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SAC305 solder electromigration kinetics

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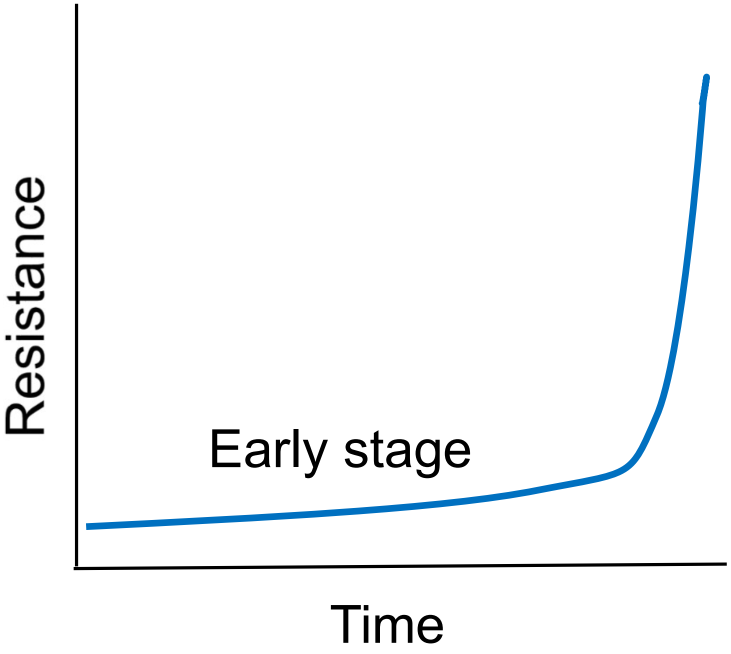
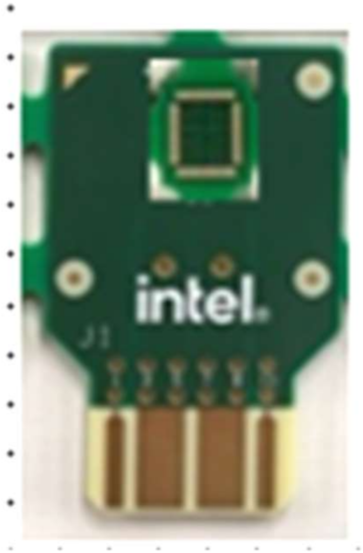
Objective

- To study the kinetics and the microstructural evolution in SAC305 bottom-terminated component (BTC) solder joints during the early stage of electromigration before the voids, growing at the cathode, coalesce into an open circuit.



SAC305 is a tin-based solder containing 3 wt. % Ag and 0.5 wt. % Cu

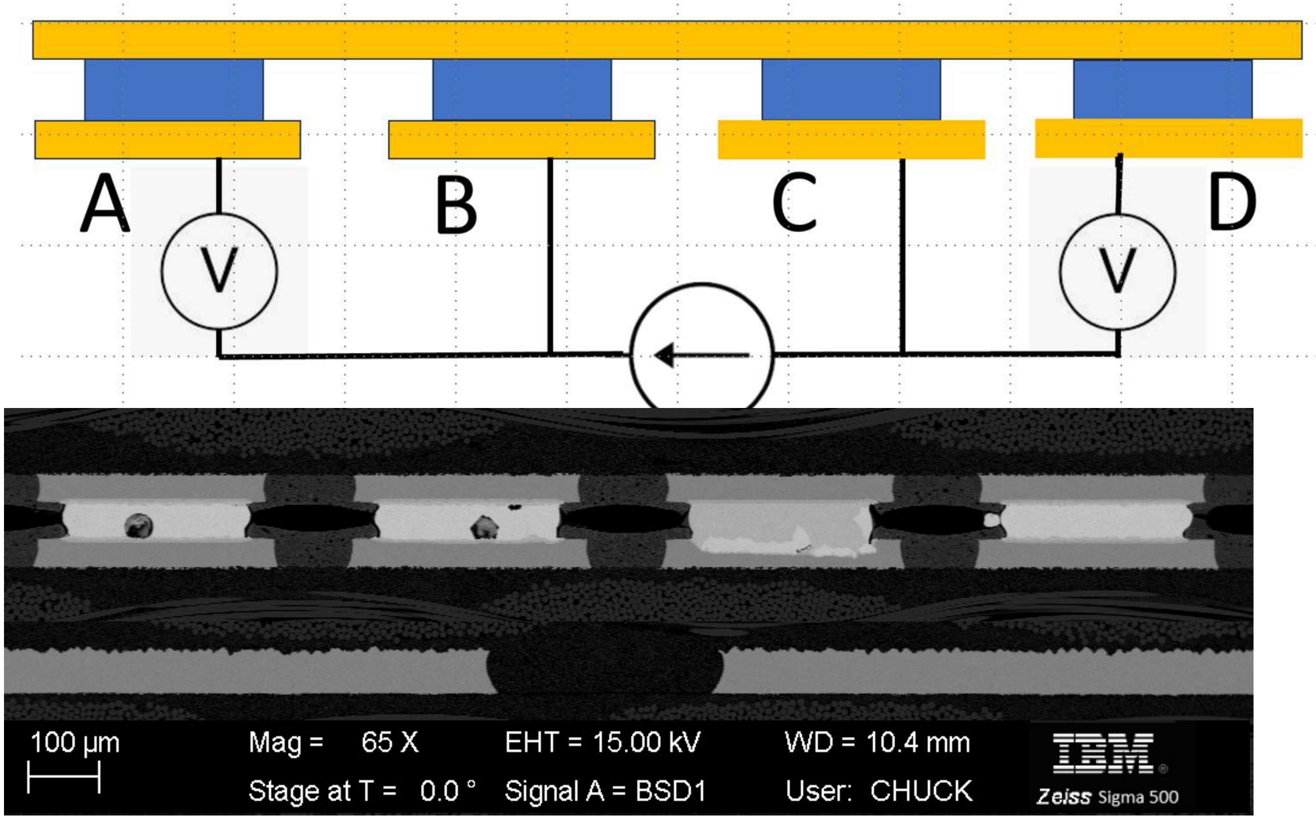
Test card with BTC solder joints

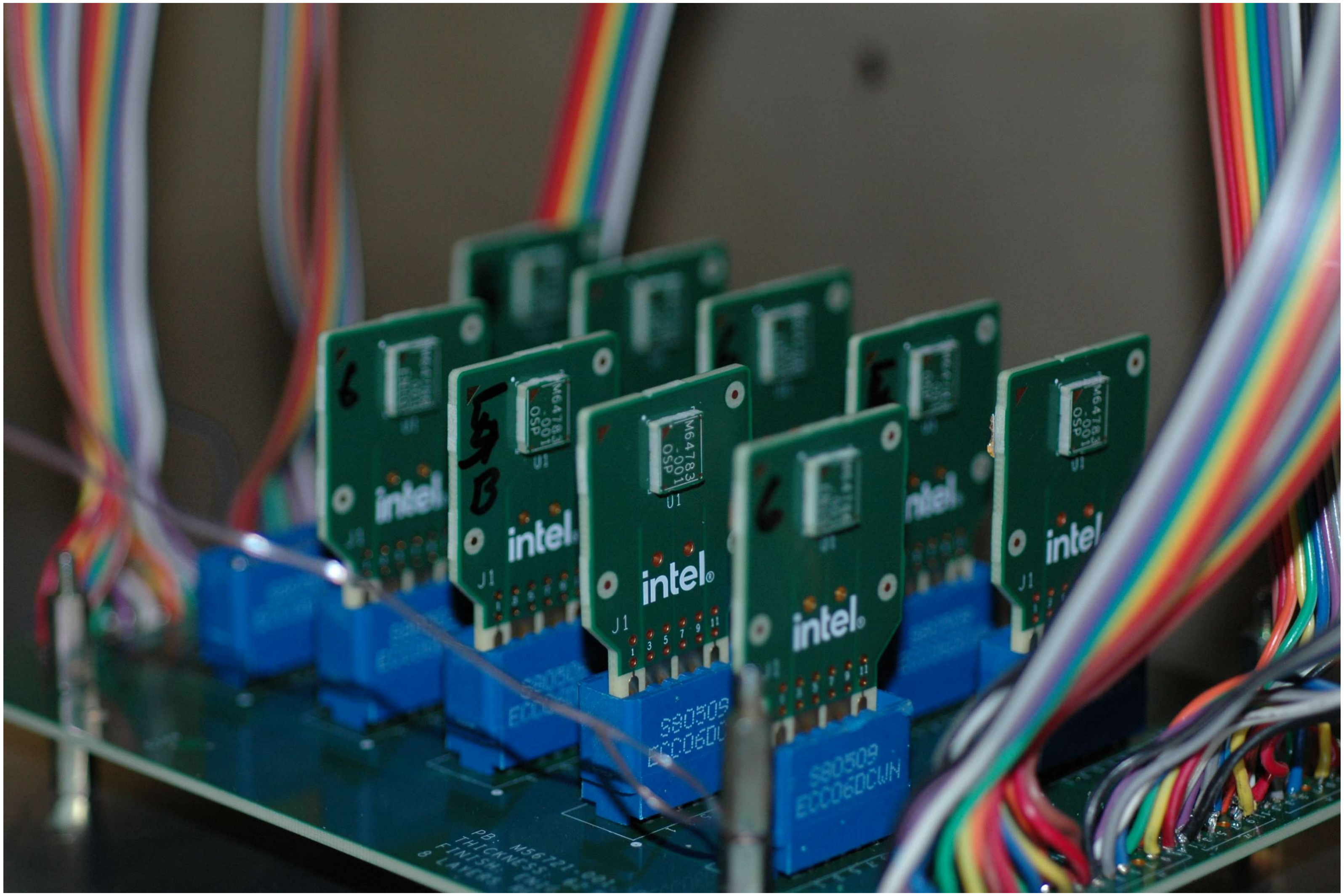


Area = 0.25x0.60 mm^2

j = 2.7 to 5.3 kA/cm^2

Temp = 93 to144 ^{o}C

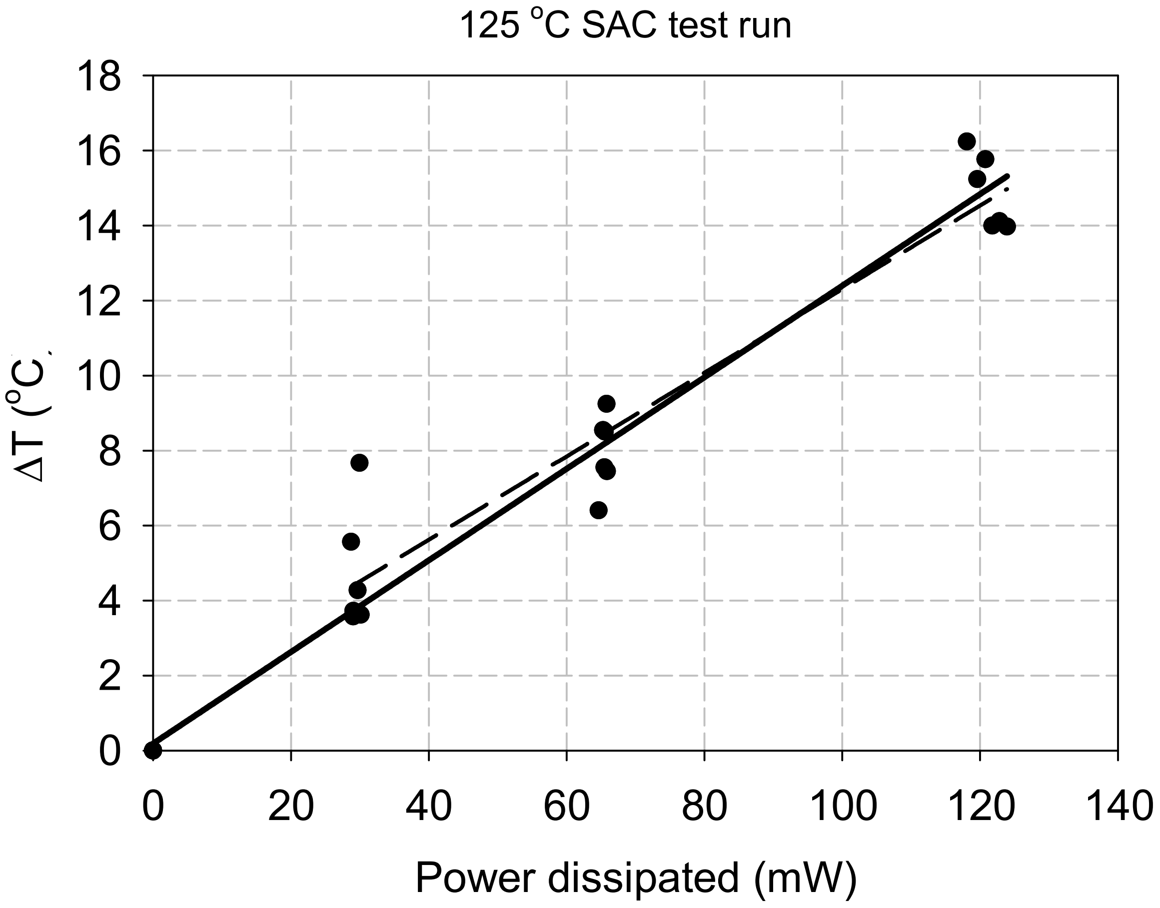



intel
M64783
-001
OSP
U1
J1
S80509
ECC06DCWN

Joule heating of BTC solder joints

First step was to determine the temp coeff of resistance of the solder joints.

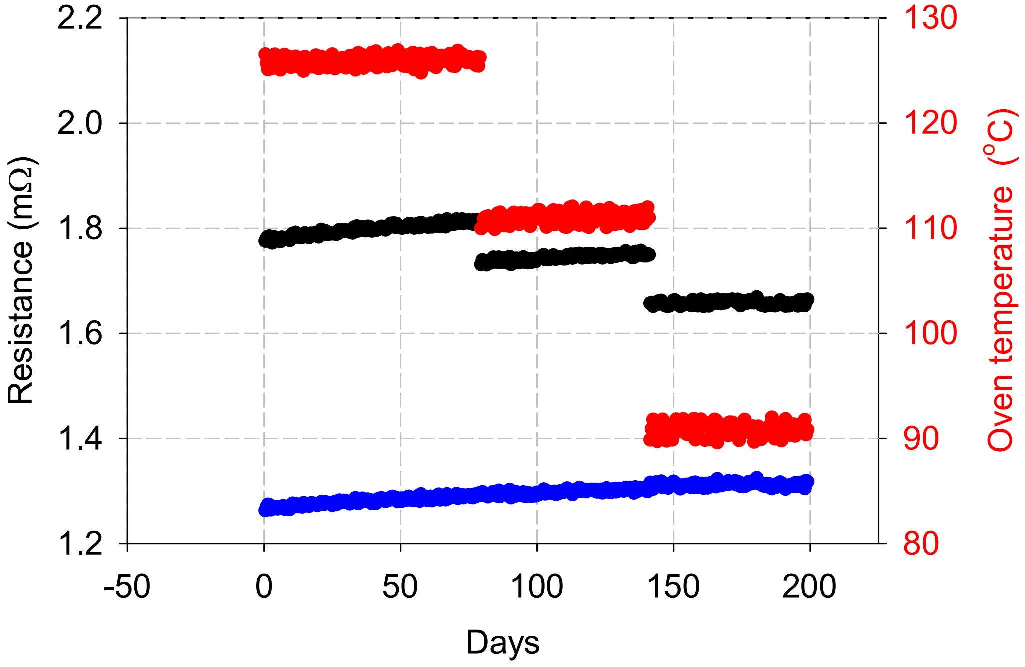
Temp rise due to joule heating = 0.12x(mW of heat dissipated) °C.

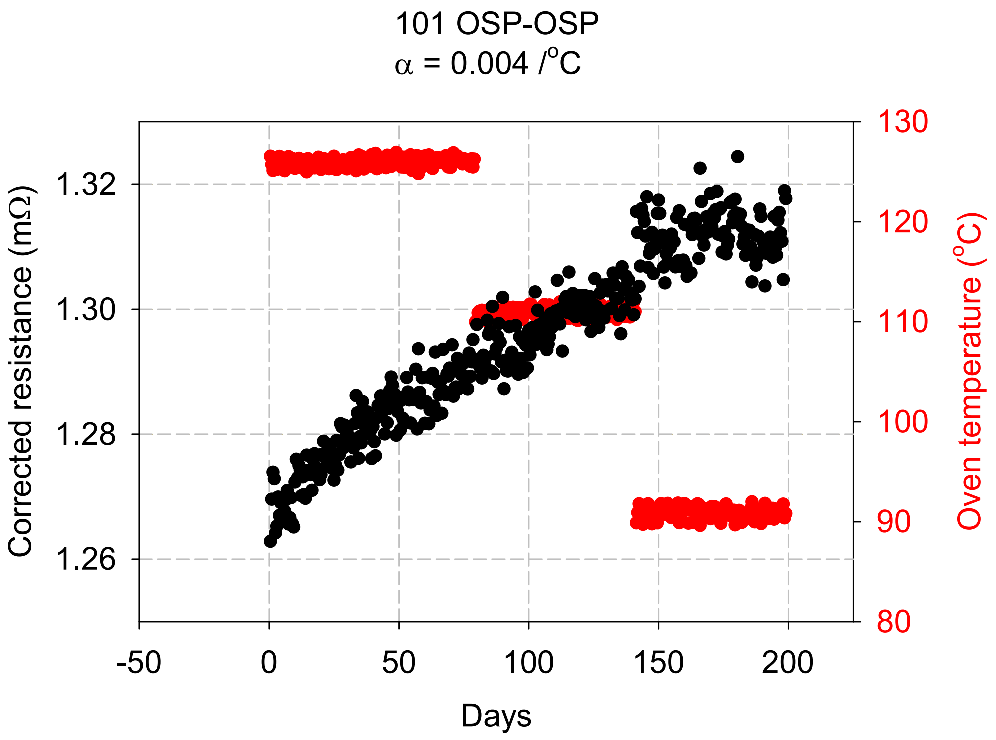


Resistance normalized to room temperature

101 OSP-OSP
α = 0.004 /°C
Black plot is for measured resistance temperature
The blue plot is for resistance normalized to 25 °C

$$R_{25} = \frac{R_1}{1+\alpha\left(T_1 - 25\right)}$$





SAC305 electromigration rates

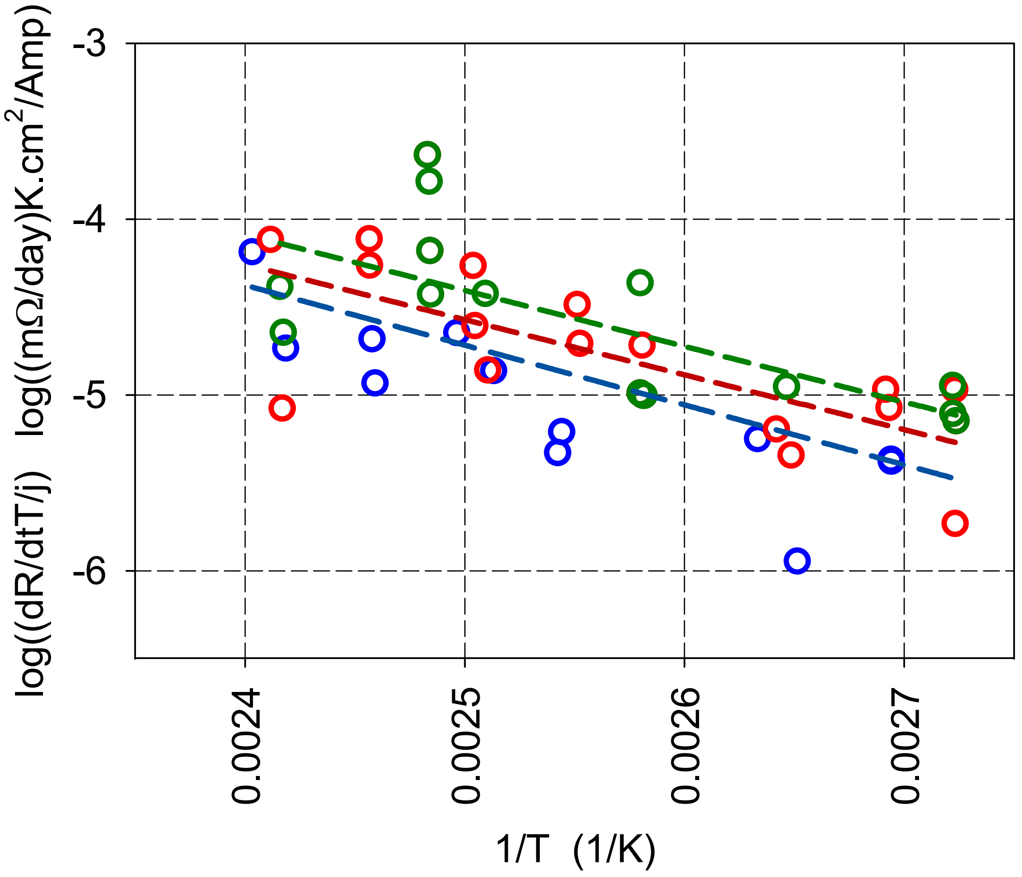
$$v = \frac{DF}{kT} = \frac{DZ^{*}eE}{kT} = \frac{DZ^{*}e\rho j}{kT}$$

$$\frac{vT}{j} = \frac{DZ^{*}e\rho}{k} = \frac{D_0 Z^{*}e\rho}{k} e^{-\frac{Q}{kT}}$$

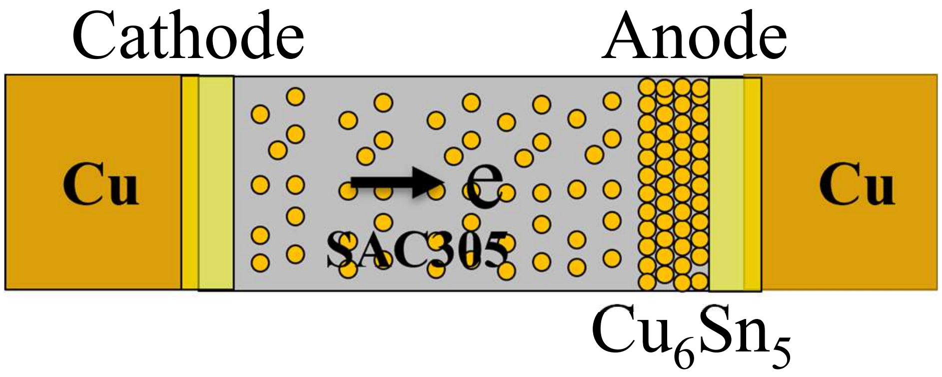
$$v \propto \frac{\Delta R}{\Delta t} = \frac{\Delta R}{days}$$

$$\boxed{\frac{\left(\Delta R/days\right)T}{j} = \frac{D_0 Z^{*}e\rho}{k} e^{-\frac{Q}{kT}}}$$

SAC BTC
OSP-OSP is blue (Q=0.68 eV)
ENIG-ENIG is red (Q=0.62 eV)
ENIG-OSP is green (Q=0.63 eV)



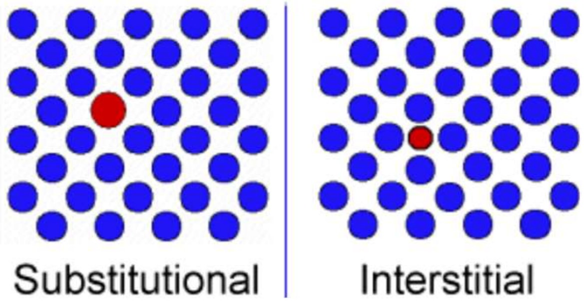
Formation of Cu_6Sn_5 at the anode due to Cu electromigration

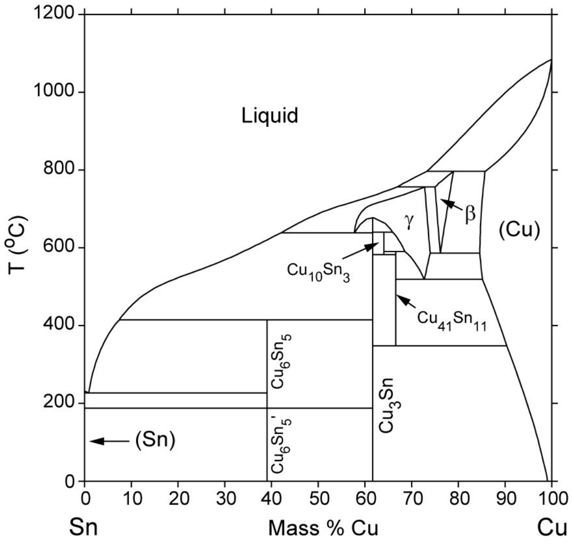


Interstitial Cu atom

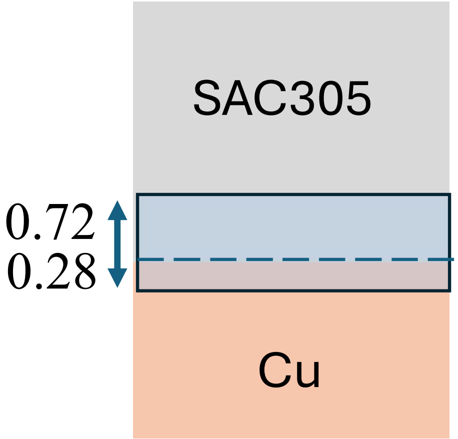
Cu_6Sn_5 formation when Cu=39 wt. %

Interstitial Cu wt % ≈ 0.5





How much SAC305 will be consumed by the growth of 1 µm Cu_6Sn_5 layer



Mass of Sn in 1 g of Cu_6Sn_5 = $\frac{118.7\times5}{118.7\times5+63.5\times6} = 0.61$ g

Assume 1x1 µm solder cross section.
Mass of 1 µm thick Cu_6Sn_5 layer = $8.3\text{x}10^{-12}$ g
Mass of Sn in 1 µm thick Cu_6Sn_5 layer = $8.3\text{x}10^{-12}$ x0.61 = $5.25\text{x}10^{-12}$ g

Thickness of Sn consumed by 1 µm thick Cu_6Sn_5 layer = $\frac{5.25\times10^{-12}}{7.3\times10^{-12}} = 0.72\ \mu\text{m}$

Thickness of Sn consumed by 1 µm thick Cu_6Sn_5 layer = 0.72 µm.

Thickness of Cu_6Sn_5 if all the 0.5 wt. %Cu migrated to the anode: Case of Sn sandwiched between inert metals

Mass of SAC305 = $7.4 \times 60 \times 10^{-12} = 444 \times 10^{-12}$ g

Mass of 0.5% Cu in SAC305 = $0.005 \times 444 \times 10^{-12}$ g

$= 2.22 \times 10^{-12}$ g

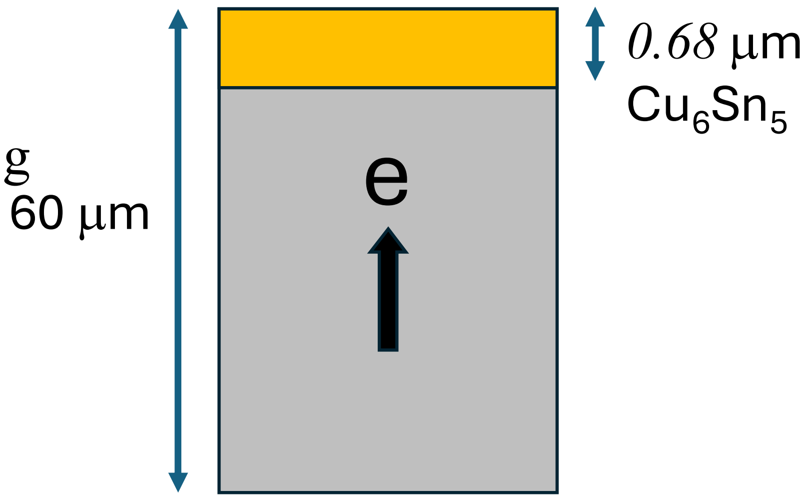
Mass of Cu_6Sn_5 containing 2.22×10^{-12} g Cu

$$= \frac{2.22 \times 10^{-12}}{63.5} \times \frac{5}{6} \times 118.7 + 2.22 \times 10^{-12} = 5.68 \times 10^{-12} \text{ g}$$

Density of Cu_6Sn_5 = 8.3 g/cm^3 = 8.3×10^{-12} g/µm^3

$$x = \frac{5.68}{8.3} = 0.68 \quad \mu\text{m}$$

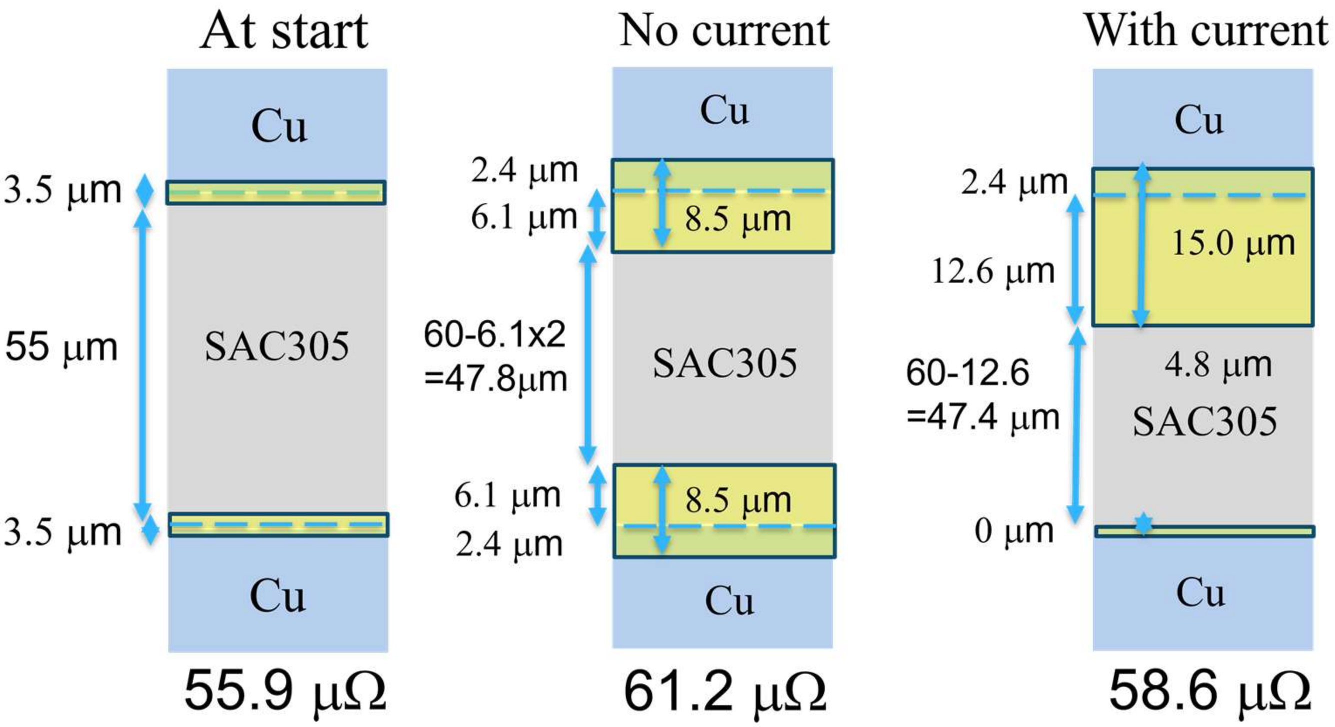
when the starting solder thickness is 60 µm.



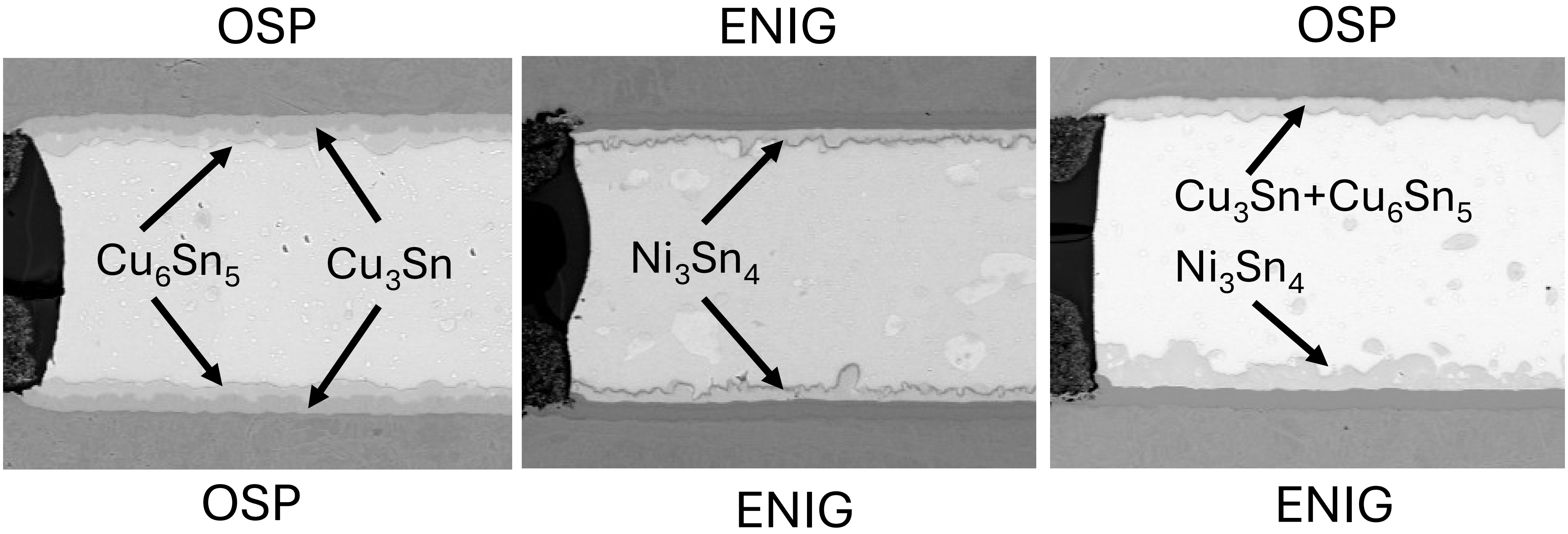
Assume width and thickness to be 1 µm.

SAC305 solder joint resistance: t=0, aged at 150 °C and with electromigration at 150 °C and $2x10^4$ A/cm^2

The intermetallic growth dictates the joint resistance increase.



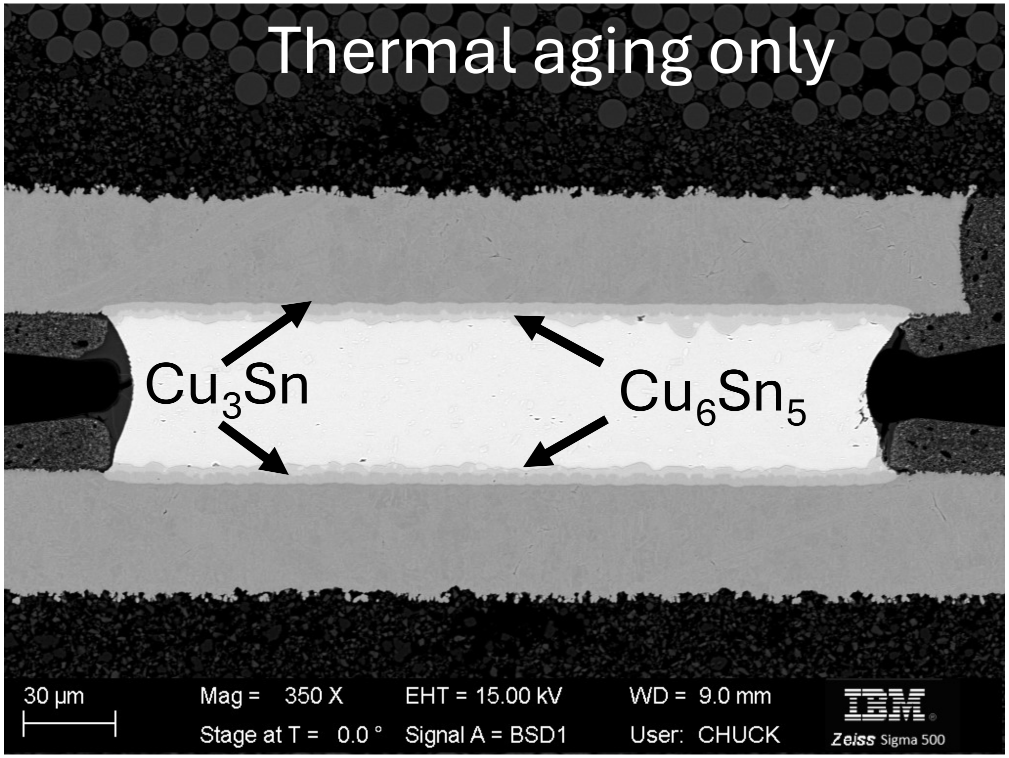
Intermetallic growth during thermal aging

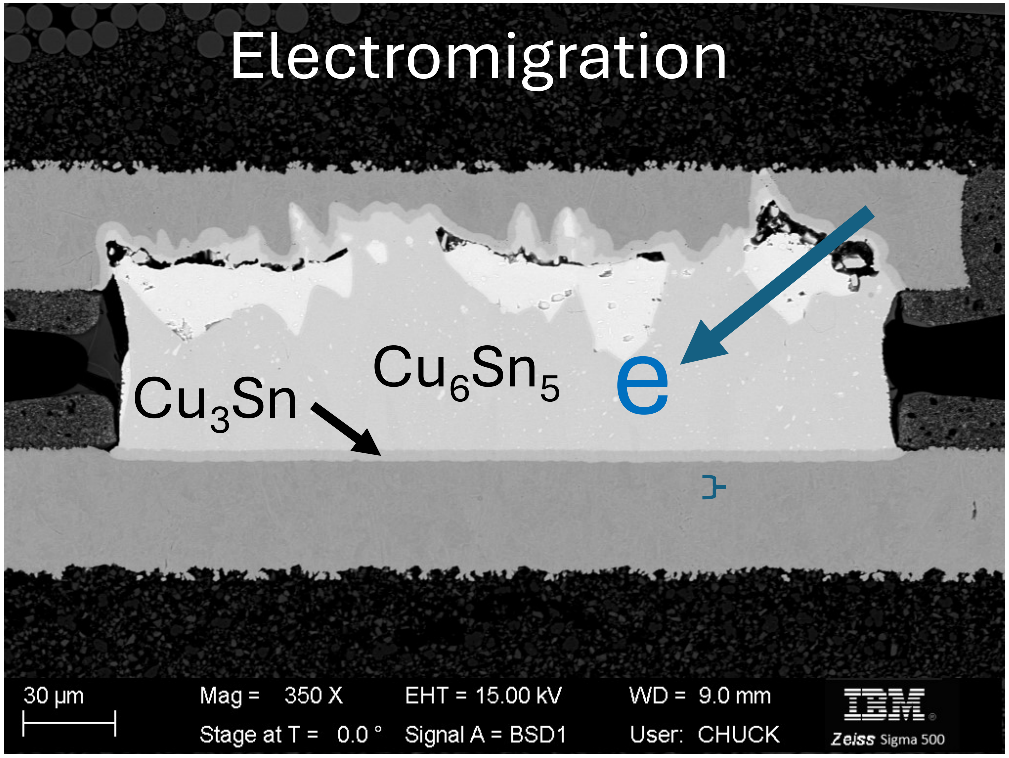


80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

Electromigration in OSP-OSP SAC solder joint at 4 Amp

80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

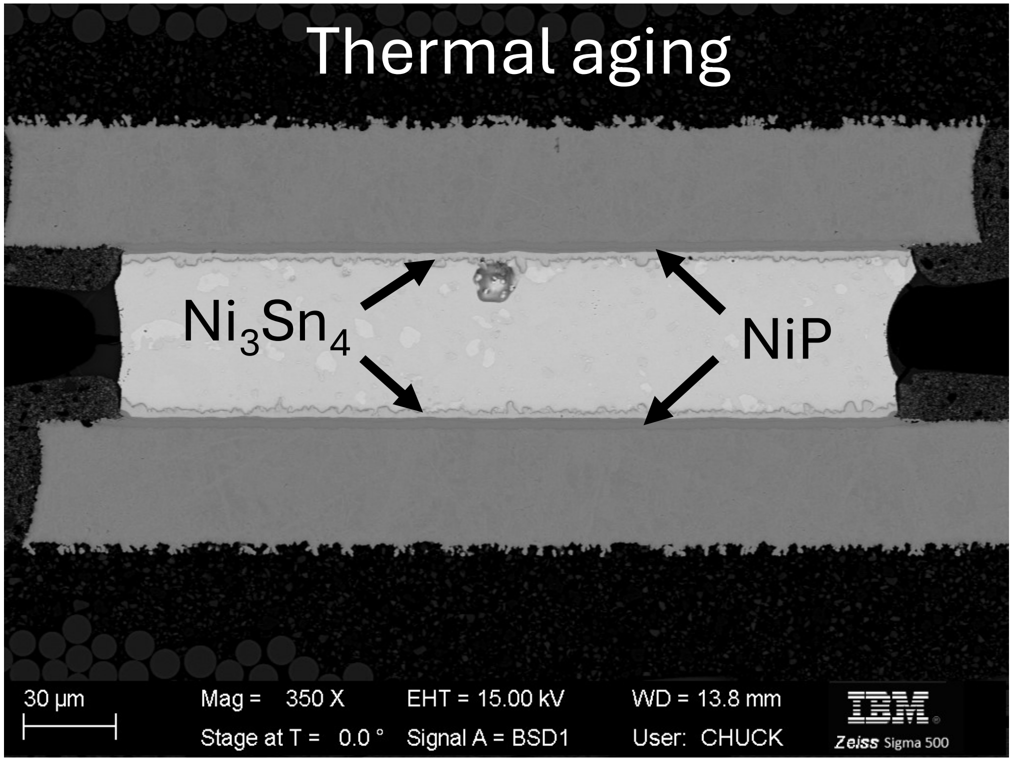


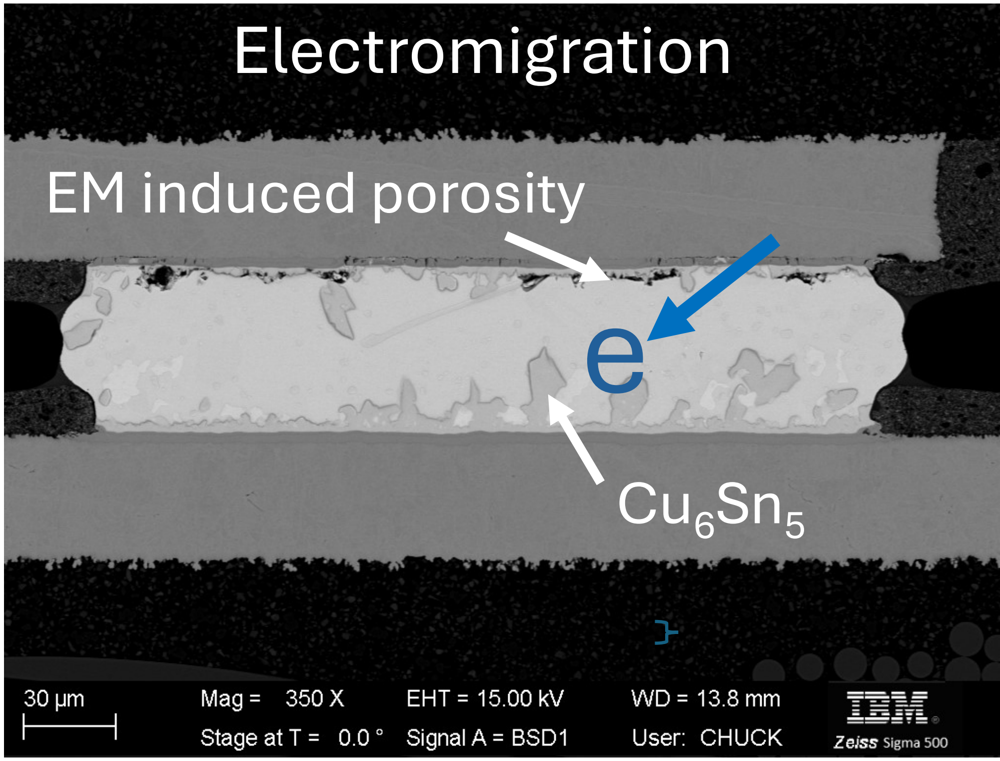


The Cu_6Sn_5 grew from the anode towards the cathode.

Electromigration in ENIG-ENIG SAC solder joint at 4 Amp

80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

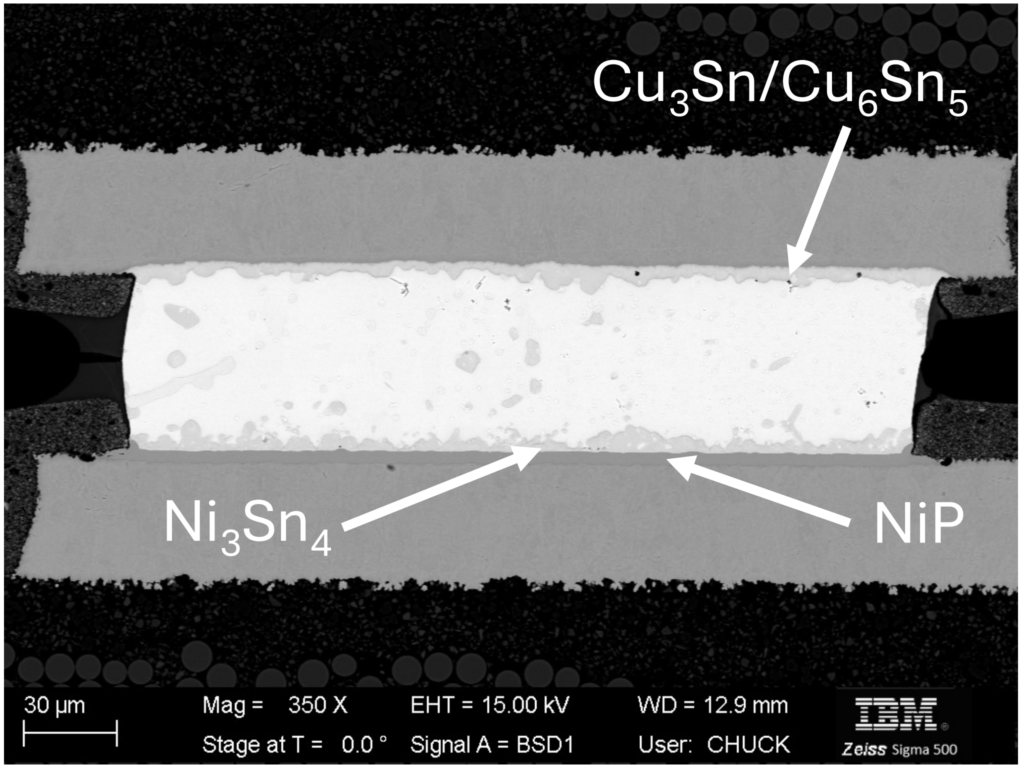


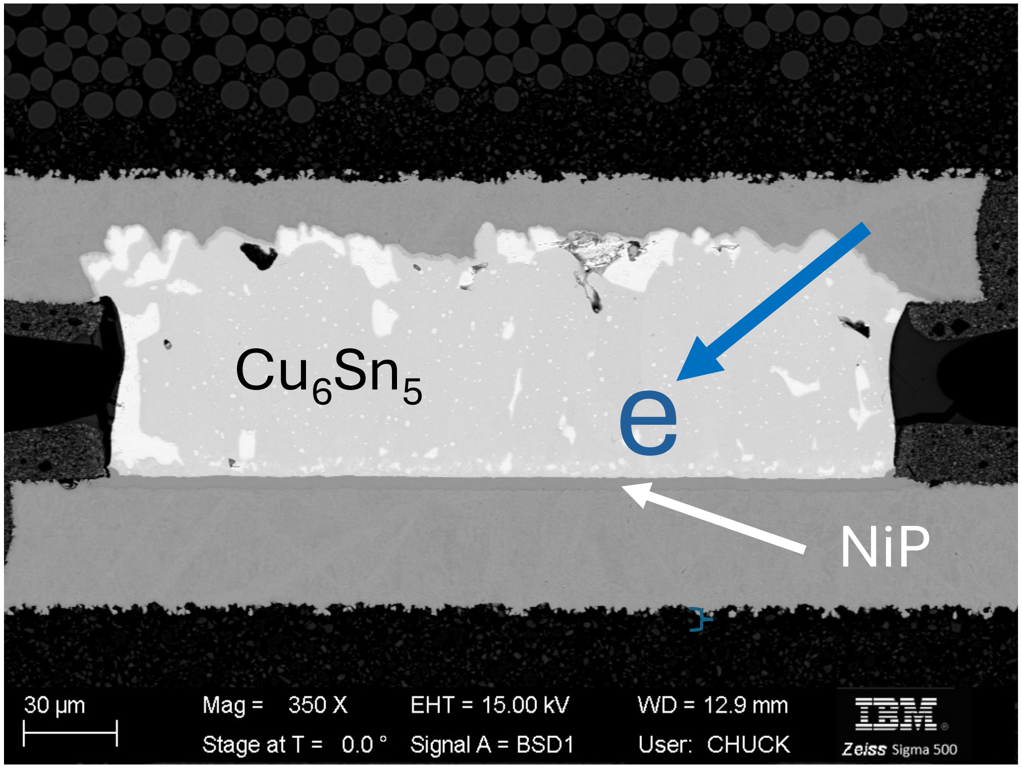


The Cu_6Sn_5 grew from the anode towards the cathode.

Electromigration in ENIG-OSP SAC solder joint at 4 Amp

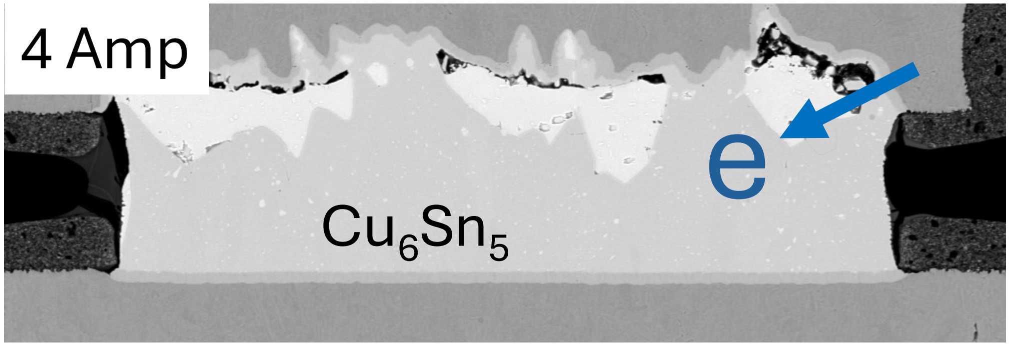
80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

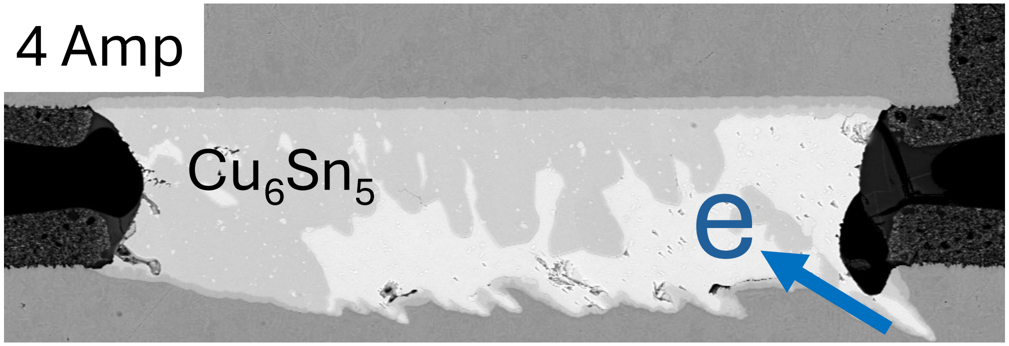


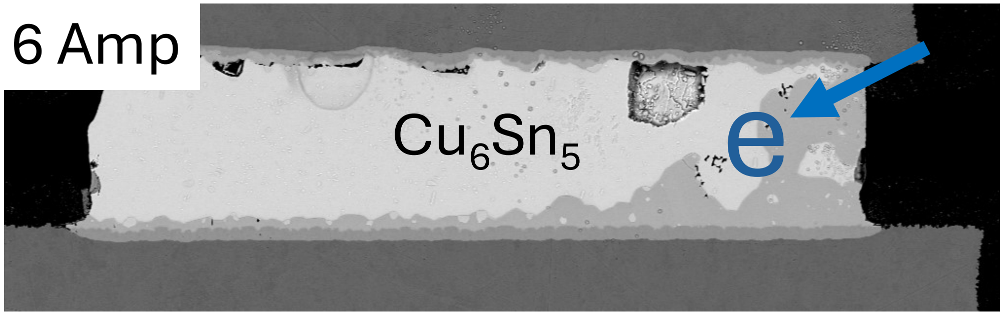


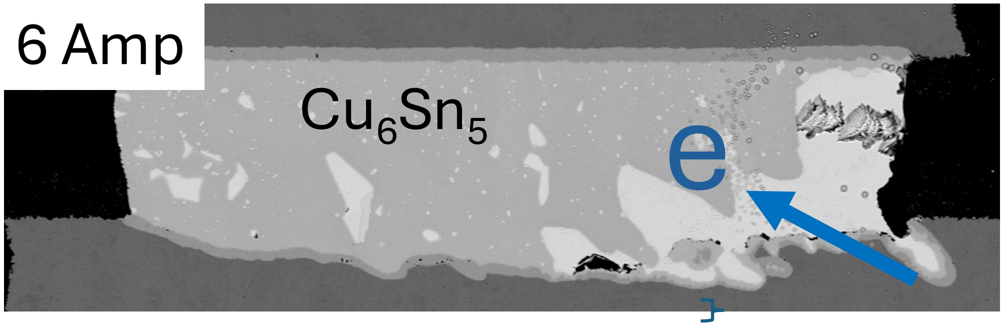
The Cu_6Sn_5 grew from the anode towards the cathode.

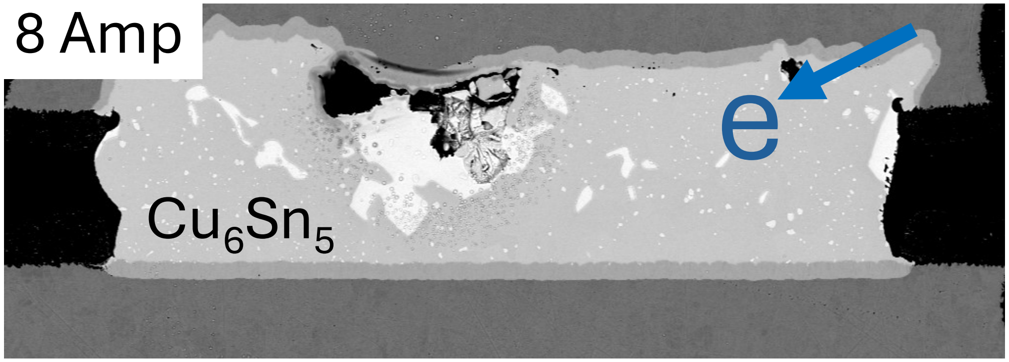
Electromigration in OSP-OSP SAC solder joints

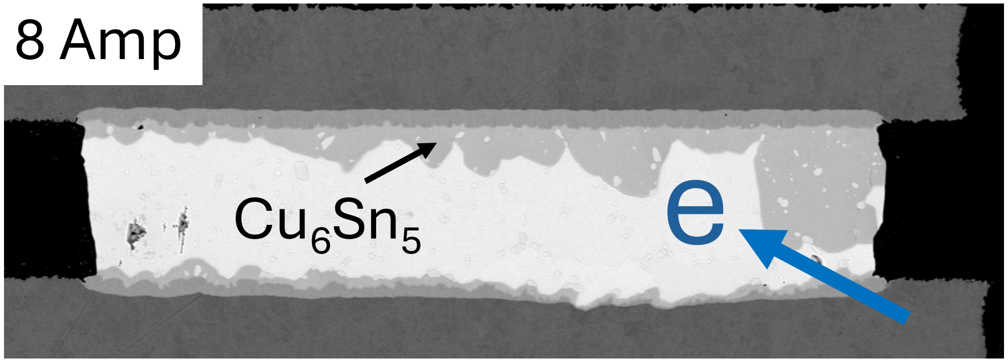






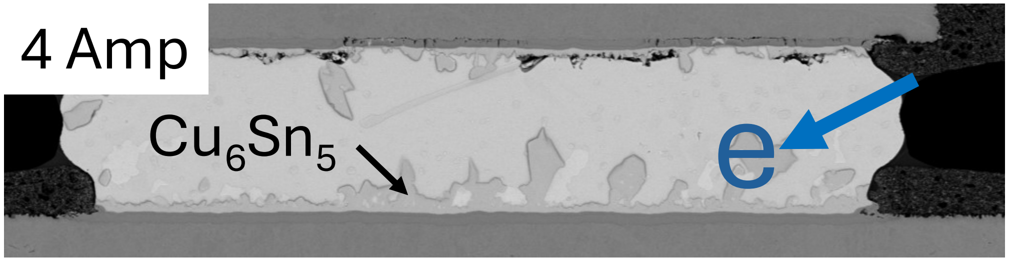


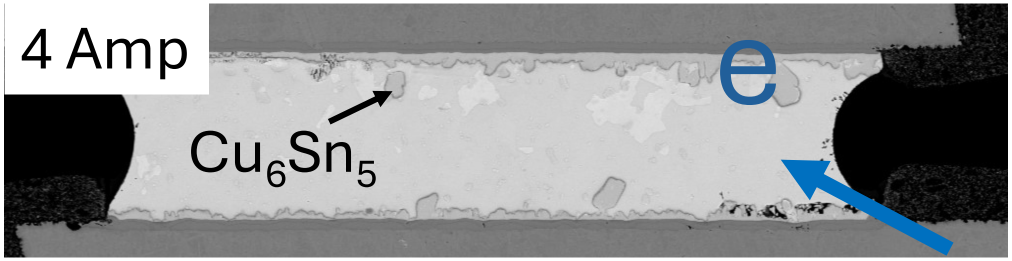


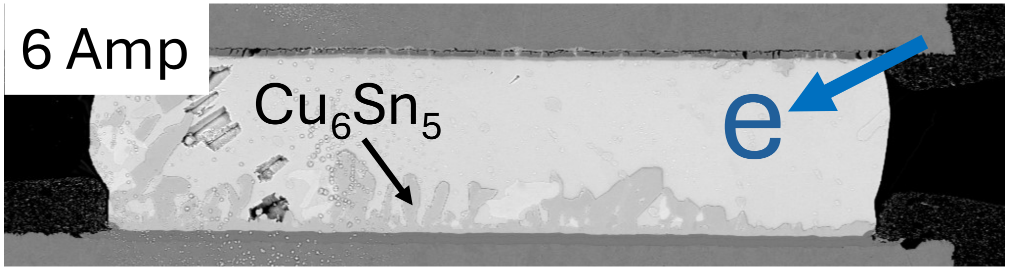


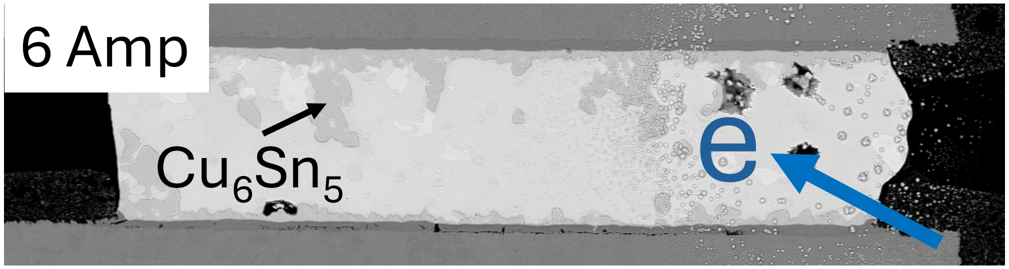
Electromigration in ENIG-ENIG SAC solder joints

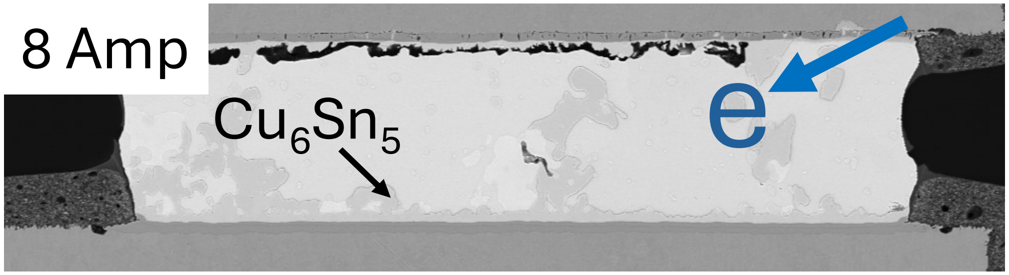
80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

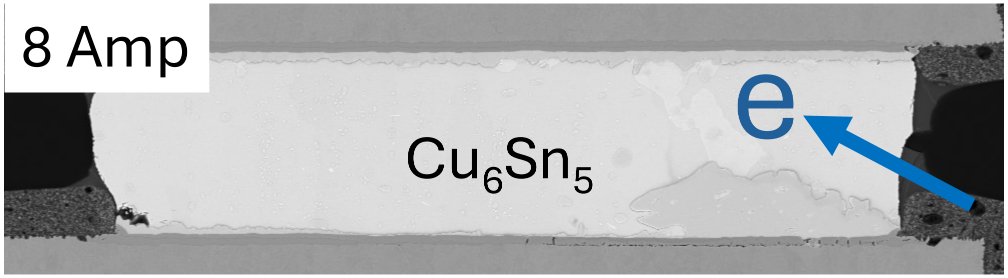






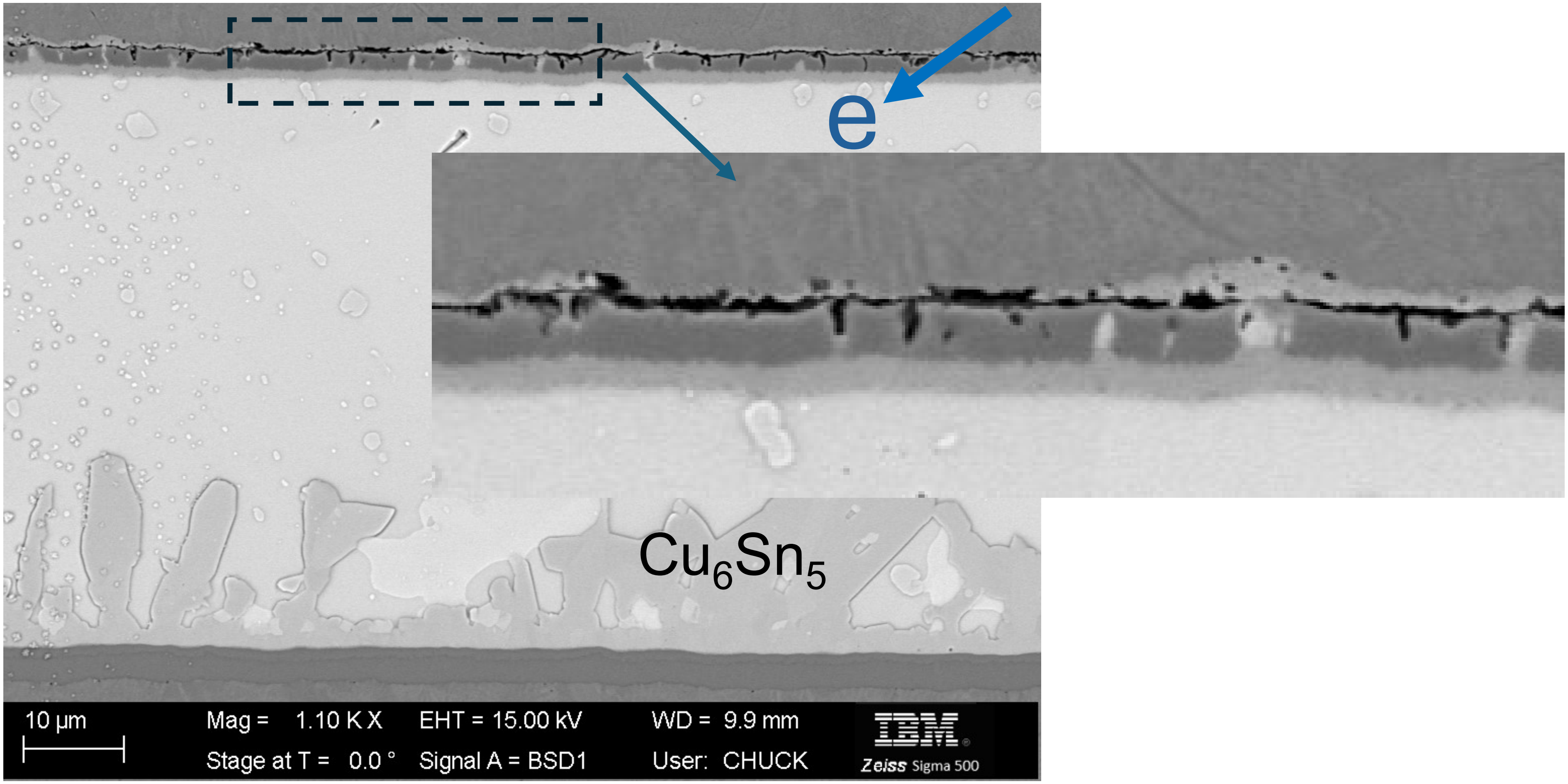






Electromigration in ENIG-ENIG SAC solder joints

80 days at 126 °C, 60 days at 111 °C and 60 days at 91 °C

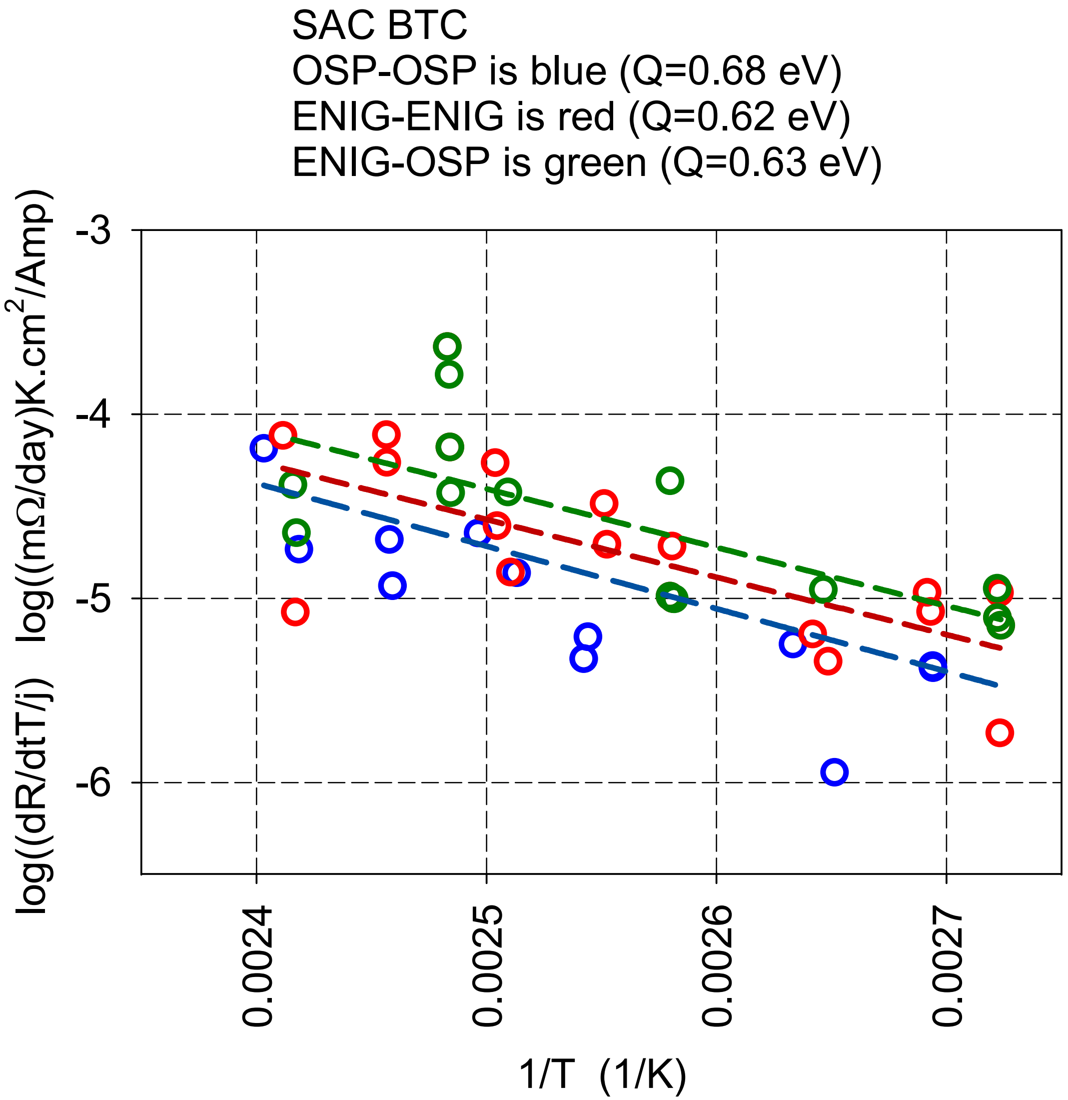


The SAC305 solder electromigration activation energy is 0.62-0.68 eV.

The Sn-Cu intermetallic growth activation energy is 0.61-0.93 eV.

The Cu electromigration activation energy is 0.34 eV.

Based on activation energy, the SAC305 resistance increase is due to the Sn-Cu intermetallic growth.



Conclusions

- In the early stage of electromigration in SAC305 solder, Cu atoms migrate towards the anode interface of the joint where they react with Sn forming Cu_6Sn_5.
- In SAC305 solder between inert metallization, Cu_6Sn_5 can grow to only 0.7 μm in a 60-μm thick solder joint.
- In SAC305 solder between Cu metallization, Cu atoms migrating into the solder from the copper metallization react with tin forming a very thick Cu_6Sn_5 layer.
- The thick Cu_6Sn_5 layer growth starting at the anode and moving towards the cathode is the main contributor to the solder joint resistance increase.
- Voids nucleate, grow and coalesce into one big void spanning the complete cathode interface leading to an electrical open.

Q&A

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