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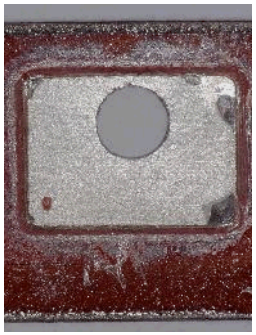

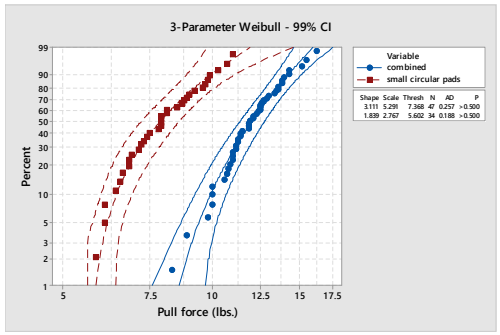

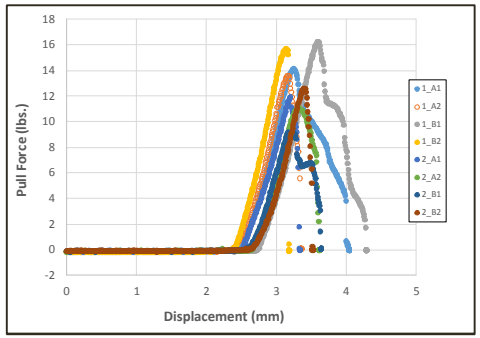

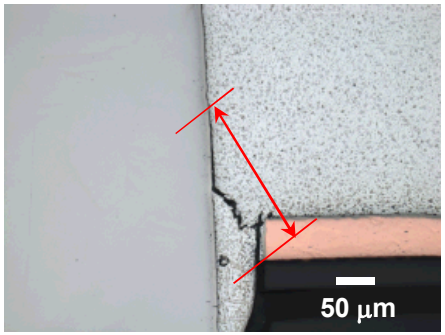

Metallurgical Analysis of Pin-to-Flex Circuit Solder Joints

Don Susan, J.T. Norris, A.C. Kilgo, S. Williams, and L.M. Lowery

InterPack 2017, San Francisco, CA

August 30, 2017

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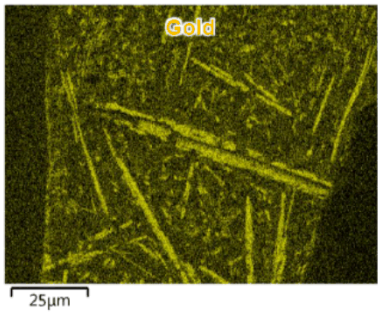
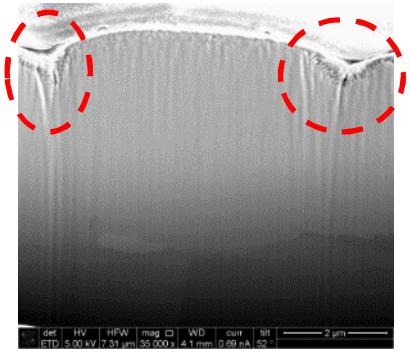
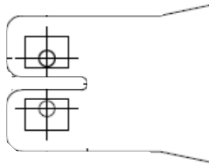
Outline

- Overview of pin-to-flex circuit solder joints
- Three Areas Investigated
  1. Gold-rich Intermetallic Compound (IMC) embrittlement
     - Gold plating thickness study
  2. “Black Pad” Effect,
     - ENIG vs. ENEPIG surface finish
  3. Solder pad geometry change and variability from hand-soldering.
- Pin pull-testing

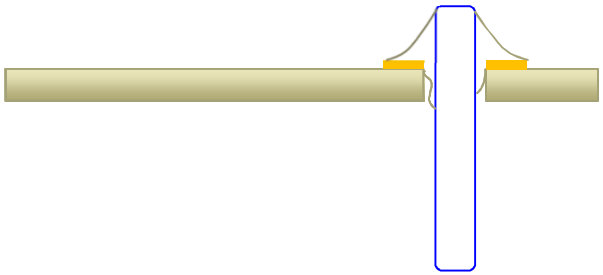


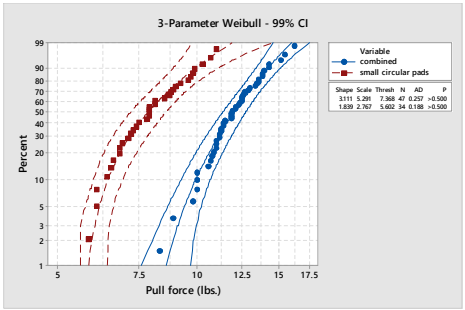


Small, circular



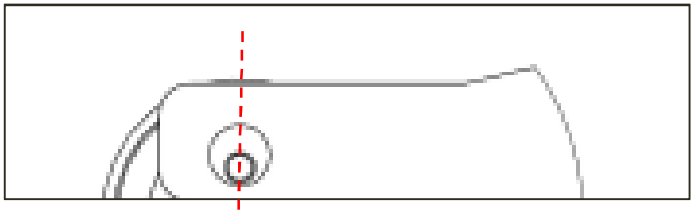
Large, rectangular

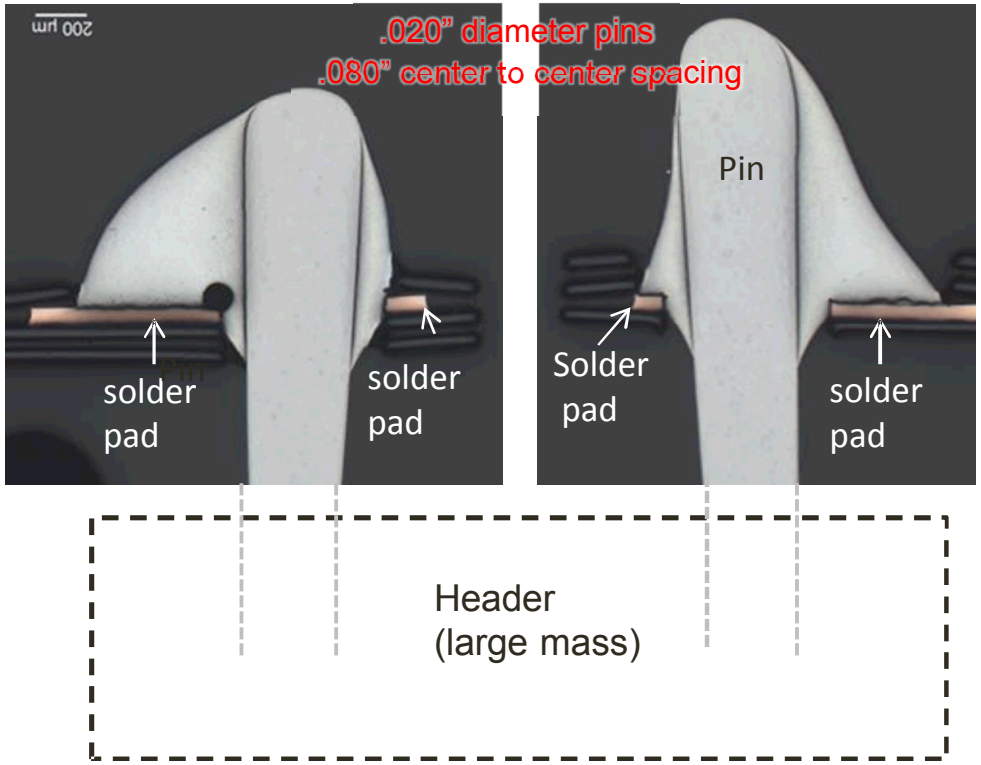


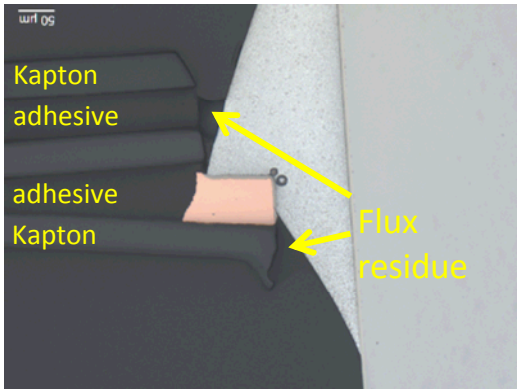


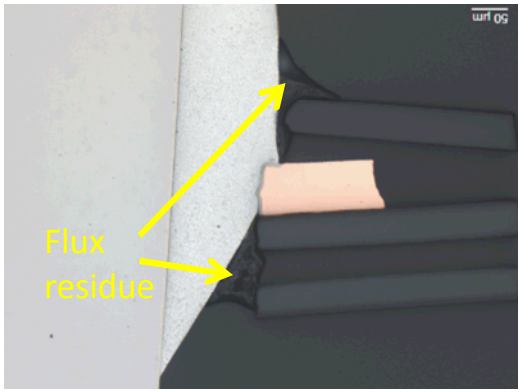
Overview of Pin-to-Flex Circuit Solder Joints

- Pins soldered normal to and through the flex circuit
- Surface mount solder joints on one side, but “through-hole” as well. But, no plating of the thin through-hole region, i.e. no Cu-plated barrel. Considerable variability in solder joint fill in through-hole region.
- Assymetric solder pad. High voltage application, several kilovolts standoff
- High reliability assembly, high shock and vibe requirement



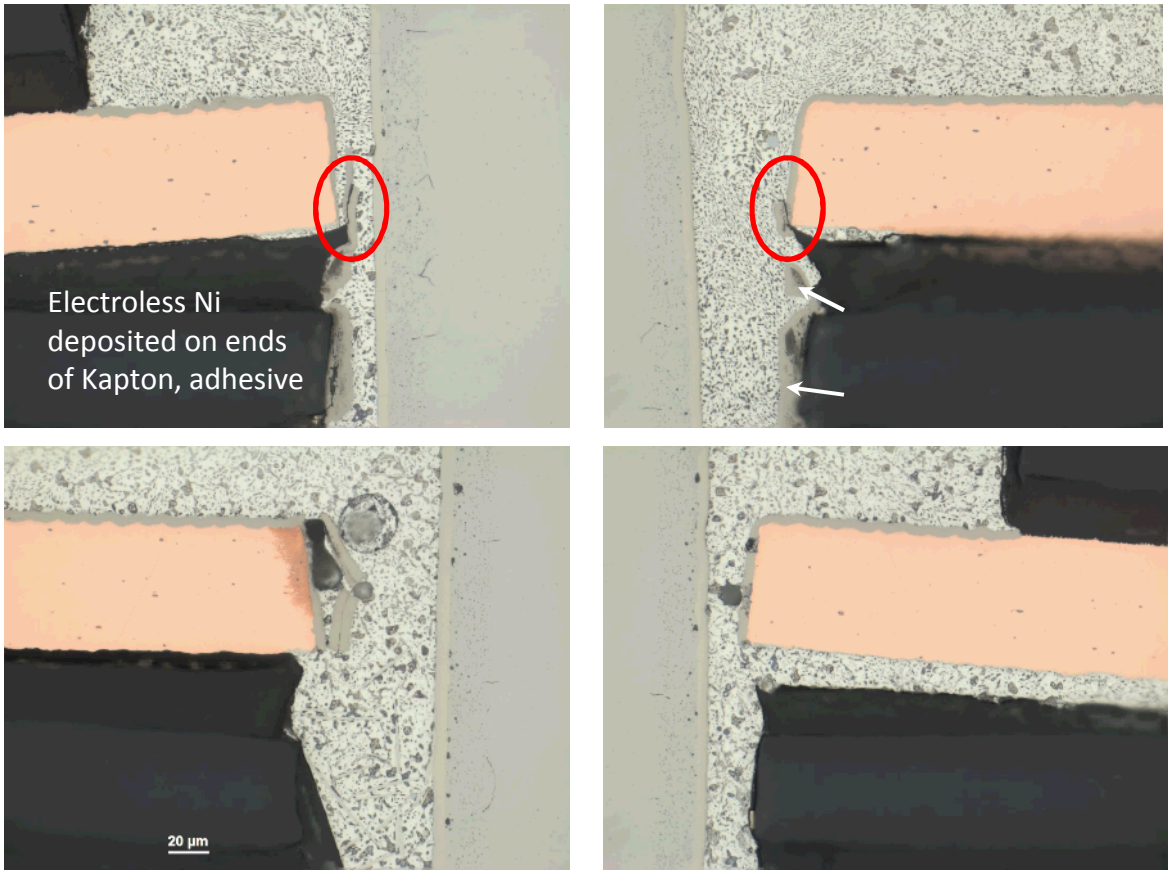






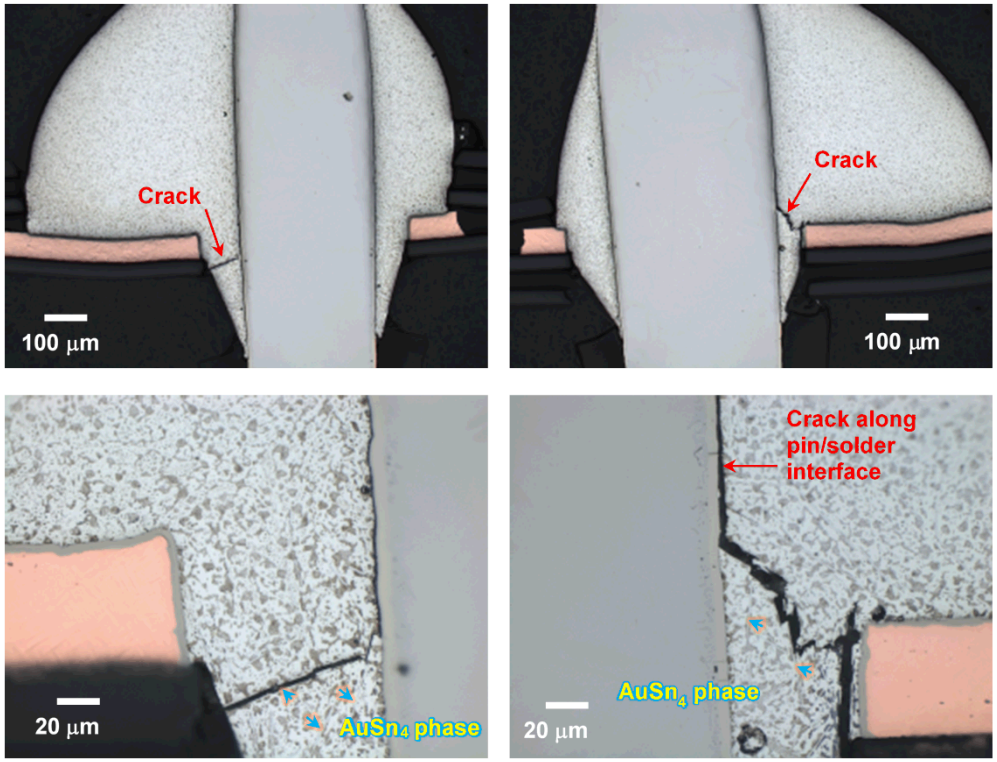
Variability of features in through-hole region

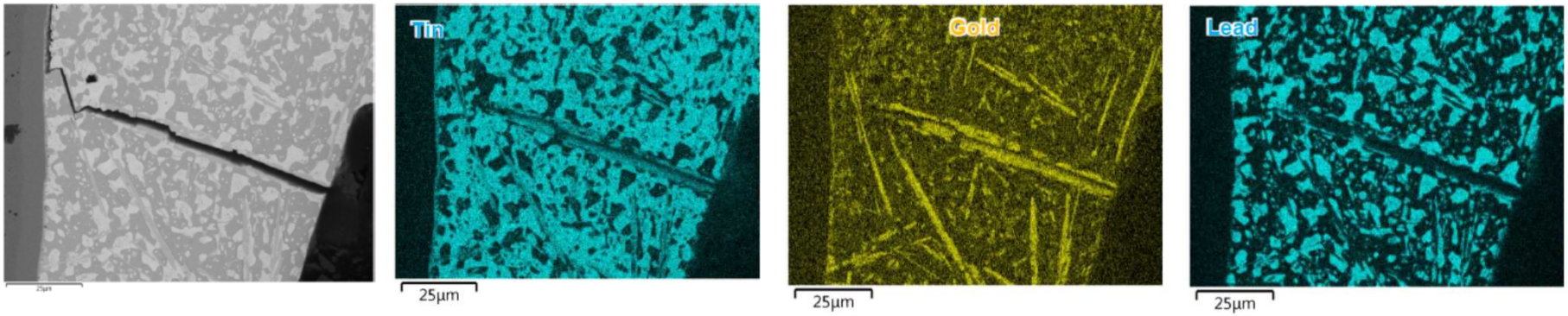
- ENIG (Electroless Nickel, Immersion Gold) or ENEPIG (Electroless Ni, Electroless Pd, Immersion Au) surface finish on pads
- Electroless plating adheres loosely to adhesive and Kapton layers. Can de-bond and move during soldering. Can lead to incipient cracks.
- Electrical and mechanical robustness is only thru the surface mount pad geometry



Gold IMC Embrittlement

- Cracks observed after shock testing.
- Cracking exacerbated by Au-rich IMC ($AuSn_4$) embrittlement. Pins are gold-plated prior to soldering to ensure solderability throughout piece part shelf life.

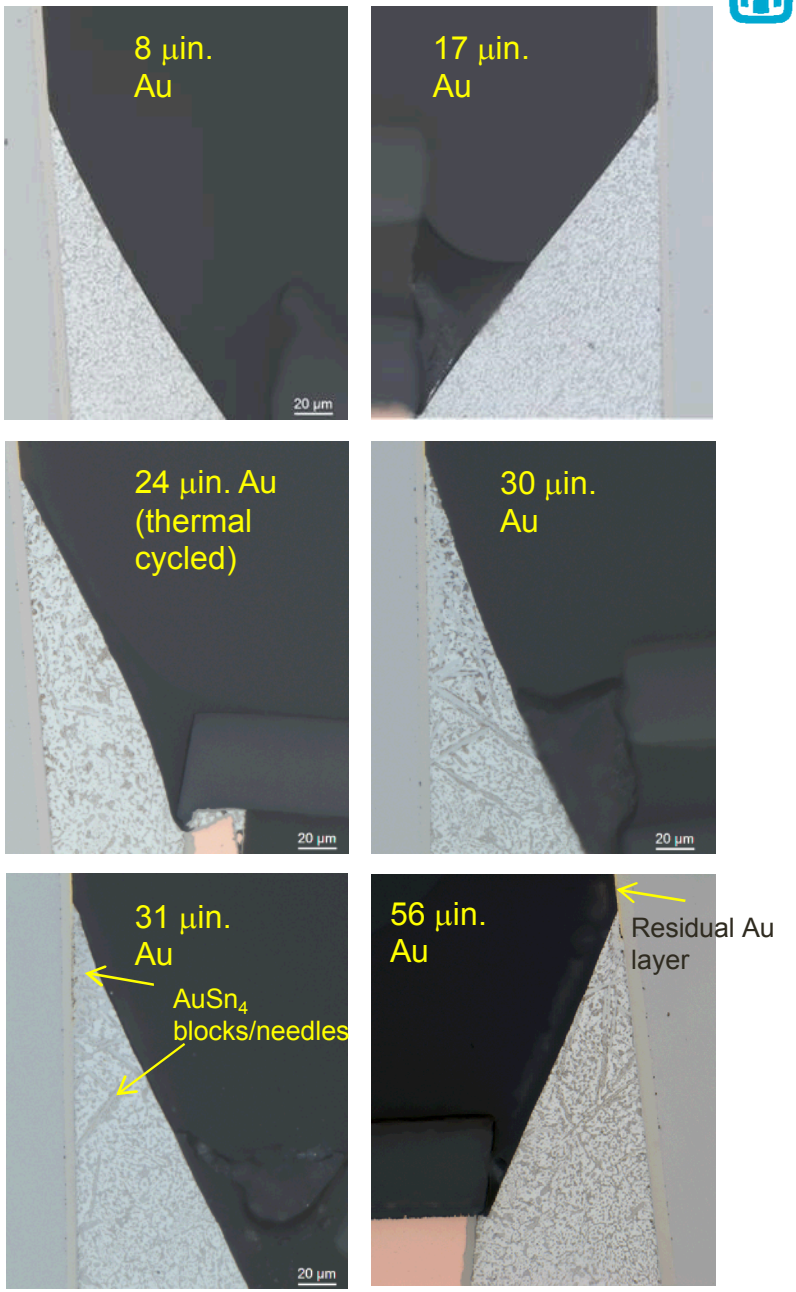




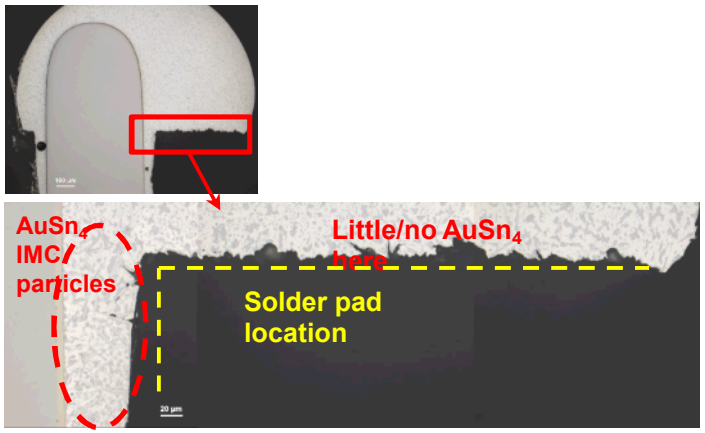
Gold Plating Study

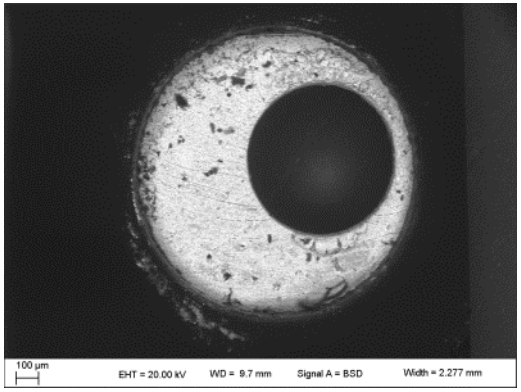
- Plated gold layer must be thin to avoid excess IMC formation because low volume of solder in the pin/flex circuit gap. Pre-tinning (hot solder dip) cannot be performed in this application.

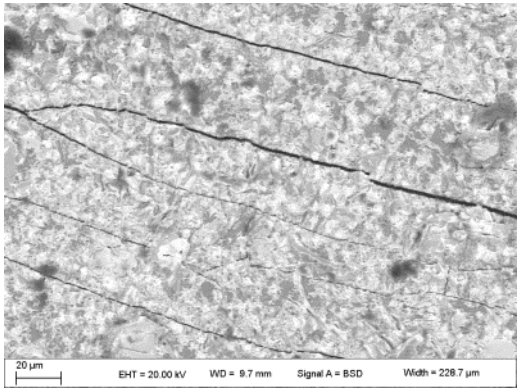
- Study to determine an acceptable thickness of gold for both solderability and mitigation against embrittlement. In this case 15-25 µin. (0.38-0.64 µm) is acceptable.

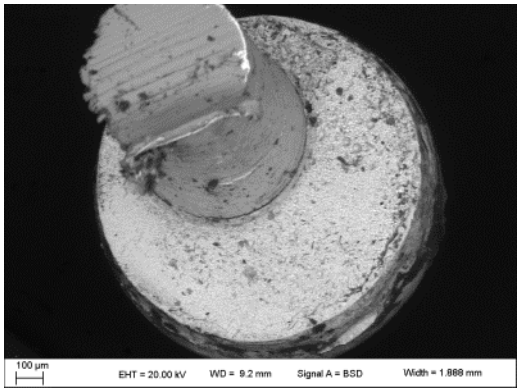


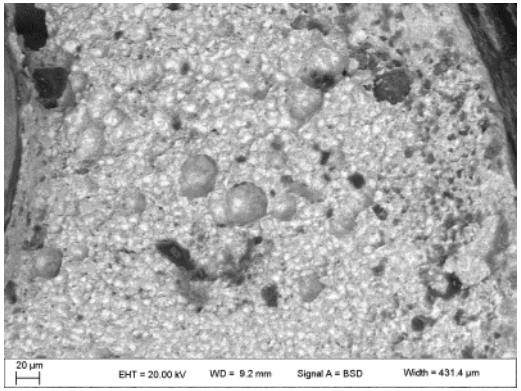
Black Pad Concern





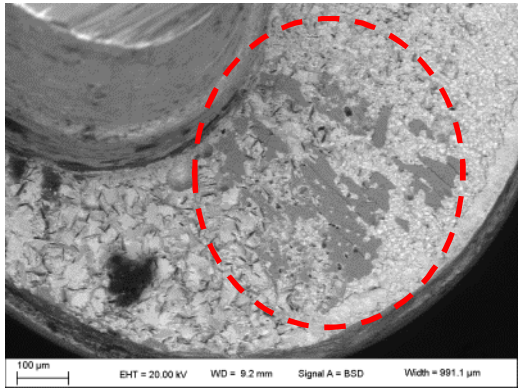


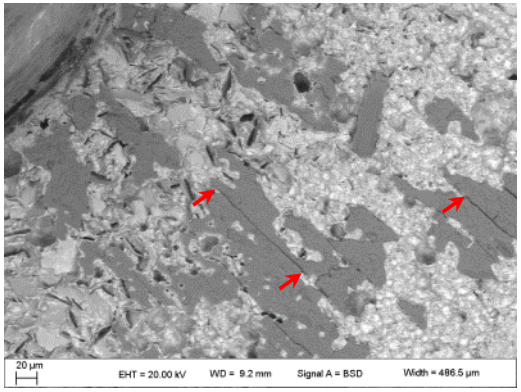


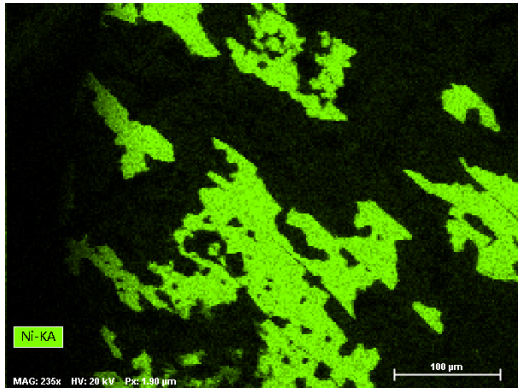


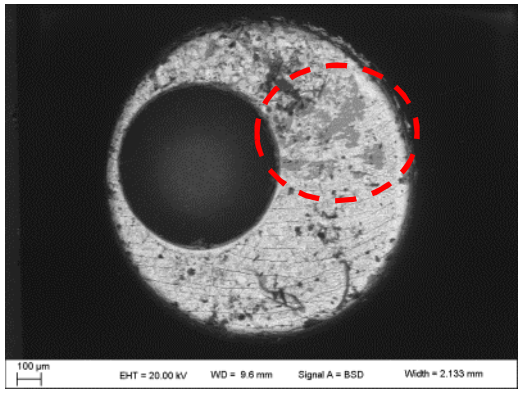
- Failures at the solder/pad interface prompted concerns about “black pad” effect, a well-known phenomenon with ENIG surface finish.
- In addition, increased circuit resistance observed post thermal-mechanical environments. 60 milliohms to several kilohms

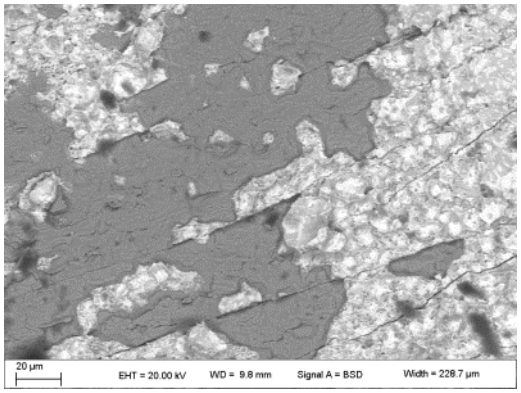
SEM/EDS Characterization

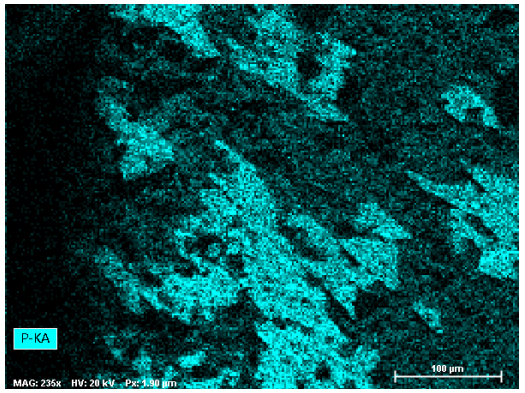




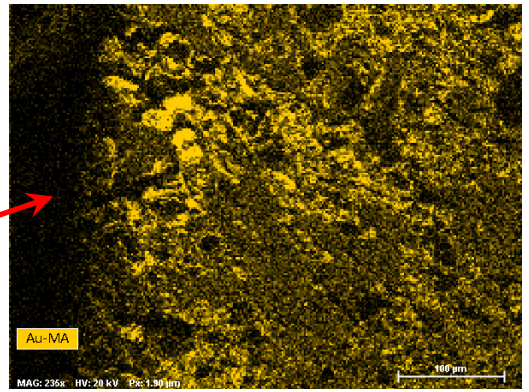








- Failure at solder/ENIG interface and/or directly through the Ni-plate layer.
- Rapid solidification of small solder volume can hamper affective dilution of Au plating



What is “Black Pad”?

Traditional ENIG = electroless Ni, immersion Au. The nodular Ni-plate surface can display deep grooves or even cracks caused by “hypercorrosion” from the highly corrosive Au immersion bath. These features, along with residual plating solution trapped in the grooves, can degrade the solder/ENIG bond strength. Solder/ENIG pad failures can have a black appearance.

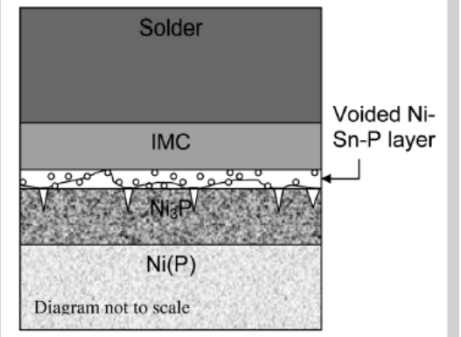
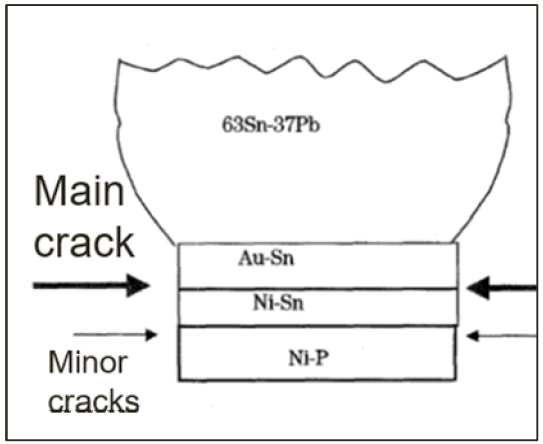


Figure 9. A schematic illustration of a solder joint with ENIG that was corroded during the gold plating process. Black pad failure is the result of propagation of the mud-cracks in the Ni(P) plating through a voided thin layer of Ni-Sn-P between IMC and Ni_3P layers.



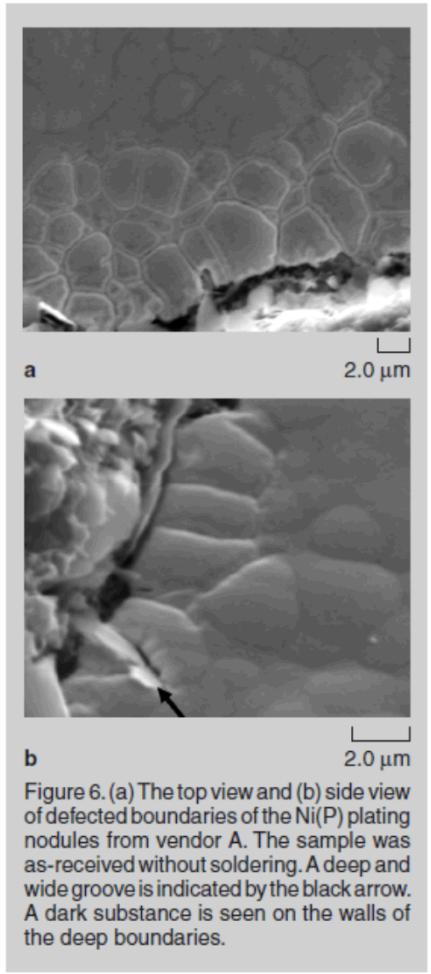


Figure 6. (a) The top view and (b) side view of defected boundaries of the Ni(P) plating nodules from vendor A. The sample was as-received without soldering. A deep and wide groove is indicated by the black arrow. A dark substance is seen on the walls of the deep boundaries.

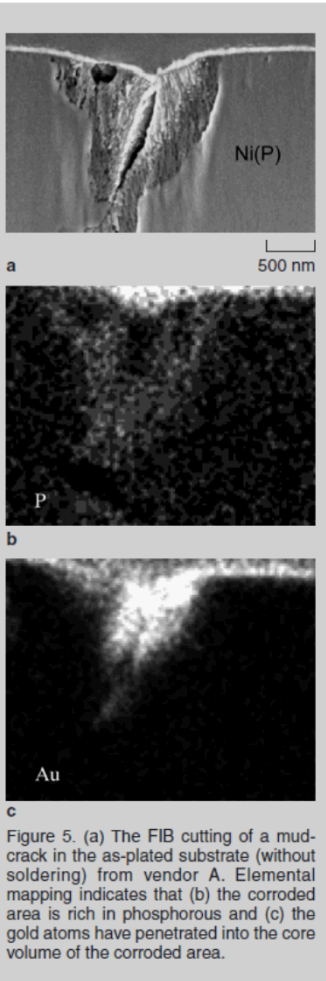
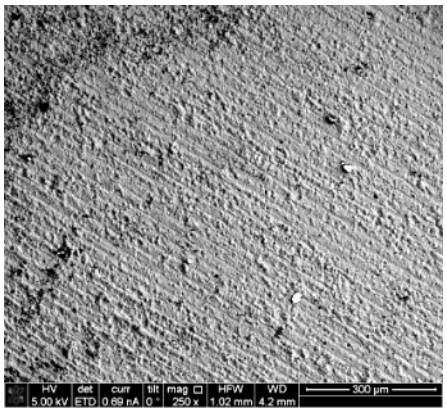


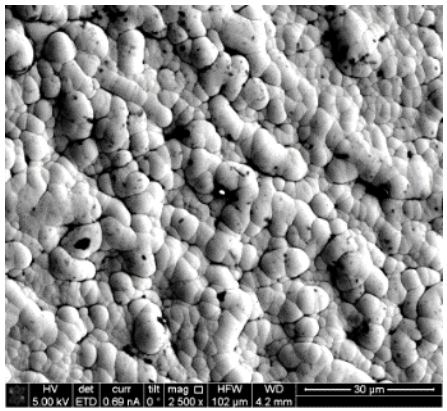
Figure 5. (a) The FIB cutting of a mud-crack in the as-plated substrate (without soldering) from vendor A. Elemental mapping indicates that (b) the corroded area is rich in phosphorous and (c) the gold atoms have penetrated into the core volume of the corroded area.

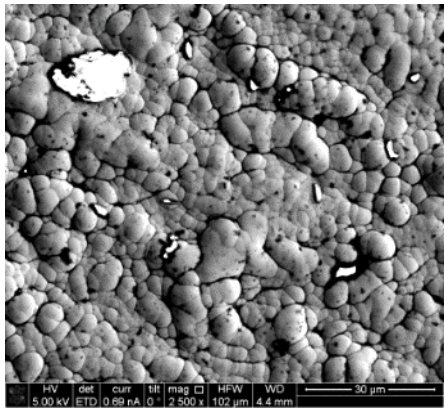
Zeng et al., *JOM*, June 2006, 75-79.
Mei et al., *IEEE Elect. Comp. Tech. Conf.*, 1998, 952-961.

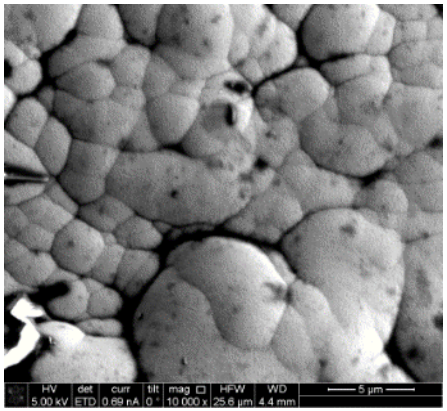
ENIG surface finish characterization

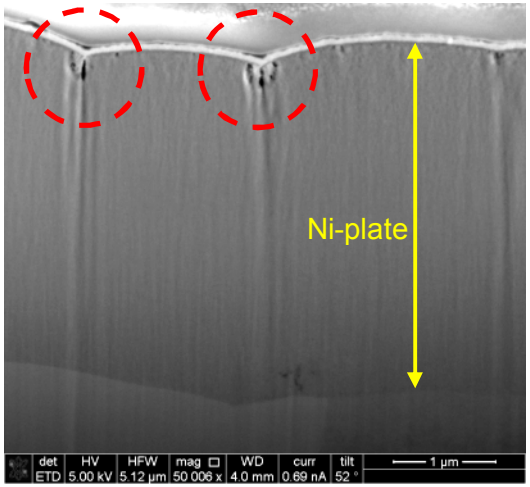
- Surface SEM and FIB cuts show some indications of Black Pad, as well as large voids.
- Decision to change to ENEPIG finish.

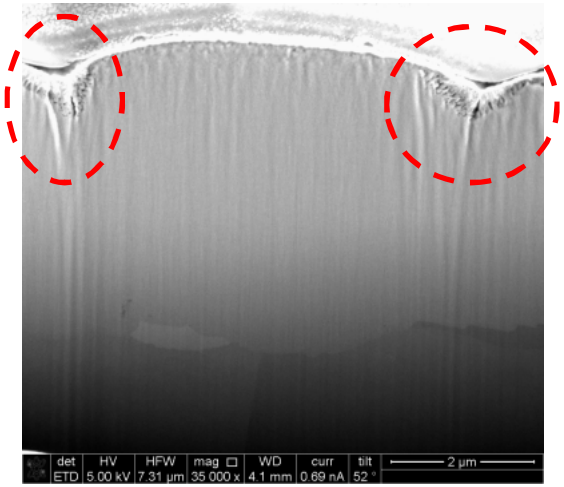


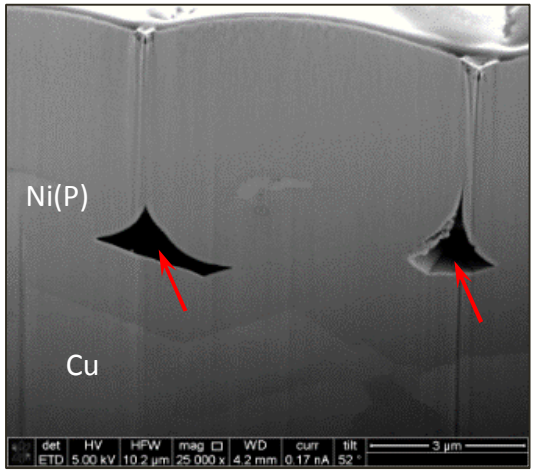




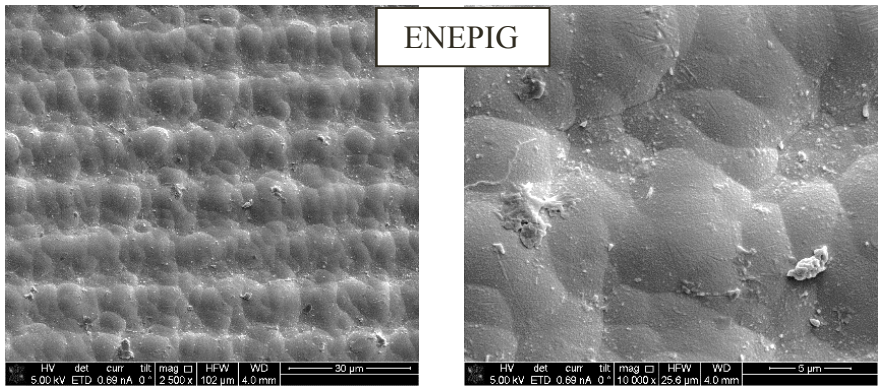


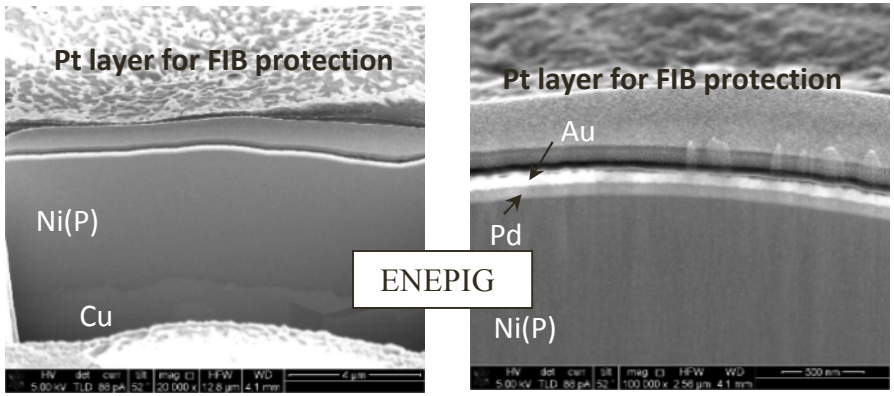


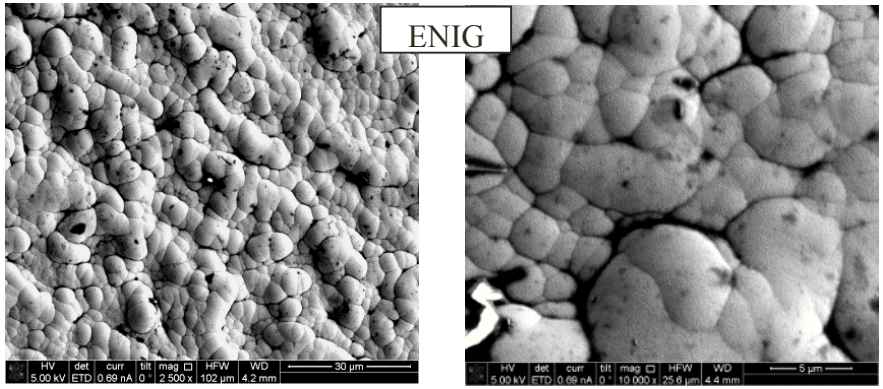


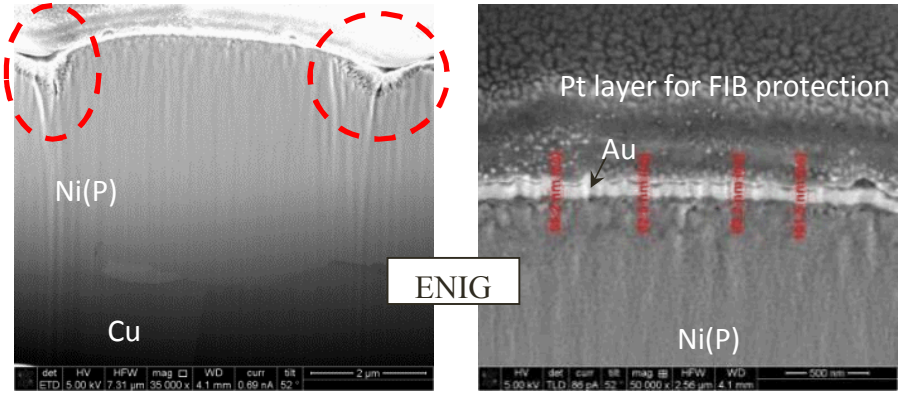


ENIG vs. ENEPIG









SURFACE

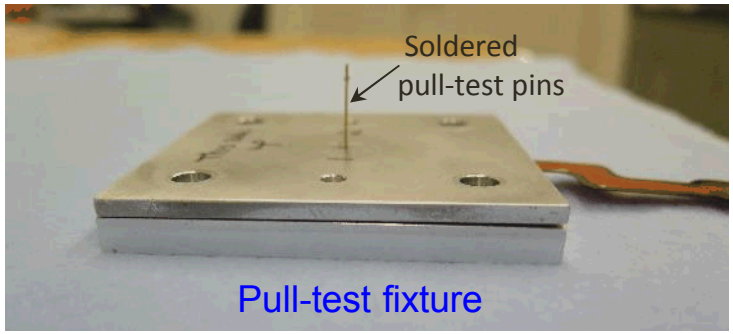
FIB Cross-section

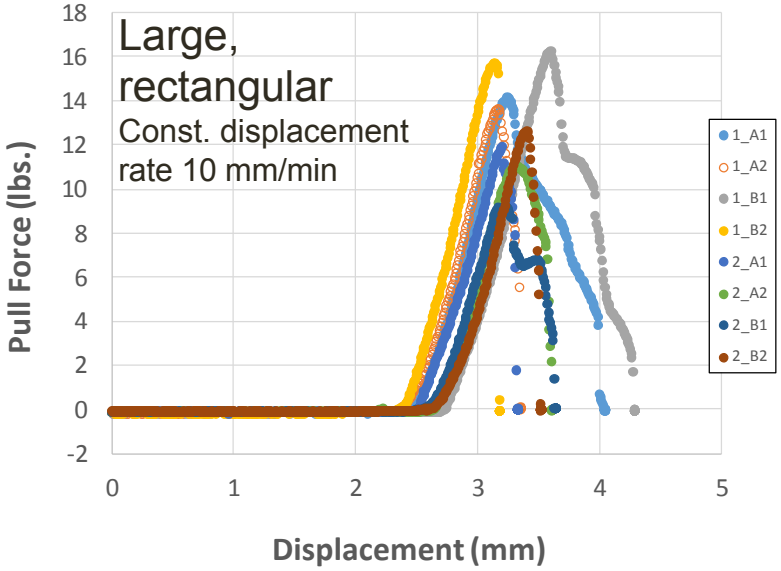
ENEPIG: Electroless Ni, Immersion Pd, Immersion Au

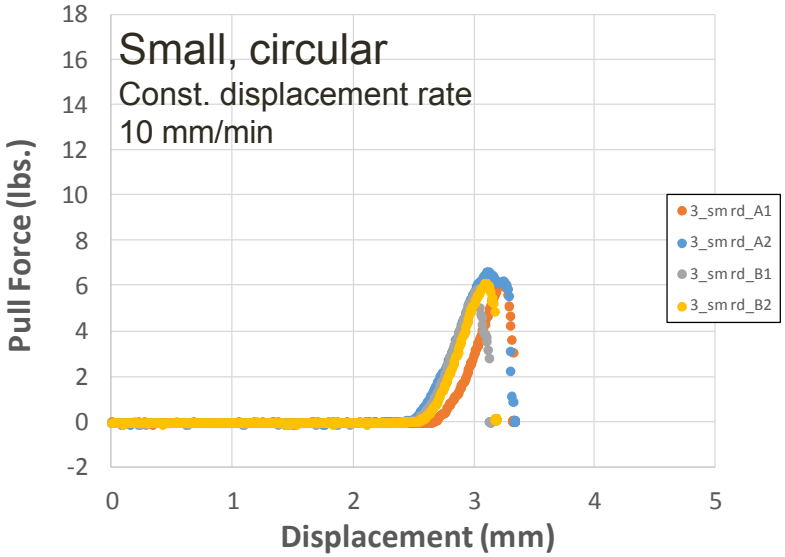
Electroless Pd layer is applied to prevent hypercorrosion of Ni layer. Immersion Au layer applied on top of Pd for good solderability.

Solder Joint Pull-Testing

- *Maximum pull force used as metric of solder joint quality.* Total of 81 tests performed.
- The main focus was solder pad geometry: large rectangular vs. small circular
  - Larger pad aids to mitigate against IMC formation (2x more solder)
- But, we tried to gain insight into the effects of ENIG vs. ENEPIG surface finish as well. (i.e. two variables changed at once…)
- Weibull statistical analysis

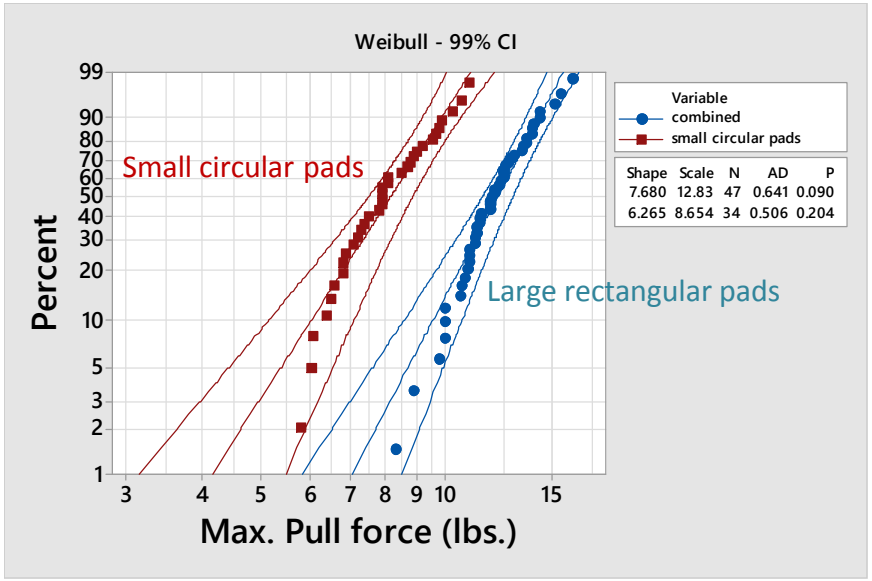


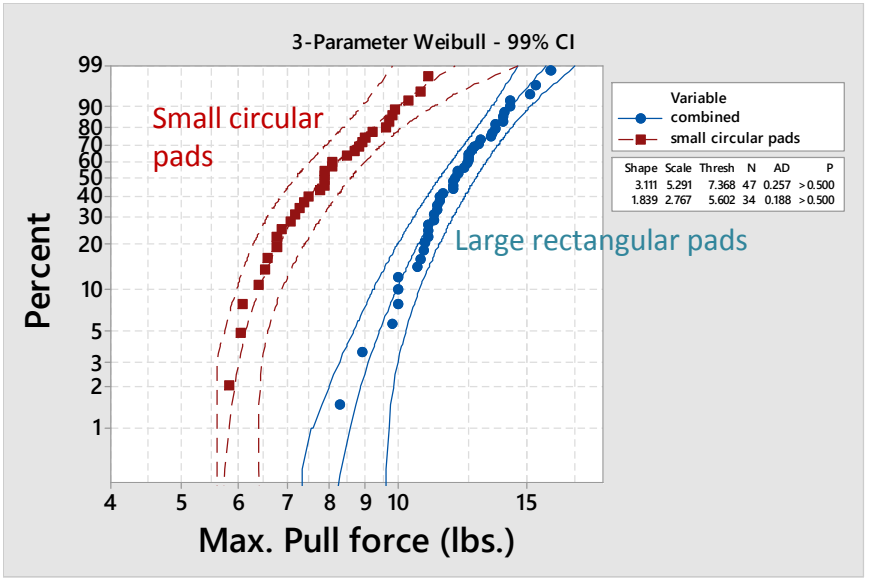




Pull-Test Results & Weibull Statistical Analysis

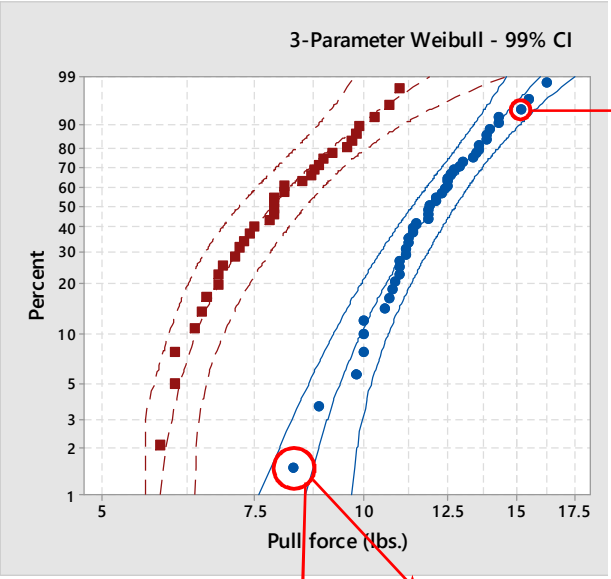
- Two-parameter and 3-paremeter Weibull statistics. Large, rectangular pads obviously display higher strength as expected. Fairly broad range of pull strengths, even within data for a given pad geometry.

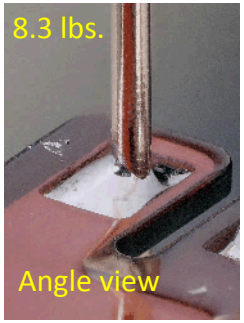


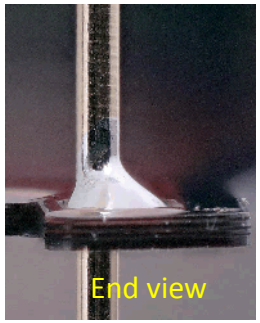


Design	Lowest pull force, lbs.	Highest pull force, lbs.	Average pull force, lbs.
Small Circular pads	5.8	11.0	8.1 +/- 1.4
Large rectangular pads	8.3	16.3	12.1 +/- 1.7

Pull-test Sample Characterization



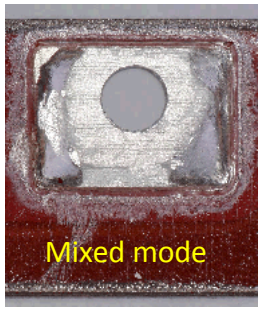


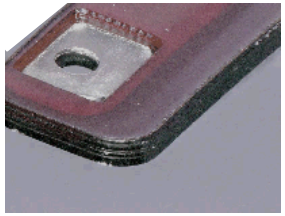


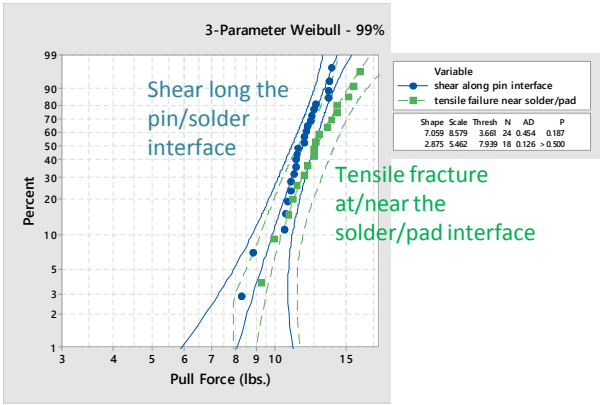
- Joints with low solder volume, low solder meniscus height, exhibit low pull strength. Joints with large solder volume give high pull strength.
- Hand soldering: amount of solder wire fed into the joints will vary. Cleanliness of surfaces and pre-heating of surfaces with soldering iron can also affect meniscus height. More consistency expected as experience is gained for a given solder technician.

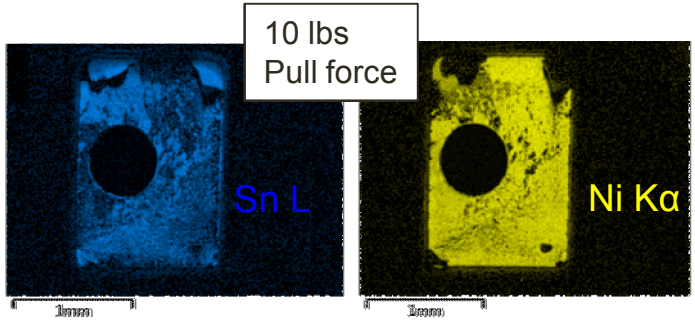
Post-test Characterization

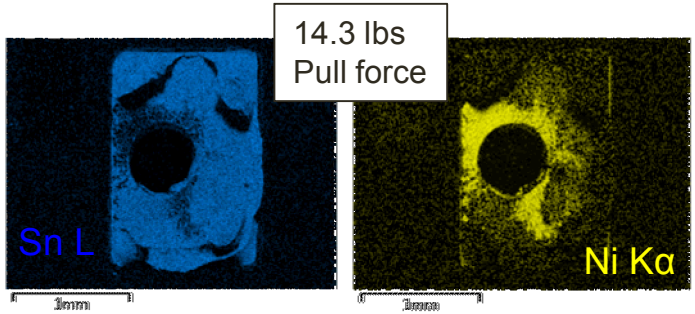
- Failure types: 1. Solder/pin interface, 2. Solder/substrate interface, 3. mixed mode. Only slight differences between types 1 & 2, although significant (95% confidence).
- What determines failure mode? … could be tradeoff based on solder volume/height, amount of solder in the through-hole region, and phases present at the interfaces. So far, no clear evidence of black pad effect, but fracture through the solder is stronger than failure at the solder/pad interface.











Summary

- Based on microstructural characterization and failure analyses, pin-to-flex circuit solder joints were optimized with regard to Au-rich IMC embrittlement and black pad effect. Thin Au-plating on pins preserves solderability while minimizing IMC formation. ENEPIG surface finish on solder pads alleviates black pad concerns.

- Pin pull testing provides a quantitative measure of the effects of solder pad geometry changes. Larger rectangular pads result in solder joints with >50% higher pull strength. Analysis of failure modes can help elucidate any solder/pad adhesion issues.

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