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Electrical Performance of Organic Substrate Materials and Coatings Aged at High Temperature

Adam Lewis, Christine Thorogood and Martin Wickham

11/07/17

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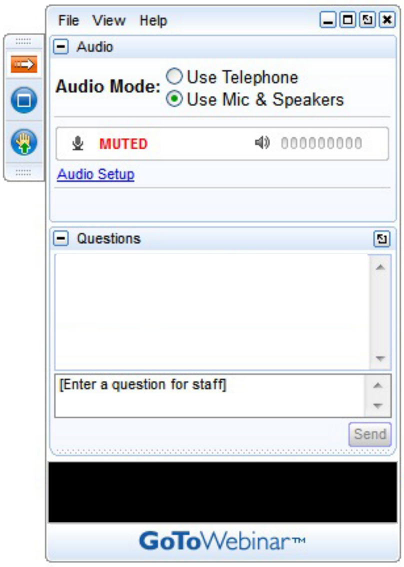

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Outline

- Introduction to NPL
- Current Research Projects
- Motivation and Challenges for High Temperature Substrates
- Overview of Experiments
- Results and Discussion
- Conclusions and Ongoing Work
- Questions

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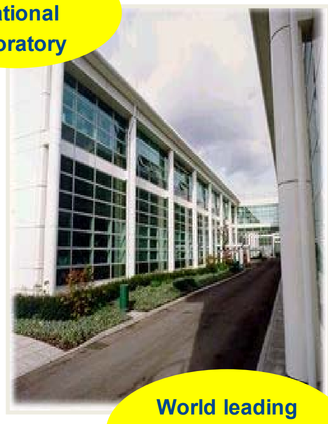
Introduction to NPL

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**



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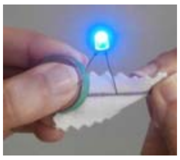
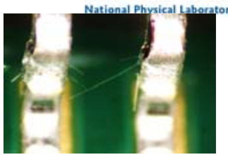
Current Research Areas

Wearables

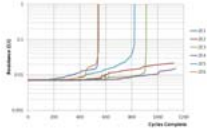


Tin Whiskers Mitigation

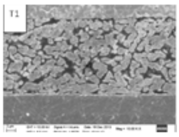


Printed Electronics

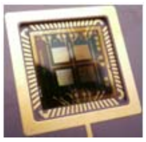
Prognostics/ Testing/ Prediction



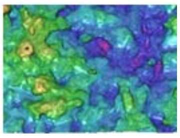
High Temp. Interconnect



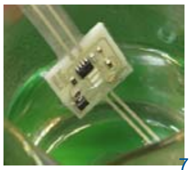
Coatings/SIR/ Condensation Testing



Printed Sensors



Electronics Recycling



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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.

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Issues in operating at higher temperatures

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- 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*

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Tamessa Project

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- Development of protective coatings to improve performance of organic PCBs at high temperatures
- Inhibiting copper track oxidation
- Potential for high temperature solder resist applications
- Based on silicone resin systems
- Initial trials using immersion coatings

Microsemi | GWENT GROUP | Innovate UK Technology Strategy Board

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Pros and Cons of using Organic PCBs for High Temperature Applications

- Utilising conventional PCB substrates (rather than ceramic or insulated metal substrates) at higher temperatures results in a range of benefits and challenges.
- Benefits:
  - Lower cost
  - Number of suppliers
  - Familiarity with technology
  - Opportunity to utilise existing SM production facilities
- Challenges:
  - Obvious issues with using 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

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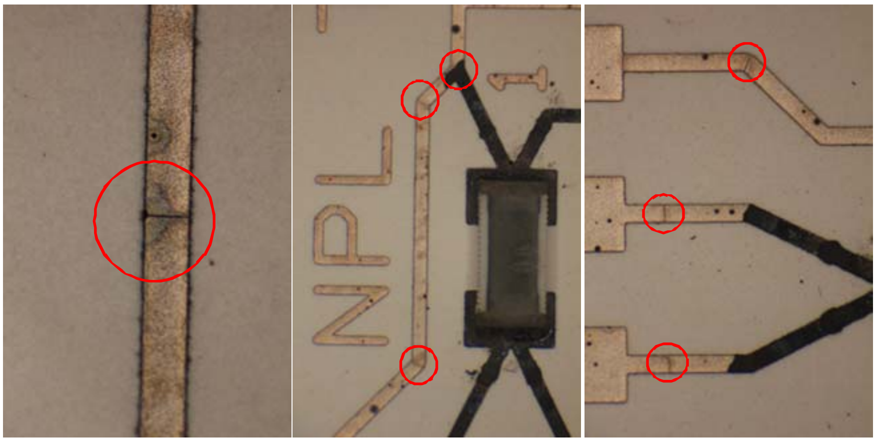
Ageing at 250 ˚C - Cu failures



- Copper oxidising becoming brittle and cracking resulting in open circuits i.e. copper failing before substrate

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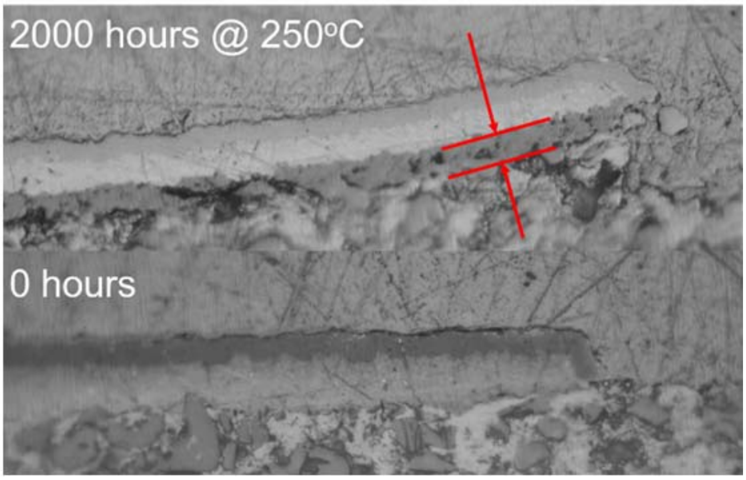
Oxide Growth



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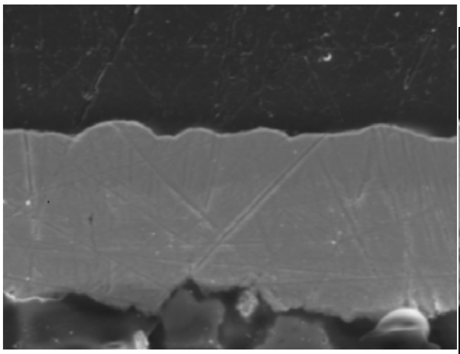
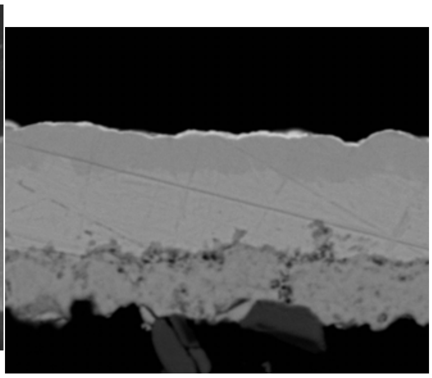
Oxide growth – ENIPIG

As-received



3000hrs @ 250C



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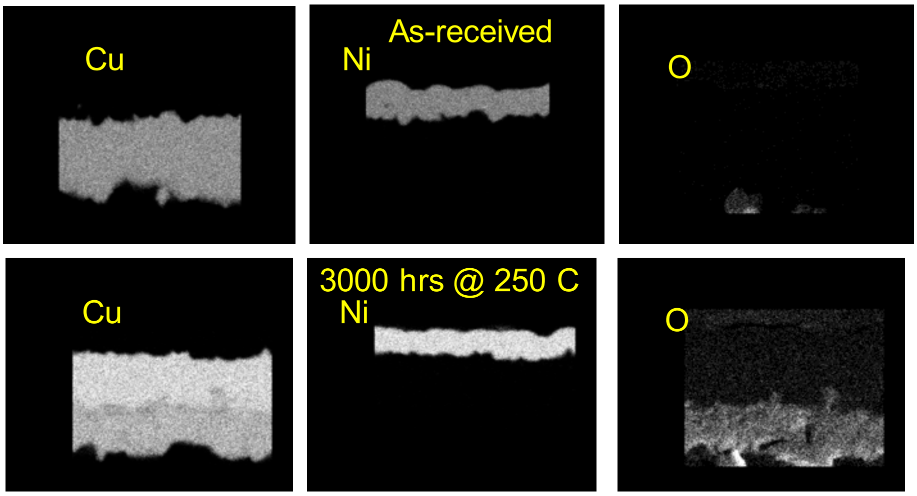
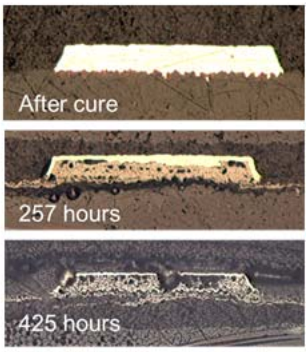
Oxide growth – ENIPIG EDAX scans



Improved High Temperature PCB Performance. Ageing at 250 °C - Tamessa

PI No coating



Improved High Temperature PCB Performance. Ageing at 250 °C - Tamessa

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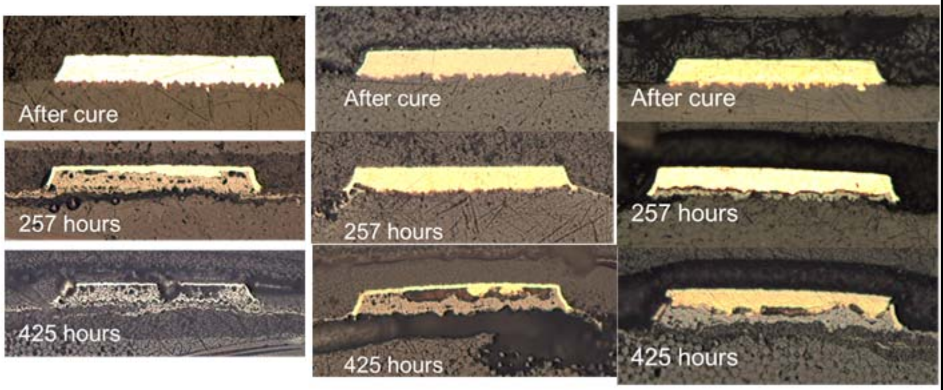
PI No coating | PI Coating A | PI Coating B



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Experimental Setup

Christine Thorogood

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Experimental Plan and Measurements

- Variables:
  - Substrate A: Tamessa PCB Material
  - Substrate B: Polyimide Material
  - Coated/Uncoated
- The capacitance was measured with an LCR meter
- SIR was measured with a source meter
  - *Wires were connected to the boards in the oven from outside to enable measurements to be made in-situ at 250 °C*

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SIR Measurements

- Surface Insulation Resistance
  - Interdigitated comb pattern
  - Resistance measured between fingers across surface of substrate using source meter

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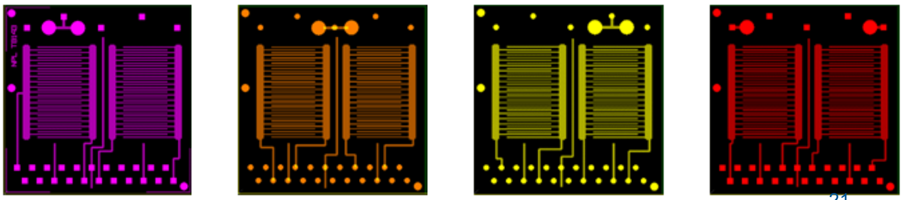
Test Boards

- Each board has two interdigitated patterns repeated on four layers
- Capacitance and SIR can be measured between following points:
  1. **Surface 1:** Interdigitated pattern on layer 1
  2. **Surface 2:** Interdigitated pattern on layer 2
  3. **Surface 3:** Interdigitated pattern on layer 3 [should be same 2]
  4. **Surface 4:** Interdigitated pattern on layer 4 [should be same as 1]
  5. **Gap A:** Between interdigitated pattern on layer 1 and layer 2
  6. **Gap B:** Between interdigitated pattern on layer 2 and layer 3 [bigger gap]
  7. **Gap C:** Between interdigitated pattern on layer 3 and layer 4 [should be same as (5)]

TB143: 4 layers of interdigitated patterns

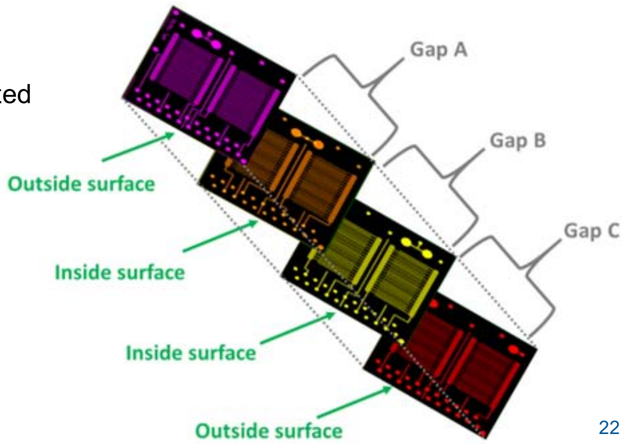


Layer 1 Layer 2 Layer 3 Layer 4

Experimental Setup

Two Substrate Materials
- Substrate A: Tamessa PCB Material
- Substrate B: Polyimide Material

One Coating
- Uncoated, Coated



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Results

Adam Lewis

Results

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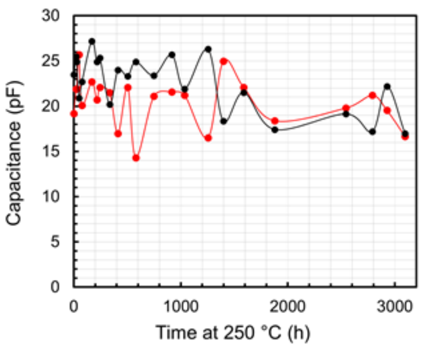
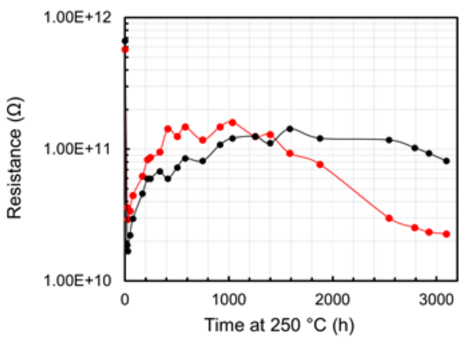
Uncoated: Red
Coated: Black

- Substrate A: Tamessa PCB Material | **Outside surfaces**





- Decrease in resistance for the uncoated samples (after 2000 h) suggests either the conductivity or geometry of the material has changed. The stability of the capacitance measurement for the same electrodes may suggest that the electrode geometry and relative permittivity are unchanged. Therefore the resistivity is likely to have decreased for uncoated substrates.

Results

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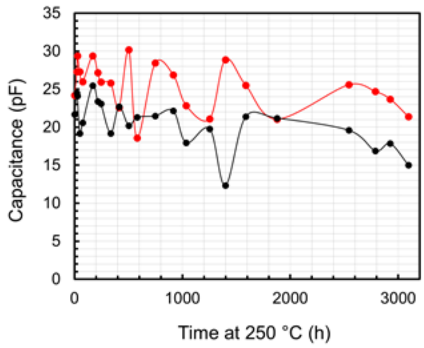
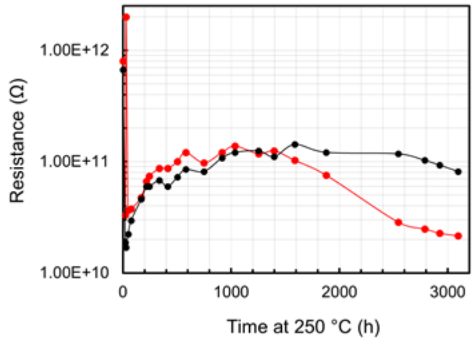
Uncoated: **Red**
Coated: **Black**

- Substrate A: Tamessa PCB Material | **Inside surfaces**





- Similar trend to Substrate A outside surfaces. High Resistance maintained for ~2000 h after which it starts to drop. Capacitance remains mostly constant.

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Results

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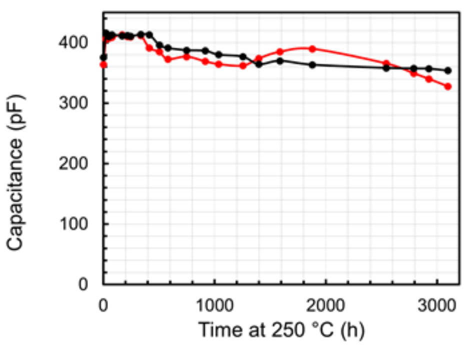
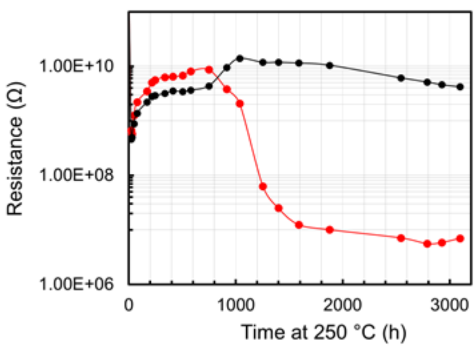
Uncoated: **Red**
Coated: **Black**

- Substrate A: Tamessa PCB Material | **Gap A/C**





- Slight decrease in capacitance over time. Large decrease in resistance after 1000 h for uncoated boards. Coated boards retained high resistance.

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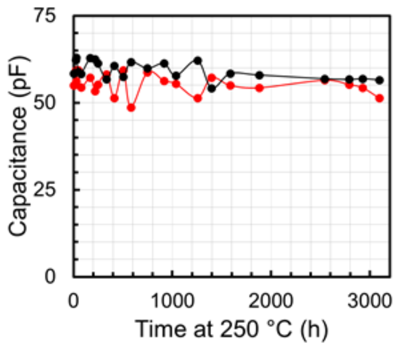
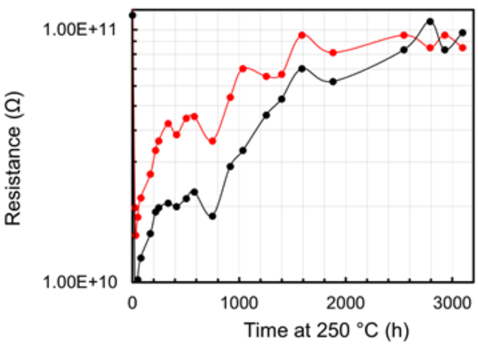
Results

Uncoated: Red
Coated: Black

- Substrate A: Tamessa PCB Material | **Gap B**





- Stable capacitance and gradual increase in resistance across Gap B (middle of substrate) for both coated and uncoated substrates.

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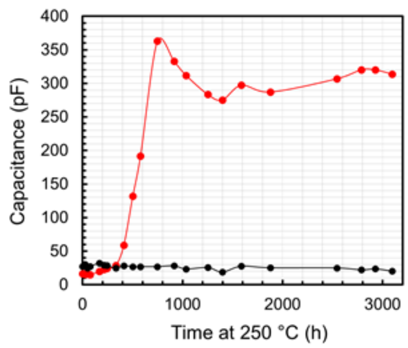
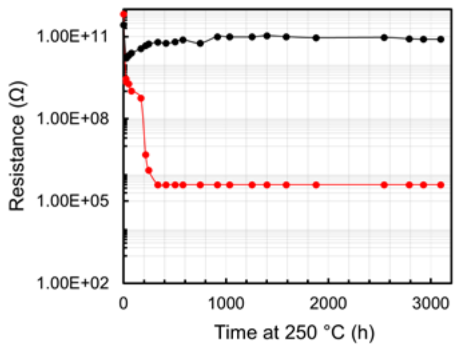
Results

Uncoated: Red
Coated: Black

- Substrate B: Polyimide Material | **Outside surfaces**





- Coated Substrate B boards showed improved lifetime compared with uncoated boards when looking at outside surfaces. Resistance of uncoated board drops to low resistance after ~200 h.

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Results

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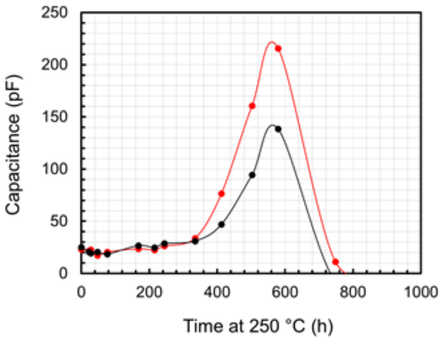
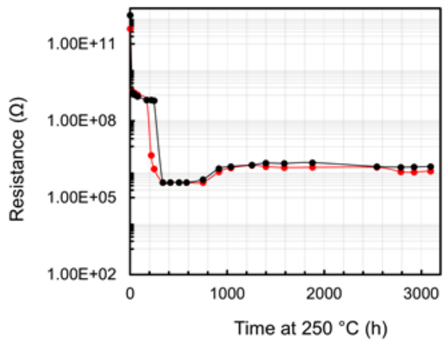
Uncoated: Red
Coated: Black

- Substrate B: Polyimide Material | **Inside surfaces**





- For the inside surfaces measurement (i.e. interdigitated finger pattern inside the board) there did not appear to by any significant difference between the coated/uncoated performance. Resistance of both boards decreased after ~200 h. The capacitance steadily roses from 200 h to 600 h and then became unreadable.

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Results

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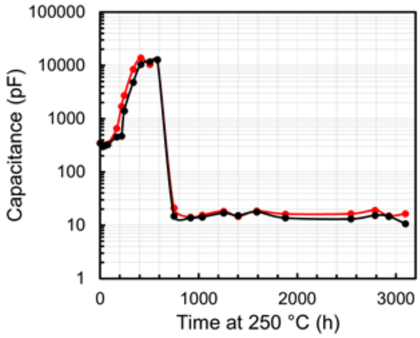
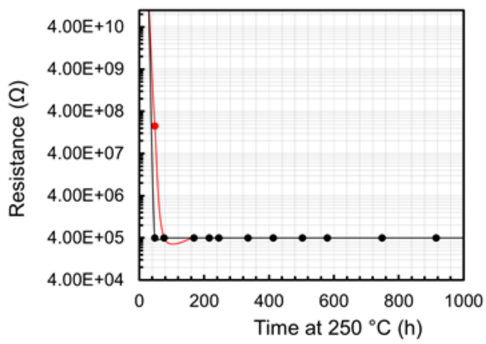
Uncoated: Red
Coated: Black

- Substrate B: Polyimide Material | **Gap A/C**





- Capacitance rises sharply before plummeting at ~600 h. Resistance drops almost within 100 h.

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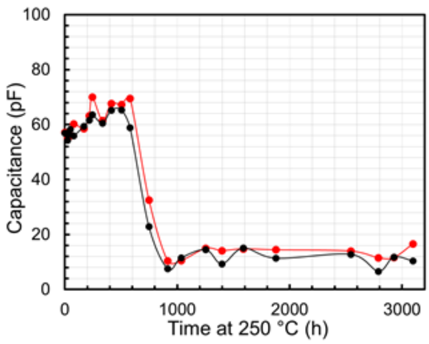
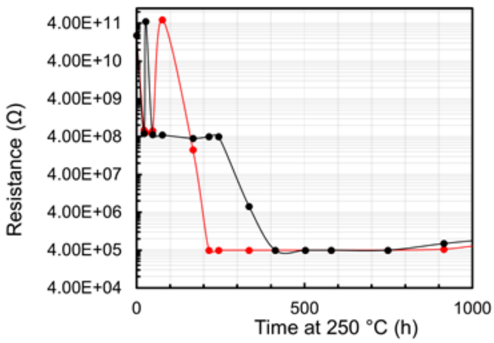
Results

Uncoated: Red
Coated: Black

- Substrate B: Polyimide Material | **Gap B**





- Similar trends to previous slide (Gap A/C) may suggest that the Substrate B material degrades within ~200 h or that the inner electrodes degrade within 600 h.

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Optical Analysis of Cross-Sections and µ-FTIR

Christine Thorogood

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Experimental Setup

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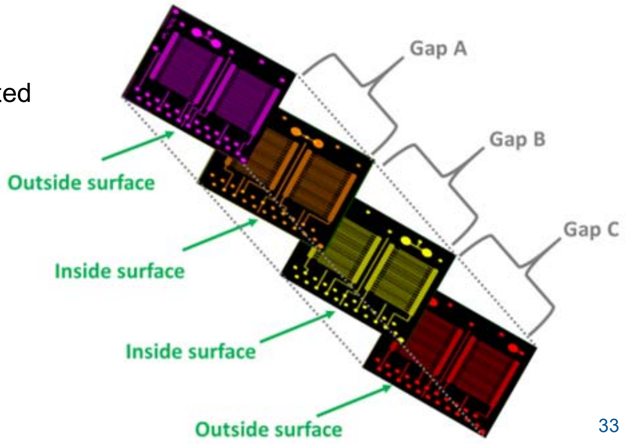
Two Substrate Materials

- Substrate A: Tamessa PCB Material
- Substrate B: Polyimide Material

One Coating

- Uncoated, Coated



4 tests

- A uncoated
- A coated
- B uncoated
- B coated

Change in capacitance for A and B

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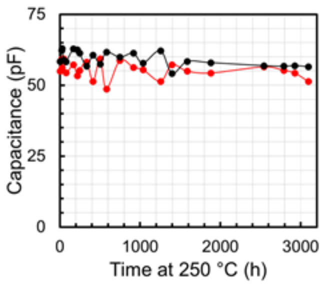
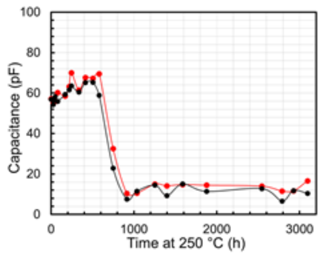
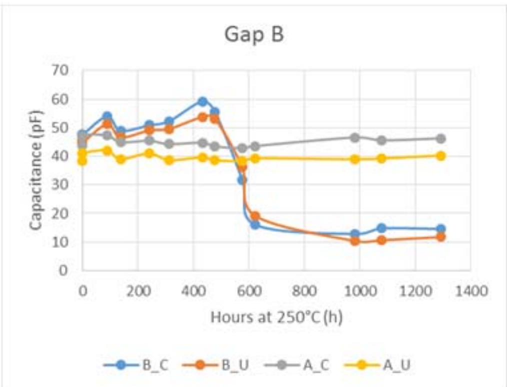
Substrate A



Substrate B





- Repeatable results
- Substrate A is stable
- Substrate B drop after 500 hours

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

A- Uncoated

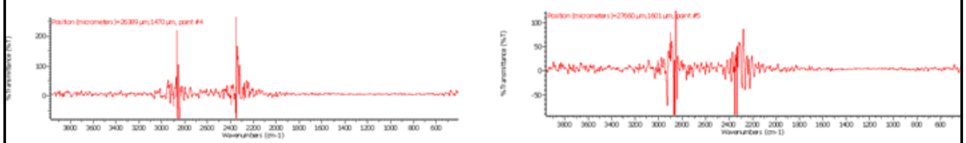
0 hrs | 250 hrs | 500 hrs

B- Uncoated

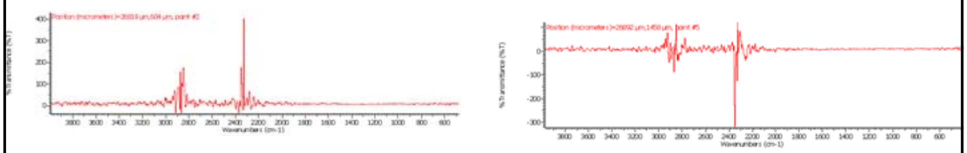
µ-FTIR for A and B

A- Uncoated | B- Uncoated

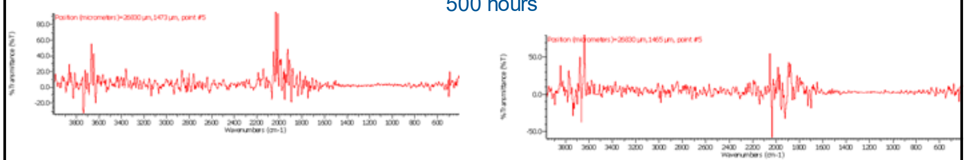
0 hours



250 hours



500 hours



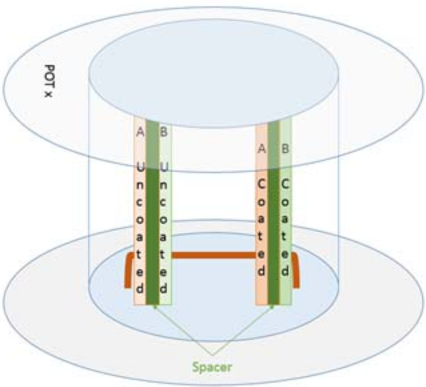
µ-FTIR

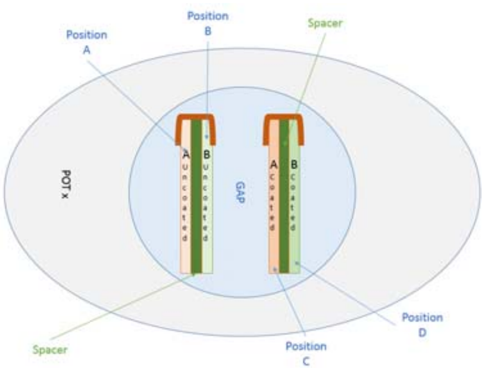
- New capability
- Transmittance and reflectance spectra
- Identifies functional groups

- Used to determine changes in the epoxy systems of the substrates during ageing

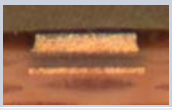
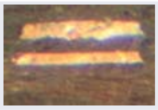
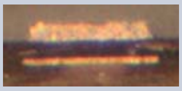
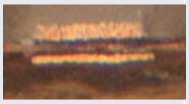
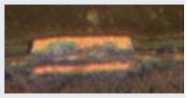
Potting

- Sectioned samples
- µ-FTIR of surface area
- Potted in low temperature curing resin
- Cross sections images and µ-FTIR to be done

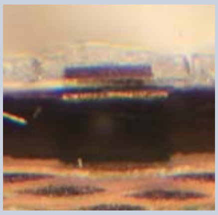
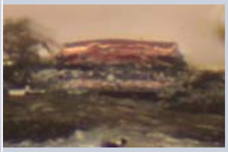
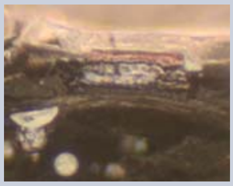
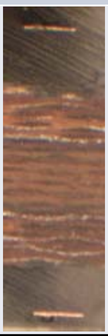
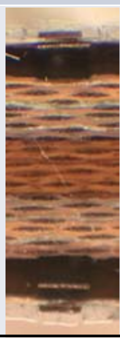
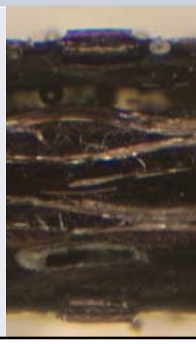
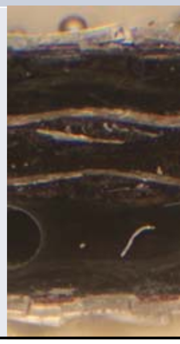




Long Term Ageing: Tamessa PCB Material

Aged at 250 °C	A - Uncoated	A - Coated	B – Uncoated	B - Coated
0 hours				
100 hours				
250 hours				
500 hours				
1000 hours				

3000 hours

A - Uncoated	A - Coated	B – Uncoated	B - Coated
			
			

Conclusions and On-going Work

Adam Lewis

Conclusions and Ongoing Work

- Substrate A: Tamessa PCB Material
  - Material performed much better than polyimide substrate
  - Coating clearly improved reliability enabling testing over 3000 h
- Substrate B: Polyimide Material
  - Coating did not appear to give any significant improvement in lifetime except between fingers on outside surface
- Ongoing work: using µ-FTIR to analyse change in chemical composition of substrate materials and coatings as samples age

Thank you for listening!
Any questions?

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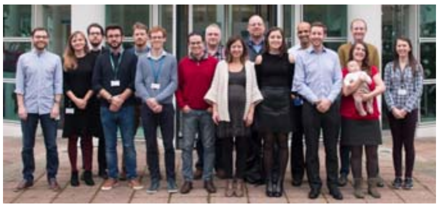

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