

The Morphology Evolution and Voiding of Solder Joints on QFN Central Pads with a Ni/Au Finish

Julie Silk¹, Jianbiao Pan², Mike Powers¹

¹Agilent Technologies, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403

²California Polytechnic State University, San Luis Obispo, CA 93407

Abstract

In this paper, we report on a comprehensive study regarding the morphology evolution and voiding of SnAgCu solder joints on the central pad of two different packages – QFN and an Agilent package called TOPS – on PCBs with a Ni/Au surface finish. Samples were isothermally aged at the equivalent of 0, 2, 7 and 14 years service life. Representative solder joints were cross-sectioned and analyzed using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) in order to investigate the evolution of the solder joint morphology as a function of Au content and isothermal aging. IMC thickness was measured. The effect of Au content on the void percentage was studied as well. The results show that if copper is available to dissolve into the solder joint, the AuSn₄ IMC from the bulk does not migrate to the interface as a result of thermal aging. The IMC thickness grew with aging as expected, however with Cu base metallization the IMC was dominated by Cu₆Sn₅, and with Ni base metallization on both sides of the joint the IMC was dominated by AuSn₄. Voiding analysis showed that thick Au metallization on thermal pads leads to more voiding and larger standoff height.

Introduction

The Quad Flat No-lead (QFN) package is increasingly popular due to its small size, easy trace routing, and good thermal and electrical performance [1]. It has a large central underbelly pad, which dissipates heat from the die inside the package through a solder connection to the printed circuit board (PCB). The short standoff distance between the QFN package and the PCB also reduces inductance thus providing excellent electrical performance. An Agilent package called TOPS has features similar to a QFN, being leadless with a large underbelly pad.

Although the QFN package and the TOPS packages offer a number of benefits, to the authors' knowledge, the evolution of morphology of the solder joint on the central underbelly pad has not been reported. In this paper, we report on a comprehensive study regarding the effect of Au content on the morphology of SnAgCu solder joints on the underbelly pad, assembled on PCBs with a Ni/Au surface finish. Samples were isothermally aged at the equivalent of 0, 2, 7 and 14 years service life. Representative solder joints were cross-sectioned and analyzed using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) in order to investigate the evolution of the solder joint morphology as a function of Au content and isothermal aging.

Another issue with these leadless packages with a large underbelly pad is that excessive voiding often occurs in the solder joint on the underbelly pad. If the void area is large, thermal performance will be reduced. There are a few application notes that provide guidelines for pad pattern design, stencil design, reflow profile, and others [2-6]. To the authors' knowledge, no paper has been published on the effect of Au content on the voiding. In this paper, the effect of Au content on voiding in the underbelly solder joint is reported.

Experiment

Component, Test Vehicle, and Assembly Process

The test vehicle is shown in Figure 1. The board finish is electrolytic Au over Ni. There are two different Au thicknesses: a flash Au finish with 0.08 ~ 0.38 μm Au over 5 μm Ni and a thick Au finish with 2 ~ 2.54 μm Au over 5 μm Ni. Two types of leadless packages, QFNs and TOPS, were assembled on the test vehicle. Figure 2 shows these packages. The QFNs were two different sizes: QFN5 is 5 mm x 5 mm and QFN6 is 6 mm x 6 mm. The size of the TOPS package is 10 mm x 10 mm. The pad finish on the QFN5 and QFN6 is matte Sn over Cu and that on the TOPS is electrolytic Au over Ni.

The assembly process was done using a standard surface mount assembly line in a realistic production environment. The solder paste used is Sn3.0Ag0.5Cu (SAC305) Type 3 with no-clean flux and metal content of 88% by weight. The stencil used is electroformed Nickel, laser cut with a foil thickness of 0.1 mm (4 mils). The solder paste coverage of the central pad for QFN5 and QFN6 is 43% and that for TOPS is 56%. Since the volume of solder paste on the central pad was not measured, the nominal solder paste volume is calculated based on the stencil aperture size and the coverage. The calculated nominal Au content of solder joint on the central pad for QFN5, QFN6, and TOPS package is shown in Table 1. For details about the reflow profile and Au content calculation, please refer to papers published by the authors [7-9].

The assembled PCBs were randomly divided into three groups. The boards in Group 1 were not subjected to thermal aging. The boards in Group 2 were subjected to isothermal aging at 125°C for 30 days. The boards in Group 3 were subjected to isothermal aging at 125°C for 56 days. The three thermal aging times represent 0, 7.8 and 14.6 years of service when the device is operated at 60°C. Activation energy of 0.8 eV is used. One flash Au board and one thick Au board from each group were randomly selected for cross-sectioning and SEM/EDX analysis. An additional thick Au board was aged at 125°C for 209 hours, or 2.25 years of service when the device is operated at 60°C. Aging at 125°C for 209 hours is equivalent to 1000 hours at 100°C. The SEM used in this study was a JEOL JSM-6390 equipped with a Thermo Scientific 6733A EDX.

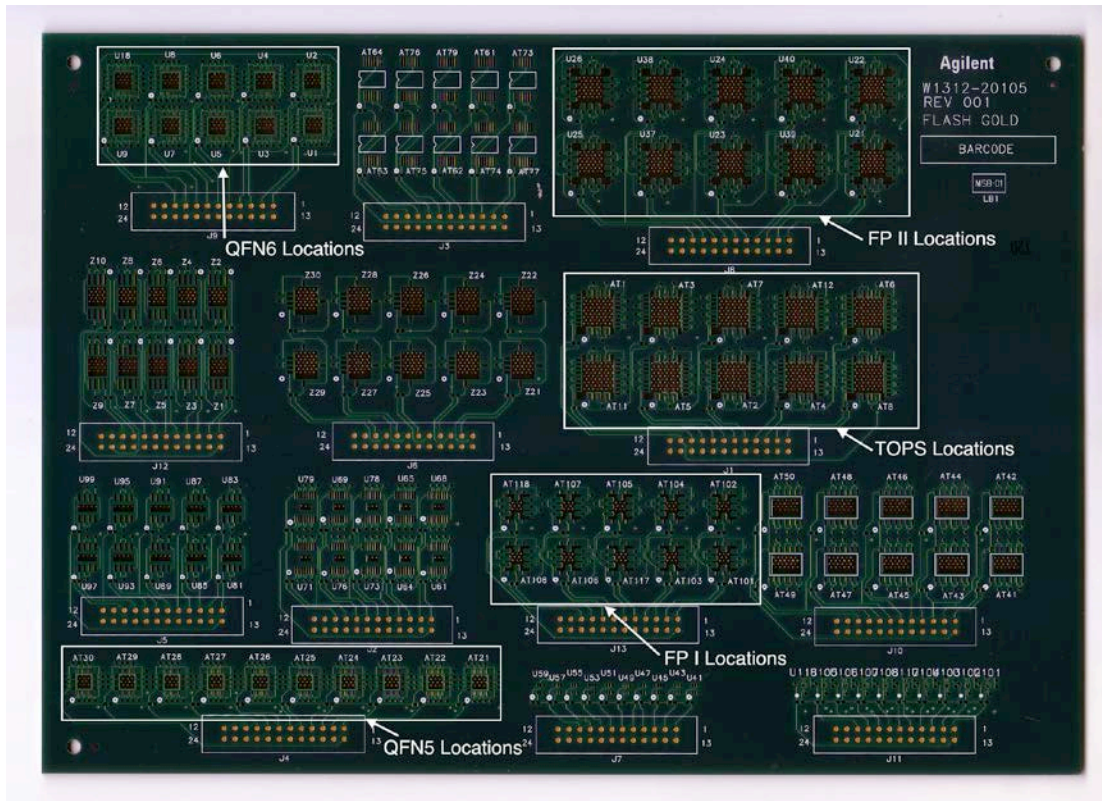
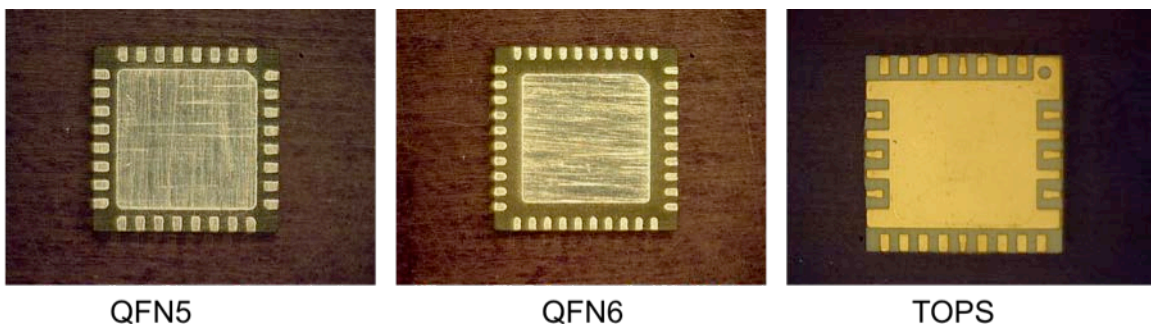


Figure 1. Test Vehicle



QFN5

QFN6

TOPS

Figure 2. Packaged QFN Components

Table 1. Nominal Au Content in Weight Percentage in Solder Joints on Central Pad

	Flash Au	Thick Au
QFN5 or QFN6	1.2%	10.9%
TOPS	4.1%	11.2%

Results and Discussion

Evolution of Solder Joint Morphology

The evolution of the microstructure for both QFN and TOPS solder joints on the underbelly central pad was evaluated. The substrate finish on the QFN package does not have a Ni diffusion barrier and the TOPS package includes a Ni barrier layer in the substrate finish. In both part types, the solder joint microstructure is compared as a function of isothermal aging times and relative Au content in the solder joints.

QFN and TOPS on Flash Au Board

The SEM micrograph of two as-built solder joints between the central pad of a component and a board with a flash Au finish is shown in Figure 3. The Au content in the QFN solder joint is about 1.2% by weight and the Au content in the TOPS solder joint is about 4.1%. The interfacial intermetallic compound (IMC) on the component side of the QFN solder joint is Cu_6Sn_5 while that of the TOPS solder joint is $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$. This is because the finish of the QFN package does not have a Ni diffusion barrier layer and allows Cu to diffuse into the joint. The TOPS package has a Ni layer. The interfacial IMC on the board side of the QFN joint is $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$ or $(\text{Cu}, \text{Ni}, \text{Au})_6\text{Sn}_5$ while there are two different IMC layers that can be seen in the board side of the TOPS joint: $(\text{Au}, \text{Ni})\text{Sn}_4$ over $(\text{Ni}, \text{Au})_3\text{Sn}_4$ layer. The IMC in the bulk solder of the QFN joint is pebble-like $(\text{Cu}, \text{Au})_6\text{Sn}_5$ while that of the TOPS joint is needle-like AuSn_4 .

Figure 4 shows the SEM micrograph of two aged solder joints between the central pad of a component and a board with a flash Au finish. The joints were aged at 125°C for 30 days. For the QFN joint, there is no significant difference in the IMCs and microstructures between the aged sample and the as-built sample except that $(\text{Cu}, \text{Au})_6\text{Sn}_5$ in the bulk solder coalesces to larger sizes. The driving force for this coarsening behavior is the energy reduction associated with a lower surface area to volume ratio. In the TOPS joints, needle-like AuSn_4 IMCs in the bulk solder of the as-built sample changed to stone-like AuSn_4 IMCs after aging. Some AuSn_4 IMCs in the bulk solder migrated with aging to form a continuous $(\text{Au}, \text{Ni})\text{Sn}_4$ layer next to the $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$ IMC at the interface. In the QFN joints, there is not a continuous layer of detrimental $(\text{Au}, \text{Ni})\text{Sn}_4$ IMC in the interface on the flash Au board.

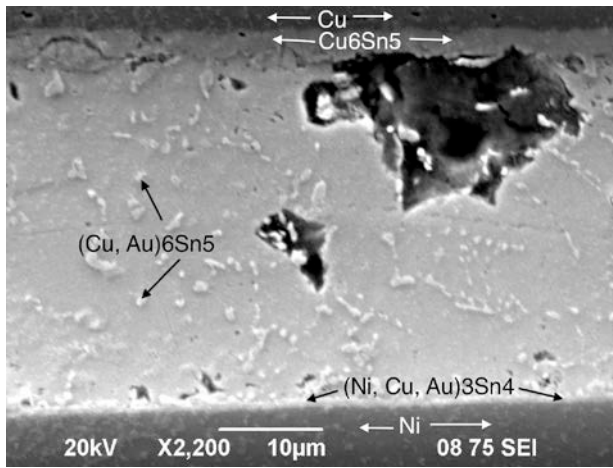
After aging at 125°C for 56 days, one QFN solder joint and one TOPS joint on a flash Au board are shown in the SEM micrographs in Figure 5. The IMCs and microstructures are similar to that of samples aged for 30 days. However, the interfacial IMC thickness increased.

QFN and TOPS on Thick Au Board

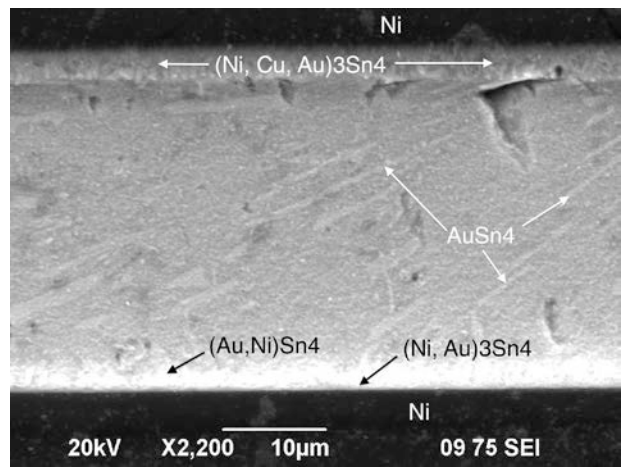
The SEM micrograph of two as-built solder joints between the central pad of a component and a board with a thick Au finish is shown in Figure 6. The Au content in the QFN solder joint is about 10.9% by weight and the Au content in the TOPS solder joint is about 11.2%. The interfacial intermetallic compound (IMC) on the component side of the QFN solder joint is $(\text{Cu}, \text{Ni}, \text{Au})_6\text{Sn}_5$ while that of the TOPS solder joint is $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$. The IMC in the bulk solder of the QFN joint is pillar-like and/or stone-like AuSn_4 , same as that of the TOPS joint.

Figures 7 and 8 show the SEM micrographs of solder joints on thick Au boards after aging at 125°C for 30 days and 56 days, respectively. It is interesting to note that the interfacial IMC of the TOPS joint on the board side is a continuous $(\text{Au}, \text{Ni})\text{Sn}_4$ layer next to the $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$ IMC while there is no continuous layer of $(\text{Au}, \text{Ni})\text{Sn}_4$ at the QFN joint. The result is significant. It is the effect of Cu on AuSn_4 IMC migration. When copper is available, as with the QFN, the AuSn_4 IMCs did not form a continuous interfacial layer. The driving force for the migration of AuSn_4 is a reduction of Gibbs free energy by mixing, consequently establishing an AuSn_4 equilibrium between the bulk and the interface. With the fast diffusion of Cu into the IMC, there is less drive to absorb Ni and thus less migration to the Ni interface.

We also noticed that there are large fractures in the solder joint between the central pad of a TOPS and a thick Au board as shown in Figure 9. Such fractures did not occur in solder joints between a TOPS and a flash Au board. Such fractures also did not occur on solder joints between a QFN and a thick Au board. This indicates that high Au content (over 10 wt% Au) has a more severe effect on the reliability of solder joints without Cu (Ni layer on both sides of the joint) than those with the availability of Cu. When copper is available, AuSn_4 IMCs are less likely to migrate to the interface and form a continuous IMC layer, thus improving the reliability.

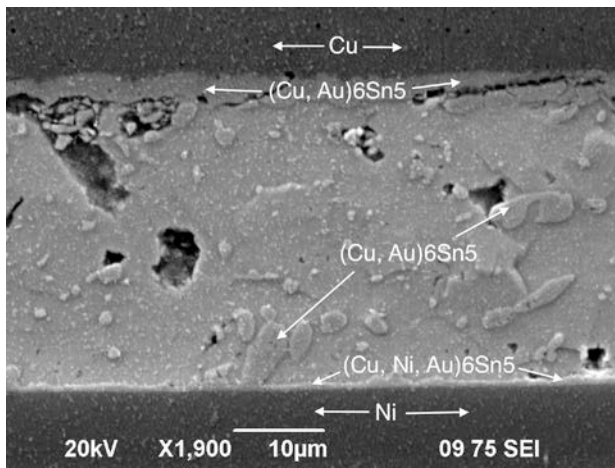


a) QFN

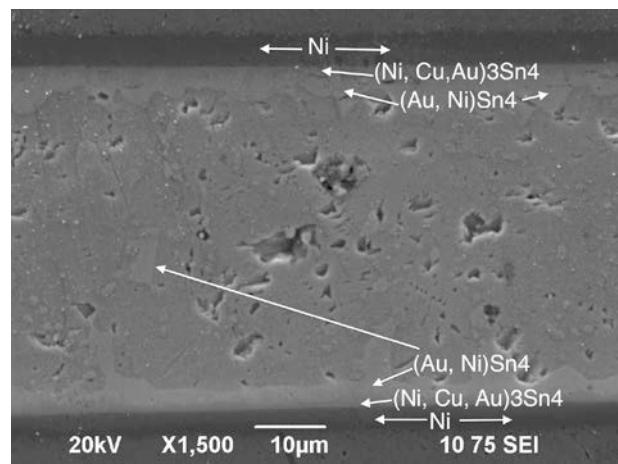


b) TOPS

Figure 3. SEM micrograph of an as-built solder joint between the central pad and a board with flash Au finish.

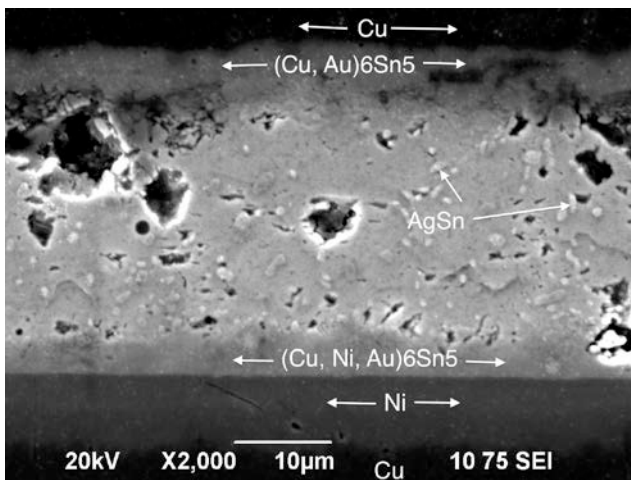


a) QFN

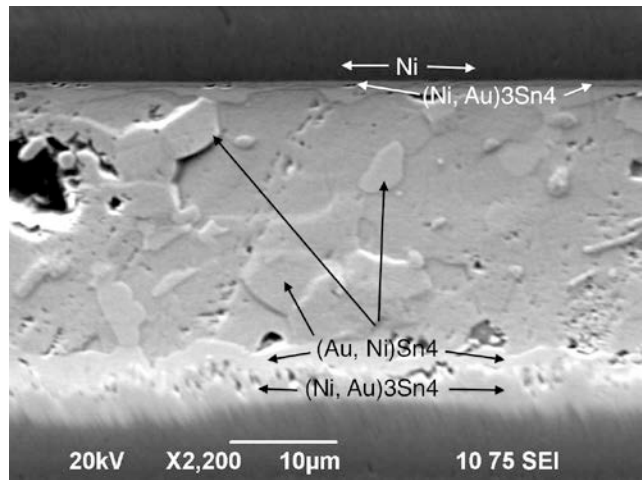


b) TOPS

Figure 4. SEM micrograph of an aged solder joint between the central pad and a board with flash Au finish. The sample was aged at 125°C for 30 days.



a) QFN

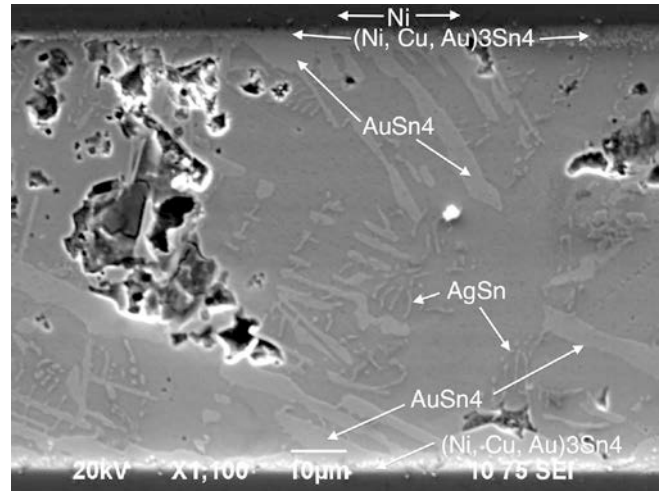


b) TOPS

Figure 5. SEM micrograph of an aged solder joint between the central pad and a board with flash Au finish. The sample was aged at 125°C for 56 days.

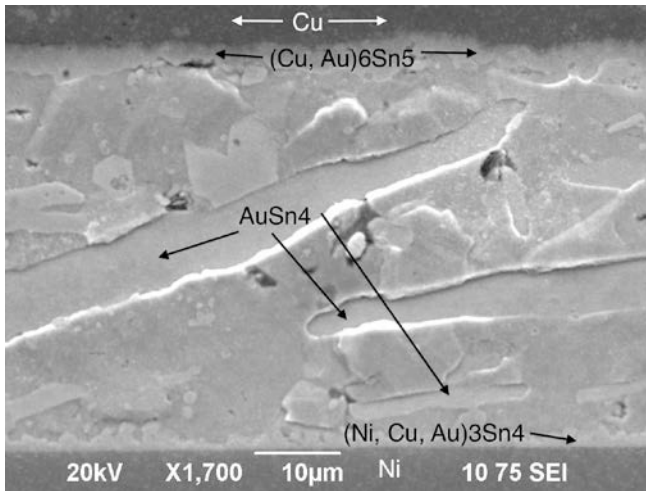


a) QFN

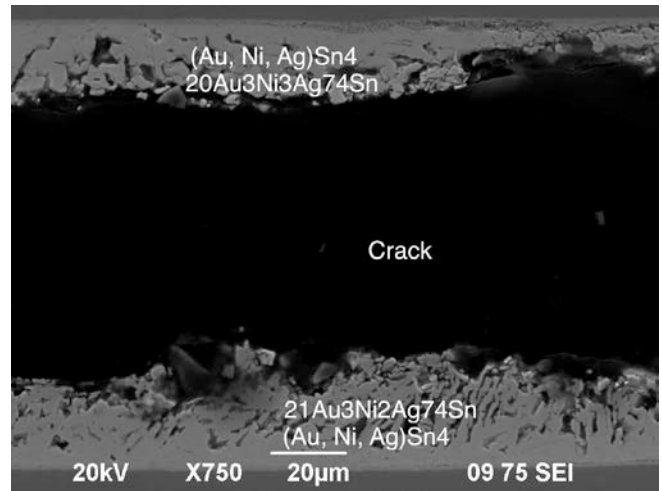


b) TOPS

Figure 6. SEM micrograph of an as-built solder joint between the central pad and a board with thick Au finish.

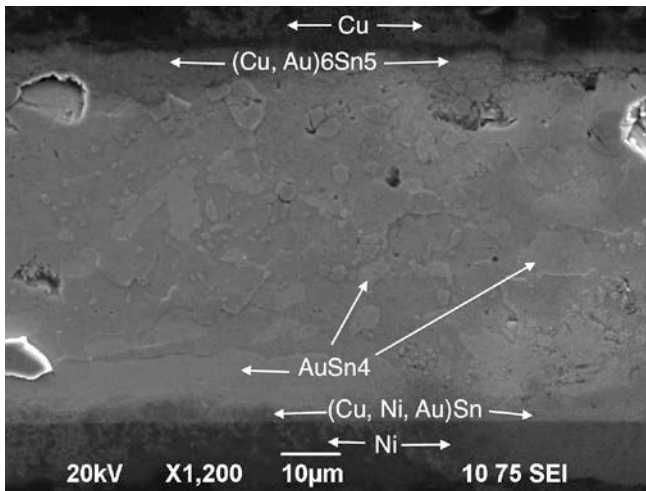


a) QFN

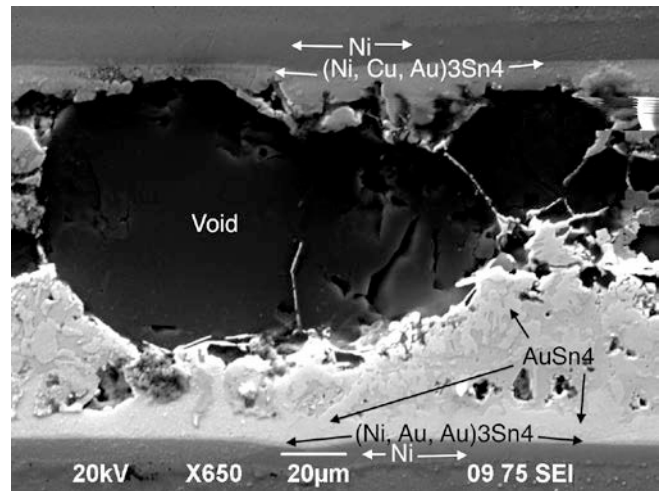


b) TOPS

Figure 7. SEM micrograph of an aged solder joint between the central pad and a board with thick Au finish. The sample was aged at 125°C for 30 days.



a) QFN



b) TOPS

Figure 8. SEM micrograph of an aged solder joint between the central pad and a board with thick Au finish. The sample was aged at 125°C for 56 days.

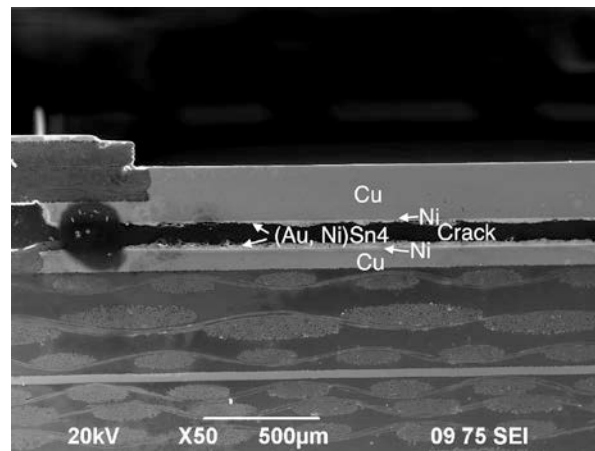


Figure 9. SEM image of the solder joint between the central pad of TIPS component and a thick Au board.

Thermal aging time

It is useful to know how long is enough for thermal aging. In this study, we compared the microstructure and IMC thickness of solder joints aged at 125°C for 209 hours vs. for 30 days and 56 days.

Figure 10 shows the SEM micrograph of a solder joint between the central pad of a QFN and a thick Au board aged at 125°C for 209 hours. Comparing with the SEM image of as-built solder joint in Figure 6 a) and the SEM image of aged solder joint in Figure 7 a), it seems the coalescence process of the AuSn₄ IMCs in the bulk solder has completed after aging for 209 hours. There is no significant difference in microstructure between the solder joint aged for 209 hours and the joint aged for 30 days, except that the IMC layer is thicker in the sample aged for 30 days. Figure 11 shows the SEM images of a solder joint between a perimeter lead of a TIPS and a thick board aged at 125°C for 209 hours, compared with solder joints as-built, aged for 30 days, and aged for 56 days. The same conclusion can be drawn that there is no significant difference in microstructure of the bulk solder joint between the solder joint aged for 209 hours and the joint aged for 30 days or 56 days. However, at the interface, the migration of AuSn₄ to a continuous layer has not yet occurred. This indicates that the 2 year equivalent aging time appears to not be sufficient to see significant migration of the AuSn₄ IMC.

Figures 12 and 13 show the changes in mean IMC thickness (four measurements per group) at the component and board interfaces, respectively, as a function of thermal aging time and board finish (thick vs. flash Au) for the QFN platform. For the case of QFN, the IMC thickness and composition at the component and board interfaces can evolve independently, due to the difference in the surface finish stack-up. The evolution of IMC thickness as a function of thermal aging and board finish for the TIPS platform is shown in Figure 14, where the IMC thickness at both interfaces is included in the calculation of the mean thickness (four measurements per group) because composition at the two interfaces is essentially the same for the TIPS platform, owing to the presence of a Ni diffusion barrier at both interfaces. For both platforms, the mean IMC thickness increases with thermal aging time and increases at about the same rate. However, it is interesting to note that for the QFN packages the increase in IMC thickness is higher on the flash Au boards, whereas for the TIPS packages the mean IMC thickness increase is higher for the thick Au boards. Since Cu is readily available in the QFN solder joints, migration of AuSn₄ type IMCs from the bulk to the interfaces during thermal aging is mitigated (i.e. AuSn₄ does not contribute to the increase in IMC thickness) and the IMC growth is dominated by formation of the (Cu, Ni, Au)₆Sn₅ IMC. In contrast, the presence of a Ni diffusion barrier at both interfaces for the case of the TIPS packages results in migration of (Au, Ni)Sn₄ IMC from the bulk to the interfaces during thermal aging where it contributes to the overall IMC thickness. Since more Au is available in the case of the thick Au boards, it makes sense that the contribution to overall IMC thickness is enhanced.

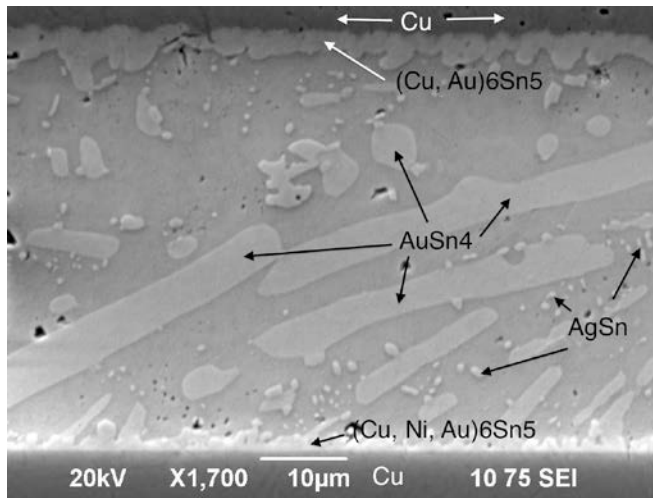
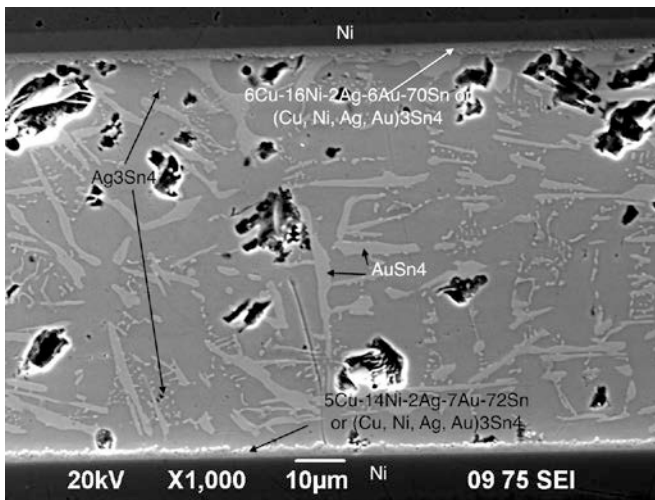
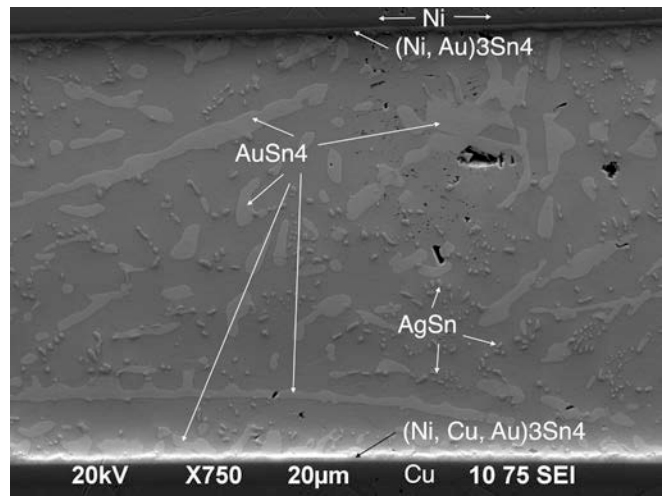


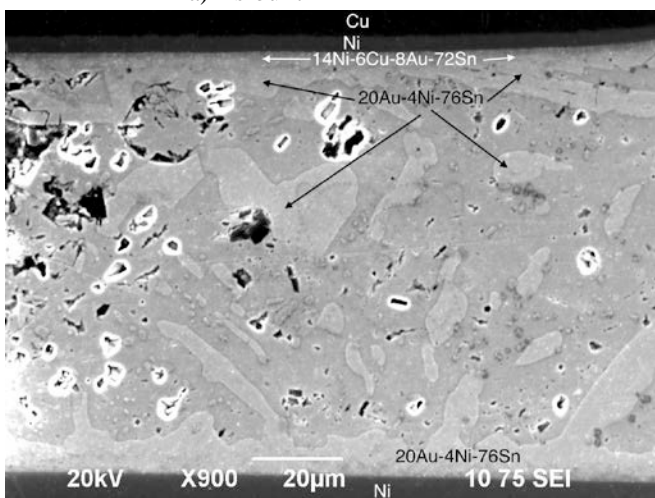
Figure 10. SEM micrograph of an aged solder joint between the central pad of a QFN and a board with thick Au finish. The sample was aged at 125°C for 209 hours



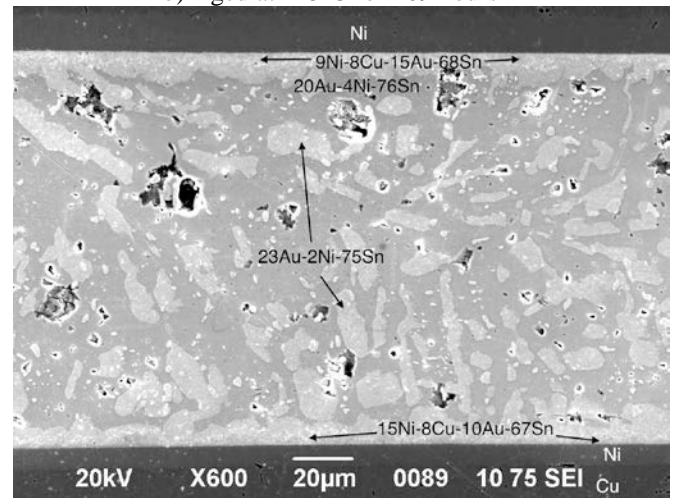
a) As-built



b) Aged at 125°C for 209 hours



c) Aged at 125°C for 30 days



d) Aged at 125°C for 56 days

Figure 11. SEM images of solder joints of a TOPS component on a thick Au board

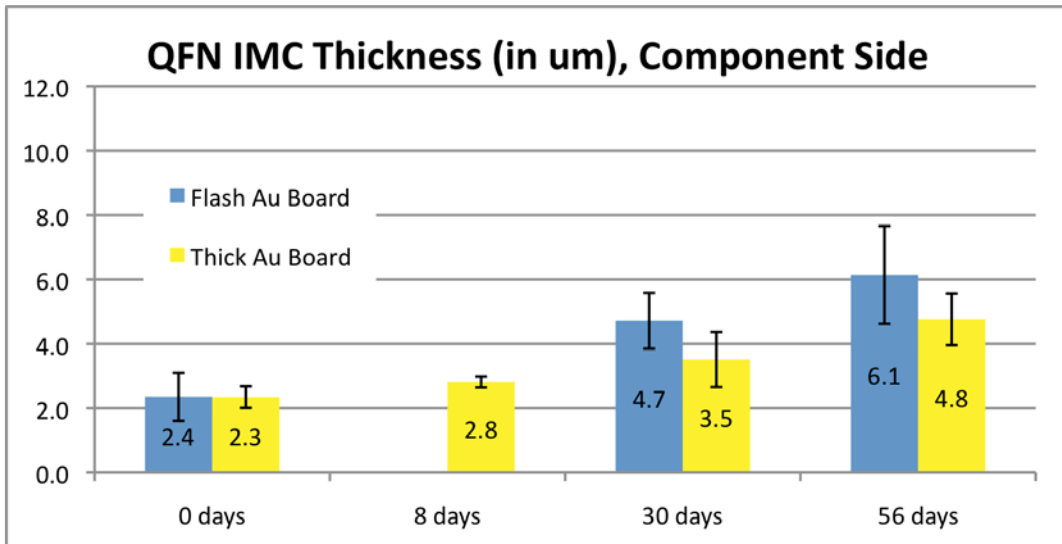


Figure 12. IMC thickness for QFN on flash and thick Au boards, component side of interface (error bars are $\pm 1\sigma$)

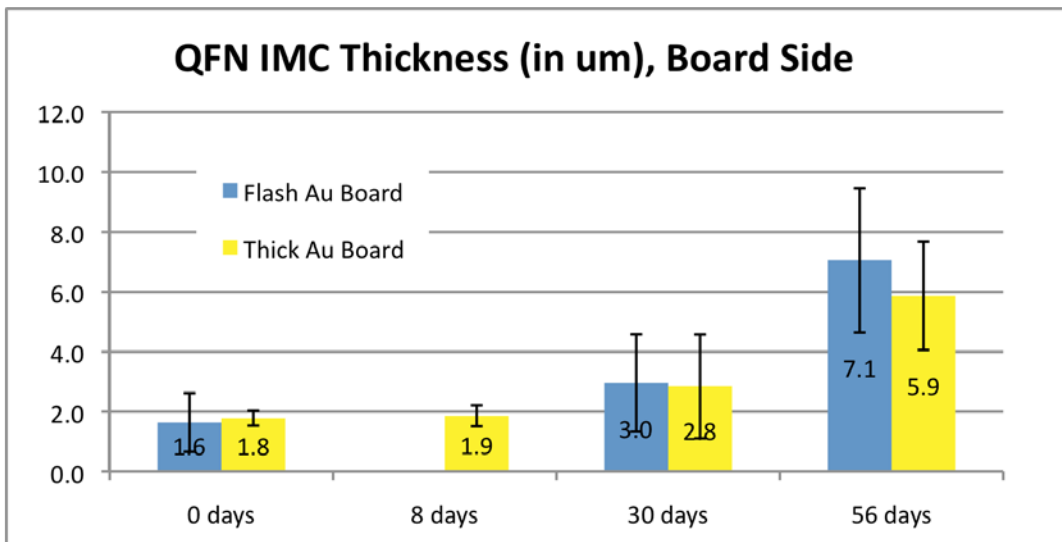


Figure 13. IMC thickness for QFN on flash and thick Au boards, board side of interface (error bars are $\pm 1\sigma$)

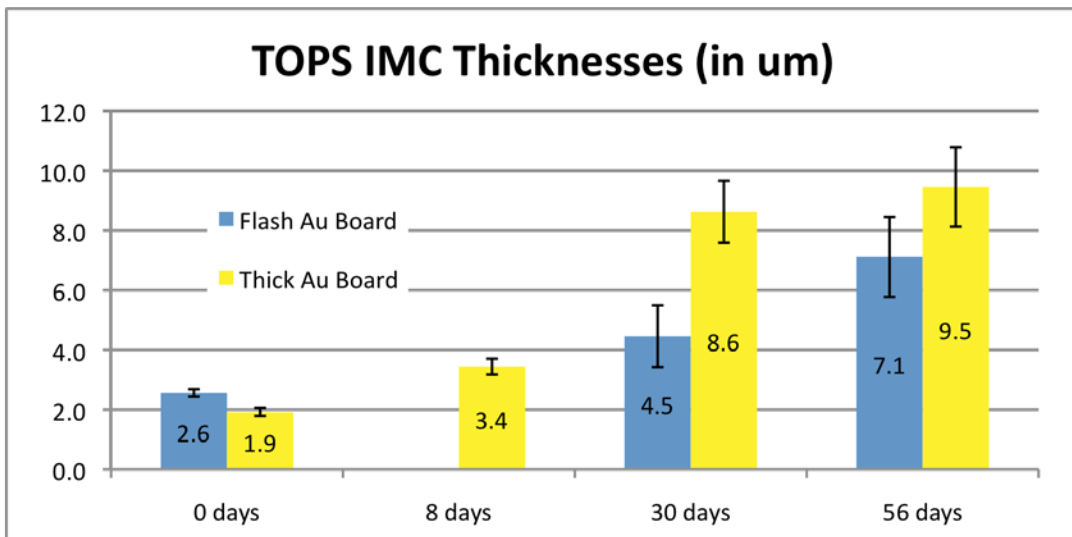


Figure 14. IMC thickness for TOPS on flash and thick Au boards (error bars are $\pm 1\sigma$)

Voiding in the central underbelly pad solder joint

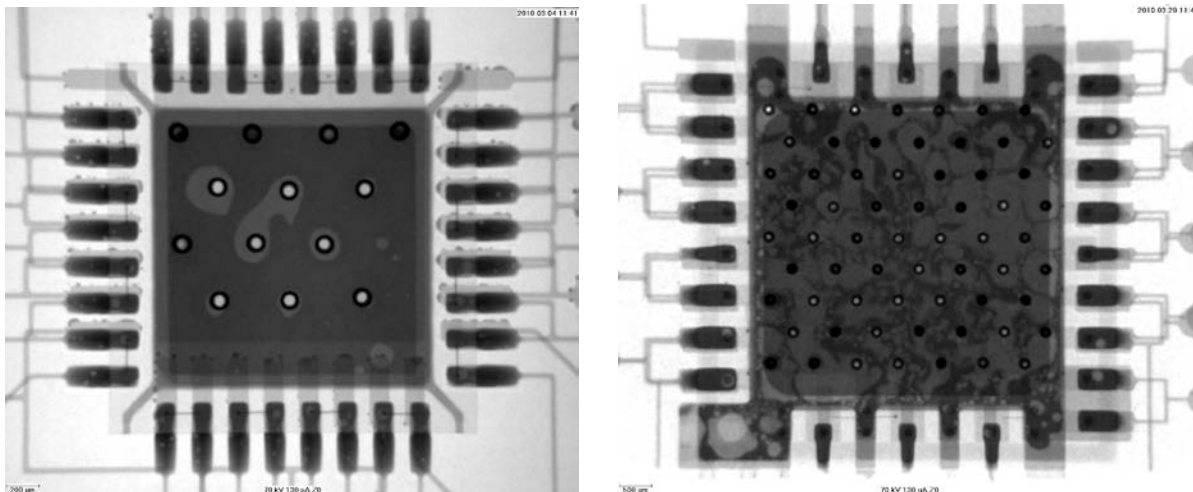
It is well known that excessive voiding often occurs on the solder joint on the underbelly pad. In this study, a 2D X-ray image was taken on every component on every board after assembly. Figure 15 shows two X-ray images. A total of 540 images were analyzed including nine QFN5, nine QFN6, and nine TOPS components on 10 flash Au boards and 10 thick Au boards.

The analysis was done using the software ImageJ [10]. By adjusting the contrast and setting a threshold, the software is able to determine all voiding area and calculate the total voiding area. The software also shows the area of each void in the image. Voiding is characterized using void percentage, which is defined as the ratio of all voiding areas to the central pad area.

Figure 16 shows the average void percentage of each component type on the flash Au board and the thick Au board. The number for QFN is an average of 120 components and the number for TOPS is an average of 60 components. It is clear that thick Au metallization on thermal pads leads to more voiding. We also noticed that the majority of voids cover thermal vias in the center of the pad. Note that all thermal vias in the study are un-filled, which was an error in board fabrication. The intended design was to epoxy-fill and plate over these vias, or “vippo” (via in pad plated over).

The SEM image in Figure 17 shows that voids are due to solder loss resulting from solder flowing through thermal vias. Figure 18 shows that interfacial IMCs have been formed on the void area. This indicates that solder wetted the pad on the PCB and on the component, formed IMCs, then solder flowed through thermal vias and voids are created due to the solder loss.

The standoff distance of the solder joint on the central pad was measured and reported in Table 2. Note that the stencil thickness is 100 μm (4 mils), and the solder paste coverage of the central pad for QFN5 and QFN6 is 43% and that for TOPS is 56%. If the standoff height of the solder joint were only determined by the solder paste coverage, the standoff would be 21.5 μm (or 43% of stencil thickness times 50% solder volume) for QFNs and 28 μm (or 56% of stencil thickness times 50% solder volume) for TOPS. The measured standoff is much larger than this even though there is solder loss to the thermal vias. The standoff was higher with more gold. The complete separation between the TOPS component and the thick Au board was due to high Au content leading to AuSn_4 IMC across the whole joint as shown in Figure 19.



a) a QFN component on a Flash Au board b) a TOPS component on a thick Au board

Figure 15. X-Ray images

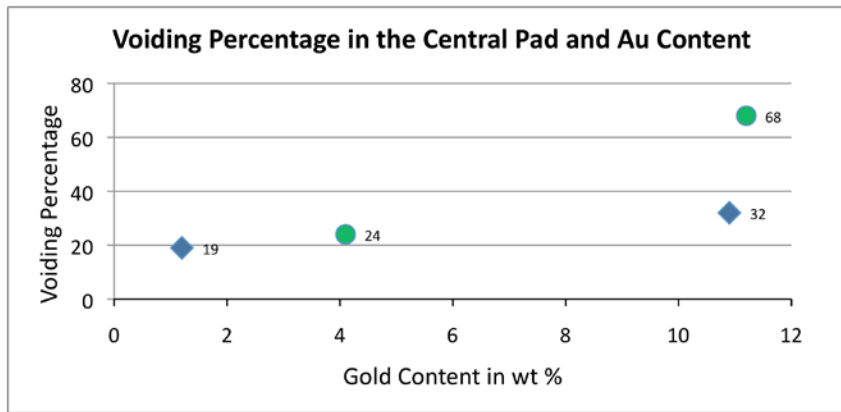


Figure 16. Graph of voiding percentage vs. gold content (Diamonds are QFN, Circles are TOPS)

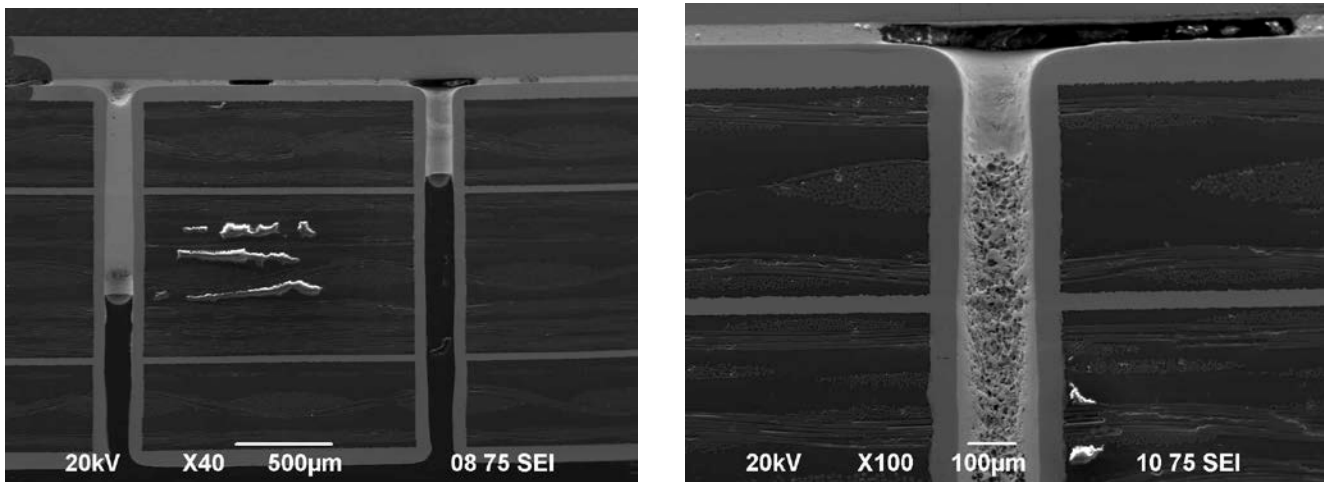


Figure 17. SEM images showing voids due to solder loss

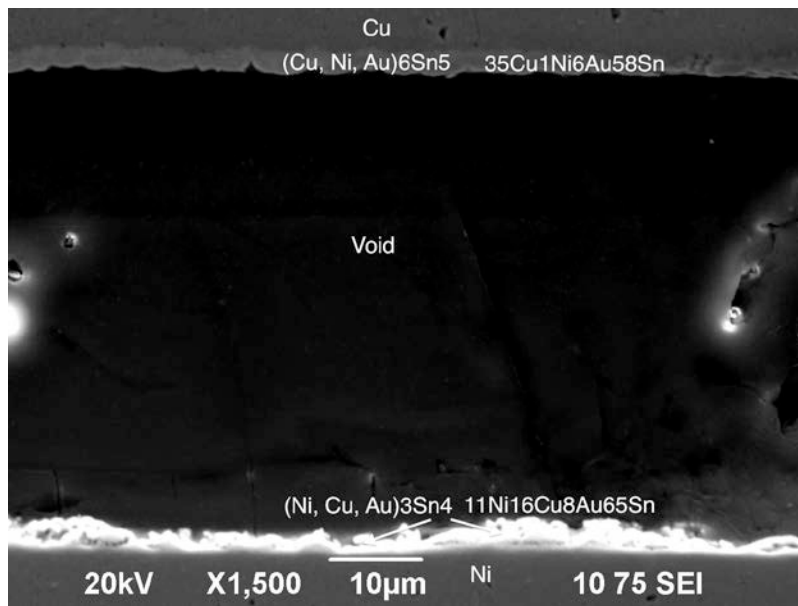


Figure 18. SEM image showing interfacial IMCs on the void of a QFN component on a flash Au board

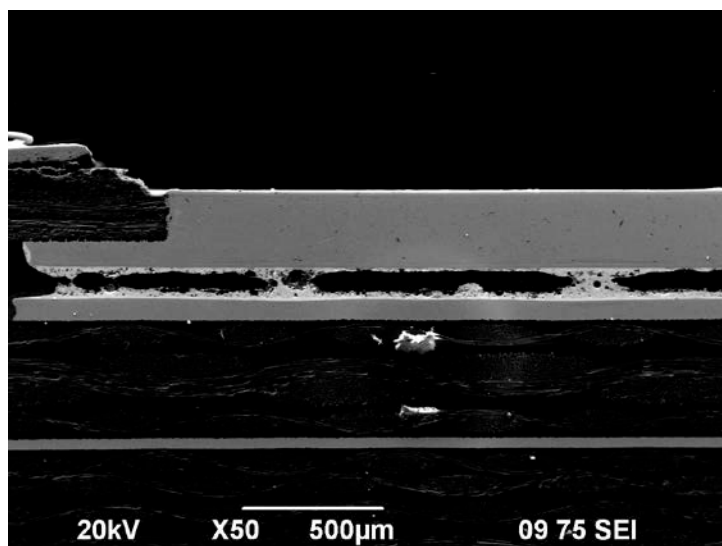


Figure 19. SEM image showing cracks/voids of a TOPS component on a thick Au board

Table 2. Average solder standoff thickness (μm)

	Flash Au board	Thick Au board
QFN	35	51
TOPS	37	100

Conclusions

A comprehensive study has been conducted investigating the morphology evolution and voiding of SnAgCu solder joints on the central pad on PCB with a Ni/Au surface finish. The following conclusions can be drawn from this study:

- The significant result was the effect of Cu on AuSn_4 IMC migration. When copper is available, as with the QFN, the AuSn_4 IMCs did not form a continuous interfacial layer. The driving force for the migration of AuSn_4 is a reduction of Gibbs free energy by mixing, consequently establishing a AuSn_4 equilibrium between the bulk and the interface. With the fast diffusion of Cu into the IMC, there is less drive to absorb Ni and thus less migration to the Ni interface. Thus, the availability of Cu mitigates the negative effects of AuSn_4 IMC.
- For both platforms, AuSn_4 IMCs are dispersed through the bulk solder as-built. With aging, AuSn_4 IMCs have coalesced decreasing the surface area to volume ratio.
- For both platforms, the mean IMC thickness increases with thermal aging time and increases at about the same rate. However, the relative thicknesses of $(\text{Cu}, \text{Ni}, \text{Au})_6\text{Sn}_5$ IMC or $(\text{Ni}, \text{Cu}, \text{Au})_3\text{Sn}_4$ IMC vs $(\text{Au}, \text{Ni})\text{Sn}_4$ IMC are distinctly different. For the QFN packages the increase in IMC thickness is higher on the flash Au boards. IMC growth is dominated by formation of the $(\text{Cu}, \text{Ni}, \text{Au})_6\text{Sn}_5$ IMC. For the TOPS packages, the mean IMC thickness increase is higher for the thick Au boards. $(\text{Au}, \text{Ni})\text{Sn}_4$ IMCs from the bulk migrate to the interfaces during thermal aging, contributing to the overall IMC thickness. More Au is available in the case of the thick Au boards, so the contribution to overall IMC thickness is enhanced. The increase in Ni_3Sn_4 IMC is minimal.
- The microstructure of solder joints thermally aged at 125°C for 209 hours is similar to those aged for 30 days or 56 days other than the expected difference in IMC thickness. This indicates that thermal aging at 125°C for 209 hours, equivalent to 1000 hours at 100°C , is sufficiently long to have IMCs in the bulk solder coalesce. The TOPS joint did not show a continuous layer of AuSn_4 IMC at the interface, so 125°C for 209 hours was not long enough for this migration to occur.
- Voiding analysis showed that thick Au metallization on thermal pads leads to more voiding and larger standoff height.

Acknowledgements

The authors want to thank Patrick Hyland for cross-sectioning and EDX analysis, and Sundar Sethuraman of Jabil for assembling the boards.

References

- [1] D. Herron, Y. Liu, and N.C. Lee (2011), "Pad Design and Process for Voiding Control at QFN Assembly," Proceeding of IPC Printed Circuits Expo, APEX and the Designers Summit 2011, Las Vegas, NV, Apr. 12-14, 2011.
- [2] Xilinx Corporation, "PCB Pad Pattern Design and Surface-Mount Considerations for QFN Packages", Application Note: CoolRunner, CPLD, XAPP439 (v1.0) April 11, 2005, available online http://www.xilinx.com/support/documentation/application_notes/xapp439.pdf
- [3] Texas Instruments, "DAC348x PCB Layout Guidelines for the Multi-Row QFN Package," Application Report, SLAA493, July 2011, available online at <http://www.ti.com/lit/an/slaa493/slaa493.pdf>
- [4] Texas Instruments, "QFN Layout Guidelines," Application Report, SLOA122, July 2006, available online at <http://www.ti.com/lit/an/sloa122/sloa122.pdf>
- [5] Cirrus Logic, "Thermal Considerations for QFN Packaged Integrated Circuits", AN315REV1, July 2007, available online at <http://www.cirrus.com/en/pubs/appNote/AN315REV1.pdf>
- [6] Actel, "Assembly and PCB Layout Guidelines for QFN Packages", Application Note AC322, May 2008, available online at http://www.actel.com/documents/QFN_AN.pdf
- [7] M. Powers, J. Pan, J. Silk, and P. Hyland, "Effect of Gold Content on the Microstructural Evolution of SAC305 Solder Joints under Isothermal Aging," *Journal of Electronic Materials*, accepted, 2011.
- [8] J. Pan, J. Silk, M. Powers, P. Hyland, "Effect of Gold Content on the Reliability of SnAgCu Solder Joints," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, accepted, 2011.
- [9] J. Pan, J. Silk, M. Powers, P. Hyland, "Effect of Gold Content on the Reliability of SnAgCu Solder Joints," Proceeding of IPC Printed Circuits Expo, APEX and the Designers Summit 2011, Las Vegas, NV, Apr. 12-14, 2011.
- [10] ImageJ, can be downloaded at <http://rsbweb.nih.gov/ij/>



Morphology Evolution and Voiding of Solder Joints on QFN Central Pads With a Ni/Au Finish

Authors:

Julie Silk, Agilent Technologies

Jianbiao Pan, California Polytechnic State University, San Luis Obispo

Mike Powers, Agilent Technologies



Gold in Solder Joints

- The limit for gold in tin-lead solder joints is well-documented at 3 wt% Au
- For lead-free solder joints, the limit and morphology are not well-known
- The solder joint morphology and effect of gold on voiding in QFN underbelly pad solder joints is not documented
- This report covers our work on these topics

Test Vehicle

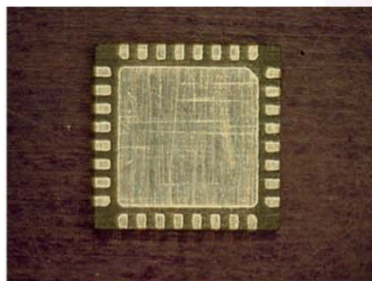
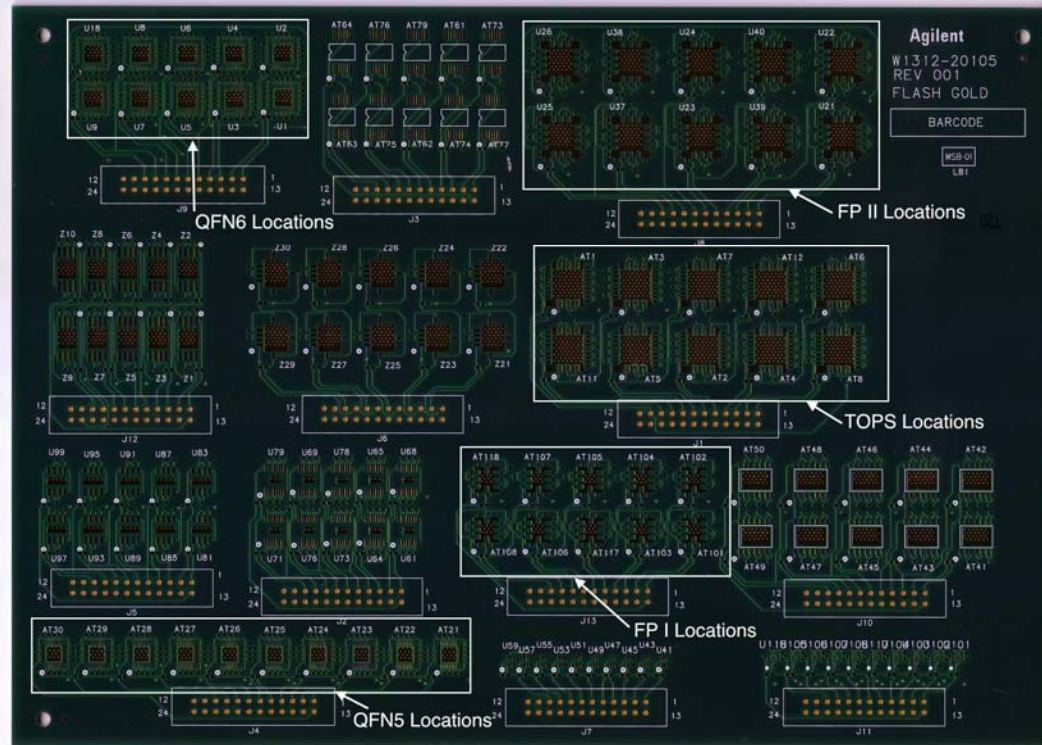


PCB

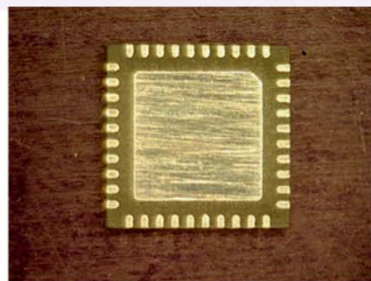
Components

QFNs

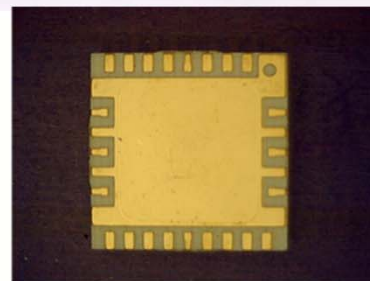
TOPS



QFN5



QFN6



TOPS



Experimental Plan

- The board finish is electrolytic gold over electrolytic nickel,
 - Plated with 2 levels of gold:
Flash ($\sim 0.3 \mu\text{m}$) and Thick ($\sim 2.5 \mu\text{m}$)
- Soldering was with SAC305 solder in a standard reflow oven
- Isothermal aging at 125°C at 4 levels
 - As-built, 2.25 years, 7 years, 14 years equivalent



Gold Content Calculation

- Gold content of central pad joint was calculated based on nominal solder apertures and thickness, and actual measurements of gold thickness on pin pads and component

	Flash Au	Thick Au
QFN5 or QFN6	1.2%	10.9%
TOPS	4.1%	11.2%

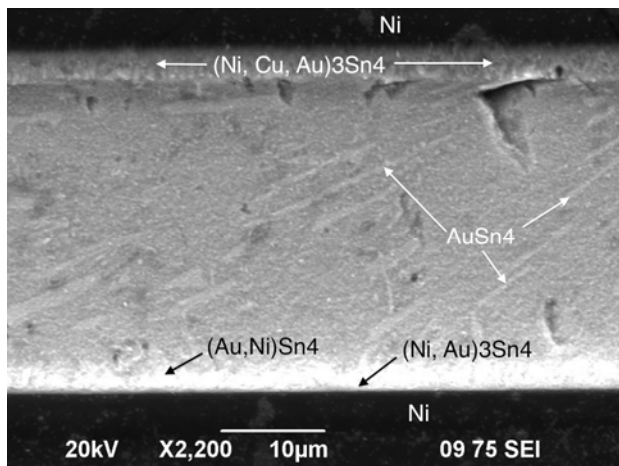


Aging Times

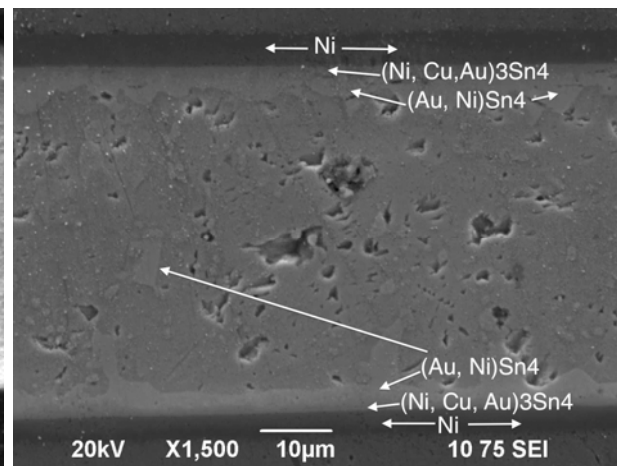
- Aging was done at 125° C
- Times calculated based on 60° C service temperature, activation energy of 0.8eV
 - No aging, as built
 - 209 hours, equivalent to 2.25 years, also equivalent to 1000 hours at 100° C
 - 30 days, equivalent to 7 years
 - 56 days, equivalent to 14 years

Aging, Morphology Results

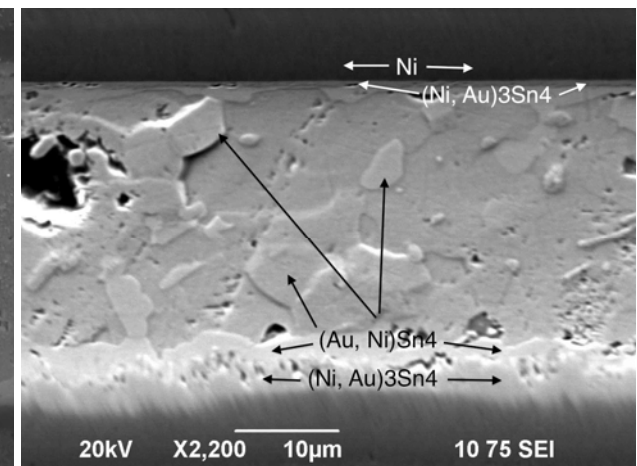
- TOPS, a Ni-Au-solder-Au-Ni structure
- On flash gold PCB



As built



7 years



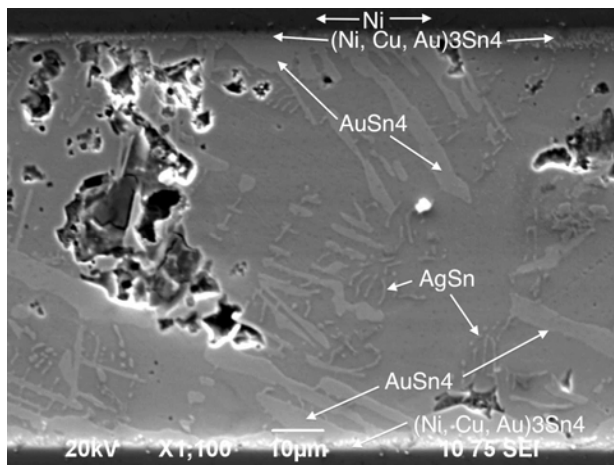
14 years

The (Au,Ni)Sn₄ layer grows with age

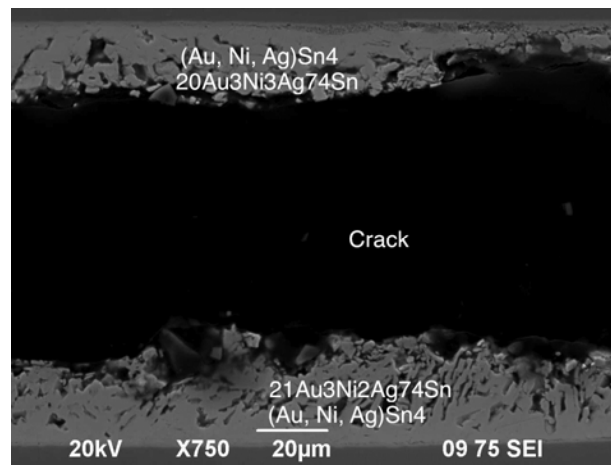


Aging, Morphology Results

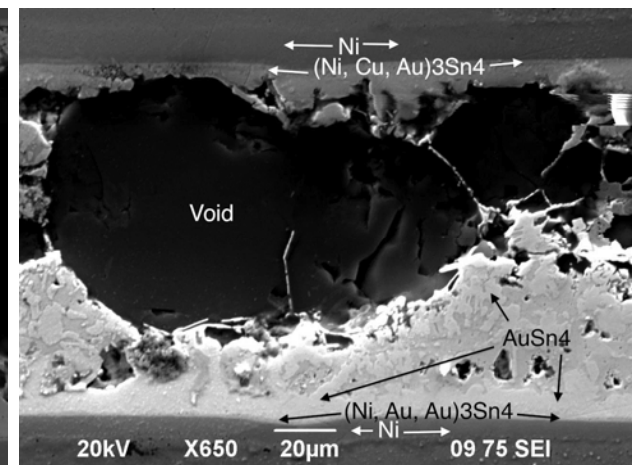
- TOPS, a Ni-Au-solder-Au-Ni structure
- On thick gold PCB



As built



7 years



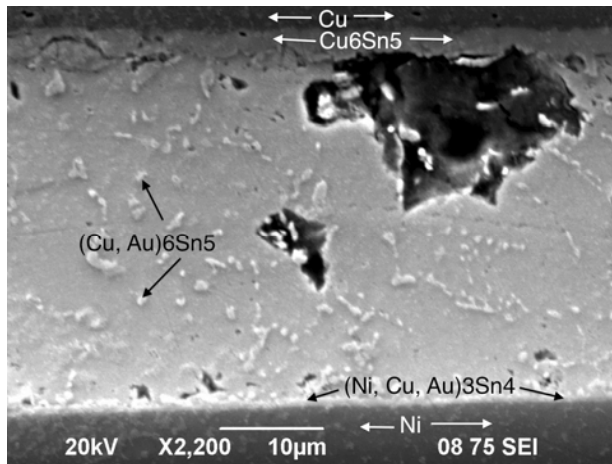
14 years

High incidence of fracture and voiding at all ages

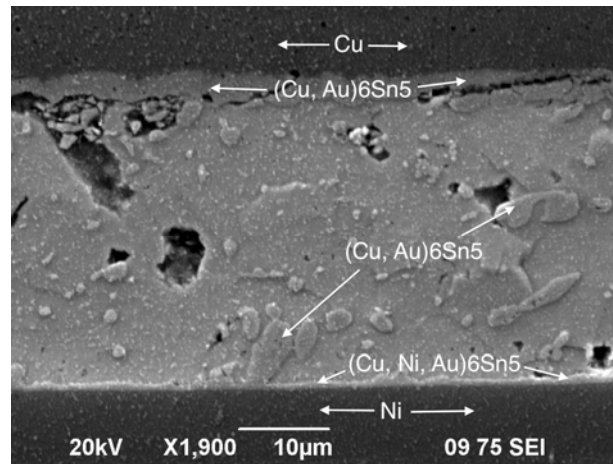


Aging, Morphology Results

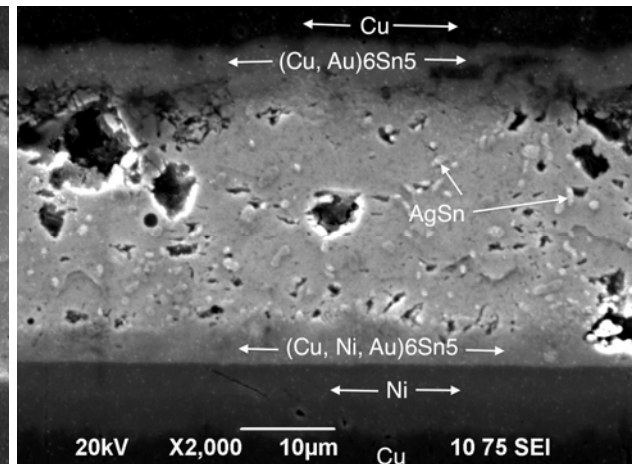
- QFN, a Cu-solder-Au-Ni structure
- On flash gold PCB



As built



7 years



14 years

The $(\text{Cu}, \text{Ni}, \text{Au})_5\text{Sn}_6$ layer grows with age,
No AuSn_4 layer at interface

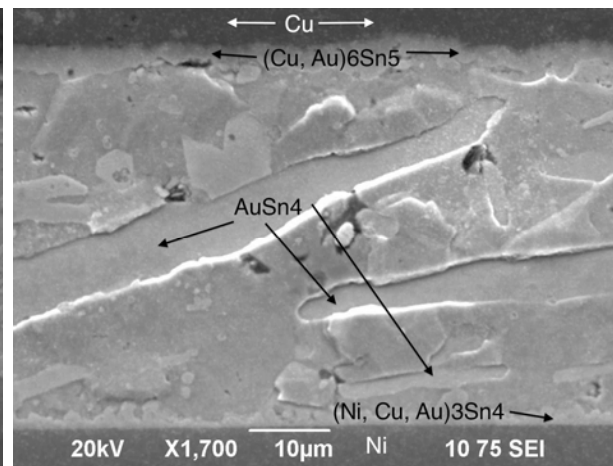


Aging, Morphology Results

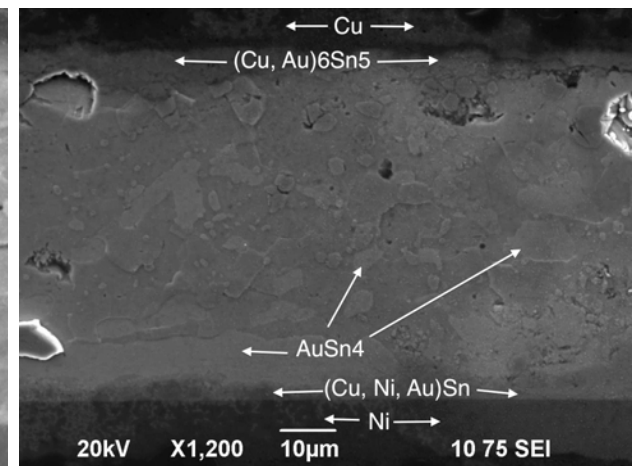
- QFN, a Cu-solder-Au-Ni structure
- On thick gold PCB



As built



7 years



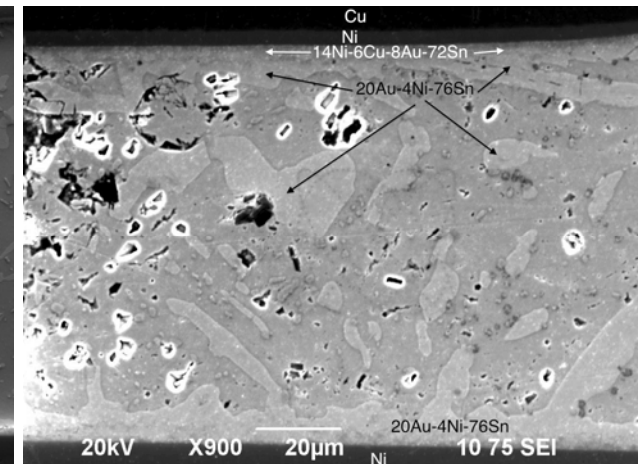
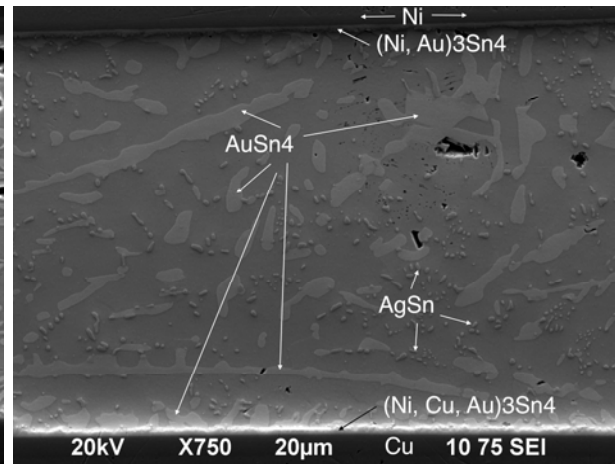
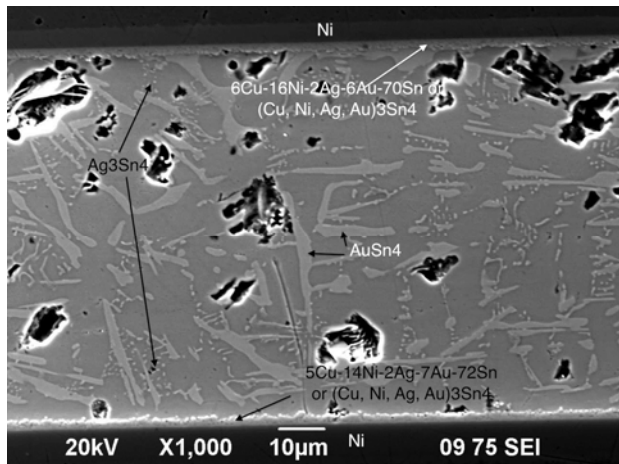
14 years

The $(\text{Cu}, \text{Ni}, \text{Au})_5\text{Sn}_6$ layer grows with age,
No AuSn_4 layer at interface



Aging, Morphology Results

- Is 2 years equivalent aging enough?
- Single sample was a thick gold PCB



As built

2 years

7 years

TOPS: IMCs have coalesced in the bulk joint, but AuSn_4 has not migrated to a continuous layer

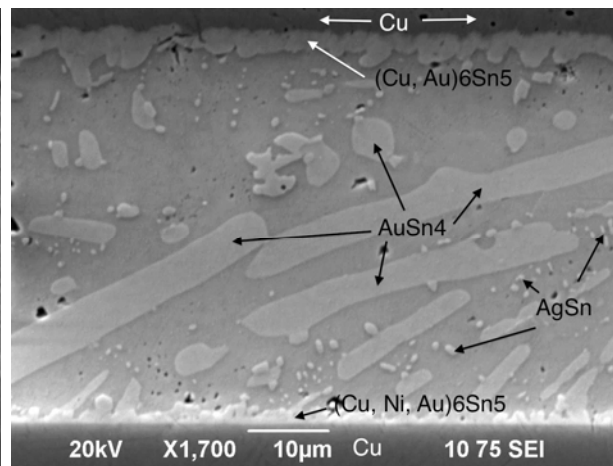


Aging, Morphology Results

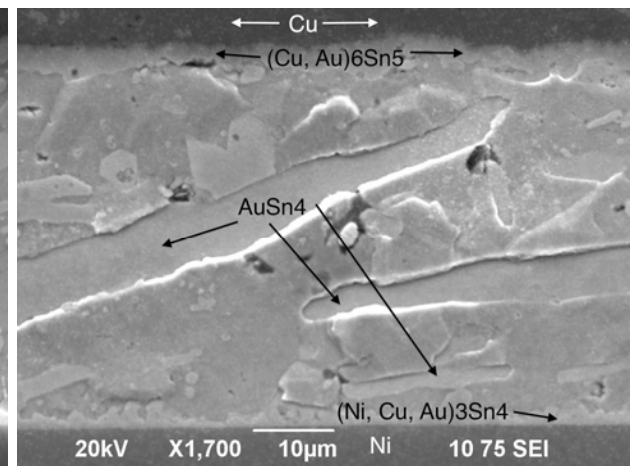
- Is 2 years equivalent aging enough?
- On a thick gold PCB



As built



2 years

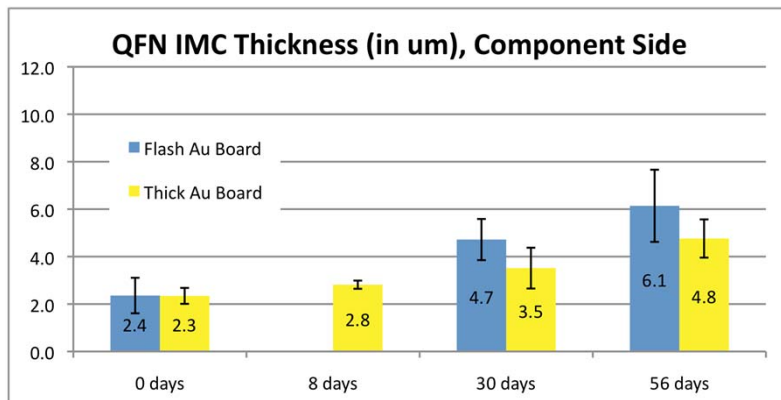


7 years

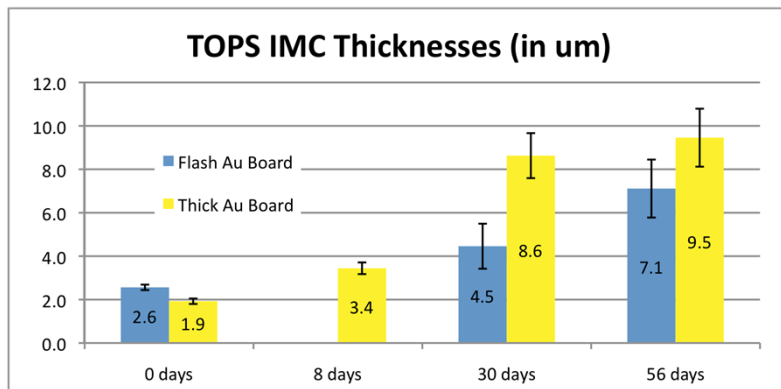
QFN: IMCs have coalesced in the bulk joint

Aging, Morphology Results

- IMC thickness measurements



QFN: IMC increase is higher for flash Au, dominated by Cu_6Sn_5



TOPS: IMC increase is higher for thick Au, dominated by AuSn_4



Morphology Conclusions

- The equivalent of 2 year aging was sufficient to show IMC coalescence but not AuSn_4 migration
- The total IMC thickness increased with age, as expected. However, the type of IMC differed between the Ni-solder-Ni joints (dominated by AuSn_4) and the Cu-solder-Ni joints (dominated by Cu_6Sn_5)

Morphology Conclusions,

continued



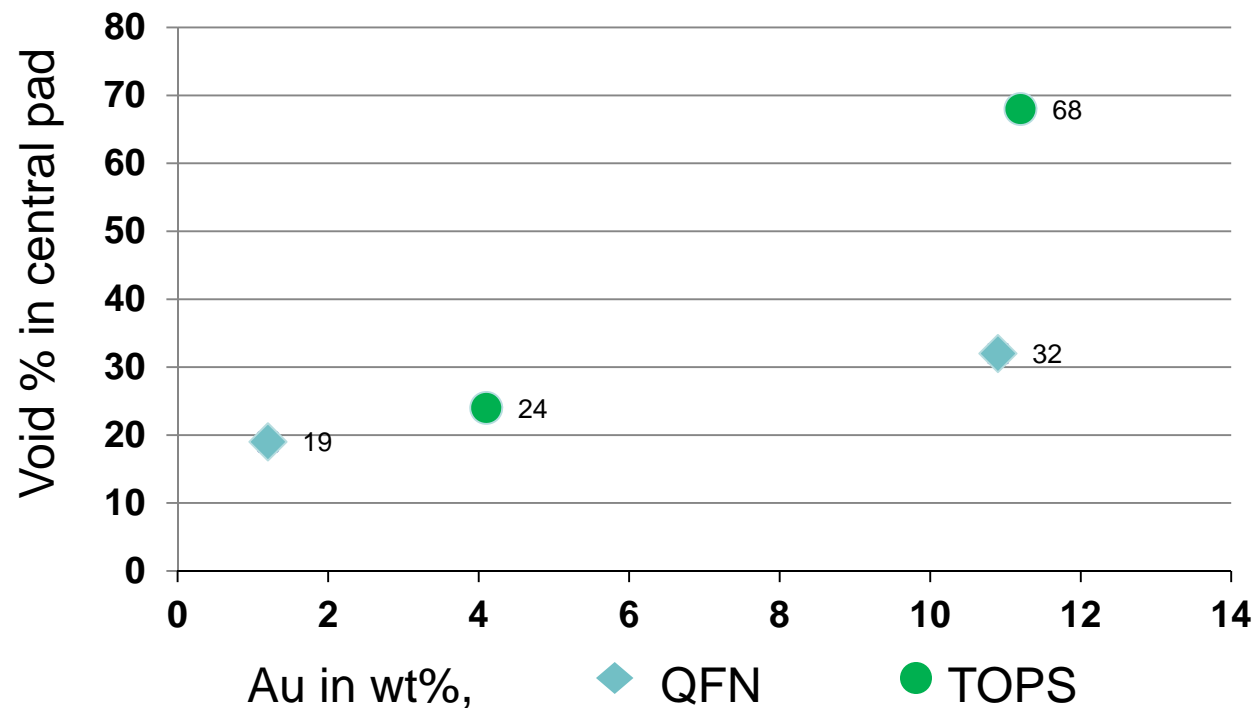
- When copper is available to diffuse into the joint, AuSn_4 does not form a continuous interfacial layer with age.
 - The driving force for migration of AuSn_4 to the nickel layer is a reduction of Gibbs free energy by mixing. With the fast diffusion of Cu into the IMC, there is less drive to absorb Ni.



Voiding Analysis

- Voiding increased with more gold

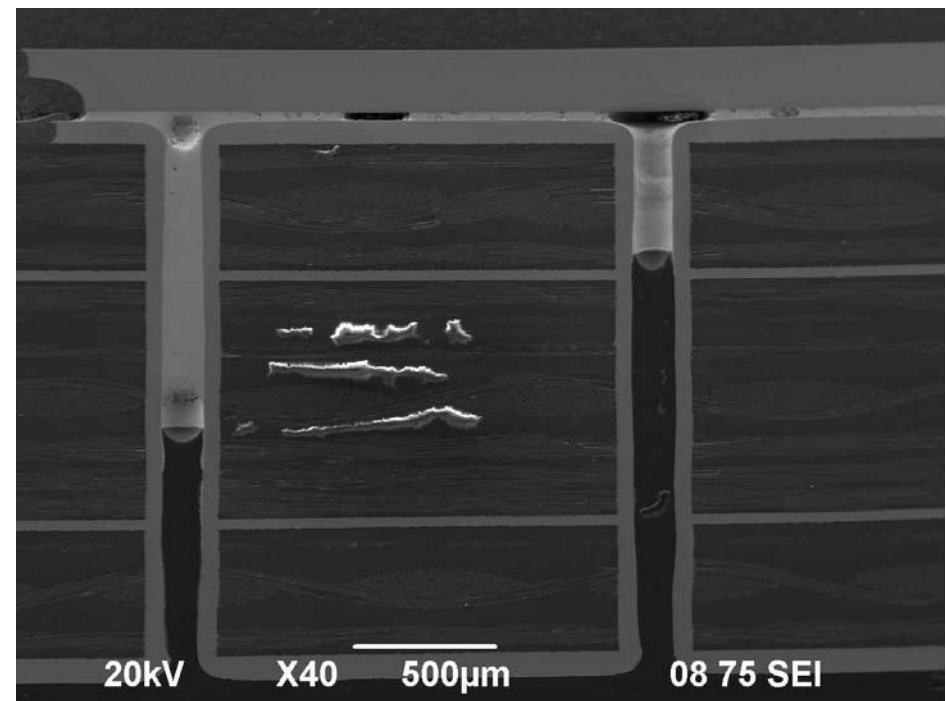
Voiding percentage vs gold content





Voiding Analysis

- Voiding was heavily influenced by unfilled vias in the central pad, which robbed solder





Voiding Analysis

- Standoff height by calculation from coverage and solder volume % would be significantly smaller than what was found

Standoff height at central pad, in microns

	Calculated	Flash Au board	Thick Au board
QFN	21.5	35	51
TOPS	28	37	100

High voiding and taller standoff correlate



Voiding Conclusion

- Thickly plated gold increases voiding and standoff height in QFN ground pads



Key Conclusions

- Copper diffusing into gold-containing solder joints inhibits the formation of a continuous AuSn_4 layer at the interface
- The total IMC thickness increased with age, as expected. However, the type of IMC differed between the Ni-solder-Ni joints (dominated by AuSn_4) and the Cu-solder-Ni joints (dominated by Cu_6Sn_5)
- Voiding and stand off height increase with gold content



Acknowledgements

- Patrick Hyland of Cal Poly for cross-sections and SEM-EDX
- Sundar Sethuraman of Jabil Circuit for assembling the boards, and
- Prof. Richard Savage at Cal Poly for assistance in SEM analysis.



Questions?