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Au-Al Intermetallic Formation in a Resistance Weld (A New Outbreak of "Purple Plague"?)

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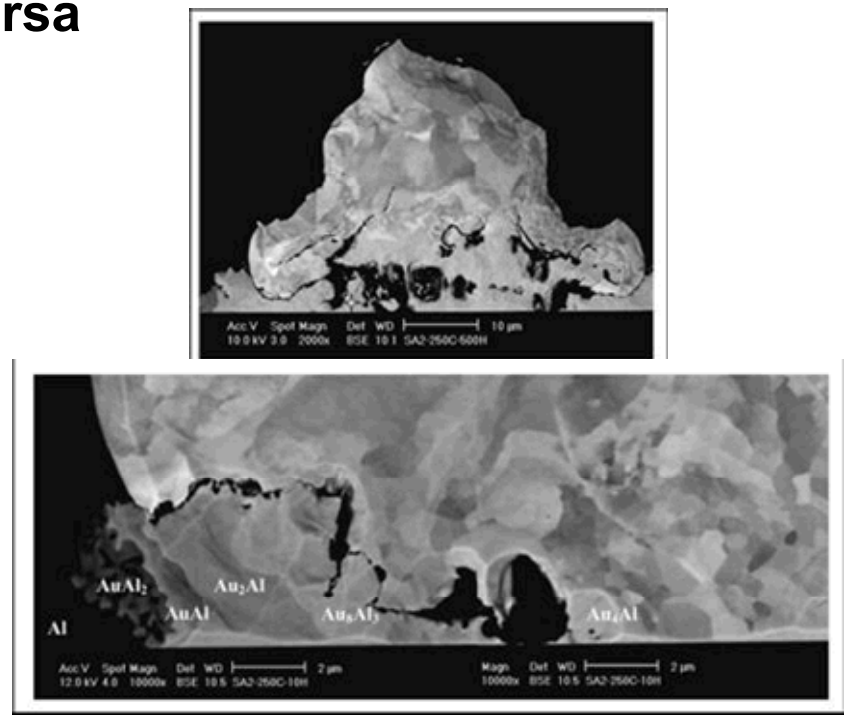
Au-Al Intermetallic Compound (IMC) Formation

- **"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.

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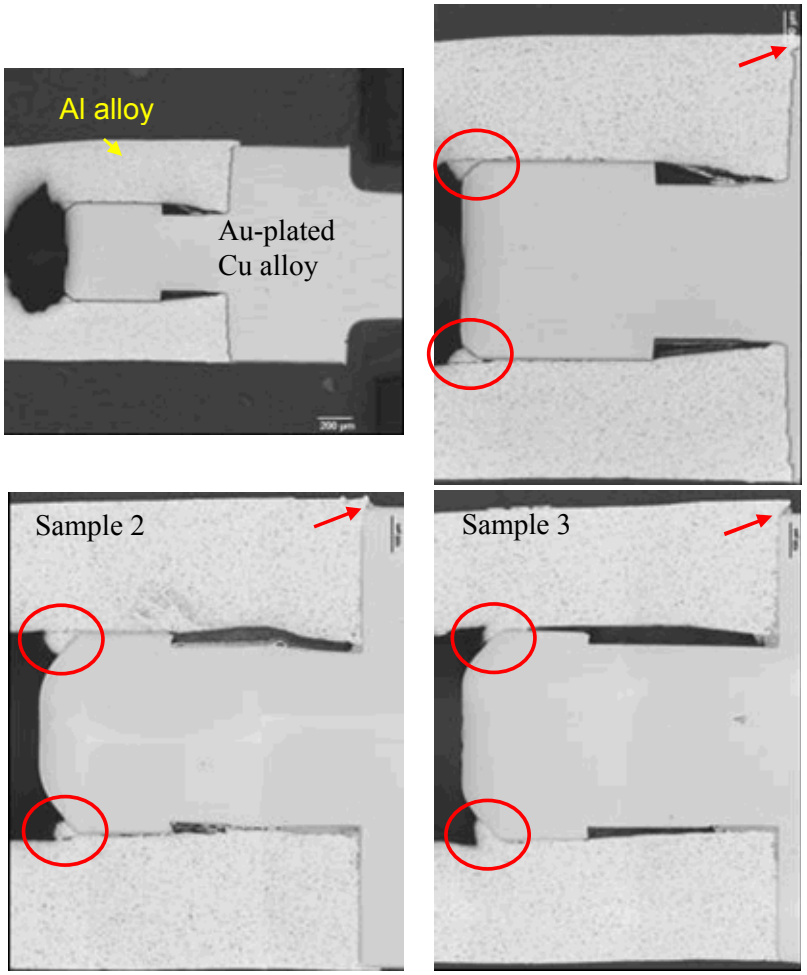
Au-Al IMC Found in a Resistance Weld Joint

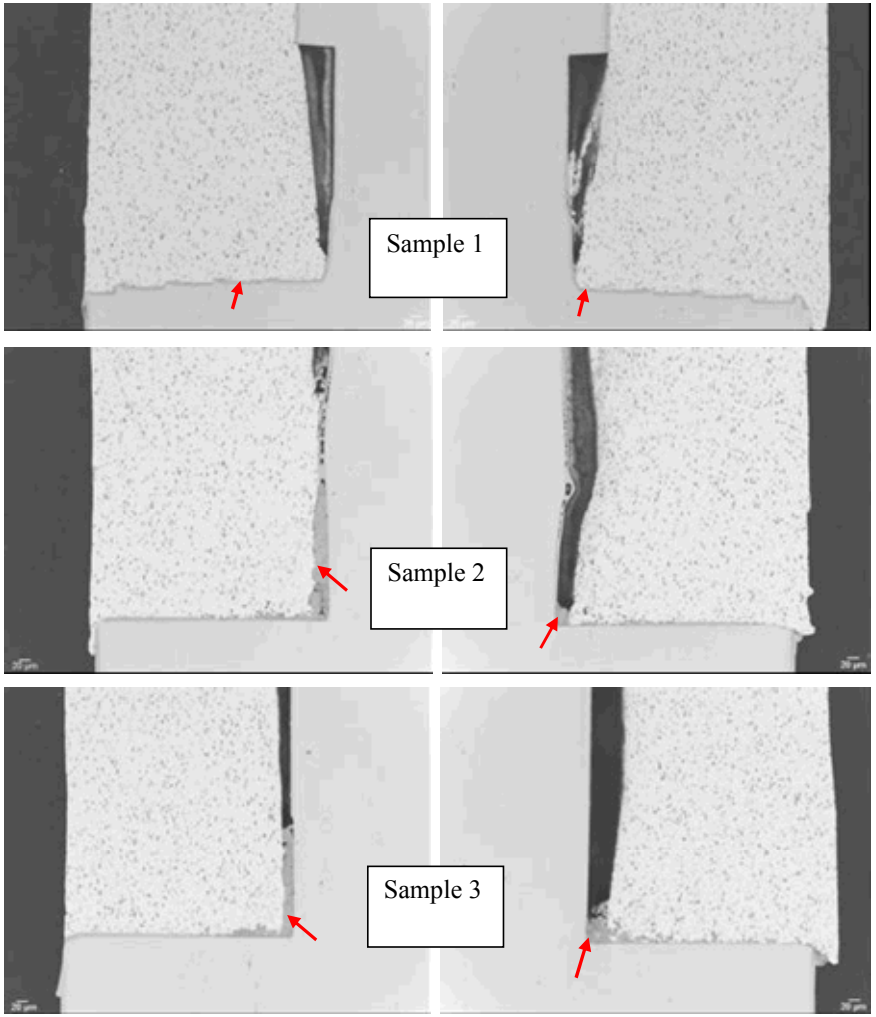
- In this investigation, Au-Al IMC phases were found in a resistance weld joint between a Au-plated Cu alloy plug and an Al alloy sleeve
- This is a much more mechanically robust joint with high amount of bonded surface area
- However, the presence of purple plague IMC phases still raised concerns about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



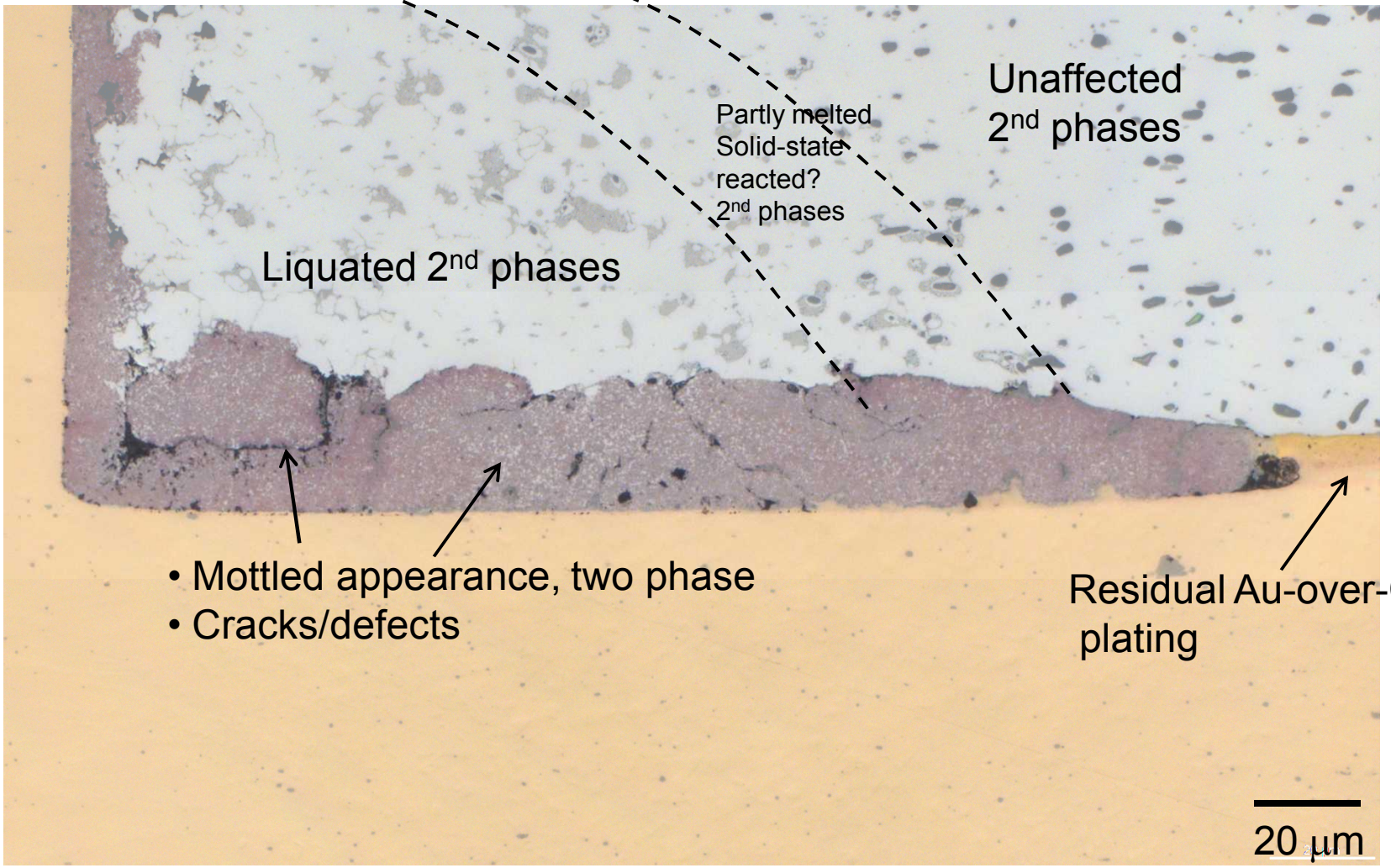
Examples of joints in this study: Circles indicate material pushed ahead of the pin "plunger" during joining, and arrows indicate deformation at the receptacle base/pin shoulder interface. Like a "forge+resistance weld"…

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.

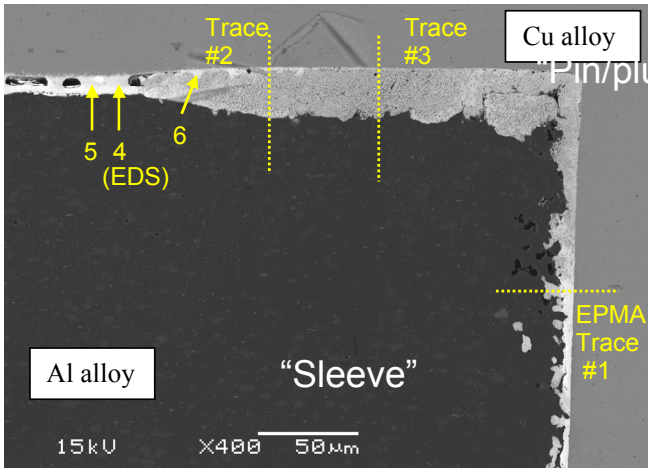


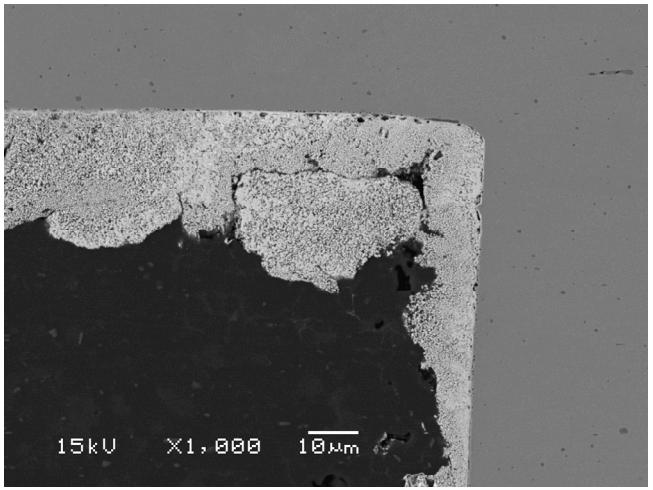
Color Metallography



SEM and EPMA Analysis of IMC Layer

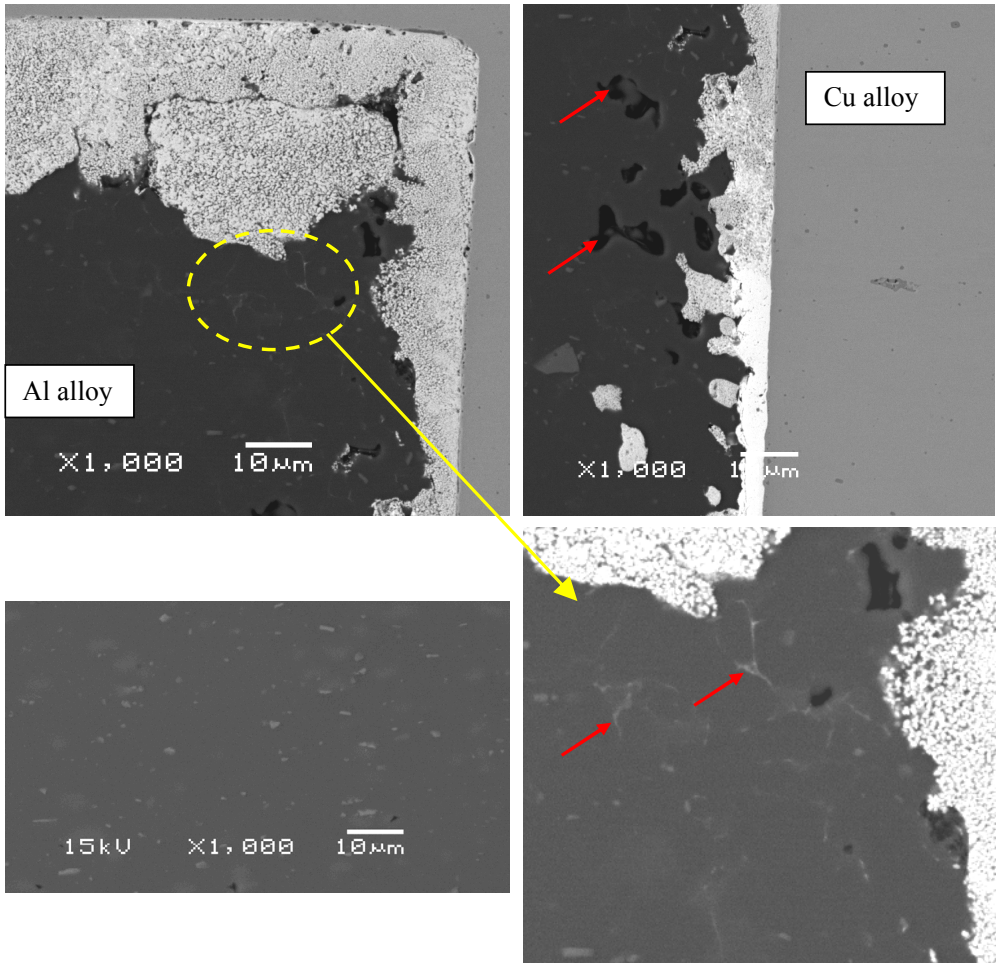
- BSE photomicrographs show multi-phase IMC microstructure with fine-scale porosity and some cracking.
- Locations of EDS and electron probe microanalysis (EPMA) traces are shown.



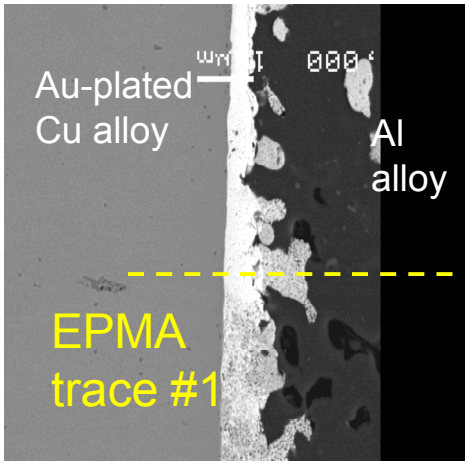


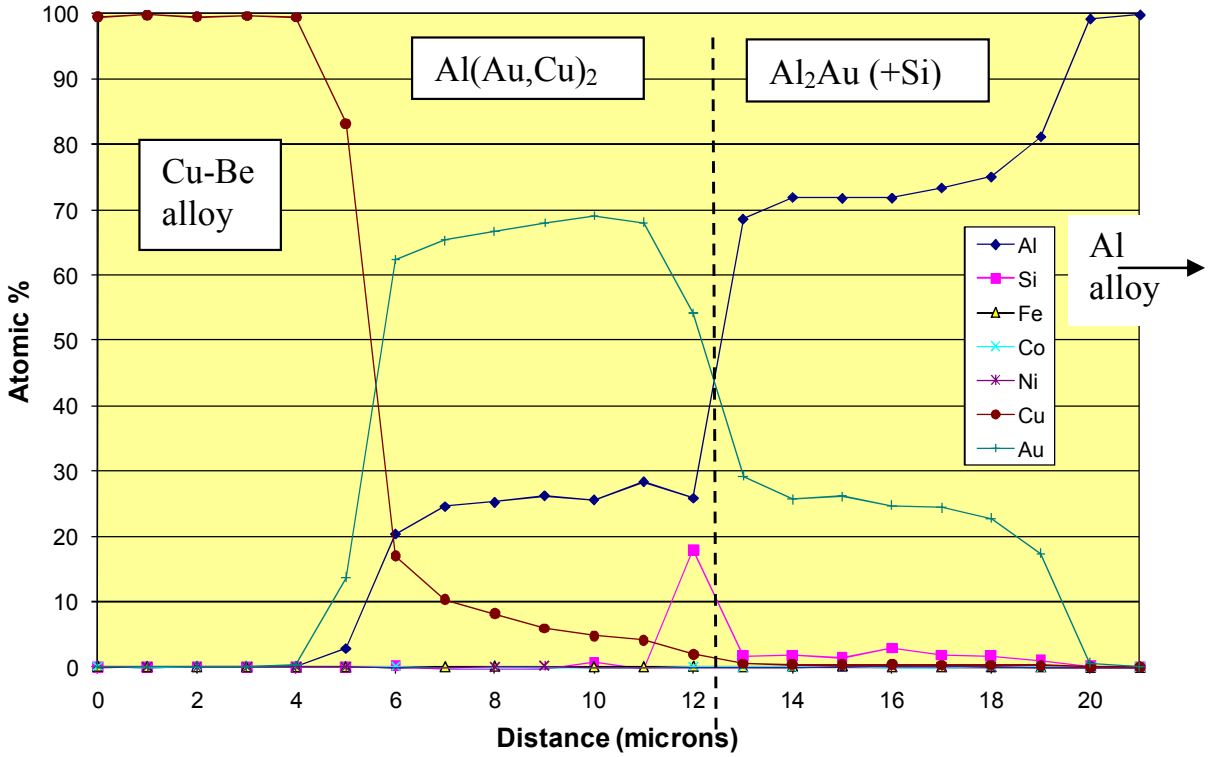
Evidence for Partial Melting of Al Alloy

- **Evidence for partial melting of the Al alloy during resistance joining:**
  - **Porosity (non-spherical)**
  - **Changes in morphology of 2nd 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**



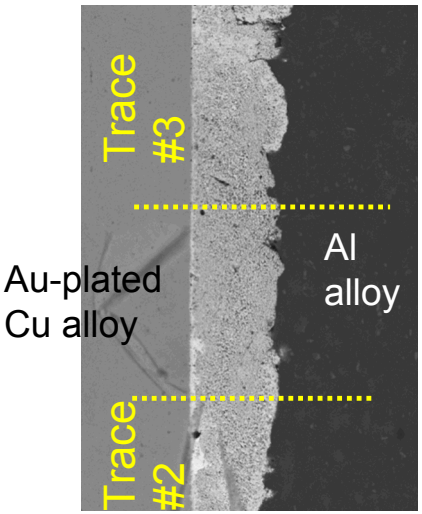
Two IMC Phases Found in EPMA Trace #1

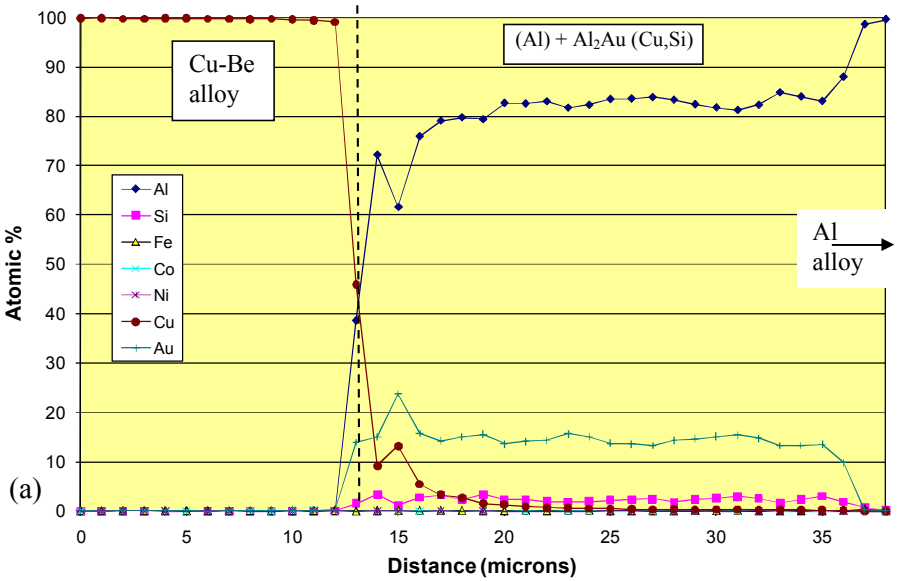


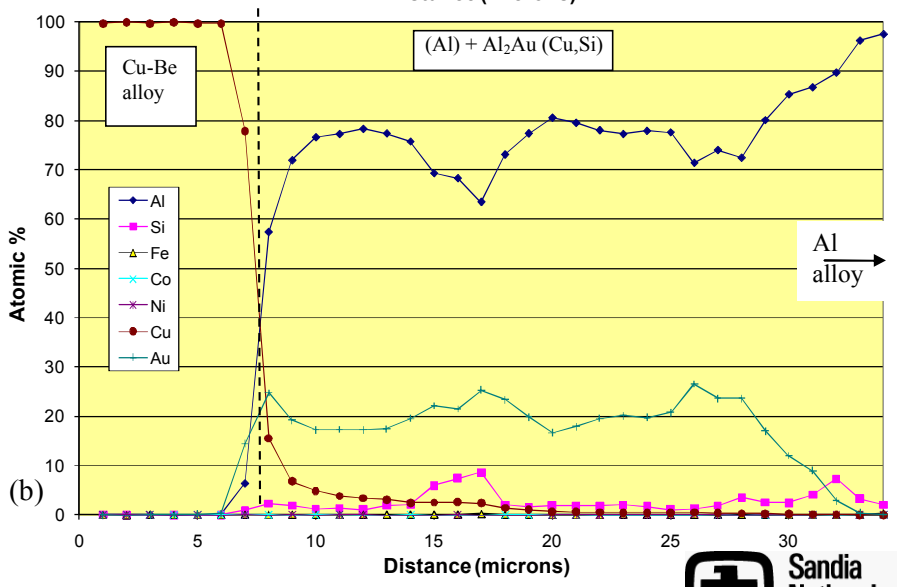


- **Two IMC phases, one Au-rich: $Al(Au,Cu)_2$ and one Al-rich: Al_2Au in a layered structure in this region**

EPMA Results (continued)



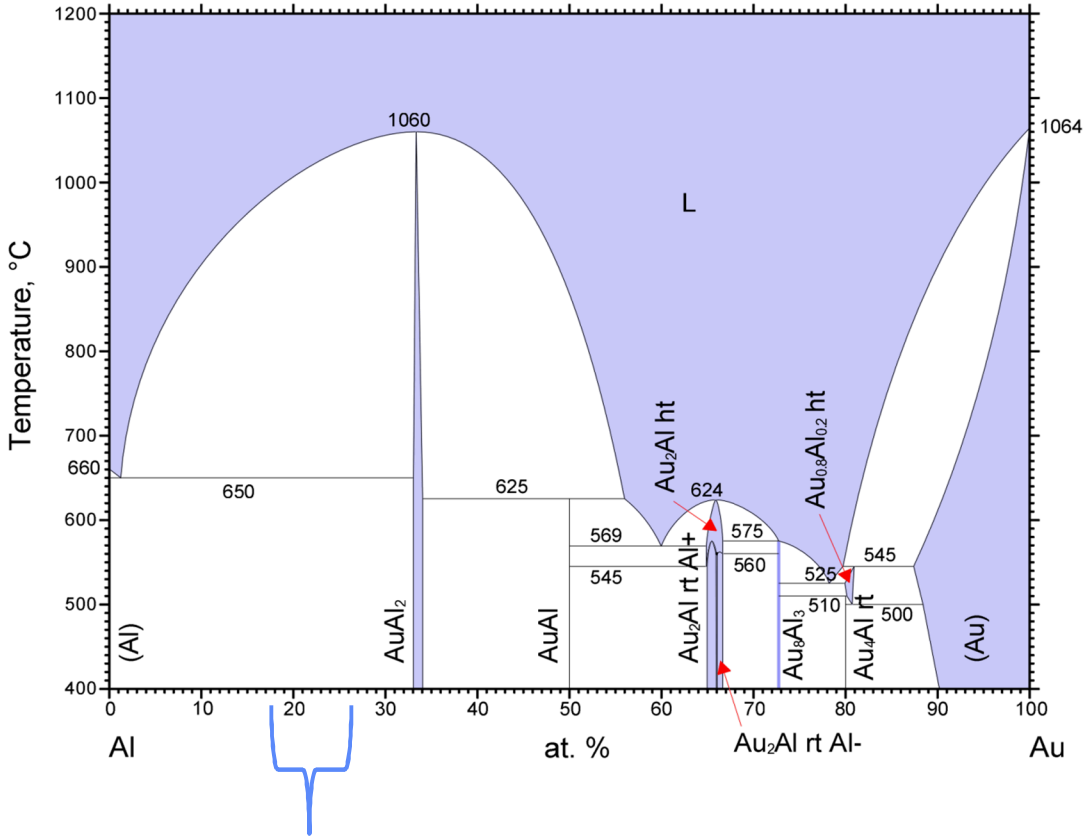




- **Main thick IMC layer composition is Al-rich (~70-80 at.% Al). The microstructure suggests a two-phase mixture of:**

(Al) solid solution + Al_2Au

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

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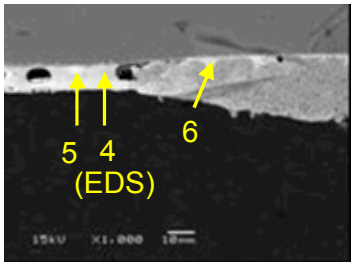
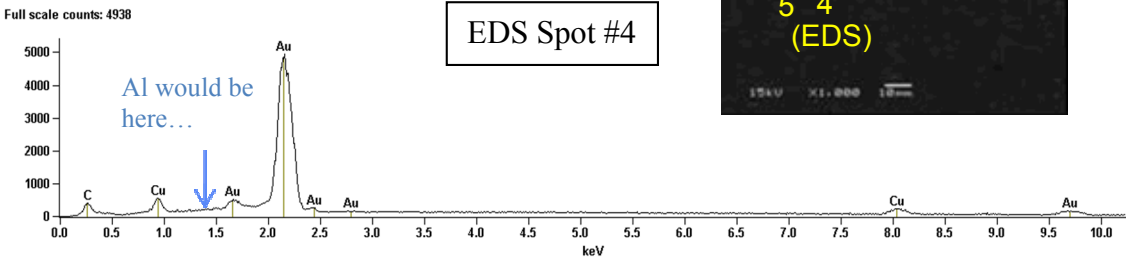
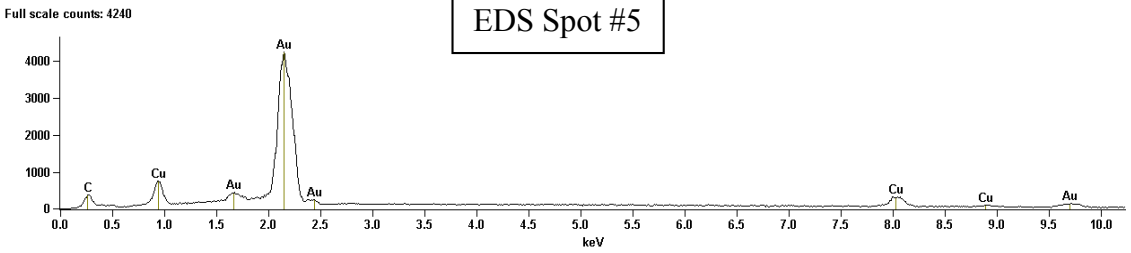
Analysis of Adjacent Areas with only thin IMC or no IMC at all



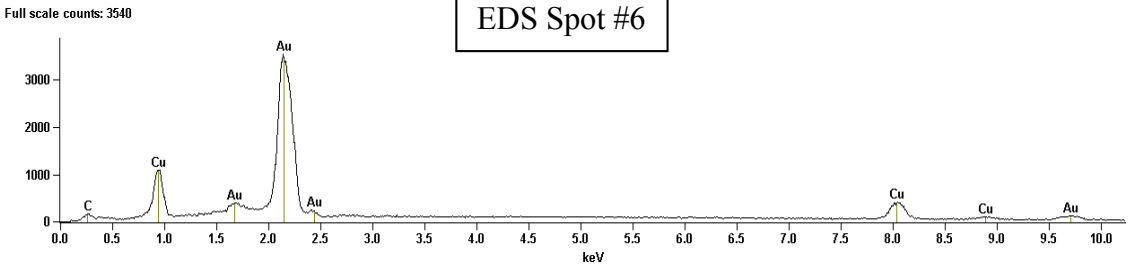
EDS Spot #4



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…

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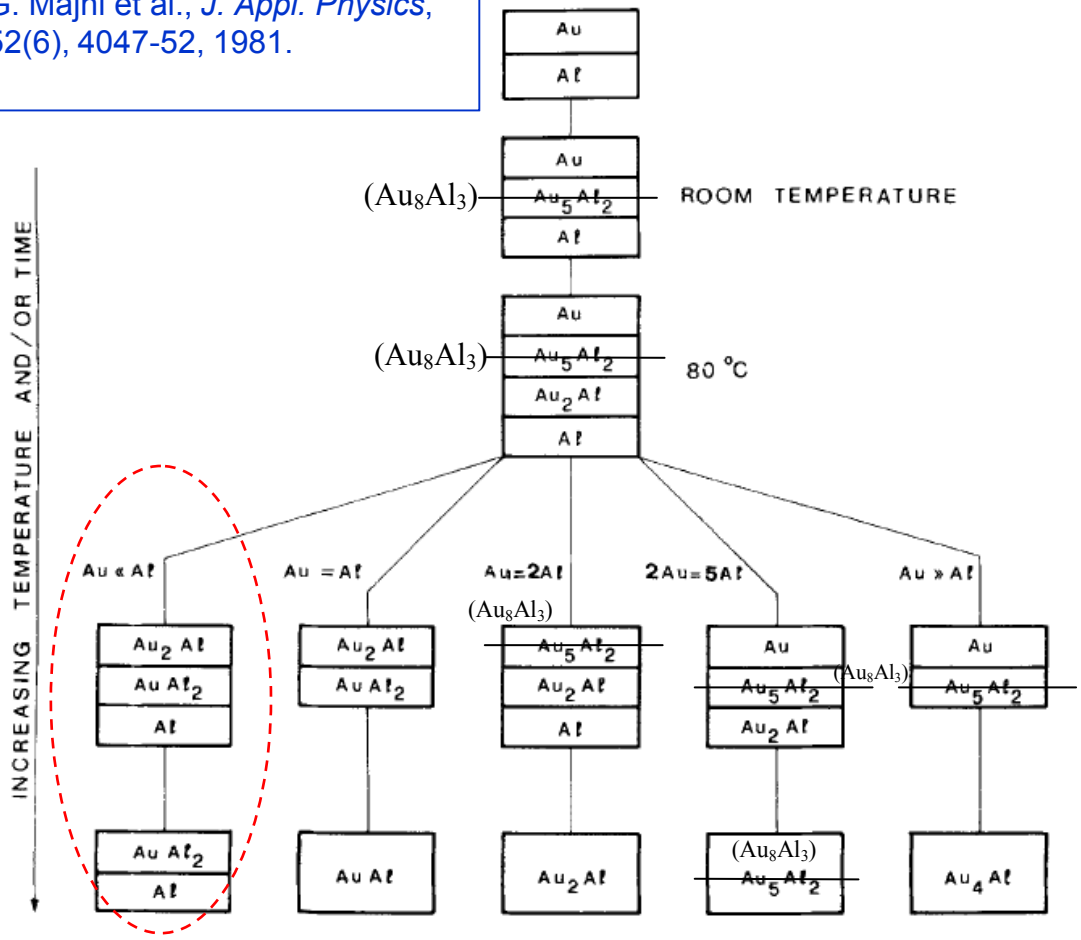
Phase Sequence Maps have been Developed in the Literature

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>>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.**

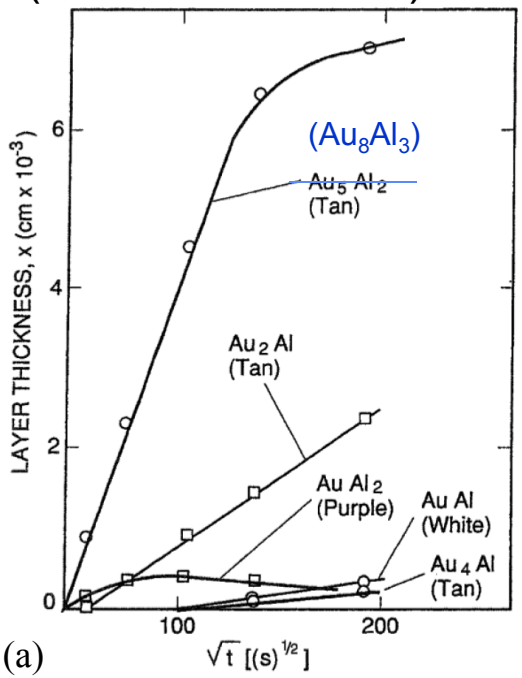
There was Still a Concern for Long-term Solid-State IMC Growth (in service)

- **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?**

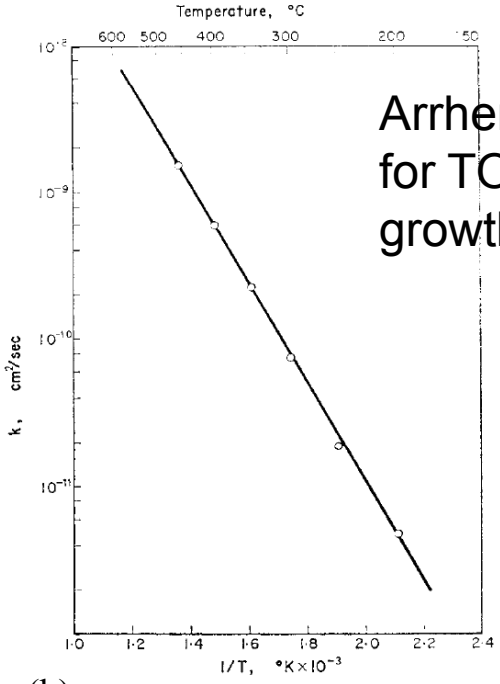
Growth of individual phases at 400˚C (“colors” identified)

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

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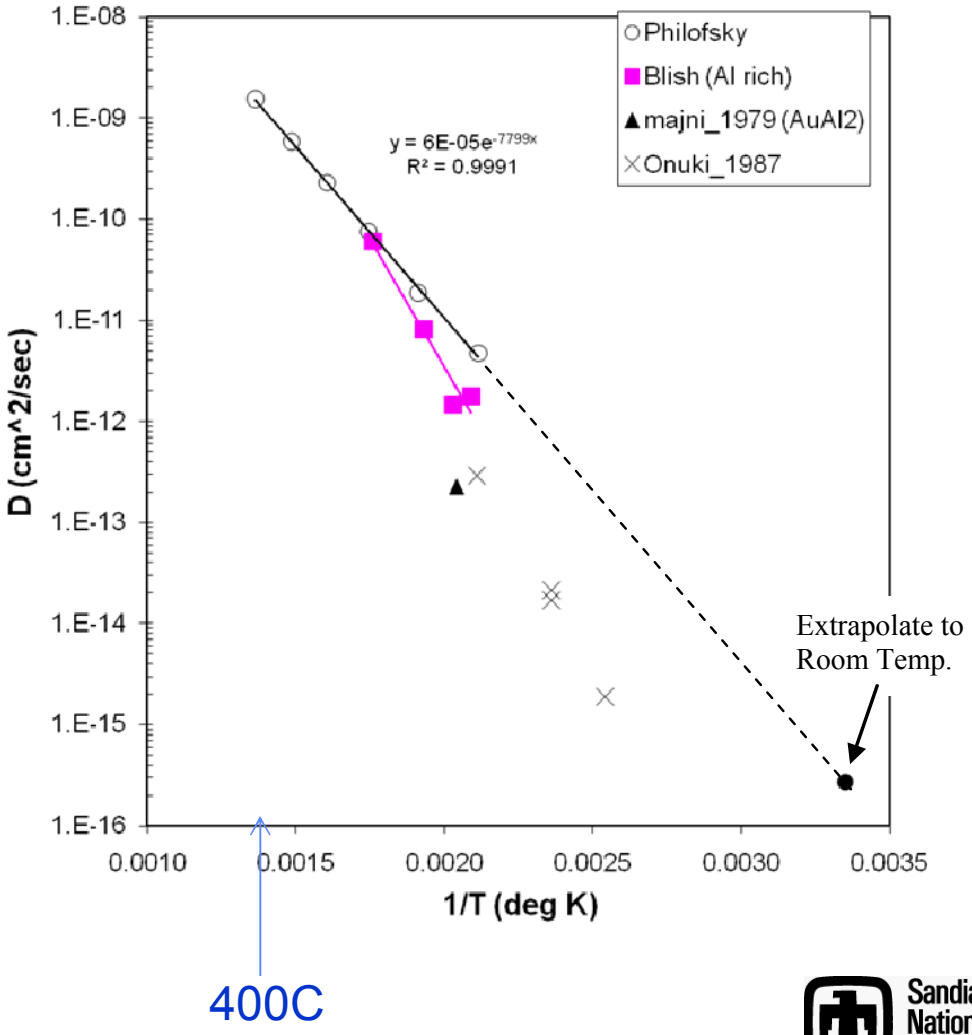
Slow Solid-State Growth Kinetics Cannot Explain Observed thick IMC

- **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 μm layer in 25 yrs.(Philofsky, total IMC mainly Au8Al3, which we don't see…)

or only

~0.3 μm layer in 25 yrs. (Blish/Onuki, Individual IMC layers)

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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.

- Analysis of solid-state kinetics does 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_2Au 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.