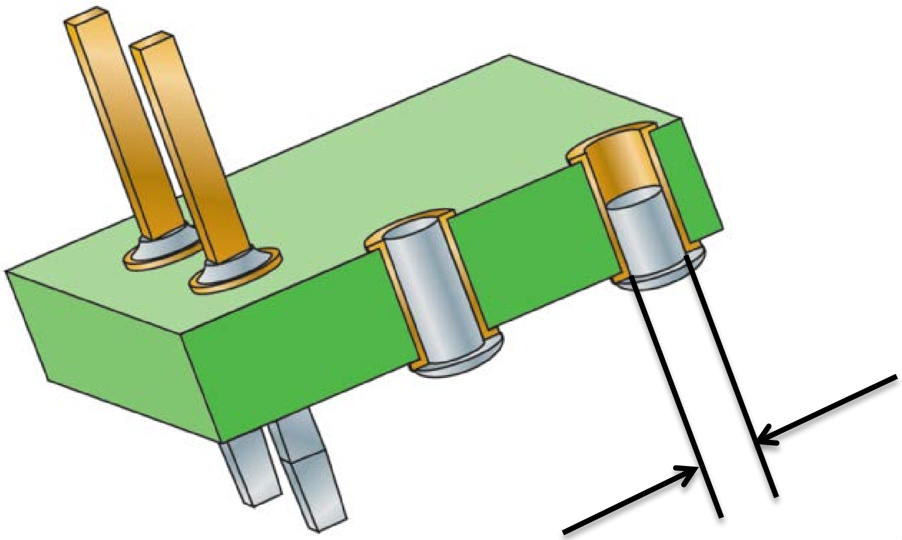
Hole dimensions DIL barrel



Preferred diameter:
0,9 mm

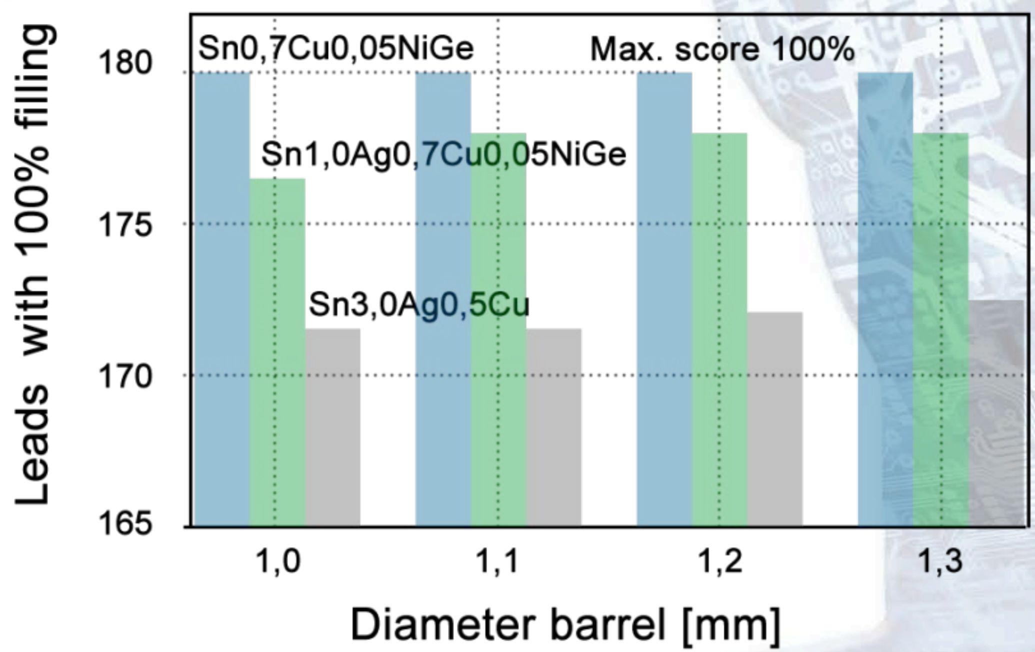


Hole dimension pin connector



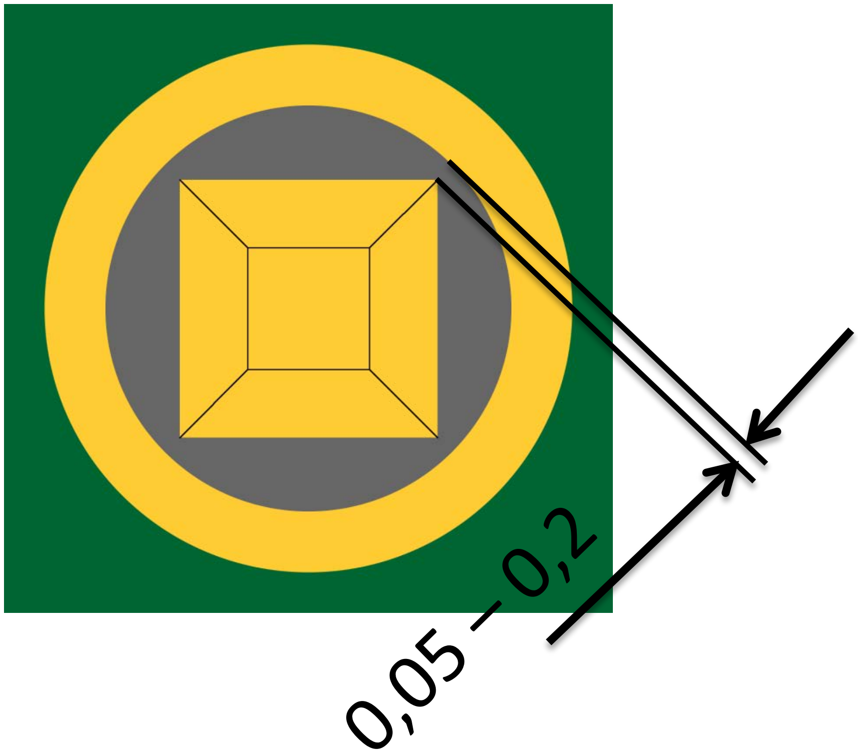
No significant differences between 1,0 – 1,3 mm barrels

For Sn3,0Ag0,5Cu larger holes slightly better

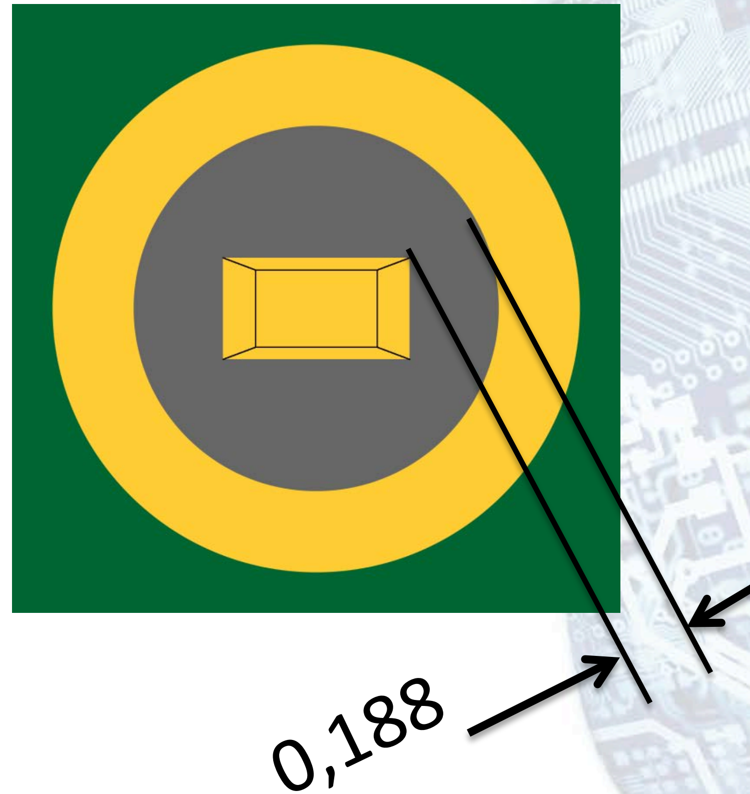


Pin to hole ratio

Pin 1,0 – 1,3 mm



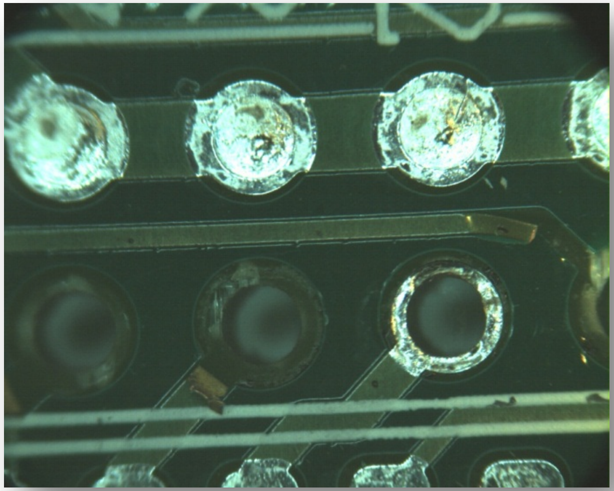
DIL – 0,9 mm

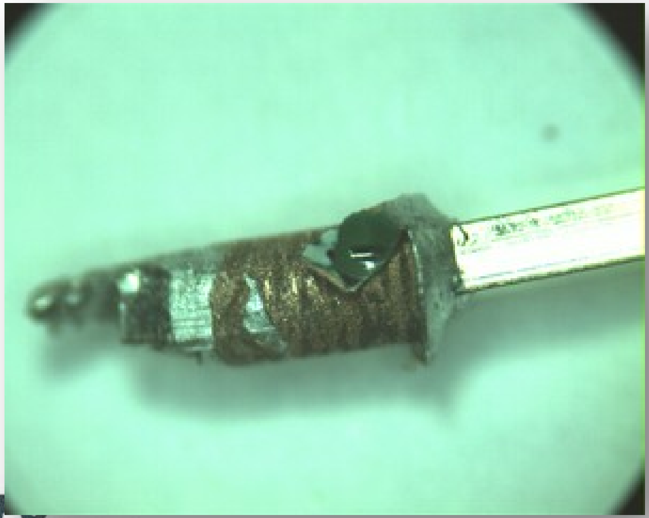


Area 1:1,9 (1,0 mm)
1: 3,3 (1,3 mm)

Ratio 1:1,72
Area 1:5,5

Tensile strength solder joint

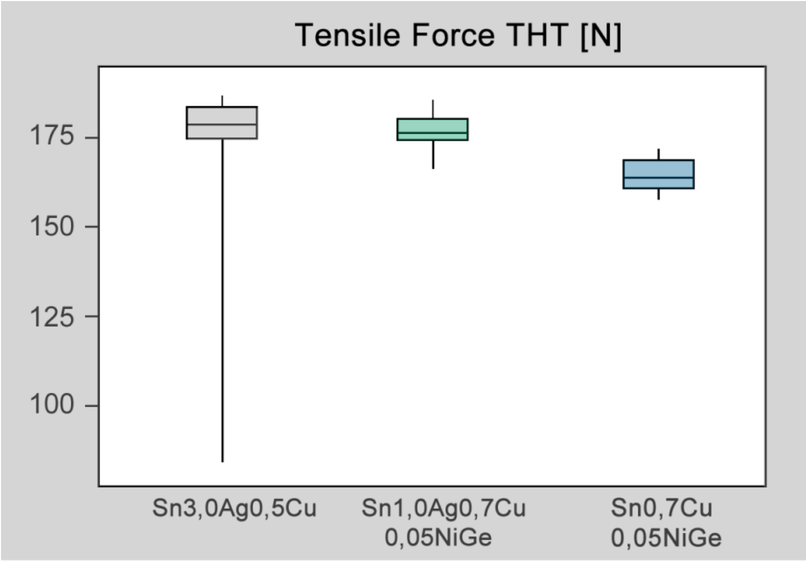




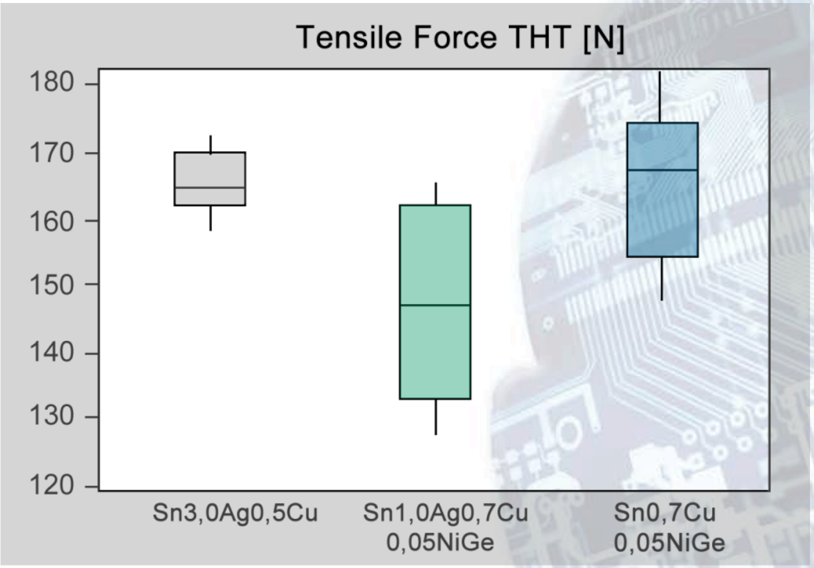
Failure mechanisms:

- Complete Copper Barrel out of board
- Tears in the solder
- Tears along the intermetallic layer

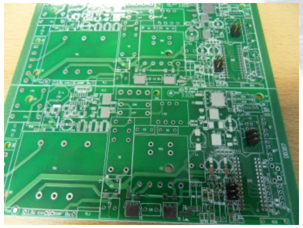
Tensile Strength



Cu-OSP Test Vehicle
(360 datapoints)



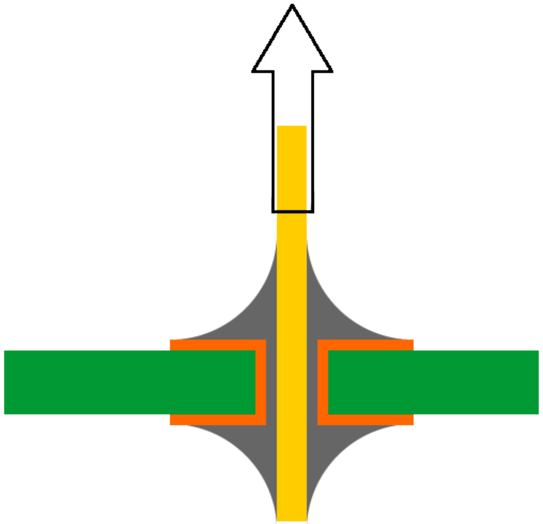
HAL Test Vehicle
(324 datapoints)

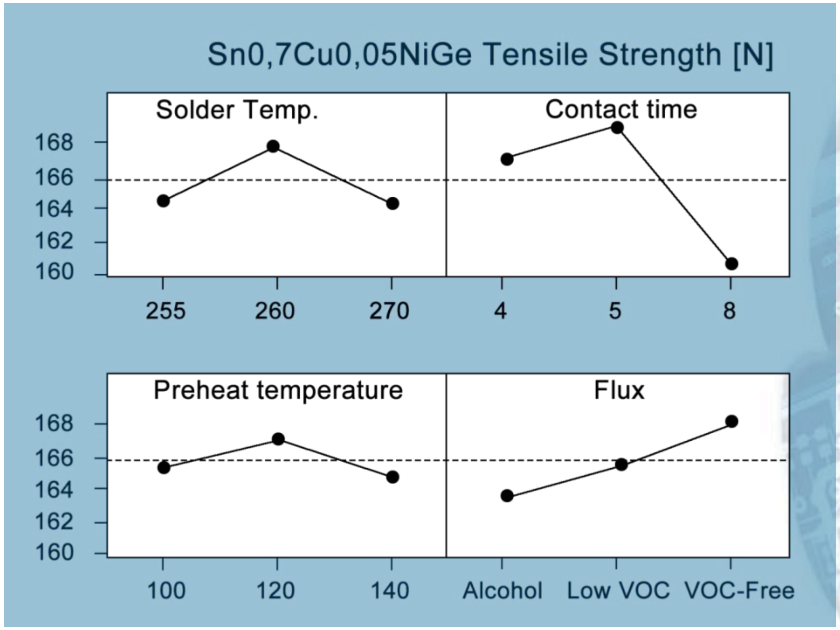


Taguchi Results:
Average scores per Run in Box-Plot

Sn0,7Cu0,05NiGe Tensile strength

Measured strength

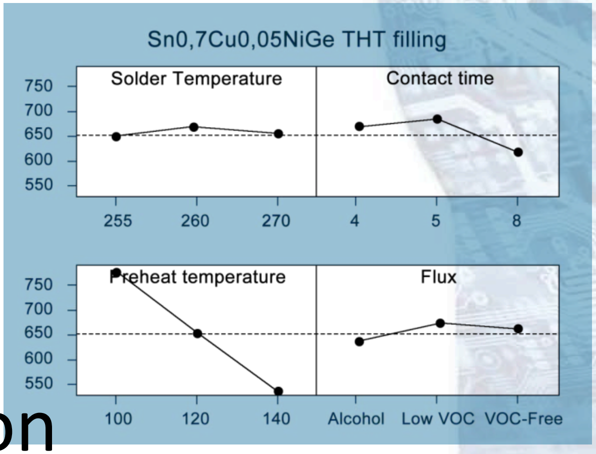




Potential risk solder temp:

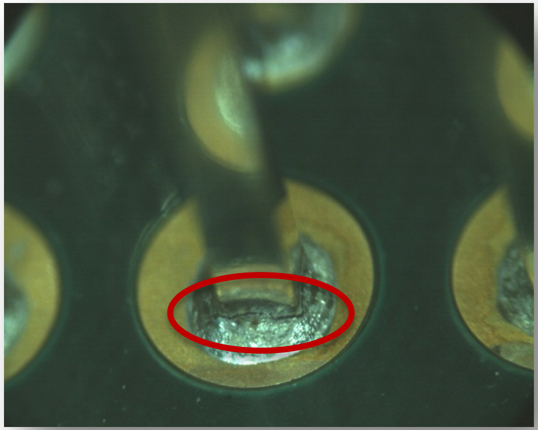
255 °C not enough hole filling

270 °C fillet/pad lifting



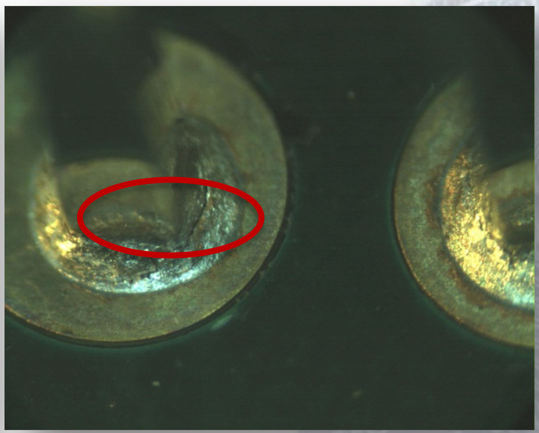
Visual inspection

Test board after 500 cycles TC



Sn3,0Ag0,5Cu

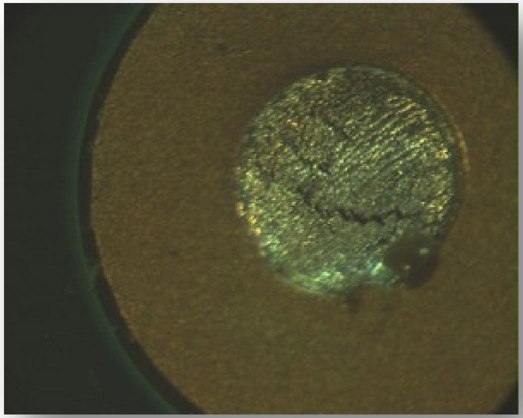
Sn1,0Ag0,7Cu
0,05NiGe



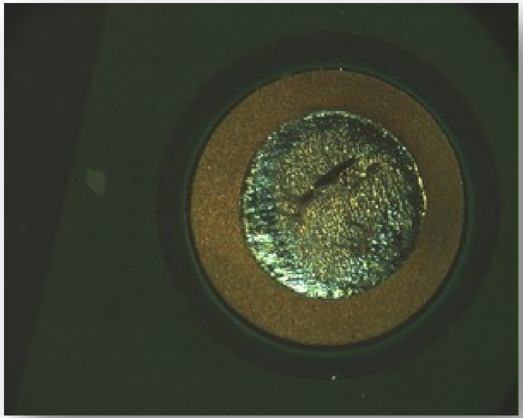
Sn0,7Cu
0,05NiGe

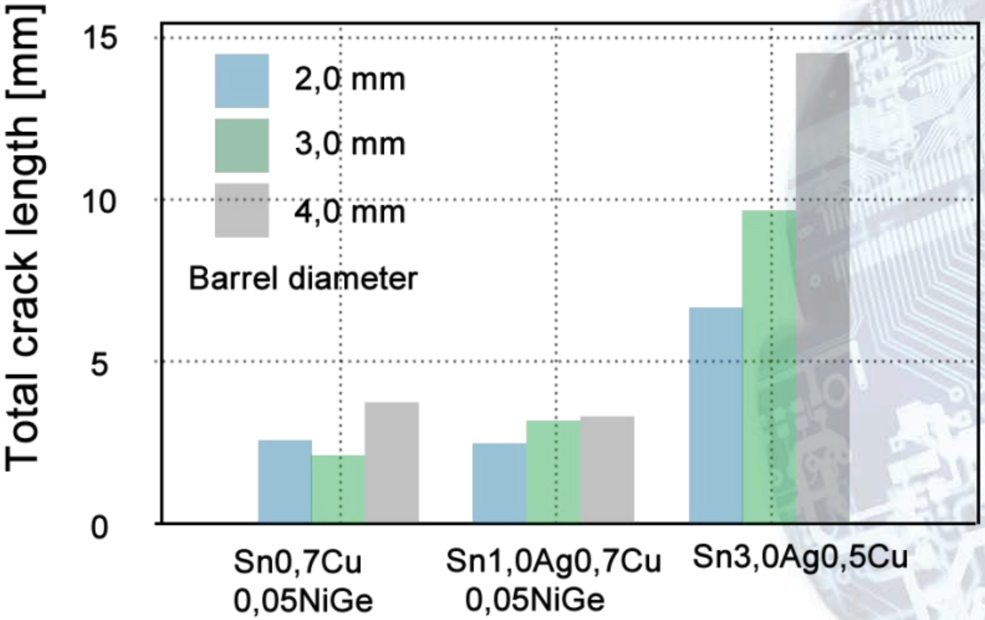
All alloys show cracks in the solder.
Due to these cracks the failure mode in the tensile experiments changes.
Pins now tear in the solder (IMC) or along the cracks.

Cracks in vias after 500 cycles TC



Sn3,0Ag0,5Cu

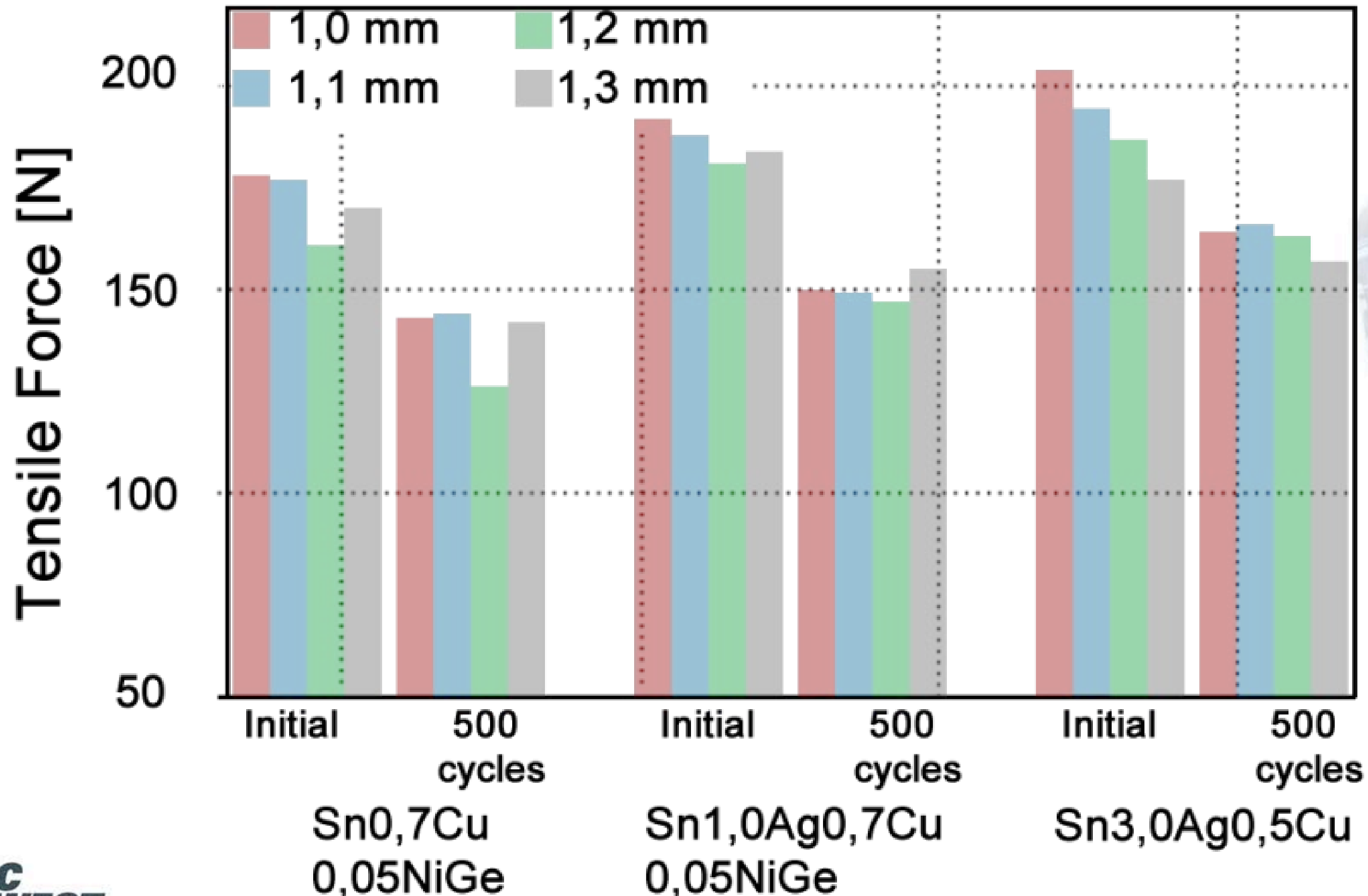




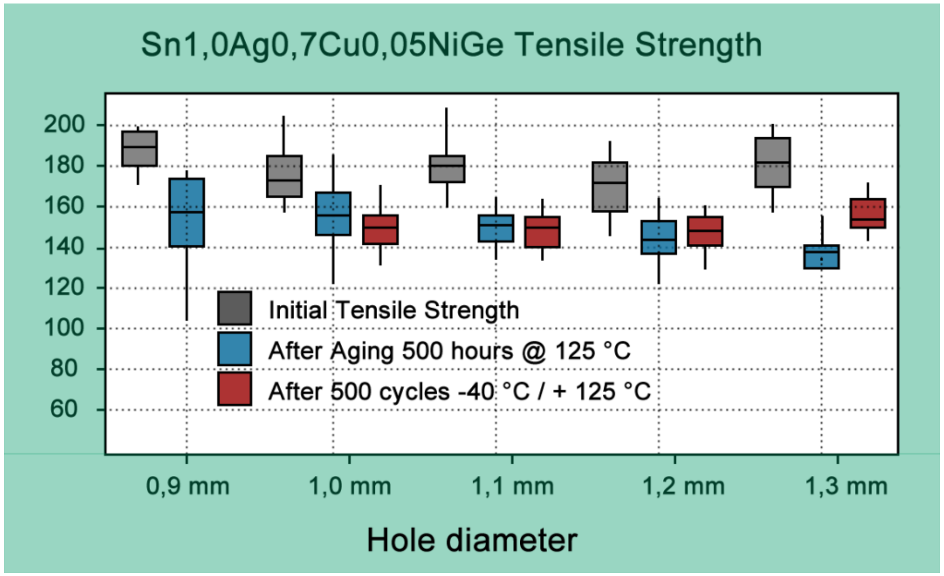
After thermal cycling -40 / + 125°C some solder joints show cracks on the surface. The length of these cracks can be determined by microscope.

Tensile strength after TC 500 cycles

-40°C / +125 °C (30’/10”/30’)

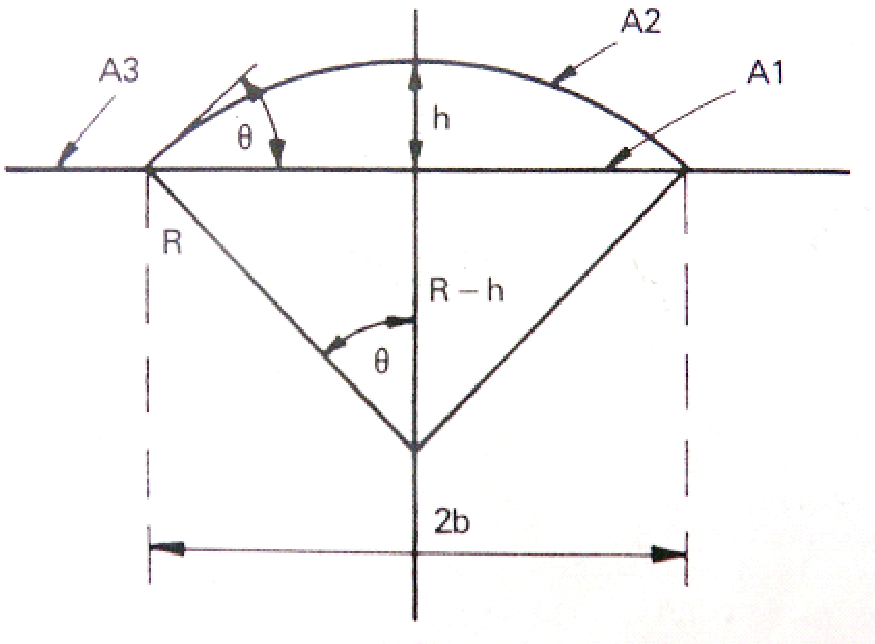


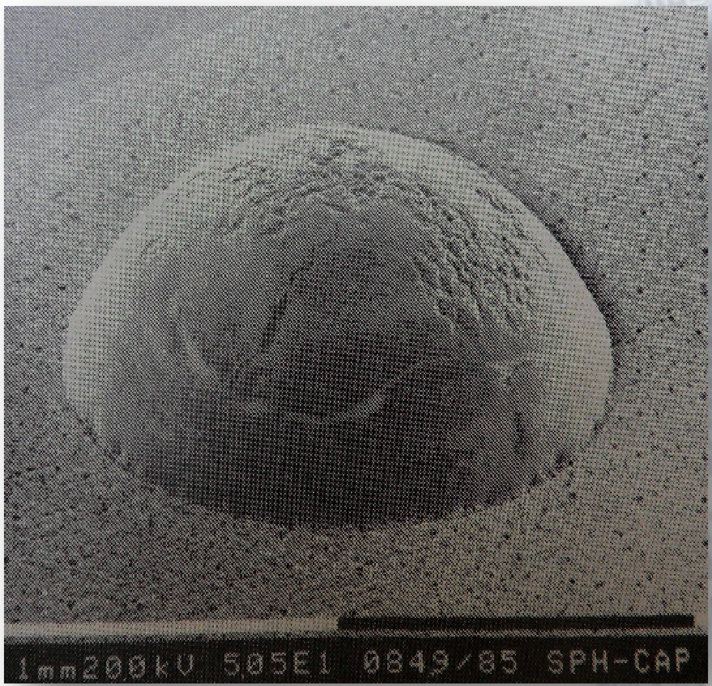
Aging and TC Sn1,0Ag0,7Cu0,05NiGe



After TC and/or aging the tensile strength decreases (Approx. 20% for 500 cycles or 500 hrs at 125 °C) Different failure mode due degradation of solder (IMC).

Reflow – Wetting

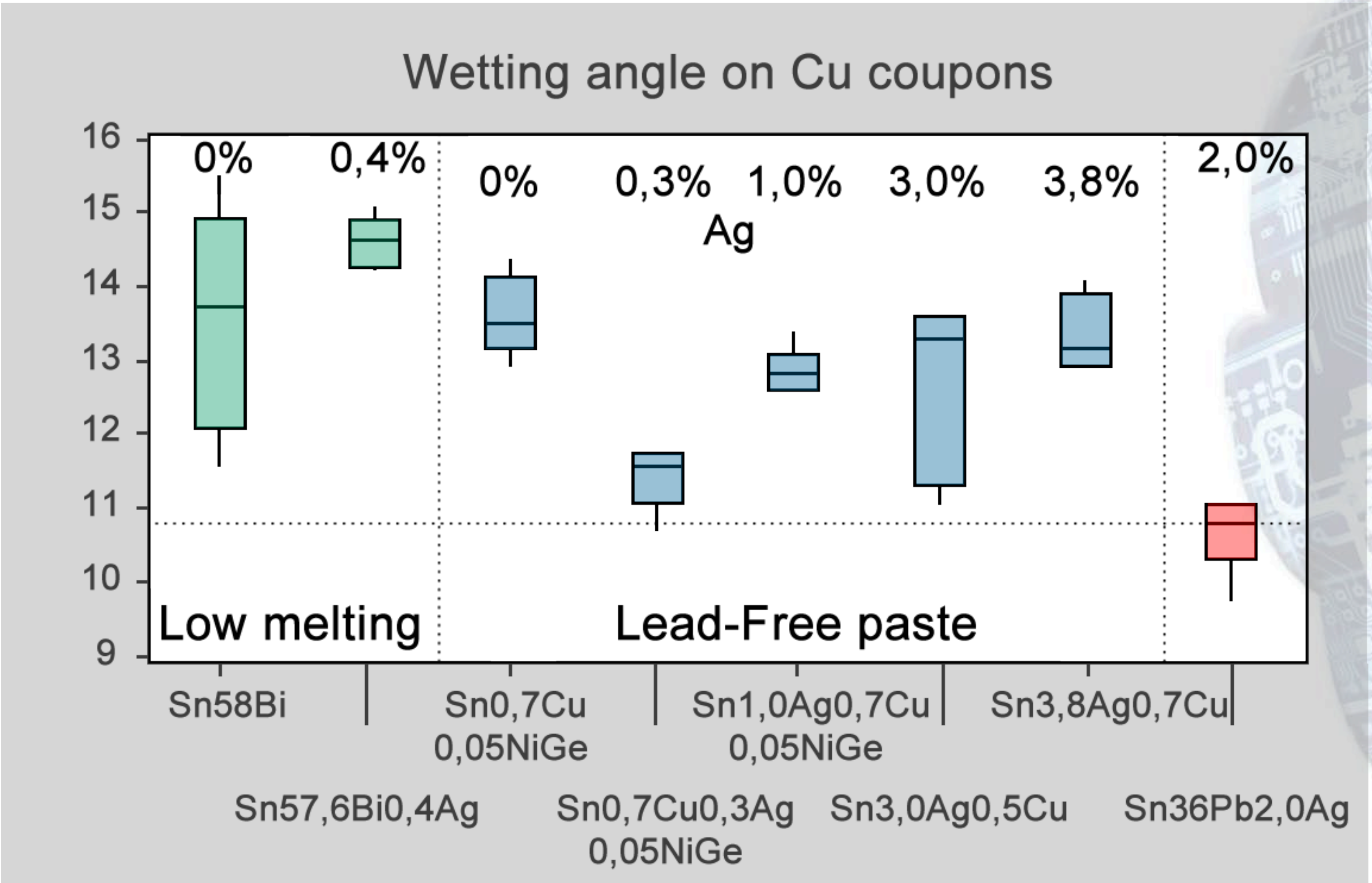




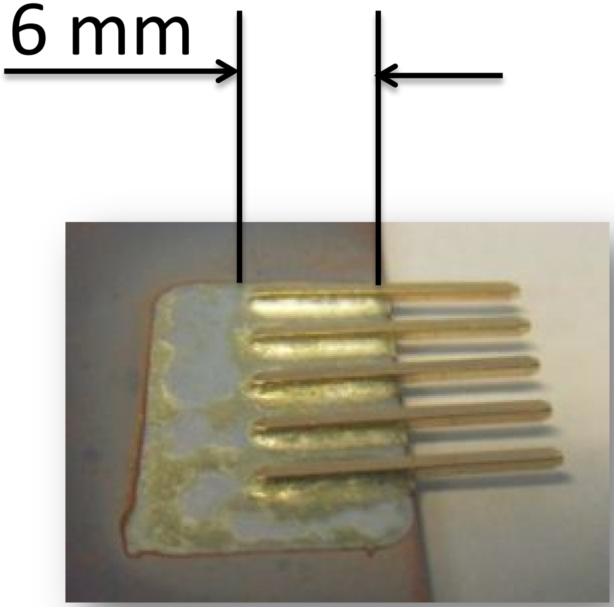
Info: Klein Wassink

- Geometry of a spherical cap (solder dot)
- Calculate the wetting angle θ

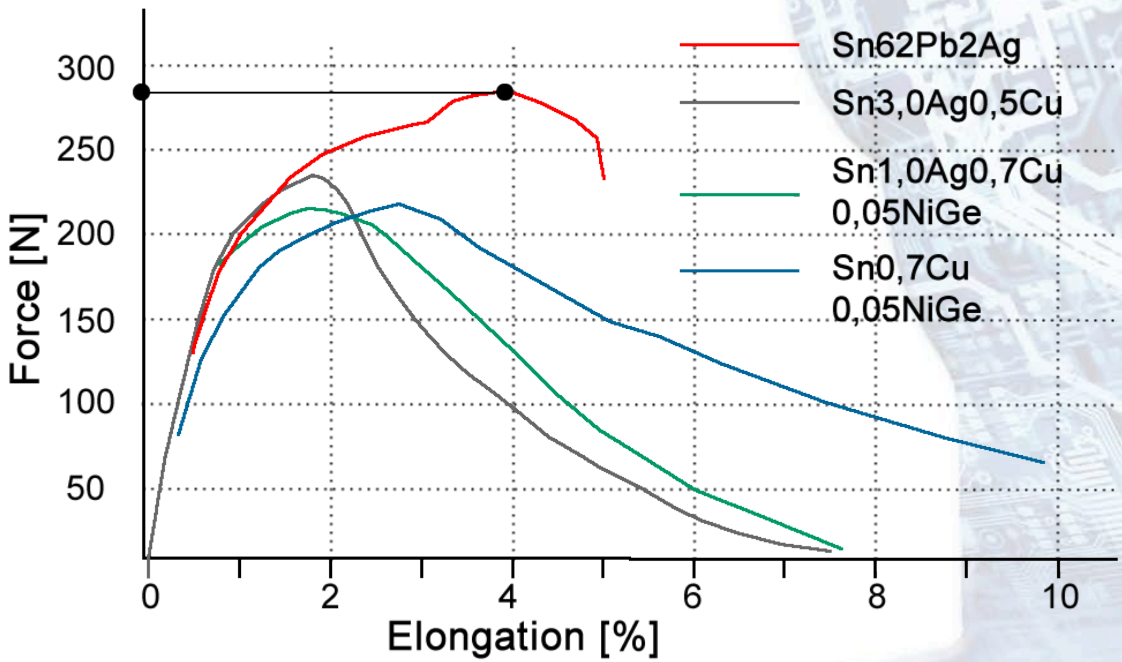
Reflow wetting-angle θ



Tensile strength reflowed pins



Cu coupons:
50 micron thick stencil
Gold finished
6 mm wetted length
[All have the same flux system]



After Tensile test

Sn3,0Ag0,5Cu – some voids visible in remaining solder.

Sn57,6Bi0,4Ag - so strong that some of the pins broke instead of the solder

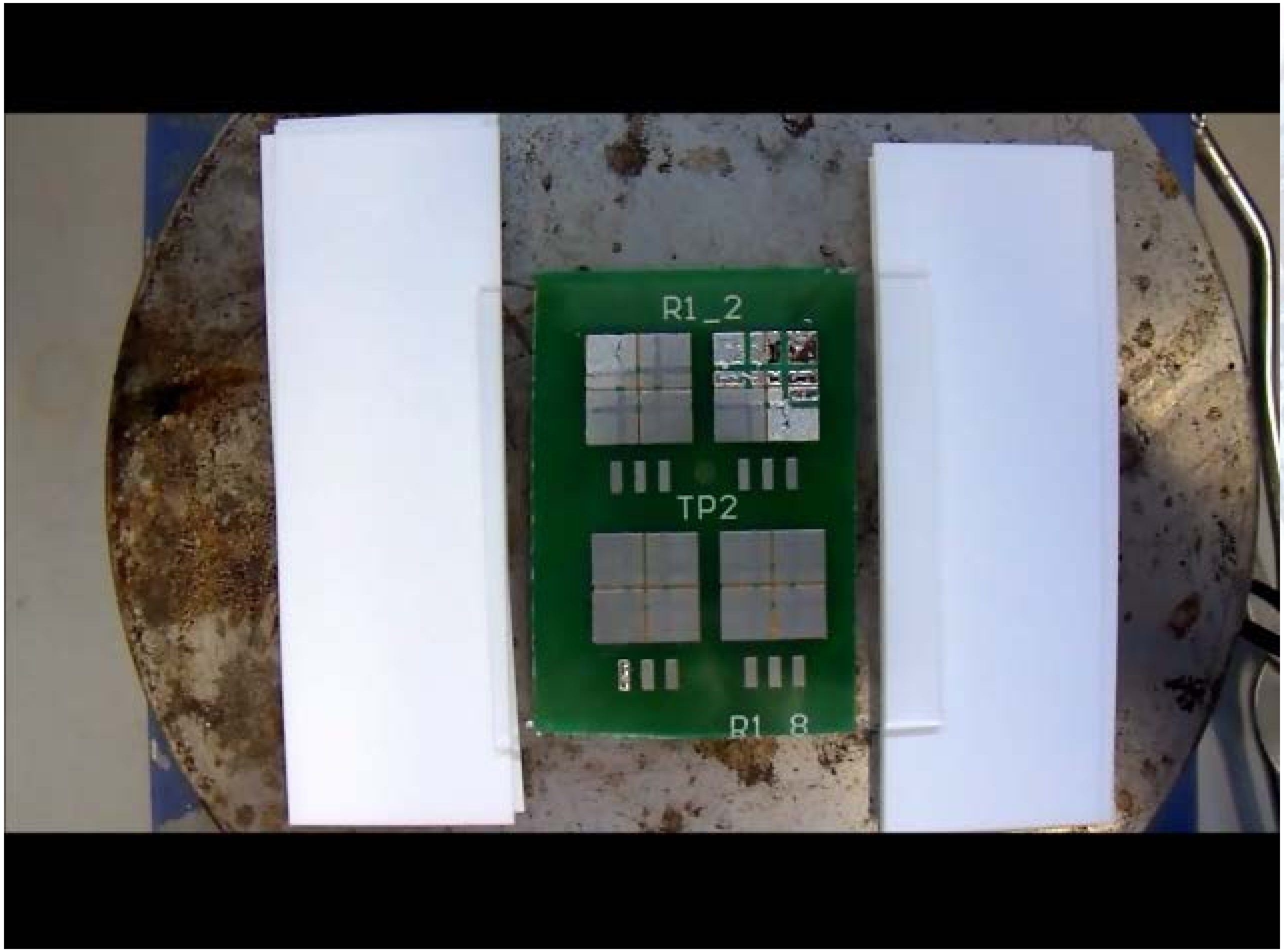
Results

Parameters affecting the result:

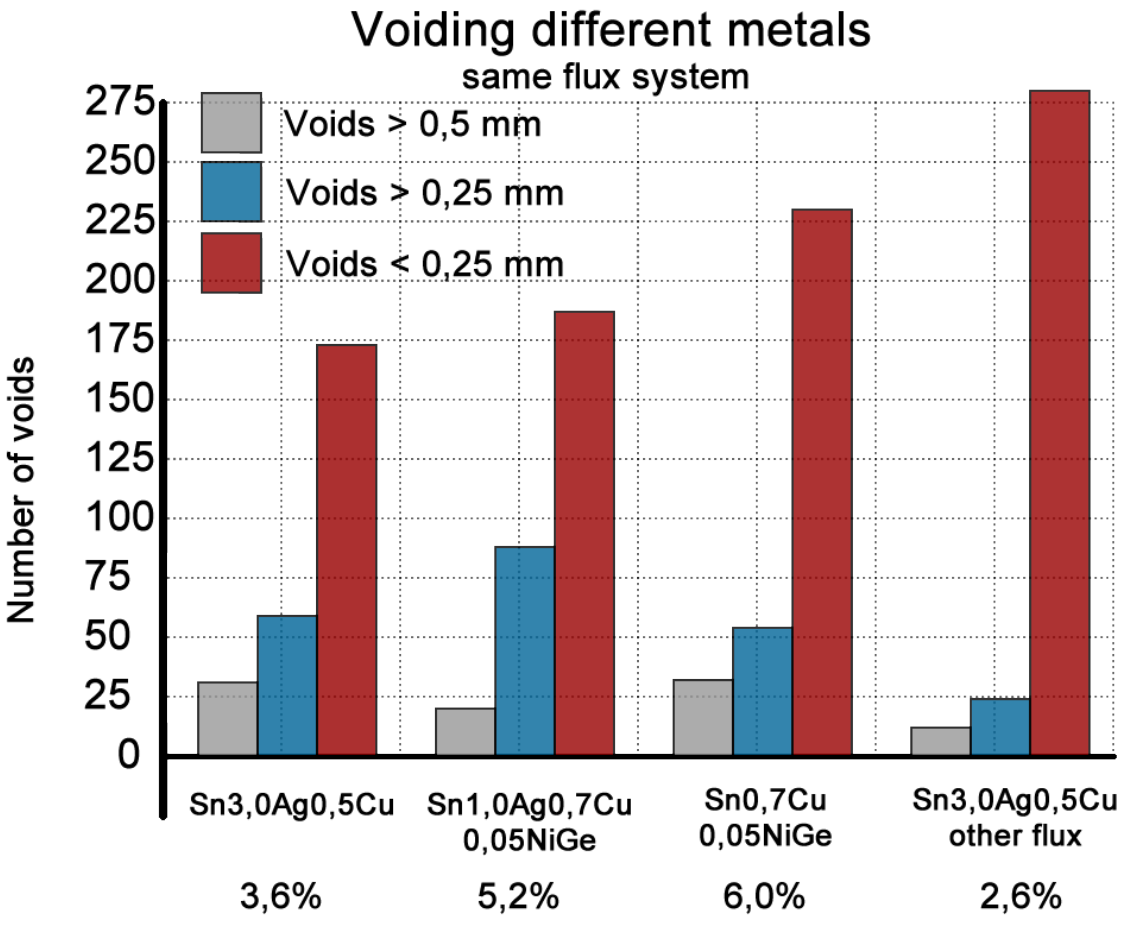
- Wetting
- Flux
- Voiding
- Reflow conditions (Siemens P4 profile)

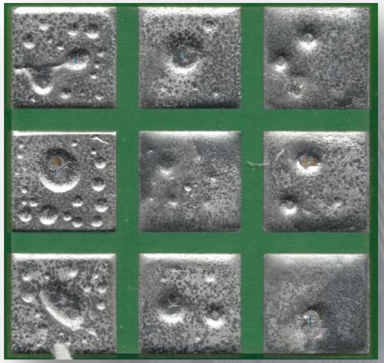
Alloy	% Ag	Melting [°C]	Tensile [N]	St.dev. [N]
Sn4,0Ag0,5Cu	4,0	217	221	17
Sn3,0Ag0,5Cu	3,0	217-219	230	28
Sn1,0Ag0,7Cu0,05NiGe	1,0	217-224	223	14
Sn0,3Ag0,7Cu0,05NiGe	0,3	217-228	195	23
Sn0,7Cu0,05NiGe	0	227	211	14
Sn62Pb36Ag2	2,0	179	265	48

Voiding

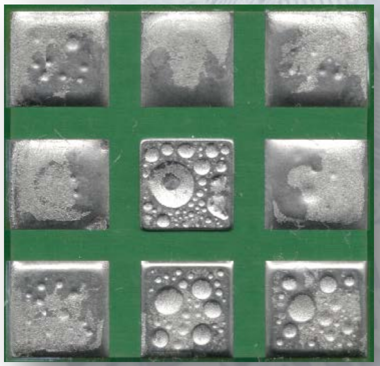


Alloys and voids

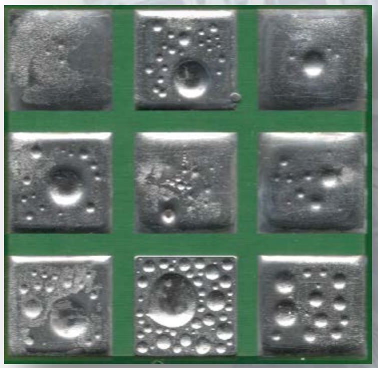




Sn3,0Ag05Cu
[217°C]



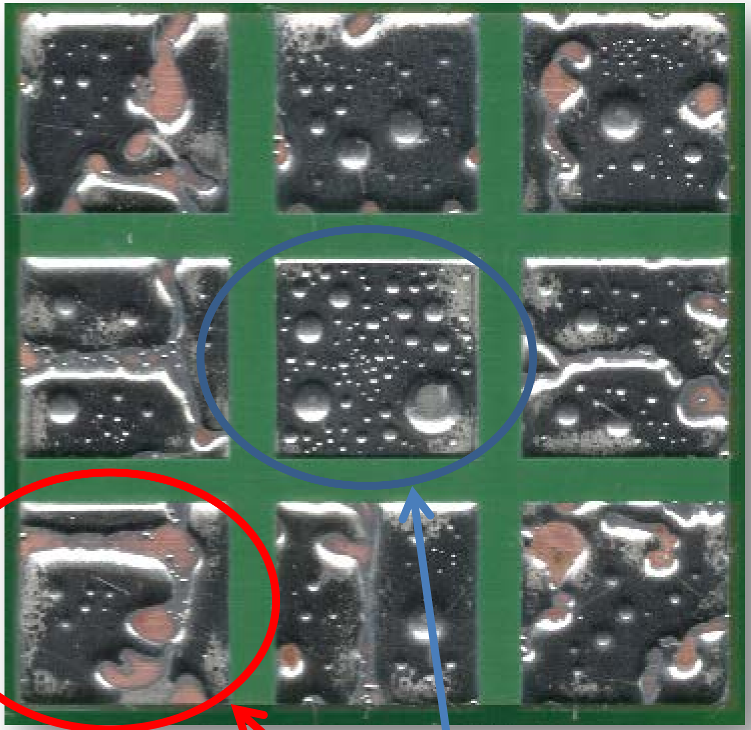
Sn1,0Ag0,7Cu
0,05NiGe
[217-224°C]



Sn0,7Cu
0,05NiGe
[227°C]

Higher melting point – more voids

Voiding on Cu OSP



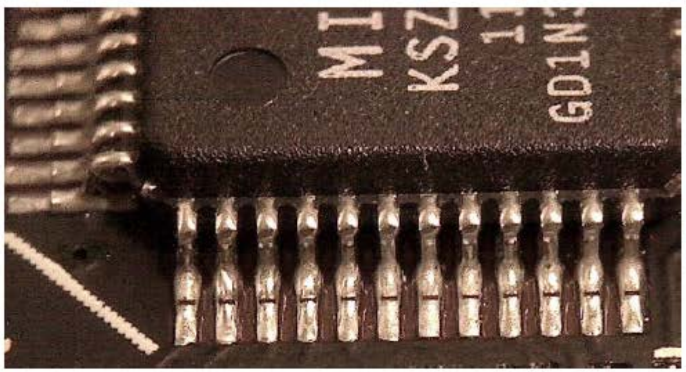
- Voids have impact on wetting.
- Due to dewetting/no wetting of the Cu surface it was not possible to make a sensible conclusion about parameters affecting voiding.

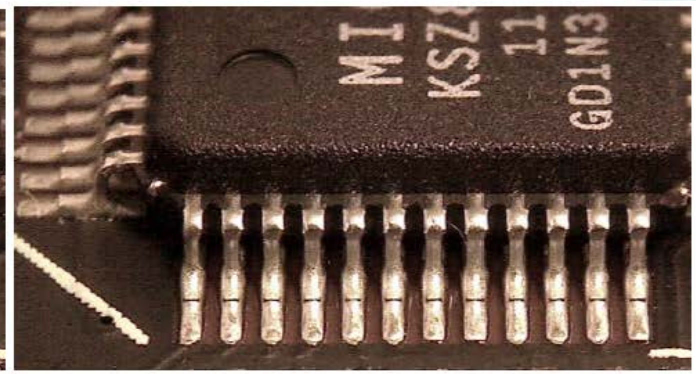
In case of poor wetting there is less voiding.

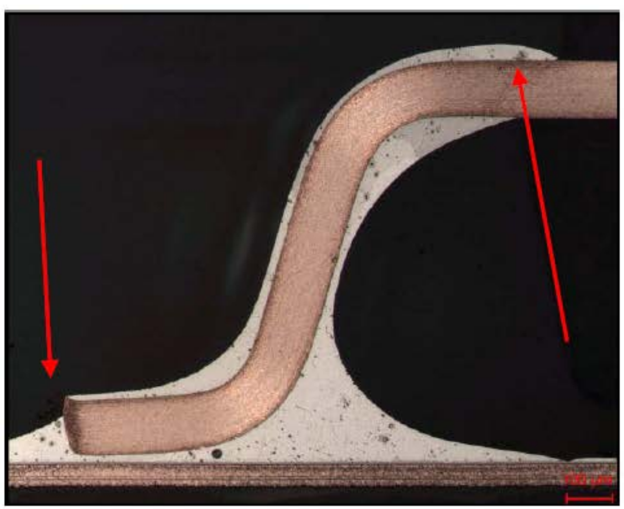
Field experience

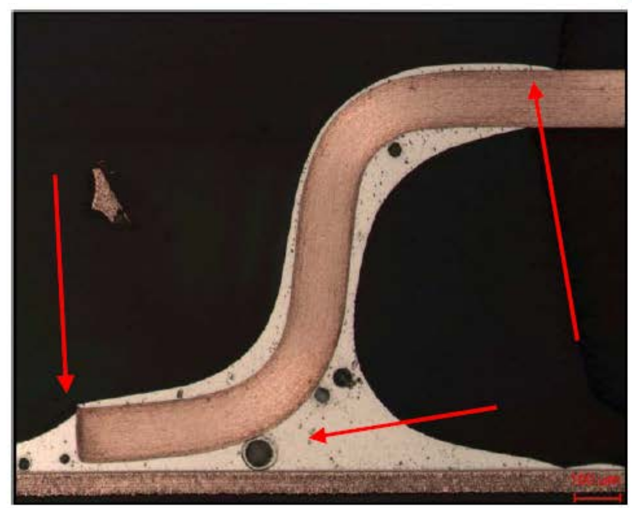
Sn3,0Ag0,5Cu

Sn1,0Ag0,7Cu0,05NiGe









Reliability and Ag content

Higher % Ag increase Thermal Cycling reliabiliy

Lower % Ag increase drop performance

Volume fraction of the Ag3Sn IMC particles in the microstructure tends to increase with increasing Ag-content

Add elements (dope) to improve TC properties

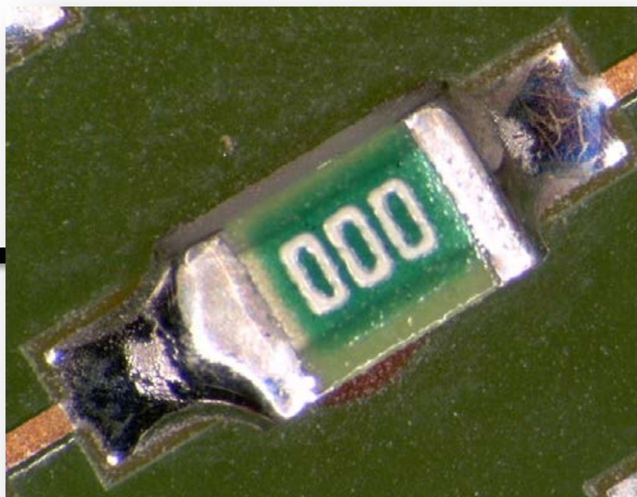
Soldering material selection

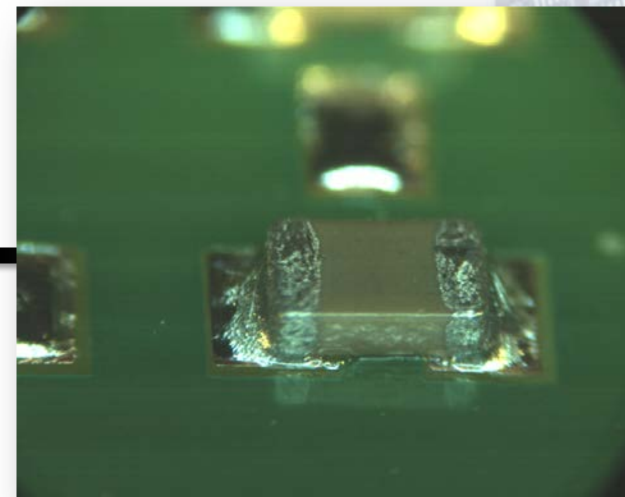
Wave soldering:

Sn37Pb

Reflow soldering:

Sn36Pb **+ 2% Ag**





Sn0,7Cu 0,05NiGe

Sn0,7Cu 0,05NiGe **+ 1% Ag**

Pb - Free

Wave soldering:

Sn0,7Cu0,05NiGe
Five Reasons:

1. Shiny solder joints/no shrinkage
2. Minimal generation of dross due to Ge
3. Ni inhibits Cu erosion
4. Reliable in harsh environments
5. Value for money

Reflow soldering:

Sn0,7Cu0,05NiGe + **1,0Ag**
Five Reasons:

1. Drop in for SAC305
2. Good wetting properties
3. Has small melting range => no tombstoning
4. Ni inhibits Cu erosion
5. Ni reduce IMC growth

Conclusions

- Industry is looking for alternatives for high silver containing alloys.
- NiGe added low SAC alloys have shown high reliability in many studies.
- The Sn0,7Cu0,05NiGe alloy system is one of the most promising lead-free soldering alloys available for wave soldering.
- Data in this study confirms outcomes of earlier publications.

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