

# **Au-Al Intermetallic Formation in a Resistance Weld (A New Outbreak of “Purple Plague”?)**

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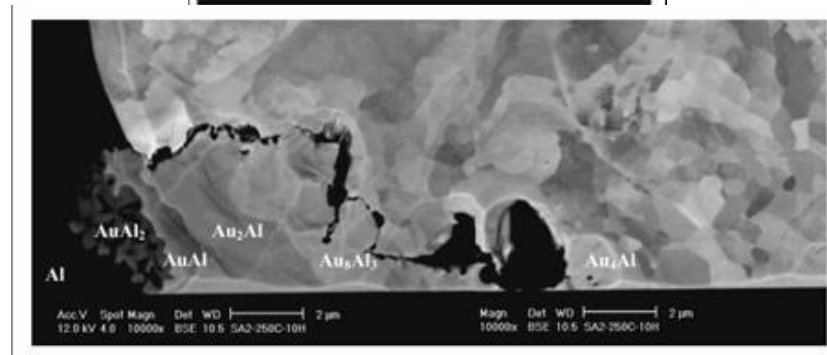
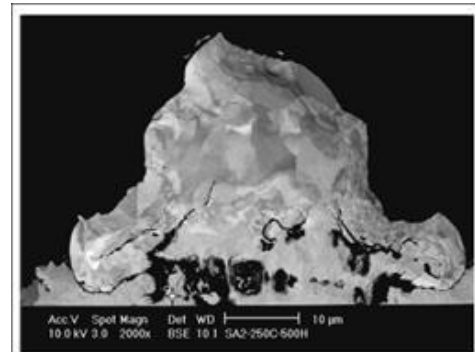
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# Au-Al Intermetallic Compound (IMC) Formation

- “Purple Plague” is a well known issue in microelectronics wire bonding. Wire bonds are thin, delicate joints.
- Au-Al IMC phases (some with purple color in light optical microscopy) cause porosity, cracking, and brittle behavior
- This is a long-standing issue in bonding of Au wire to Al bond pads or vice-versa

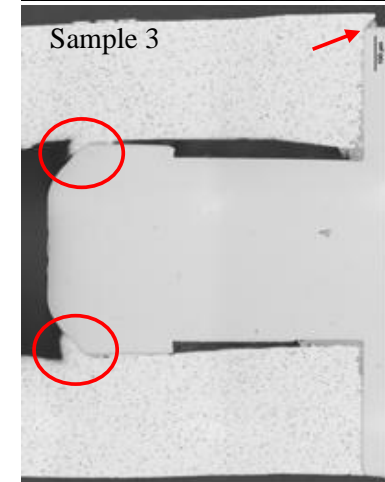
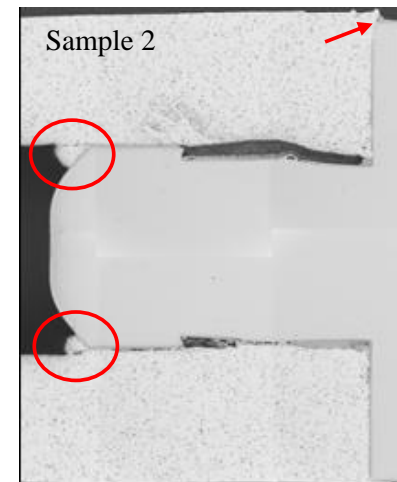
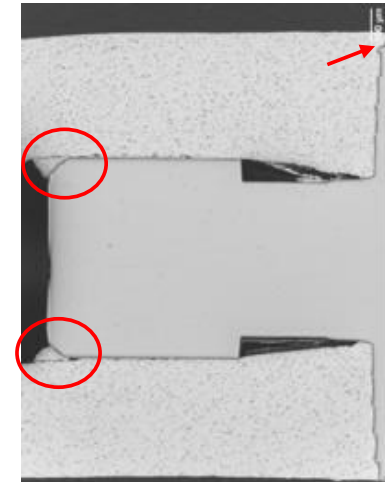
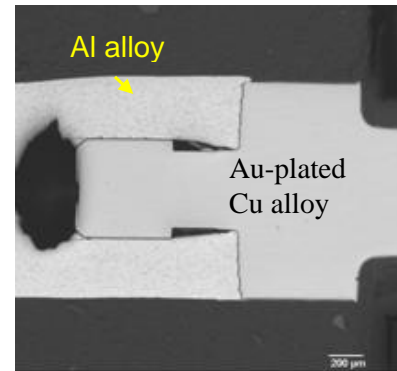
Backscatter electron images of wire bond thermally exposed for 150 hr. at 250°C (top) and higher magnification image of wire bond exposed for 10 hr. at 250°C (bottom). Cracks and cavity growth are observed in the vicinity of the  $Au_8Al_3$  and  $Au_4Al$  phases.



N.J. Noolu et al., *J. Mater. Res.*,  
19(5), 1374-85, 2004.

# Au-Al IMC Found in a Resistance Weld Joint

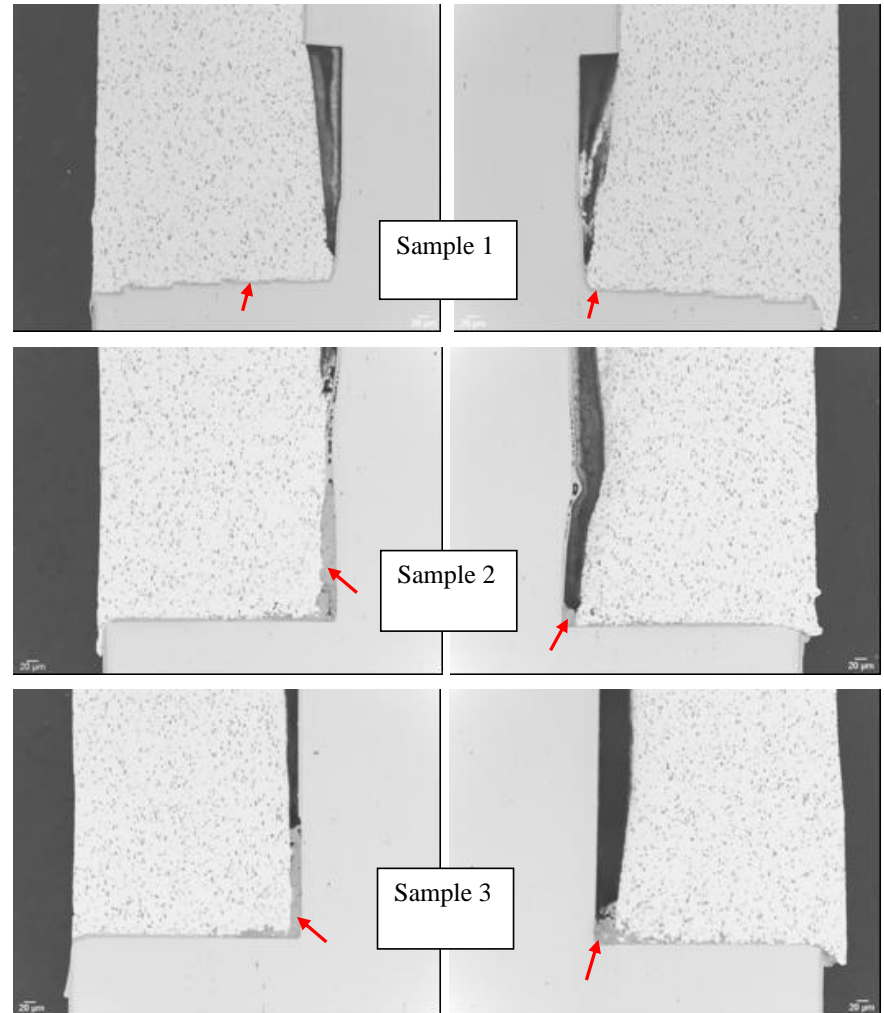
- In this investigation, Au-Al IMC phases were found in a resistance weld joint between a Au-plated Cu alloy plug and an Al alloy sleeve
- This is a much more mechanically robust joint with high amount of bonded surface area
- However, the presence of purple plague IMC phases still raised concerns about joint integrity and long-term growth of these IMC phases at the interface



Examples of joints in this study: Circles indicate material pushed ahead of the pin “plunger” during joining, and arrows indicate deformation at the receptacle base/pin shoulder interface. Like a “forge+resistance weld”...

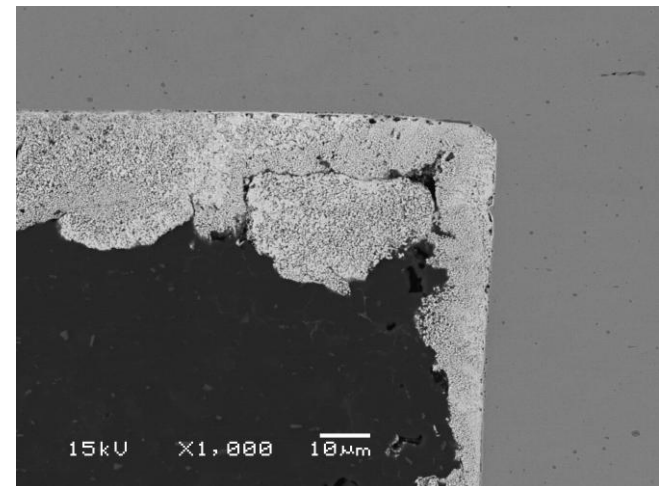
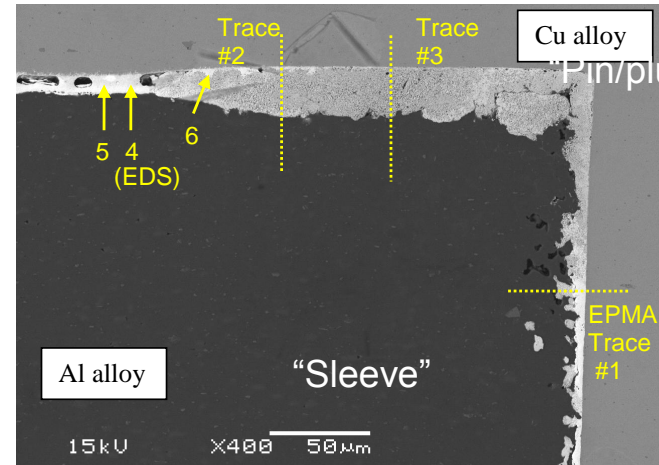
# Varying Amounts of IMC in Different Samples

- IMC was ~25 microns (1 mil) thick in some cases
- IMC concentrated near I.D. of the sleeve and where the pin meets the base (shoulder of the pin). Good interface contact, no gap in these areas.



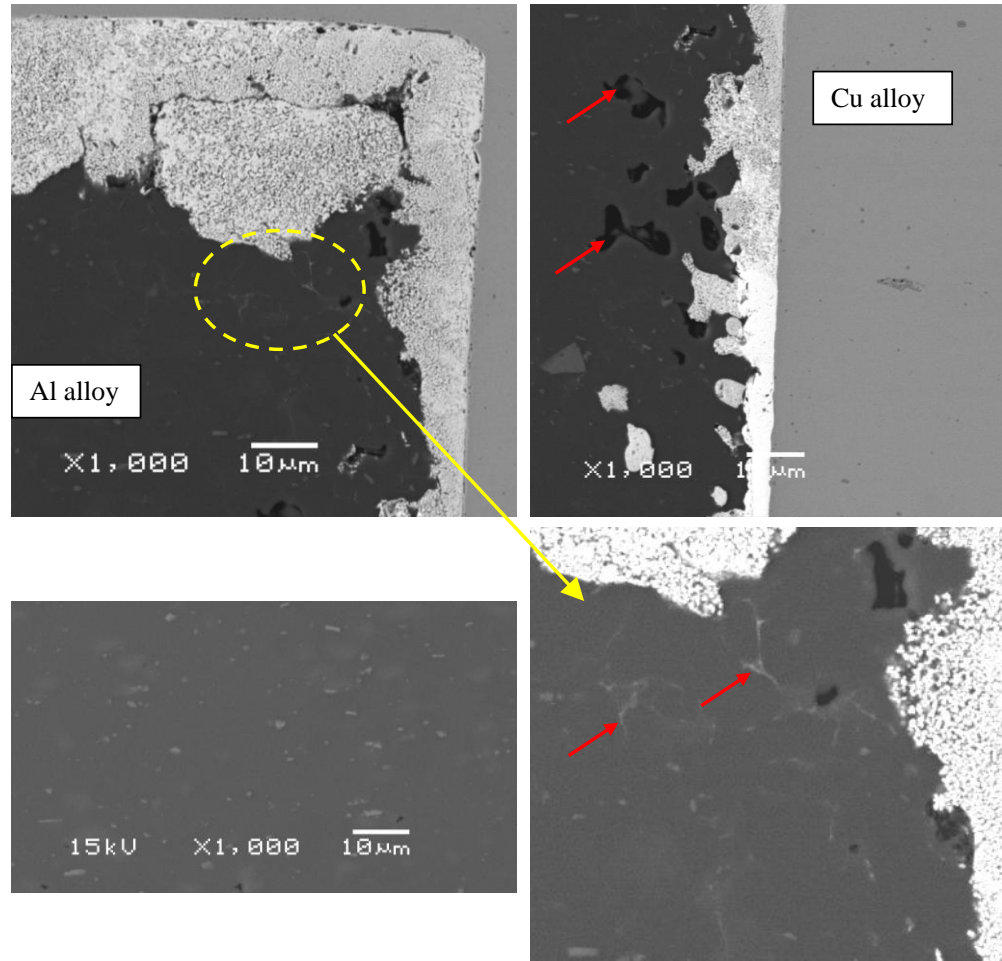
# IMC Microstructure

- BSE photomicrographs show multi-phase IMC microstructure with fine-scale porosity and some cracking.
- Locations of EDS and electron probe microanalysis (EPMA) traces are shown.

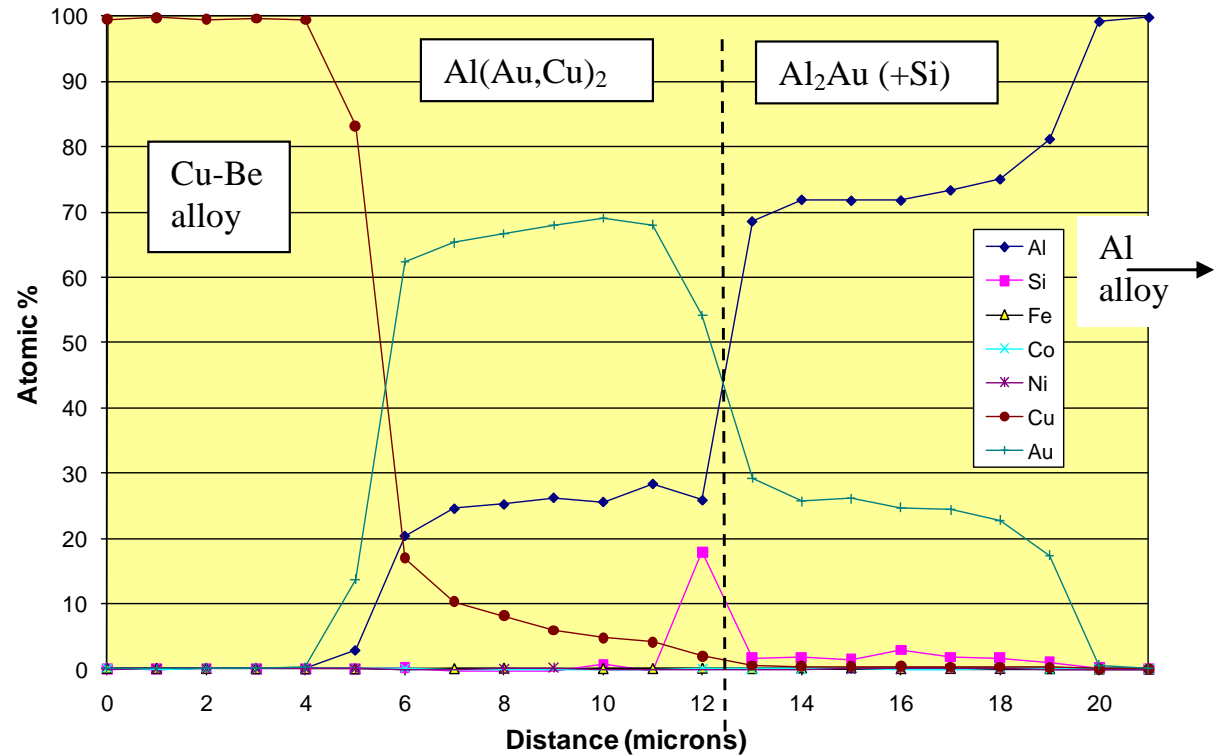
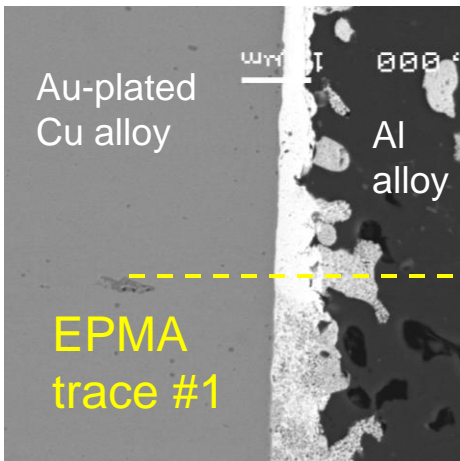


# Evidence for Partial Melting of Al Alloy

- Evidence for partial melting of the Al alloy during resistance joining:
  - Porosity (non-spherical)
  - Changes in morphology of 2<sup>nd</sup> phase in the alloy near the joint. More akin to a cast microstructure.
  - Pieces of IMC apparently “broken off” from the main layer
  - Mottled/porous nature of the IMC itself

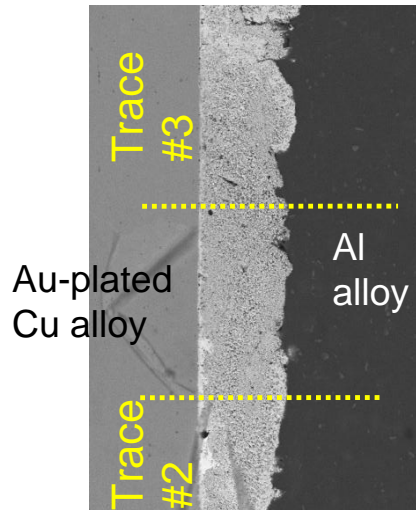


# Two IMC Phases Found in EPMA Trace #1



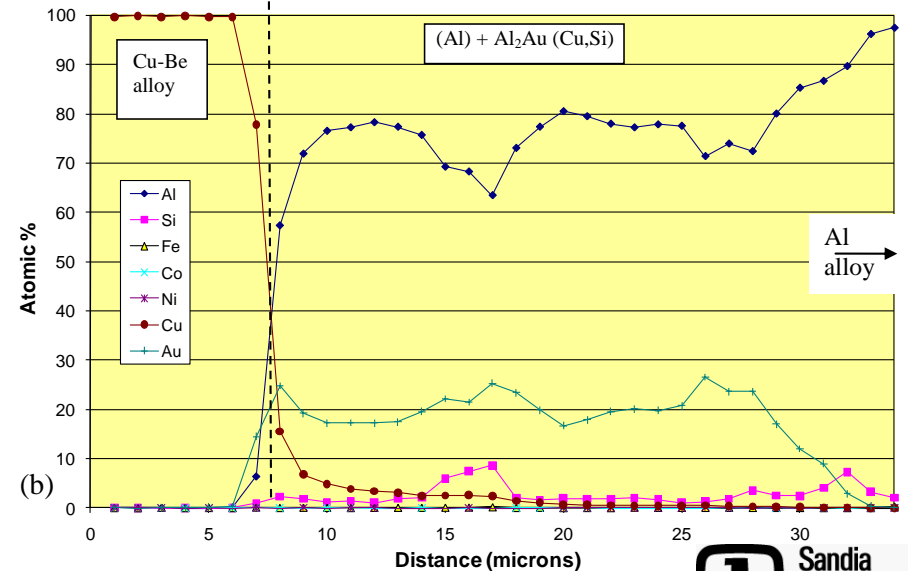
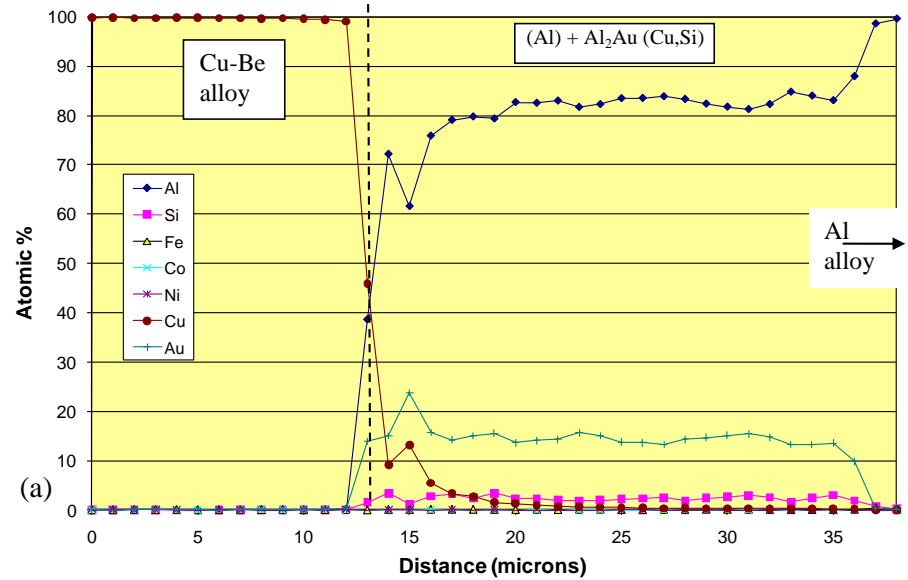
- Two IMC phases, one Au-rich:  $\text{Al}(\text{Au,Cu})_2$  and one Al-rich:  $\text{Al}_2\text{Au}$  in a layered structure in this region

# EPMA Results (continued)

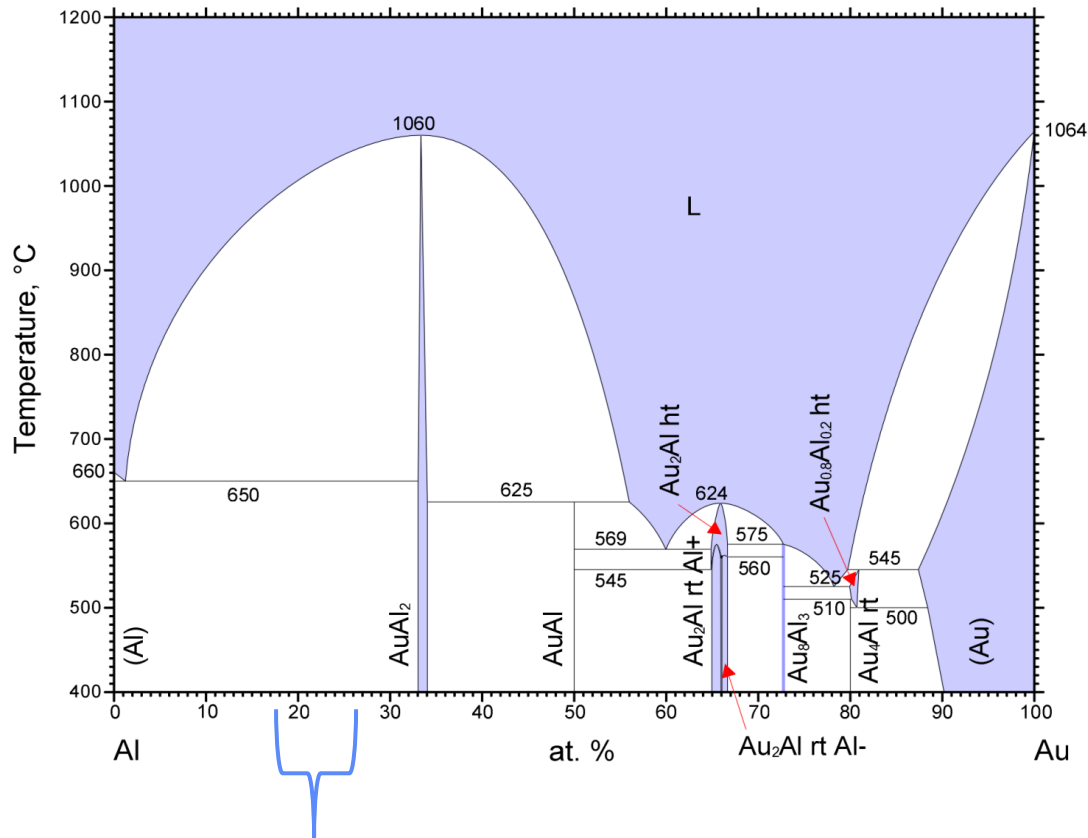


- Main thick IMC layer composition is Al-rich (~70-80 at.% Al). The microstructure suggests a two-phase mixture of:

(Al) solid solution +  $\text{Al}_2\text{Au}$

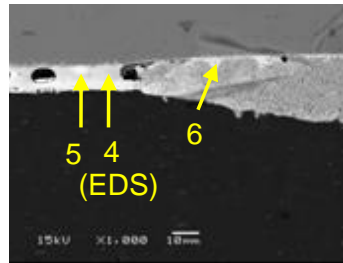


# Al-Au Phase Diagram, correlation with Microstructure

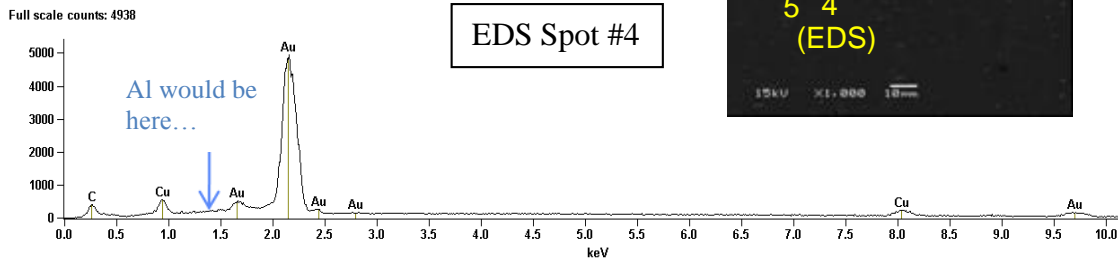


Approximate composition of main thick IMC layer,  
Two-phase eutectic mixture of (Al) +  $Al_2Au$ ,  
(Equilibrium) eutectic temperature is 650°C

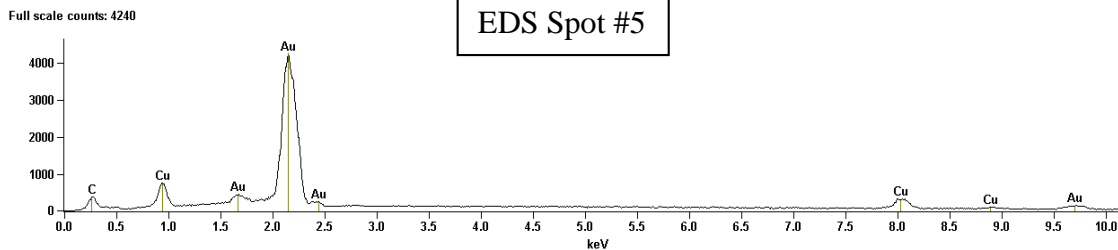
# Analysis of Adjacent Areas with only thin IMC or no IMC at all



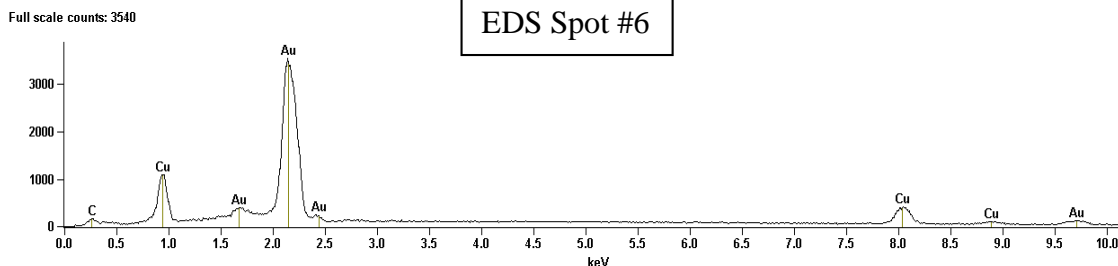
EDS Spot #4



EDS Spot #5



EDS Spot #6

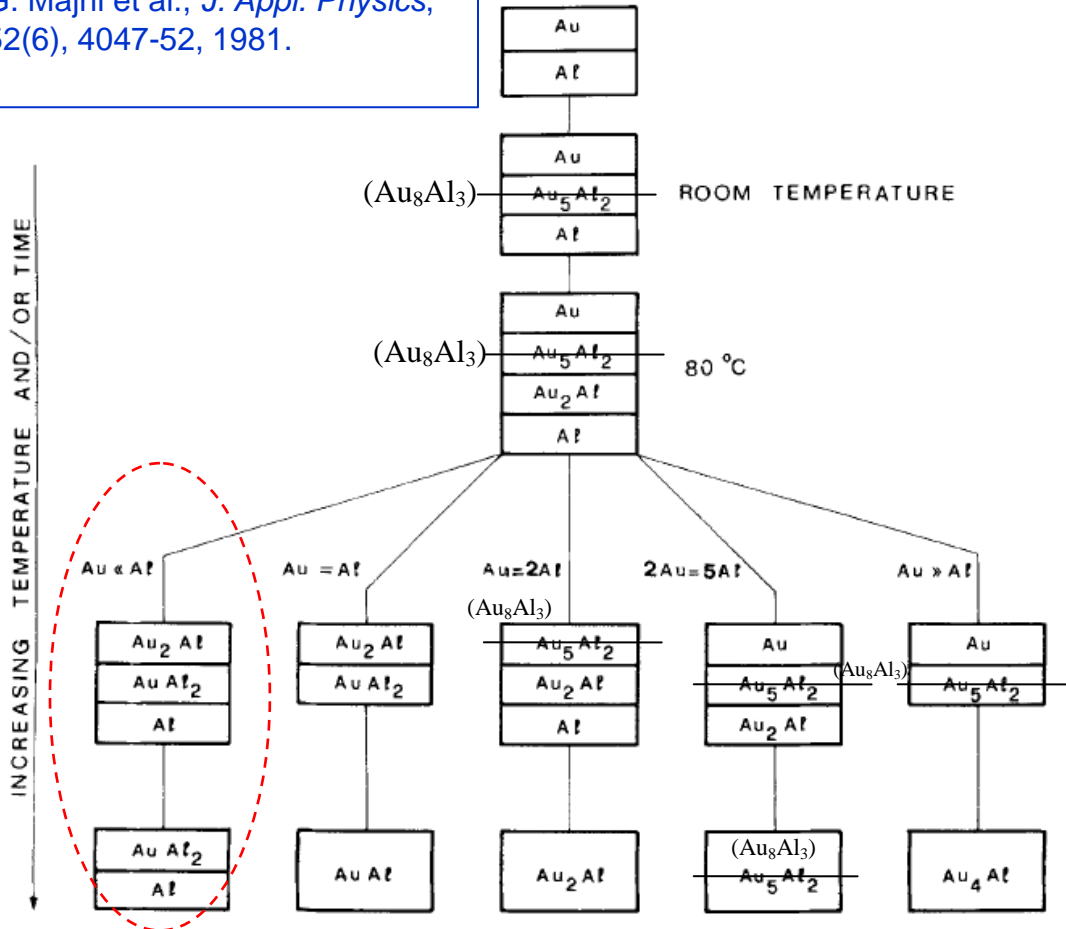


## Spot EDS Analyses

- Adjacent areas show residual Au-plating layer, with some Cu diffusion, but no Al present.
- Presume Al alloy did not melt here...

# Phase Sequence Maps have been Developed in the Literature

G. Majni et al, *J. Crystal Growth*, Vol. 47, 583-8, 1979.  
 G. Majni et al., *J. Appl. Physics*, 52(6), 4047-52, 1981.



- The microstructure is *as expected* for an Al-rich joint ( $Al \gg Au$ ) with high temperature and/or long times.
- Final thickness of IMC will be limited by finite supply of Au (from thin Au plate layer)
- This is the opposite scenario compared to a typical microelectronics wire bond with Au wire on a thin Al bond pad.

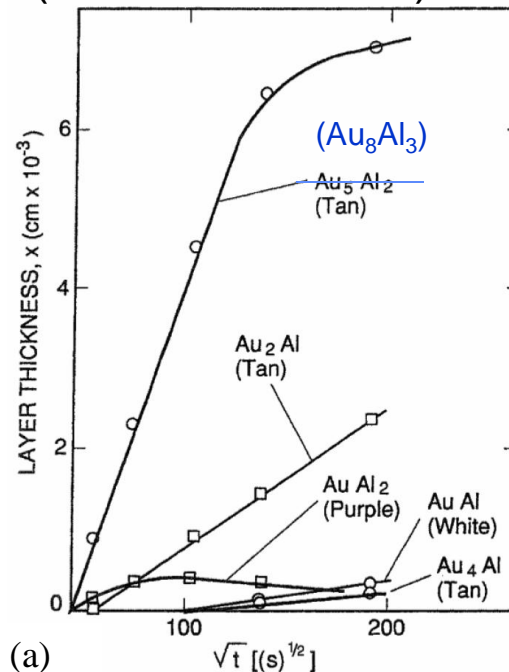
# There was Still a Concern for Long-term Solid-State IMC Growth (in service)

- Comparisons of observed IMC thicknesses to IMC layer growth kinetics found in the literature.
- Did IMC growth occur during long-term storage or during welding (short time/high temperature)?
- Will appreciable IMC growth be observed in the future?

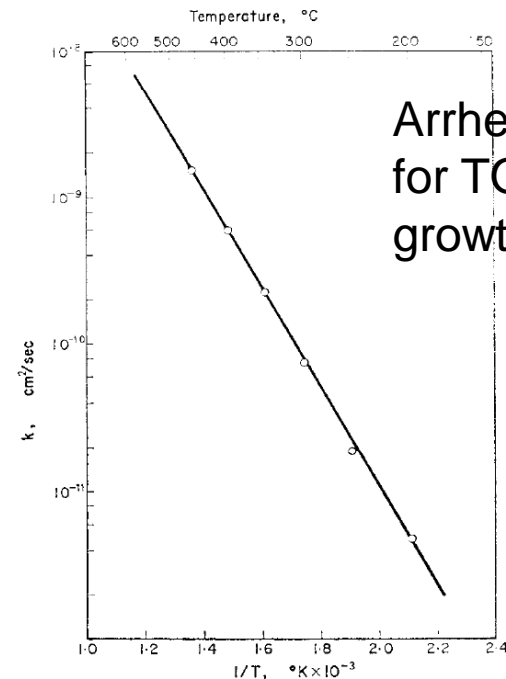
Growth of individual phases at 400°C (“colors” identified)

Example of classic IMC growth kinetics study by Philofsky.

E. Philofsky, *Solid State Electronics*, Vol. 13, 1391-9, 1970.



(a)



(b)

Arrhenius plot for TOTAL IMC growth

# Slow Solid-State Growth Kinetics Cannot Explain Observed thick IMC

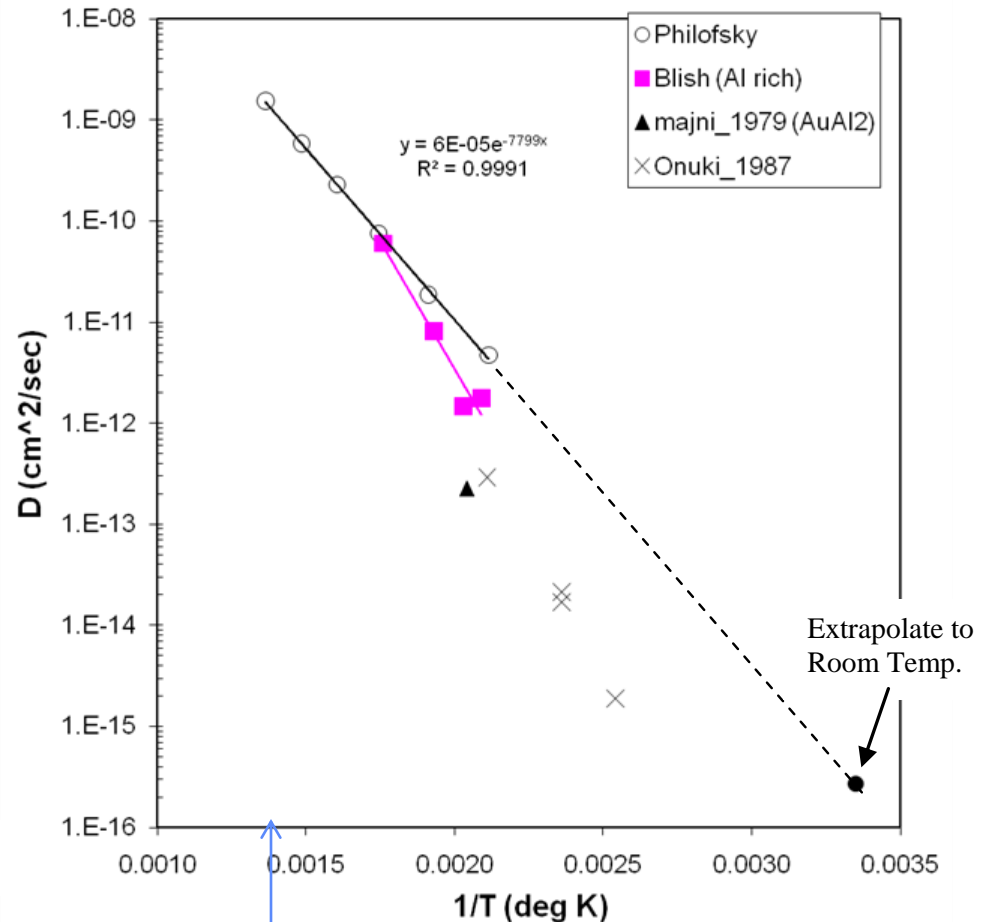
- Plot shows solid-state IMC layer growth kinetics from several studies and extrapolation of Philofsky kinetics to room temperature.
- The slow growth kinetics cannot explain the observed thick main IMC layers.

Using simple estimate of diffusion distance  $x \sim (Dt)^{1/2}$ :

~ 4.6  $\mu\text{m}$  layer in 25 yrs. (Philofsky, total IMC mainly  $\text{Au}_8\text{Al}_3$ , which we don't see...)

or only

~0.3  $\mu\text{m}$  layer in 25 yrs. (Blish/Onuki, Individual IMC layers )





## Results Indicate IMC formed *During* Resistance Joining Process and not During Long-term Storage

- Even extrapolating solid-state kinetics to high temperature (solid-state resistance joint) does not correlate with observations.
  - At 400°C, the estimated time required for the thick IMC would be 67 minutes. Even at 600°C, the estimate is 11 minutes. The actual resistance joint is formed in ~ milliseconds.
- **Therefore, a liquid-phase (and temperatures above the Au-Al eutectic of 650°C) are required for the fast IMC formation kinetics and observed thick IMC layers.**
- The other microstructural evidence also supports partial melting during joint formation.



# Summary

- The resistance weld joints appear to be mechanically robust with significant deformation and mechanical capturing of the Cu-alloy pin by the Al alloy receptacle.
- The microstructural evidence of partial melting of the Al alloy (a liquid-state reaction at the interface) indicates that the thick IMC layer formed during resistance welding and not during long-term storage.
- Solid-state kinetics do not correlate to the observed thick IMC, even if high temperatures are considered (400°–600°C). **The only condition that could produce the observed thick IMC is the presence of liquid -- the local temperature at the interface reached at least 650°C (the (Al) + Al<sub>2</sub>Au eutectic temperature).** No concern for significant future IMC growth.
- Variations in the amount of IMC were observed from sample to sample. There may still be concern for electrical and mechanical performance variations -- recommend electrical testing and mechanical pull-testing be performed on these components.



# Acknowledgements

**We thank Dick Grant for EPMA analysis and Alice Kilgo for expert metallography of these difficult-to-polish specimens.**