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Microscopy of Solder Joint Failures Due to Gold Intermetallic Embrittlement[1]

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Many microelectronic assemblies are nickel plated for solderability and over-plated with gold for corrosion protection. The gold layer must be wicked away by molten tin prior to soldering, a process known as "pre-tinning". Pre-tinning removes most or all of the Au layer and leaves a solderable Ni finish for good bonding. If pre-tinning is not performed or is inadequate, for example if the initial Au layer is too thick, a $AuSn_4$ intermetallic (IMC) layer will form between the Ni-plated part and the solder. Alternatively, the Au can diffuse into the solder and form IMC needles or blocks within the solder itself. In either case, the solder joint can be susceptible to failure due to embrittlement by the $AuSn_4$ intermetallic phase. The objectives of this work were to characterize the microstructures of solder joints contaminated by gold and to discuss the microscopy techniques used to determine the extent of gold embrittlement.

Figure 1a shows the interface between Pb-Sn solder and a part which was initially Ni and Au plated. After soldering, a thick $AuSn_4$ IMC layer is present indicating inadequate pre-tinning prior to soldering. The layer actually consists of closely spaced needles which grow from the Au-plated region into the solder. Quantitative image analysis (QIA) is commonly applied to determine the thickness of the $AuSn_4$ IMC layer and degree of embrittlement. If a Au-contaminated solder joint is subjected to mechanical loading or thermomechanical cycling, cracks can develop along the IMC layer or in the solder adjacent to the IMC layer. Figure 1b shows microcracks within and around $AuSn_4$ particles in a region close to a solder/Cu component interface. Failure can occur if these microcracks link up during mechanical loading or fatigue cycling.

Figure 2a shows the microstructure of a 95Sn-5Ag (high temperature solder) fillet with a high volume percent of $AuSn_4$ IMC needles/blocks. The solder microstructure also contains particles of Ag_3Sn in the Sn matrix, which is expected for this solder. Failure was discovered in this joint after fatigue testing of the assembly. The region adjacent to the fracture surface was analyzed by QIA and found to contain about 15.2 vol. % $AuSn_4$. This corresponds to approximately 5.3 wt.% Au in the solder. Other researchers have determined that 3-5 wt.% of Au can cause embrittlement of solders [1-3]. Therefore, the cause of failure in this case was attributed to buildup of $AuSn_4$ phase and subsequent solder embrittlement. The presence of secondary cracking along the IMC particles adjacent to the main fracture surface also provides evidence for $AuSn_4$ embrittlement. It is also interesting that a gradient was found in the $AuSn_4$ content with distance away from the main fracture surface. Figure 2b shows electron microprobe (EPMA) data along with QIA results for a trace from the main fracture surface into the solder fillet. A gradient in Au contamination can occur if only one component in a solder fillet joint is pre-tinned and the other is not. In addition, the extremely fast cooling rates during soldering and the relatively slow diffusion rate of gold at solder eutectic temperatures may prevent full mixing of Au throughout the solder joint.

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In summary, optical microscopy, image analysis, SEM, and EPMA can be used to determine the level of Au contamination in solder joints. Quantitative analysis for Au and identification of $AuSn_4$ particles or layers are essential steps in determining whether Au embrittlement is the cause of failure.

References

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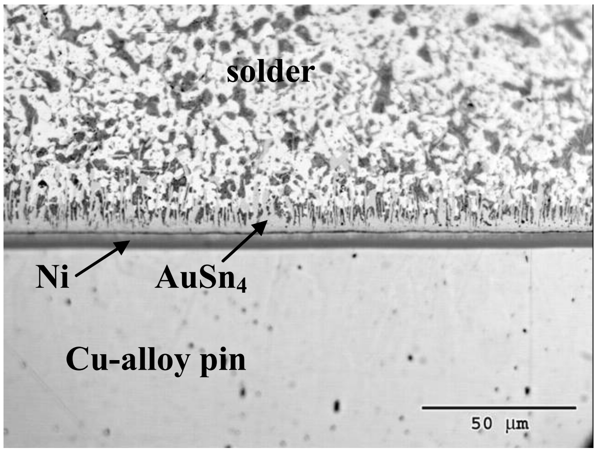


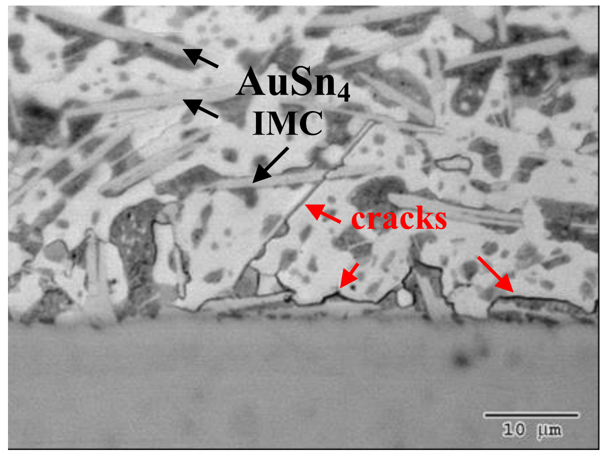
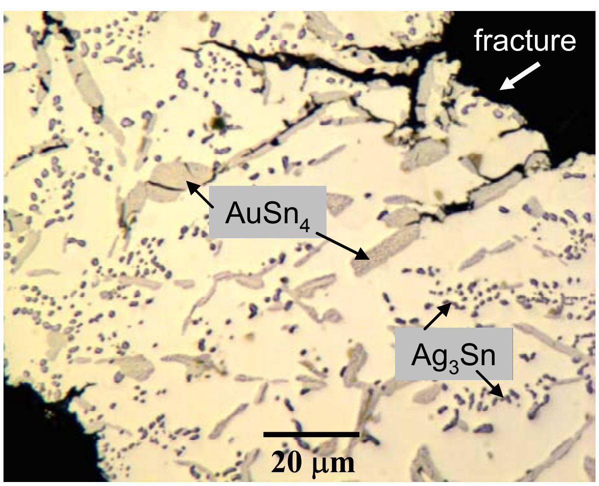


Fig. 1a. Optical photomicrograph of $AuSn_4$ IMC layer at the interface between solder and a Ni plated Cu-alloy connector.
Fig. 1b. Microcracks developed around and through $AuSn_4$ IMC needles adjacent to a solder/Ni-plated steel interface.



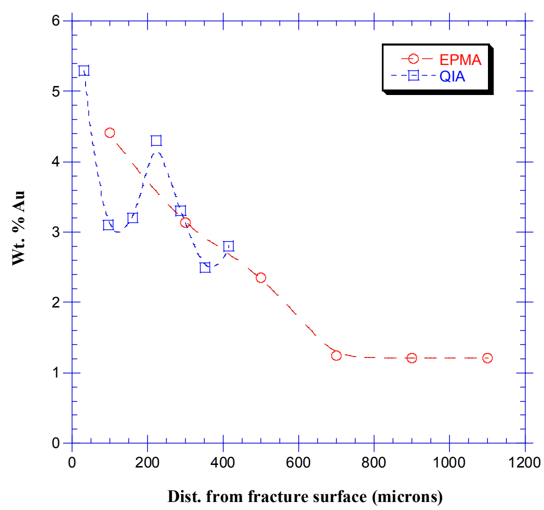


Fig. 2a. Optical photomicrograph of solder microstructure near the main fracture surface.
Fig. 2b. Results of Au content measurements by EPMA and image analysis. Each EPMA trace data point represents the average of 20 individual probe data points. Image analysis was performed on seven optical photomicrographs at 1000x magnification.

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