Surface Treatment for Soldering Aluminum PCBs to Conventional Copper PCBs

Authors:

Divyakant Kadiwala

Nazarali Merchant, PhD

Benny Lam

Technical Conference January 25–27, 2022

Outline/Agenda

- Introduction
- Flexible Al-PCBs and their challenges
- Al-PCBs using Al-PET substrates and their FOM
- Reliability of Al-PCBs
  - SIR test
  - Temperature Cycling Test
- Cu-PCBs and Pigtails soldered to Flexible Al-PCBs using Advanced Surface Treatment
- Conclusions
- Q & A

Introduction

- SMT products are focused on building Copper based flex and rigid PCBs
  - Solder wires, pastes, fluxes and tach agents
- Aluminum is second to Copper for PCBs despite advantages
  - It is 3 times lighter than Copper
  - It is 3 times less expensive on actual weight basis and 6 times less expensive on actual usage basis compared to Copper
- Reliability tests would apply to both Al-PCBs and Cu-PCBs
  - Surface Insulation Resistance Test (SIR test)
  - Air to Air Thermal Cycling (AATC)
- Integration of Al-PCBs to Cu-PCBs is essential for large scale adoption

Al-PCBs – challenges and solutions

- Al-PCBs (Rigid or Flex) are difficult due to problems with soldering SMDs
  - All aluminum surface has a thin oxide layer that inhibits soldering
- Soldering of SMDs to Al-PCBs previously required Zincate and plating finish
  - Intense and expensive wet chemistry, practical only for thicker Aluminum
- Silver based conductive epoxies have been preferred option for attaching SMDs
  - Commonly used for Al-PET based flexible PCBs
  - Expensive and less reliable
- Surface Treatment enables soldering using conventional SMT equipment and is new alternative

Al-PCBs using Al-PET substrates, FOM

- Flexible circuits made using Aluminum on Polyethylene terephthalate film (Al-PET substrates)
  - Substrates available in varying thickness of foil laminated onto PET film
  - Increasingly popular method for making flexible circuits over Cu-PI PCBs
    - Lower cost is major driver for increased use
    - Aluminum is less expensive than copper and PET is significantly cheaper than polyimide

Al-PET laminate

Figure of Merit for flex PCBs

Conductor/Substrate	Conductor Thickness Adjustment[1]	Conductor Price[2]	Substrate Price[3]	Net FOM[4]
Cu/Polyimide	1	1	1	1
Cu/PET	1	1	0.06	17
Al/PET	1.64	0.24	0.06	**42**

Notes:

Electrical conductivity of Al : 0.61X that of Cu

Price of conductors [$/kg] on 3/24/2021: Cu: 9.02, Al: 2.21

Price of substrate materials [$/kg] on 3/24/2021: Polyimide: 19.56, PET: 1.11

FOM = 1 / (product of Columns 2 — 4),

FOM = Figure of Merit; here, higher is better

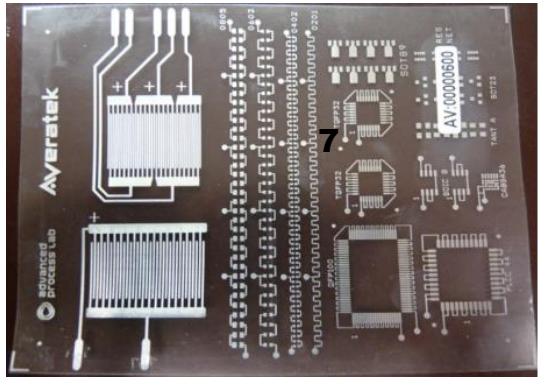
Al-PCB on Al-PET substrate

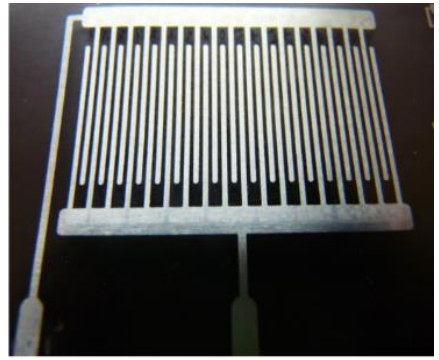
Reliability of Al-PET PCBs

- Reliability tests are important before qualifying for use
- Several tests specified in IPC-9701A, IPC-TM-650 etc.
- Vary per field of use/application
  - Consumer, Automotive etc.
- Our focus
  - SIR (Surface Insulation Resistance) test
  - Thermal cycling or Air to Air Thermal Cycling (AATC)

SIR test on Surface Treatment

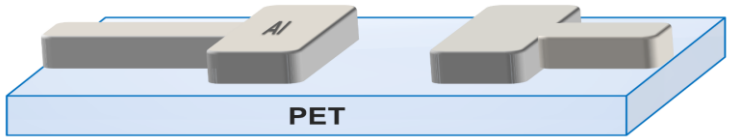
- Surface insulation resistance (SIR) test is a reliability test
  - Subjects products under high temperature & humidity to accelerate failures
  - Electrical attributes are evaluated during and after time in environmental chamber
  - Usually performed on standard test board coupons containing interlocking comb pattern
- Surface treatment was tested at an independent lab
  - SIR test was per specifications: IPC-TM-650-2.6.3.7, 40C / 90%rh / 10VDC for 168hrs
  - Test pattern used was IPC B-24 style and the substrate was Al 10um/PET 125um
  - Surface Treatment was printed and cured over the test pattern using a 50um thick stainless-steel stencil
  - Printed coupons were put into a test chamber that was maintained at 90% relative humidity (RH) and under a bias of 10volts for a total time of 168 hours
- Test results - Pass
  - No surface electrochemical migration, dendrite formations, foreign materials, issues, or anomalies were observed on coupons upon completion and subsequent removal from the test chamber



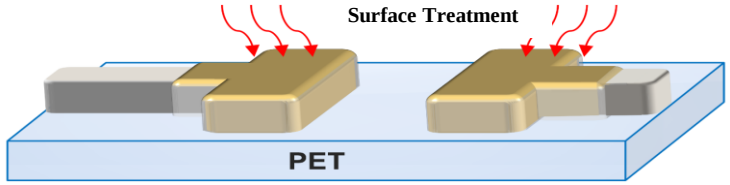


Coupon and Single Net IPC-B-24 Style Comb Pattern

Al-PET PCBs using Surface Treatment



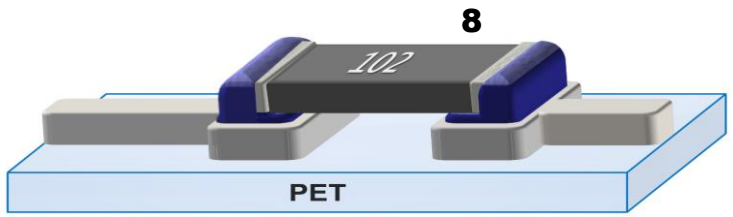
Print and etch Al-PET



Print & cure Surface Treatment

Store or take to assembly

Print solder



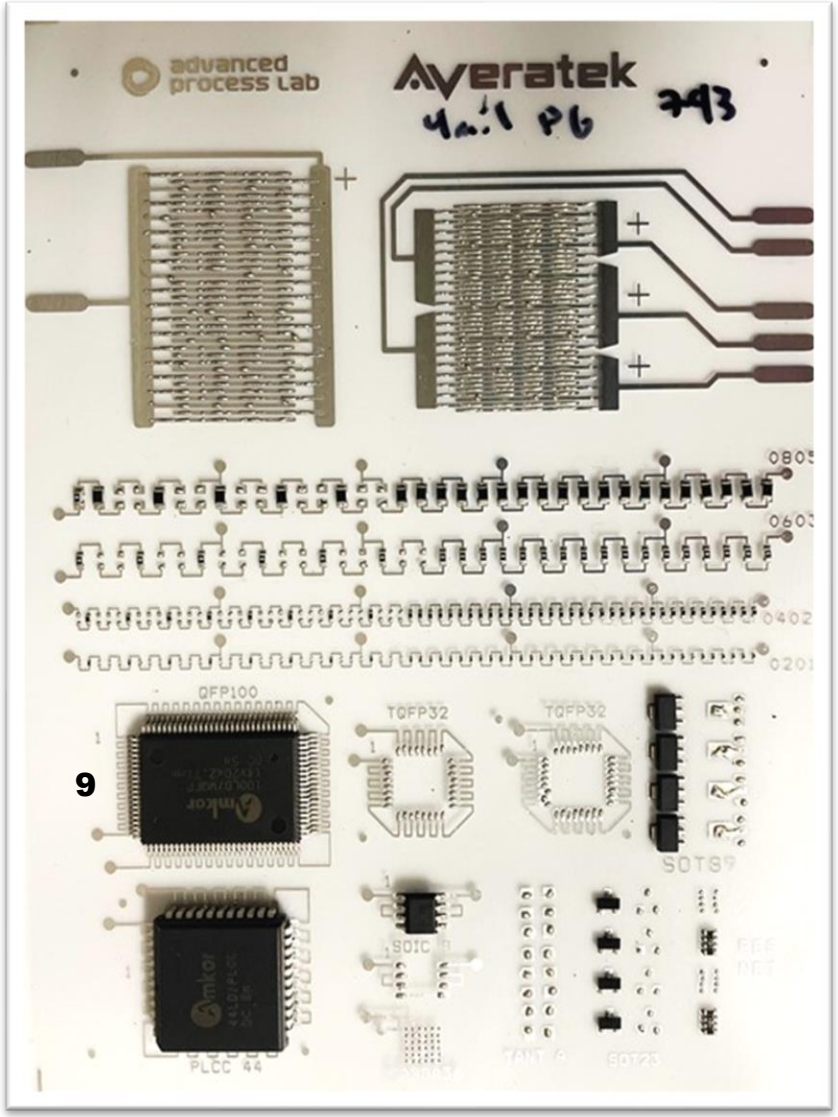
Place components

Reflow solder

Done!

AATC on Al-PCBs assembled using Surface Treatment

- Boards were processed at PCB assembly house
  - Had Stencil printers, Pick and Place machines and Reflow ovens
- Design used was Averatek's Design 1 Test board
  - Boards were made using substrates - Al 10um/PET 125um
  - SMDs included 'zero' ohm resistors of various sizes in a daisy chain pattern and other components
    - Resistors 0805 and 0603 were monitored for Thermal Cycling
- Special fixtures and tooling were designed and built to process the boards
  - SS stencils, 737x737mm made for Surface Treatment and Solder paste
    - Surface Treatment – 50um thick, Solder – 150um thick
  - Solder used was Lead-free, Low temperature, No clean
    - Sn/Bi/Ag with a melting point of 138°C
    - Solder reflow cycle per manufacturer's recommendation
- All AATC tests were run at external laboratory

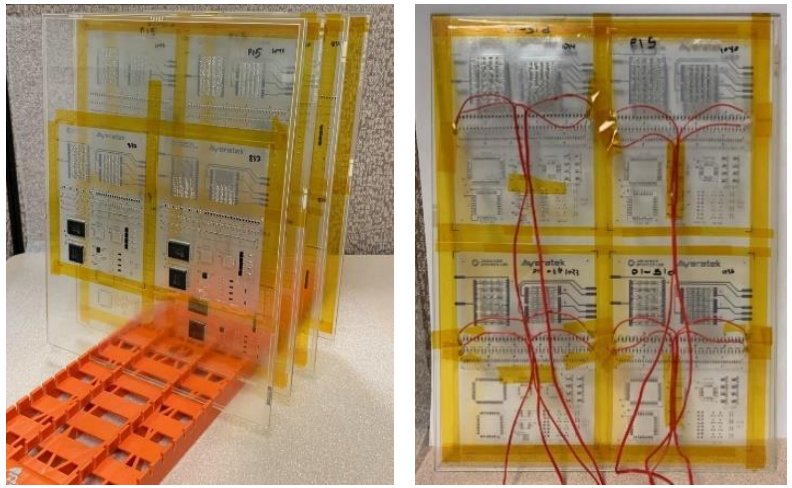


Averatek's Design 1 Test Board

AATC Objective - To test per IPC methodology

- Temperature extremes from -40 °C to +105 °C
- Temperature transition rate between extremes estimated 8-10 °C per minute, with soak time at peak temperature of 15 minutes
- All samples to be subjected to 1000 cycles with electrical event detection, approximately 50-60 days
- Sample submission included 14 assembled boards to be tested which included 7 fully assembled boards and 7 partially assembled boards

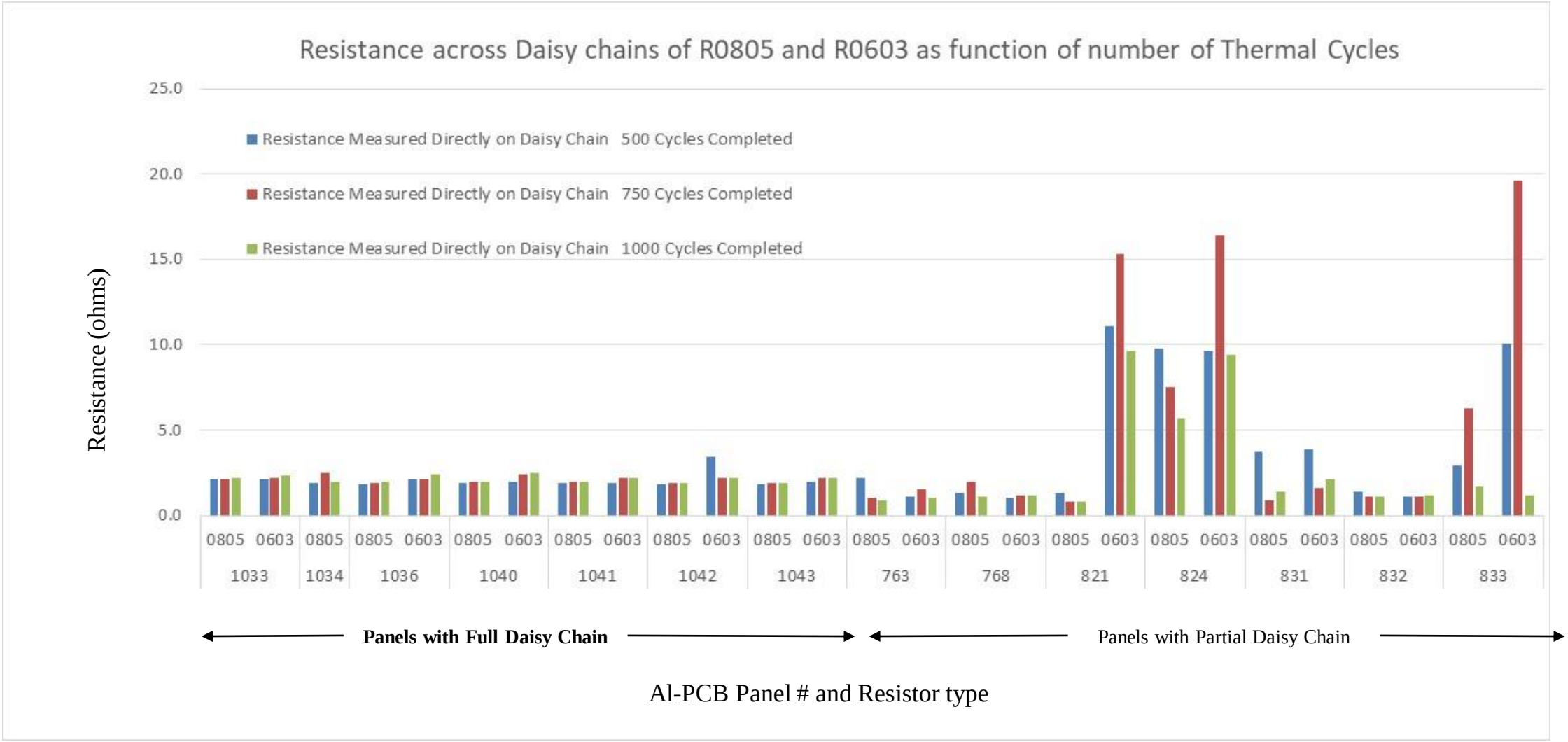
AL-PCB wiring and Thermal Chamber used for Thermal Cycling



Al-PCB panels taped to glass sheets and wired for thermal cycling test

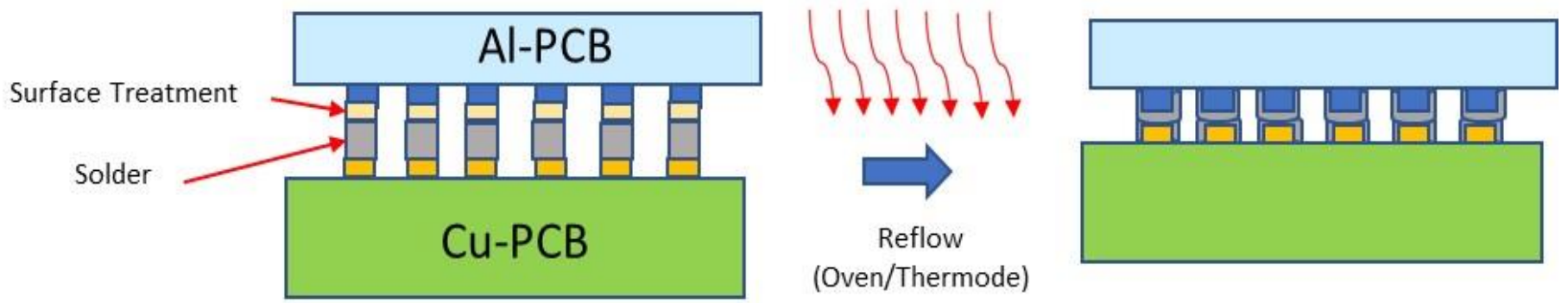
Thermal chamber and wiring harness for Resistance monitoring

Plot of Resistance Data



All resistor chains passed the temperature cycling tests with no failures after 1000 cycles.

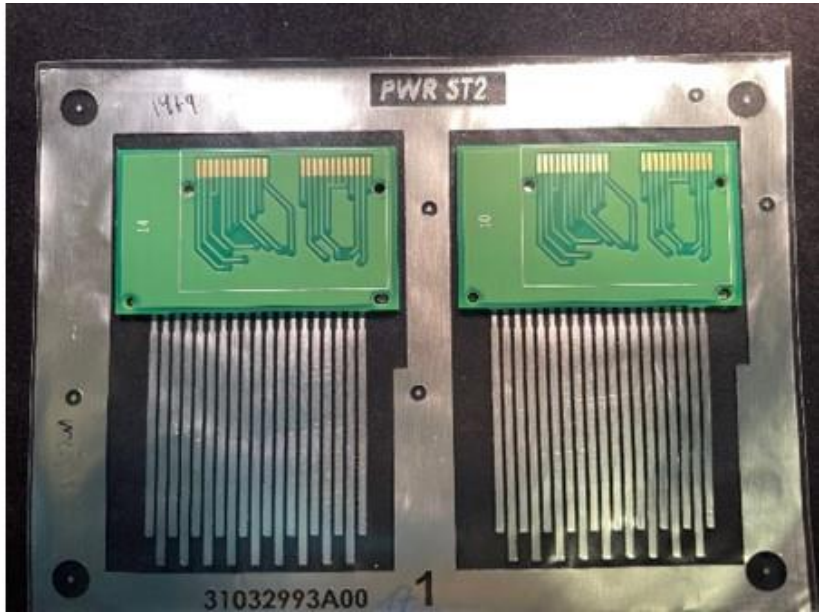
Soldering Al-PCBs to Cu-PCBs – Experimental Stack Up



Al-PCBs soldered to Cu-PCBs with standard reflow or Hot bar soldering

Rigid Cu-PCB soldered to Flex Al-PET board using reflow oven

Fixture set up before reflow

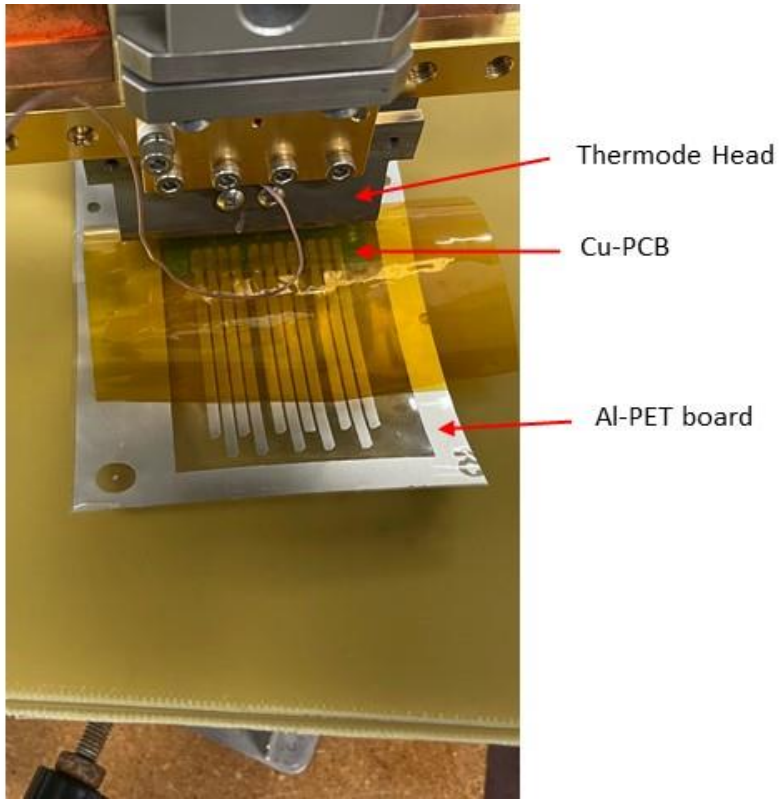


Cu-PCB soldered to Al-PCB

Good solder joints obtained between Cu-PCB and Al-PCB using reflow oven

Hot Bar Soldering/Thermode used for soldering Cu-PCBs to Al-PCBs

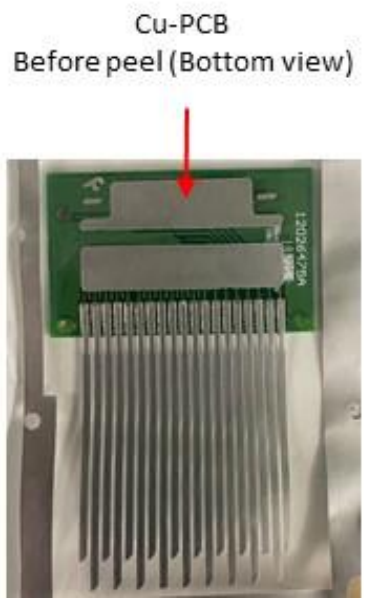
Hot bar soldering Machine/Thermode



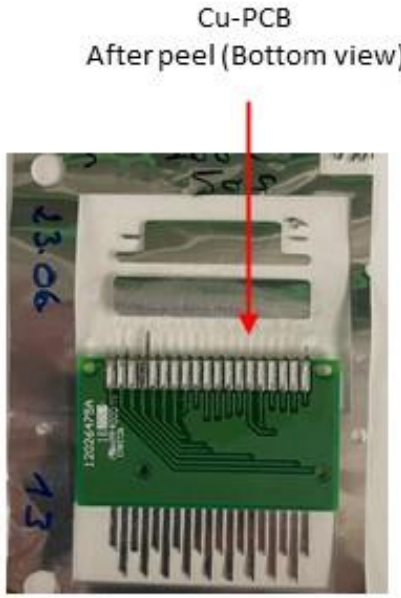
Soldering of Cu-PCBs to Al-PCBs with Thermode

Adhesion of solder joint between Al-PCBs and Cu-PCBs

Top View



Back View



Peeled PCB

Hot bar settings – temperature 200 °C for 50 seconds, pressure of 6 psi
Good adhesion with failure between Al-PET interface

Adhesion of solder joints made using Thermode under varying pressure

6 psi

6 psi

7 psi

Hot bar settings of 210 °C for 15 seconds and pressure of 6 psi demonstrates very good adhesion

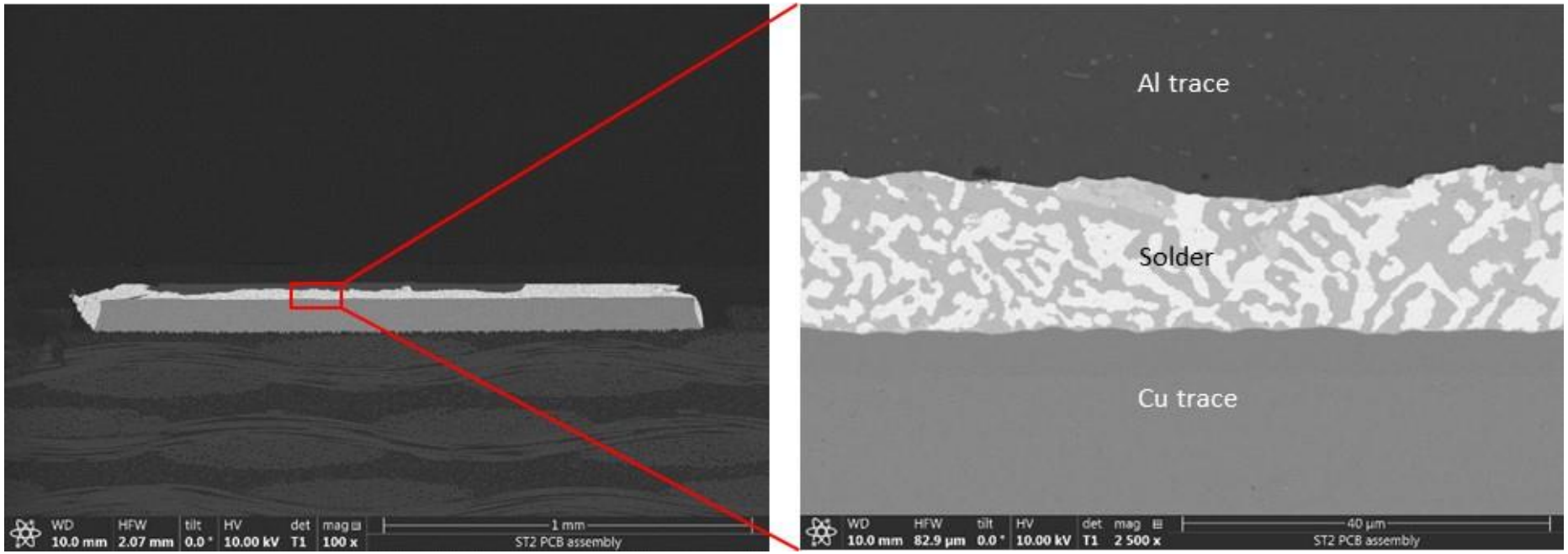
Summary of Electrical tests of Cu-PCBs soldered to Al-PET with Hot Bar soldering machine

Sample ID	Peak Temp C	Soak Time (sec)	Pressure (psi)	Opens	Bridging
1	200	13	4	ND	ND
2	200	13	4	0	0
3	200	13	4	0	0
4	200	13	2	5	0
5	200	13	2	0	0
6	200	13	2	5	0
7	200	13	6	0	0

ND implies electrical testing not done.

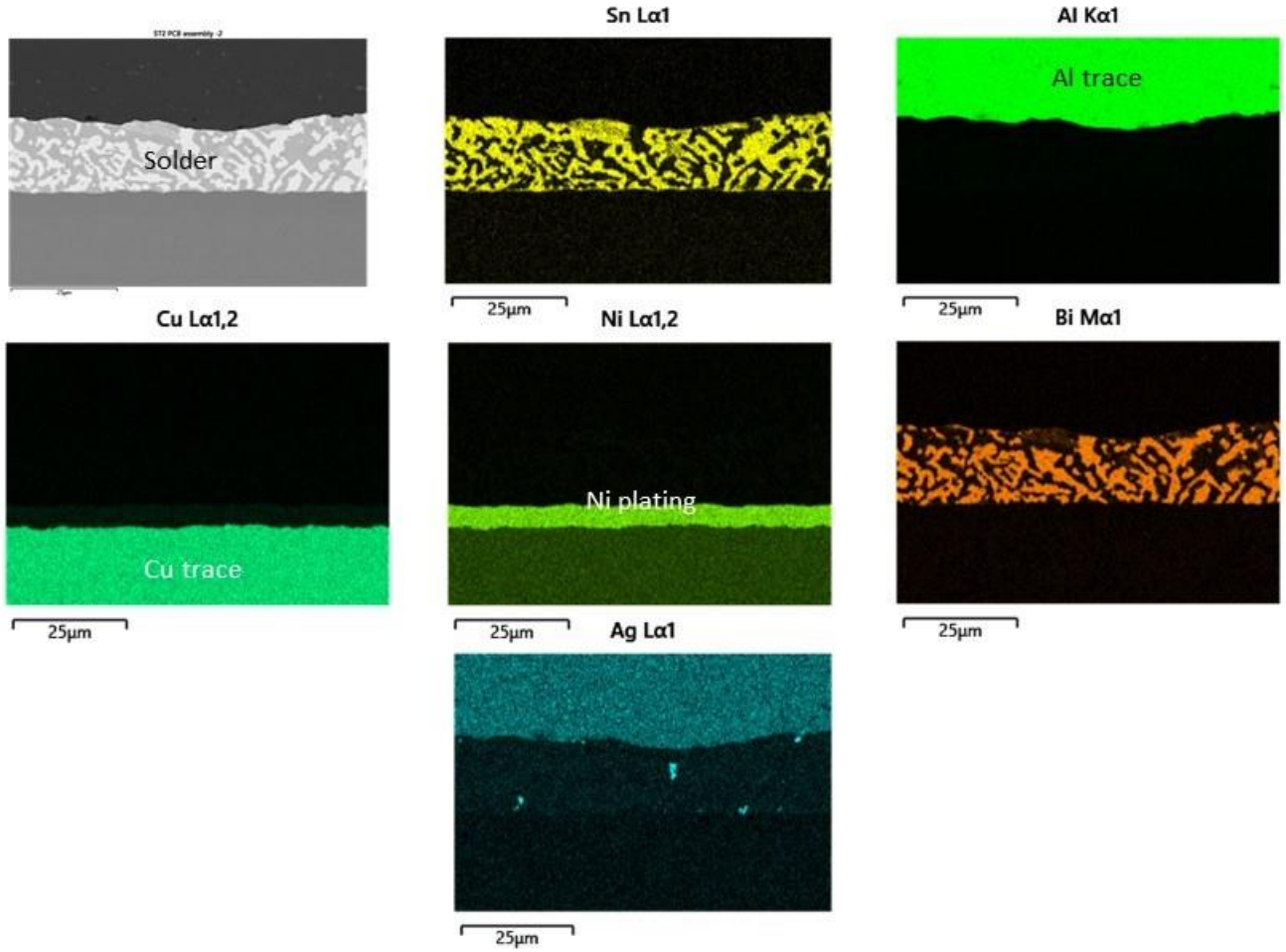
The summary table shows that peak temperature of 200°C, soak time 13 seconds, and pressures of 4 and 6 psi gave best results with no opens or bridging defects

SEM Cross sections of Cu-PCB soldered to Al-PCB using Hot Bar Soldering



Good solder wetting observed between Al-PCB and Cu-PCB

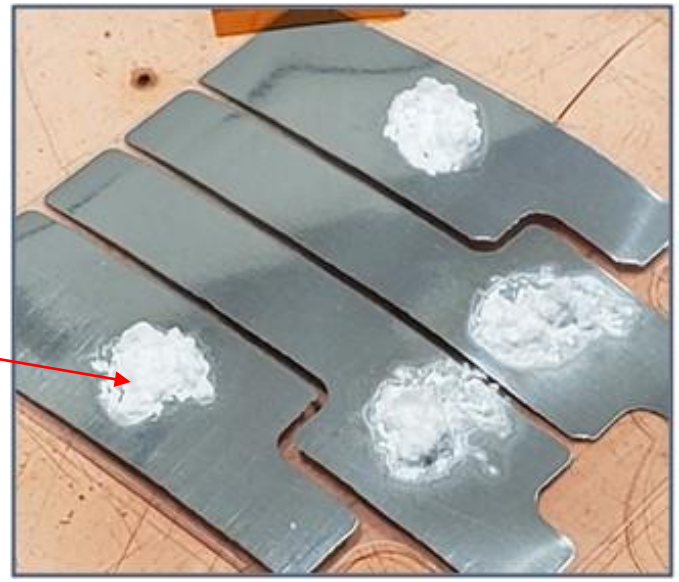
Xray maps of various elements at Al/solder/Cu-PCB joint made using Thermode

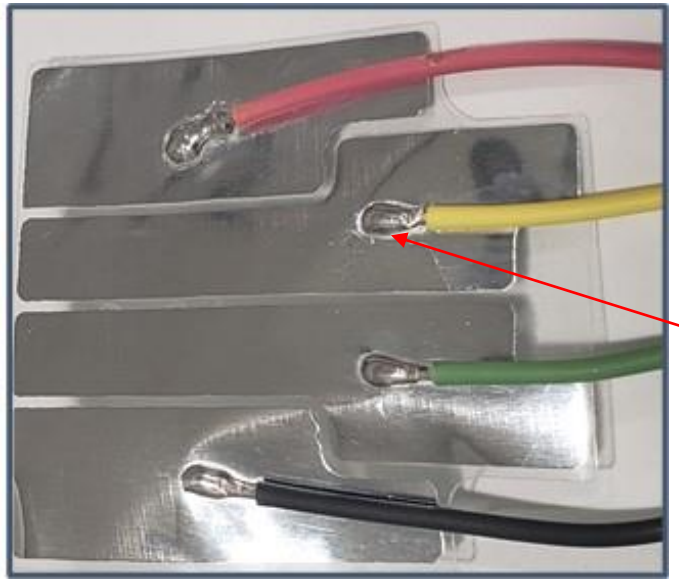


Good solder wetting observed between Al-PCB and Cu-PCB
Silver remains in bulk of the solder

Soldering of Cu Pigtails to Al-PET using solder wire

Surface Treatment



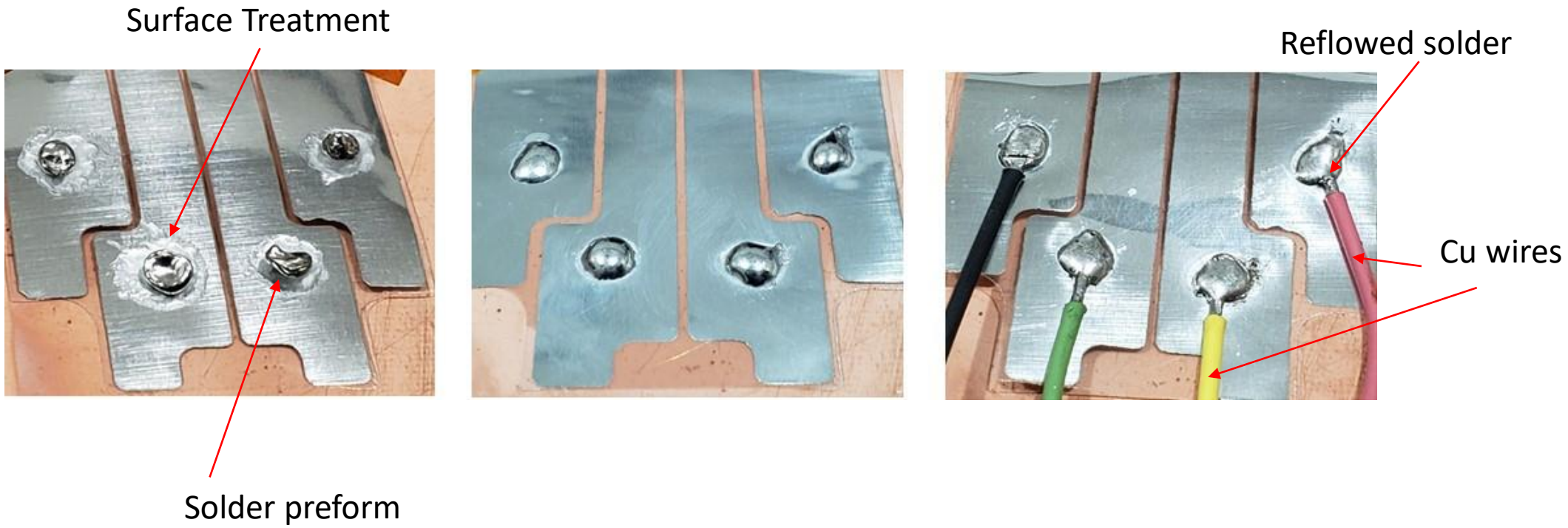


Cu wire soldered
To Al-PET

Al-PET with surface treatment after
Cure at 85 °C

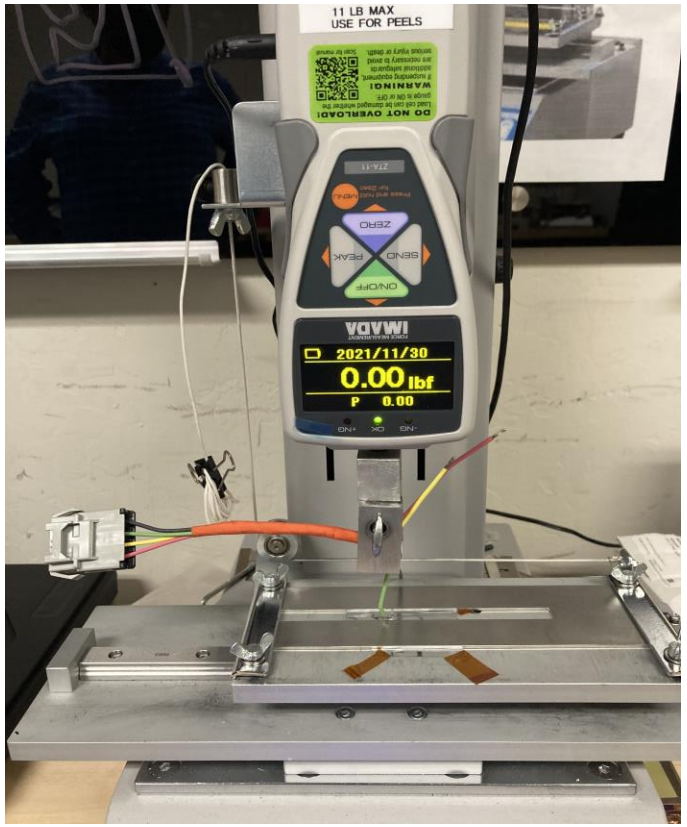
Cu wires attached with heat gun
at 190 °C.

Cu Pigtails soldered to Al-PET Flex panel using solder preforms

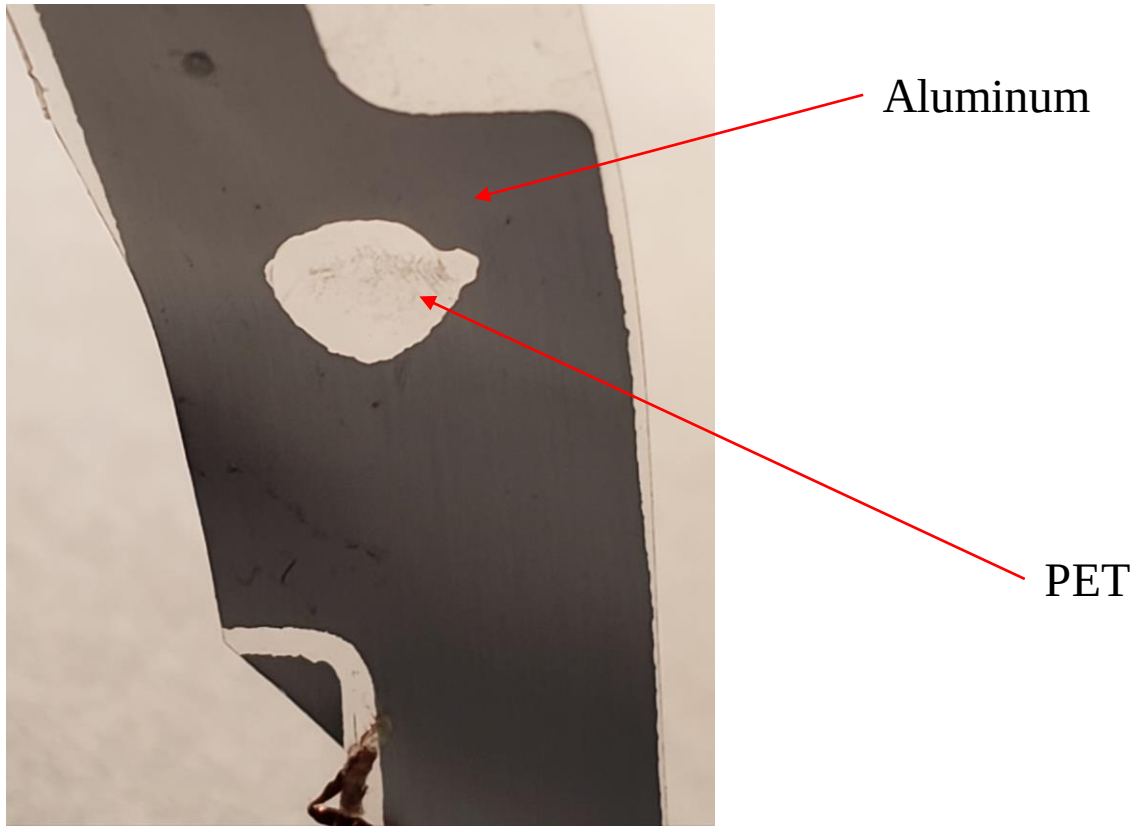


Process steps showing Cu Pig tails soldered to Al-PET panels using BiSnAg preforms

Adhesion of solder joints between Cu Pigtails and Al-PET



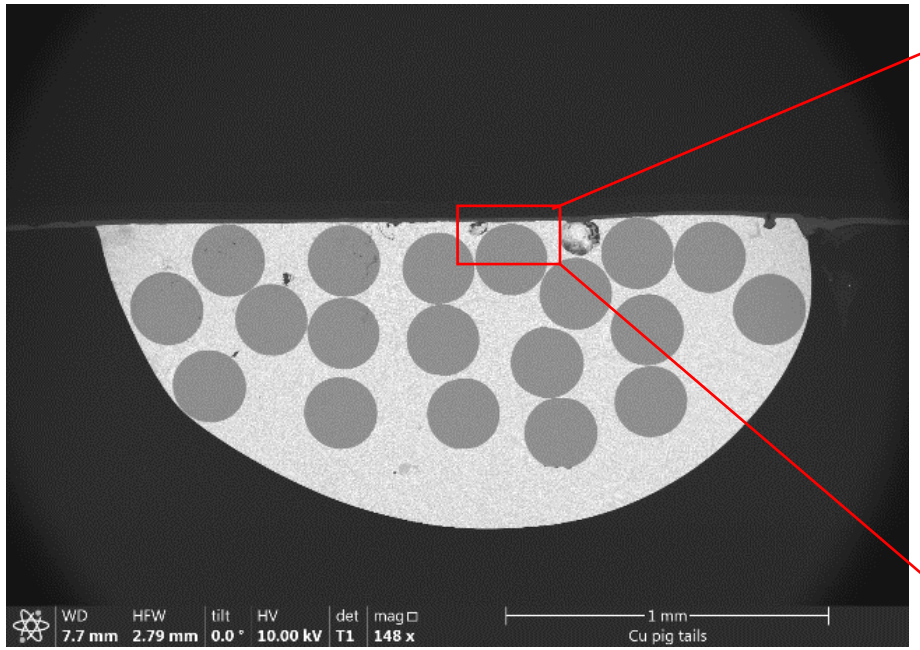
Pull Tester



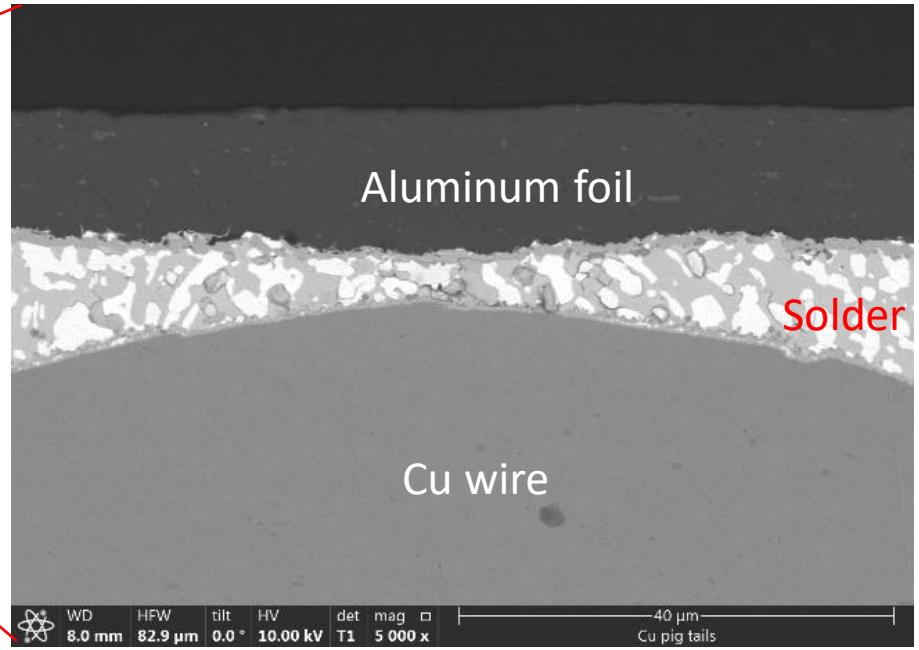
Al-PET laminate after pull test

Solder pull strength of over 10 psi obtained with failure at Al-PET interface.

SEM Cross sections of soldered copper pig tail assembly on Al-PET panel



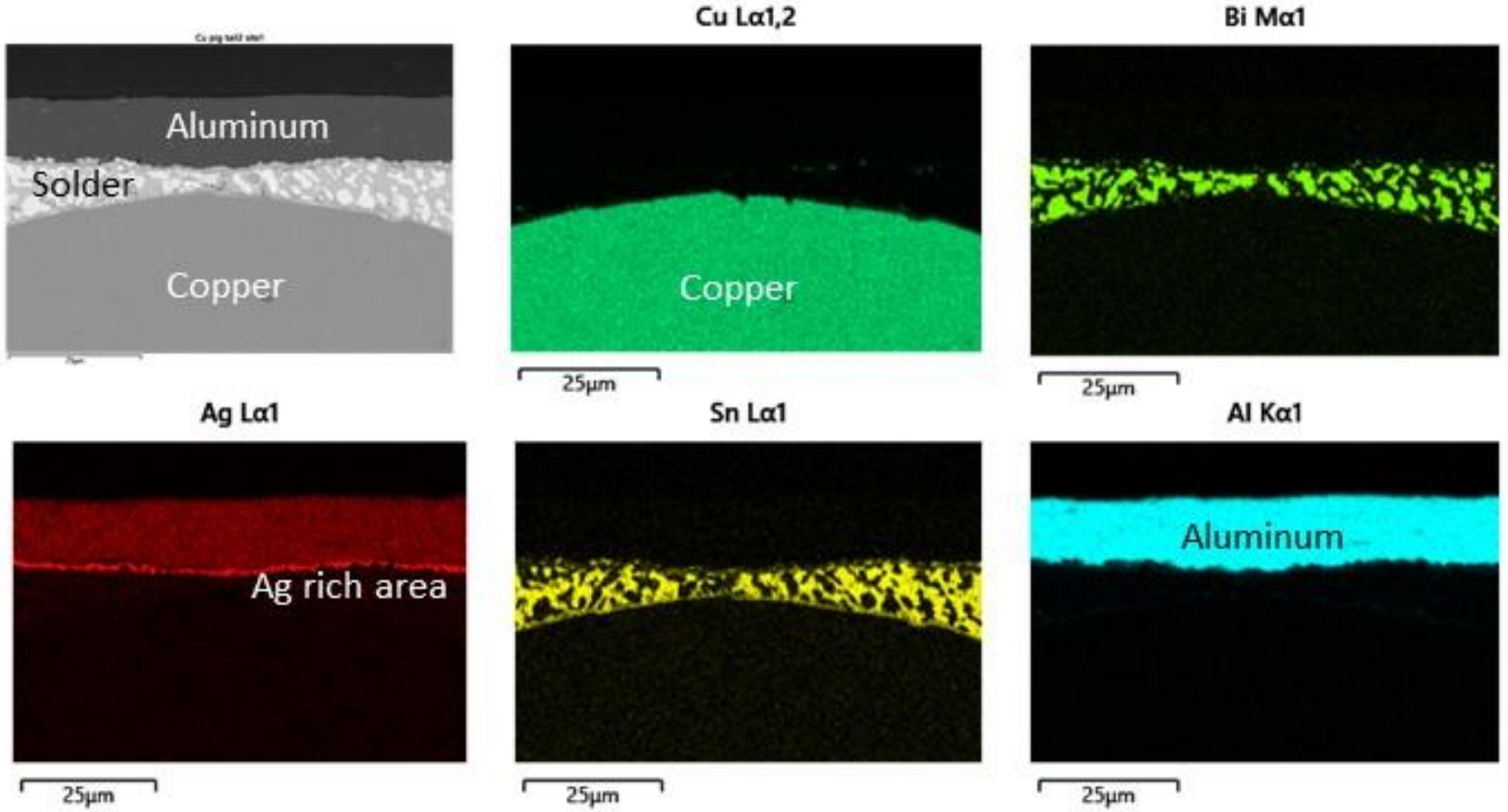
SEM cross section of Cu Pigtails soldered to Al-PET laminate



High mag. image of Al/solder/Cu interfaces.

Good solder wetting observed on aluminum foil and on copper wire with no delamination.

Xray maps of various elements seen in cross section of Cu pig tails soldered to Al/PET



X-ray maps of soldered Cu pigtails to Al-PET foil shows diffusion of silver to Al foil

Conclusions

- Surface Treatment has passed the SIR test
- Al-PCB panels assembled using Surface Treatment passed AATC for 1000 cycles
  - The R0603 and R0805 resistor nets, tested by thermal cycling in the temperature range of -40 °C to +105 °C for 1000 cycles, have survived the exposure and were considered acceptable to IPC standards and requirements for solder reliability acceptance
- Rigid Cu-PCBs have been soldered to flexible Al-PCBs using conventional reflow oven and , Hot bar soldering and have shown to produce strong solder joints
- Cu Pigtails have been soldered to flexible Al-PET panels with solder wires and preforms, resulting in strong solder joints
- Reliability test success and ability to solder rigid Cu-PCBs to Al-PET boards now paves the way for Al-PCBs made with Surface Treatment, to replace Cu-PCBs in applications such as automotive, LED and power devices

Thank You!

Special thanks

Wayne Jones – Universal Instruments Corp

Chrys Shea– Shea Engineering Corporation