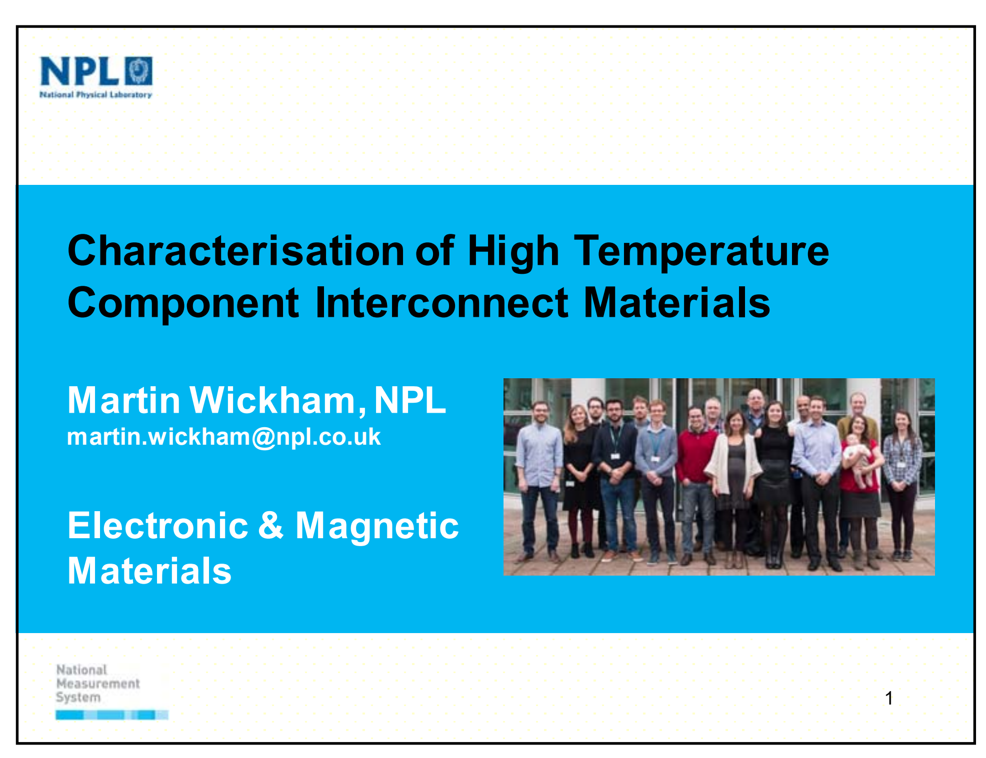
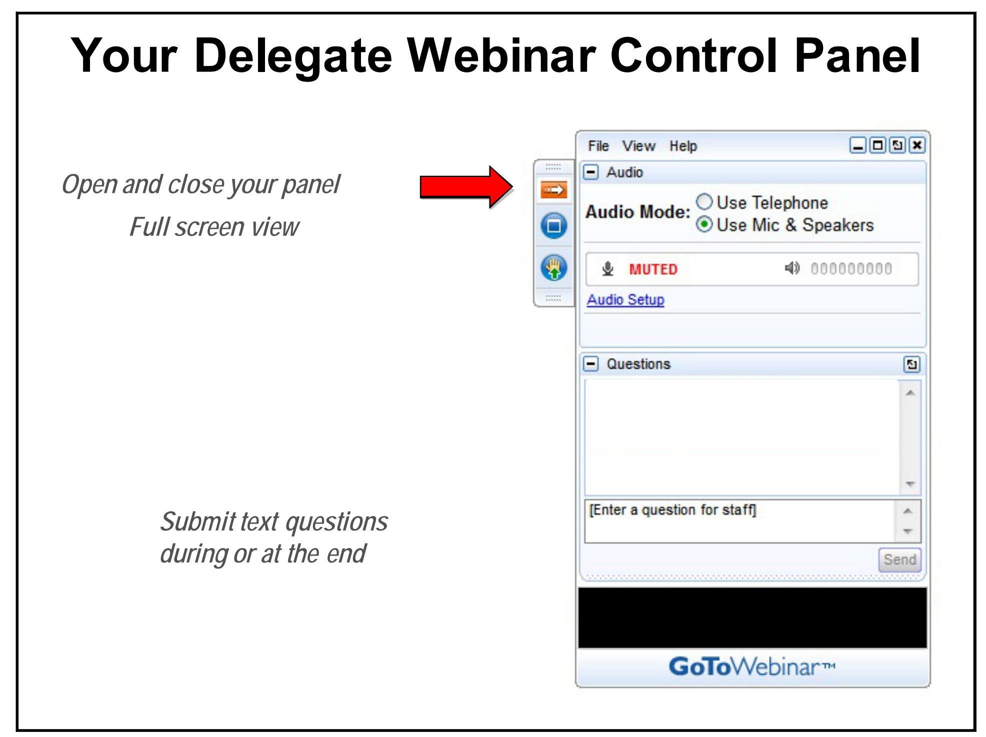

NPL
National Physical Laboratory
Characterisation of High Temperature Component Interconnect Materials
Martin Wickham, NPL
martin.wickham@npl.co.uk
Electronic & Magnetic Materials
National Measurement System
1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Characterisation of High Temperature Component Interconnect Materials
Tuesday 10th January Martin Wickham – National Physical Laboratory

Techniques for the Characterisation of Printed Electrodes & Sensor Materials
Tuesday 14 March Martin Wickham

UV Inspection and Thickness Measurement of Conformal Coatings
Tuesday 9 May Vimal Gopee

Electrical Performance of Organic Substrate Materials and Coatings Aged at High Temperature
Tuesday 11th July Dr Adam Lewis, Christine Thorogood & Martin Wickham

Electrical Metrology for Flexible & Printed Electronics
Tuesday 12 September Dr Adam P. Lewis

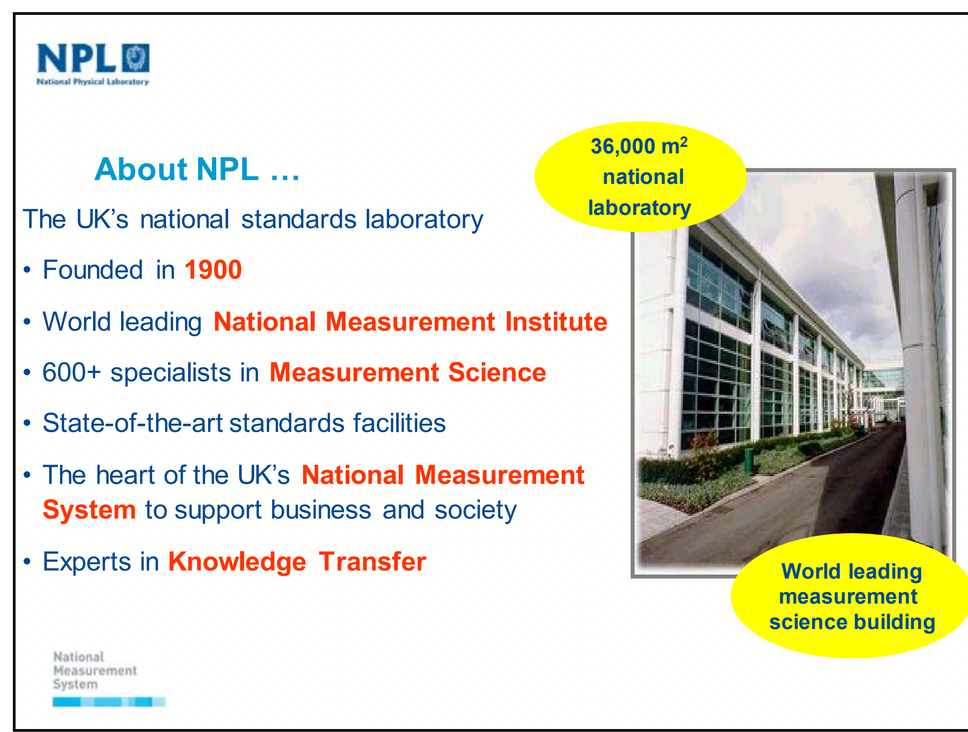
Condensation Failure & Improved Testing for Electronic Assemblies
Tuesday 14 November Ling Zou

Characterisation of High Temperature Component Interconnect Materials

Martin Wickham, NPL
martin.wickham@npl.co.uk

Electronic & Magnetic Materials

National Measurement System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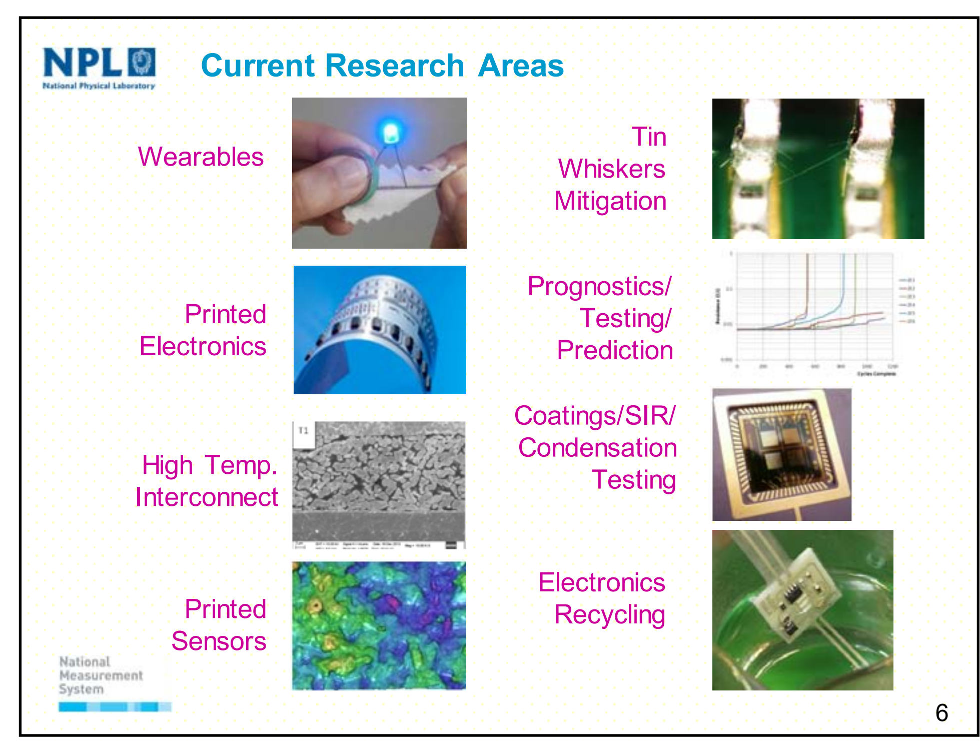
National Physical Laboratory
About NPL …
The UK's national standards laboratory
• Founded in 1900
• World leading National Measurement Institute
• 600+ specialists in Measurement Science
• State-of-the-art standards facilities
• The heart of the UK's National Measurement System to support business and society
• Experts in Knowledge Transfer
36,000 m2 national laboratory
World leading measurement science building
National Measurement System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Current Research Areas
Wearables
Printed Electronics
High Temp. Interconnect
Printed Sensors
Tin Whiskers Mitigation
Prognostics/ Testing/ Prediction
Coatings/SIR/ Condensation Testing
Electronics Recycling
National Measurement System
6

High Temperature Electronics
Pushing the boundaries for solder?

- Operating at higher temp. will enable sensors and electronics to be moved closer to their application positions, resulting in lighter, more efficient vehicles with lower energy consumption and CO_2 emissions.
- The increased operating temp. enable improved performances in power applications, renewable energy generation, hybrid and electrical vehicles and other sustainable transport solutions. This will result in energy savings and reduced CO_2 emissions.
- Applications in the oil, gas and mining industries will allow improved access to hard to harvest, scarce materials resources.
- Operating temperatures above 250°C are a current road block for SiC developments. Overcoming this will allow improved high-voltage switching in public electric power distribution and electric vehicles, resulting in energy savings and lower CO_2 emissions.

7

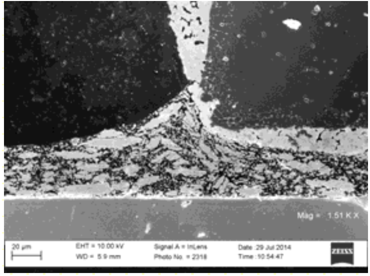
Issues in operating at higher temperatures

- Components
  - SOI, SiC, passives now increasingly available
- Packaging
  - Non-ceramic options still a challenge
  - Low-cost and better CTE match to potential substrate options
- *Interconnect*
- *Substrates*

8

NPL High Temp Interconnect Research

- High temperature conductive adhesives – ELCOSINT
  - Comparison with HMP solder
- On-going projects
  - Tamessa – high temperature protective coatings
  - ORCA – high temperature substrates
- Sintered Ag (MTC)



Organic PCBs for High Temperature

- Utilising conventional PCBs at higher temperatures instead of ceramic or insulated metal substrates offers benefits in terms of cost, no. of suppliers, familiarity with technology, opportunity to utilise existing SM production facilities.
- Obvious issues with attempting to use materials with low decomposition temperature (Td) or maximum operating temperature (MOT) i.e. likely to degrade significantly above 200°C
- Range of organic resin based laminates materials becoming available which offer improved high temperature performance
  - High temperature polyimides
  - Liquid Crystal Polymer (LCP)
  - Polyether ether ketone (PEEK)
- Current offerings are copper clad options

National
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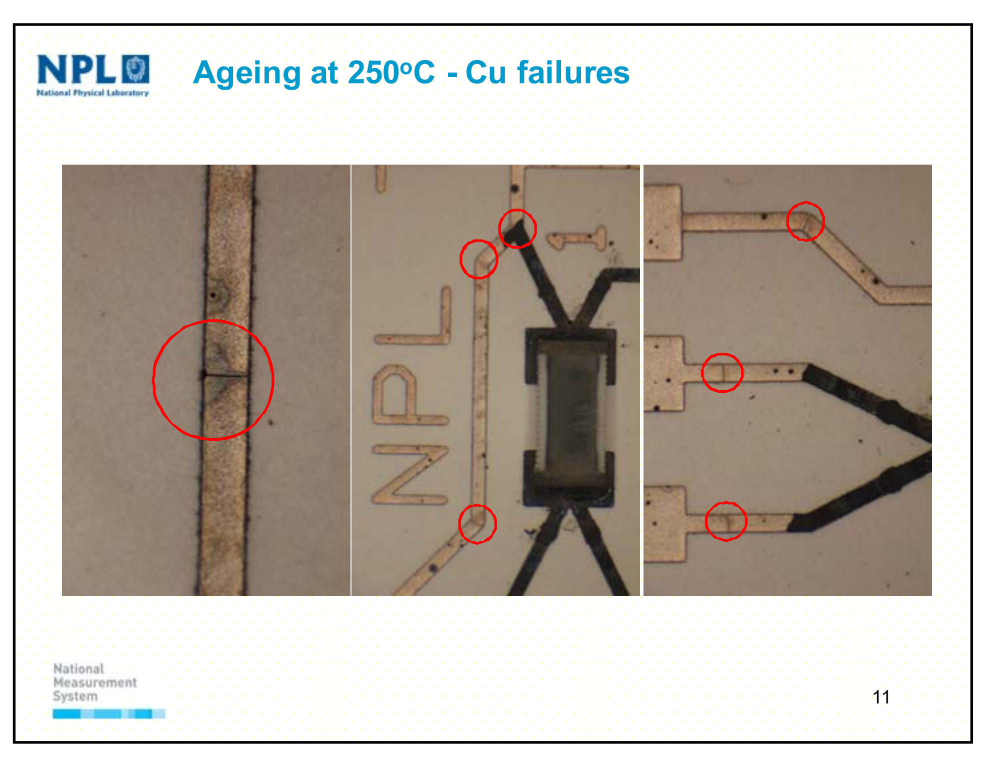
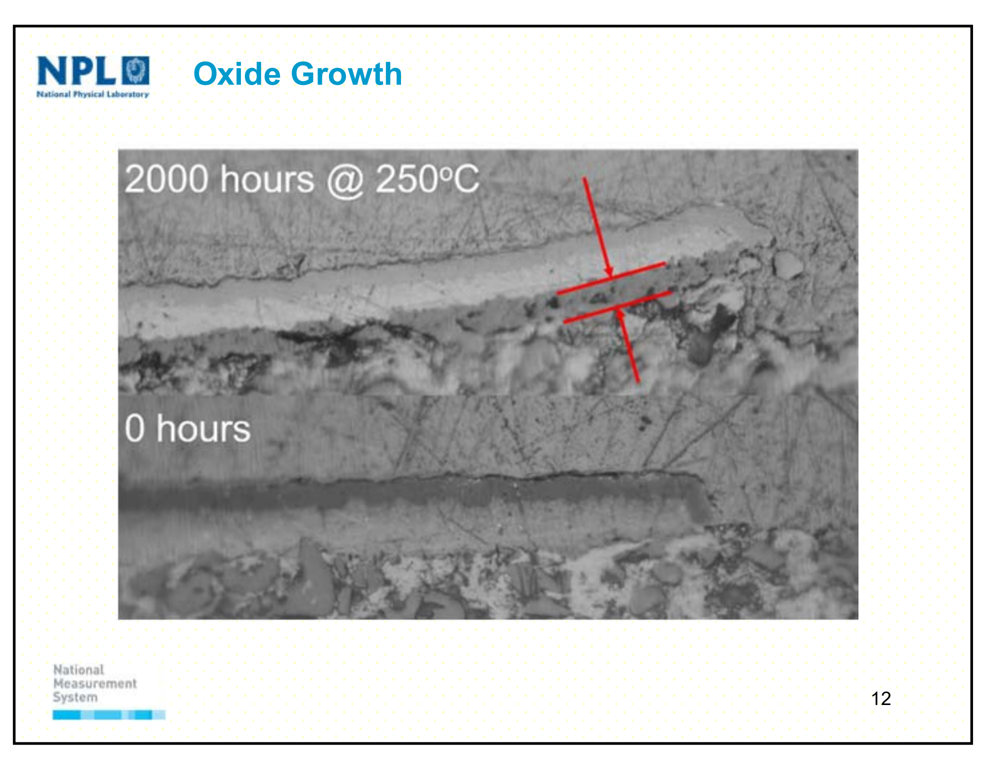
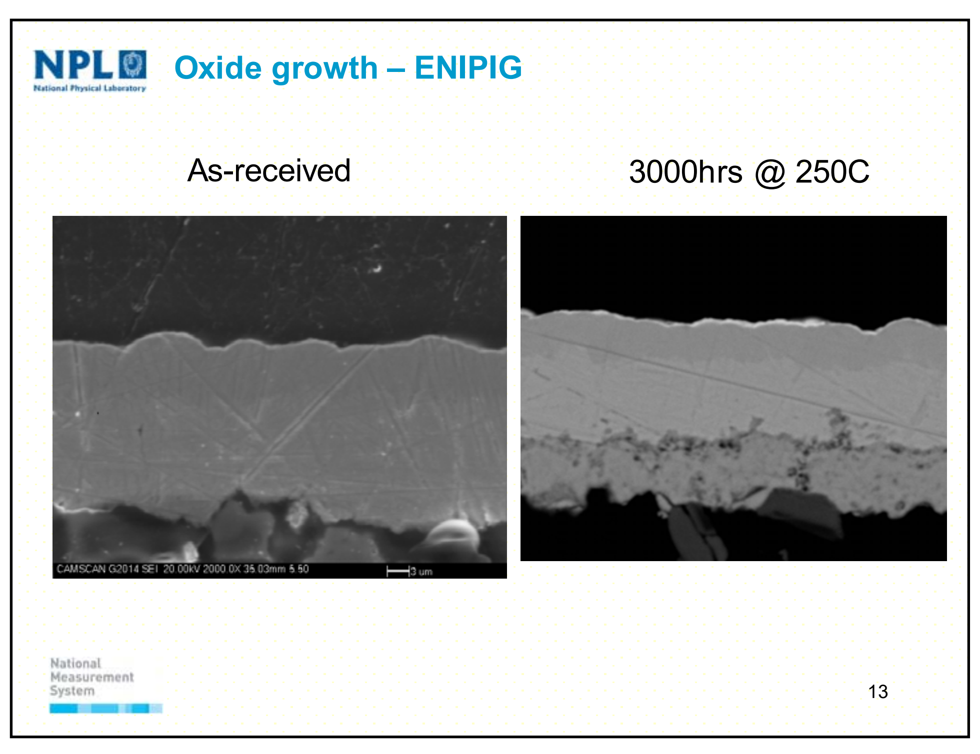
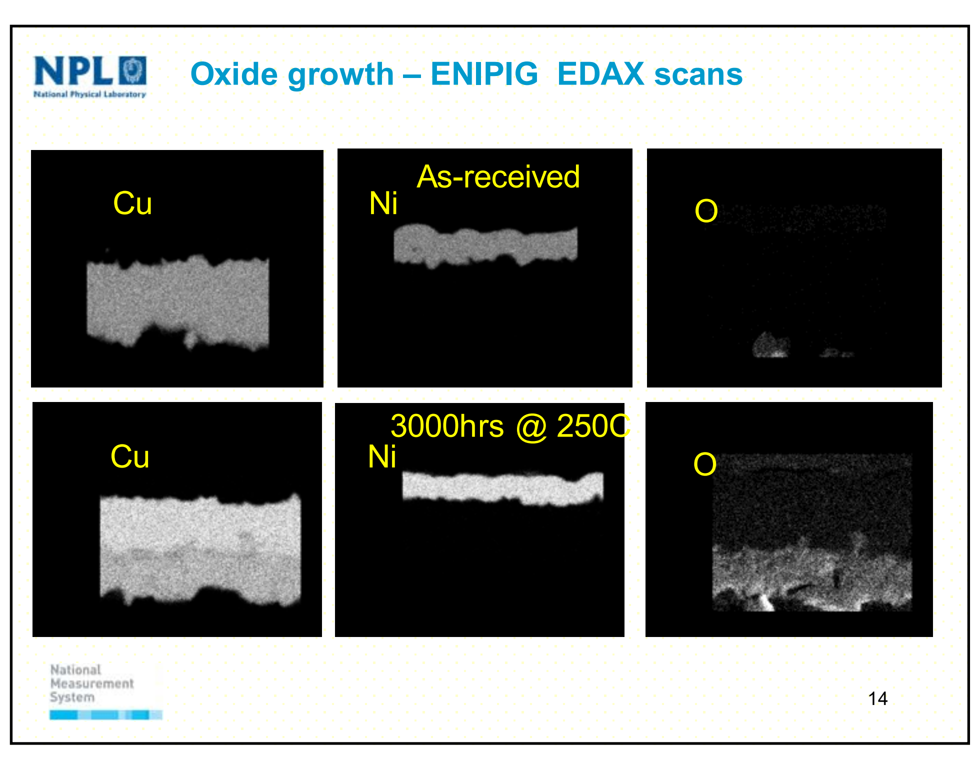
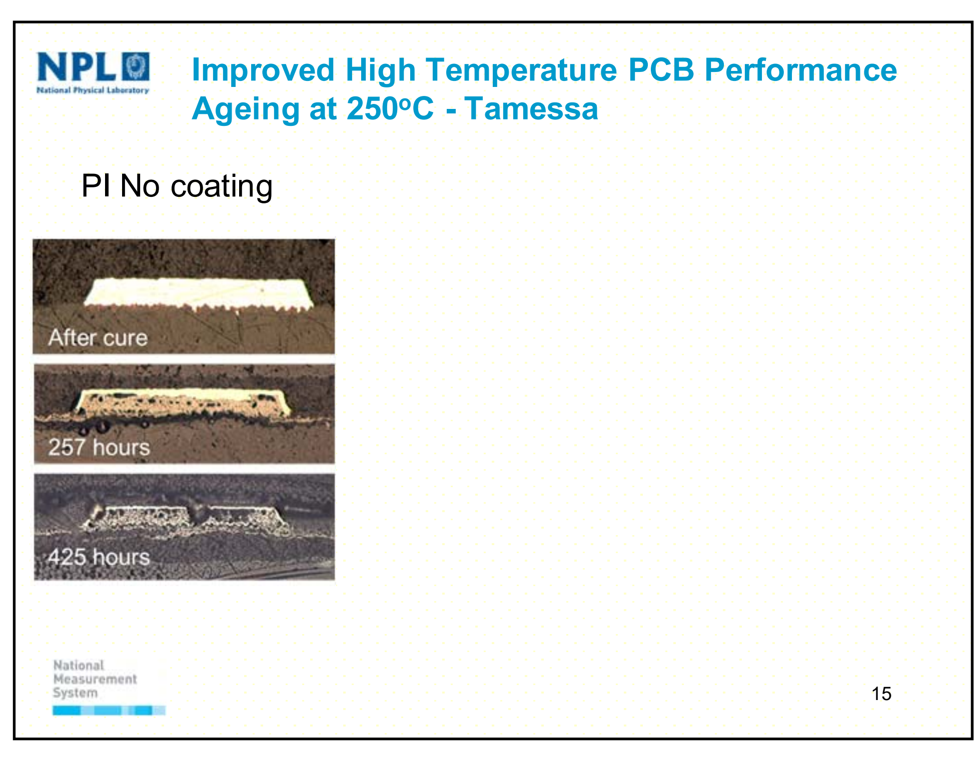
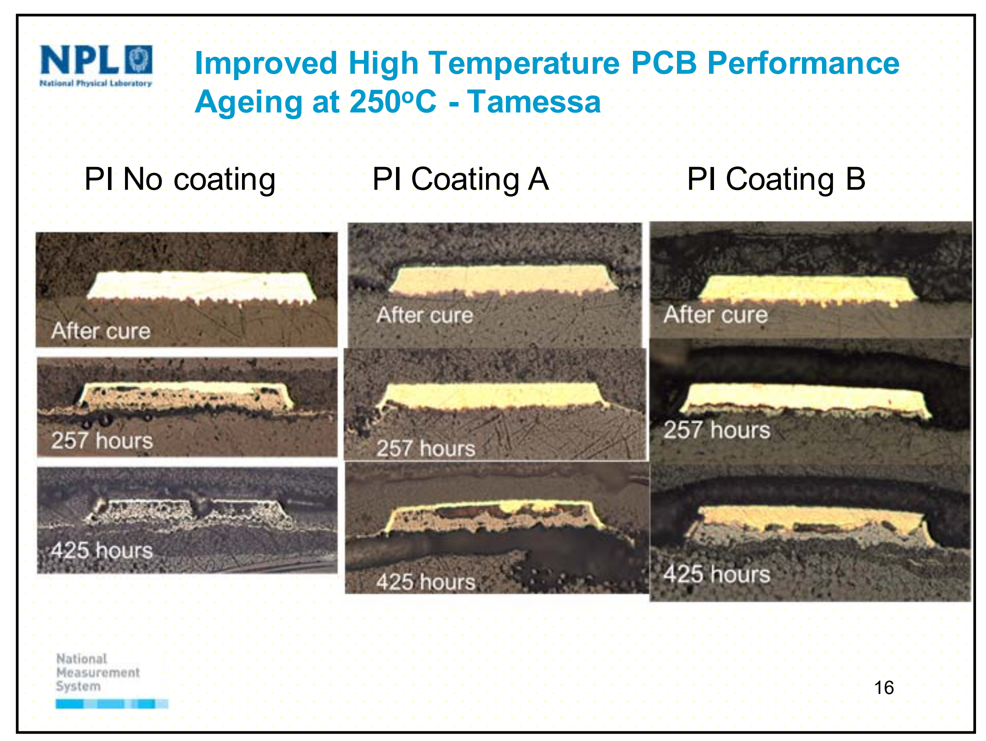

NPL
National Physical Laboratory
Ageing at 250°C - Cu failures
NPL
National
Measurement
System
11

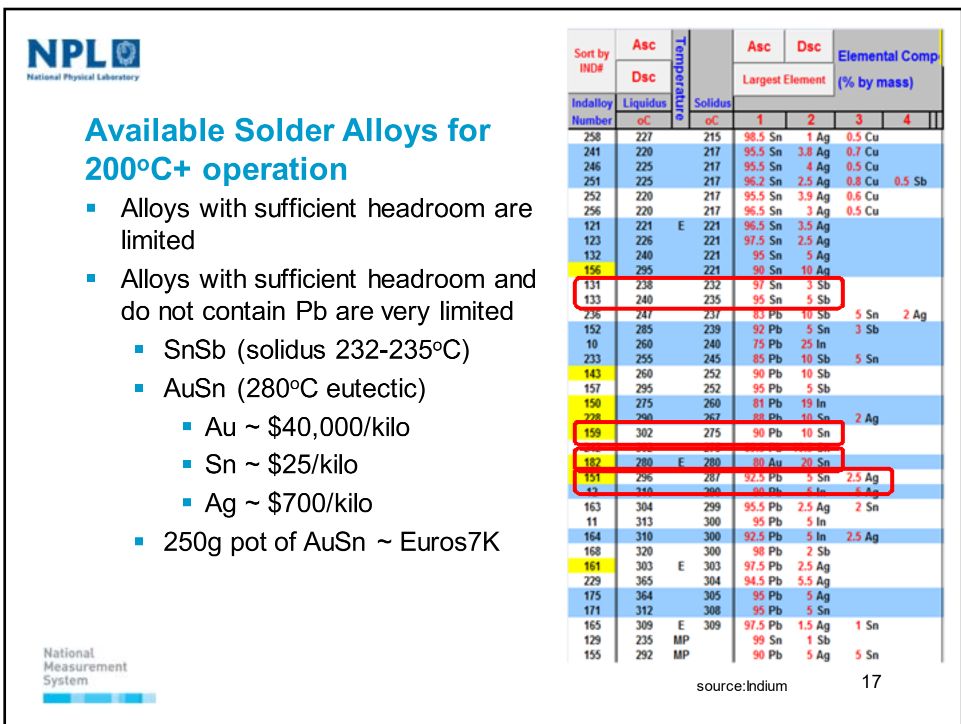

NPL
National Physical Laboratory
Oxide Growth
2000 hours @ 250°C
0 hours
National
Measurement
System
12


NPL
National Physical Laboratory
Oxide growth – ENIPIG
As-received
3000hrs @ 250C
National Measurement System
13


NPL
National Physical Laboratory
Oxide growth – ENIPIG EDAX scans
Cu
Ni
As-received
O
Cu
3000hrs @ 250C
Ni
O
National Measurement System
14


NPL National Physical Laboratory
Improved High Temperature PCB Performance
Ageing at 250°C - Tamessa
PI No coating
After cure
257 hours
425 hours
National Measurement System
15


NPL National Physical Laboratory
Improved High Temperature PCB Performance
Ageing at 250°C - Tamessa
PI No coating
PI Coating A
PI Coating B
After cure
257 hours
425 hours
After cure
257 hours
425 hours
After cure
257 hours
425 hours
National Measurement System
16



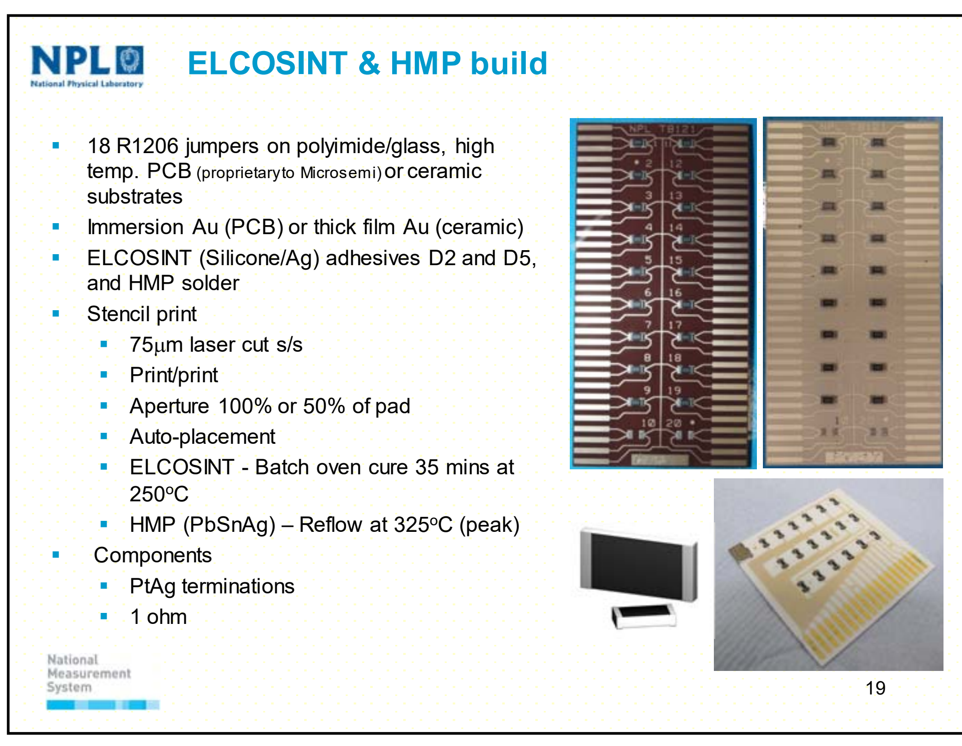
Indalloy Number (Sort by IND#)	Liquidus °C	Temperature	Solidus °C	1	2	3	4
258	227		215	98.5 Sn	1 Ag	0.5 Cu	
241	220		217	95.5 Sn	3.8 Ag	0.7 Cu	
246	225		217	95.5 Sn	4 Ag	0.5 Cu	
251	225		217	96.2 Sn	2.5 Ag	0.8 Cu	0.5 Sb
252	220		217	95.5 Sn	3.9 Ag	0.6 Cu	
256	220		217	96.5 Sn	3 Ag	0.5 Cu	
121	221	E	221	96.5 Sn	3.5 Ag		
123	226		221	97.5 Sn	2.5 Ag		
132	240		221	95 Sn	5 Ag		
156	295		221	90 Sn	10 Ag		
131	238		232	97 Sn	3 Sb		
133	240		235	95 Sn	5 Sb		
236	247		237	83 Pb	10 Sb	5 Sn	2 Ag
152	285		239	92 Pb	5 Sn	3 Sb	
10	260		240	75 Pb	25 In		
233	255		245	85 Pb	10 Sb	5 Sn	
143	260		252	90 Pb	10 Sb		
157	295		252	95 Pb	5 Sb		
150	275		260	81 Pb	19 In		
228	290		267	88 Pb	10 Sn	2 Ag	
159	302		275	90 Pb	10 Sn		
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		
182	280	E	280	80 Au	20 Sn		
151	296		287	92.5 Pb	5 Sn	2.5 Ag	
[illegible]	310		290	90 Pb	5 In	5 Ag	
163	304		299	95.5 Pb	2.5 Ag	2 Sn	
11	313		300	95 Pb	5 In		
164	310		300	92.5 Pb	5 In	2.5 Ag	
168	320		300	98 Pb	2 Sb		
161	303	E	303	97.5 Pb	2.5 Ag		
229	365		304	94.5 Pb	5.5 Ag		
175	364		305	95 Pb	5 Ag		
171	312		308	95 Pb	5 Sn		
165	309	E	309	97.5 Pb	1.5 Ag	1 Sn	
129	235	MP		99 Sn	1 Sb		
155	292	MP		90 Pb	5 Ag	5 Sn	

European RoHS Legislation

- RoHS recast - 2011
  - RoHS2 has a more dynamic approach to exemptions, creating an automatic expiration if exemptions are not renewed by requests from industry
  - New substances added
- Current RoHS exemptions may well stay
  - “until alternatives become available”
  - “then those without the alternatives will have to play catch-up”

National Measurement System

18


NPL
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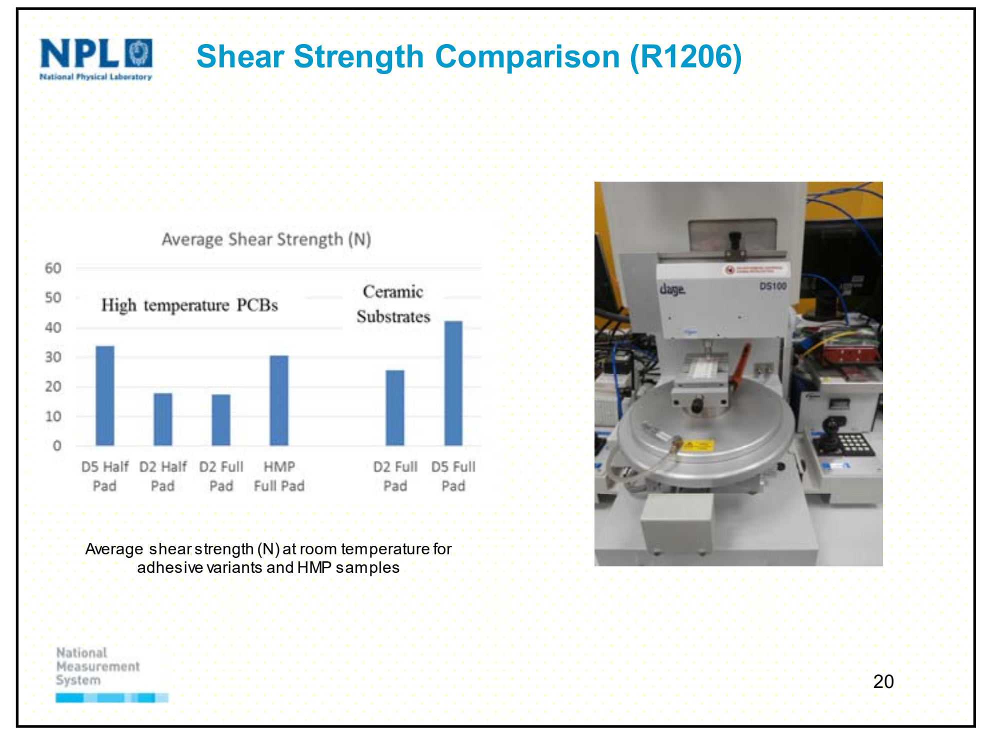
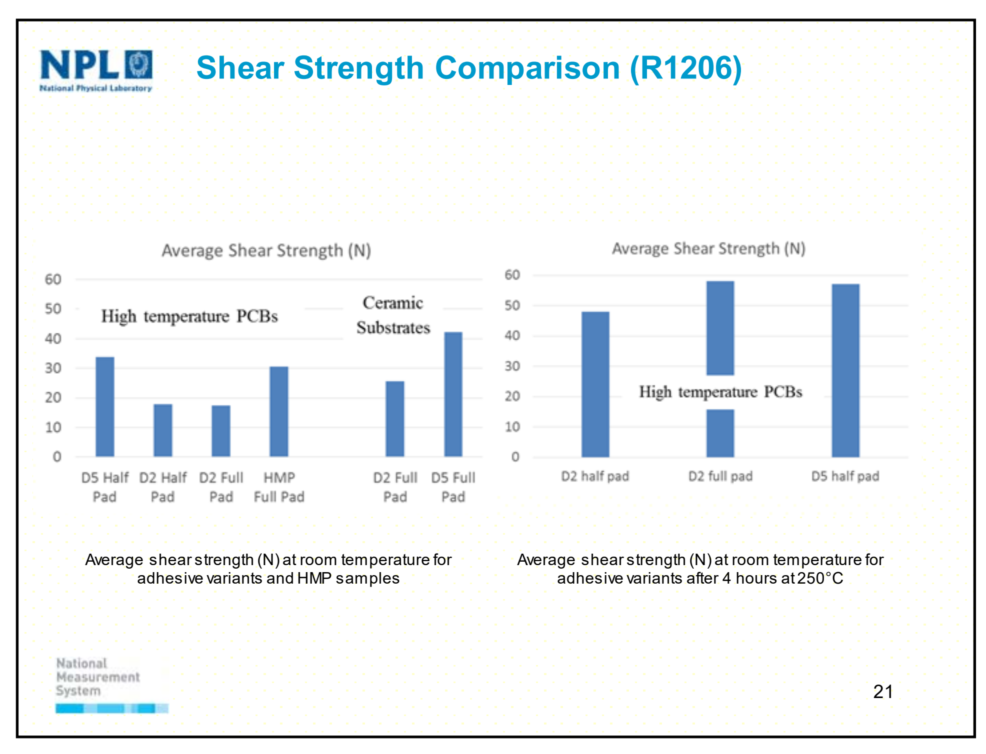
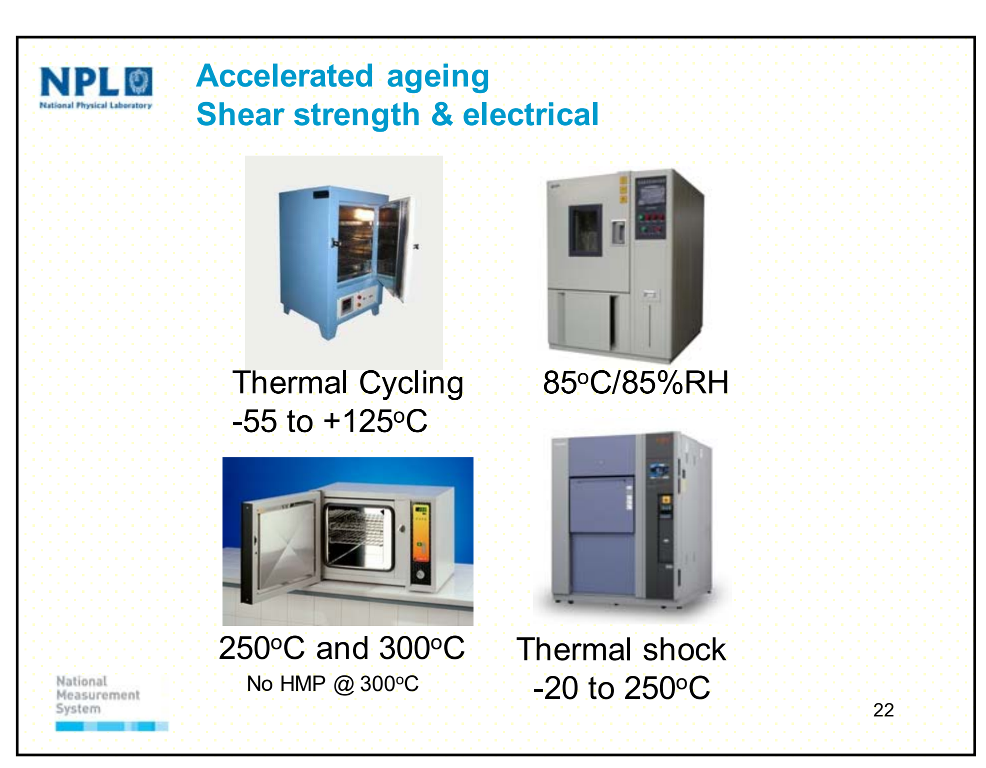
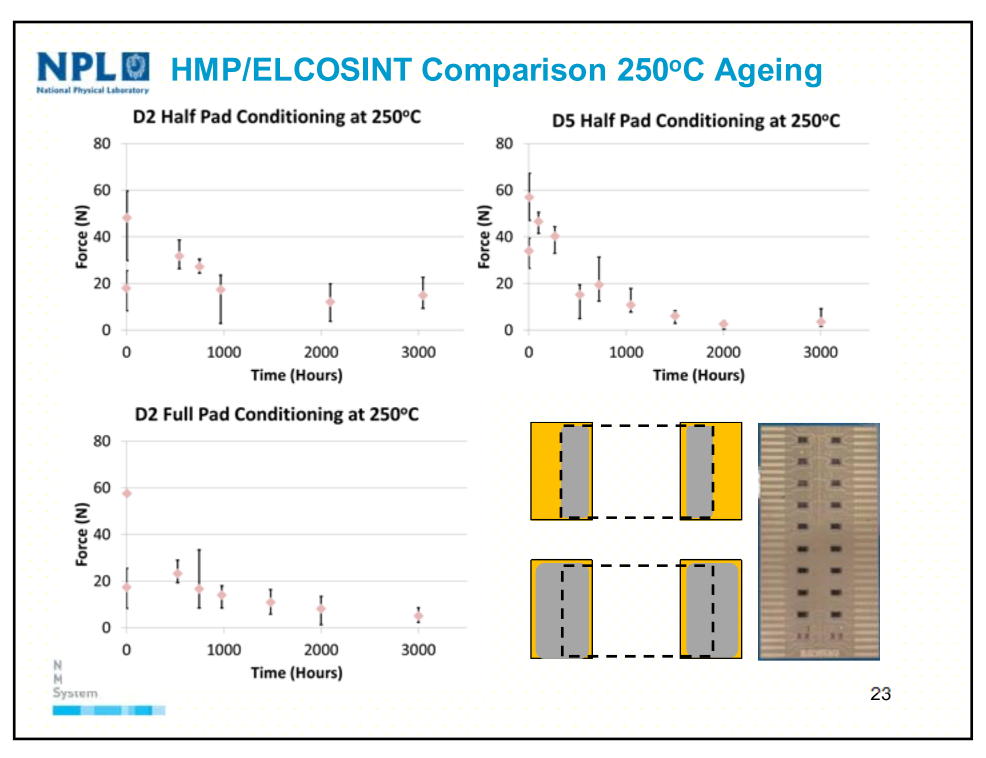
ELCOSINT & HMP build
18 R1206 jumpers on polyimide/glass, high temp. PCB (proprietary to Microsemi) or ceramic substrates
Immersion Au (PCB) or thick film Au (ceramic)
ELCOSINT (Silicone/Ag) adhesives D2 and D5, and HMP solder
Stencil print
75µm laser cut s/s
Print/print
Aperture 100% or 50% of pad
Auto-placement
ELCOSINT - Batch oven cure 35 mins at 250ºC
HMP (PbSnAg) – Reflow at 325ºC (peak)
Components
PtAg terminations
1 ohm
National Measurement System
19

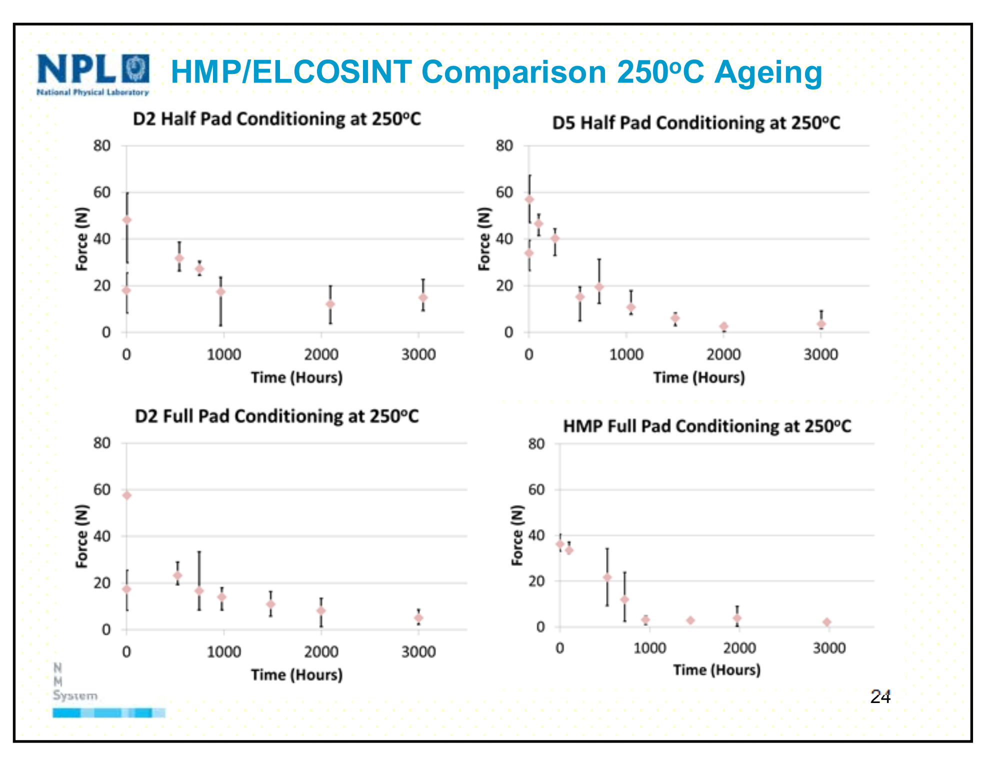

NPL
National Physical Laboratory
Shear Strength Comparison (R1206)
Average Shear Strength (N)
60
50
40
30
20
10
0
High temperature PCBs
Ceramic Substrates
D5 Half Pad
D2 Half Pad
D2 Full Pad
HMP Full Pad
D2 Full Pad
D5 Full Pad
Average shear strength (N) at room temperature for adhesive variants and HMP samples
dage
DS100
National Measurement System
20


NPL National Physical Laboratory
Shear Strength Comparison (R1206)
Average Shear Strength (N)
60
50
40
30
20
10
0
High temperature PCBs
Ceramic Substrates
D5 Half Pad
D2 Half Pad
D2 Full Pad
HMP Full Pad
D2 Full Pad
D5 Full Pad
Average shear strength (N) at room temperature for adhesive variants and HMP samples
Average Shear Strength (N)
High temperature PCBs
D2 half pad
D2 full pad
D5 half pad
Average shear strength (N) at room temperature for adhesive variants after 4 hours at 250°C
National Measurement System
21

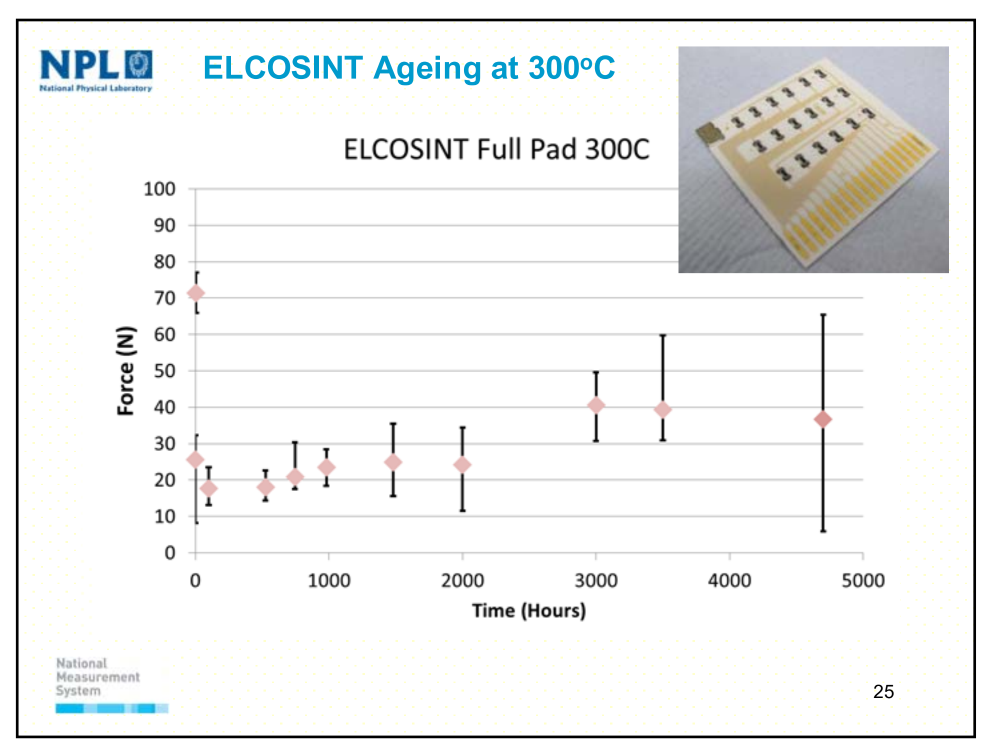

NPL National Physical Laboratory
Accelerated ageing
Shear strength & electrical
Thermal Cycling
-55 to +125°C
85°C/85%RH
250°C and 300°C
No HMP @ 300°C
Thermal shock
-20 to 250°C
National Measurement System
22

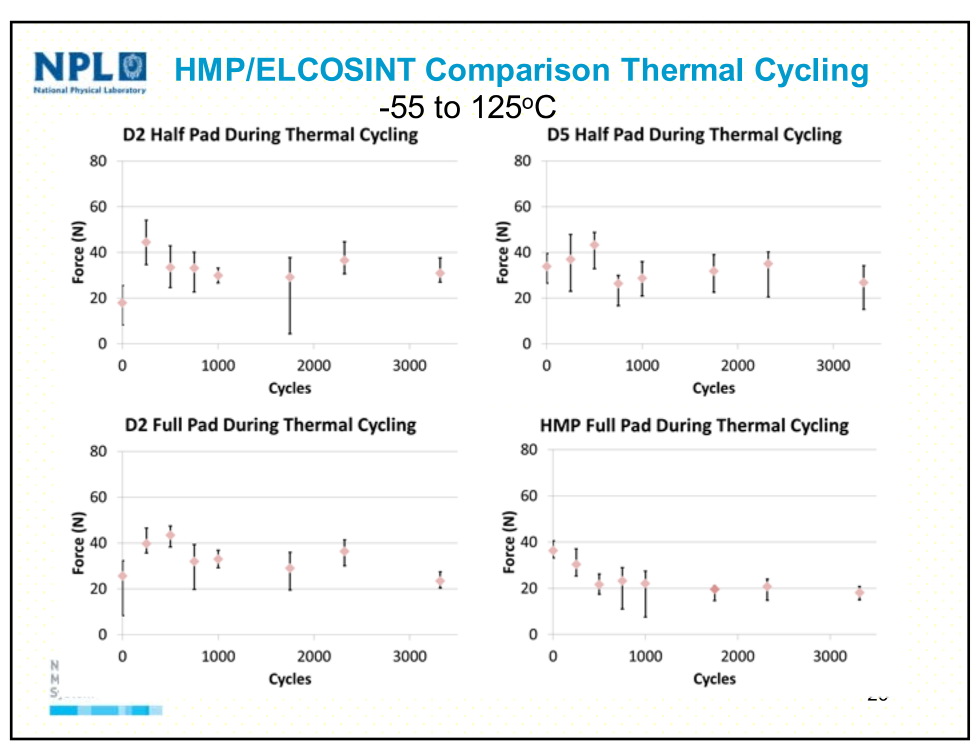


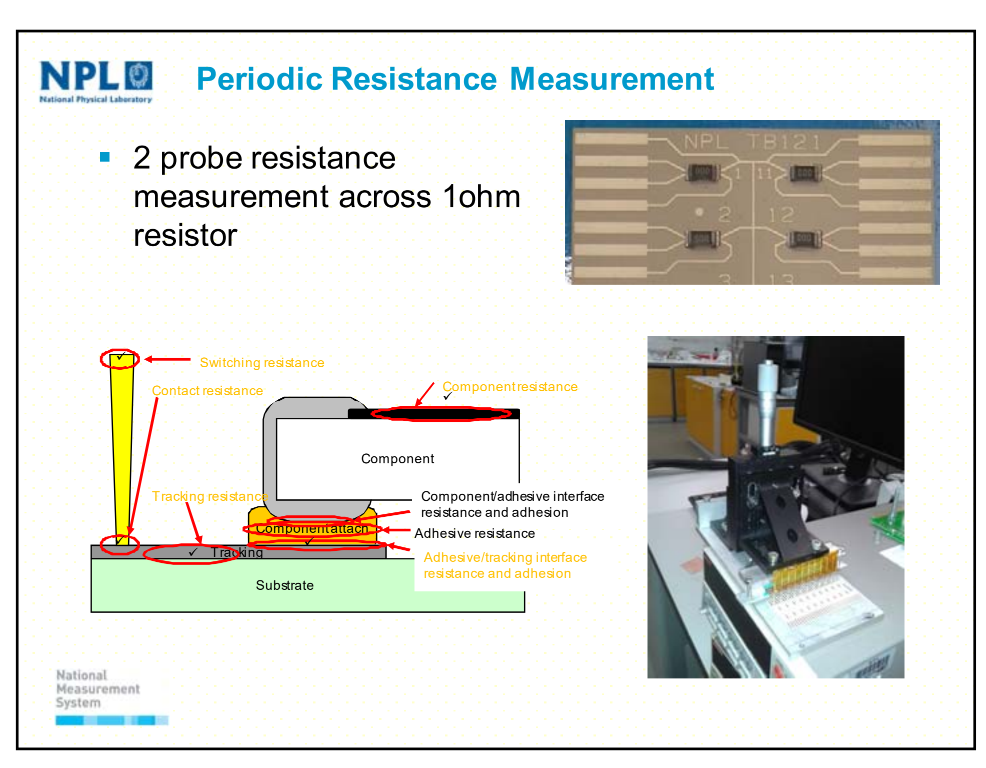
NPL National Physical Laboratory
HMP/ELCOSINT Comparison 250°C Ageing
D2 Half Pad Conditioning at 250°C
D5 Half Pad Conditioning at 250°C
D2 Full Pad Conditioning at 250°C
Force (N)
Time (Hours)
23

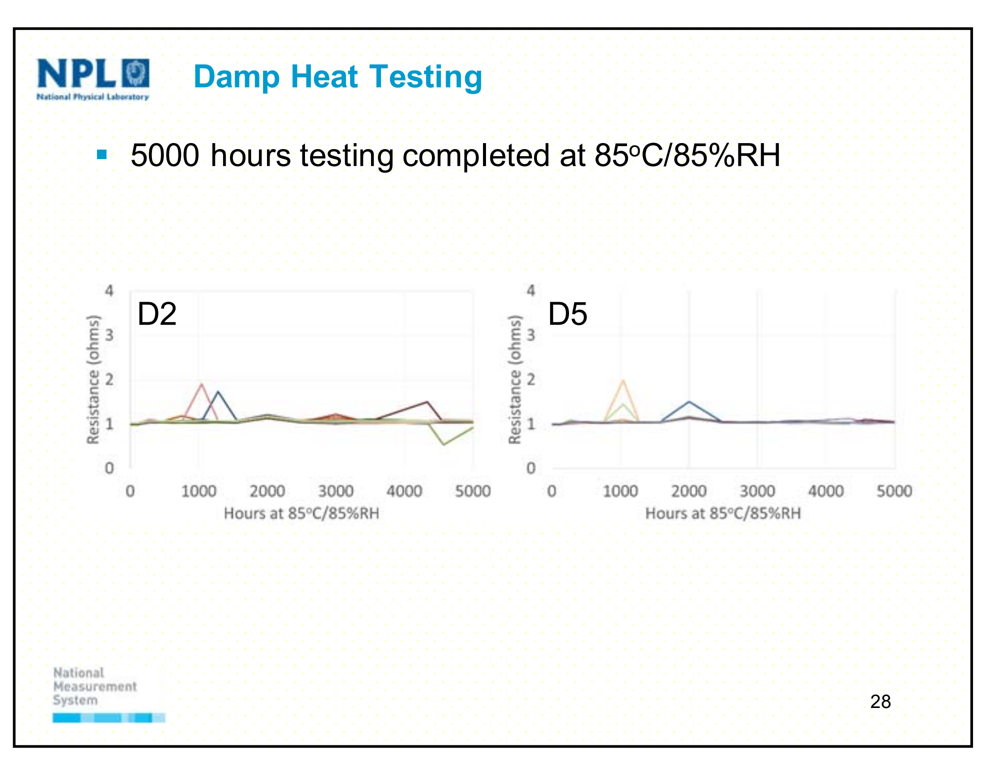


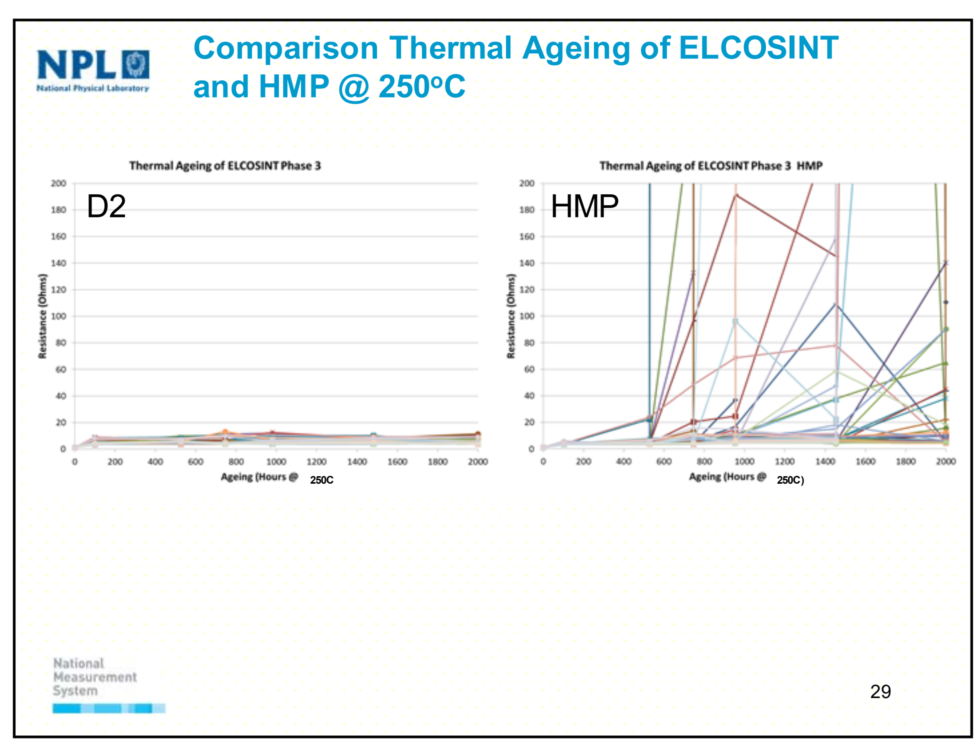
NPL National Physical Laboratory
HMP/ELCOSINT Comparison 250°C Ageing
D2 Half Pad Conditioning at 250°C
D5 Half Pad Conditioning at 250°C
D2 Full Pad Conditioning at 250°C
HMP Full Pad Conditioning at 250°C
Force (N)
Time (Hours)
24

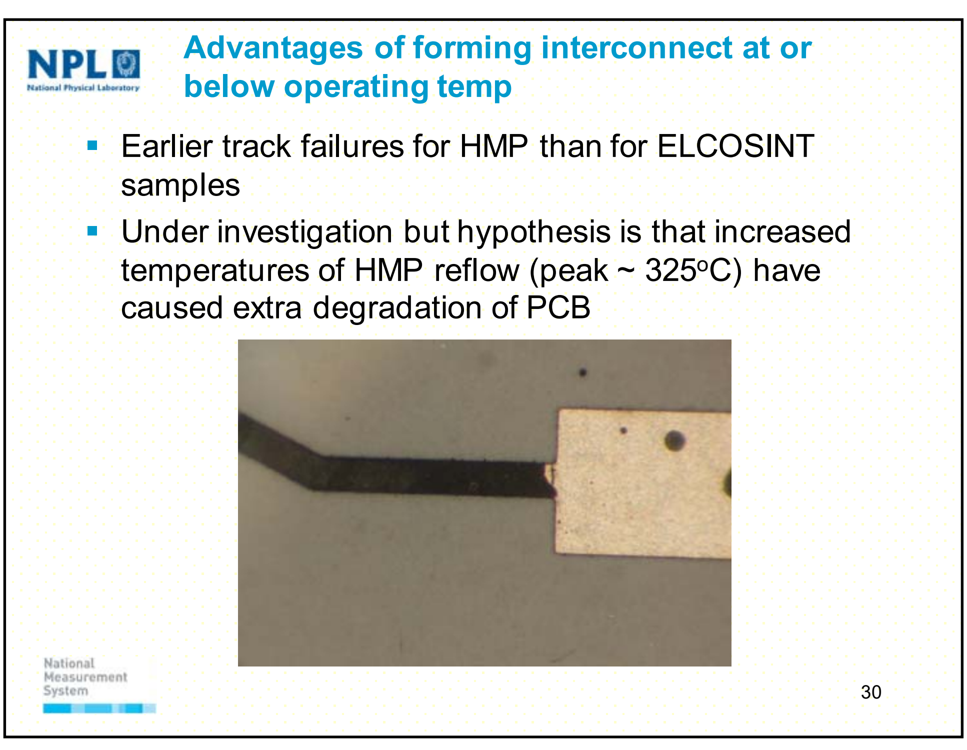

NPL National Physical Laboratory
ELCOSINT Ageing at 300ºC
ELCOSINT Full Pad 300C
Force (N)
Time (Hours)
0
1000
2000
3000
4000
5000
100
90
80
70
60
50
40
30
20
10
0
National Measurement System
25


NPL National Physical Laboratory
HMP/ELCOSINT Comparison Thermal Cycling
-55 to 125ºC
D2 Half Pad During Thermal Cycling
D5 Half Pad During Thermal Cycling
D2 Full Pad During Thermal Cycling
HMP Full Pad During Thermal Cycling
Force (N)
Cycles
0
1000
2000
3000
80
60
40
20
0


NPL National Physical Laboratory
Periodic Resistance Measurement
2 probe resistance measurement across 1ohm resistor
Switching resistance
Contact resistance
Component resistance
Component
Tracking resistance
Component/adhesive interface resistance and adhesion
Component attach
Adhesive resistance
Tracking
Adhesive/tracking interface resistance and adhesion
Substrate
National Measurement System


NPL National Physical Laboratory
Damp Heat Testing
5000 hours testing completed at 85°C/85%RH
D2
D5
Resistance (ohms)
Hours at 85°C/85%RH
National Measurement System
28


NPL
National Physical Laboratory
Comparison Thermal Ageing of ELCOSINT and HMP @ 250°C
Thermal Ageing of ELCOSINT Phase 3
D2
Resistance (Ohms)
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Ageing (Hours @ 250C
Thermal Ageing of ELCOSINT Phase 3 HMP
HMP
Resistance (Ohms)
Ageing (Hours @ 250C)
National Measurement System
29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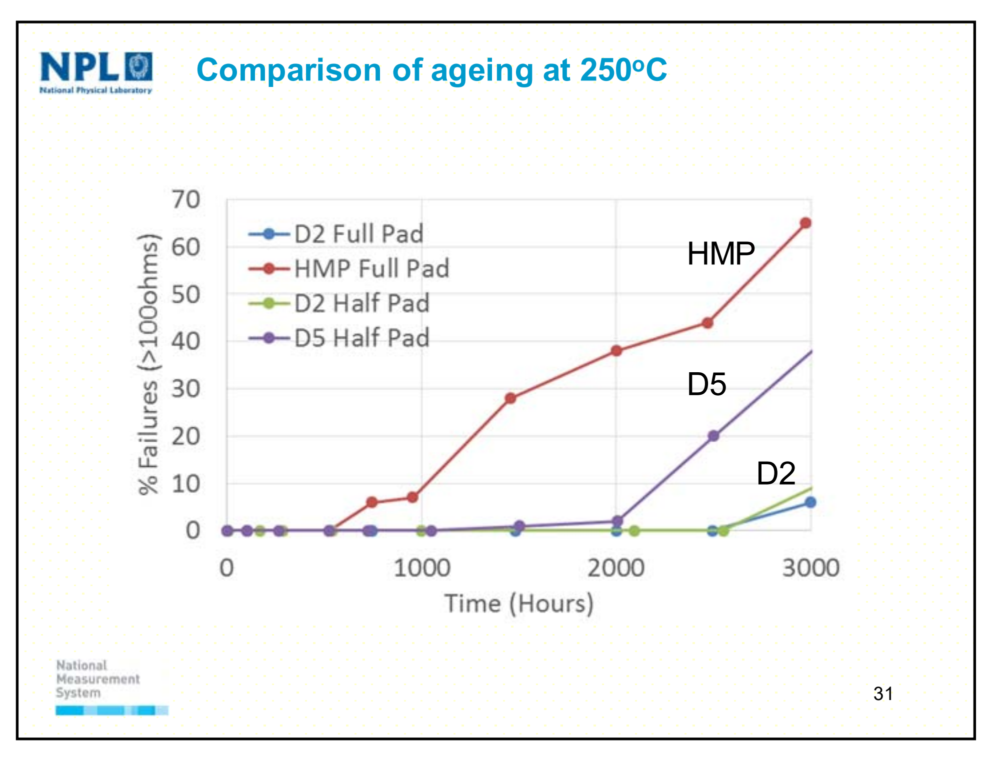
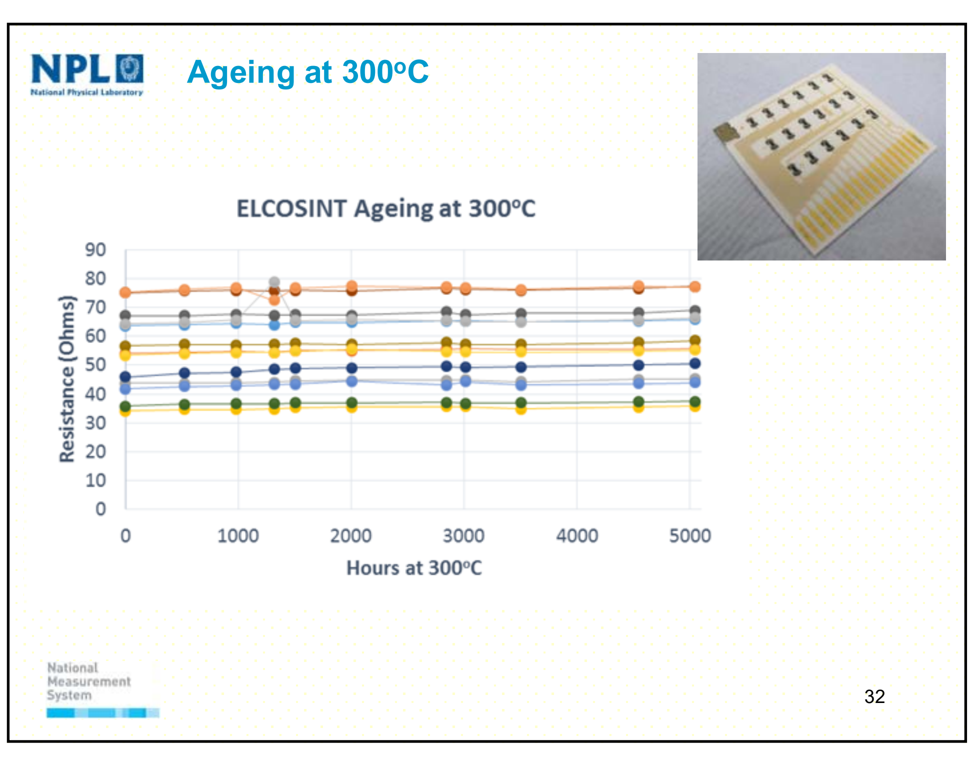
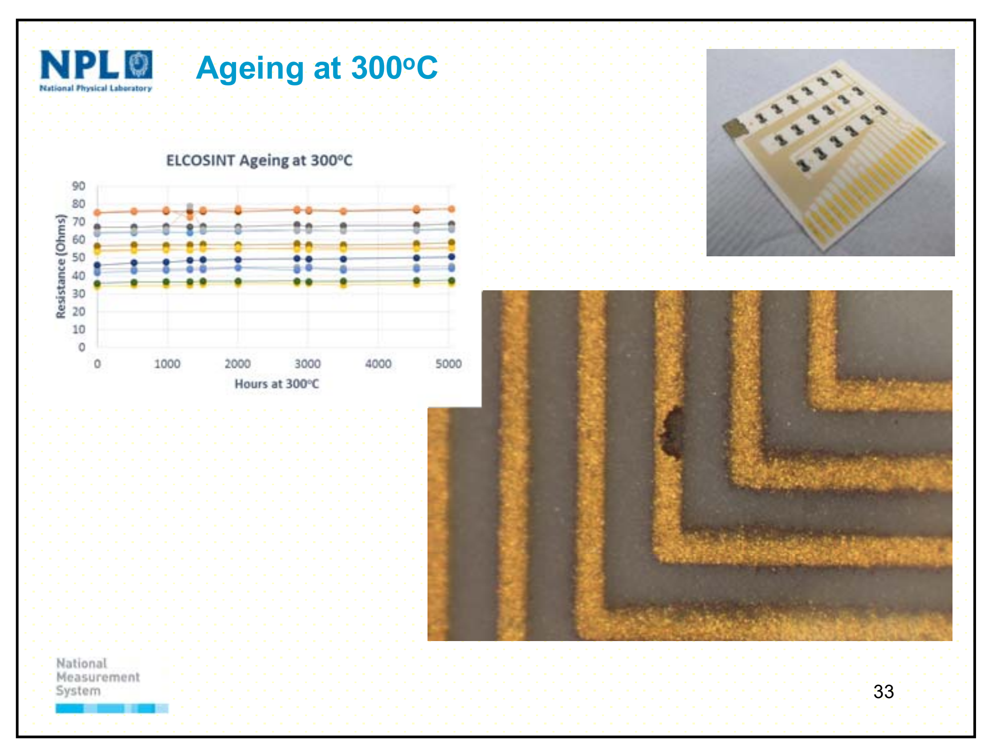
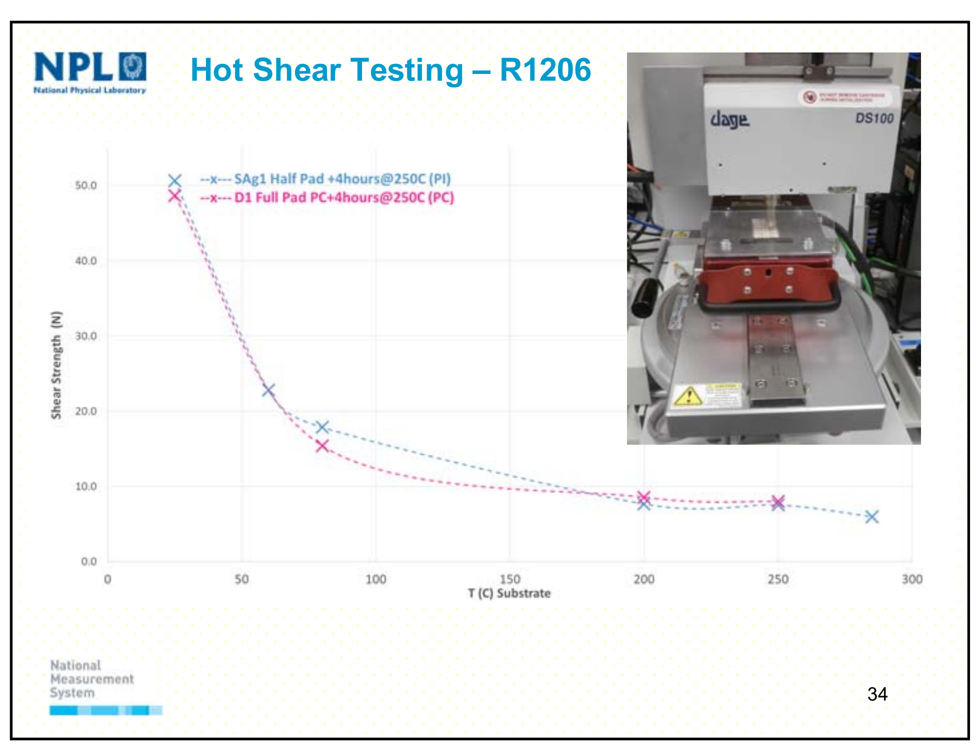
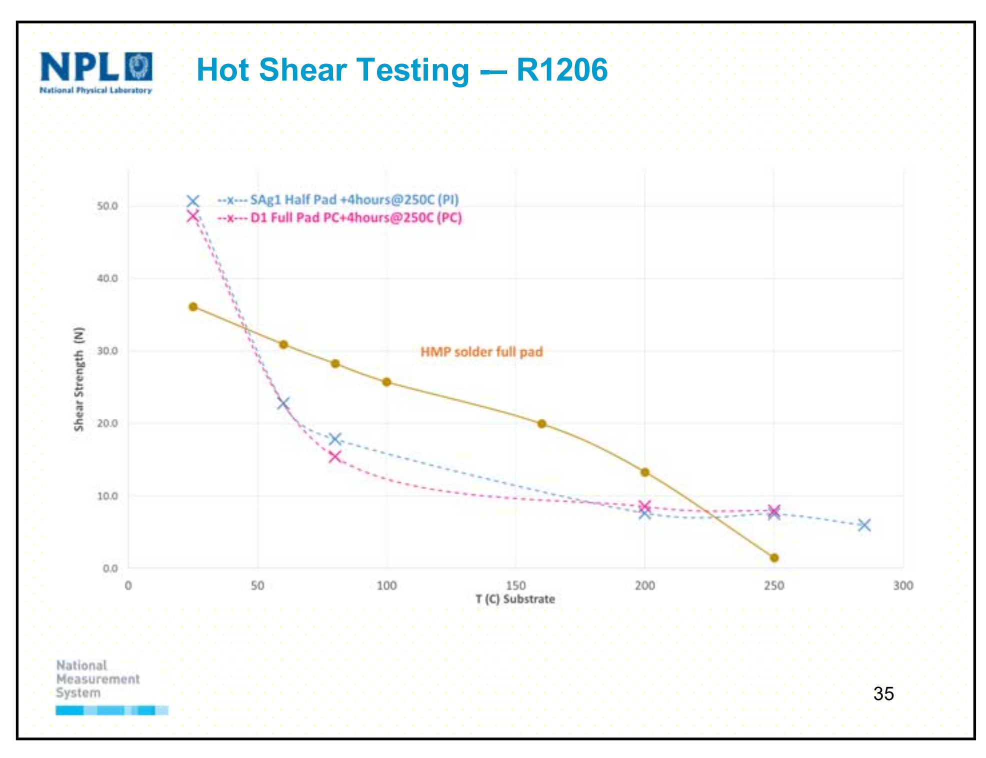
Advantages of forming interconnect at or below operating temp
Earlier track failures for HMP than for ELCOSINT samples
Under investigation but hypothesis is that increased temperatures of HMP reflow (peak ~ 325°C) have caused extra degradation of PCB
National Measurement System
30

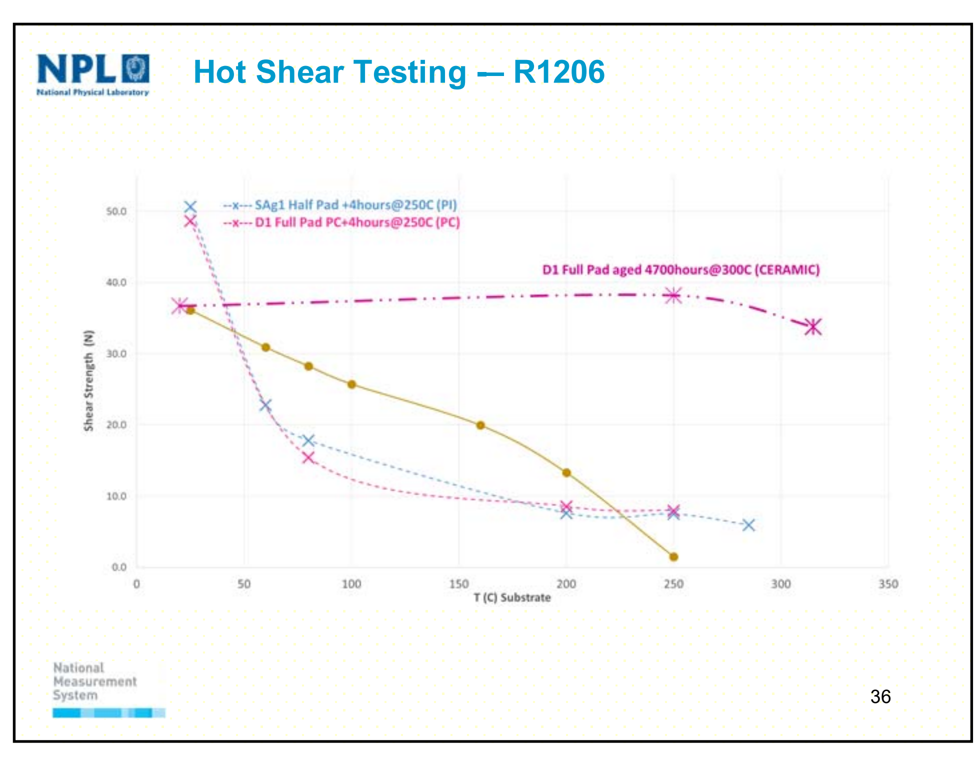

NPL National Physical Laboratory
Comparison of ageing at 250°C
% Failures (>100ohms)
70
60
50
40
30
20
10
0
D2 Full Pad
HMP Full Pad
D2 Half Pad
D5 Half Pad
HMP
D5
D2
0
1000
2000
3000
Time (Hours)
National Measurement System
31

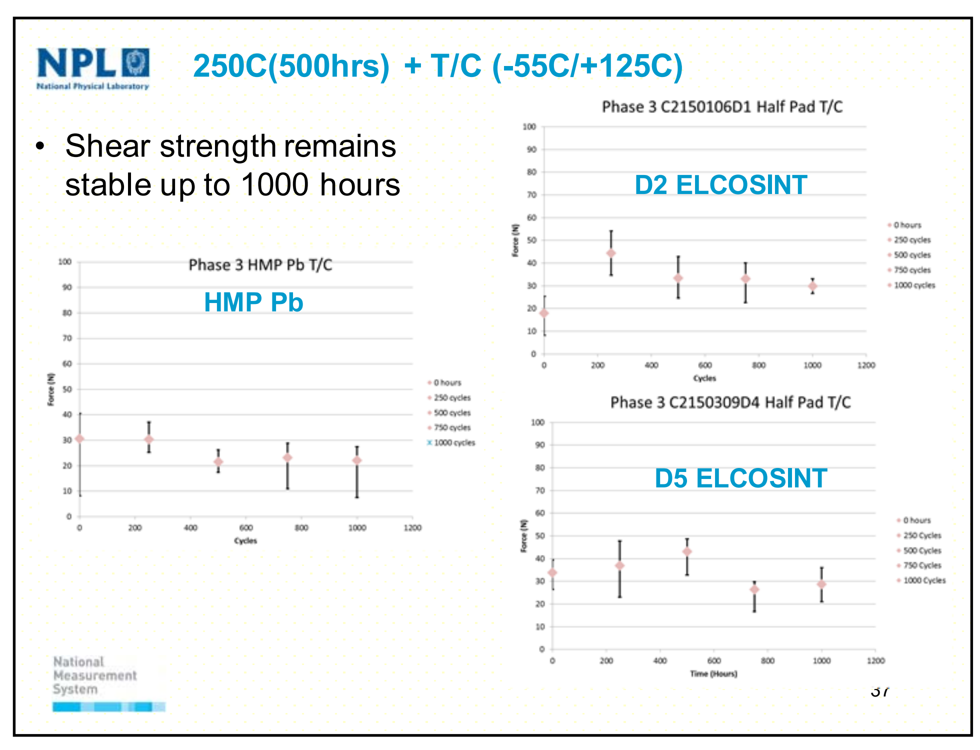

NPL National Physical Laboratory
Ageing at 300°C
ELCOSINT Ageing at 300°C
Resistance (Ohms)
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
Hours at 300°C
National Measurement System
32

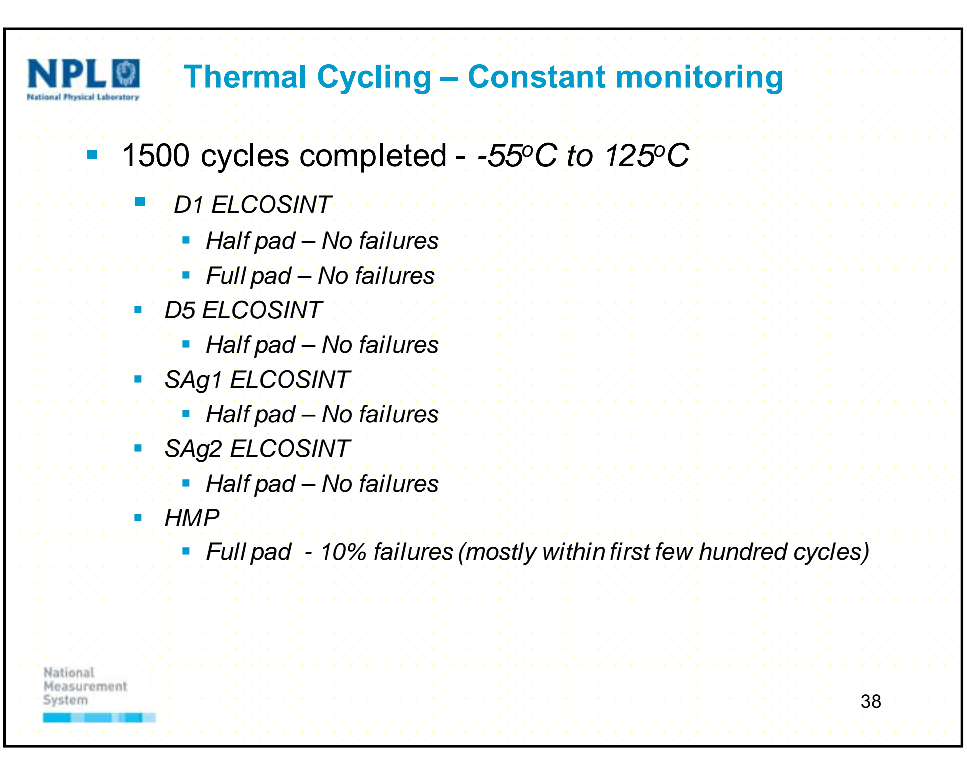

NPL
National Physical Laboratory
Ageing at 300°C
ELCOSINT Ageing at 300°C
Resistance (Ohms)
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
Hours at 300°C
National Measurement System
33


NPL
National Physical Laboratory
Hot Shear Testing – R1206
--x--- SAg1 Half Pad +4hours@250C (PI)
--x--- D1 Full Pad PC+4hours@250C (PC)
Shear Strength (N)
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
T (C) Substrate
dage
DS100
National Measurement System
34


NPL
National Physical Laboratory
Hot Shear Testing — R1206
--x--- SAg1 Half Pad +4hours@250C (PI)
--x--- D1 Full Pad PC+4hours@250C (PC)
HMP solder full pad
Shear Strength (N)
T (C) Substrate
National Measurement System
35


NPL
National Physical Laboratory
Hot Shear Testing — R1206
--x--- SAg1 Half Pad +4hours@250C (PI)
--x--- D1 Full Pad PC+4hours@250C (PC)
D1 Full Pad aged 4700hours@300C (CERAMIC)
Shear Strength (N)
T (C) Substrate
National Measurement System
36


NPL National Physical Laboratory
250C(500hrs) + T/C (-55C/+125C)
• Shear strength remains stable up to 1000 hours
Phase 3 C2150106D1 Half Pad T/C
D2 ELCOSINT
Force (N)
Cycles
0 hours
250 cycles
500 cycles
750 cycles
1000 cycles
Phase 3 HMP Pb T/C
HMP Pb
Phase 3 C2150309D4 Half Pad T/C
D5 ELCOSINT
Time (Hours)
National Measurement System
37


NPL National Physical Laboratory
Thermal Cycling – Constant monitoring
1500 cycles completed - -55°C to 125°C
D1 ELCOSINT
Half pad – No failures
Full pad – No failures
D5 ELCOSINT
Half pad – No failures
SAg1 ELCOSINT
Half pad – No failures
SAg2 ELCOSINT
Half pad – No failures
HMP
Full pad - 10% failures (mostly within first few hundred cycles)
National Measurement System
38

ELCOSINT/HMP Summary

- High temperature isotropic conductive adhesives perform well in comparison to HMP solder
- Built test vehicles and subjected them to extended ageing with electrical test and shear force measurements
  - 5000 hours at 85°C/85%RH
  - 3000 hours at 250°C
  - 5000 hours at 300°C
  - 500 hours at 250°C + 1500 thermal cycles, -55 to +125°C
- ELCOSINT materials have out performed best in class PCB materials aged at 250°C
- ELCOSINT materials have maintained electrical continuity on ceramic substrates after 5000 hours at 300°C
- Early results from inter-comparison with HMP solder show that reduced ELCOSINT assembly process has reduced manufacturing stress on substrates

39

Going Forward

- ELCOSINT and HMP comparative conditioning continuing
  - Failure analysis etc.
- ELCOSINT materials used by partners in follow-on projects
  - To develop HT processing lines at Microsemi and protective coatings – Tamessa
  - To develop HT substrates – OrCA
- Pressure-less sintered Ag component attachment
- Three year funded programme in HT electronics interconnect lifetime prediction measurement at NPL
  - Pb-free alternatives are maturing rapidly
  - Next revaluation of RoHS exemption is 2020 (?)
  - NPL organising a collaborative inter-comparison of maturing materials
  - *HMP solder, Sintered Ag, Transient Liquid Phase, High Temp ICAs, Coatings*

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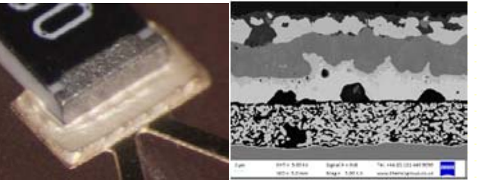
High Temperature Interconnect Studio Project

- Pb-free high temperature alternatives are maturing rapidly
- Next revaluation of RoHS exemption is 2020 (?)
- NPL to organise a multi-company evaluation of maturing materials (Estimated £8.5K contribution)
  - Available materials
  - Component and substrate capability
  - Processing parameters
  - Assembly of test vehicles
  - Reliability test vehicles
  - Testing regimes
  - Please request an invite martin.wickham@npl.co.uk

Matched funding from NMS

- *HMP solder*
- *Sintered Ag*
- *Transient Liquid Phase*
- *High Temp ICAs*
- *Coatings*



National Measurement System

Electronics Interconnection Group

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All at GEM and Microsemi

National Measurement System

NPL National Physical Laboratory
EI Group Research
Interconnect Reliability
MWCNT Interconnect
SIR and condensation testing
Printed electronics
Conformal Coatings
CAF
WEEE
Thank you for listening
Any questions?
Wearables
PCB Delamination
High Temp. Interconnects
Tin Whiskers
PCB Reliability
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NPL
NPL 2017 FREE Webinars
To book your place go to www.npl.co.uk/ei
Characterisation of High Temperature Component Interconnect Materials
Tuesday 10th January Martin Wickham – National Physical Laboratory
Techniques for the Characterisation of Printed Electrodes & Sensor Materials
Tuesday 14 March Martin Wickham
UV Inspection and Thickness Measurement of Conformal Coatings
Tuesday 9 May Vimal Gopee
Electrical Performance of Organic Substrate Materials and Coatings Aged at High Temperature
Tuesday 11th July Dr Adam Lewis, Christine Thorogood & Martin Wickham
Electrical Metrology for Flexible & Printed Electronics
Tuesday 12 September Dr Adam P. Lewis
Condensation Failure & Improved Testing for Electronic Assemblies
Tuesday 14 November Ling Zou