Microstructural Aspects & Performance Implications of Sn-Ag-Cu-Sb Solder in the Presence of Gold

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General requirements of Pb-free in mobile phone applications

- WEEE requires mobile phones be lead-free in 01, 2006
- Solder paste must be lead-free
- PWB board finish must be lead-free
- Component termination finishes & balls must be Pb-free

Purposes

- To investigate reliability of totally lead-free solder joints
- To study effects of gold coating thickness on Sn-Ag-Cu-Sb solder joint performance
- To discern failure mechanisms & microstructural evolution differences in Sn-Ag-Cu-Sb and Sn-Pb-Ag solder joints after thermal cycling

Experimental

- Materials/Hardware
  - 14 leadless component packages, Ni/Au termination finish
  - FR4 high density micro-via test boards, Ni/Au surface finish
  - Sn-Ag-Cu-Sb and Sn-Pb-Ag solder pastes
- Test
  - After reflow, after 200 cycles, after 500 cycles between –40 and 85°C
- Analysis
  - SEM, EDX for microstructural analysis

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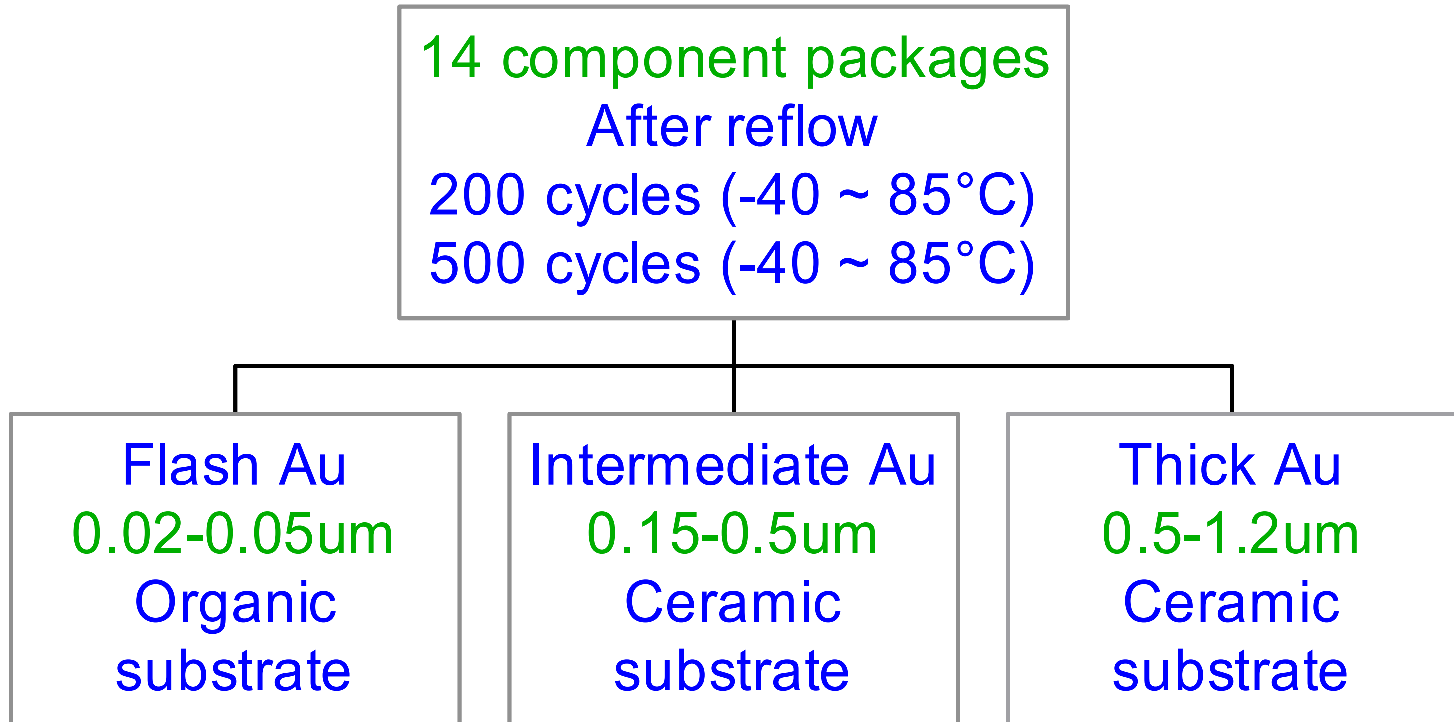
Sample Matrix



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Aspects of Analysis

- Voiding
- Phase identification
- Microstructure & interface
- Effect of gold content
- Effect of substrate
- Effect of package size
- Crack generation and development
- What is the maximum Au content that can be tolerated ????

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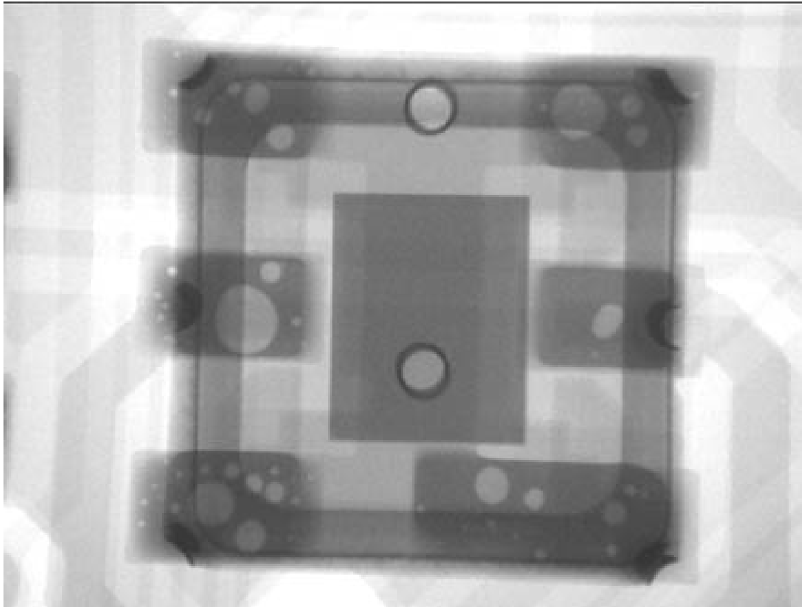
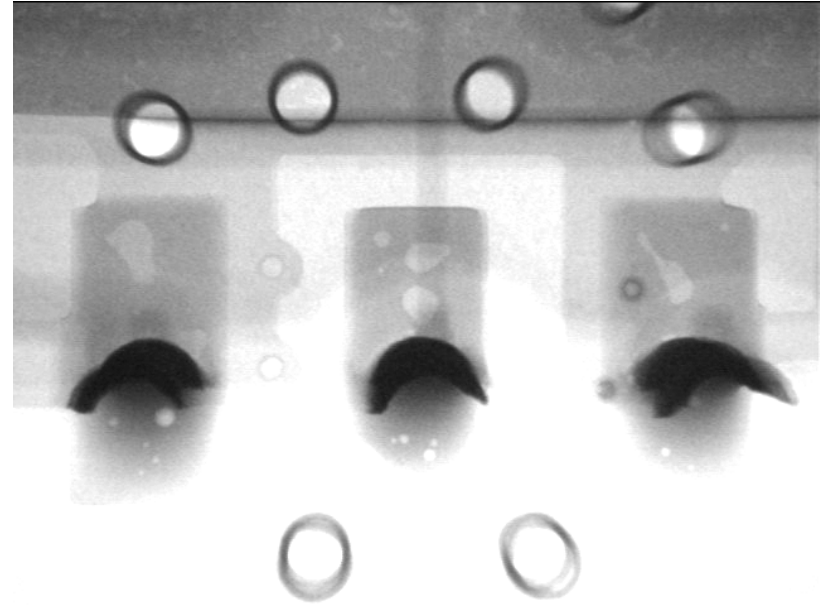
Results

Voiding vs. Au thickness





Flash gold, round voids
Sn-Ag-Cu-Sb solder

Thick gold, irregular voids
Sn-Ag-Cu-Sb solder

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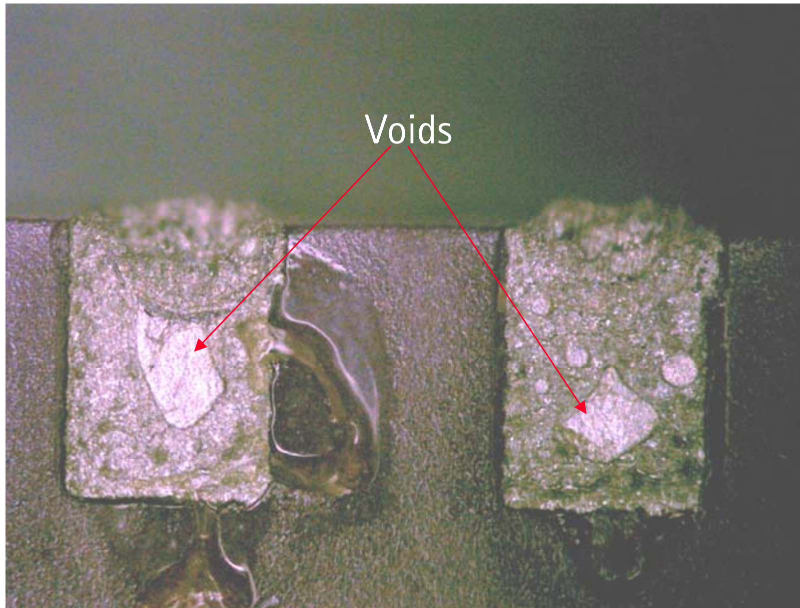
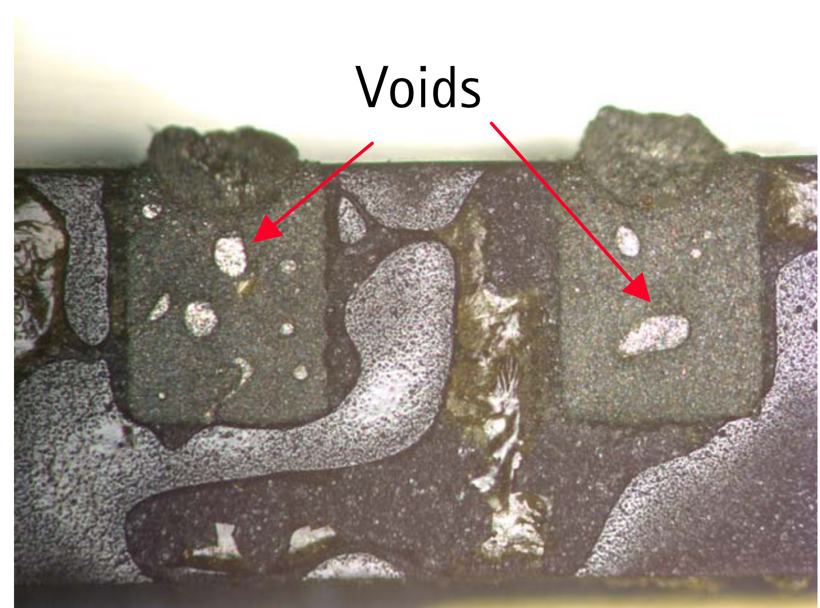
Voiding vs. solder paste





Sn-Ag-Cu-Sb, irregular shape.
Thick gold

Sn-Pb-Ag, round shape.
Thick gold

Effect of gold content on voiding

- Solubility of gold in Sn-Ag-Cu-Sb is greater than in Sn-Pb due to high Sn and high reflow temperature
- Fraction of $AuSn_4$ in the molten Sn-Ag-Cu-Sb joint is greater than in the Sn-Pb-Ag joint
- $AuSn_4$ crystals in molten solder will increase solder viscosity and degrade its spreadability
- Increased viscosity restricts the release of gasses, resulting in higher void content
- Fast cooling rate and large fraction of $AuSn_4$ results in irregular voids in thick gold joint

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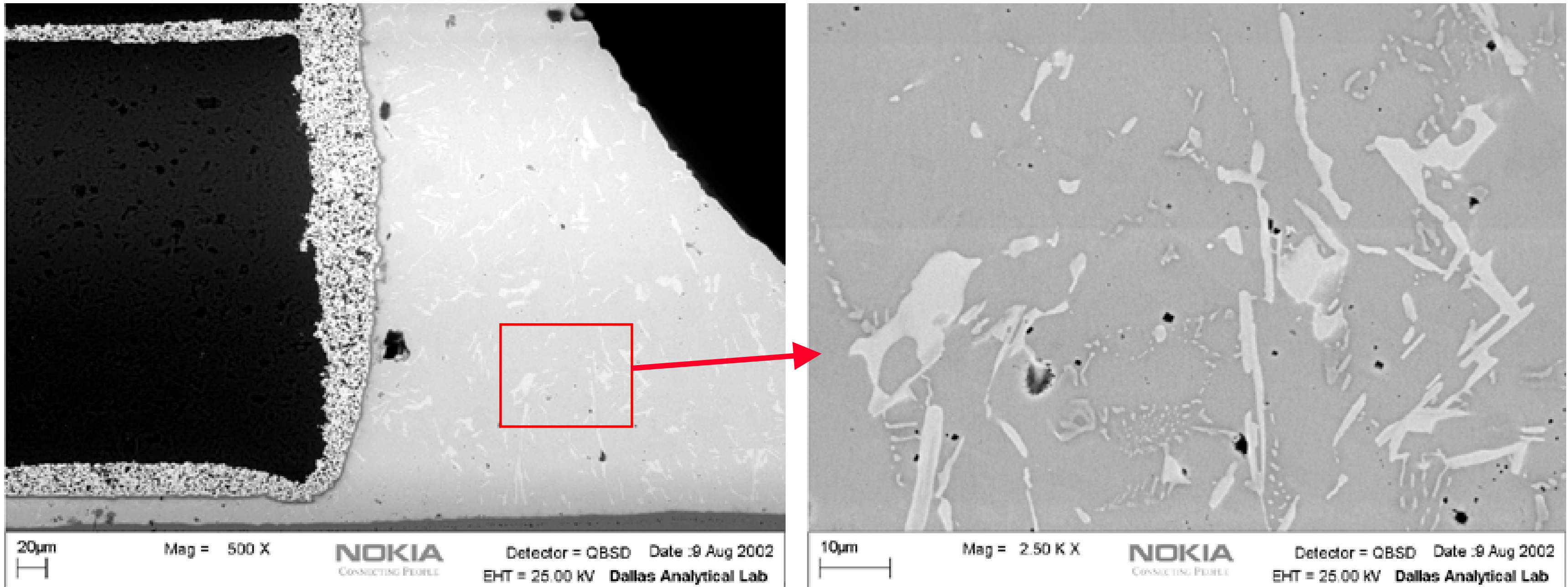
Phase identification



Sn-Ag-Cu-Sb solder joint with thick gold terminal finish

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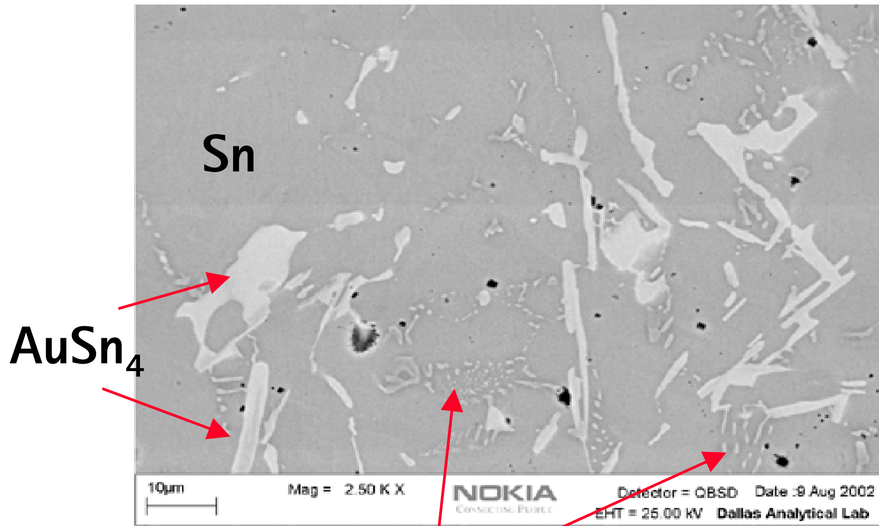
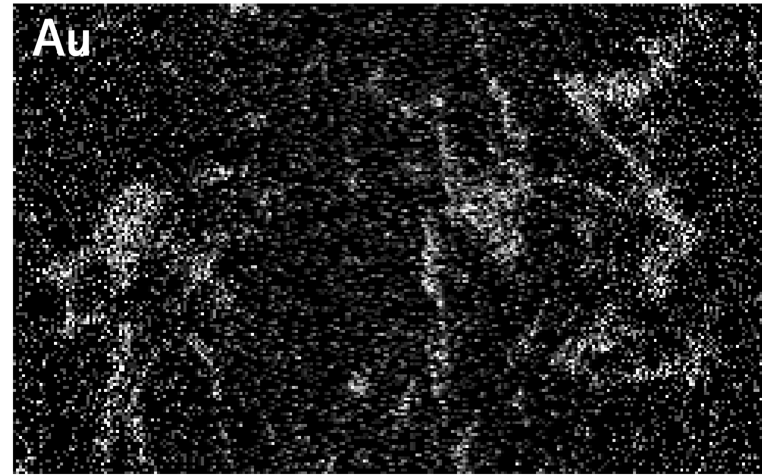
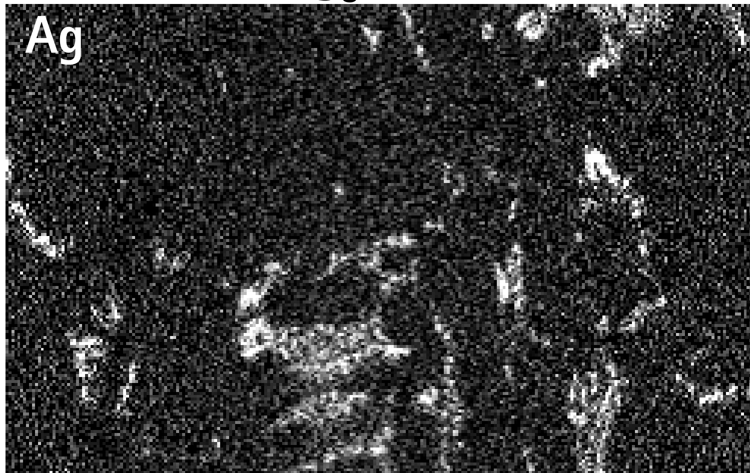
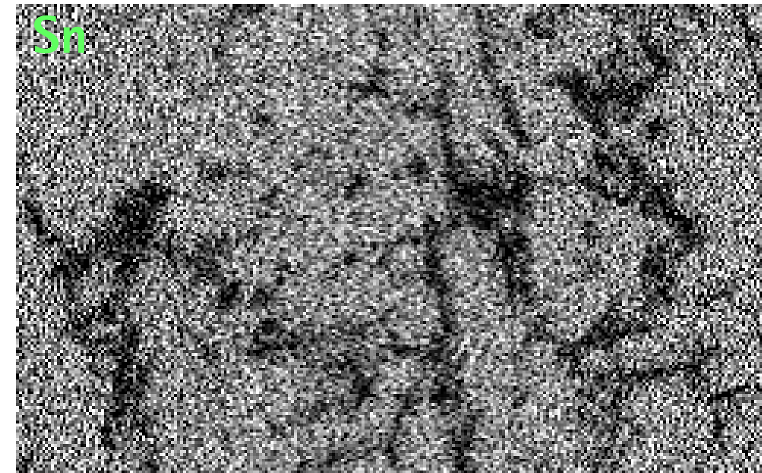
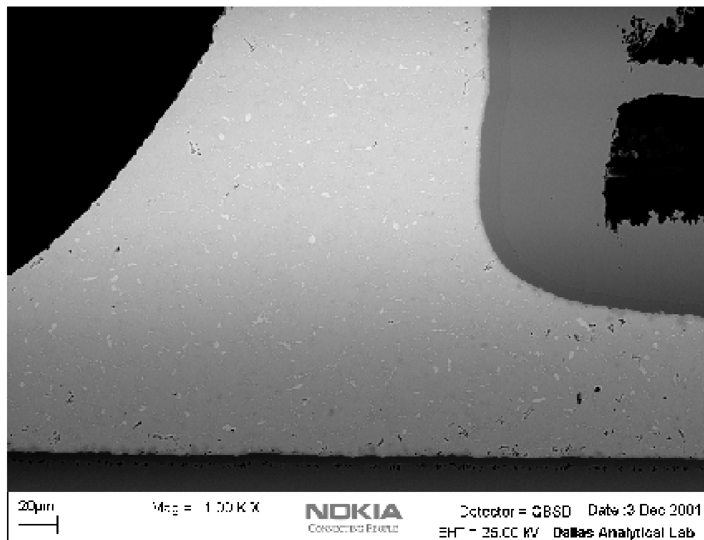

Sn
$AuSn_4$
Ag_3Sn
10µm
Mag = 2.50 K X
NOKIA
Detector = QBSD
Date :9 Aug 2002
EHT = 25.00 kV
Dallas Analytical Lab


Au
50µm

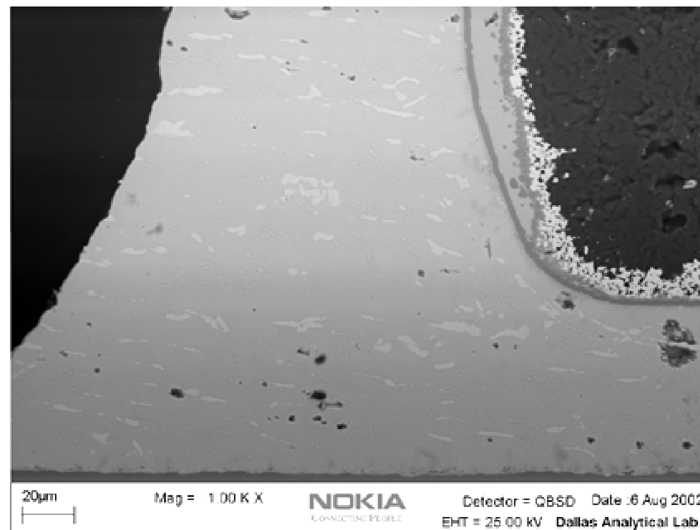

Ag
50µm


Sn
50µm

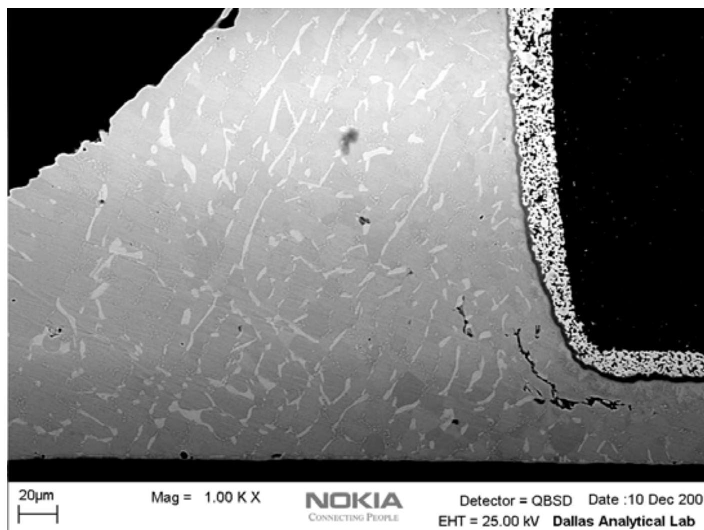
Au contents in Sn-Ag-Cu-Sb joint by EDX



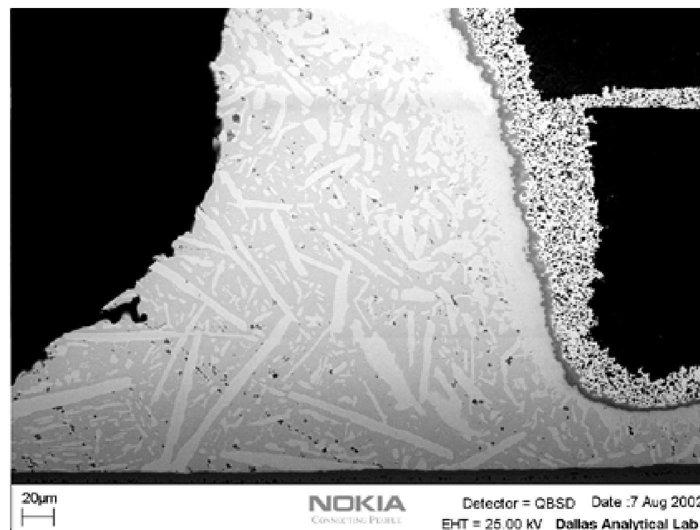
Flash gold, ~1.5wt.%



Medium gold ~ 3 wt. %



Thick gold, 5~7wt.%



Special case, 12~17wt.%

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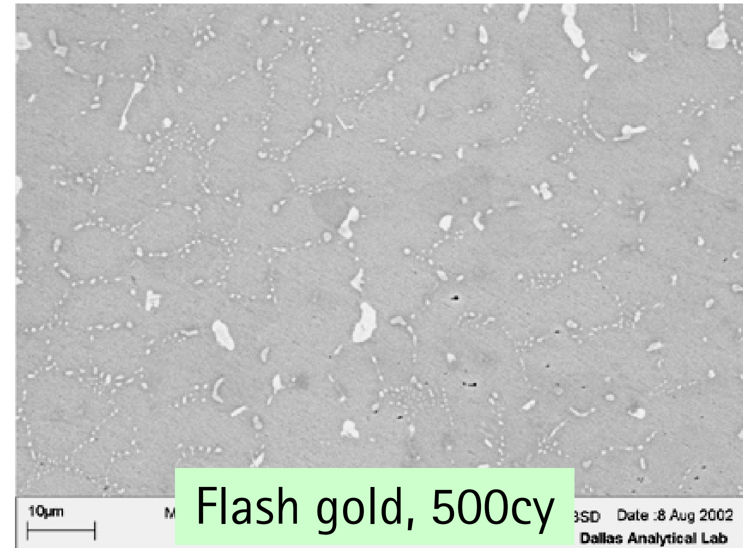
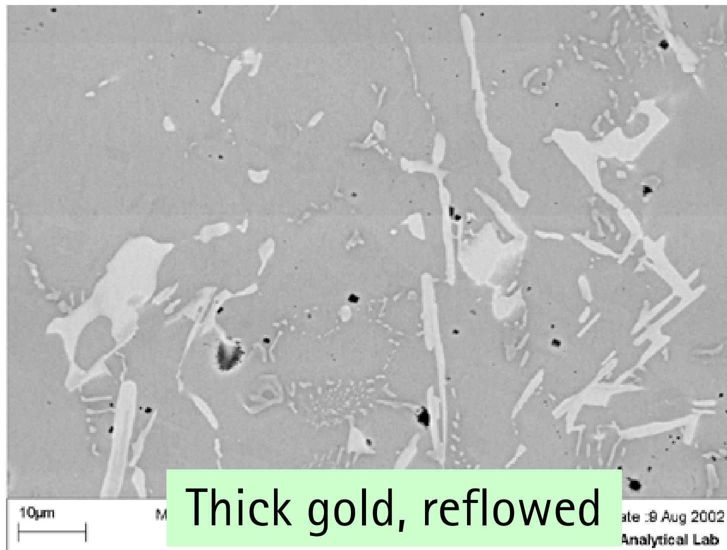
Microstructure change of Sn-Ag-Cu-Sb joint

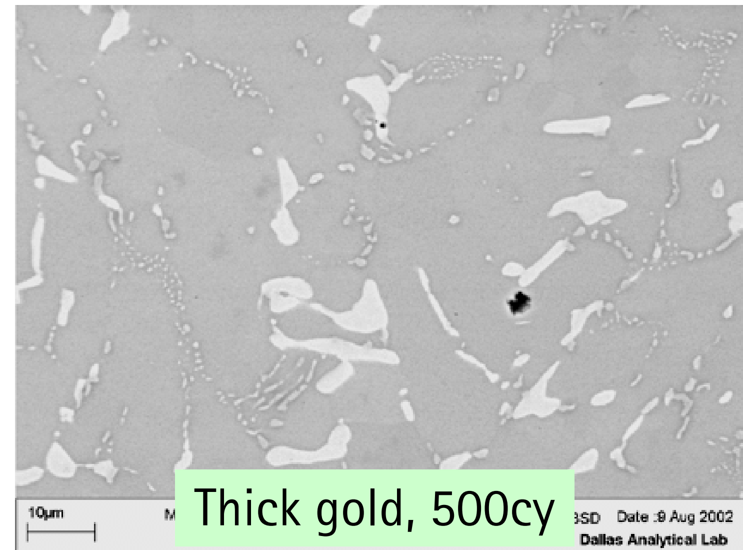
Flash gold, reflowed



Flash gold, 500cy



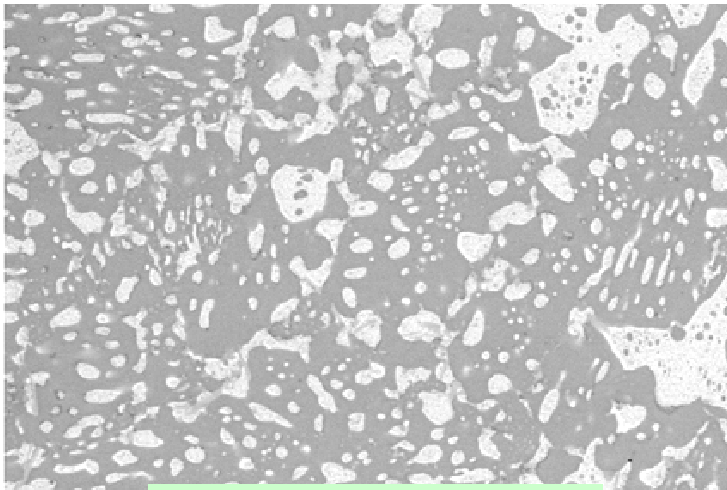
Thick gold, reflowed



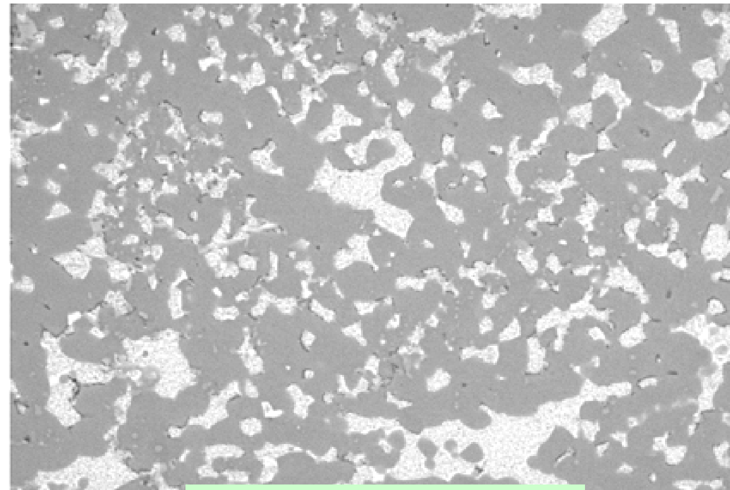
Thick gold, 500cy

No noticeable change in microstructure after thermal cycling

Microstructure change of Sn-Pb-Ag joint

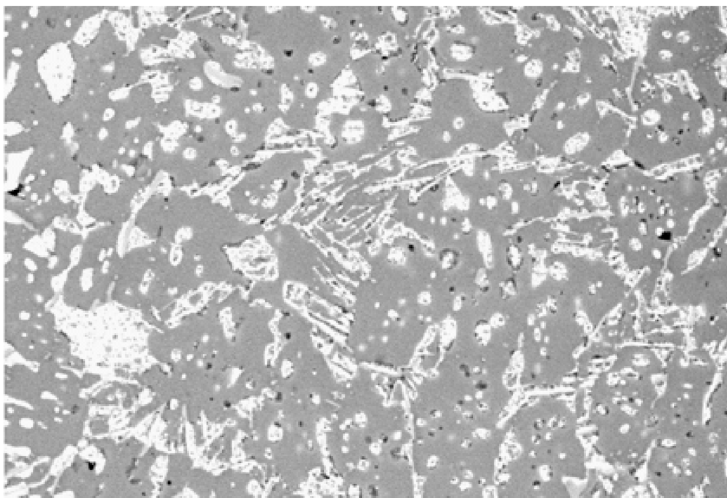


Flash gold, reflowed

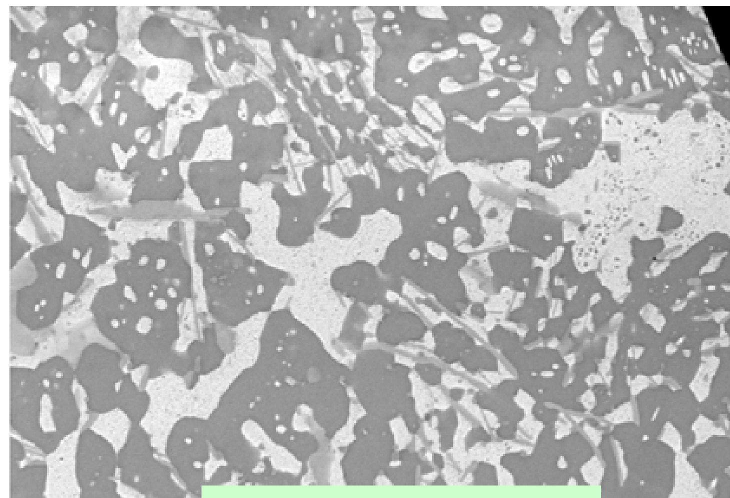


Flash gold, 500cy

Pb-rich phase becomes irregular



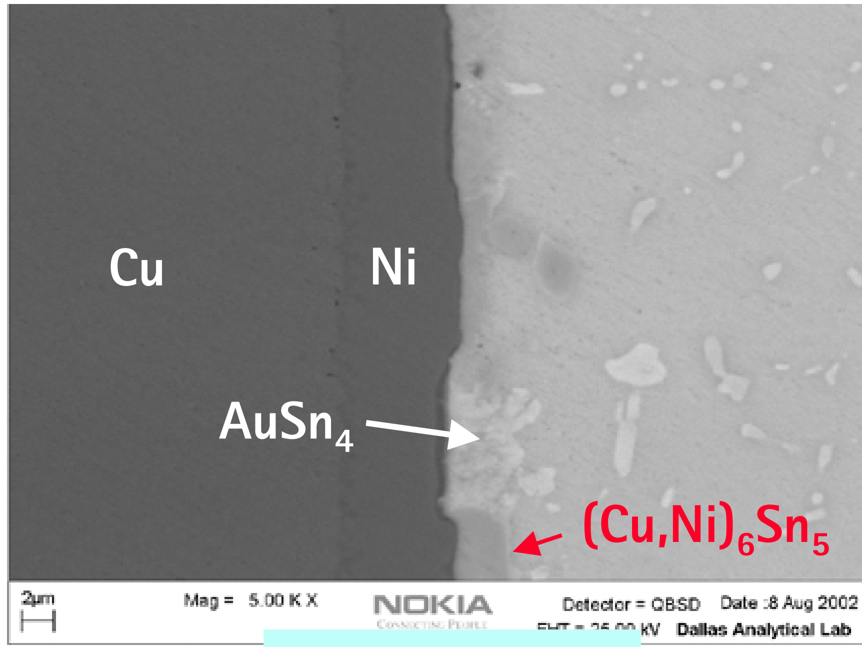
Thick gold, reflowed



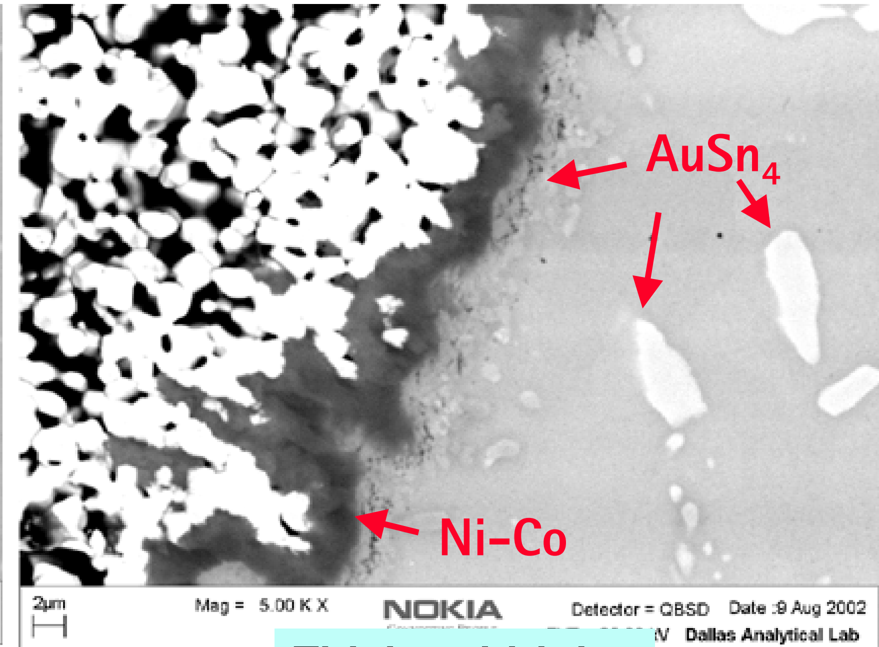
Thick gold, 500cy

Coarsened Au-needles & Pb-rich phase

Interface of Sn-Ag-Cu-Sb joint after 500 cycles



Flash gold joint



Thick gold joint

- $(Cu,Ni)_6Sn_5$ between Ni & solder

- Au, Ag, Cu & Ni mixed IMCs
- Micro-cracks at interface

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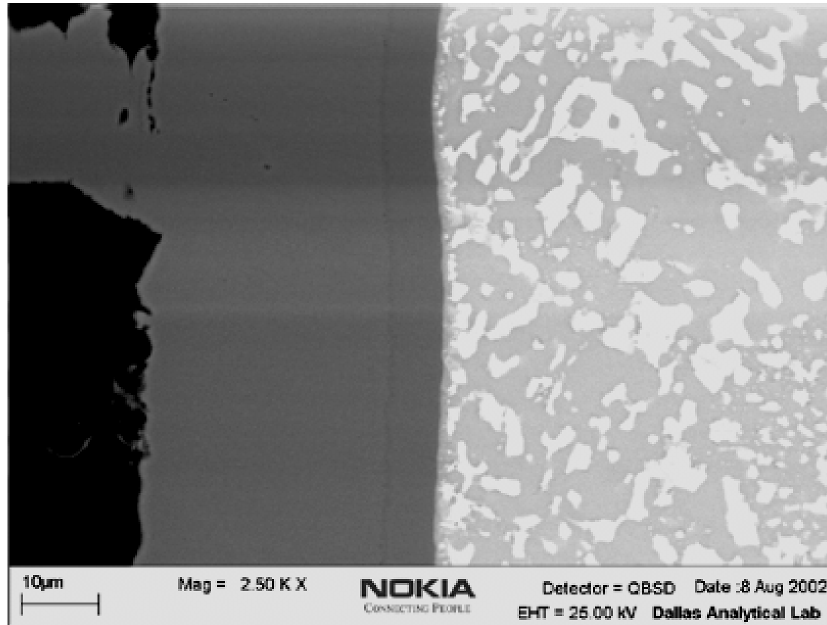
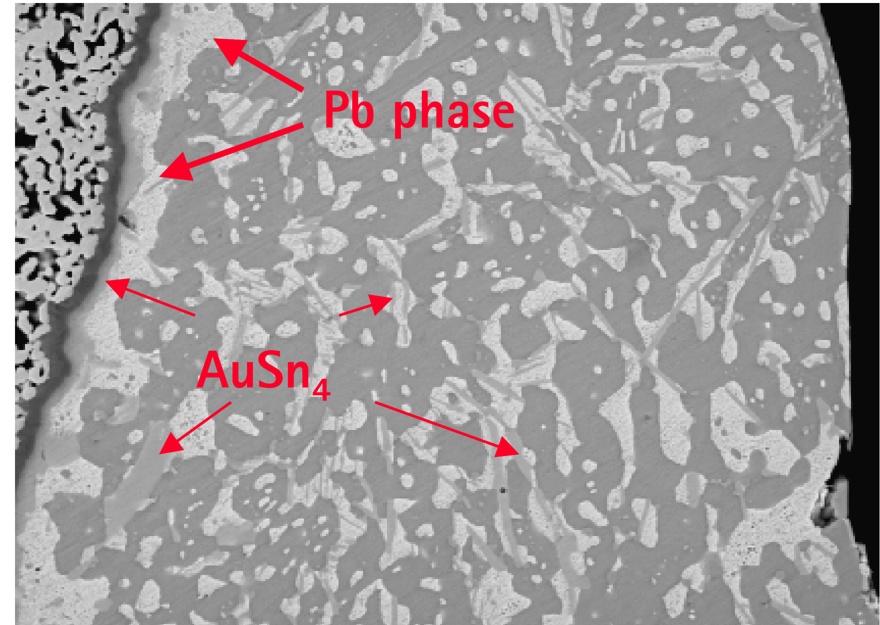
Interface of Sn-Pb-Ag joint after 500 cycles



Flash gold joint

- Ni_3Sn_4 at interface
- No Pb-rich phase at interface

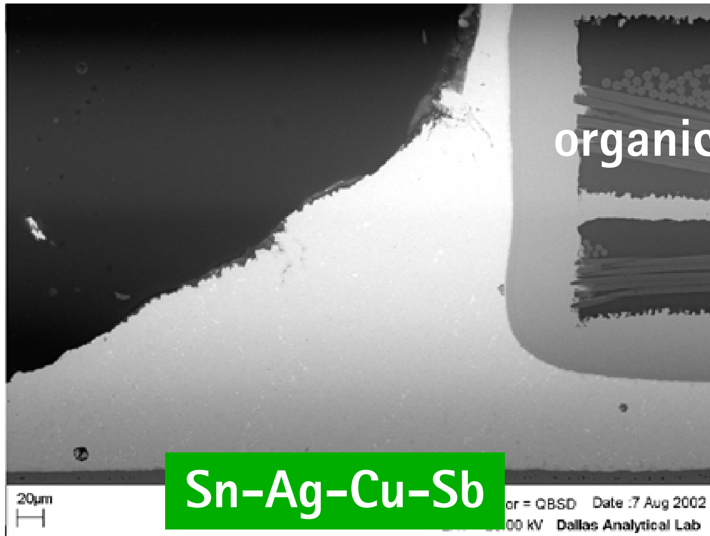


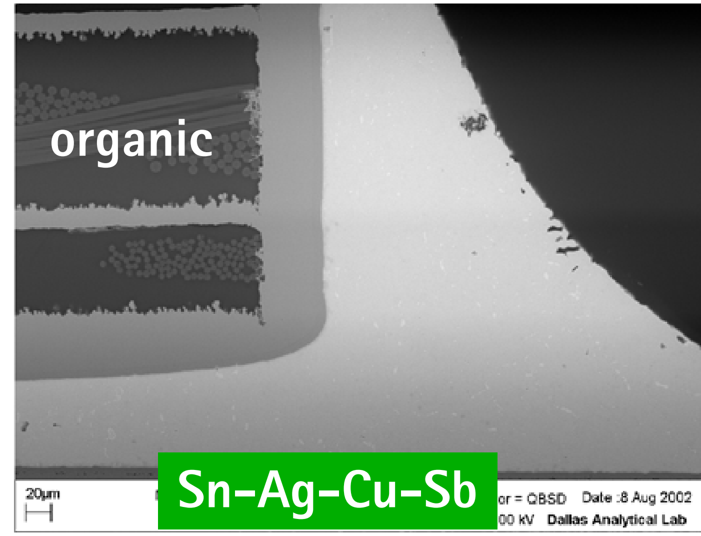
Thick gold joint

- Pb-rich layer at interface
- $AuSn_4$ layer at interface
- $AuSn_4$ needles throughout joint

Good joints: Flash gold finish & organic substrate

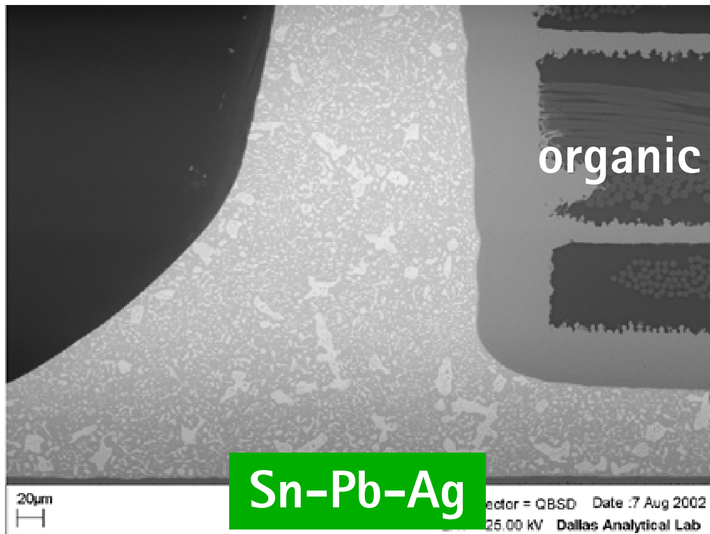
reflowed

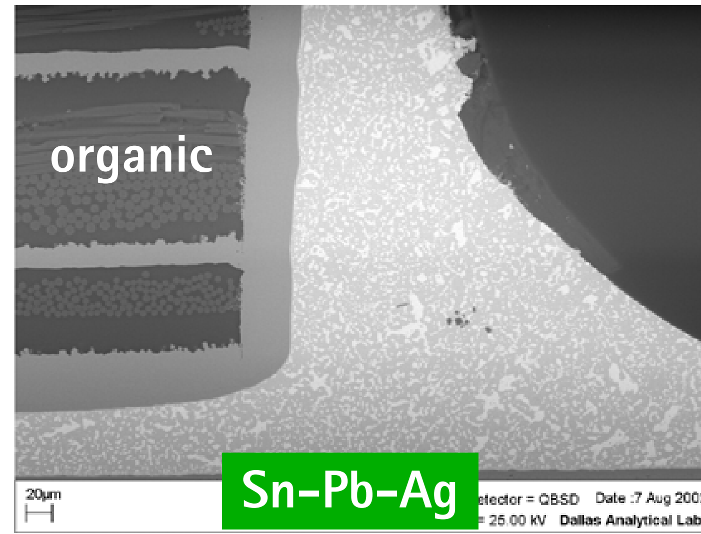




500cy

reflowed





500cy

Package size: 5.6x5.6x1.6mm

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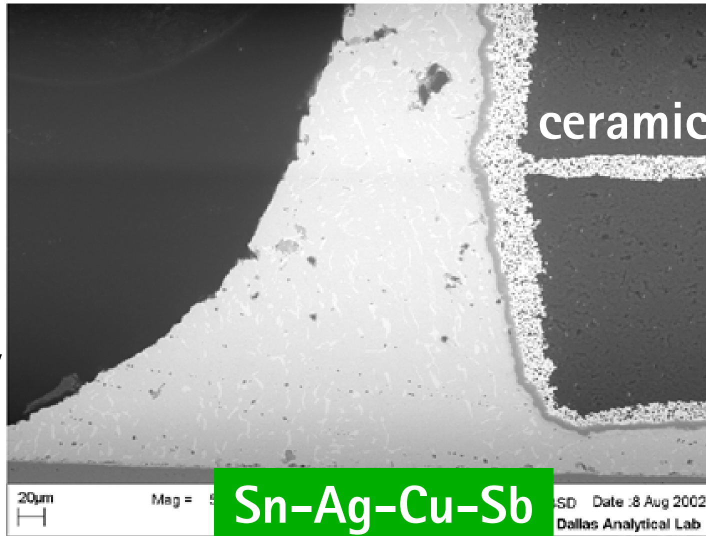
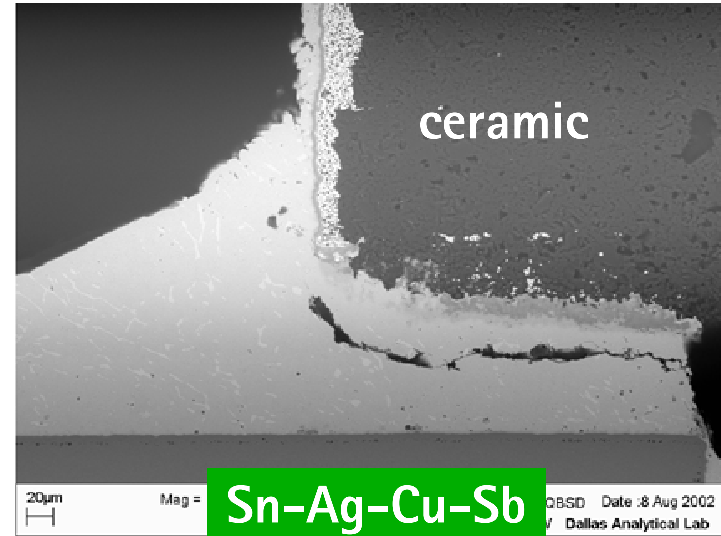
Bad joints: Thick gold finish & ceramic substrate

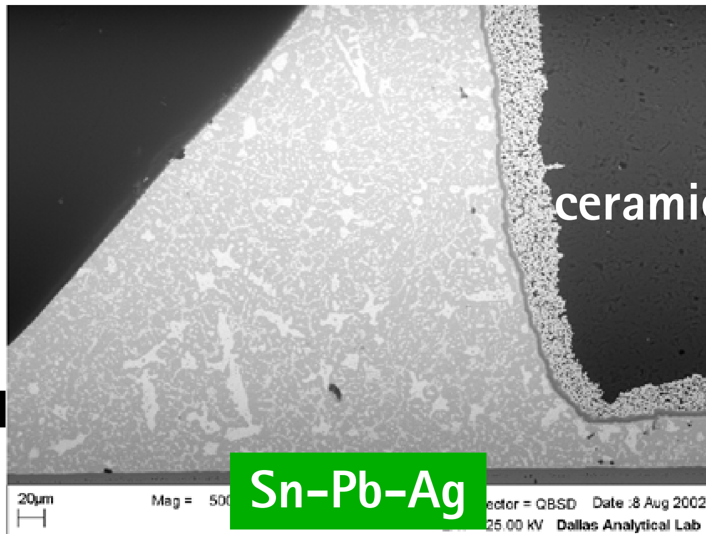
200cy



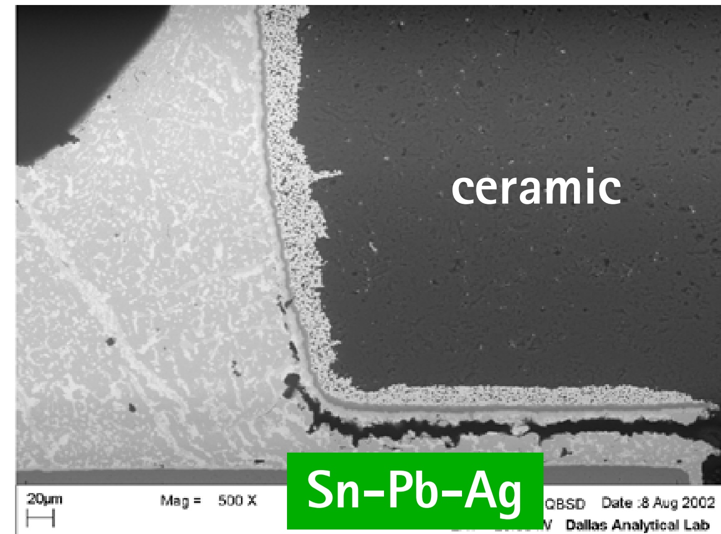
500cy



reflowed



500cy



Package size, 3.1x3.1x1.2mm

Medium Au joints are similar to thick Au joints

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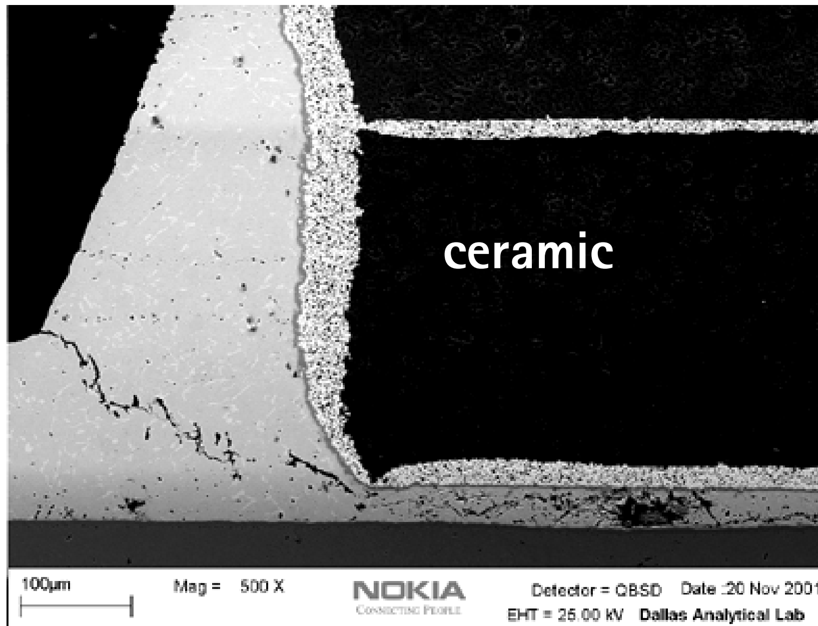
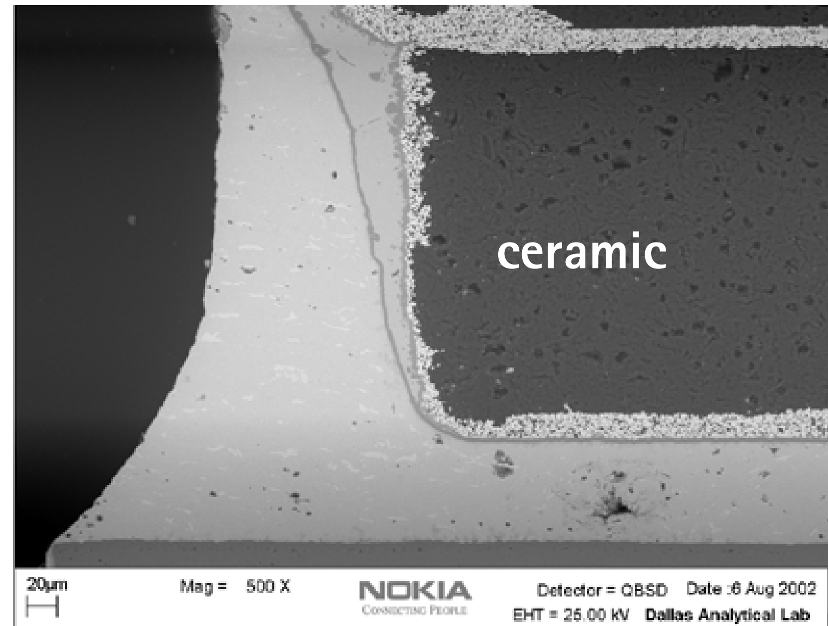
Effect of package size



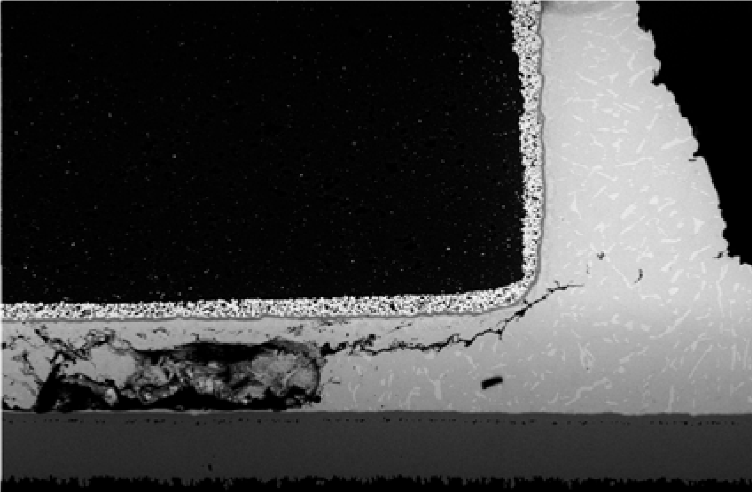
9.5x7.5x2mm, 200 cycles
Sn-Ag-Cu-Sb



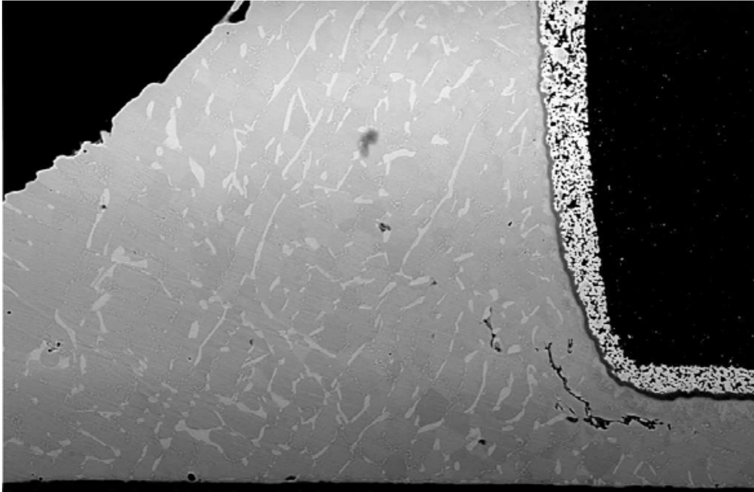
3.1x3.1x1.2mm, 200 cycles
Sn-Ag-Cu-Sb

- The joint stress is higher in larger pacakges.
- Sn-Pb-Ag presents the same situation as Sn-Ag-Cu-Sb.

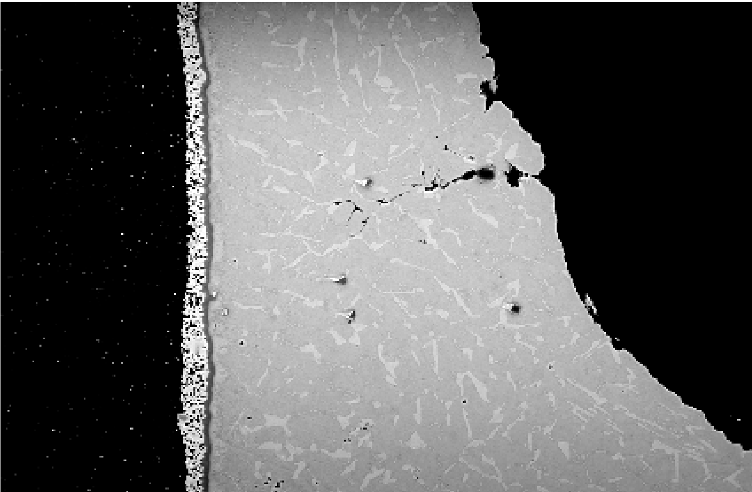
Crack generation



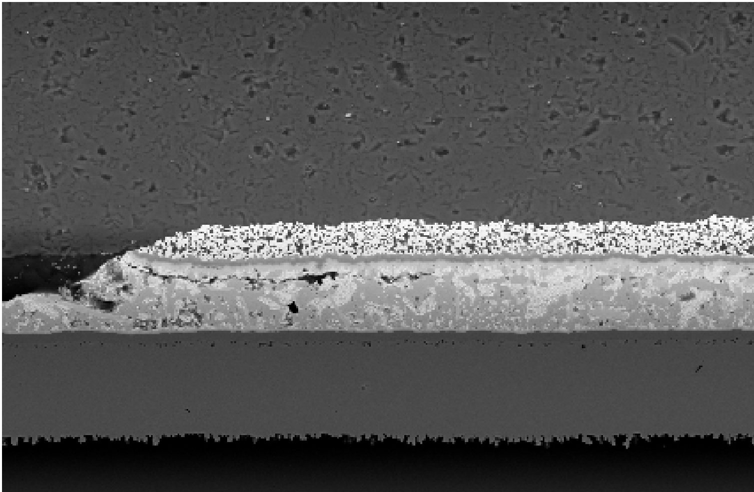
Void in solder gap



Component corner



Rough fillet surface



Joint tip

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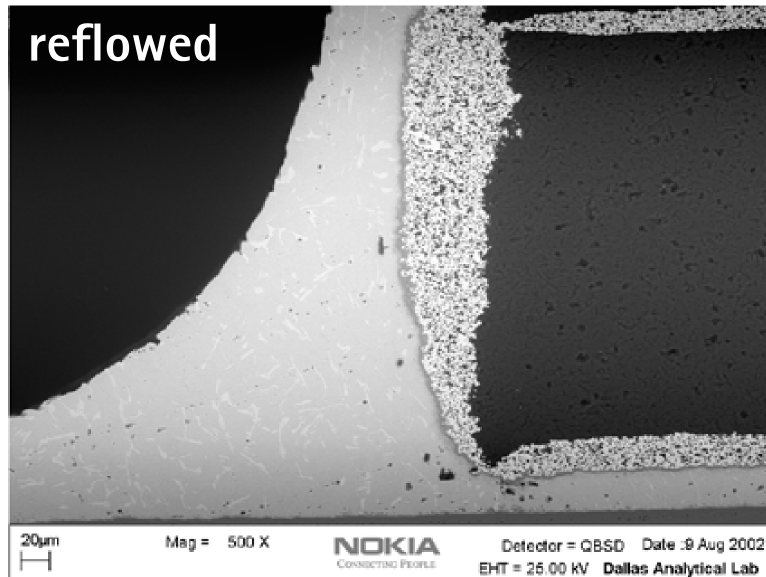
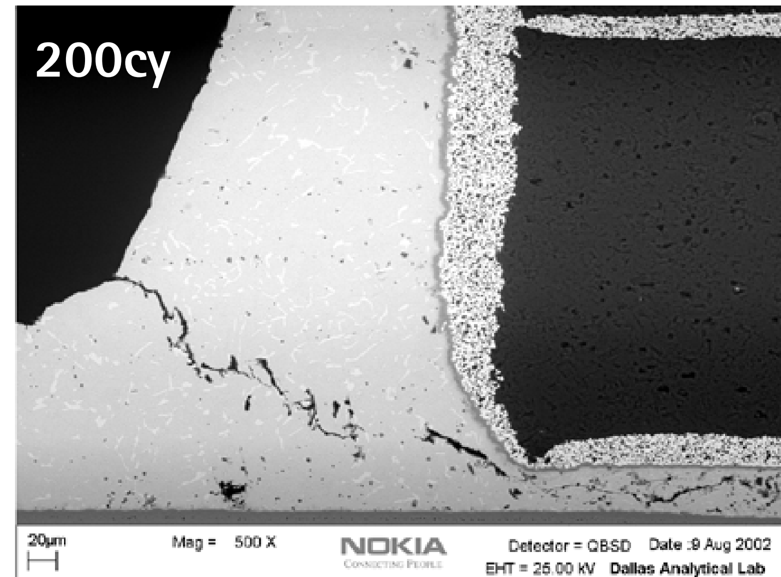
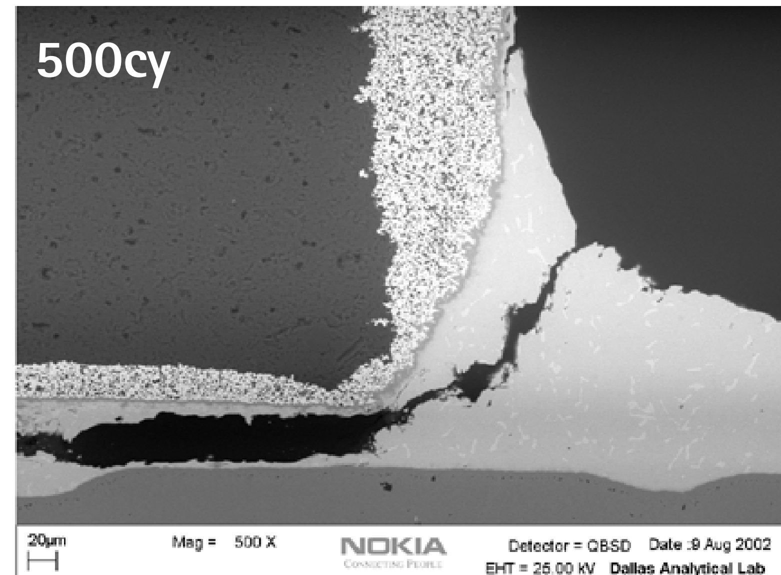
Crack development

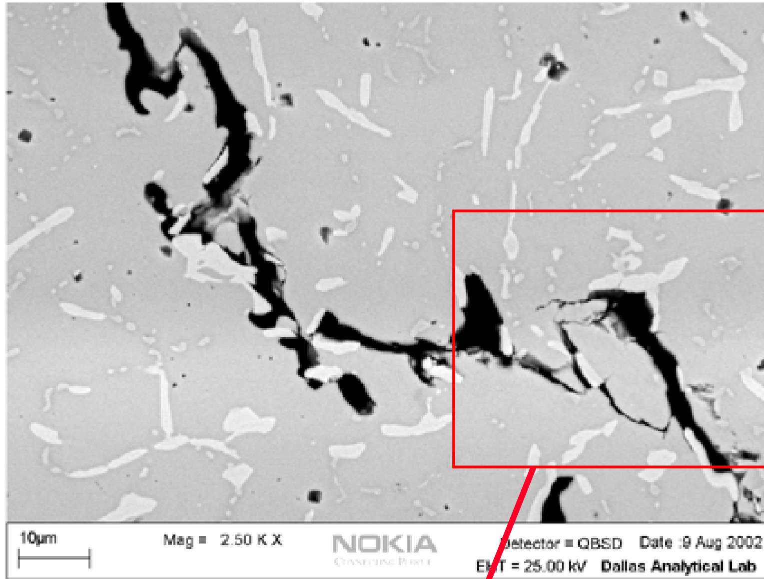


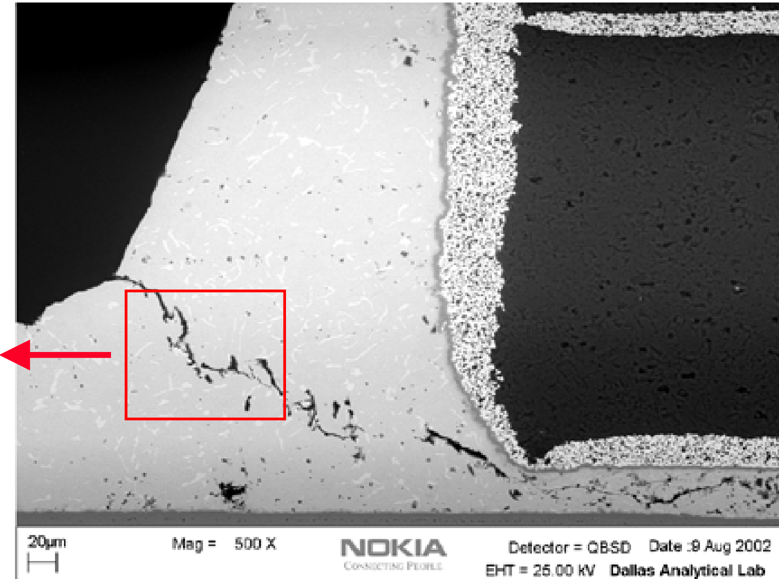


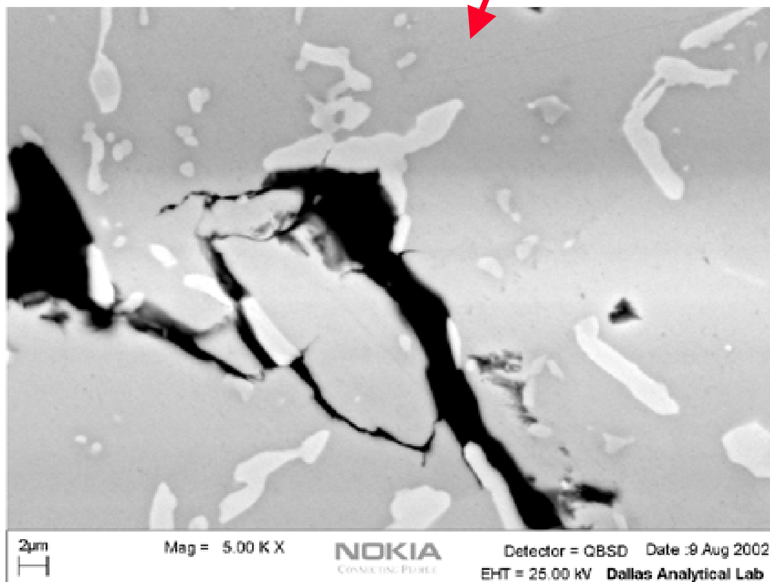
- Sn-Ag-Cu-Sb solder joints
- Package size: 9.5x7.5x2mm



Crack development







- Sn-Ag-Cu-Sb solder joint
- Cracks originate at void in gap area
- Easier crack propagation along IMC boundary

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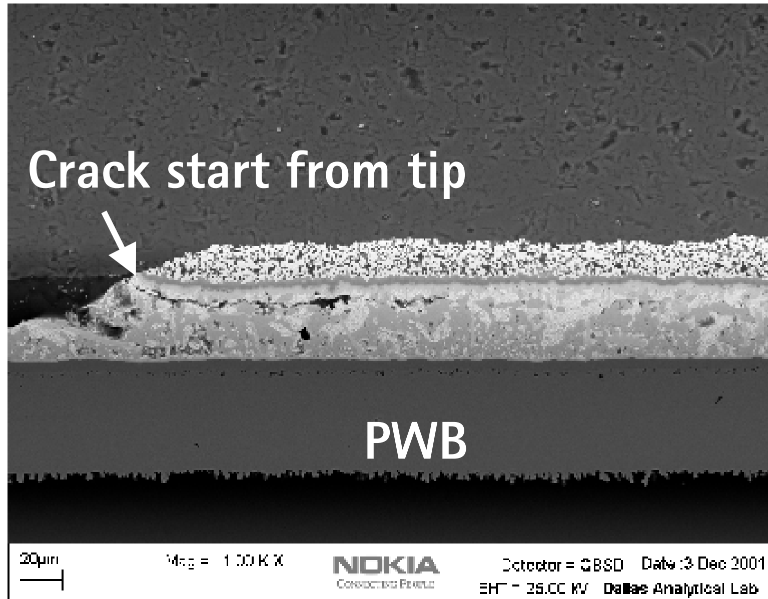
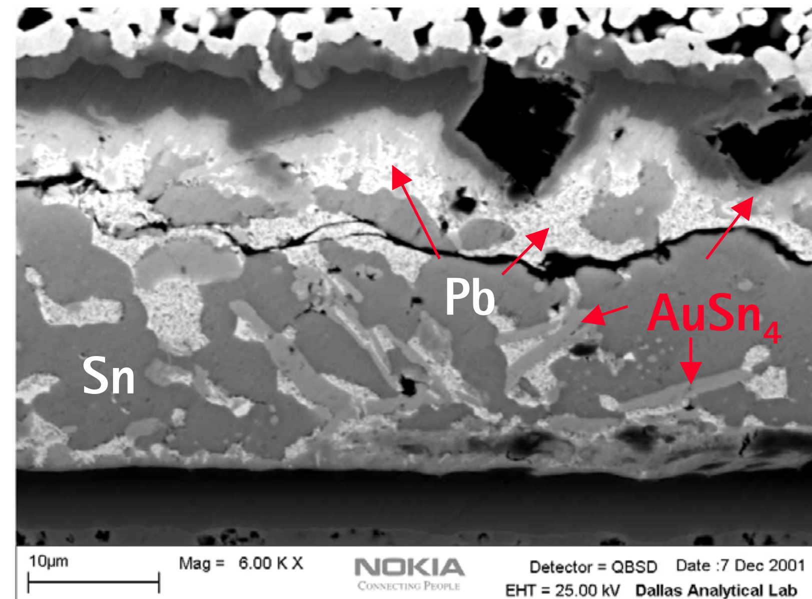
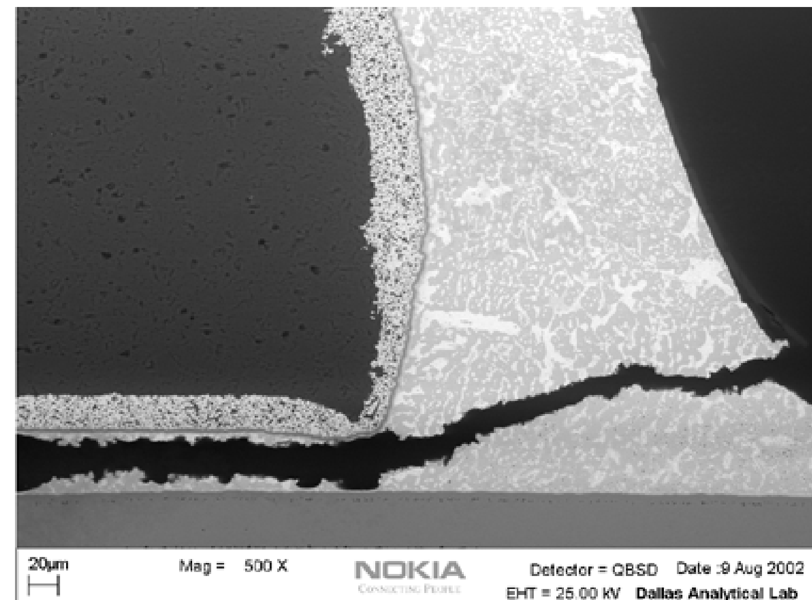
Crack development

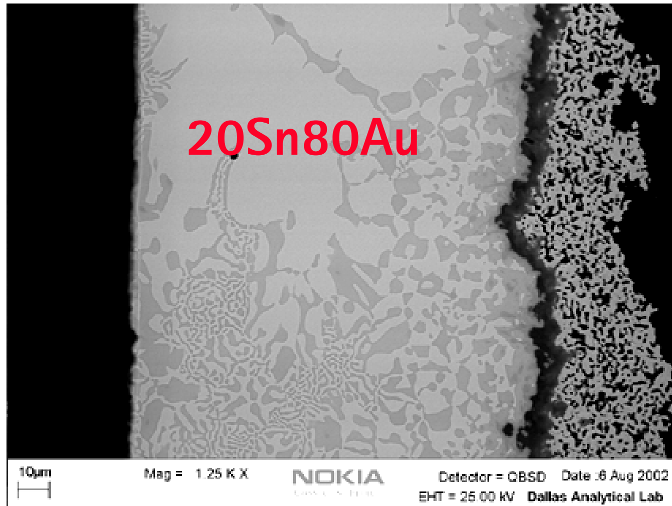


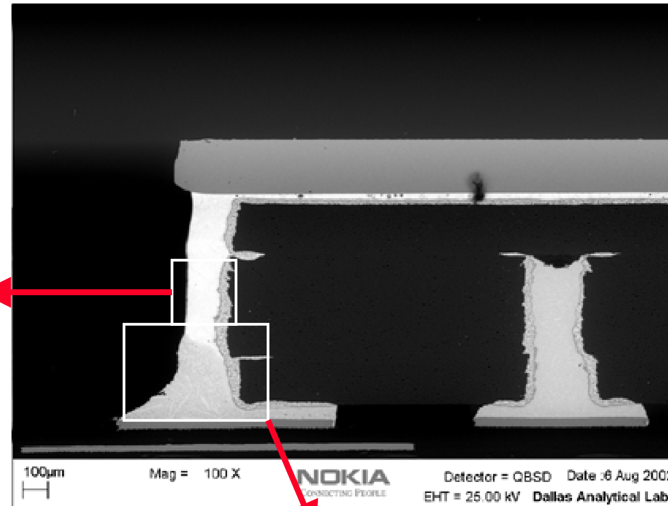


- Sn-Pb-Ag solder joint
- Cracks start from tip
- Propagated along Pb/Sn interface or in Pb-rich phase
- Cracked joint smoother than Sn-Ag-Cu-Sb joint
- Role of Pb-rich phase



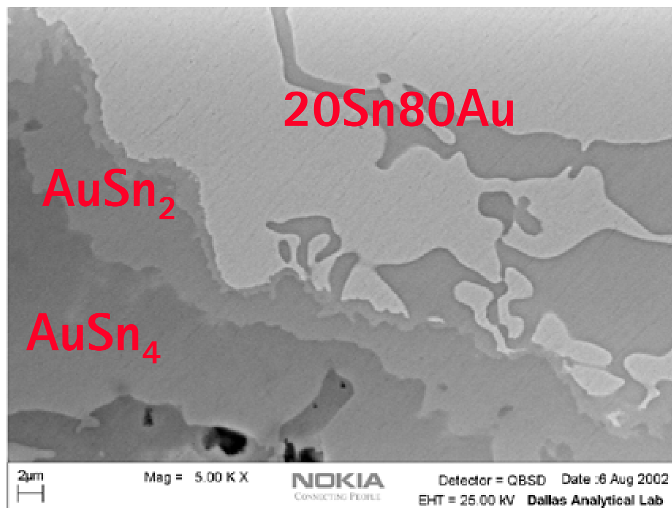
High Au content may be tolerated

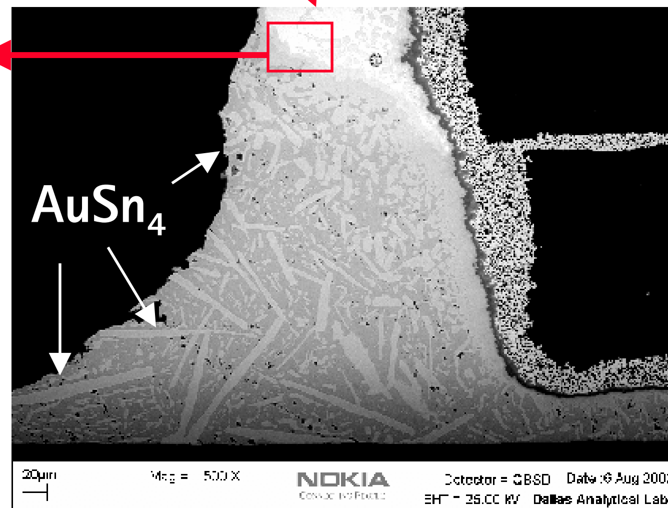


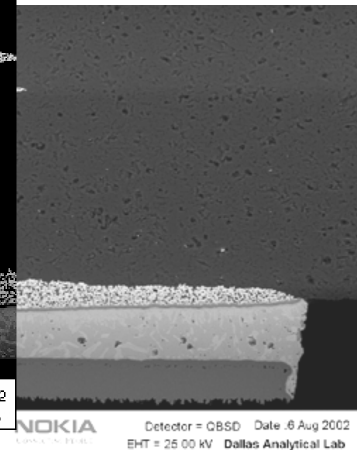


SMALL PACKAGE
3.0x3.0x1.2mm

12~17wt.% Au







Sn-Ag-Cu-Sb solder joint after 500 cycles

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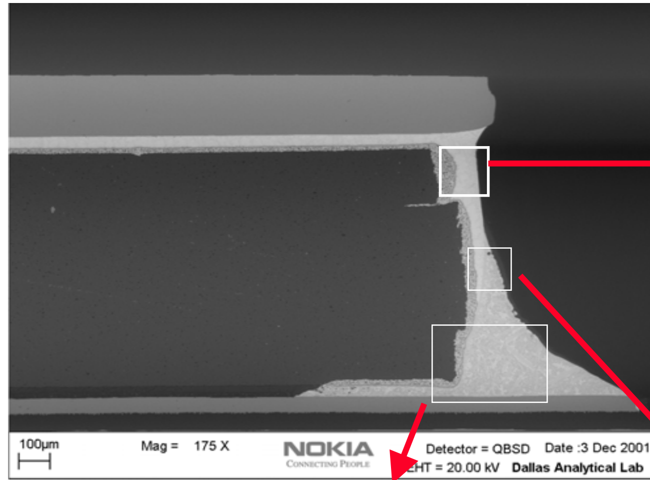
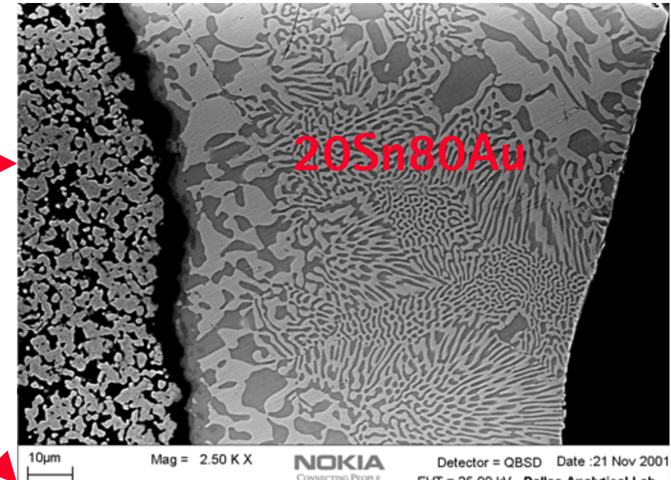
High Au content may be tolerated

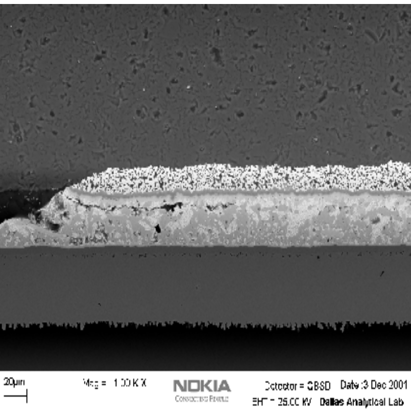
No solder joint cracks

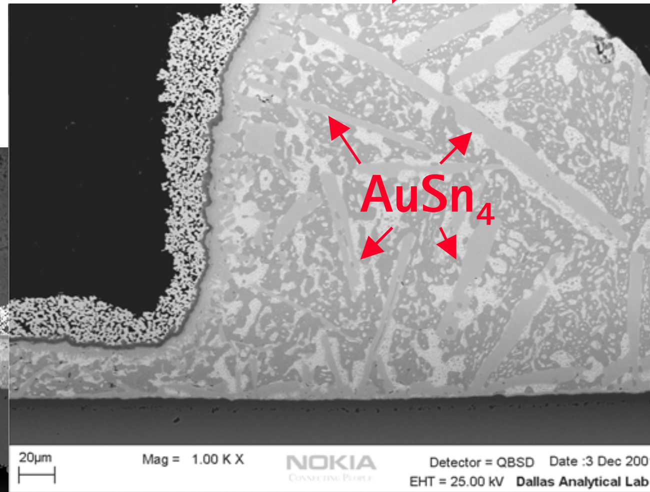
SMALL PACKAGE
3.0x3.0x1.2mm

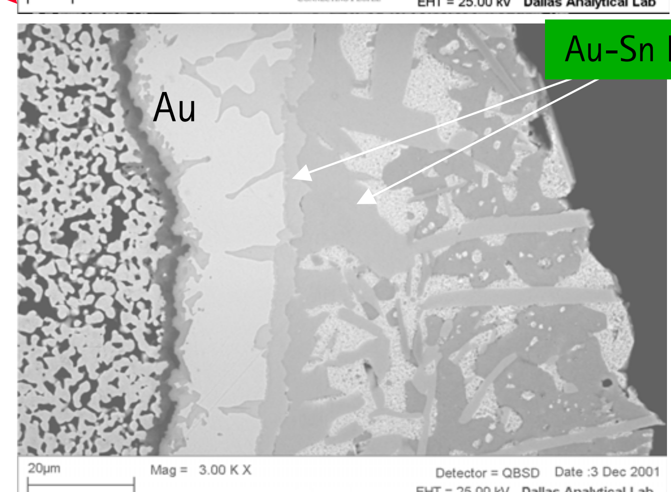
12~17wt.% Au





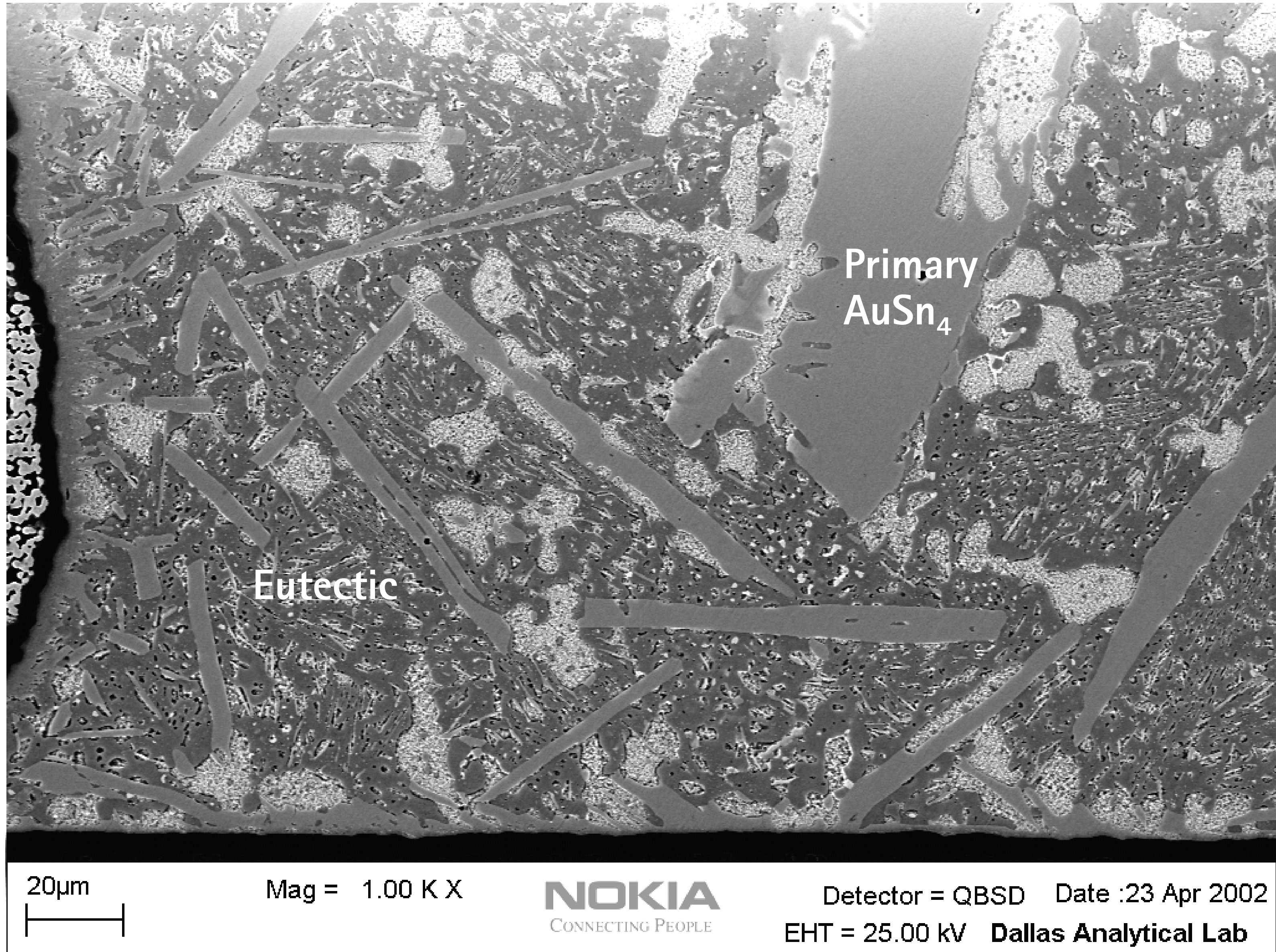




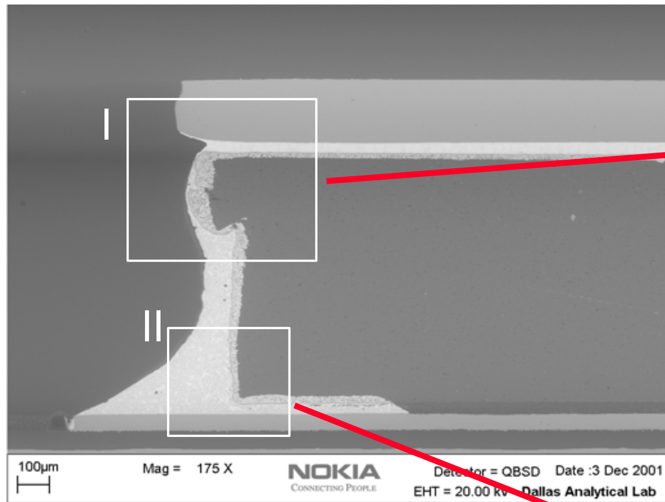


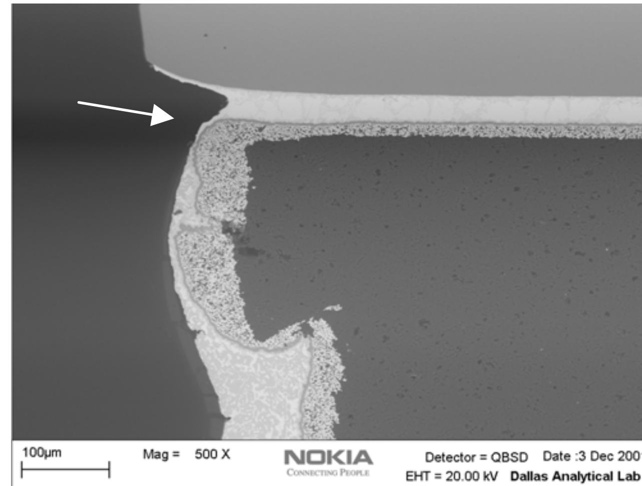
Sn-Pb-Ag solder joint after 500 cycles

Au-Sn-Pb microstructure

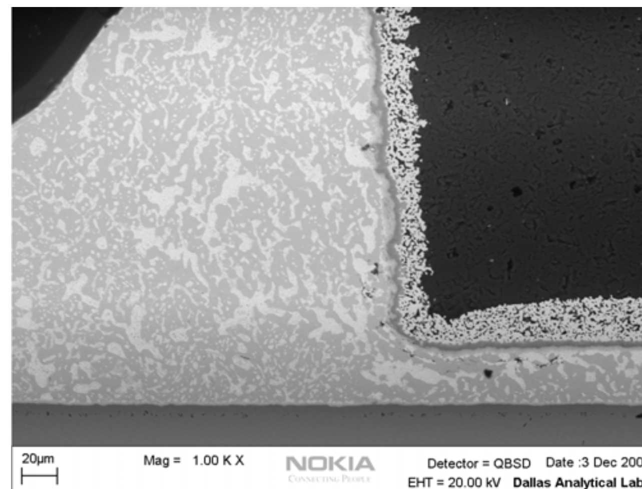


High Au can be prevented





20Sn80Au
Confined well



No big $AuSn_4$ in Sn-Pb-Ag joint

Sn-Au solder is confined in component joint as indicated by the white arrow.

Sn-Pb-Ag solder joint after 500 cycles

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Conclusions

- Microstructure of Sn-Ag-Cu-Sb solder joint is more stable than that Sn-Pb-Ag joint in the temperature range studied. (p13-16)
- Presence of Au affects voiding because of Au-Sn IMC formation.
  - ✓ Thick gold finish results in irregular voids (p7)
  - ✓ Flash gold finish results in spherical voids (p7)
  - ✓ Sn-Ag-Cu solder joint has more, bigger & irregular voids (p8)
- High Au content may be tolerated both in Sn-Ag-Cu-Sb and Sn-Pb-Ag solder joints in specific instances, but further study is needed. (p24-26)
- Combination of gold content and CTE is the main reason for the failures observed, package size plays an important role. (p17-20)
- Flash gold is recommended for all applications. (p17 -20)
- Failure mechanism of Sn-Ag-Cu-Sb solder joint is different from that of Sn-Pb-Ag solder joint. (p21-23)
- Sn-Ag-Cu-Sb solder provides better performance than Sn-Pb-Ag solder

Acknowledgements

- Ted Carper for helpful discussions
- Sridhar Canumalla and Sesil Mathew for analysis support

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