ENEPIG FINISH: AN ALTERNATIVE SOLUTION FOR SPACE PRINTED CIRCUIT BOARDS

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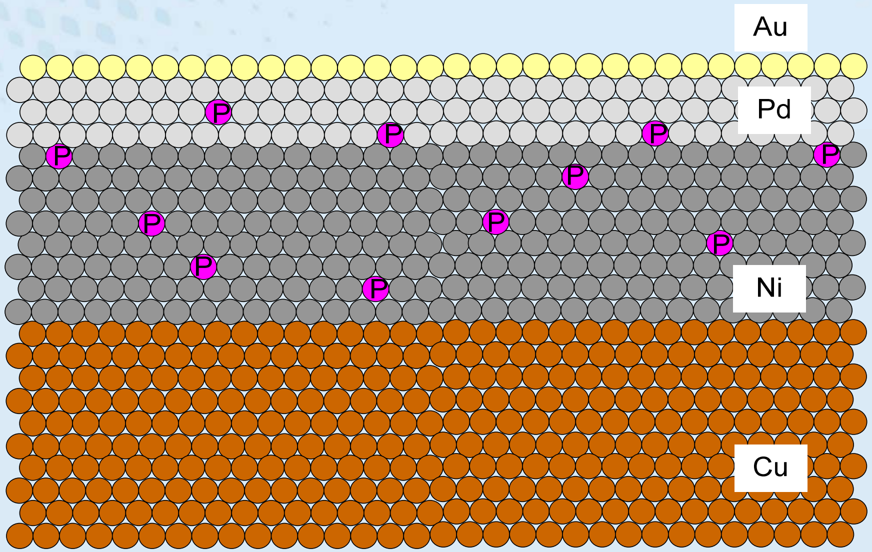
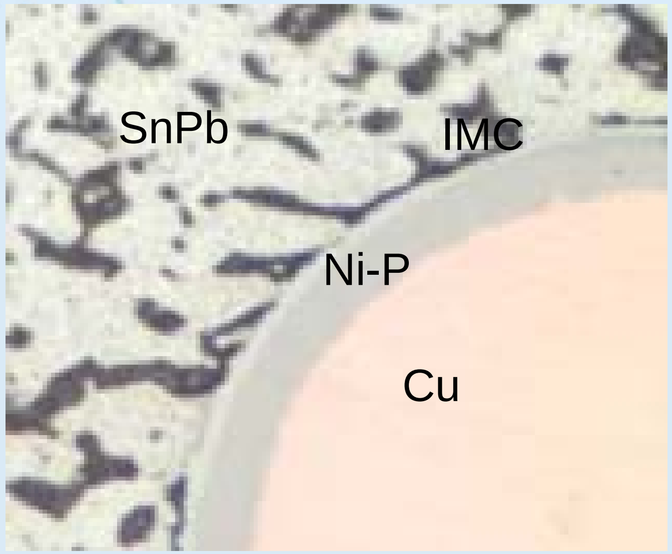


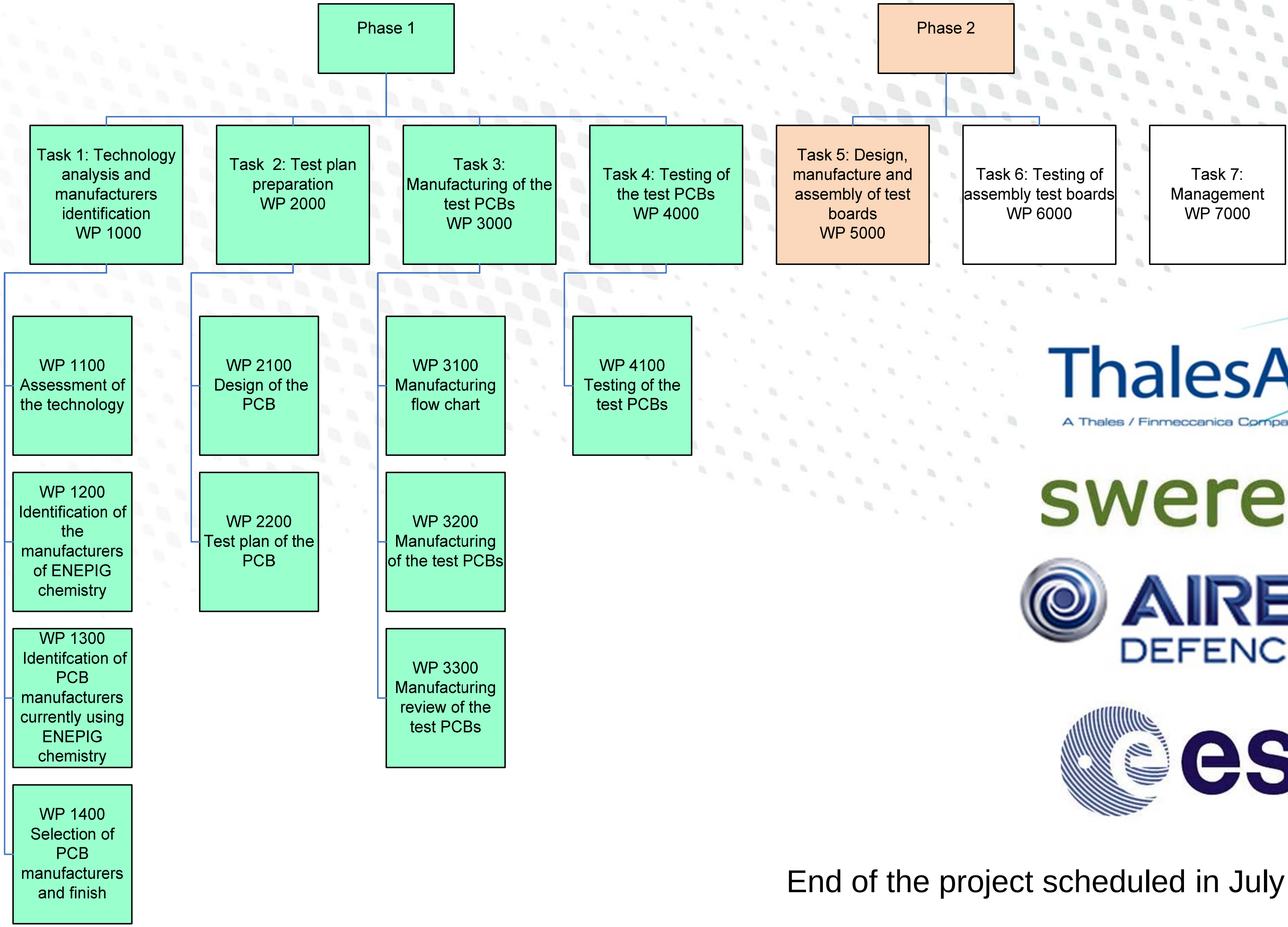


Selection of PCB finishes

- ✓Compatibility with SnPb and lead free assembly
- ✓Planar surface for fine pitch requirements
- ✓Automatic placement
- ✓Higher soldering temperatures and longer times for lead free soldering
- ✓Compatibility with new lead-free regulations
- ✓Multiple assembly operations
- ✓Ability to rework if necessary
- ✓Corrosion concerns
- ✓Shelf life of the coating
- ✓Overall end-user reliability requirements
- ✓Cost to produce the boards, including the overall final finish cost

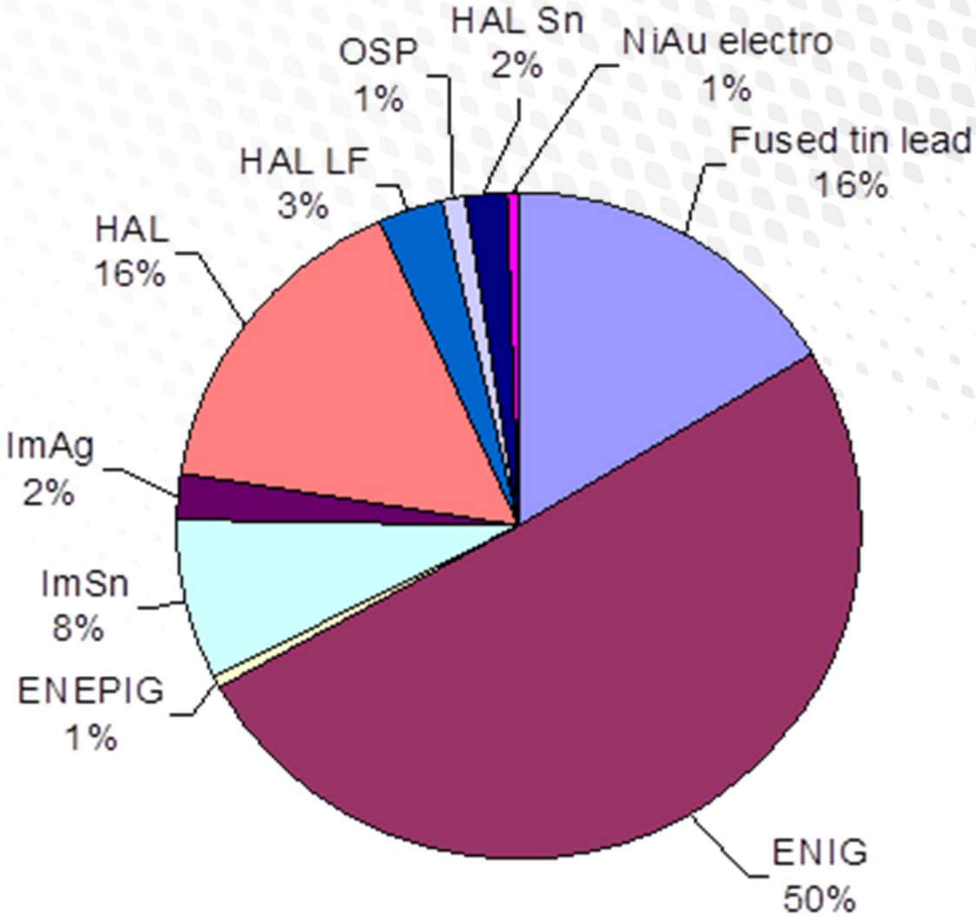
Selecting a lead-free alternative finishes a real challenge for Space industry

ENEPIG Project organisation



End of the project scheduled in July 2014

European main practices



About 50% of the PCBs in ENIG

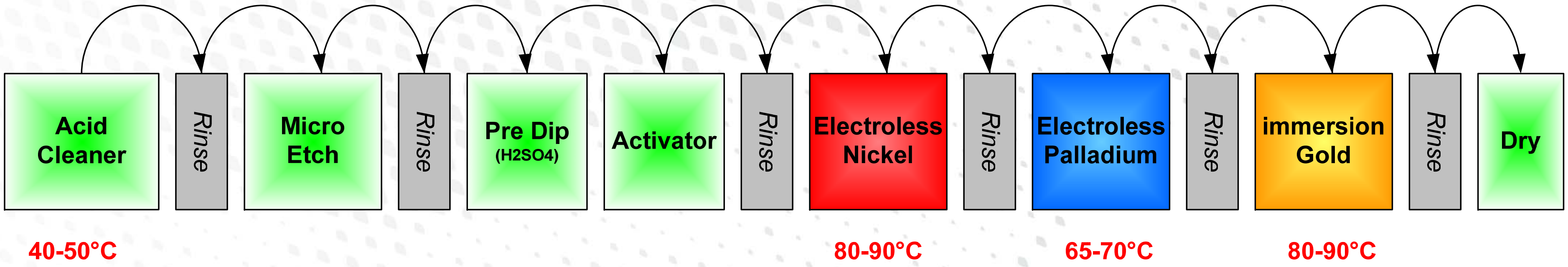
- ✓ Results linked to the high reliability applications of PCB manufacturers in Europe.
- ✓ OSP dominates in low-cost electronics such as mobile phone applications.
- ✓ Fused tin lead mainly used by PCB manufacturers specialized in Space applications.

ENEPIG finish, mainly used for package substrates, has not yet merged in the European market (less than 1%)

- ✓ ATOTECH, DOW CHEMICAL and UYEMURA > Main chemistries
- ✓ **Very few experiences in SnPb assembly**

ENEPIG

- ✓**Electroless Palladium** deposited onto **Nickel Phosphorus** layer and finished with **Immersion Gold**



- ✓Chemical deposition of nickel and gold performed with the same plating baths as the ENIG finish
- ✓Electroless palladium plating similar to electroless nickel process
- ✓Low corrosion effect at the nickel interface preventing black pad, poor solder wetting and weak solder joints

Major evolution on immersion gold process since 2010 :

Immersion gold process can now be replaced by a **new partly reductive gold-electrolyte** to minimize Ni layer corrosion and to increase Au layer thicknesses.

ENEPIG Control process tools

- ✓An **effective control of electroless bath** (agitation, pH, Ni/Pd concentrations, etc.) is the key to achieve a reliable process.

- ✓As metal in the electroless nickel bath is consumed, it has to be replaced. When the total additions of replaced metal are equal to the total amount of metal originally in the bath, that is one metal turn over (MTO).
- ✓**An MTO of 4** is recommended to assure the quality level of Ni and Pd layers.

  - ❖Impact on the thickness of the IMC layer with a change of MTO from 0 to 3,5
  - ❖Potential risk for brittle fractures in a drop test due to thicker Ni-Sn-P layer with a higher level of nanovoids

Objectives of the Phase 2

1. To test two different **ENEPIG chemistries** provided **by two finishes manufacturers**

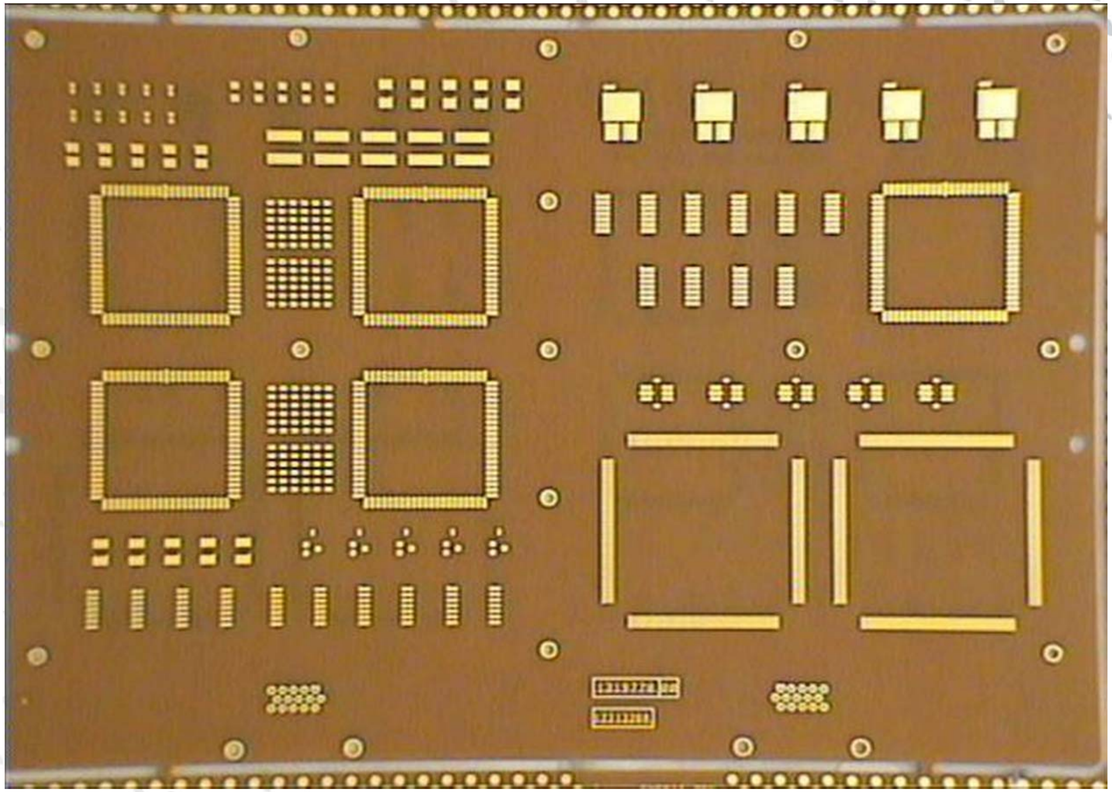
2. To **compare ENEPIG versus reflowed SnPb solutions**,

3. To evaluate ENEPIG finishes with **different kind of packages** (small SMDs and CCGA for example),

4. To estimate the impact of assembly processes on the reliability of the ENEPIG solution (**automatic process from two different OEM**: THALES ALENIA SPACE/ AIRBUS DS)

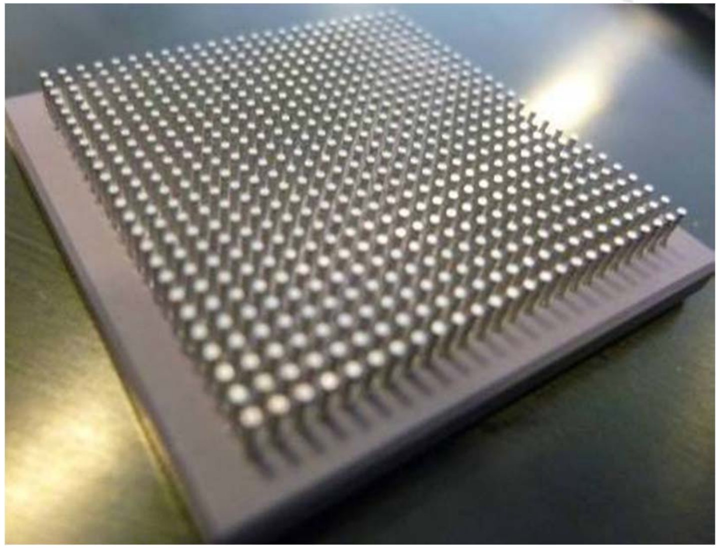
5. To submit test vehicles to **different kinds of environments** representative of storage or fatigue behaviors.

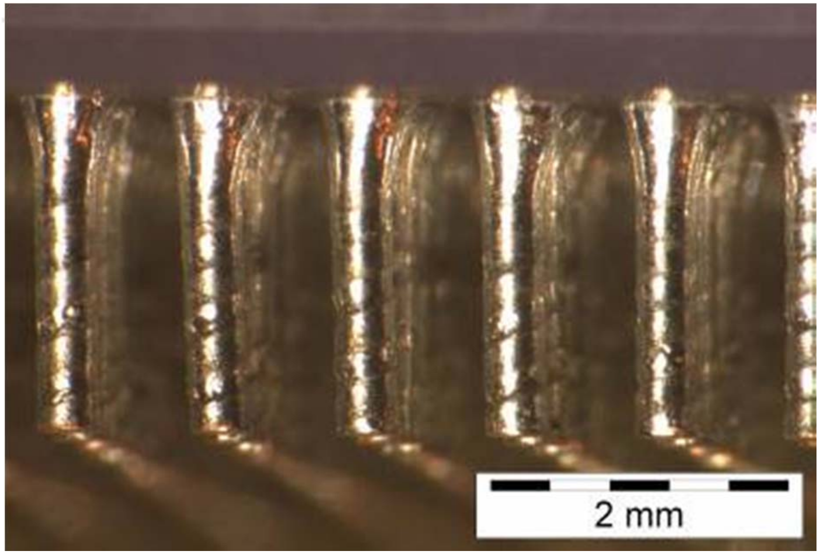
Test vehicles



Components list

- ✓ Diodes DO213 AB, D5A
- ✓ Connector SUB-D 15 points
- ✓ Resistors 0402, 0603, 0705,1206, 2512
- ✓ Capacitors 0603, 0805, 1210, 1812, 2220,2225, CRW11B
- ✓ LCC3, LCC6
- ✓ SMD0.5
- ✓ FP14
- ✓ JLCC84
- ✓ CQFP256
- ✓ TSOP54
- ✓ CCGA625





Ni/Pd/Au thickness requirements

Defined in IPC standard-4556

✓This document does not differentiate thickness according to the assembly process **(tin-lead or SAC).**

✓Required values are the following:

Ni layer: 3-6 µm

Pd layer: 0.05-0.30 µm

Au layer: >0.030 µm

✓Based on optical inspections and shear tests on BGAs, certain ENEPIG suppliers rather recommend **reducing Pd thickness to 0.05 µm or even below for SnPb assembly process.** Gold layers thicknesses could also be increased up to 0.15 µm.

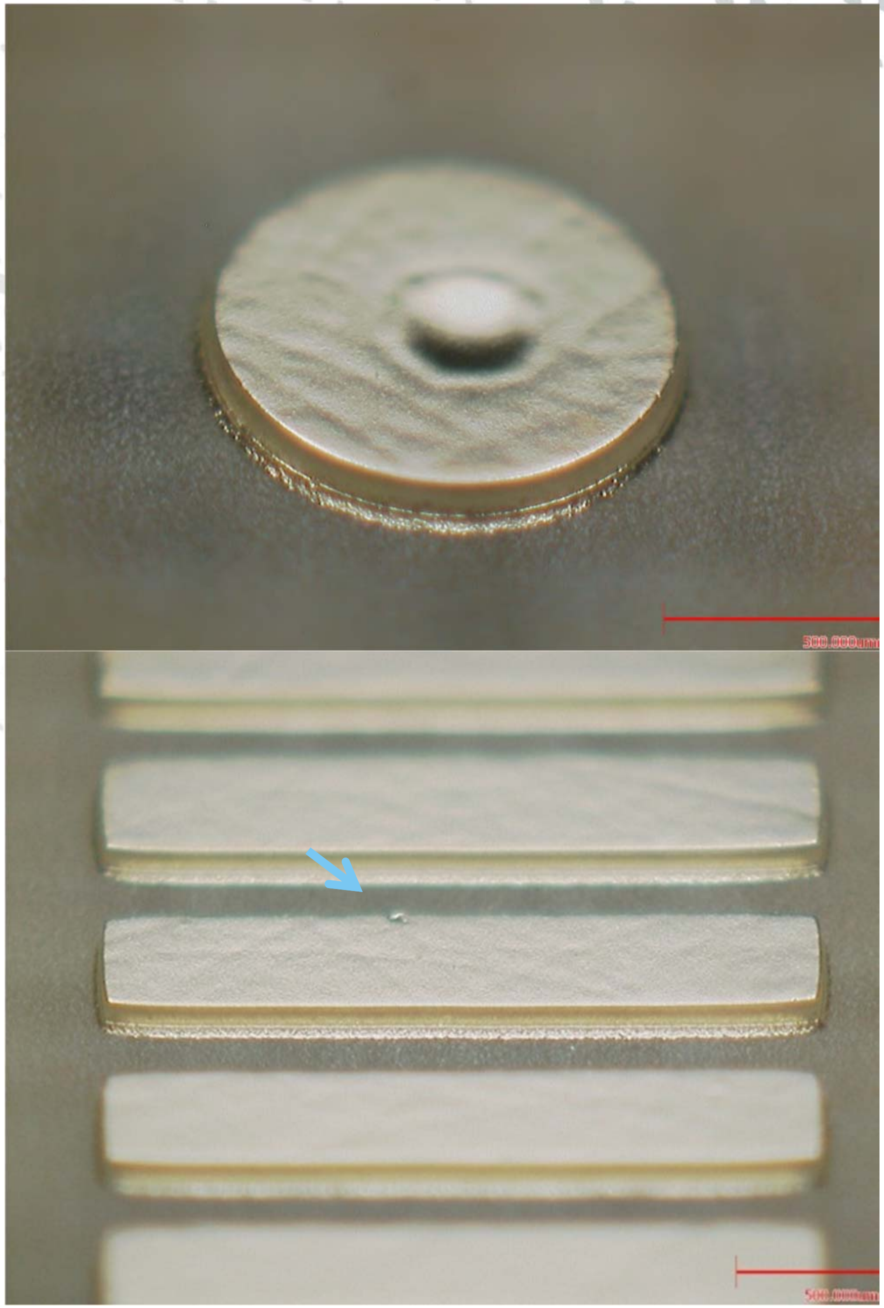
PCB incoming inspection

Very positive points

- ✓ Patterns compliant with IPC-4556
- ✓ Rough golden appearance
- ✓ Complete coverage
- ✓ Pads more flat than with fused SnPb
- ✓ Finish uniform on the plated surfaces
- ✓ No shortcuts noticed
- ✓ No differences between the finish suppliers

Only minor and local defects

- ✓ Roughness and dimples which are reflections of the original copper surface



ENEPIG thickness measurements

X-ray fluorescence (XRF)

- ✓ Non destructive and rapid results delivered by manufacturers of finishes
- ✓ Results highly dependent on program and calibration parameters
- ✓ Not adapted to very thin layers, as for ENEPIG

Ionic polishing and SEM observations

- ✓ To visualize inter-layers
- ✓ To measure thickness of Ni/Pd/Au layers
- ✓ To compare values coming from various manufacturers of finishes.

	SN1	SN2	SN3
Pd (µm) - SEM	0.122	0.055	0.120
Pd (µm) - XRF	0.132	0.044	0.089
Au (µm) - SEM	0.038	0.051	0.054
Au (µm) - XRF	0.039	0.049	0.048

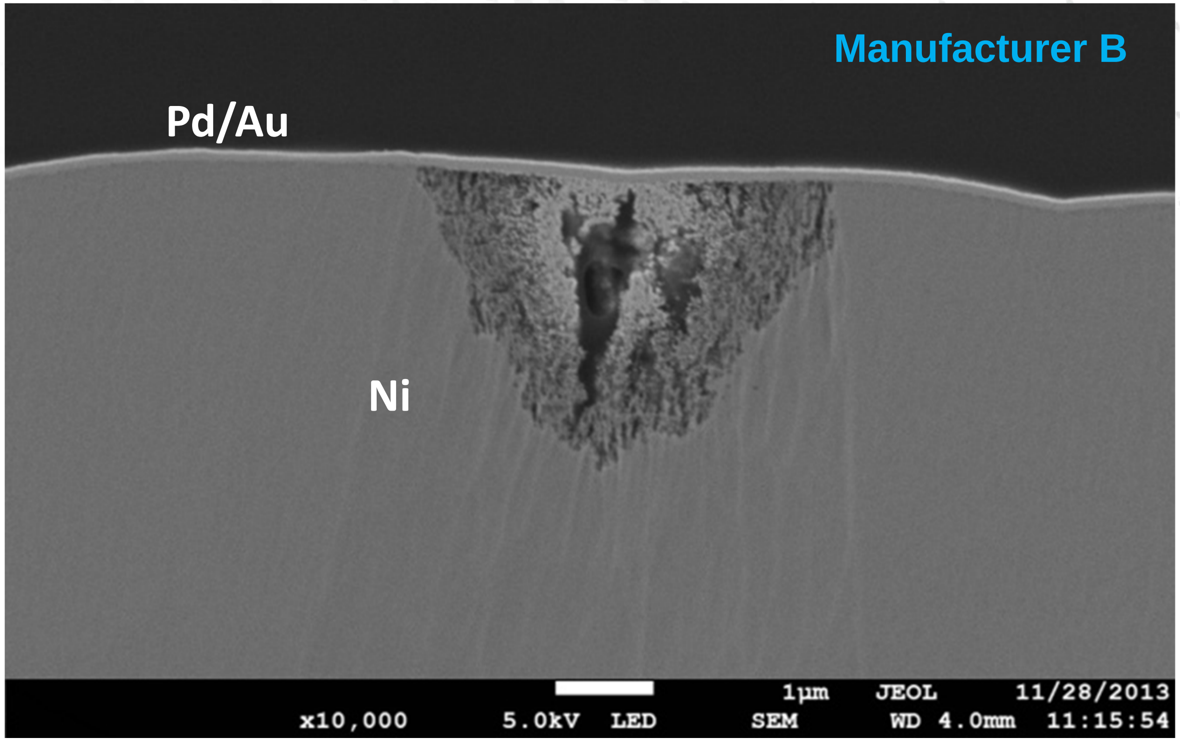
	SN4	SN5	SN6	SN7	SN8
Pd (µm) - SEM	0.077	0.053	0.103	0.107	0.115
Au (µm) - SEM	0.035	0.049	0.076	0.076	0.059

- **Poor repeatability of the thickness of Pd and Au for both suppliers**
- **XRF may deviate 25% from the true value**

SEM observations before assembly

Corrosion spikes

- ✓ Observed in the Ni layer from 1 supplier (not using partly reductive gold-electrolyte)
- ✓ ENEPIG may not be completely immune against the black pad defect.
- ✓ Small number of spikes
- ✓ Not likely to affect the reliability of the solder joints

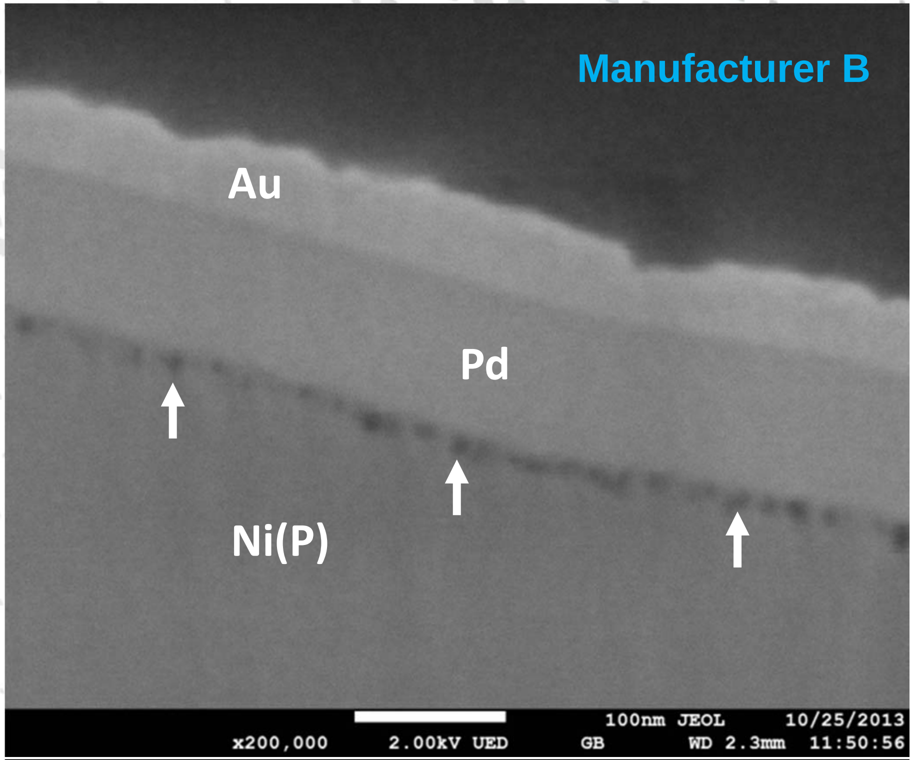


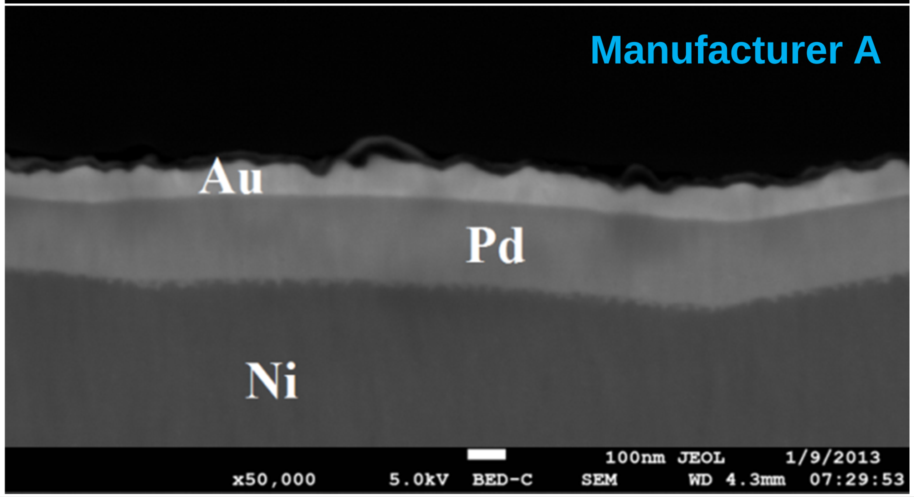
- **Rather few defects on bare boards**
- **Boards all accepted for the assembly phase**

SEM observations before assembly

With larger magnification (up to x 200 000)

- ✓ Very thin dark band with inclusions of micro-voids
- ✓ Detected at the Ni/Pd interface on PCB from supplier and chemistry B (standard and CCGA types)
- ✓ Appearance similar to the dark band formed between Au and Ni in ENIG finishes consisting of Ni_3P
- ✓ Rather smooth interface on PCB from supplier and chemistry A
- ✓ Differences linked to the chemistries or to the process parameters (time and temperature)

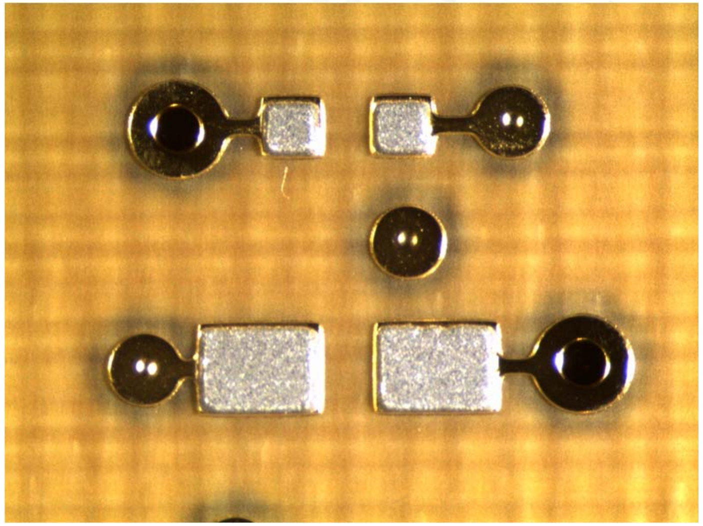


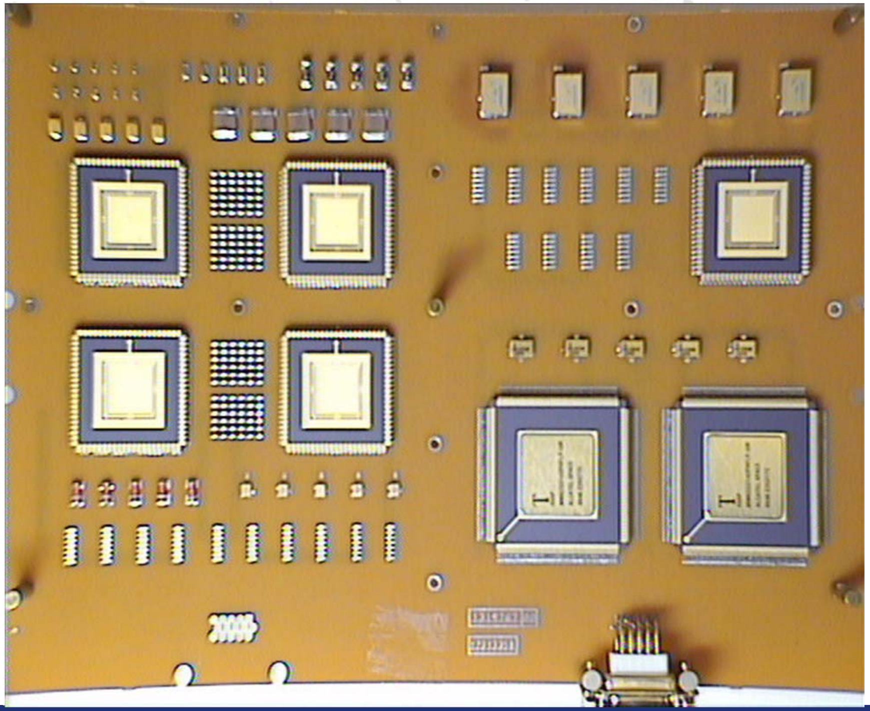


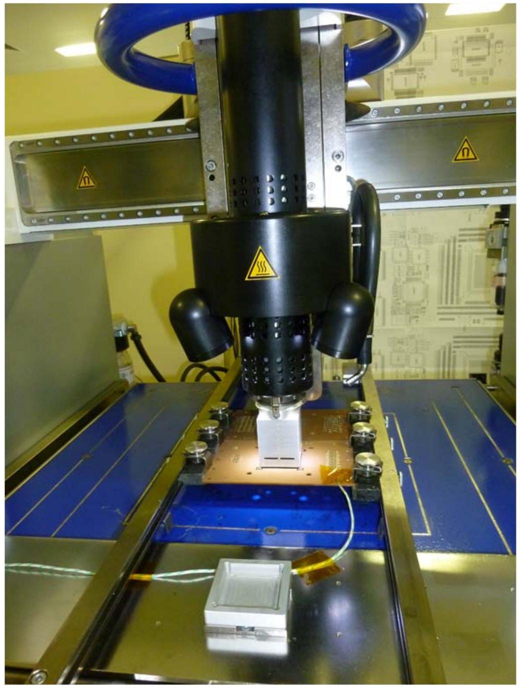
Boards assembly

Processes

- ✓ Vapour phase soldering
- ✓ Hot air process for CCGA 625 repair plus some of the SMD0.5
- ✓ Manual soldering for CQFP plus connectors
- ✓ Manual repair or touch-up
- ✓ Thermal shocks on pads

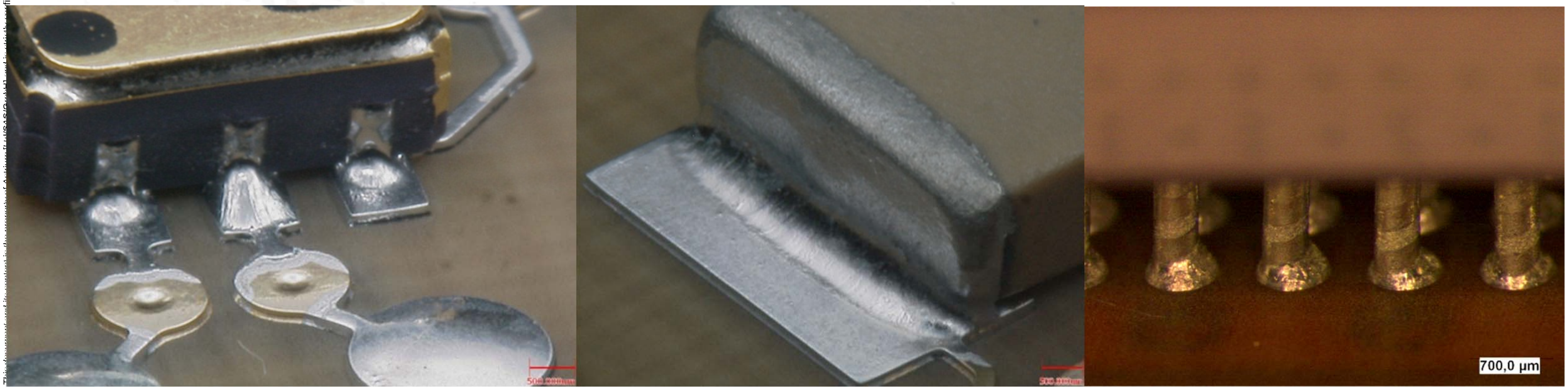




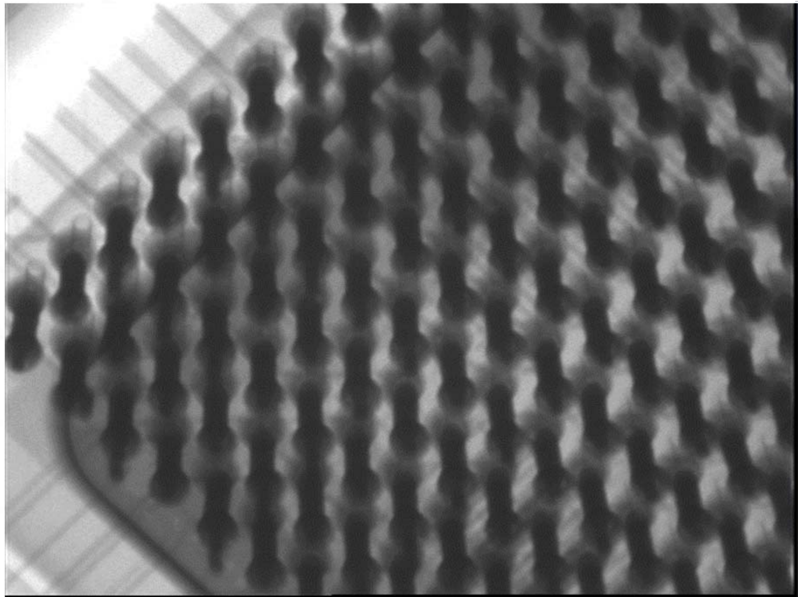


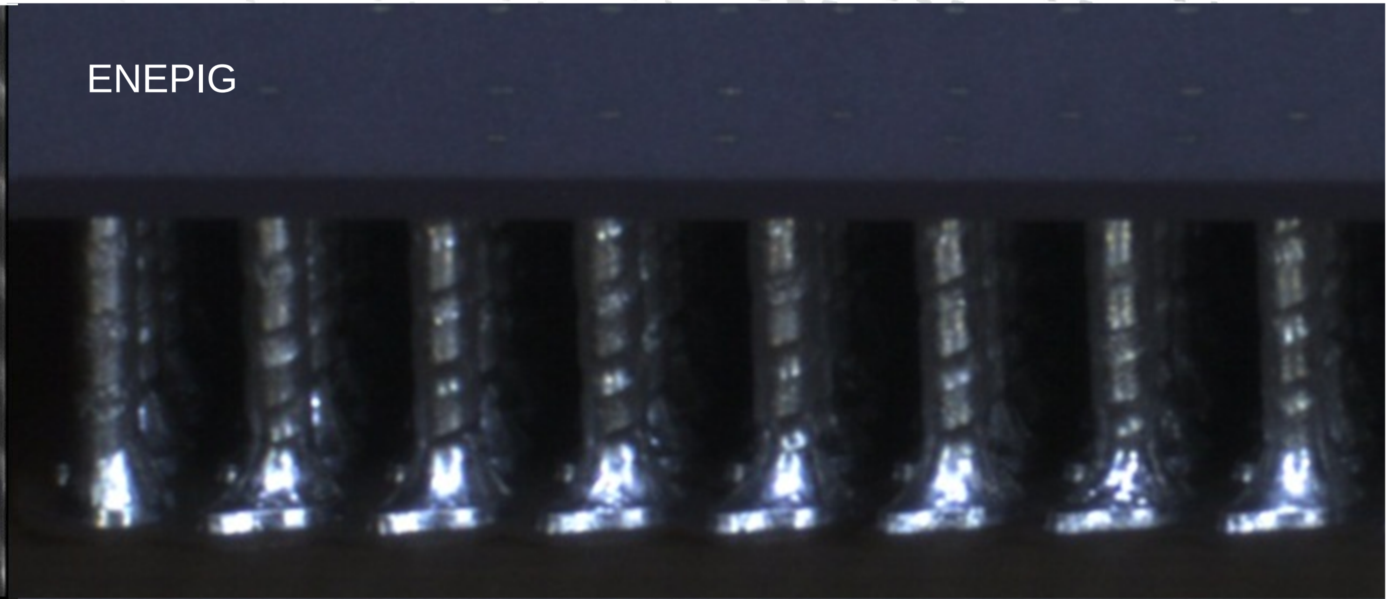
Visual inspections after assembly

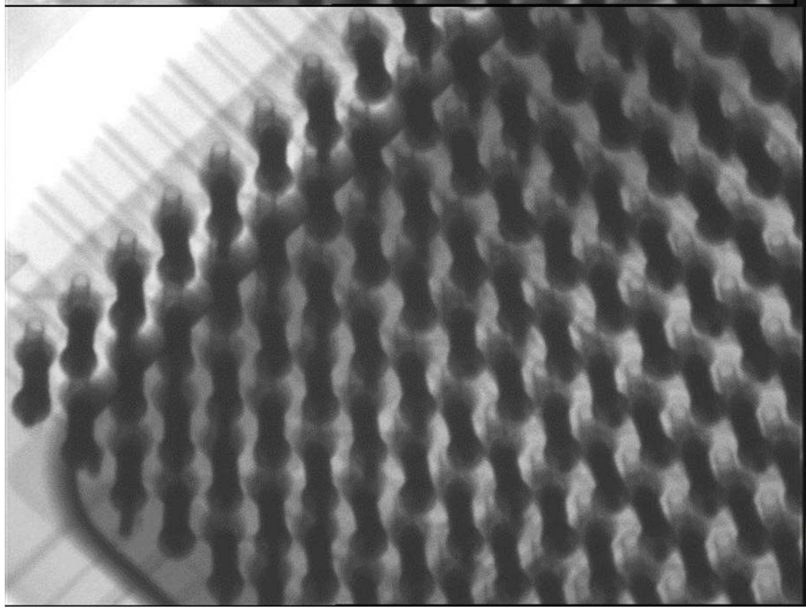
- ✓ No soldering defect (shortcut, de-wetting, cold solder joint or solder balls)
- ✓ Wettability of SnPb solders easier to observe with ENEPIG
- ✓ No great differences in the appearance between ENEPIG and fused SnPb finishes, neither for different packages
- ✓ Short reduction of stand-off

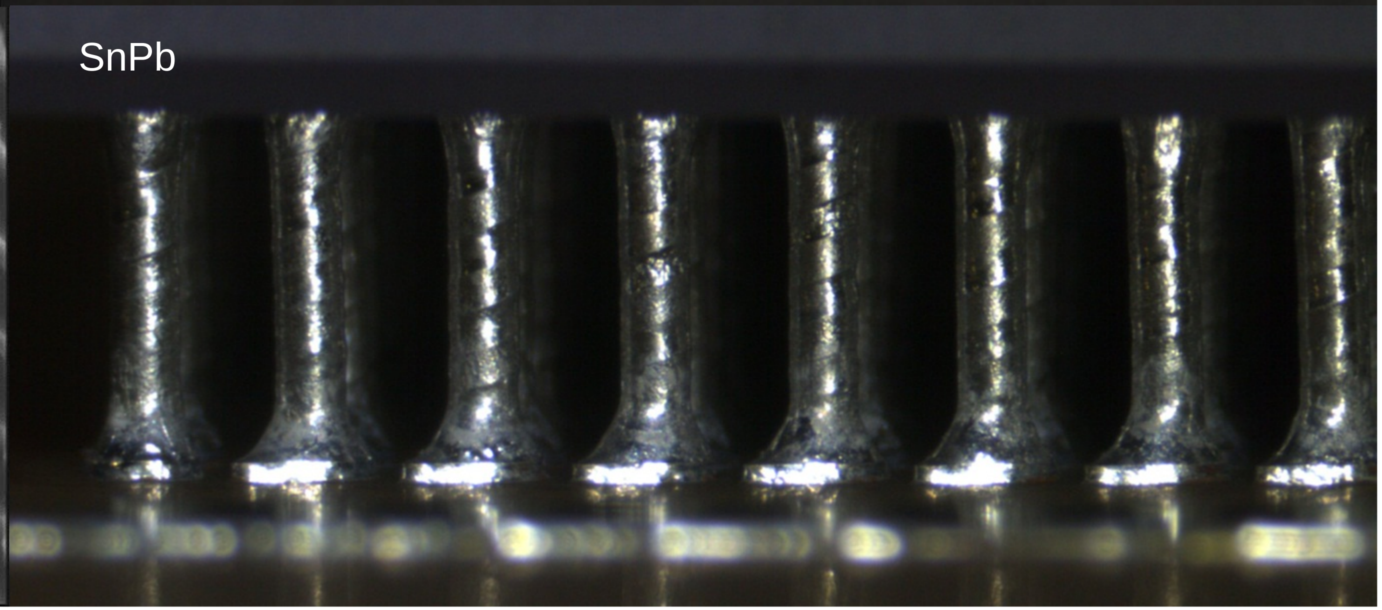


After assembly: Comparison ENEPIG / SnPb



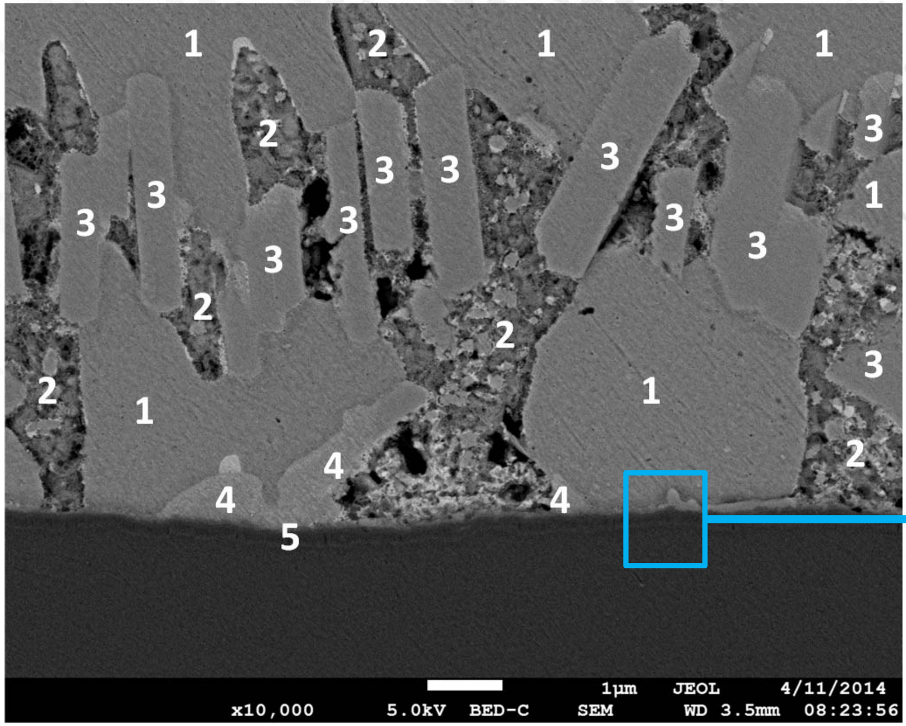


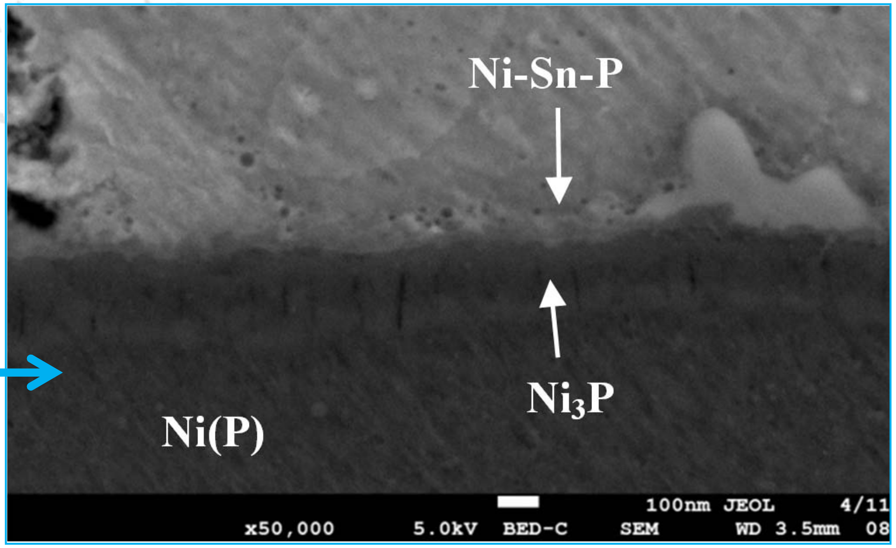




Microsections after assembly

- ✓ Similar appearance for all components on the reference board
- ✓ IMC layer almost completely spalled off because of SnPb assembly
- ✓ Layer of Ni_3P with a thickness of about 200 nm observed at the uppermost part of the Ni(P) layer
- ✓ Thin layer (<50 nm) of nanocrystalline Ni-Sn-P on top of the Ni_3P layer
- ✓ No other IMC layer on top of the Ni-Sn-P layer except some $AuSn_4$ at some locations



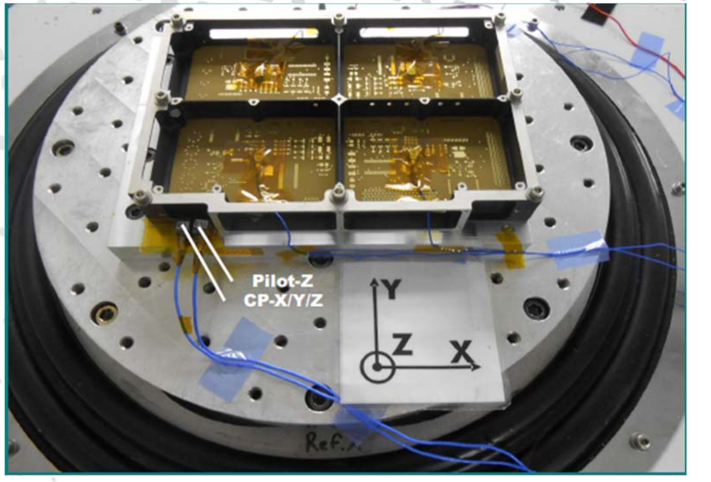


2220 capacitor on ENEPIG from manufacturer A. 1) Sn, 2) Pb, 3) $(Pd,Ni)Sn_4$, 4) $AuSn_4$ and 5) Ni_3P

Accelerated ageing tests

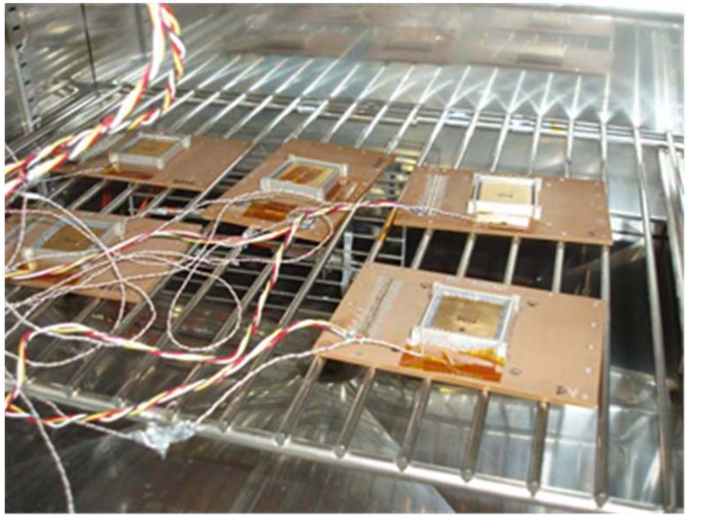
Objective

- ✓ Evaluate the ageing behavior of components on ENEPIG finish boards
- ✓ Observe the development of the IMC layers (composition, thickness and shape) and their impact on lifetime of solder joints

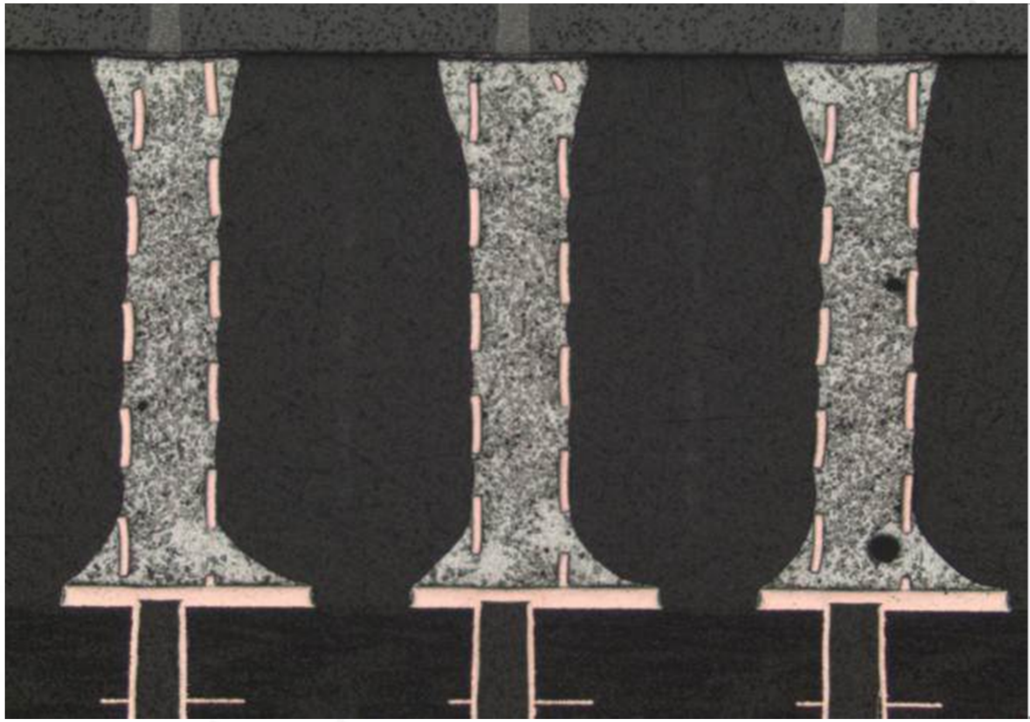


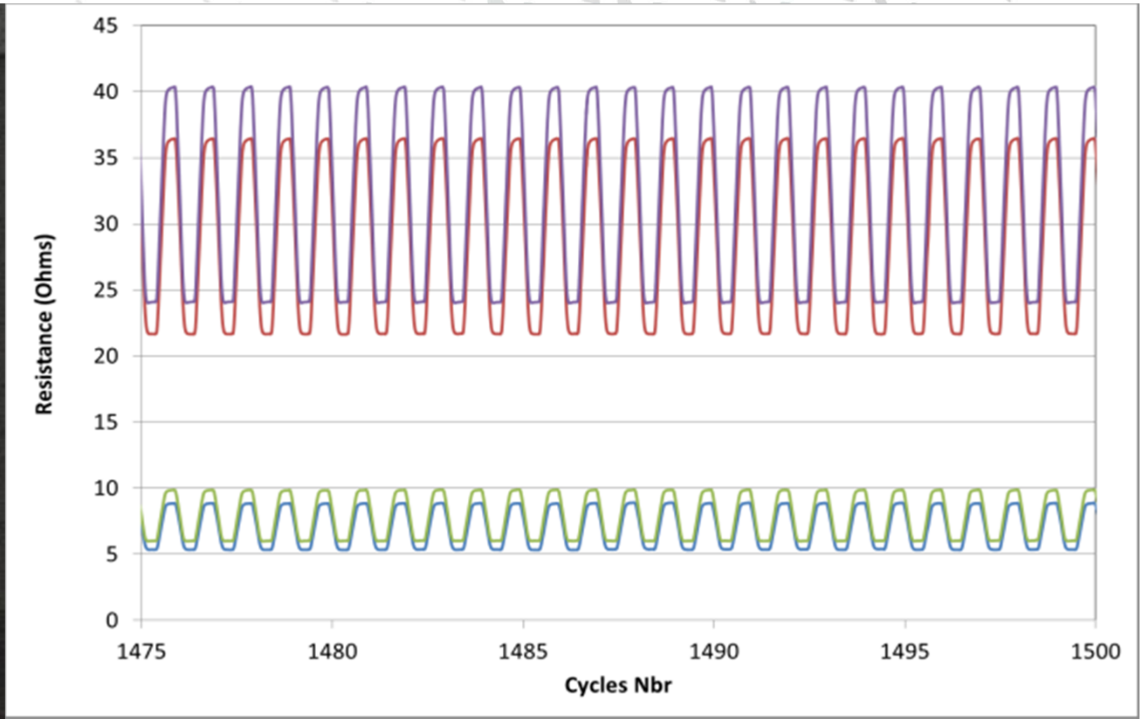
Test conditions

- ✓ Vibrations according to ECSS-Q-ST-70-38 standard levels on all boards
- ✓ Higher levels of vibrations plus shocks for part of the CCGA625 assemblies
- ✓ Thermal cycles (-55/+100°C, 15 min dwells,10°C/min ramp) up to 500 cycles for standard boards and to 1500 cycles for CCGA boards,
- ✓ High temperature storage simulation (125°C for 500 h) to be equivalent to 1 year at ambient conditions.



Focus on CCGA 625 assemblies

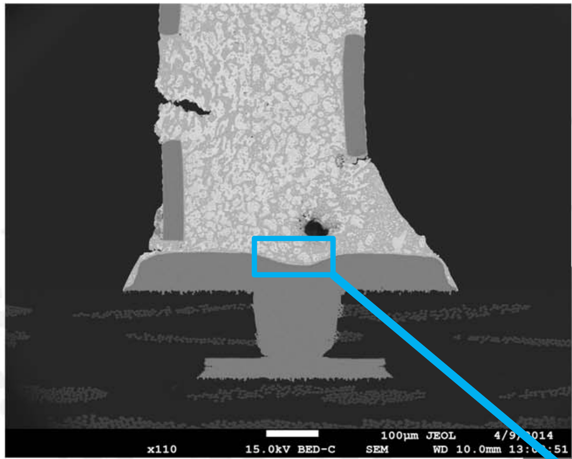




- The assembly (auto and repair) of the CCGA625 packages on board was equally successful for the two OEMs.

- All the parts passed the cumulative qualification test flow up to 1500 cycles without any electrical failure.

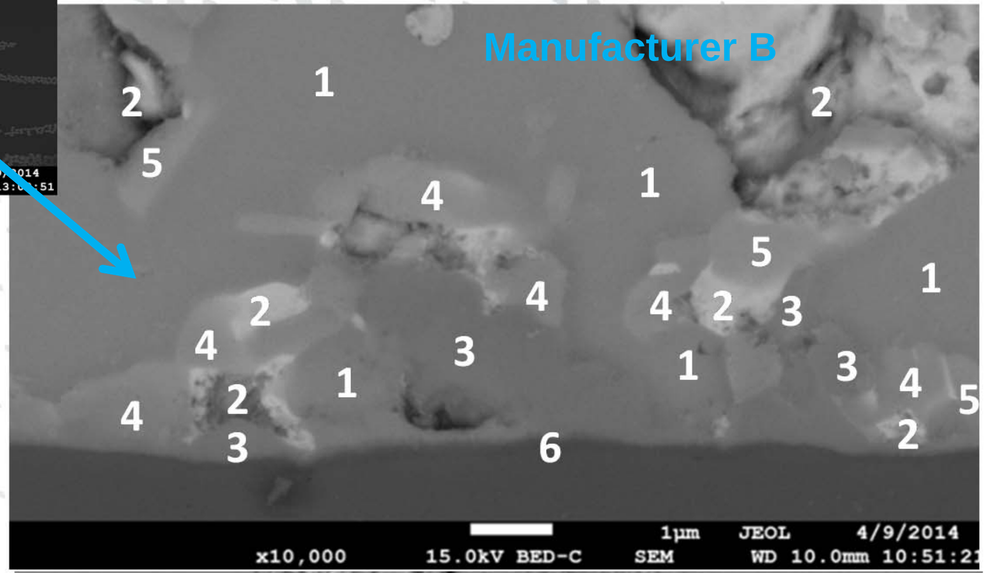
Microsections after 500 TC on CCGA 625

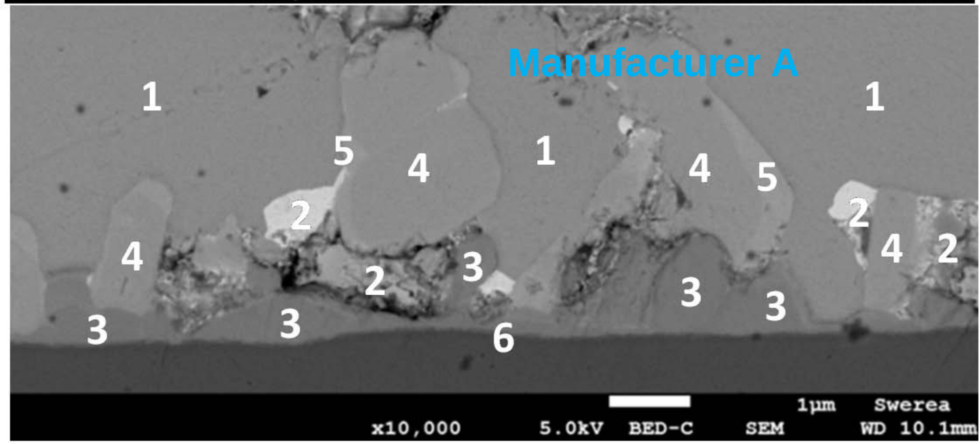


Automatic process

- ✓ Very similar for the two components from 2 different OEMs
- ✓ IMC layers are a complex mix of at least 3 phases: $(Cu,Ni)_6Sn_5$, $PdSn_4$ and $AuSn_4$
- ✓ Ni-Sn-P and Ni3P layers beneath these IMC layers with mixed IMC phases

- ✓ the Cu from the copper ribbons (or from the repair process) has prevented the spalling of the IMC layer that occurred for the other types of components



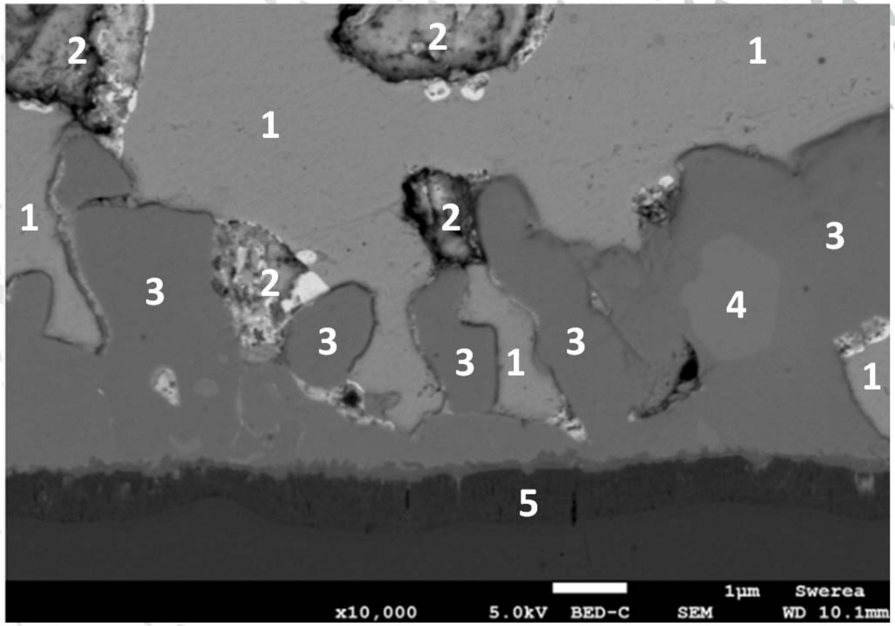


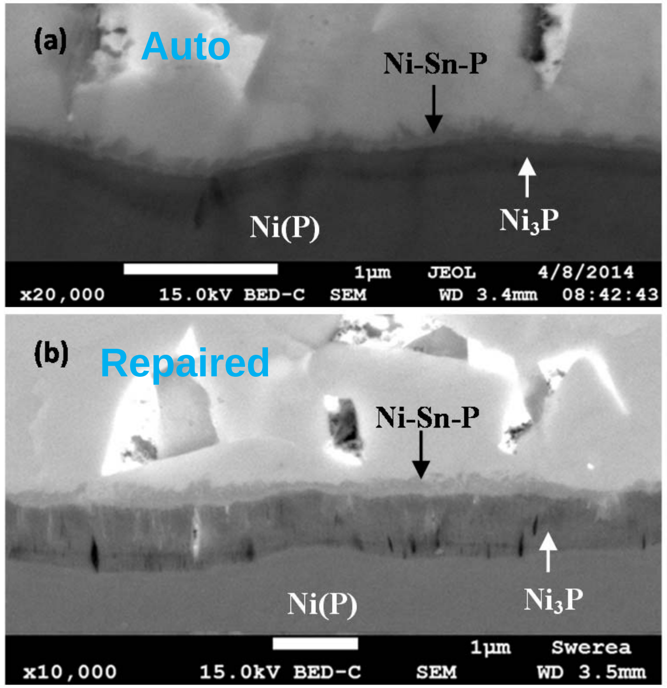
SEM/EDS analysis after 500 TC on CCGA 625 boards from manufacturers A and B
1) Sn, 2) Pb, 3) $(Cu,Ni)_6Sn_5$, 4) $PdSn_4$, 5) $AuSn_4$ and 6) Ni_3P

Microsections after 500 TC on CCGA 625

Repair/non repair process

- ✓ Pd and Au completely missing in the IMC layer (removed while stripping using a Cu solder wick braid)
- ✓ Considerably more copper in the IMC layer on the repaired sample (origin determination in progress)
- ✓ Ni_3P and Ni-Sn-P layers considerably thicker for the repaired CCGA 625 component
- ✓ Lot of crevices between the columns in the Ni_3P layer for the repaired component, of which some are filled with Sn





SEM/EDS analysis after 500 thermal cycles of repaired CCGA 625 board. 1) Sn, 2) Pb, 3) $(Cu,Ni)_6Sn_5$, 4) $(Ni,Cu)_3Sn_4$ and 6) Ni_3P

Conclusions (1/4)

- ✓ Adaptation of IPC standard on ENEPIG still needed

- ✓ One board showed a few “corrosion spikes” in the Ni layer indicating that ENEPIG may not be completely immune to the black pad defect.

- ✓ No problem related to the ENEPIG finish reported during the assembly of test vehicles with vapour phase, manual or repair process

- ✓ Optical and X-rays observations just after assembly fully compliant with ECSS-Q-ST-70-38C

- ✓ SEM/EDS analyses of the IMC layers performed to evaluate the impact of ENEPIG finishes manufacturers as well as on assembly processes

    - After vapour phase soldering and for most of the component types, the IMC layer had almost completely spalled off because of SnPb

Conclusions (2/4)

✓Assembly of the CCGA 625 packages successful equally for the two OEMs.

- All the parts still OK up to 1500 cycles
- Nominal and equivalent ageing of the solder joints after vibrations (shocks) plus 500 thermal cycles
- No critical defects likely to question the assembly of the columns on the package or on the board
- No damages at PCB level.

✓Detailed IMC analyses on CCGA 625 after vibrations, shocks and 500 cycles

- No significant changes compare to t0
- Same kind of interfaces for both manufacturers
- IMC layers had not spalled off as for the other component types
- Cu dissolved from the Cu ribbon in the solder columns seems to have a very beneficial impact on the IMC layers

Conclusions (3/4)

✓Detailed IMC analyses on CCGA 625 repaired after vibrations, shocks and 500 cycles

- Repair increases considerably the thickness of the Ni_3P and Ni-Sn-P layers
- Also increases the amount of crevices in the Ni_3P layer.
- It does not seem to have affected the reliability of the CCGA components but it might do that for components if the IMC layer is spalled off.

✓The impact of the spalling of the IMC layers on the reliability during the environmental tests for the other component types than CCGA has not yet been evaluated but this evaluation is ongoing.

Conclusions (4/4)

✓All the results given in this paper are going towards the qualification and the use of ENEPIG finishes for SnPb assembly process.

✓One last point is nevertheless still to be confirmed.

What will be the impact of long storage and multiple thermal heating of boards (caused by successive PCB baking and cleanings)?

✓The consortium proposes here to enlarge this study to this last evaluation step. It would consist in re-manufacturing one PCB per ENEPIG types. Storage plus thermal heating should then be simulated before complementary SEM analyses and components assembly.

Questions ?