MATERIAL NEEDS AND RELIABILITY CHALLENGES IN AUTOMOTIVE PACKAGING UNDER HARSH CONDITIONS

Varughese Mathew
NXP Semiconductors
6501 William Cannon Drive, Austin TX, USA

SECURE CONNECTIONS FOR A SMARTER WORLD

Automotive Innovation Driven by Electronics

Advanced Driver
Assistance Systems
(ADAS)

Safe Autonomous
Systems
Smart Sensors
Radar and Vision

Security and
Connected
Network

Infotainment
Audio & Amplifier
Application
Processors

Powertrain & chassis
Pressure/ motion
sensors
Battery management
engine controllers,
transmission controllers,
voltage regulators

Advance Energy
systems
Advance
Batteries
Electric Motor
Drivers

Body Controls
Suspension, traction,
power steering Position/
Angle sensors

Safety
Airbag
Collision avoidance
Vehicle stability
system

Harsh Environments in Automotive Electronics

- **Harsh Environments - Cause extreme stresses and device failures.**

- **Typical harsh environments for Automotive electronics include – Extreme temperatures, temperature cycling, high humidity.**
  - **Underhood components – ambient temperature can be 150˚C or higher (may range 175ºC - 200ºC, and peak temperature may even higher).**
  - **Extreme temperature cycles - thermal expansion coefficients of materials in the system and ICs are very important.**
- **Other potentially damaging conditions include corrosive environments, electrostatic discharge (ESD),high voltage environments electromagnetic interference (EMI), vibrations, physical impact etc..**

This presentation focuses on reliability and material concerns under extreme temperatures and temperature cycling.

Challenges in Automotive Packaging

Extended Reliability → Life time reliability for wide temperature range and extreme conditions

Vehicle life for >>10 years

Advanced Functionality → Basic functions → Sense → Think → Act

Zero Defect → People trust their life on some functions

Zero defect for AEC Q100 Grade 0 for production

Cost sensitive Manufacturing – Achieve the above three cost effectively

Reliability Requirements

- The Automotive Electronics Council (AEC) defines requirements for automotive grade electronic components.
- AEC Requires Grade 0 or 1 for Harsh environments.

Power Train
Grade 1 & 0

Body
Grade 1

Chasis & Safety
Grade 1

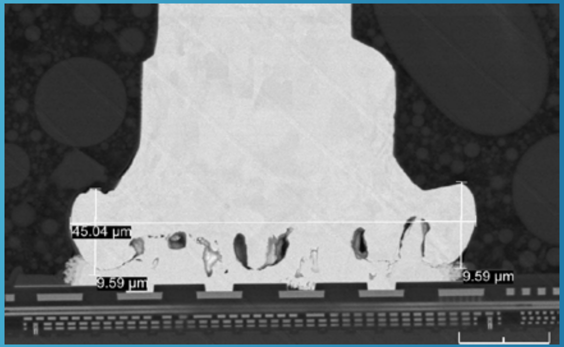
ADAS
Grade 1

Discrete
Grade 2 & 3

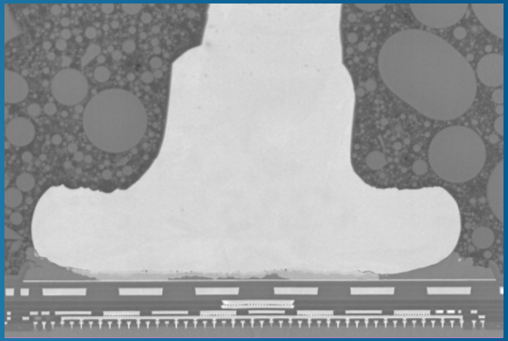
- Packaging reliability is governed by materials and interfaces.
- Wire and mold compound-metal interface reliability at high temperature / temperature cycle are two key areas of focus.

Improved high temperature reliability with Cu wirebonding

- Au wire bond (Al-Au) cannot pass high temperature (> 175º C) reliability requirements due to excessive Au-Al intermetallics and Kirkendall voiding.



Au wire
1620hr HTB-175ºC



Cu wire-
1620hr HTB-175ºC

- Leading automotive electronic packaging SO ,QFP, BGA and QFN demonstrated AEC Q100 Grade 1/0 realiability .

- Au-Al: Au-Al intermetallics and voids continue to grow with HTB. ~6um IMC measured at 1620hr HTB-175ºC.

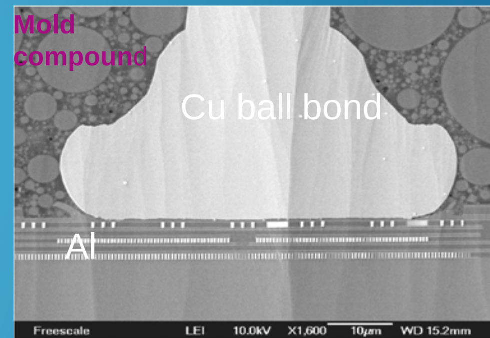
- Cu-Al: IMC thickness averaged ~1um. IMC formation with Cu wire slow and can pass AECG0 HTB conditions.

However **Cu wirebonding (**CuWB) /Epoxy mold compound (EMC) has several challenges to overcome to achieve reliability under harsh conditions.

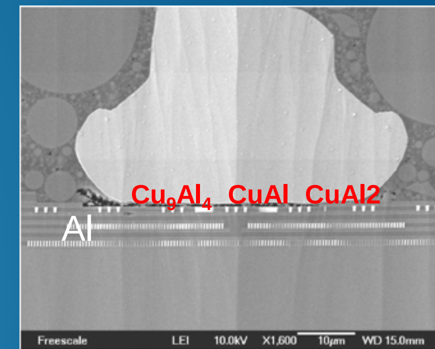
Varughese Mathew and Tu Anh Tran – IMAPS -2012 - 45th International Symposium on Microelectronics

Copper Wirebond (CuWB) Reliability

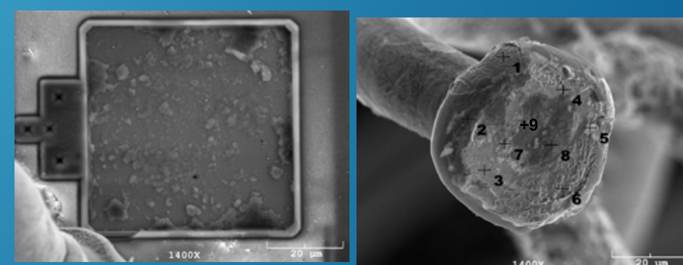
- Bonding of Cu to Al form various Cu-Al Intermetallic compounds (IMC) such as Cu_9Al_4 (close to Cu) , CuAl, CuAl2 (Close to Al).
- CuWB failure is mainly caused by the corrosive opening of IMC at the Cu-Al interface.
- Cl^- ion concentration and pH of the mold compound matrix are two of the key factors influencing corrosion.



Good Cu- Al bond



Failed Cu- Al bond



Atomic Ratio

Locations	Al :Cu
1, 3, 6	Pure Cu
2	8.07 : 18.06
4	0.91 : 20.24
5	8.78 : 8.41
7	8.13 : 16.09
8	5.97 : 14.7

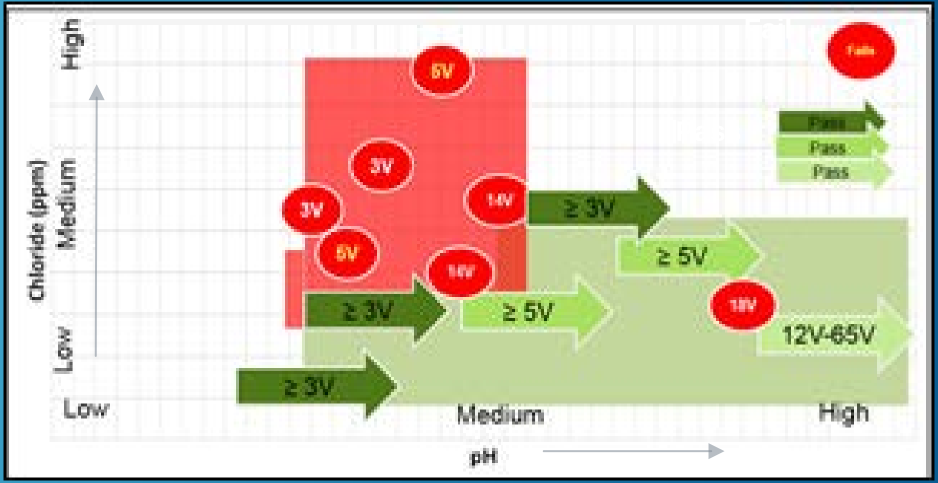
CuWB Failure Mode

Mold compound is a major source of various corrosive ions. What is impact of these ions on CuWB reliability?

Varughese Mathew, Sheila Chopin, Leo Higgins and Ingrain Zhang, IMAPS 2013 - 46th International Symposium on Microelectronics

Impact of bias voltage on CuWB corrosion reliability

- pH and corrosive ionic concentration(Cl) of the mold compound matrix along with applied bias determines/influences CuWB reliability.
- As the biased voltage increases either the pH should be higher towards the neutral region or the Cl concentration be lower in order to avoid a corrosive opening and CuWB failure.
- Bromide ions can also cause corrosion in an additive fashion with Cl.
- Some ions in the mold compound matrix is beneficial or benign.



Influence of pH , Cl concentration and bias voltage on CuWB reliability

If the mold compound matrix Cl concentration is kept low with a pH high, even at a relatively high voltage (studied up to 65V) no corrosion failure observed.

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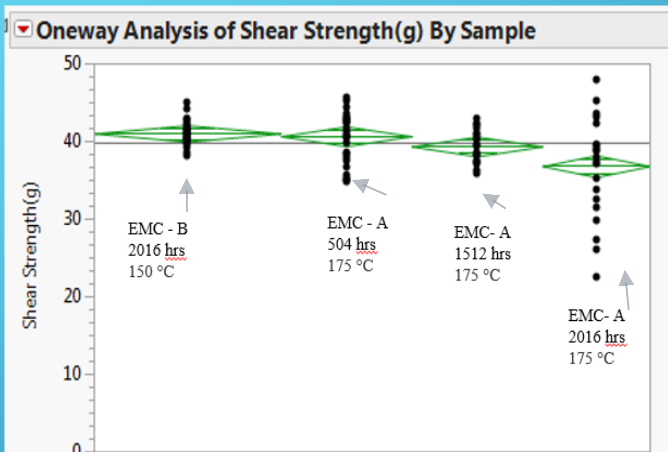
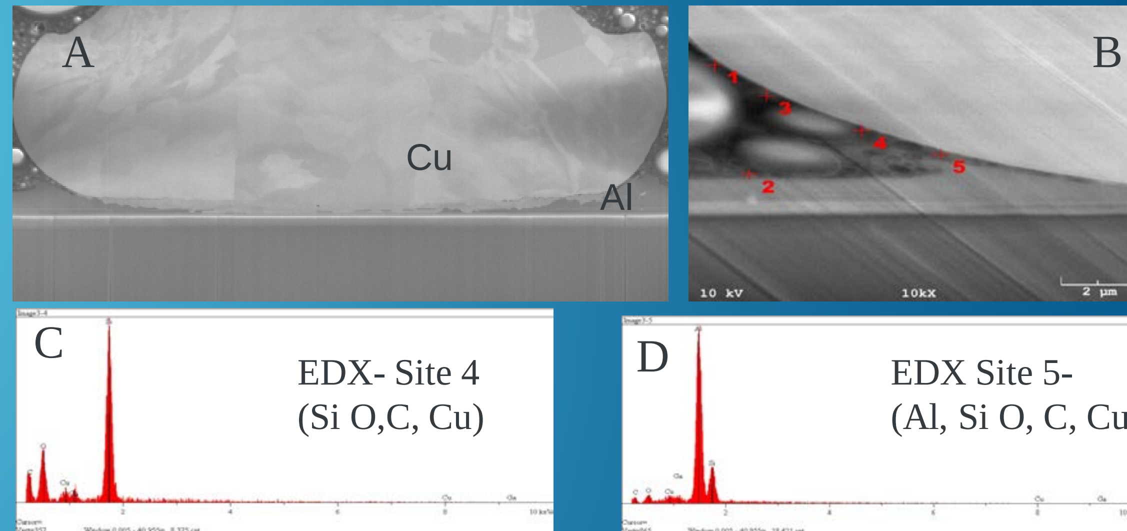
HTSL (High temperature storage life) Reliability



Copper WB ball shear strengths after HTSL for CuWB dies encapsulated with sulfur compound containing mold compounds (Sulfate – A- 35-40; B- 40-45 ppm).



FIB cross-section of CuWB ball bond after 2016 hours of HTSL at 175 °C - (A) – CuWB ball bond (B) Cu-Al interface (C) EDX spectrum of site 4 (D) EDX spectrum of site 5.

- No gaseous sulfur compound detected at high temperatures (up to 200 C)
- Bare Cu wire(1mil- passed AECG0 -2X conditions.

Pd coated Cu wire HTSL behavior different than bare Cu wire

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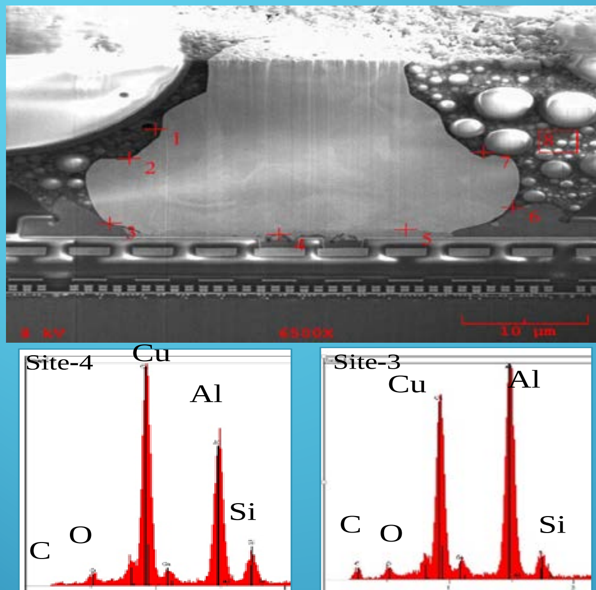
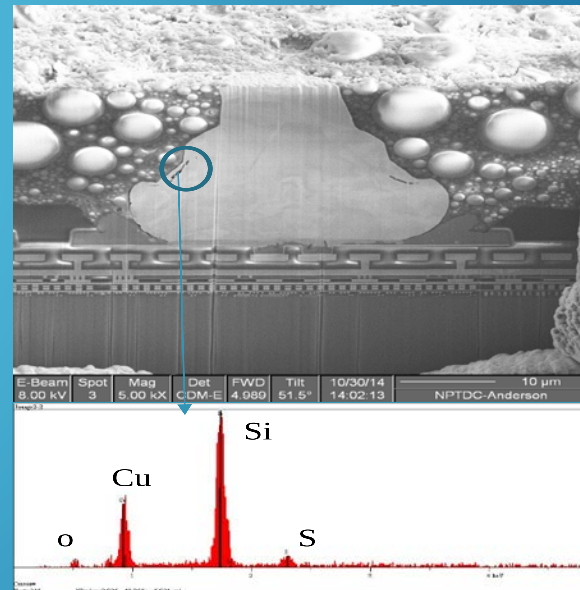
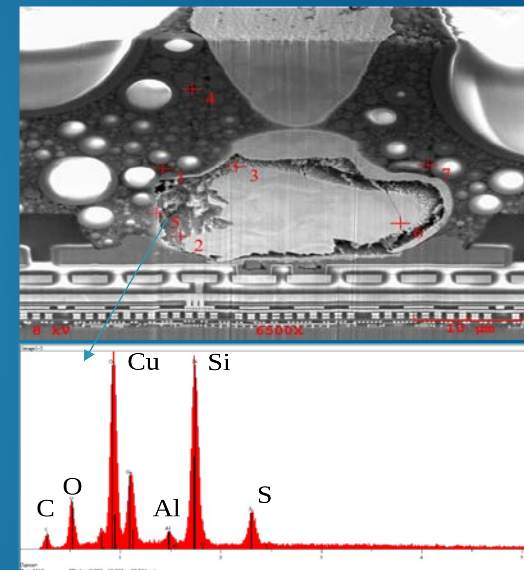
HTSL Reliability due to S compounds – Pd Coated Cu wire



(8.8 ppm sulfate) after 1008 hrs. of HTSL stress.



(34.5ppm sulfate) after 1008 hrs. of HTSL stress.



(47.5ppm sulfate) after 1008 hrs. of HTSL stress.

The CuAl IMC – Al interface was found to be intact and not corroded. No significant corrosion of any part of the ball bond. EDX at various sites did not indicate presence of S.

No corrosive opening occurred at the CuAl IMC-Al interface. Some level of copper corrosion (voiding of copper) close to the periphery of the CuWB ball bond. S is detected in the area. No open failures.

Experimental sample
Extensive corrosion was observed and corrosive opening was also present leading to electrical open failure. S was also detected.

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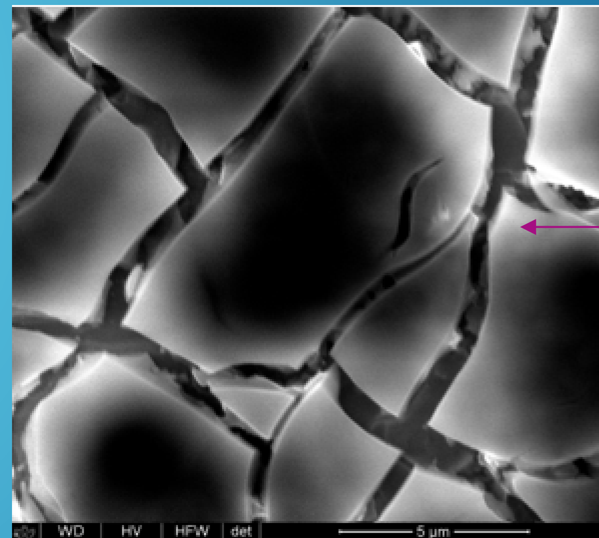
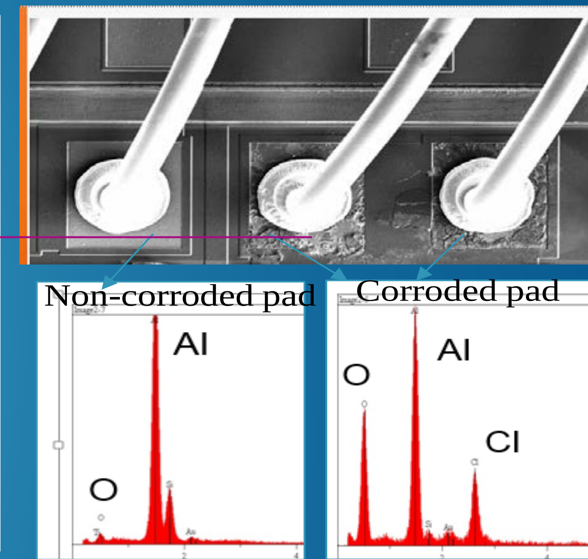
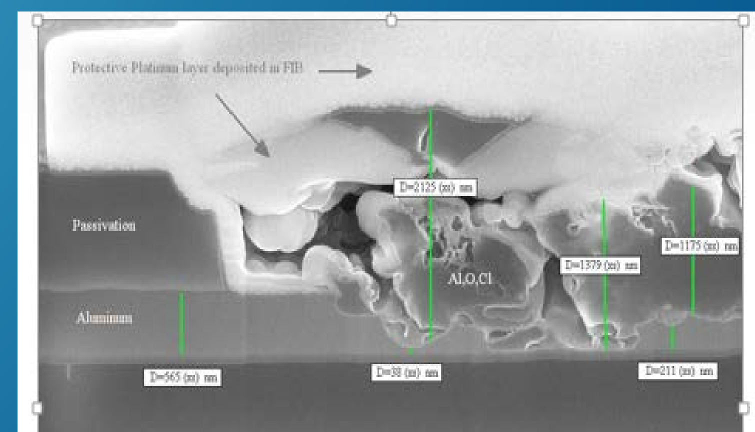
Al pad corrosion

- Al pad can also undergo extensive corrosion under certain conditions such as bias voltage, presence of high Cl etc.





- This corrosion is characterized by unusually thick Al oxide/hydroxide
- EDX detect presence of large amounts of Cl.
- Al surface has a mud-crack appearance.



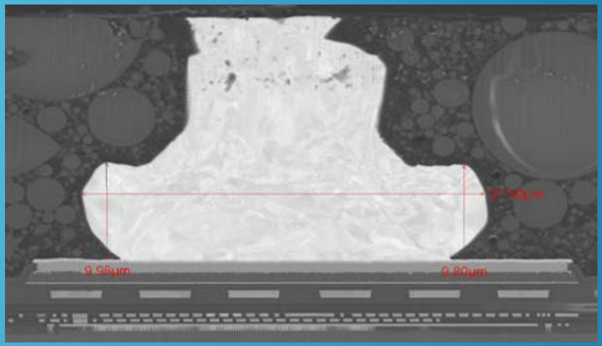
FIB Cross-section of the corroded pad

V. Mathew et al. ;IMAPS 2016- 49th International Symposium on Microelectronics

High temperature reliability with Over Pad Metallization (OPM)

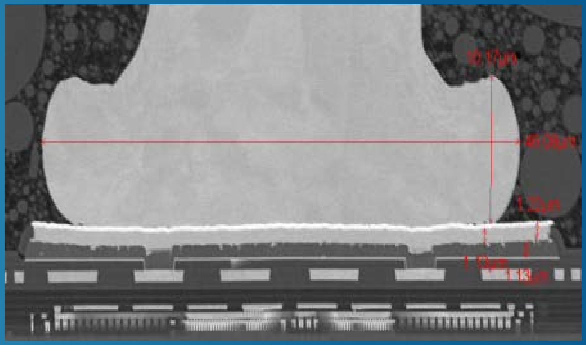
- Both Au and Cu wires on OPM(nickel / palladium / immersion gold) can meet AEC grade 0 requirements and beyond.

Since no IMC and no exposed Al pad present Cl induced corrosion can be eliminated/minimized



Au Wire on OPM (1um Ni)

No IMC



Cu Wire on OPM (1um Ni)

- No IMC
- No Al splash
- No Al remnant
- Minor Al deformation

Package Reliability Electrical Test Results for Au-OPM and Cu-OPM

Wire Type	MSL3/260C + AATC-C (-65C to 150C)	MSL3/260C + HAST (130C / 85%RH / 33.3 PSIA)	High Temperature Bake - 175C	High Temperature Bake - 150C
Au Wire	Passed 4000 cycles	Passed 240 hours	Passed 2016 hours	Passed 6048 hours
Cu Wire	Passed 4000 cycles	Passed 240 hours	Passed 2016 hours	Passed 6048 hours

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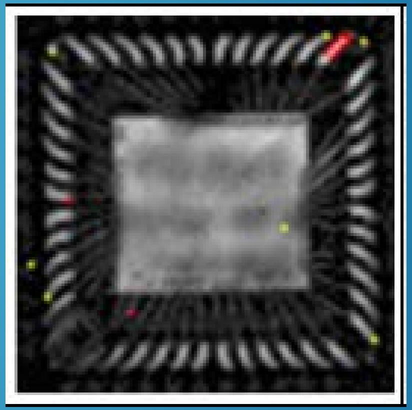
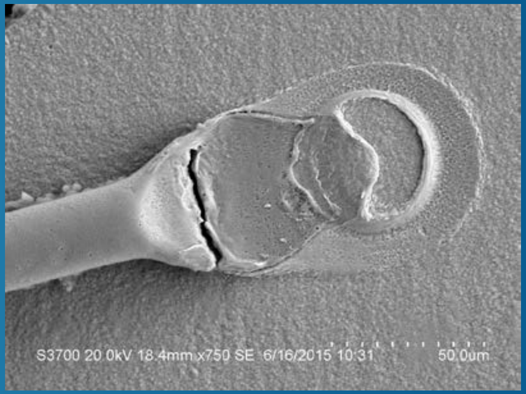
Second Bond Delamination Reliability

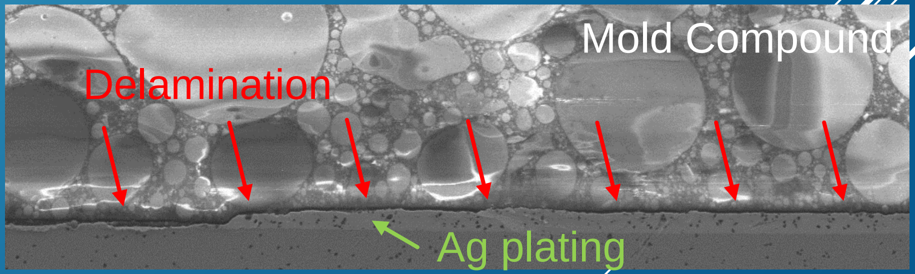
- A major difficulty in achieving AEC Grade 0 reliability is second bond delamination followed by temperature cycling.
- For lead frame products, some of the main material considerations are wire type, epoxy mold compound (EMC), die attach (DA) materials and lead frame/die design features.
- Lead frames with roughened surfaces, less Ag plating area, appropriate LF design features , die/ LF design, will help to overcome this challenge.
- Mold compound formulation can also be engineered to improve LF- mold compound adhesion.



Delamination detected by CSAM



Heel Crack



Summary

- **Materials and assembly processes play a major role in addressing reliability challenges under harsh conditions.**
    - **Copper wire and mold compounds are key players in achieving AEC – Q100 G0 conditions.**
- **Al- Cu-Al IMC corrosion ,Al pad corrosion , EMC- LF adhesion are critical factors to be considered to achieve towards zero defectivity.**

Acknowledgments

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Thank you