Understanding Cu-Al Limited-Volume Diffusion and Lifetime Prediction for Cu Wire Bonds

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Industry is moving from gold (Au) to copper (Cu) wire bonds and the understanding of their reliability is lacking. Copper wires are bonded to aluminum (Al) pads. Cu and Al interact, forming intermetallics (IMCs) that can induce a mechanical failure and/or increase in electrical resistance. Sandia is working to acquire the materials engineering knowledge to fully assess the lifetime and acceptability of Cu wires bonded to Al pads for high reliability products and applications.

PURPOSE

To develop a reliability knowledge base, a fundamental Cu-Al limited-volume diffusion study is being performed, using Cu-Al thin film stacks on silicon to simulate real world joints (Fig. 1). These thin film stacks are aged and mechanically tested to understand the influence of intermetallic formation on interface strength.

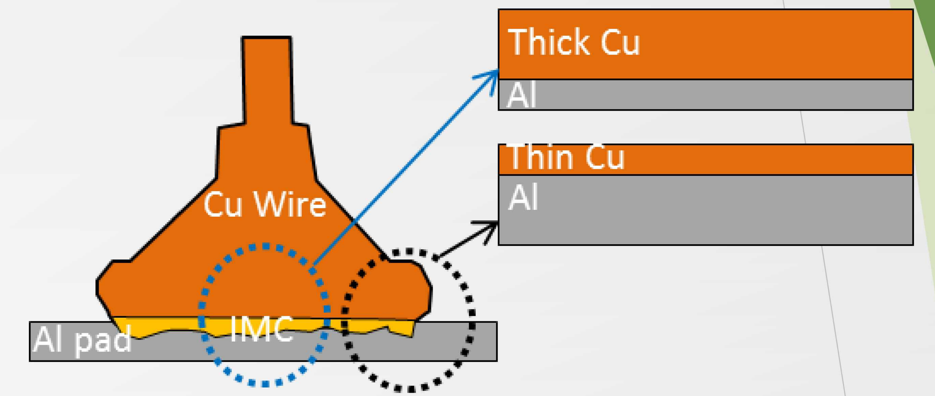


Fig.1 Schematic of real world joint - growth of Cu-Al intermetallics (IMCs) is non-uniform under bonds

APPROACH

A thin film stack of varying thicknesses of Cu and Al (varying Cu:Al ratio) on a .05um layer of titanium (Ti), was deposited onto 1”x1” silicon (Si) coupons (Fig. 2). The coupons were isothermally aged at various temperatures and times in order to study aging behavior and degradation of the simulated Cu-Al joints. Cu pins were attached to the film surface, using a thermally cured epoxy for pin-pull tensile testing (Fig. 3). The pins were pulled to failure on an MTS 858 Table Top System, 5 KIP Hydraulic Test Frame, using a displacement control of 10mm/minute. The loads were recorded, rendering the strength of the interface. Surfaces at the pull locations were investigated using scanning electron microscopy (SEM) to determine failure modes and growth of Cu-Al intermetallics, providing insights into joint reliability (Fig. 4).

Aging parameters
- Temperatures: 50, 100, 150, 200, 250, 300°C
- Time: 0, 5, 10, 25, 50, 100, 150, 200, 300 days
- Ratios:

	Al	Cu
(i)	2.0	0.2
(ii)	2.0	1.0
(iii)	2.0	2.0
(iv)	1.0	2.0
(v)	0.2	2.0
	μm	μm

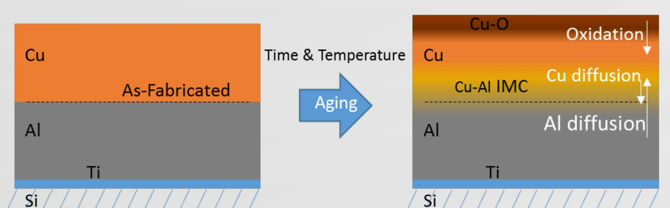


Fig. 2

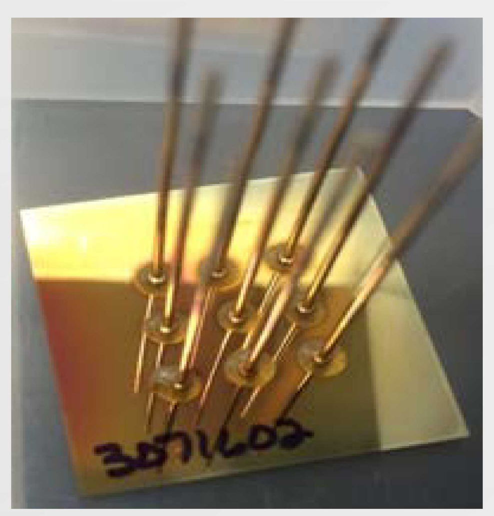
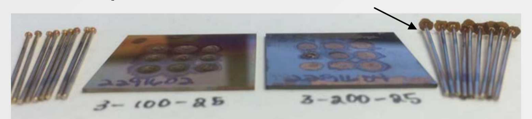


Fig. 3 Angled view showing pins attached to the samples, ready for pin-pull testing.

Fig. 4 Bird’s-eye view of pulled samples with two different types of failures—epoxy failure on the 3-100-25 sample and film interface failure on the 3-200-25 sample



Angled view showing left-over film pieces attached to the pins on the 3-200-25 samples (arrowed).

RESULTS

Pin-pull strengths (lbs) were plotted as a function of sample aging time (up to 100 days) for aging temperatures of 50°C, 100°C, 150°C, and 200°C (Fig. 5). Observed failure modes are shown in the table, schematics, and SEM images below (Fig. 6).

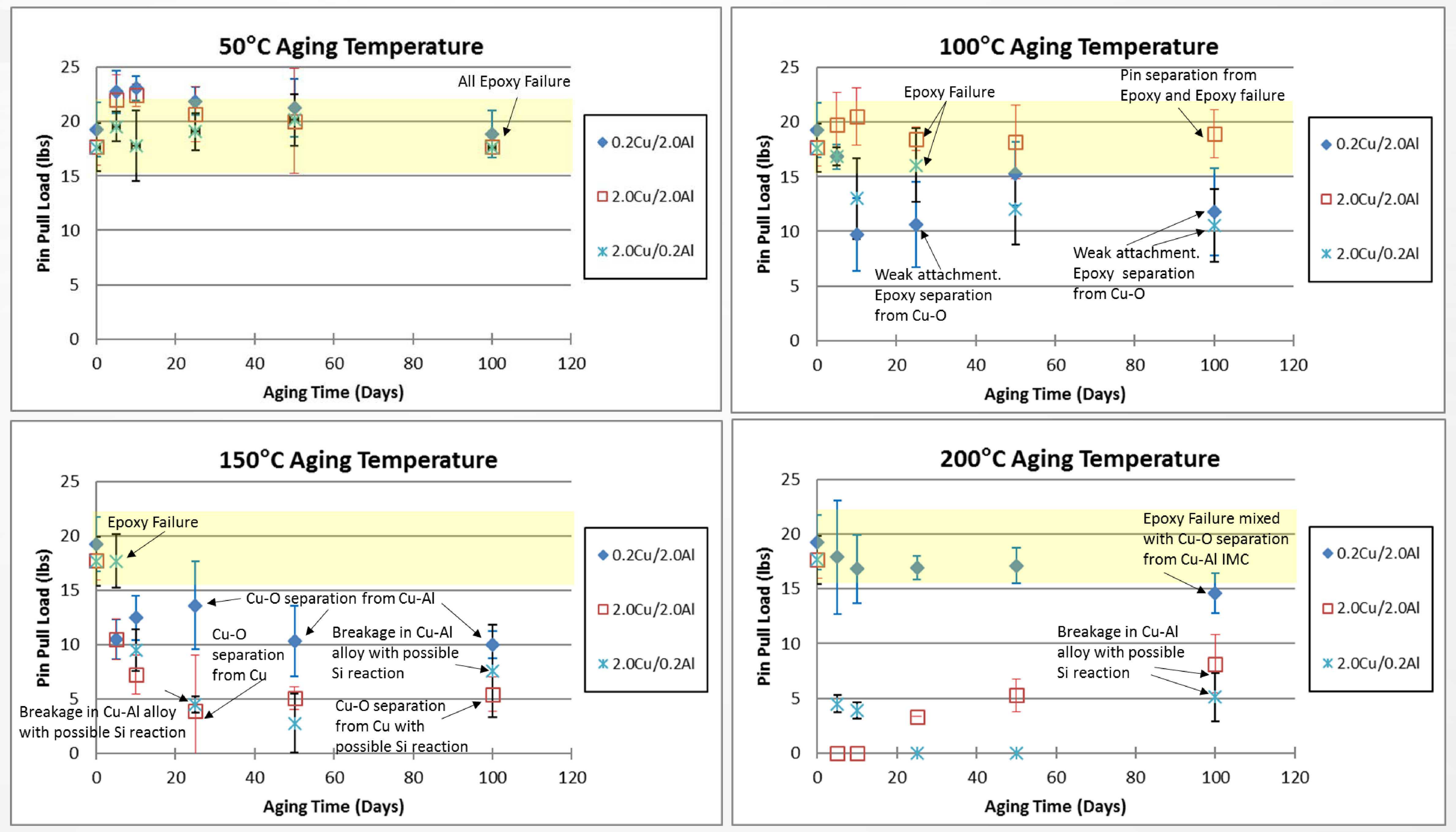
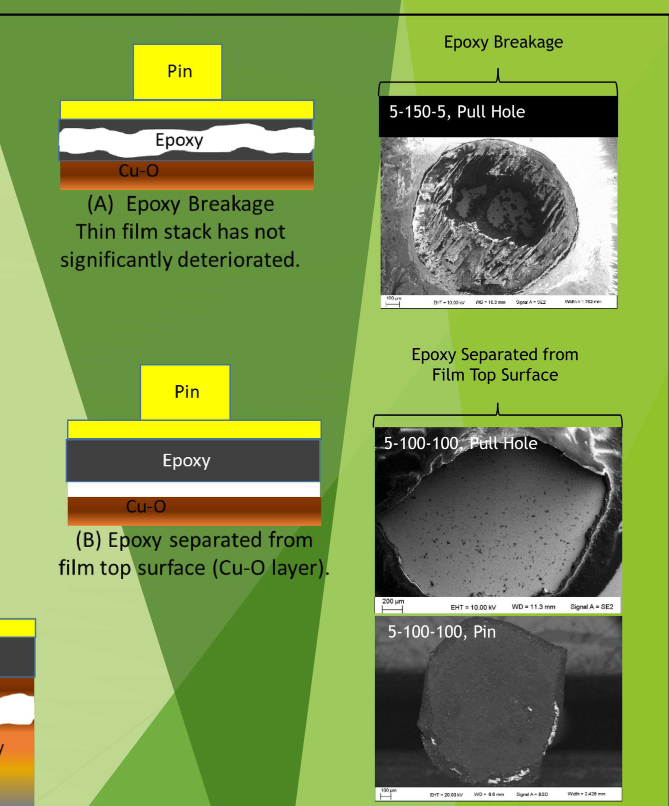


Fig. 5 Pin-pull strength (lbs) vs. aging time (days) for four aging temperatures for three Cu:Al ratios:
0.2 μm Cu / 2.0 μm Al - All Cu layer is consumed by oxidation and Cu-Al IMC formation
2.0 μm Cu / 2.0 μm Al - Not all Cu and not all Al were consumed.
2.0 μm Cu / 0.2 μm Al - All Al layer is consumed by Cul-Al IMC formation and Al diffusion through the Cu, providing Cu-Al alloy formation

Pin Pull Failure Modes		Chem 1	Chem 3	Chem 5
As-Received	Cu thickness (um)	0.2	2.0	2.0
	Al thickness (um)	2.0	2.0	0.2
50°C	25 days	Epoxy Breakage	Epoxy Breakage	Epoxy Breakage
	50 days	Epoxy Breakage	Epoxy Breakage	Epoxy Breakage
	100 days	Epoxy Breakage	Epoxy Breakage	Epoxy Breakage
100°C	25 days	Epoxy // Cu-O	Epoxy Breakage	Epoxy Breakage
	50 days	N/A	N/A	N/A
	100 days	Epoxy // Cu-O	Pin // Epoxy	Epoxy // Cu-O
150°C	25 days	Cu-O // Cu-Al	Cu-O // Cu	Cu-Al alloy breakage
	50 days	Cu-O // Cu-Al	Cu-O // Cu	Cu-Al alloy breakage
	100 days	Cu-O // Cu-Al	Cu-O // Cu	Cu-Al alloy breakage
200°C	25 days	Cu-O // Cu-Al	Cu-Al alloy breakage	Cu-Al alloy breakage
	50 days	N/A	N/A	N/A
	100 days	Cu-O // Cu-Al	Cu-Al alloy breakage	Cu-Al alloy breakage
Multiple failure modes may occur in one sample; we listed the dominant failure mode.				
//	Thin film separation between two layers			
N/A	Failure mode not confirmed			



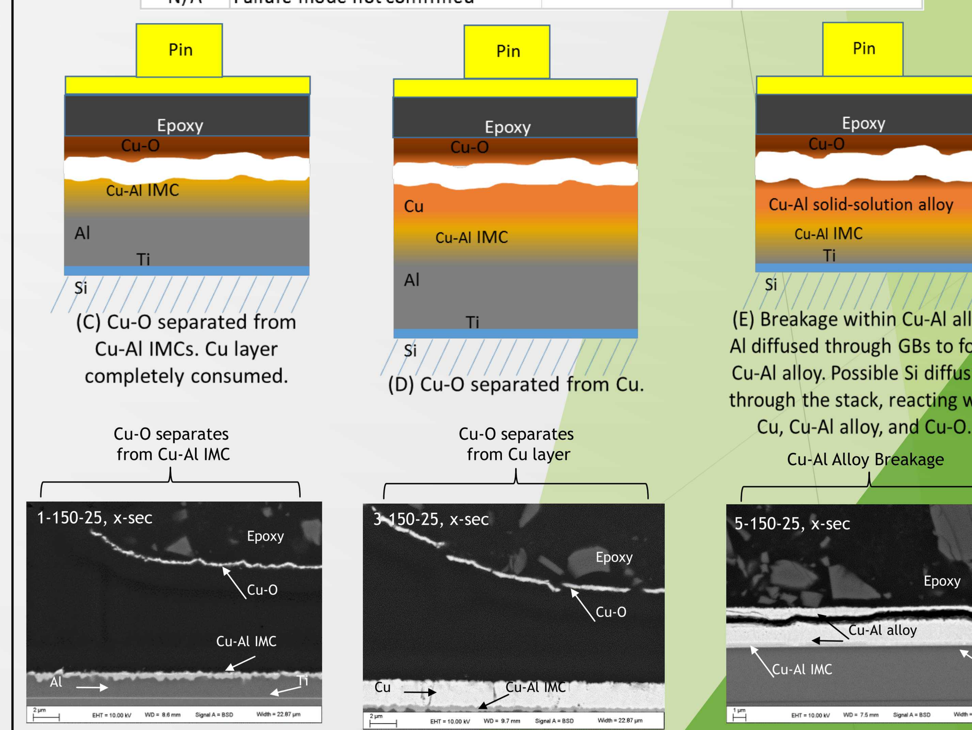


Fig. 6

Strengths and failure modes varied with Cu:Al ratios for different aging times and temperatures. Common failure modes are (A) epoxy breakage; (B) epoxy separation from the film top surface; (C) Cu-O separation from the Cu-Al IMC; (D) Cu-O separation from Cu; and (E) Cu-Al alloy breakage (Fig.6).

IMPACT

Preliminary results support the hypothesis that Cu:Al ratio affect Cu-Al interaction. The collected data will provide inputs for modelers to predict the joint lifetime and help serve as a direct comparison/validation between results from this study’s aged thin film samples, accelerated aged test vehicle samples, and field aged real world parts.

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