RT 190: Reliability of Silver Wire Bonds in Harsh Environments

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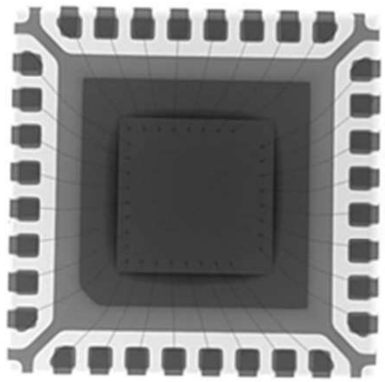
Comparison of the Effect of High Temperature on WB Systems

S. Deshpande, P. Lall

32 Pin QFN
1 mil Cu Wire
0.9 µm thick Al Pad



Objectives

- Reliability of different wirebond material candidates subjected to HTSL.
- Identify modes of failures, reasons of failures and time to failure for each wirebond pair subjected to prolonged exposure at high temperature.
- IMC phase evolution sequence and cracking phenomenon in wirebonds.
- Relation between degradation of shear force with change in electric response.

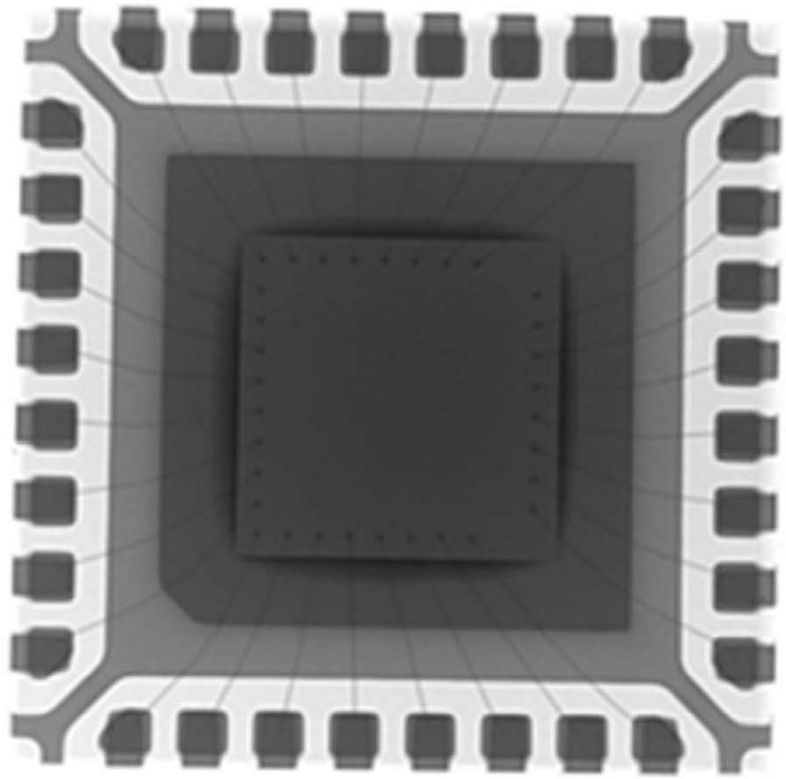
State of Art

- Prior studies on reliability of Cu, Au and PCC wirebonds have quantified time-to-failure but damage mechanisms over test time has not been studied. [1][2][3].
- Failure in Au, Cu and PCC wirebond under high temperature was studied in prior studies, however, IMC growth and phase changes over time were not correlated with the change in electric properties of the device [3][4][5].
- Ag being one of the newer alternative to Au and Cu wires is not widely discussed in the literature[6].
- Evaluation of all wirebond material candidates under same test condition will enable fair comparison between the candidates

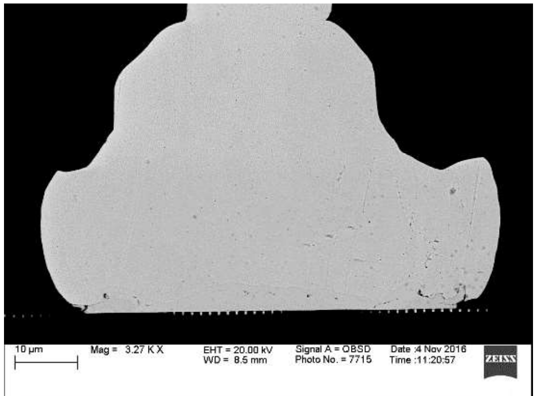
1. *Gan C., Ng E., Chan B., Classe F., Kwuanjai T., Hashim U., "Wearout reliability and intermetallic compound diffusion kinetics of Au and PdCu wires Used in Nanoscale Device Packaging", Journal of Nanomaterials, Vol 2013, Article ID 486373, pp1-9.*
2. *Goh C., Chong W., Lee T., Breach C., "Corrosion study and Intermetallics formation in Gold and Copper Wire Bonding in Microelectronics Packaging", Crystals Journal, Vol 3, 2013, pp 391-404.*
3. *Y. H. Tian, C. J. Hang, C. Q. Wang, G. Q. Ouyang, D. S. Yang, and J. P. Zhao, "Reliability and failure analysis of fine copper wire bonds encapsulated with commercial epoxy molding compound," Journal of Microelectronics Reliability., vol. 51, no. 1, pp. 157–165, 2011.*
4. *Abe H., Kang D., etc. all, "Cu Wire and Pd-Cu Wire Package Reliability and Molding Compounds", Proceedings of IEEE ECTC Conference, 2012, pp 1117-1123.*
5. *Yoo K., Uhm C., Kwon T., Cho J., Moon J., "Reliability Study of Low Cost Alternative Ag Bonding Wire with Various Bond Pad Materials", Proceedings of 11th IEEE EPTC Conference, 2009, pp 851- 857.*
6. *J. Xi et al., "Evaluation of Ag wire reliability on fine pitch wire bonding," IEEE 65th Electronic Components and Technology Conference (ECTC), San Diego, CA, 2015, pp. 1392-1395.*

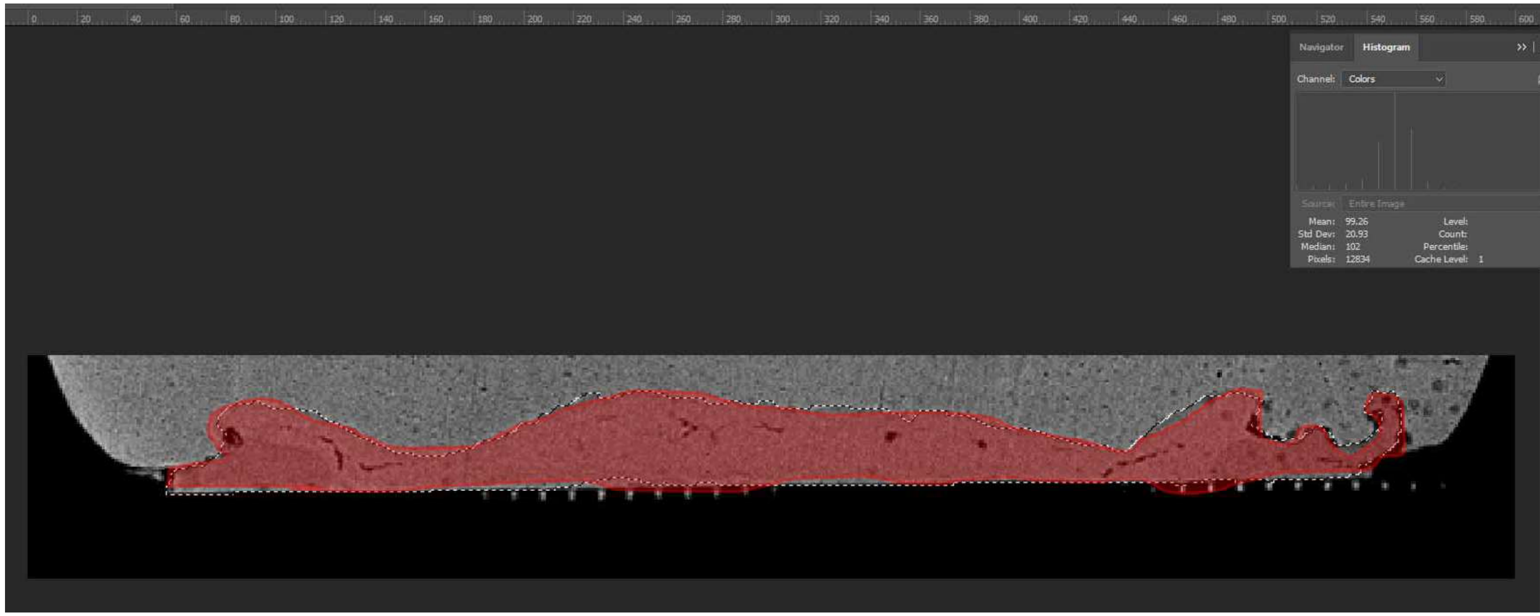
Test Matrix

- 32 Pin QFN package wirebonded with 1mil Cu, Au, Ag and PCC WB on 0.9µm Al pad.
- Packages were molded with high temperature EMC (Tg>200°C, 5ppm contamination)
- Test temperature – 200°C, unbiased test.



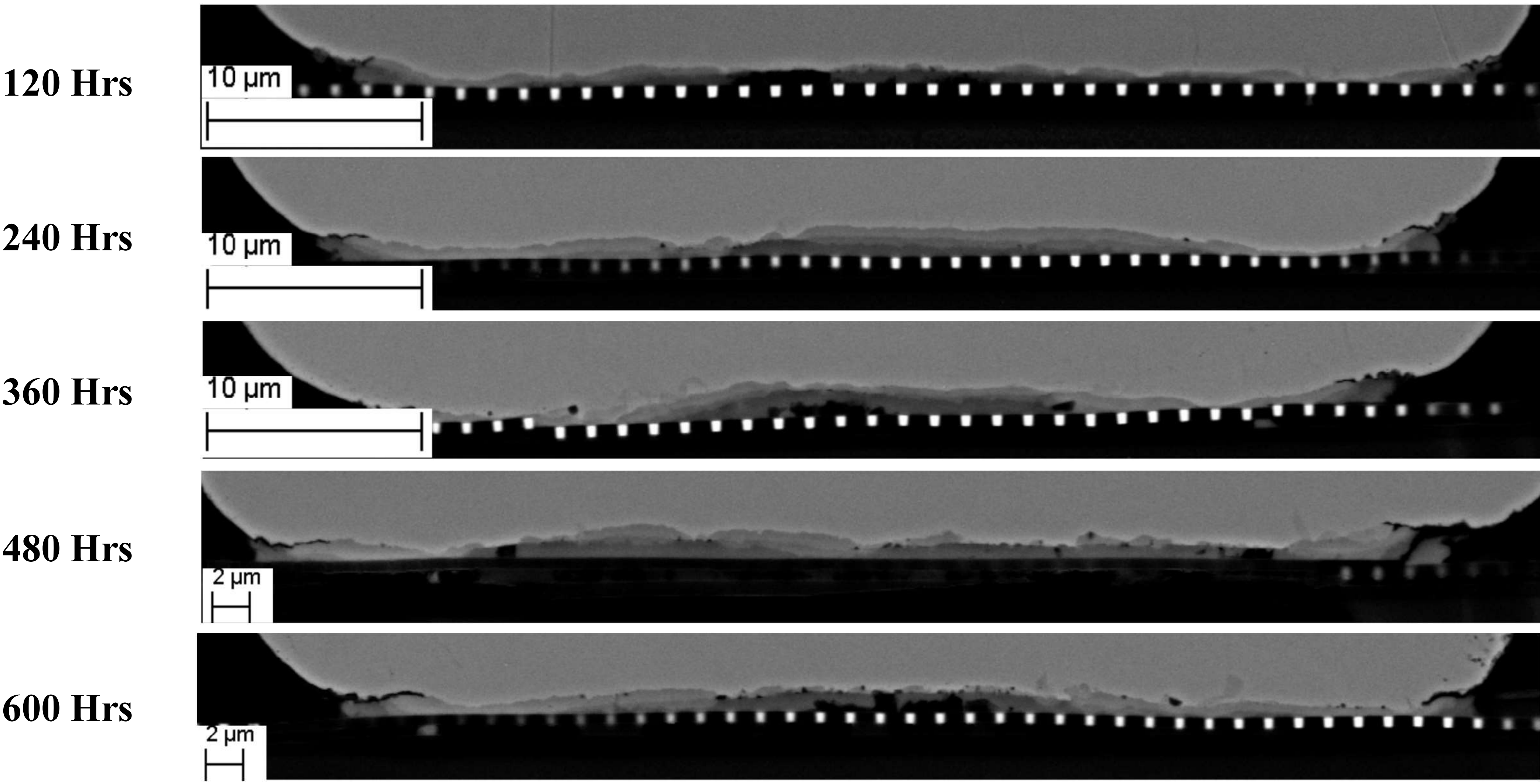
IMC Measurement



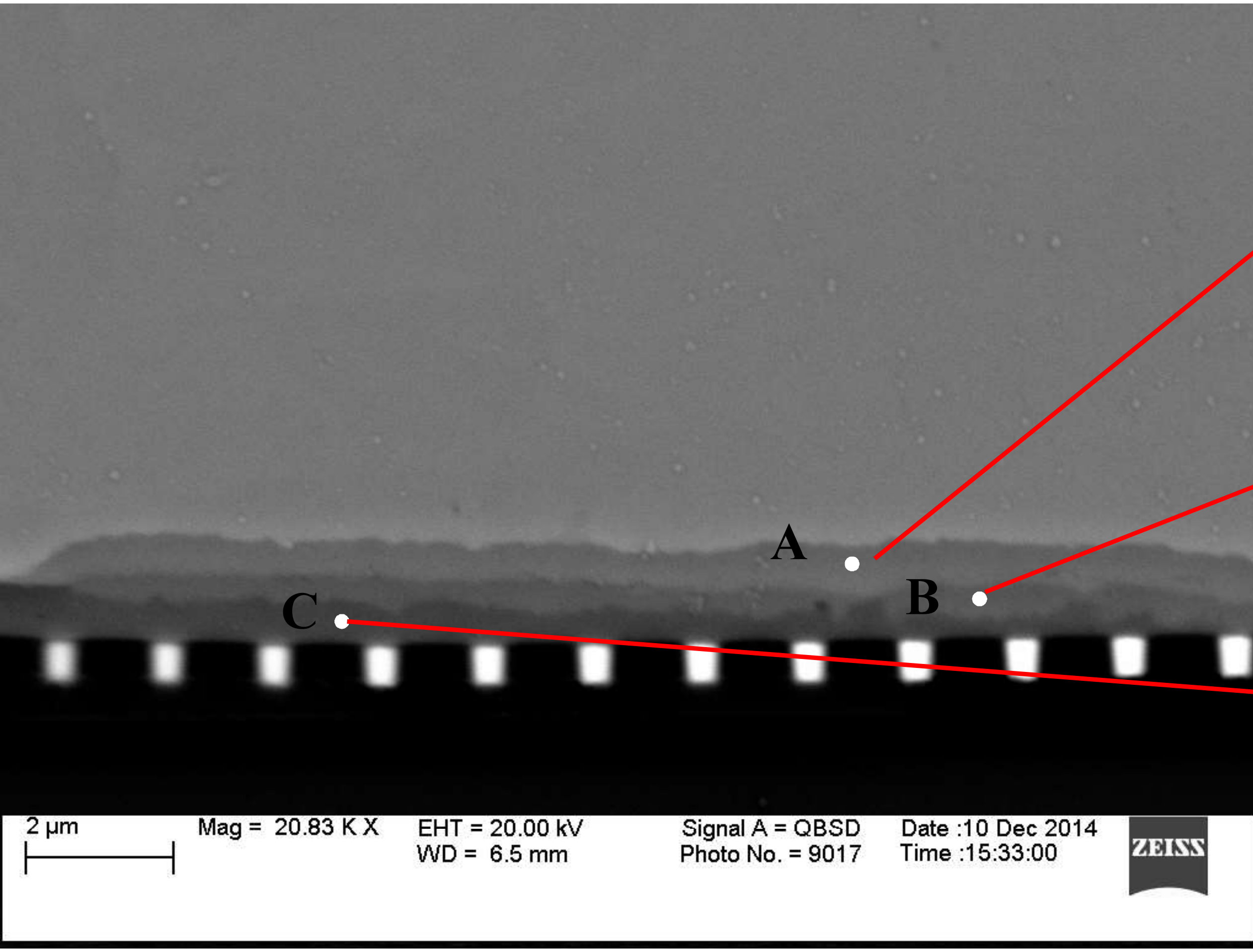


IMC Area (Pixels^2	Length (Pixels)	Height (Pixels)	No. of pixels for 1 microns	IMC Thickness (Micrometers)
27290	763	35.76671035	12	2.980559196

Cu Wirebonds IMC Growth 200°C



Cu Wirebonds EDX Analysis



3 Distinct Phases for Cu-Al IMC

Element	Atomic%
Al K	30.96
Cu K	65.48
Au M	3.56

Cu_9Al_4

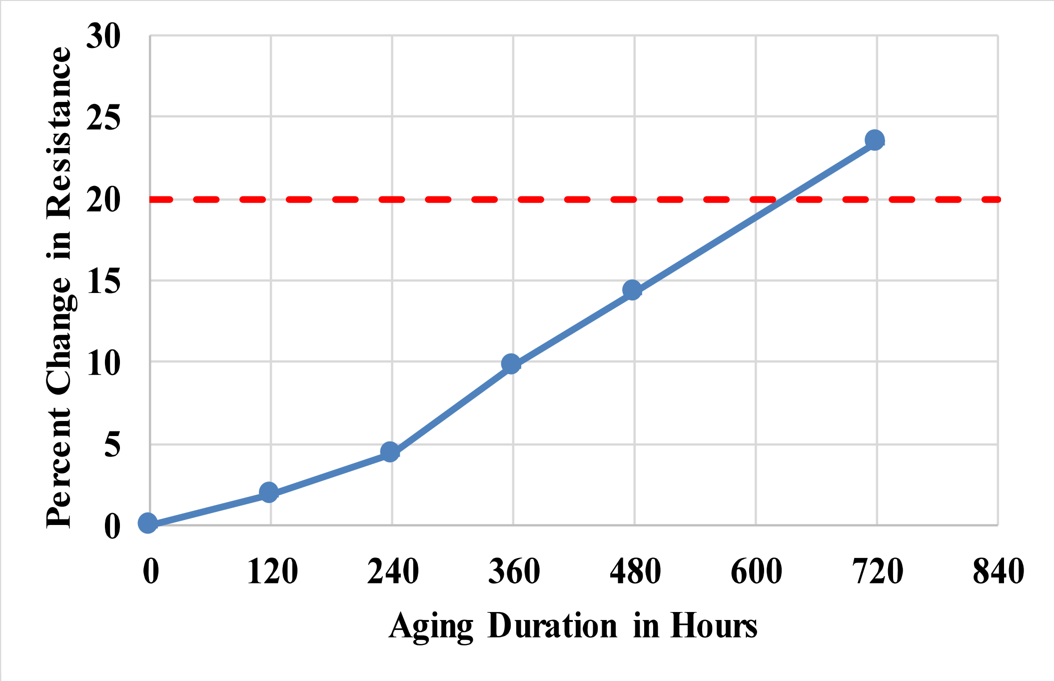
Element	Atomic%
Al K	48.64
Cu K	47.91
Au M	3.45

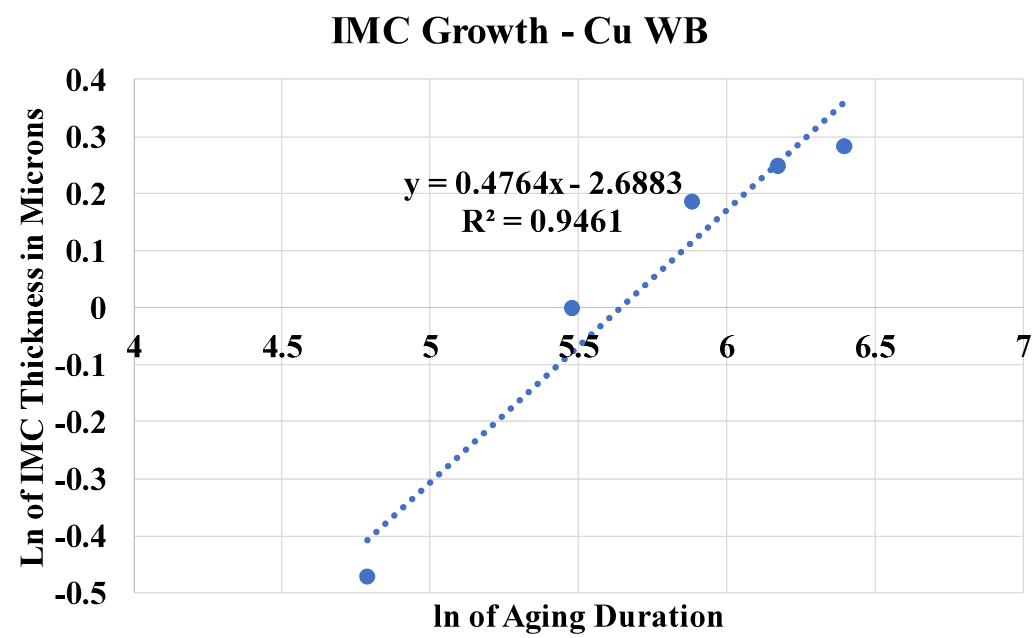
CuAl

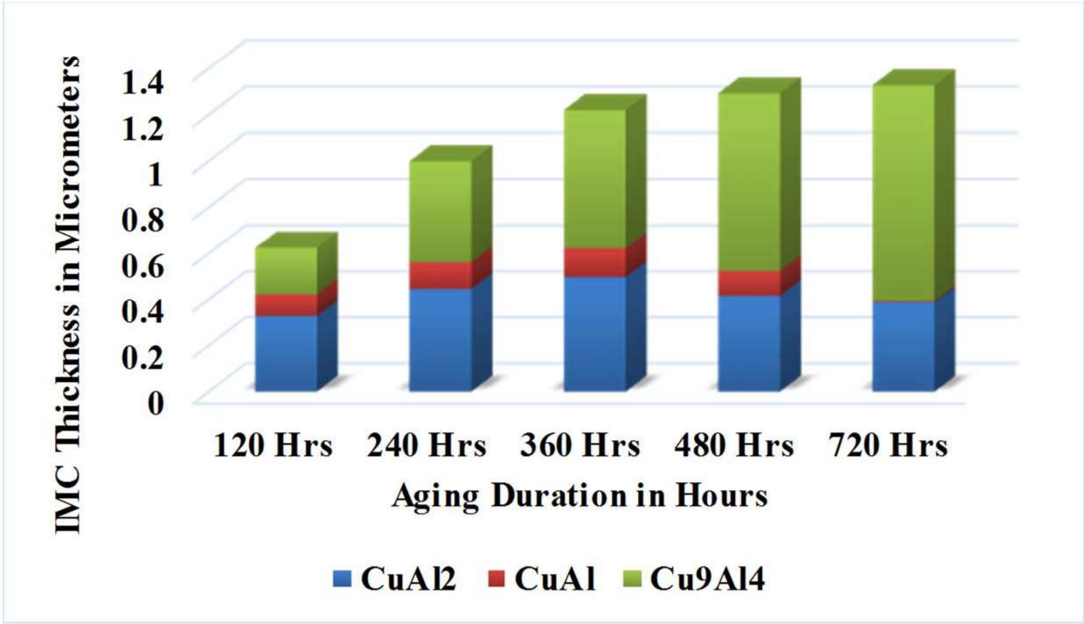
Element	Atomic%
Al K	50.63
Si K	18.40
Cu K	29.18
Au M	1.79

$CuAl_2$

Cu Wirebonds







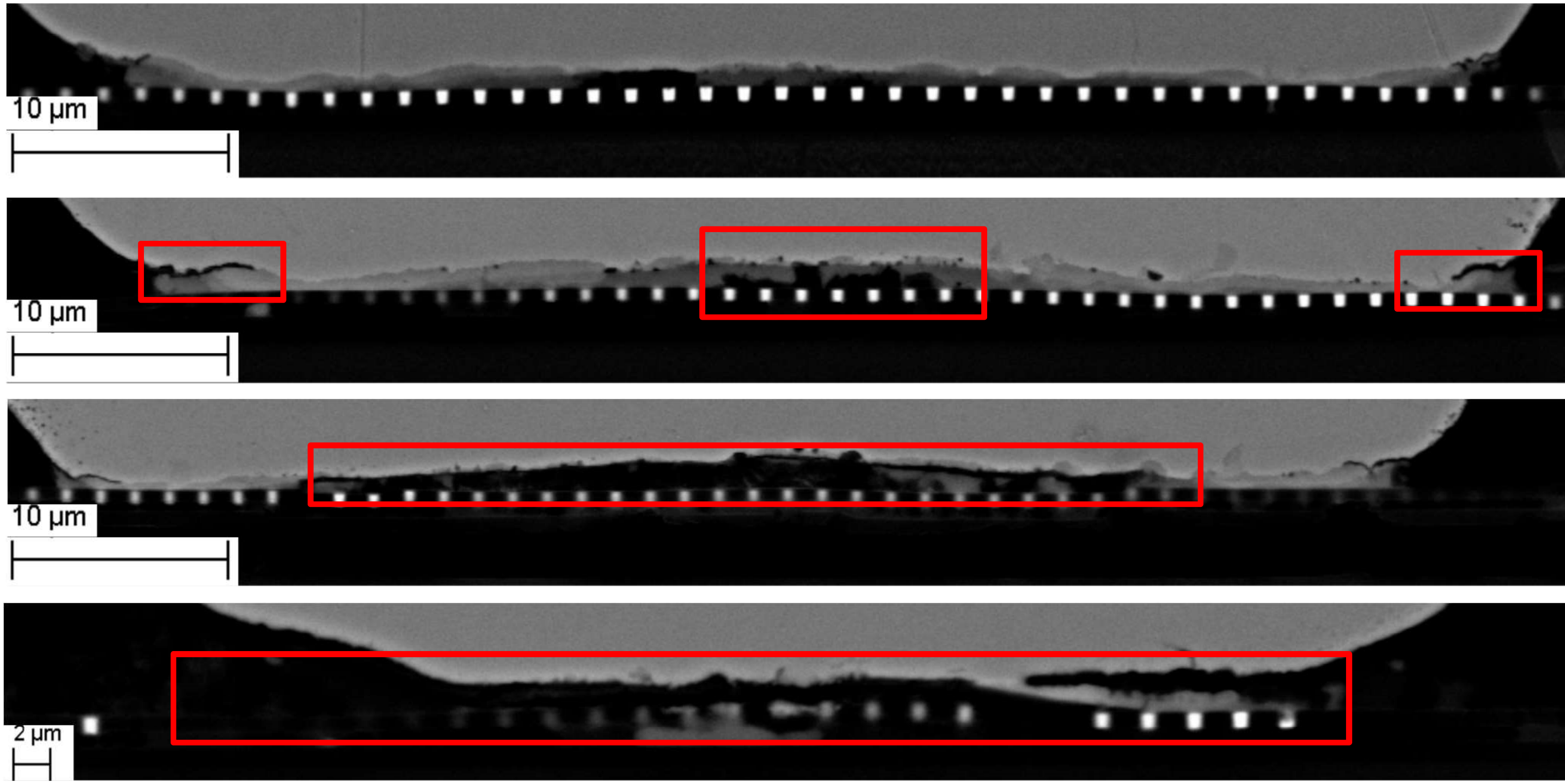
Cu Wirebonds Crack Propagation

120 Hrs
1%

360 Hrs
11%

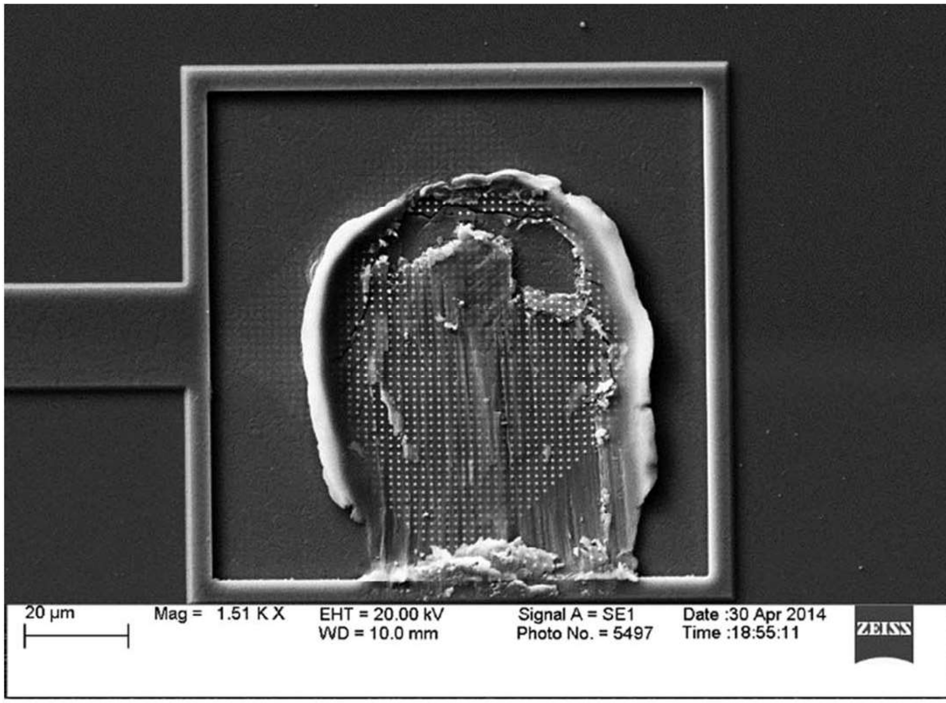
600 Hrs
24%

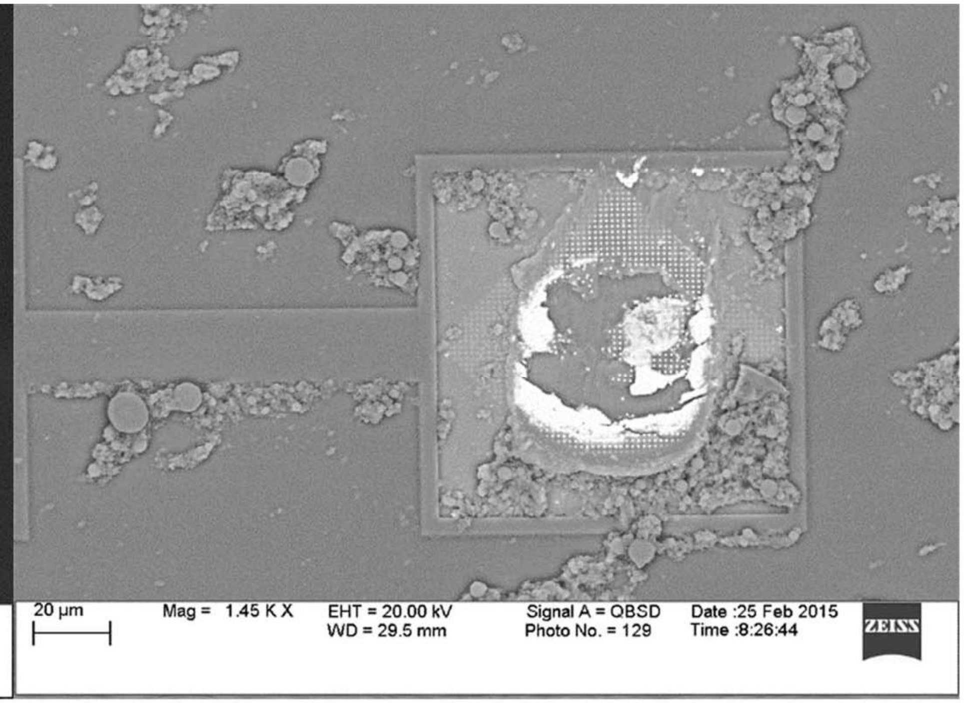
840 Hrs
Open



Initial interfacial cracking at the edges of WB.
Crack propagation during HTSL test. Diffusion of Si at the center of WB system was observed.
This system forms Al-Cu-Si-O matrix and starts WB detachment from center.
This process is faster than interfacial crack propagation.

Cu Wirebond Shear Failure Modes





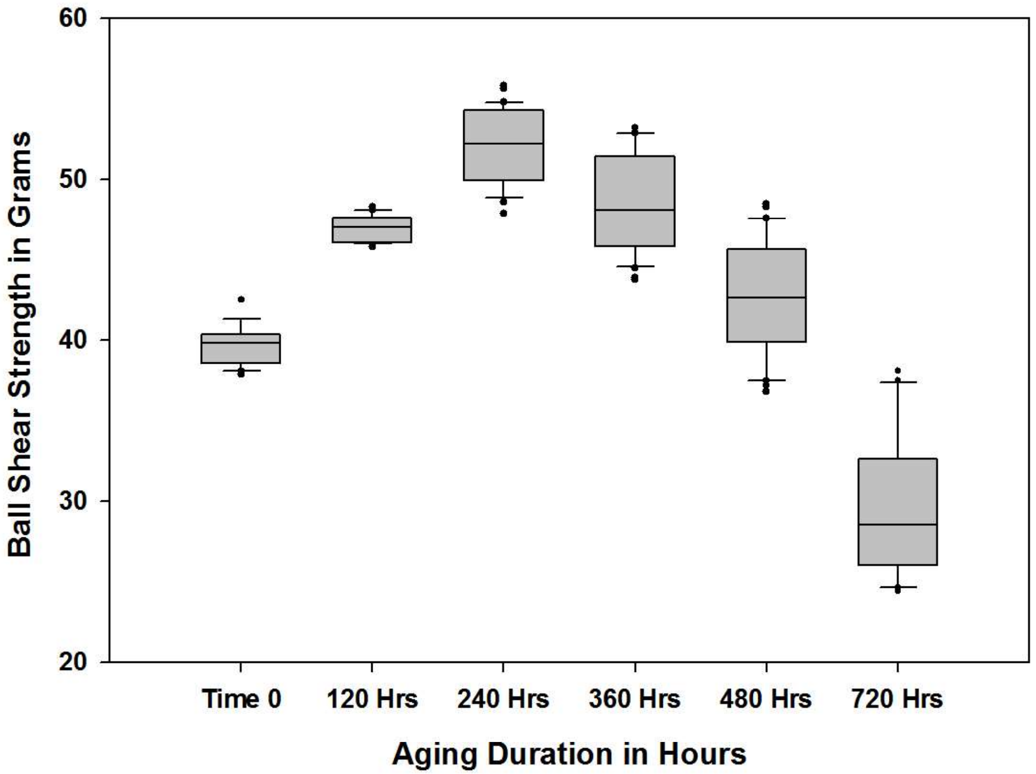
Mode 1

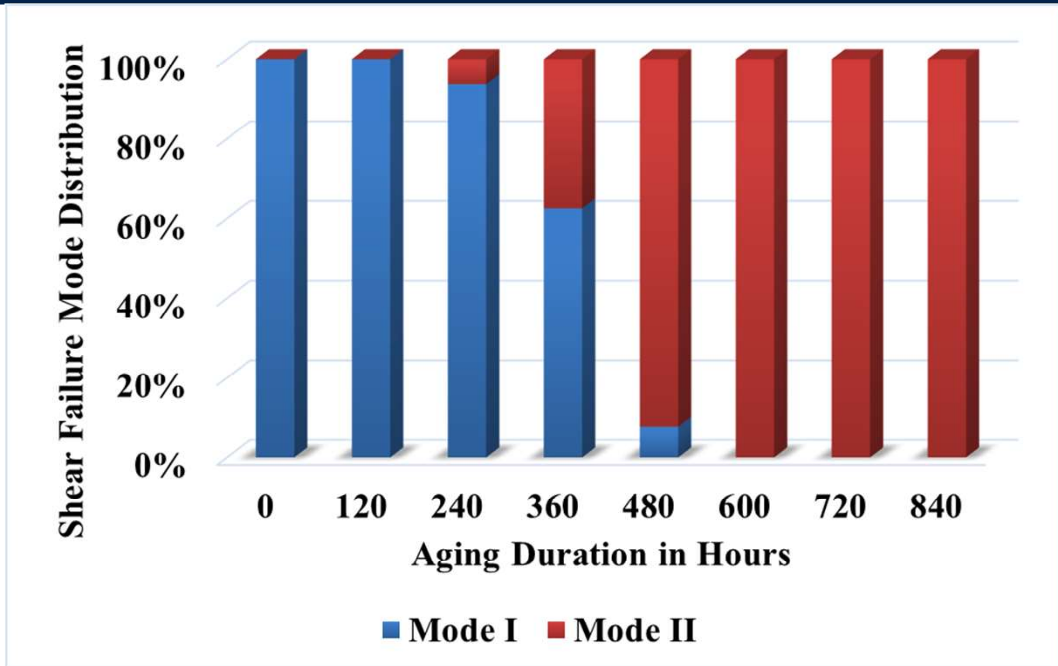
- Very small or no residue of Cu/IMC on sheared surface
- Al pad peeled off the surface
- Indication of good bond

Mode 2

- Residual IMC or Cu on sheared surface
- Part of Al pad intact below IMC.
- Indicates formation of micro cracks and degraded wirebond

Cu Wirebond Shear Strength Change





- Initial increase in shear strength of wirebonds can be contributed to IMC growth.
- Rapid decrease in shear strength indicates presence of microcracking at the interface and results into mode II type failure.

PCC Wire

PCC Wirebonds IMC Growth 200°C

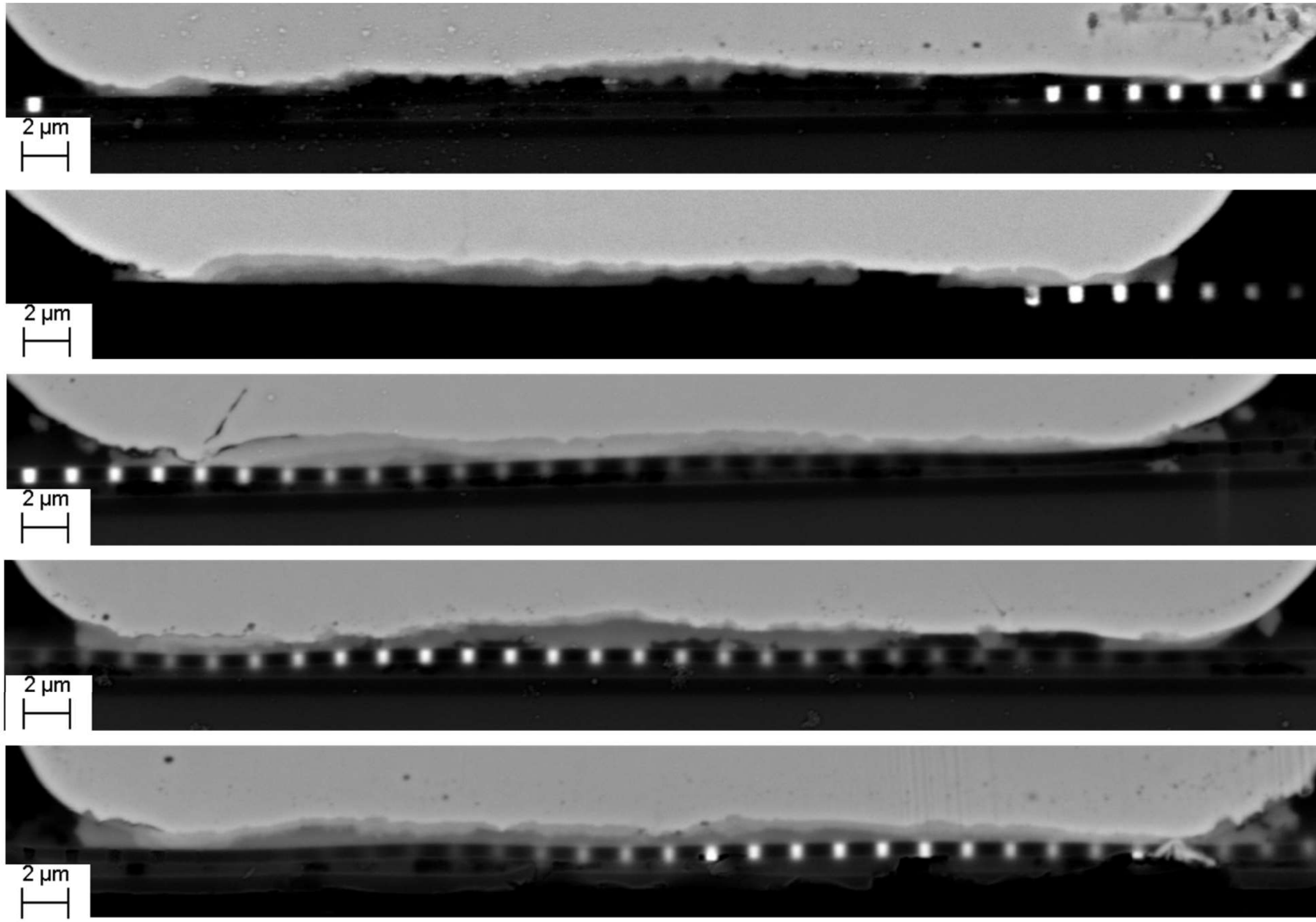
240 Hrs

360 Hrs

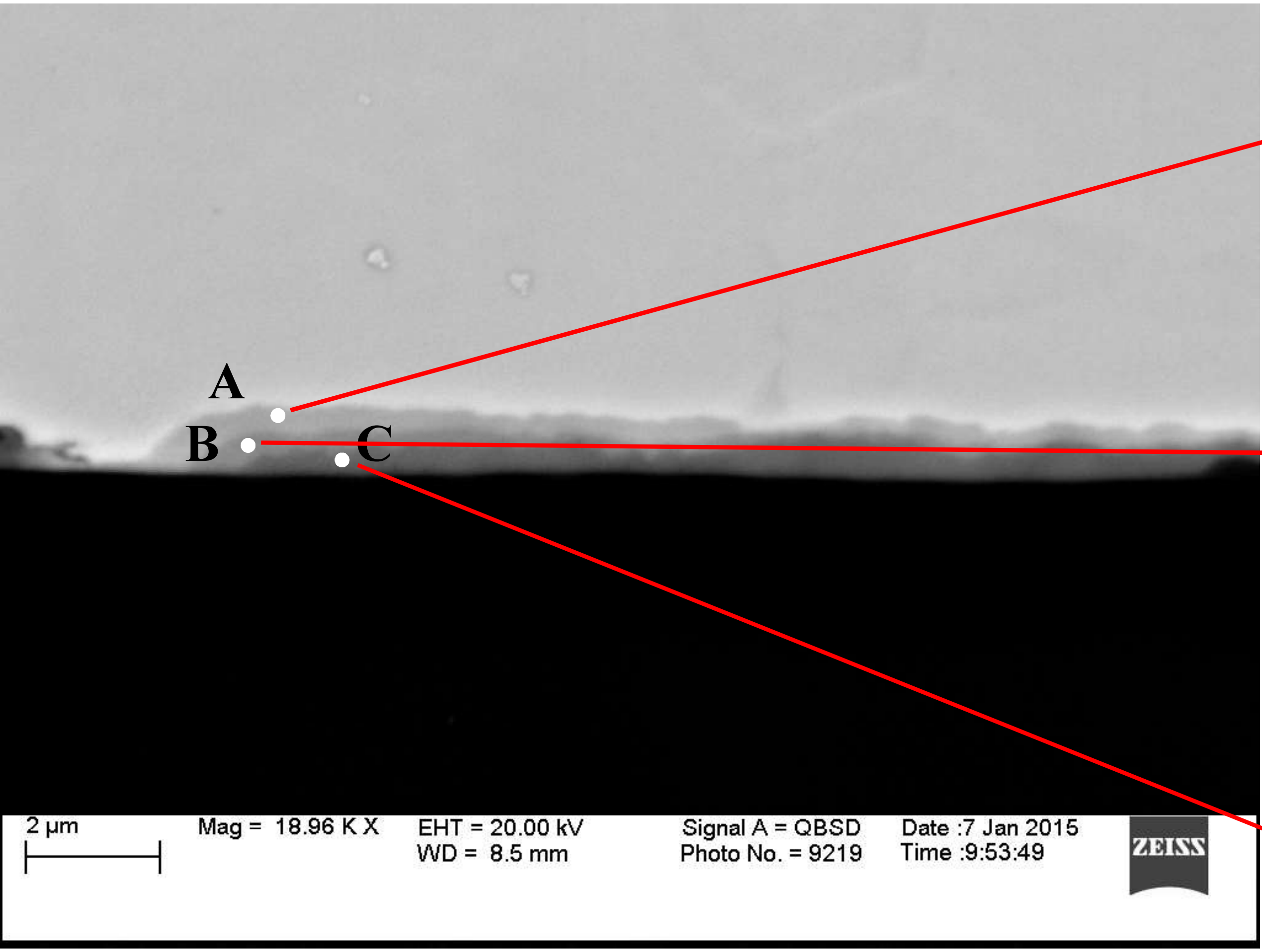
480 Hrs

600 Hrs

800Hrs



PCC Wirebonds EDX Analysis



3 Distinct Phases for PCC-Al IMC

Element	Atomic%
Al K	32.58
Cu K	63.14
Au M	4.28

Cu_9Al_4

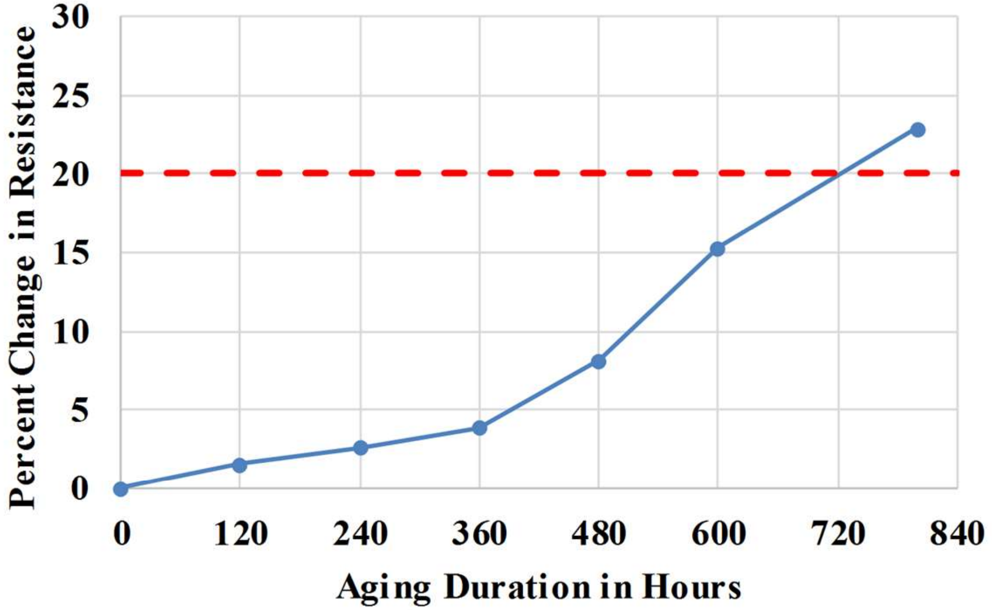
Element	Atomic%
Al K	48.96
Cu K	46.57
Au M	4.48

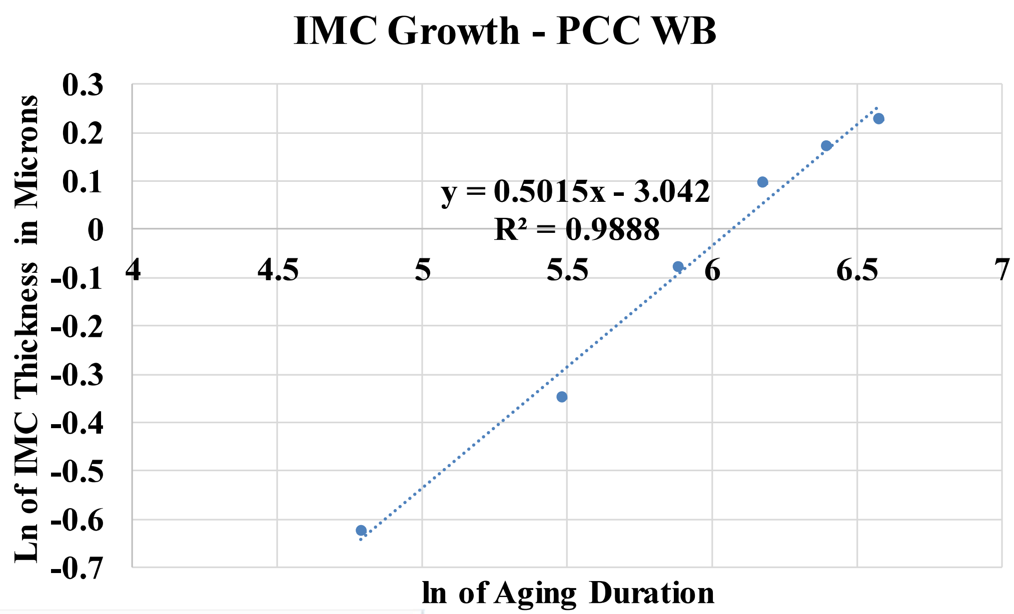
CuAl

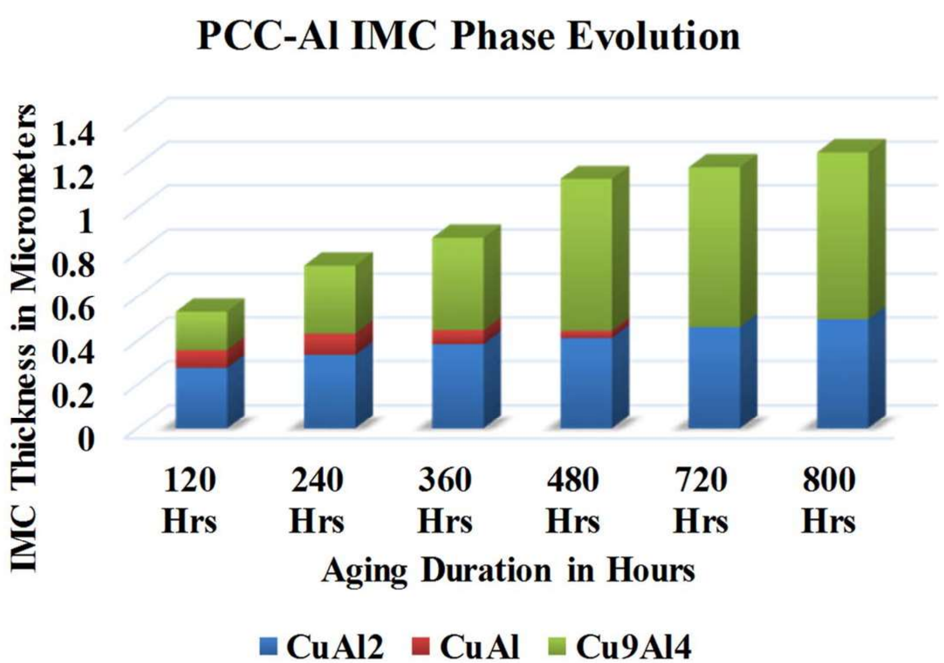
Element	Atomic%
Al K	62.80
Cu K	30.49
Au M	6.71

$CuAl_2$

PCC Wirebonds







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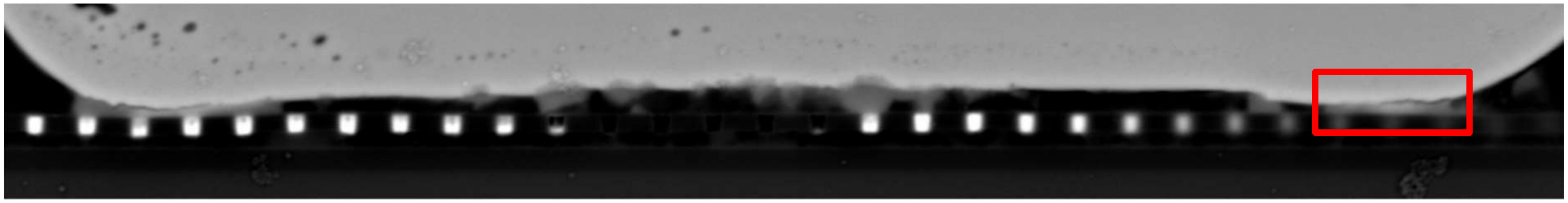
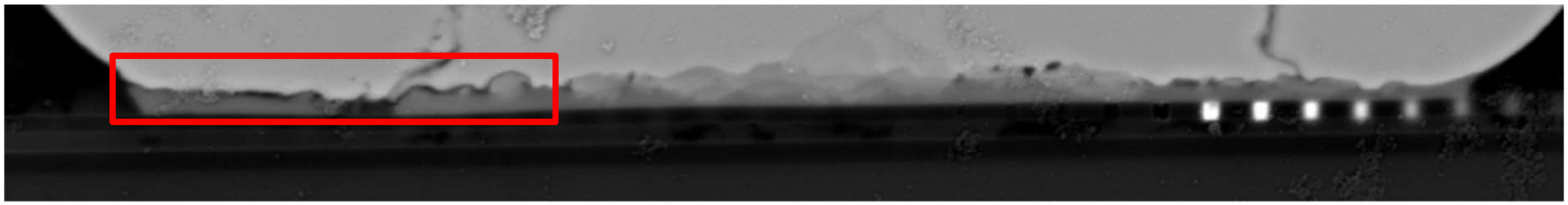
PCC Wirebonds Crack Propagation

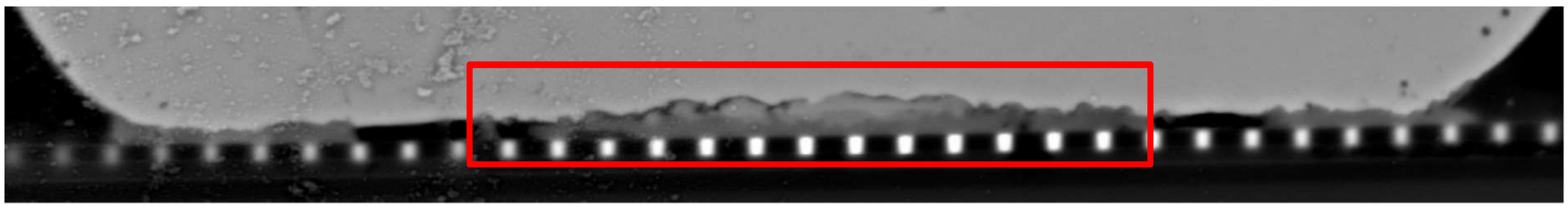
240 Hrs



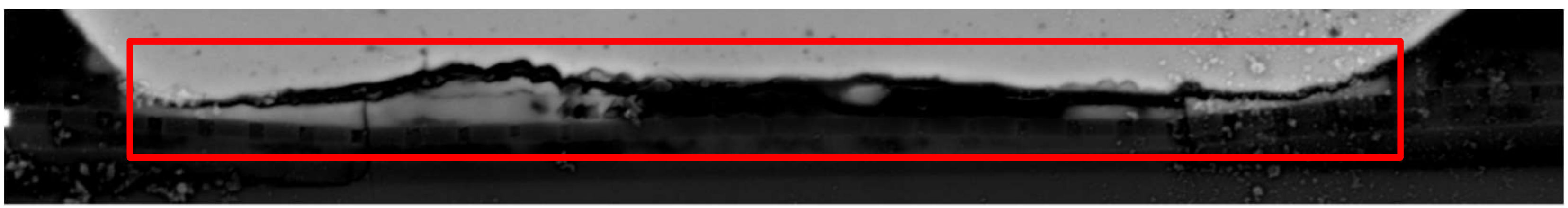
360 Hrs

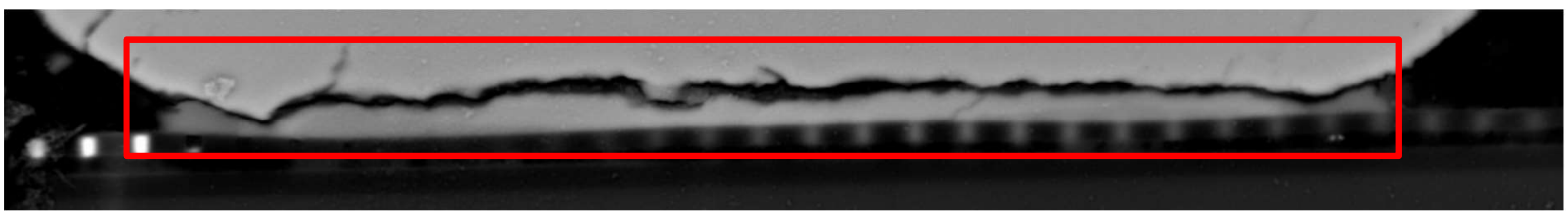


720 Hrs

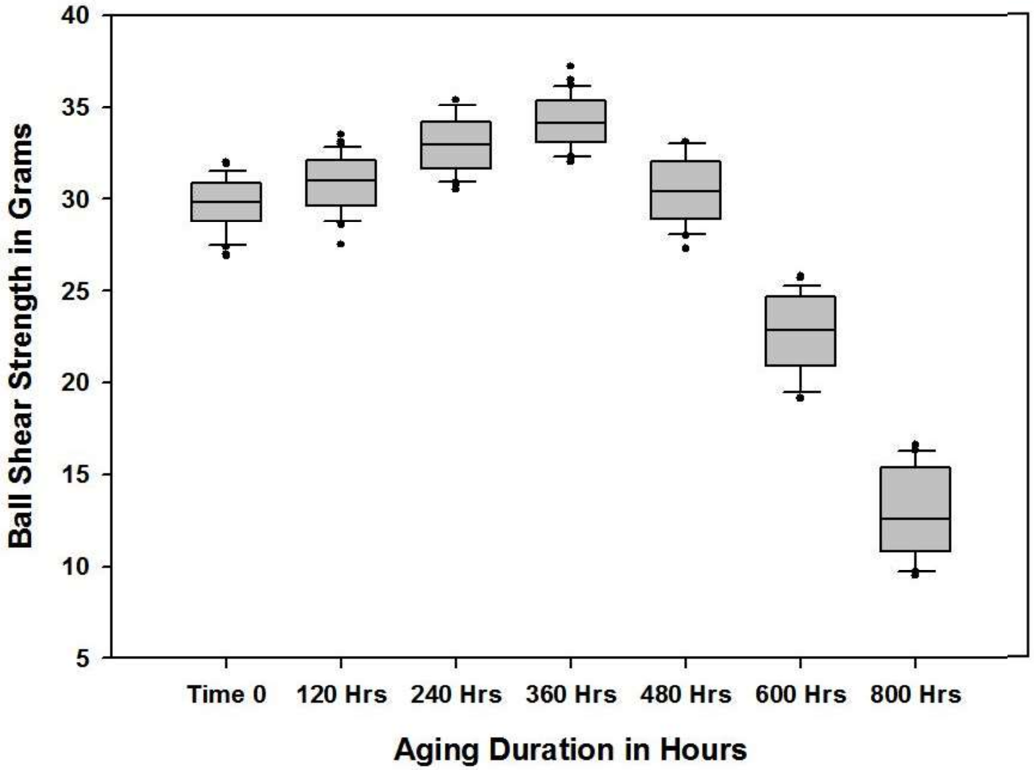


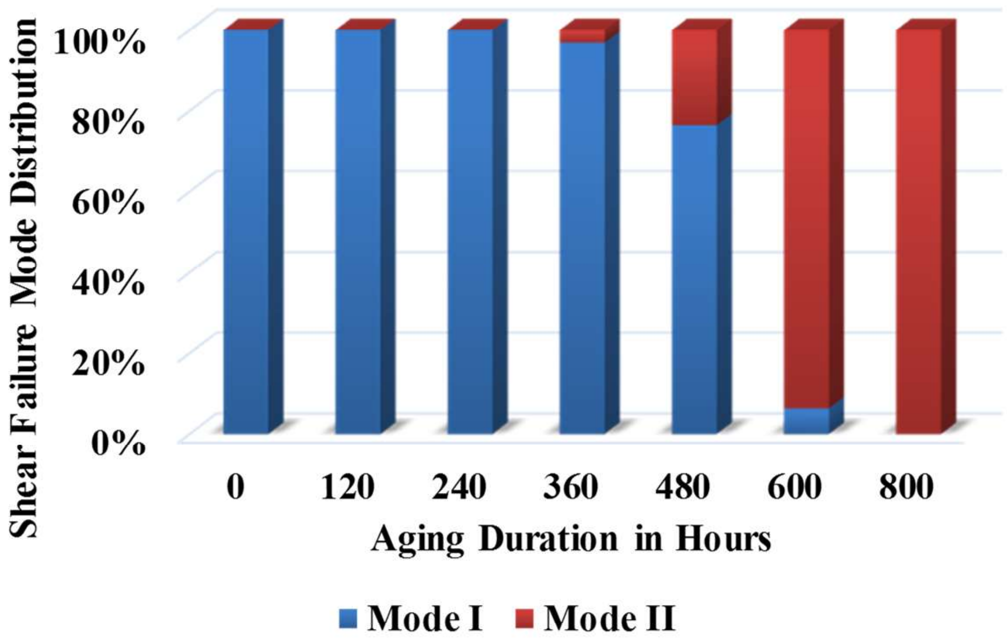
840 Hrs





PCC Wirebond Shear Strength Change



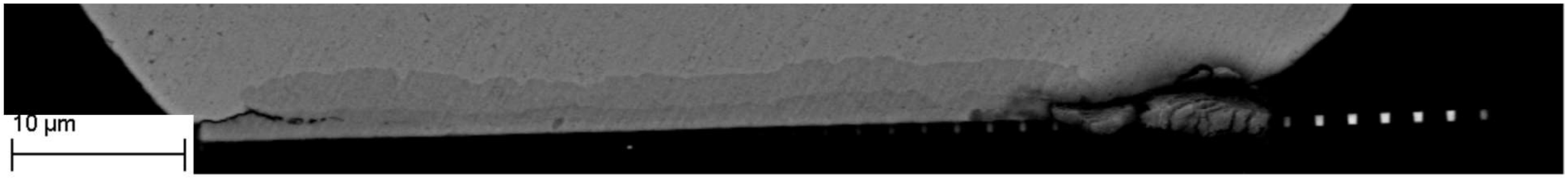


- Initial increase in shear strength of wirebonds can be contributed to IMC growth.
- Rapid decrease in shear strength indicates presence of microcracking at the interface and results into mode II type failure.

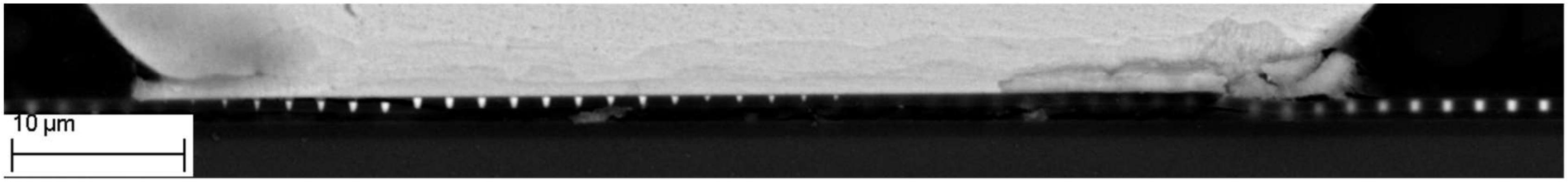
Ag Wire

Ag Wirebonds IMC Growth 200°C

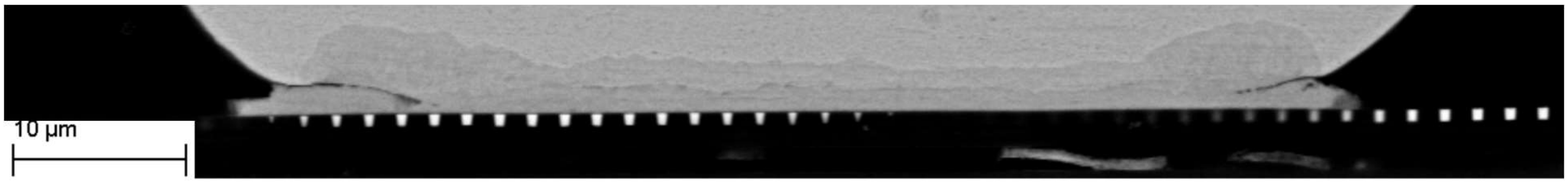
120 Hrs



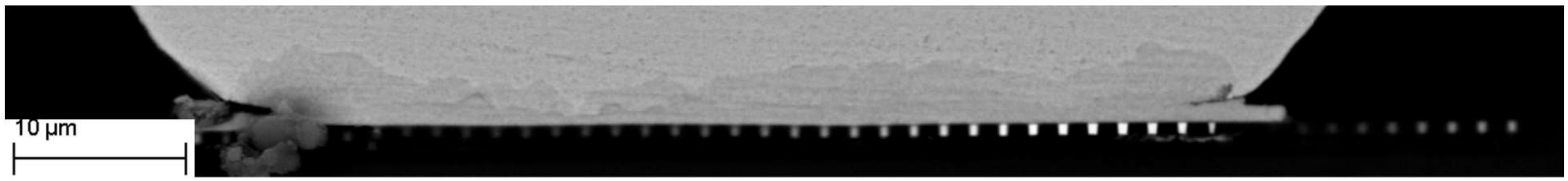
240 Hrs



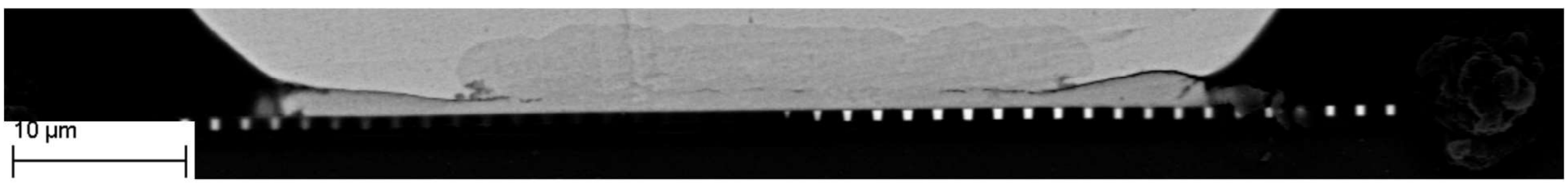
360 Hrs



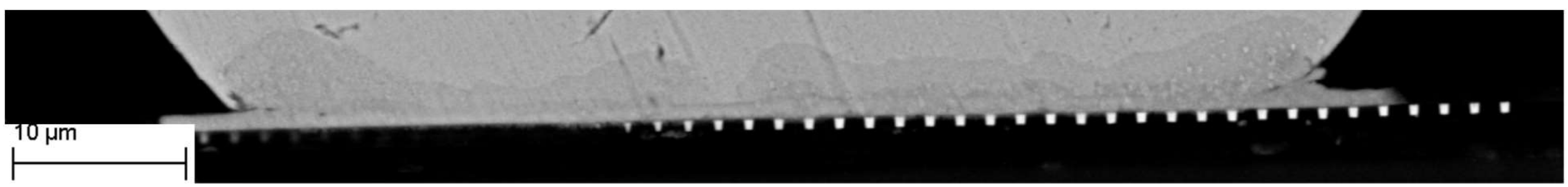
480 Hrs



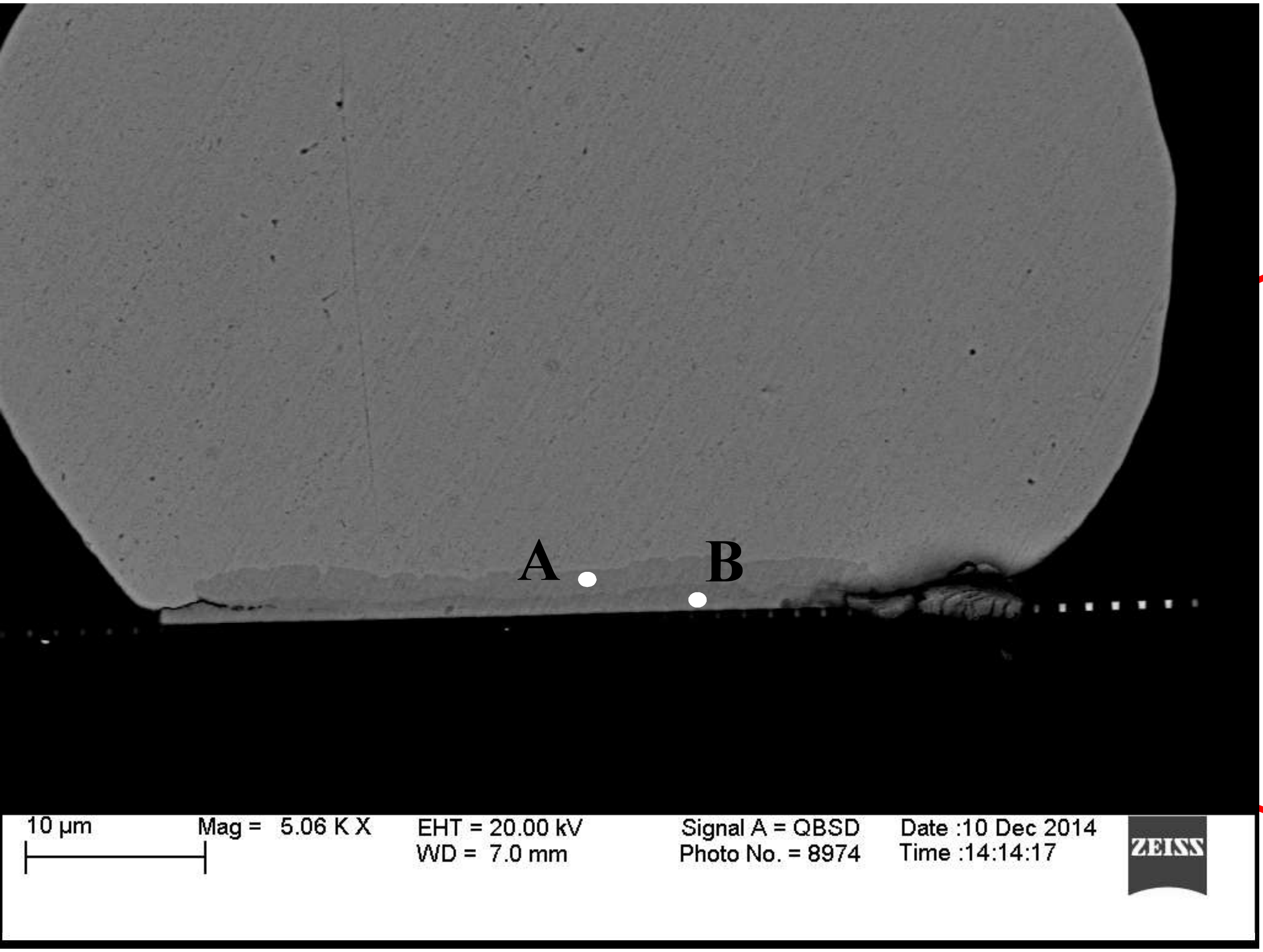
600 Hrs



720 Hrs



Ag Wirebonds EDX Analysis



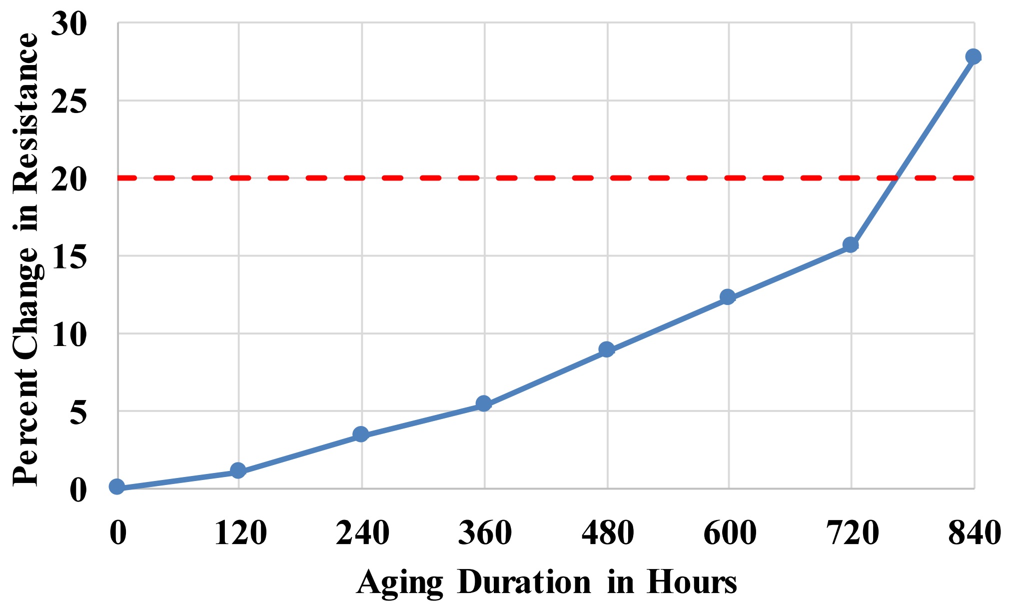
Element	Atomic%
Al	25.02
Ag	73.26
Au	1.72

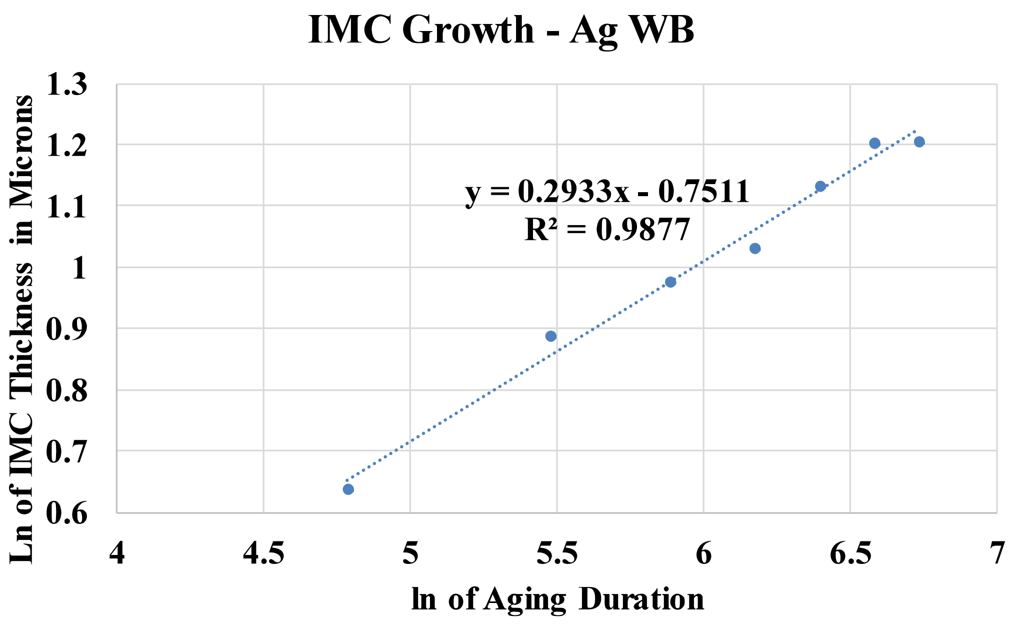
Ag_3Al

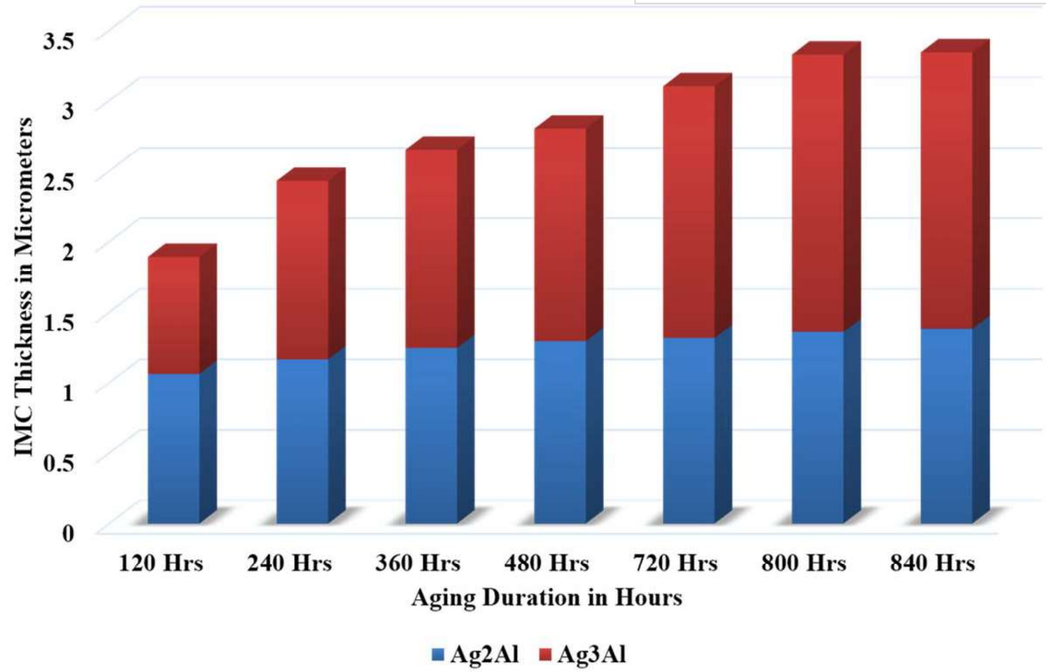
Element	Atomic%
Al	33.48
Ag	64.12
Au	2.4

Ag_2Al

Ag Wirebonds







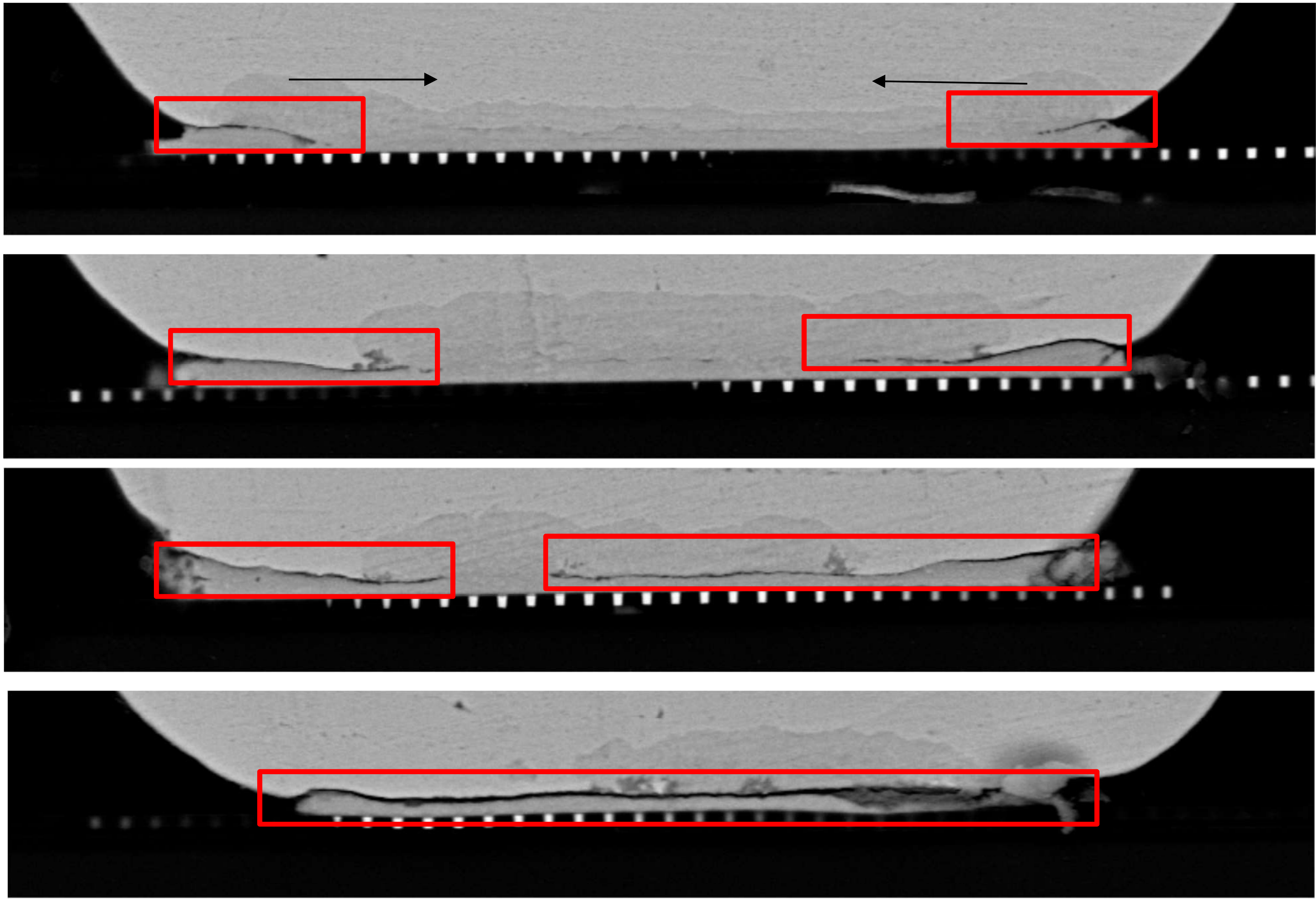
Ag Wirebonds Crack Propagation

360 Hrs

720 Hrs

840 Hrs

1200 Hrs



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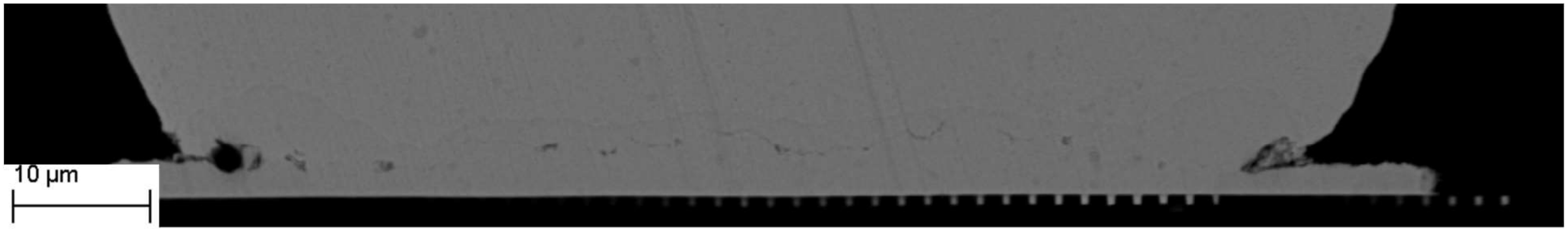
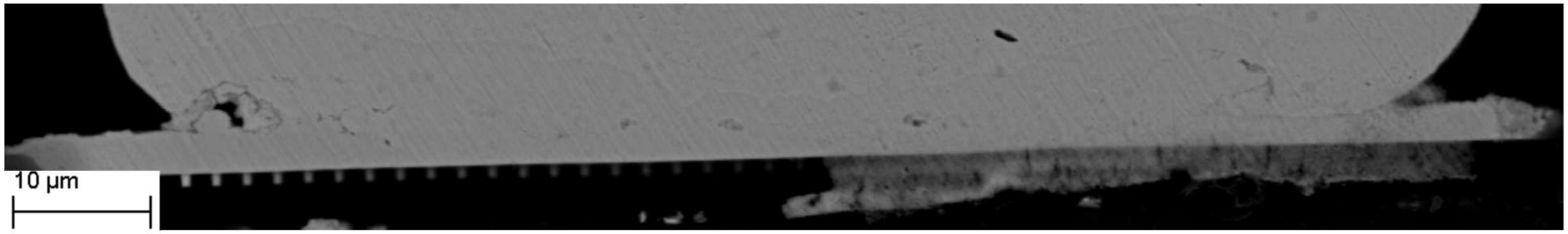
Au Wire

Au Wirebonds IMC Growth 200°C

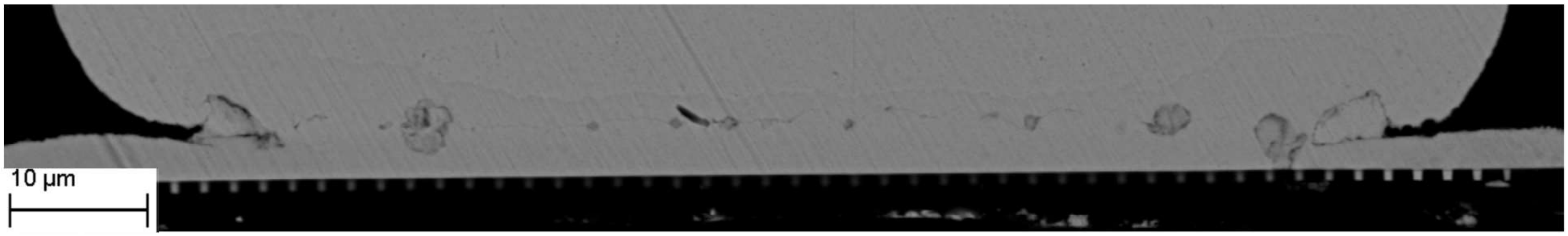
120 Hrs



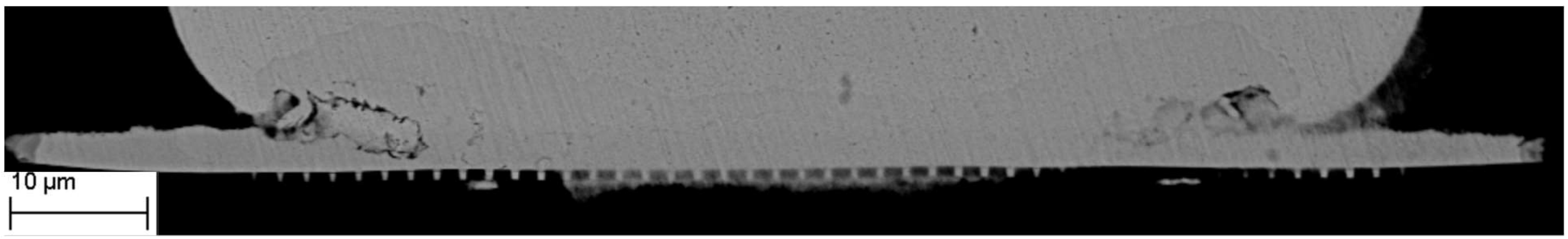
240 Hrs



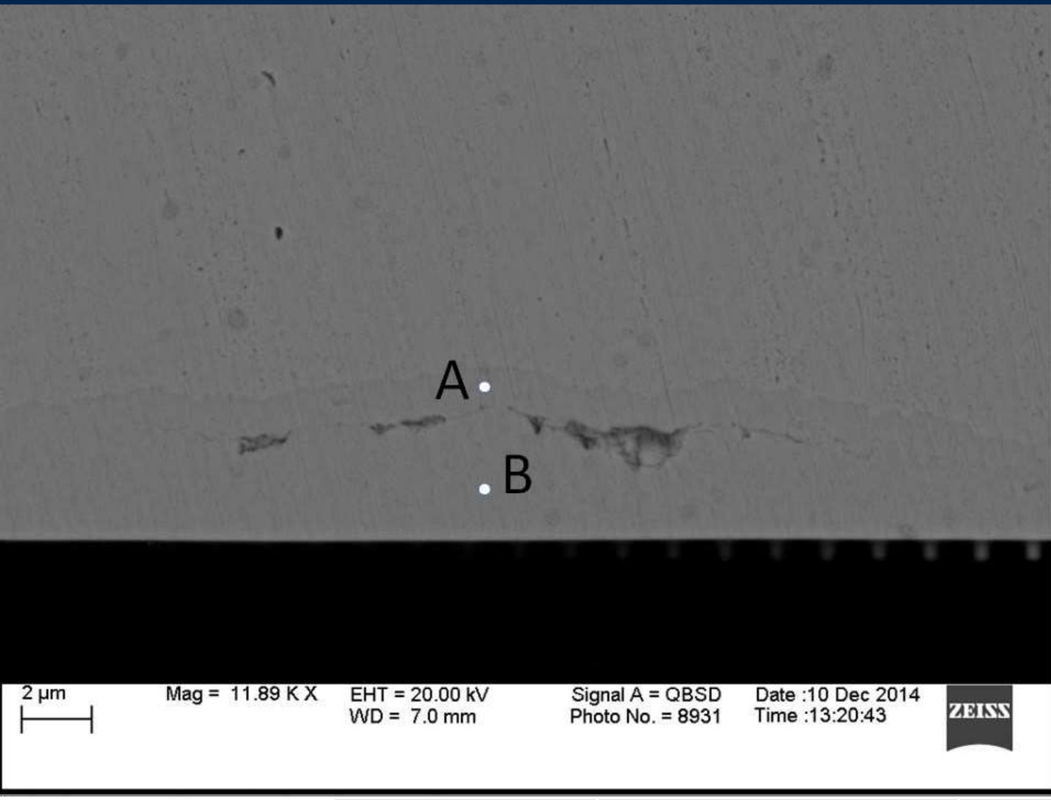
360 Hrs



480 Hrs



Au Wirebonds EDX Analysis



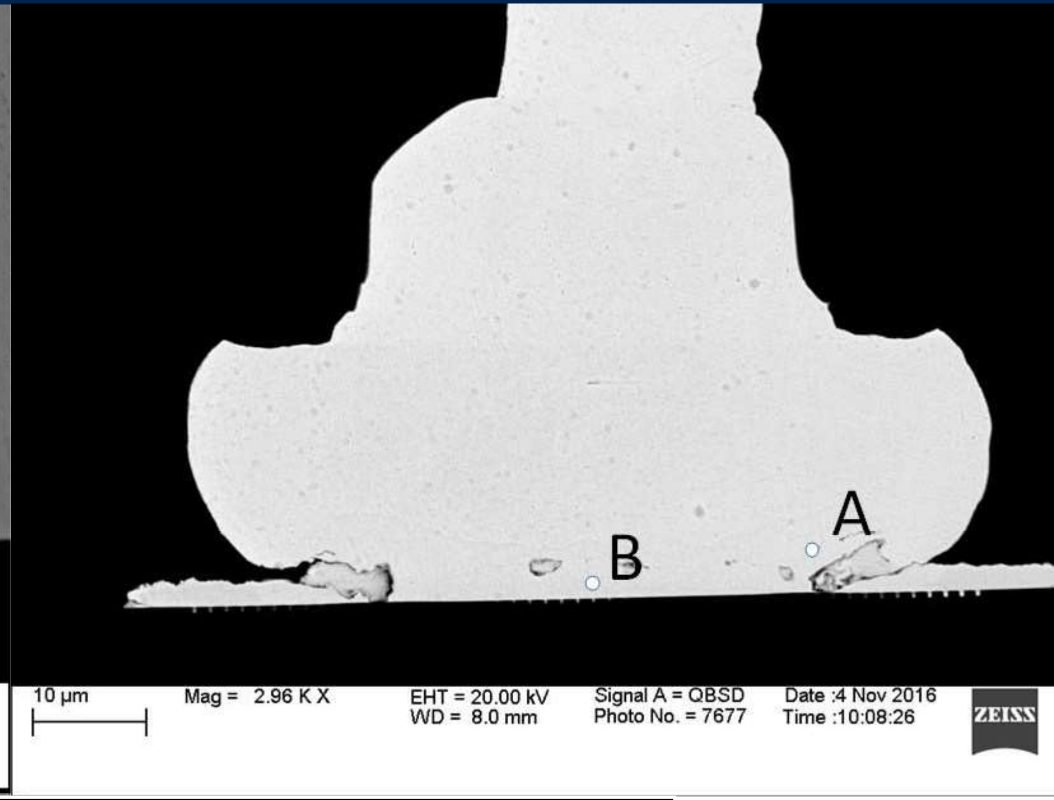
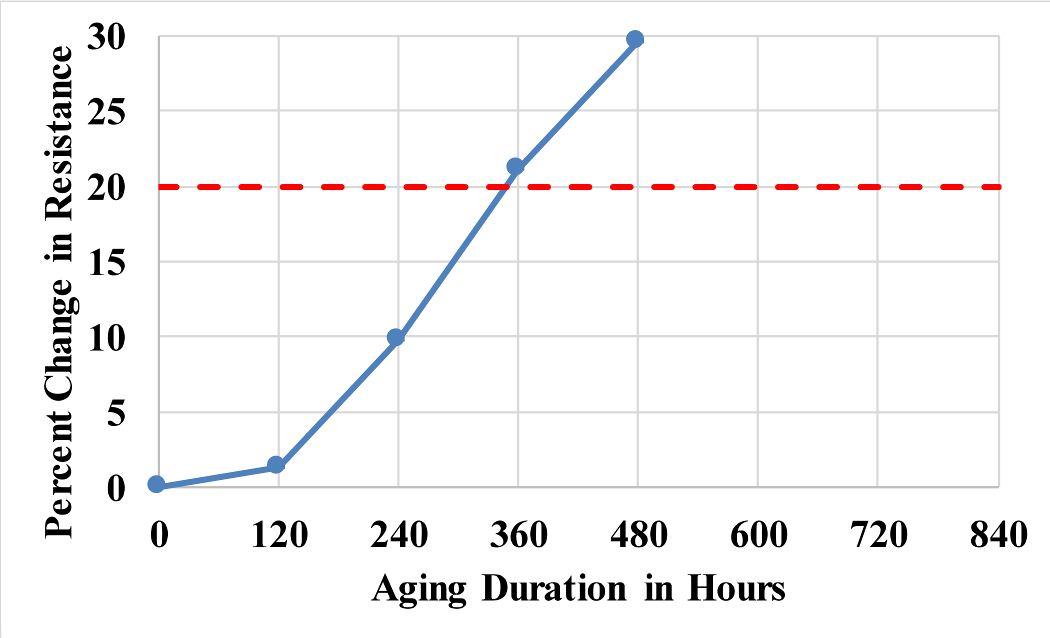
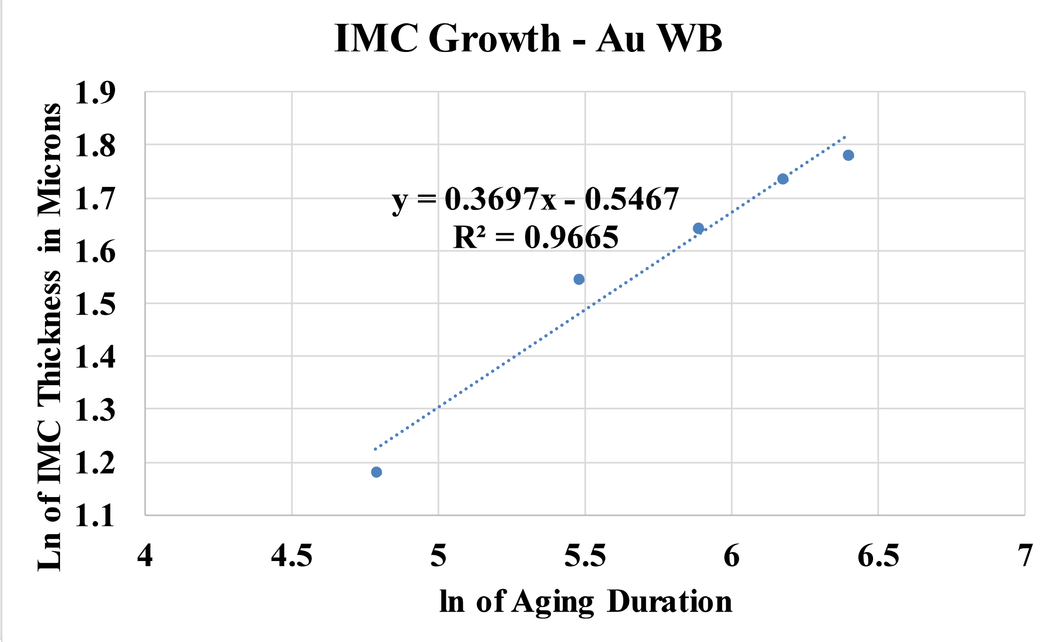


Fig. Number	Element	Percent Atomic Content	
		Point A	Point B
(i)	Au	80.38	69.40
	Al	19.62	30.60
(ii)	Au	82.26	81.53
	Al	17.74	18.47

Au Wirebonds



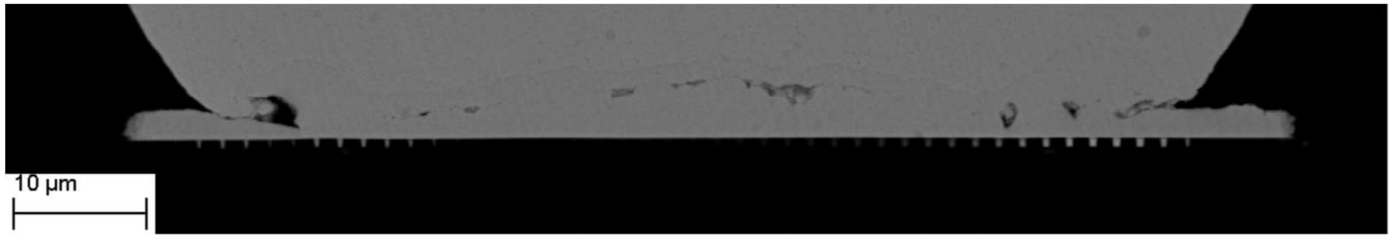


- After 240 hours of aging only Au_4Al IMC phase was observed. Au_8Al_3 IMC was not observed after 120 hours of aging.

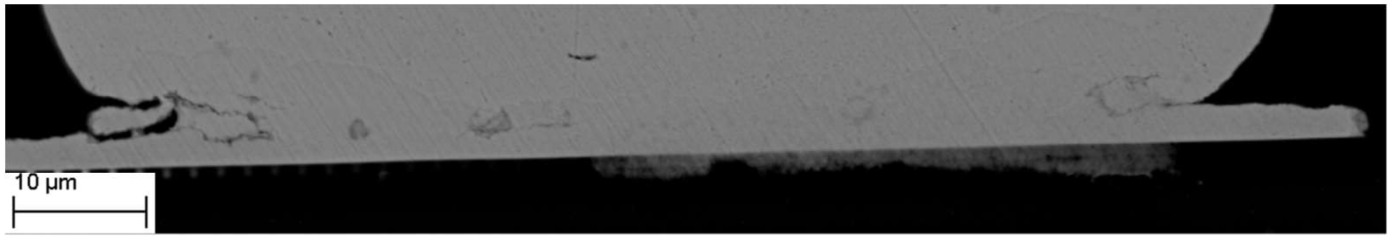
- IMC growth rate was highest for Au-Al system and IMC thickness was around 5.4μm at the time of failure.

Au Wirebonds Crack Propagation

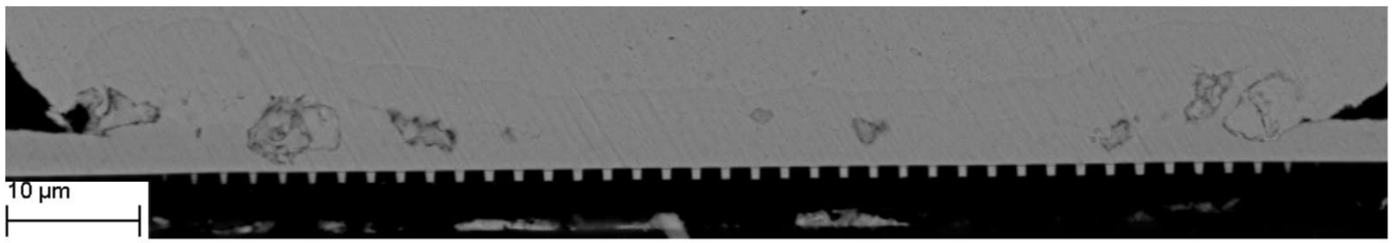
120 Hrs



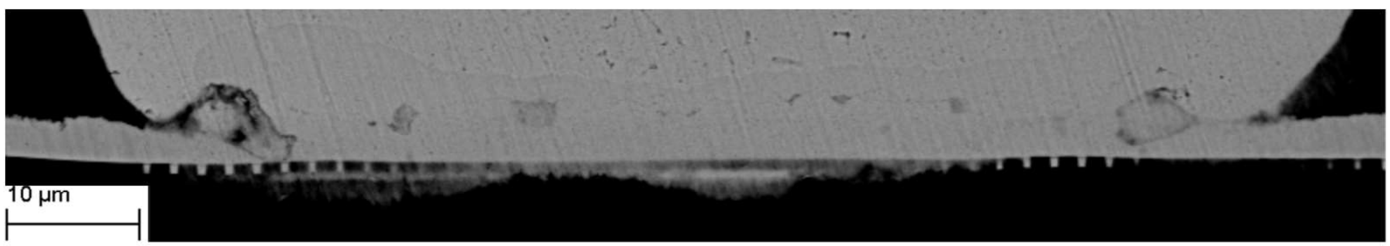
240 Hrs



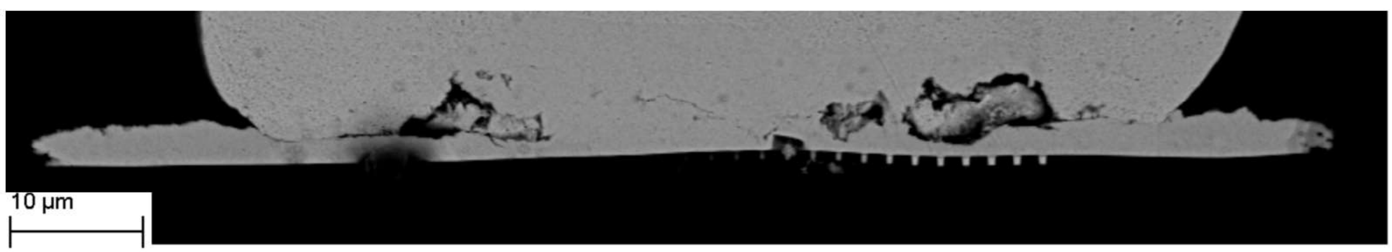
360 Hrs



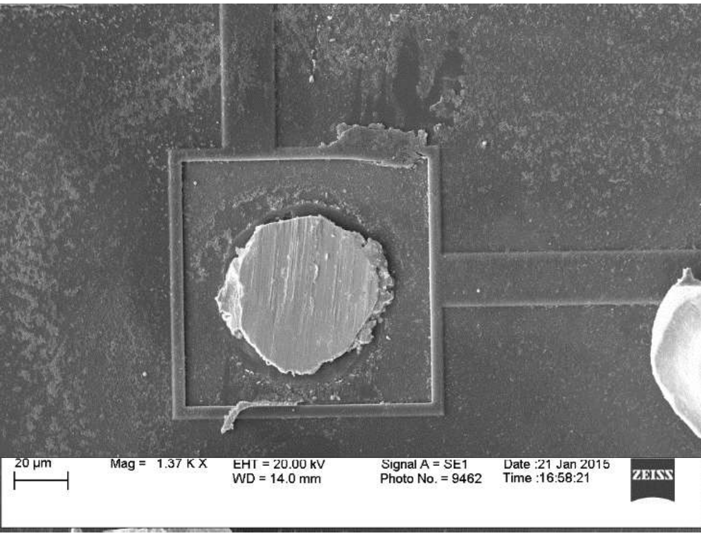
480 Hrs



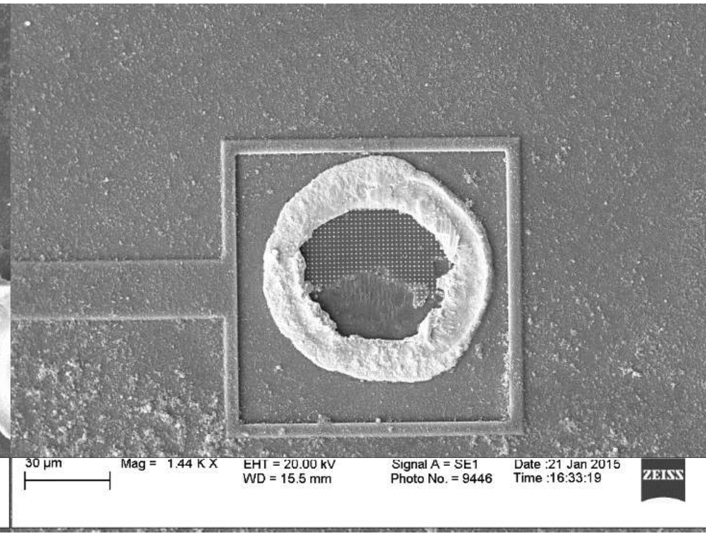
600 Hrs



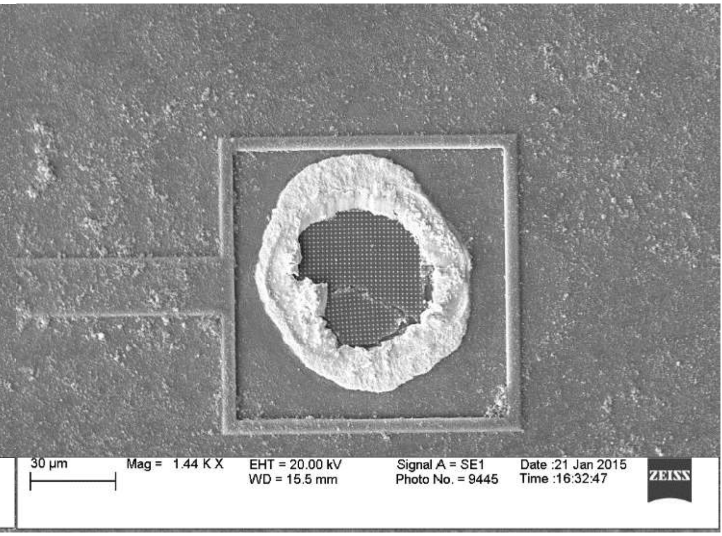
Au Wirebond Shear Failure Modes



Mode - A



Mode - B

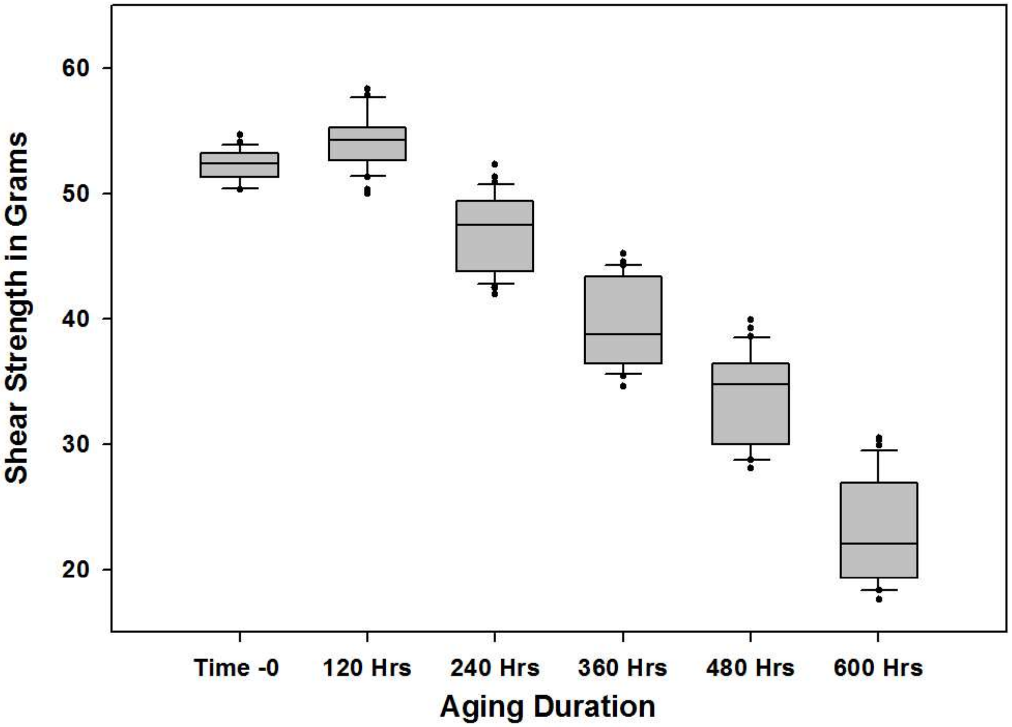


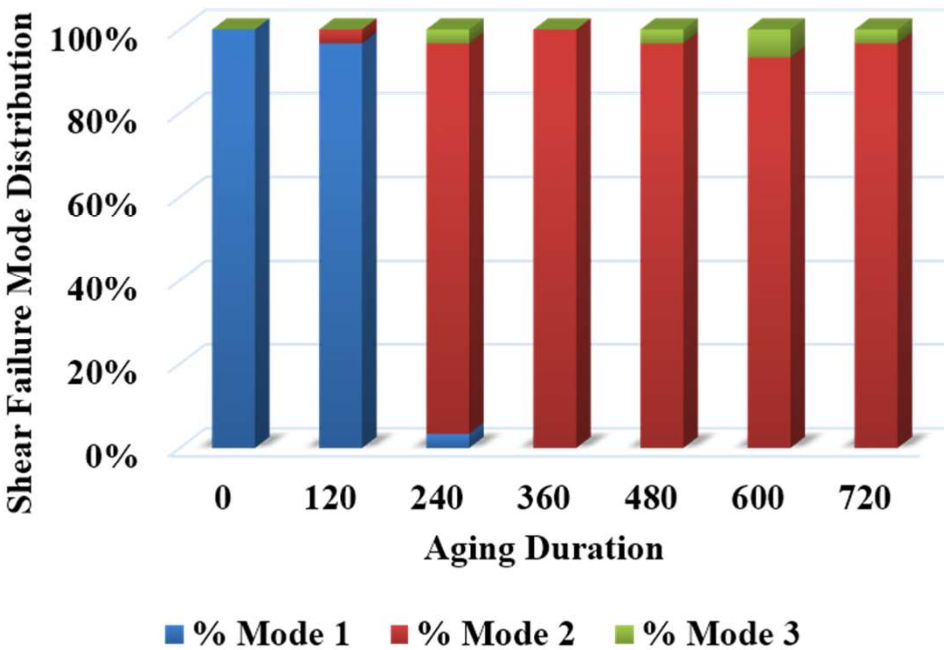
Mode - C

Mode A$ – Fracture in gold wire / IMC. Typical mode of failure for Au-Al system.
Mode B* – IMC fracture along periphery and loss of adhesion at center due to consumption of Al pad.
Mode C* – Mode B with cratering.

$ – Automotive electronic council Q100-001 Rev-C Wire Bond Shear Test Standard.
* – Clatterbaugh G., Weiner J., Charles H., "Gold-Aluminum Intermetallics: Ball Bond Shear Testing and Thin Film Reaction Couples", IEEE Tran. On Components, Hybrids, and Manufacturing Technology, Vol 7, Issue 4., Dec 1984, pp 349-356

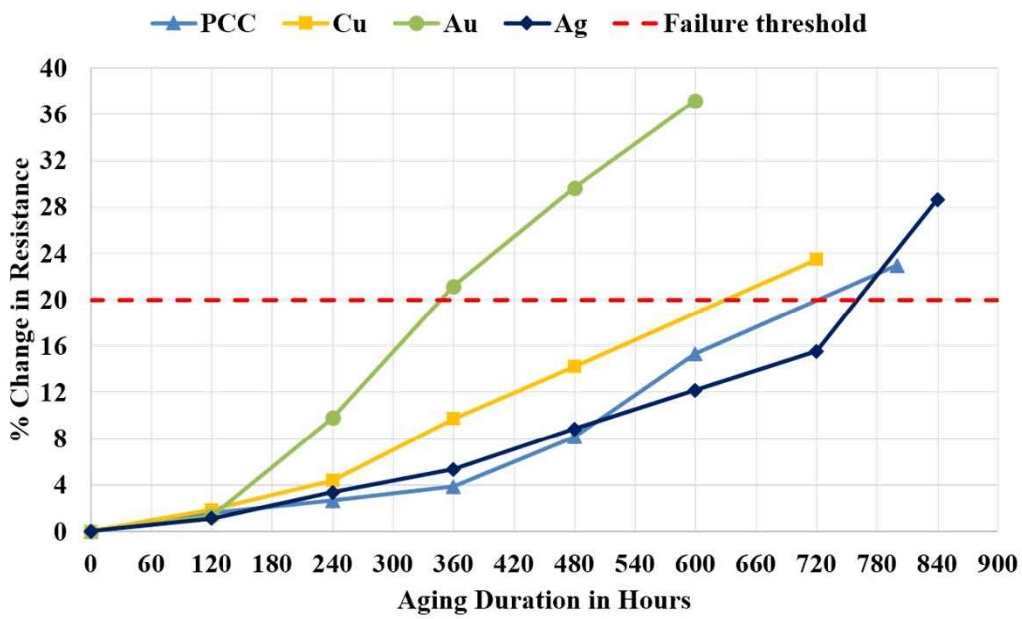
Au Wirebond Shear Strength Change

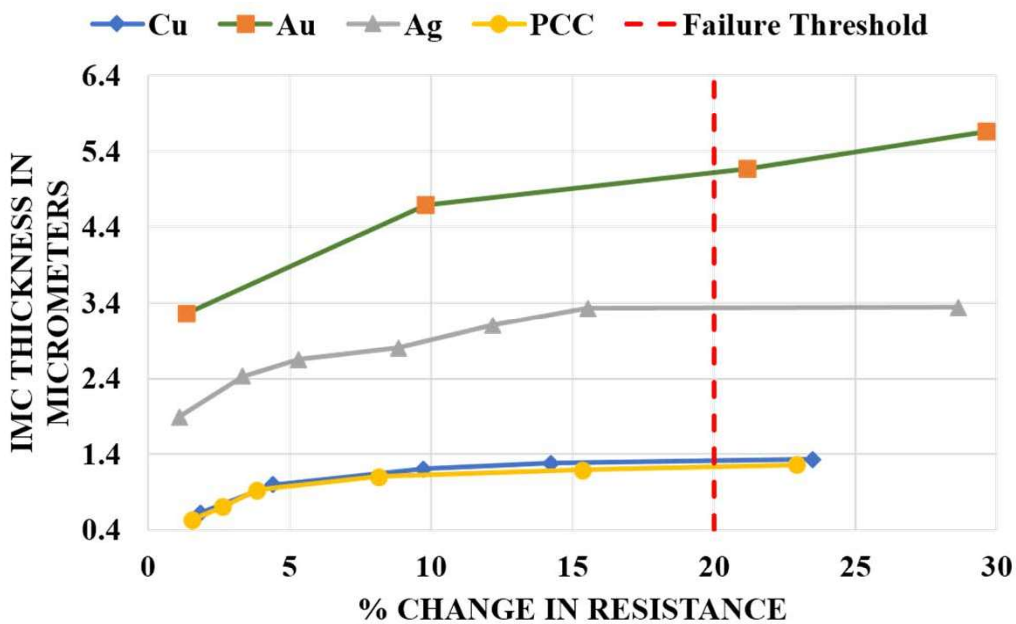


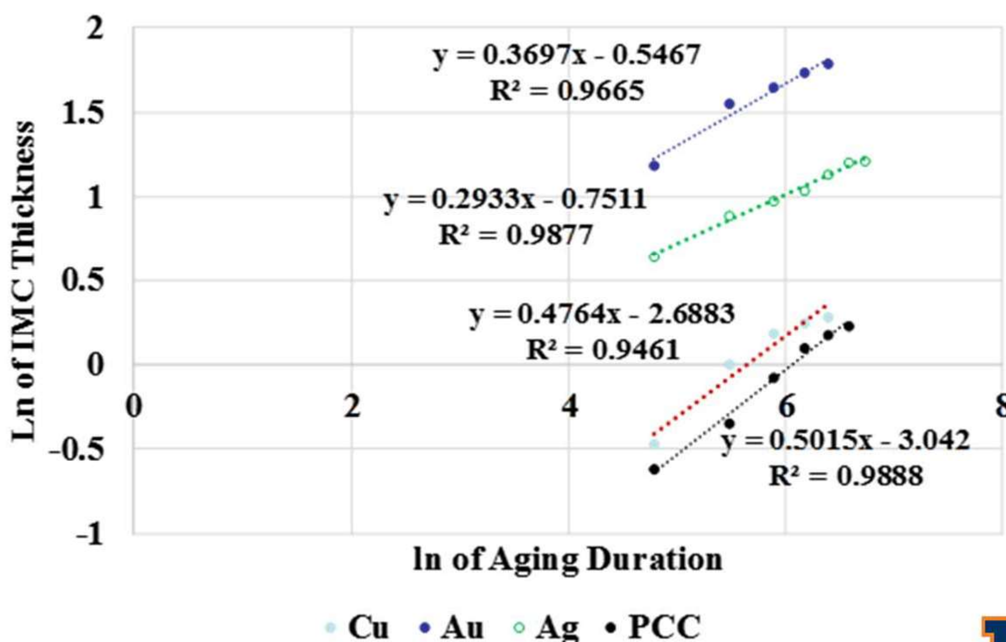


- Initial increase in shear strength of wirebonds can be contributed to IMC growth.
- Rapid decrease in shear strength indicates presence of large voiding at the periphery of ball bond and results into mode II type failure.

Compiled Results







Summary and Conclusions

- Under HTSL condition at 200°C, Au WB failed earliest; i.e. after 360 Hrs of aging, followed by Cu, PCC and Ag WB systems. They failed after 600, 720, 840 Hrs of thermal aging.
- 3 phases, $CuAl_2$, CuAl, Cu_9Al_4 were found for Cu and PCC WB system. $CuAl_2$ was major part of IMC at the early stages of aging, and Cu_9Al_4 phase was dominating phase for both cases after prolonged exposure. IMC formation rate is slower for PCC because of presence of Pd at the Cu-Al interface which restricts diffusion even at elevated temperatures.
- For Cu WB's, initial crack was observed along periphery of ball. WB detachment was observed at the same tome at the center of WB. This detachment became worse after further aging, resulting into complete cracking of bond interface.
- For PCC similar trend was observed, but rate of detachment was much lower as compared to Cu WB. Only few WB pairs showed typical interfacial fracture failure.
- For Ag wires, crack was found in-between Ag_3Al and Ag_2Al. Even though crack was formed at early stages, crack propagation speed was very slow. Early crack occurrence affected IMC development and phase transformation. Complete cracking of the interface between these two IMC's was found to be reason of failure.
- Au wires showed aggressive IMC growth, and consumed Al pad in short time. Void formation and propagation took place because of volumetric changes and phase transformation. Complete consumption of Al pad caused detachment of ball from the center, resulting into reduction of shear strength. Failure occurred due to excessive IMC growth, voiding and reduced area of electric contact because of complete consumption of Al pad.