National Physical Laboratory

Reliability testing of wearables

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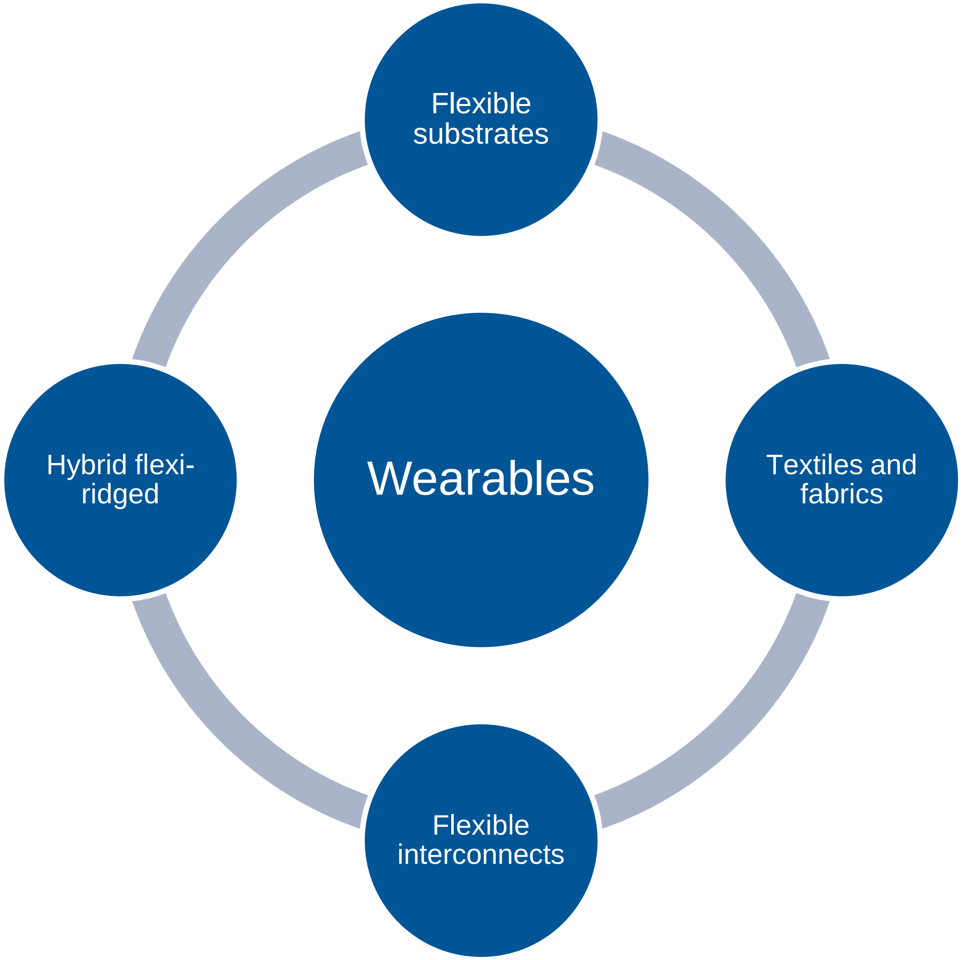
30/11/17

Outline

- What do we mean by ‘wearables’?
- Material sets
- Harsh environments
- Failure modes
- Test methods and standards
- Protection

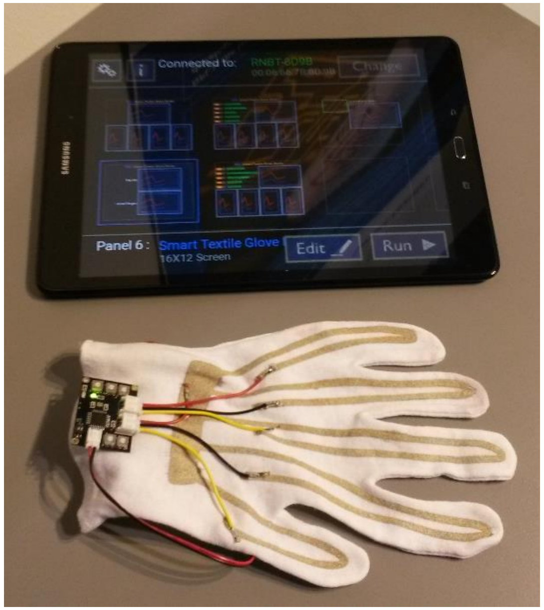
What do we mean by ‘wearables’?

- Merging of textiles and electronics
  - This could include implantable devices
- Not a conventional PCB made into a discrete wearable device, e.g. external heartrate monitor, fitness watch
  - These can be tested using conventional test methods



Wearable electronics

- Fully printed electronics
  - Very limited functionality
  - Smart labels/greeting cards
- Hybrid electronics
  - Conventional packages, ICA, printed tracking
  - Tactile feedback monitoring – sensor (printed? Or discrete+ ICA) – interconnection (printed/woven strand) – data processing/communication (PCB + ICA)



Low temperature interconnection materials sets

- Substrates

  PET , PEN, Textiles (woven, printed) …

- Adhesives (epoxy, acrylics)

  mostly silver based

- Some solders

  Low temp (SnBismth)

- Printed active devices (not typically moisture tolerant)

Harsh environments for wearables

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- Temperature

  Often high temperatures are used as an acceleration factor for conventional electronics – generally not suitable for wearables due to low melting points etc.

- Humidity/moisture
- Chemical (sweat, detergent, shampoo …)
- Mechanical (stretch, bend, flex, …)

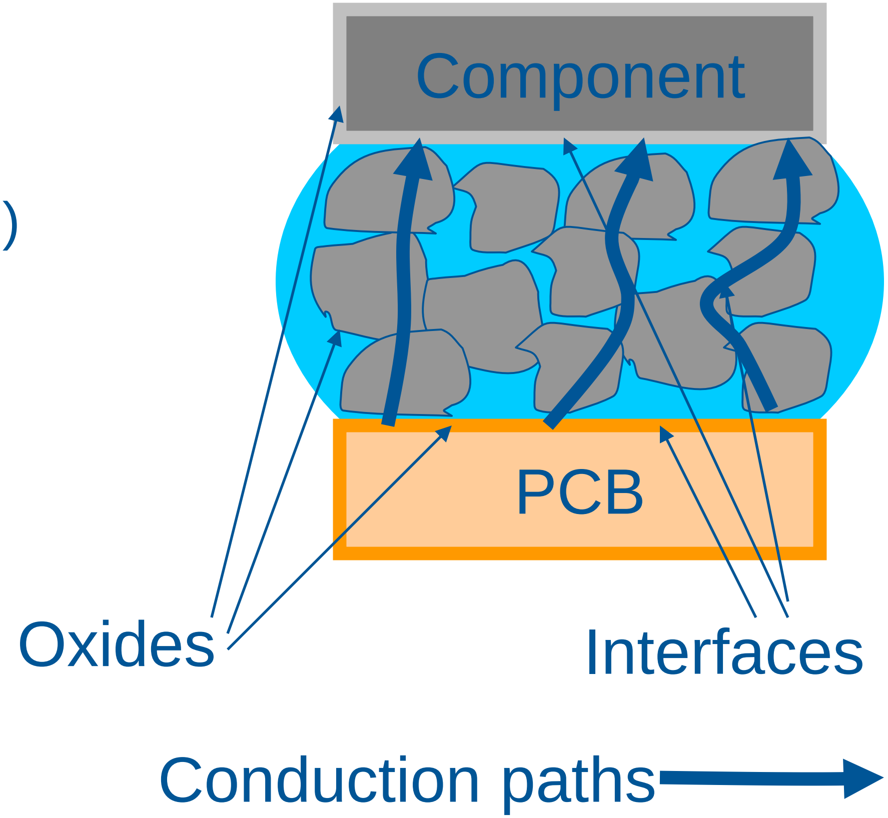
Typical daily usage. Washing machine.

A combination of chemical contamination + moisture + bias voltage will lead to electrochemical failures → protective coatings

FAILURE MODES

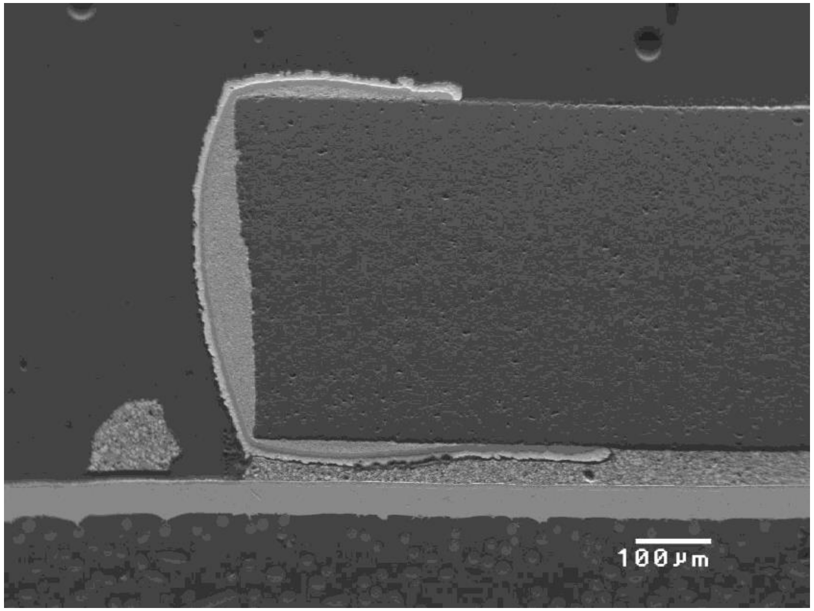
Failure modes: conductive adhesive/tracking failure

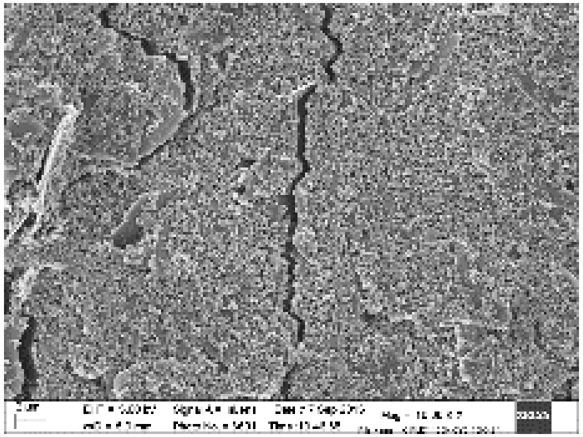
- Increase in Ω of interconnect
  - Conductive particle oxidation
    - Ag oxides conducting
  - Polymer matrix swelling (moisture)
    - Breaking contact of conductive particles
  - Bond-line failure
    - Resin to filler adhesion failure
    - Polymer relaxation (above Tg)



Failure modes: conductive adhesive/tracking failure

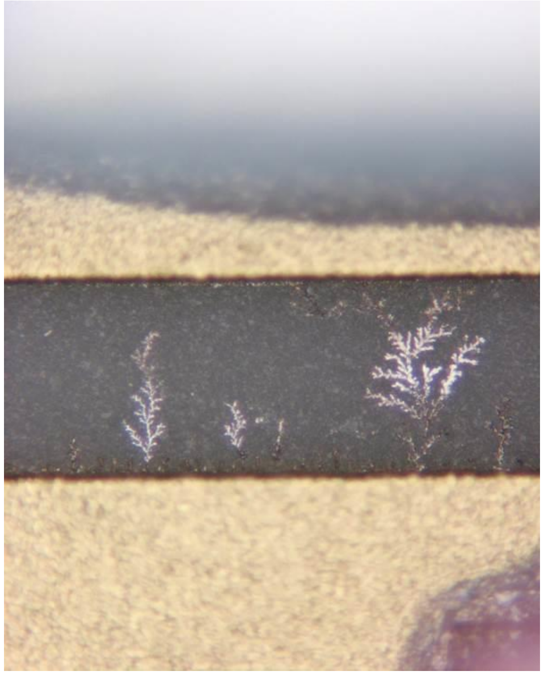
- Reduction in mechanical strength
  - adhesive/component interface adhesion
  - adhesive/substrate interface adhesion
  - bulk material failure
- Component or substrate interconnect failure
  - Fracture or delamination





Failure modes: metal migration

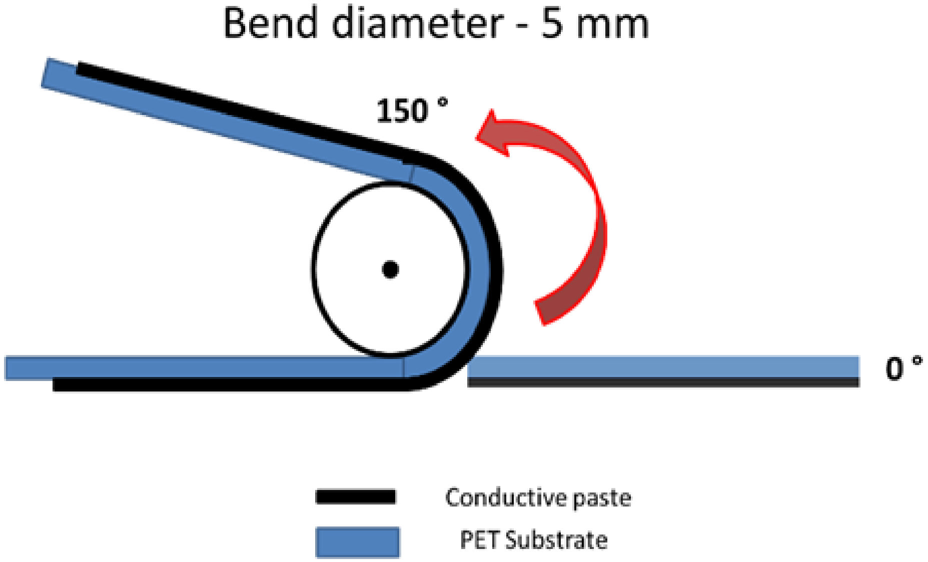
- Dendritic growth from metals (typically silver) under bias and in the presence of moisture, causing low surface insulation resistance
  - Metal fillers are encapsulated in resin and thus not in direct contact with moisture
  - NPL has encountered issues with surface insulation resistance testing of Ag tracking materials
  - Lifetime improved by printing dielectric over the top

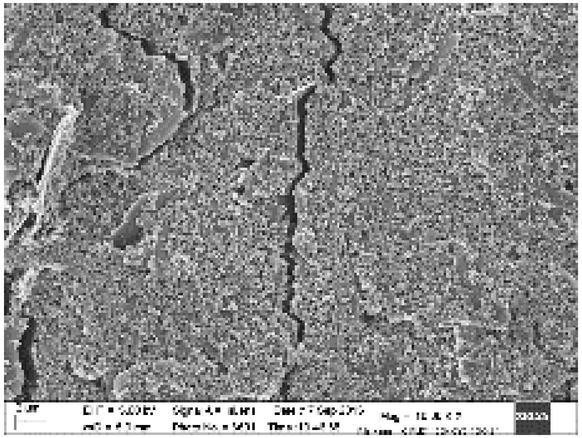


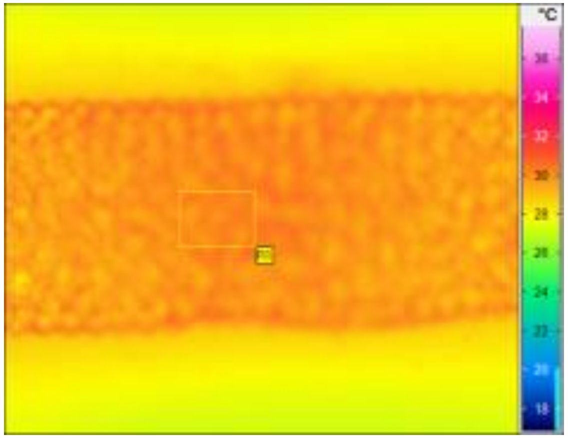
http://nepp.nasa.gov/whisker./dendrite/Ag_dendrite-02.jpg

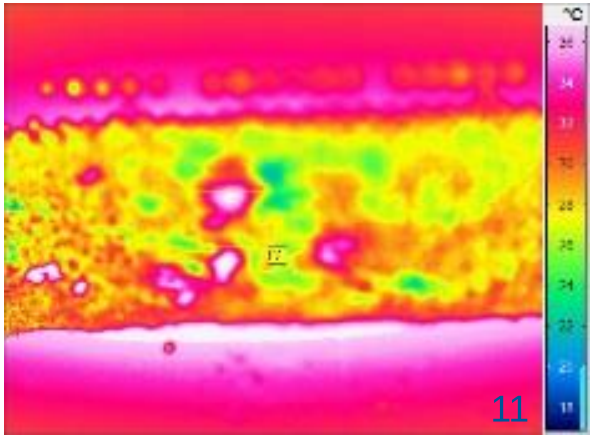
Failure modes: cracking due to bending

- Stress caused by bending can cause cracks to from across tracks:
  - increased resistance
  - open circuits.





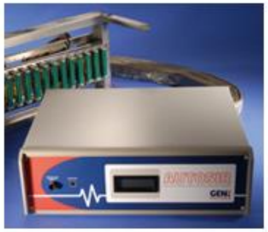




TEST METHODS

Test methods for wearables

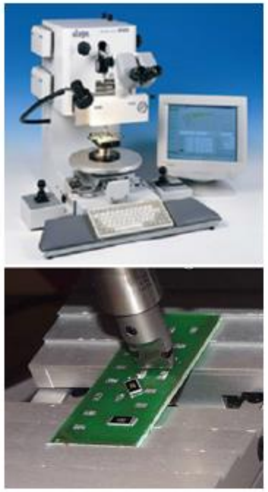
- Peel test
- Shear test
- Flex testing
- Stretch rig
- Pneumatic adhesion tester
- Washing machine trials



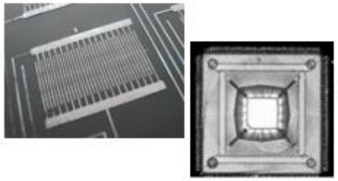
Surface Insulation Resistance

FTIR Spectroscopy

Damp Heat
40 °C/93%RH
85 °C/85%RH

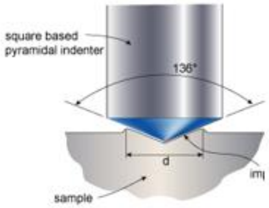


Shear Strength



Scanning Acoustic Microscope

Hardness Indentation



Dielectric Strength Test Meter

Thermal Shock
-55 to +150 °C

Dry Heat
250 °C

Standards

IPC-9204: Guideline on Flexibility and Stretchability Testing for Printed Electronics
IEC TC 119 – Printed Electronics
IEC TC 124 – Wearable Electronics Devices and Technologies

Accelerated ageing regimes

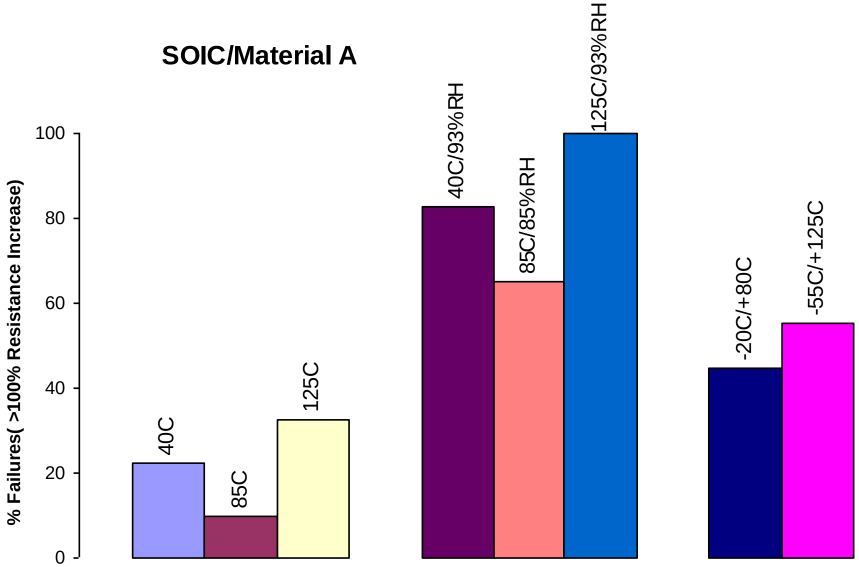
- Damp heat ageing

  Causes joint resistance rises due to oxidation of PCB, component and conductive particle surfaces

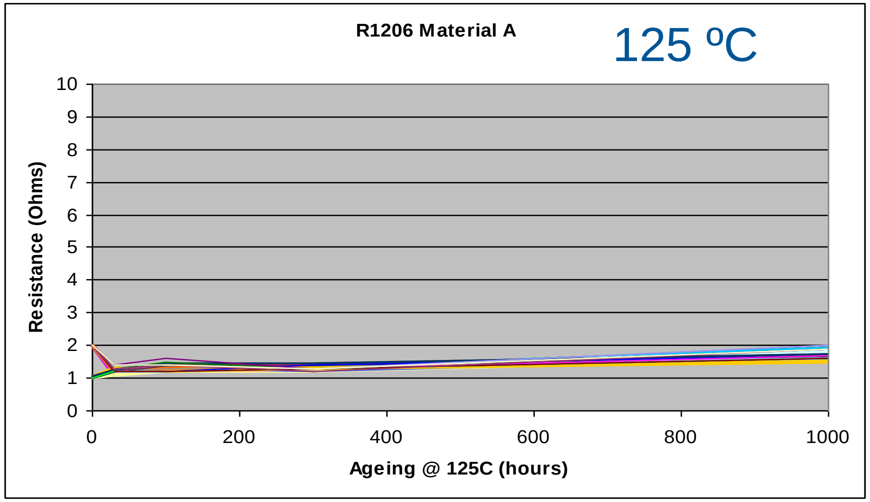
  Bond-line failures due to loss of adhesion.

- Thermal cycling

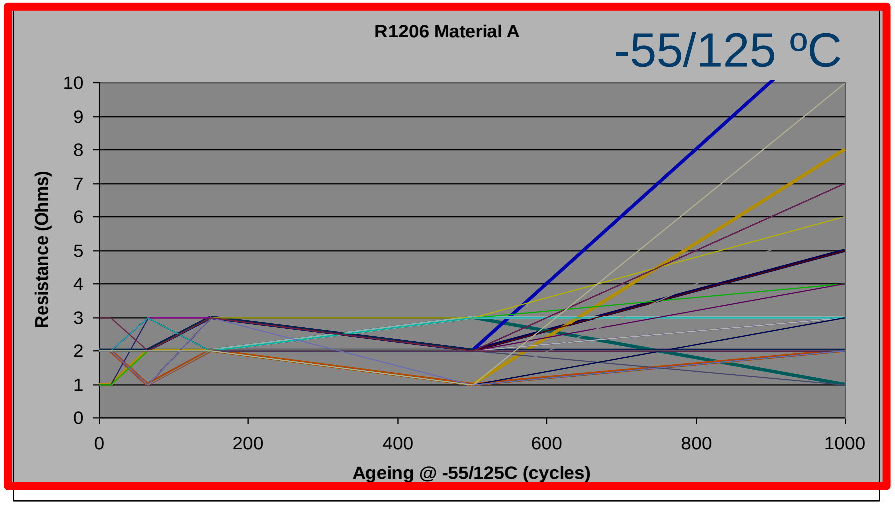
  For low TCE components, during thermal cycling, the mismatch to PCB causes strain in joints, resulting in crack initiation usually along joint interfaces, causing joint resistance increases and failure.



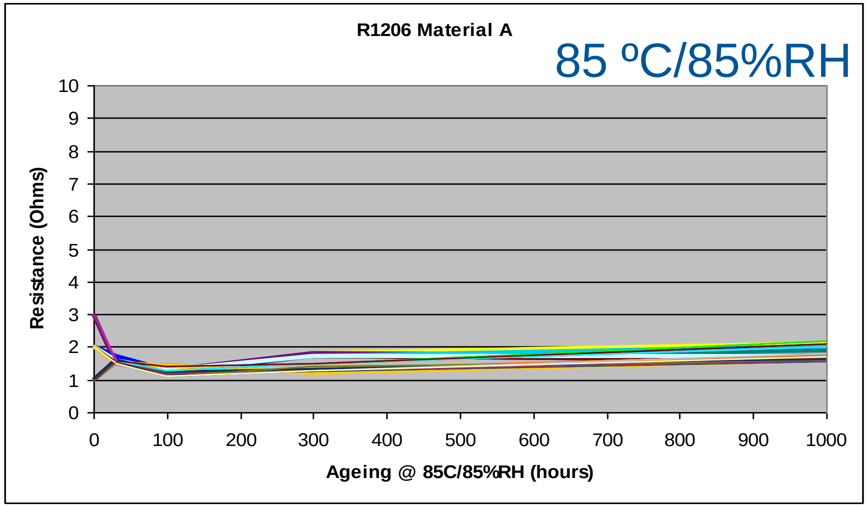
Comparison of ICA reliability -
Resistance of Sn R1206 on FR4 substrates


R1206 Material A

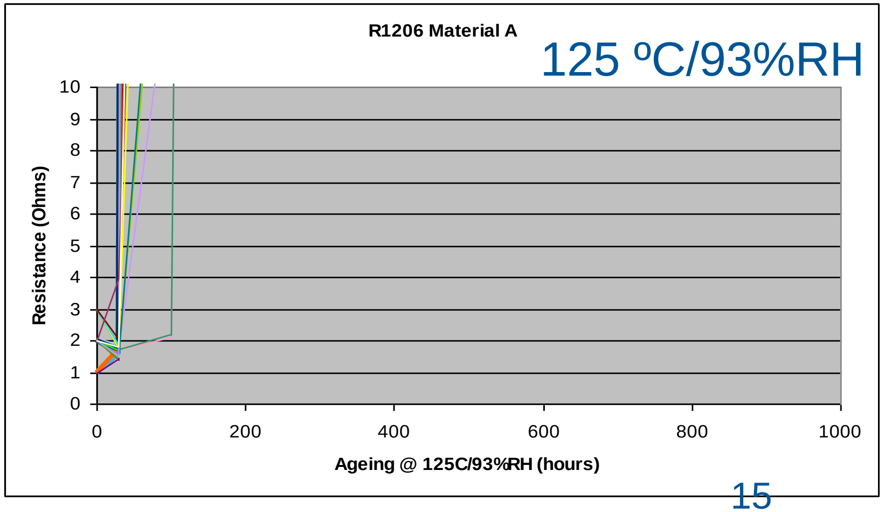
125 °C


R1206 Material A

-55/125 °C

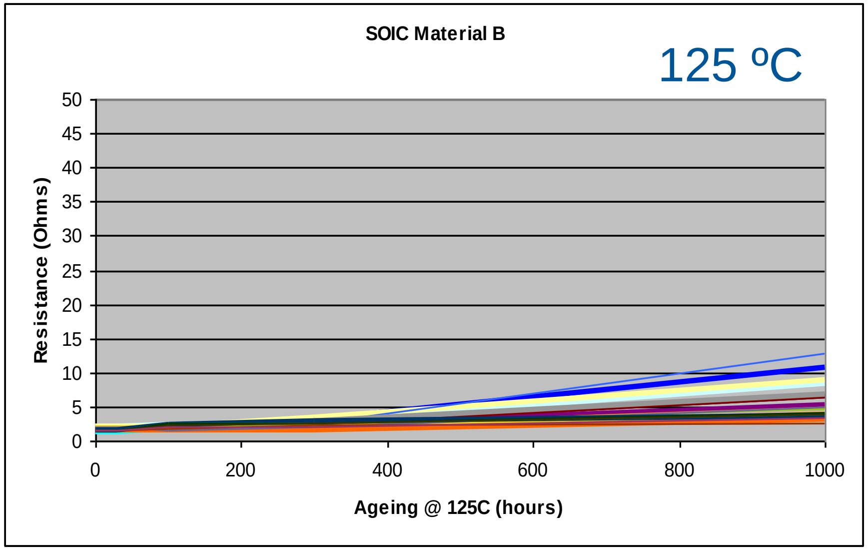

R1206 Material A

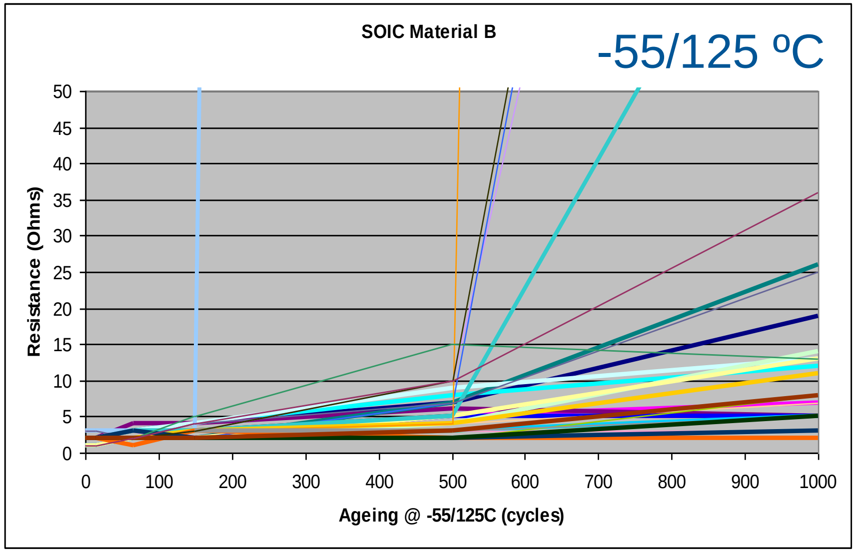
85 °C/85%RH

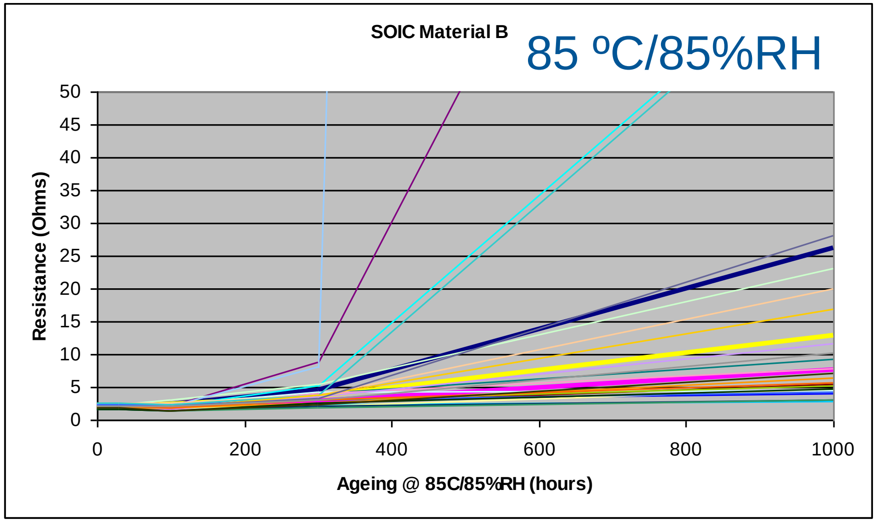

R1206 Material A

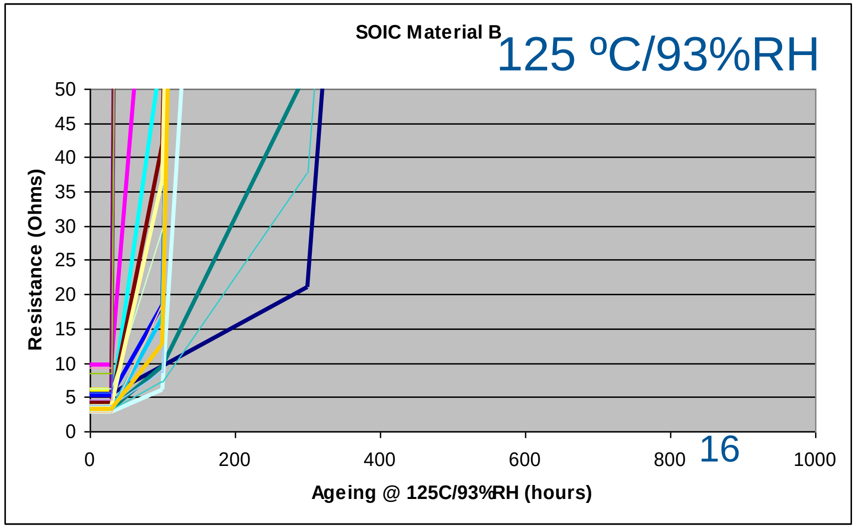
125 °C/93%RH

Resistance of Sn SOIC on FR4 substrates

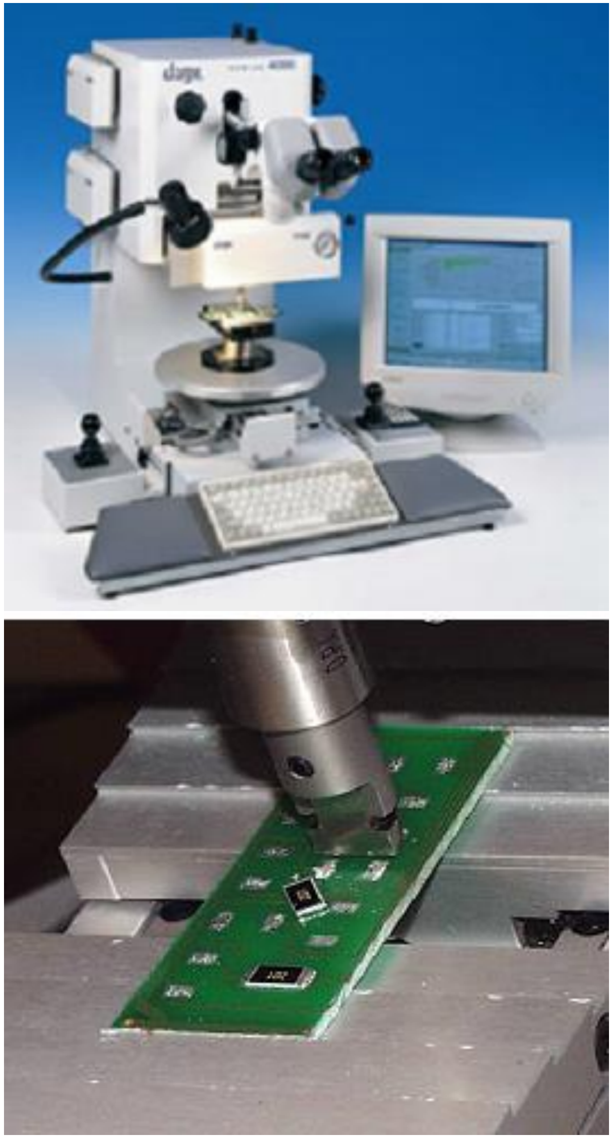








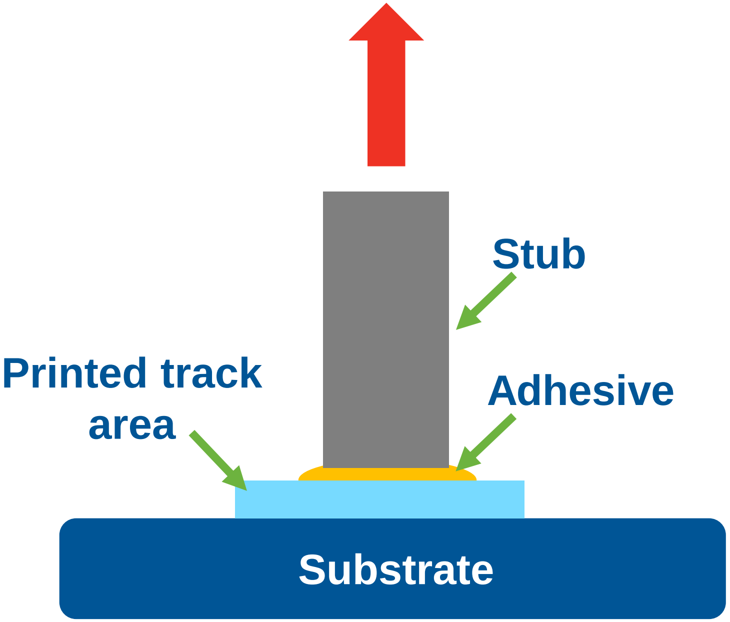
Peel/tape test, shear test



- Peel/Tape Test
  - Tape adhered to printed ink on surface and peeled off
  - Gives information about adhesion strength
- Test shear strength
  - Probe moved across surface
  - Force require to shear component measured

Pneumatic adhesion tester

- Test to measure bonding of tracking to substrate
- Attachment of 1cm stud to printed ink
- Pressurised collar used to "lift" stub from surface
- Issues with finding adhesive for stub

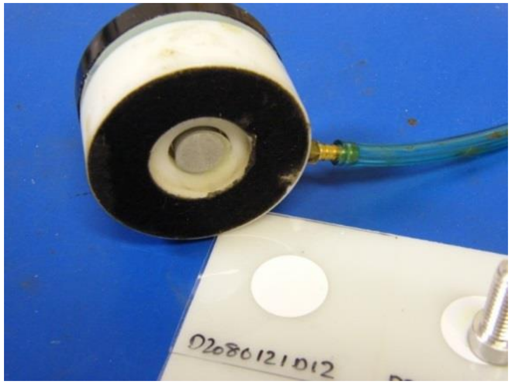


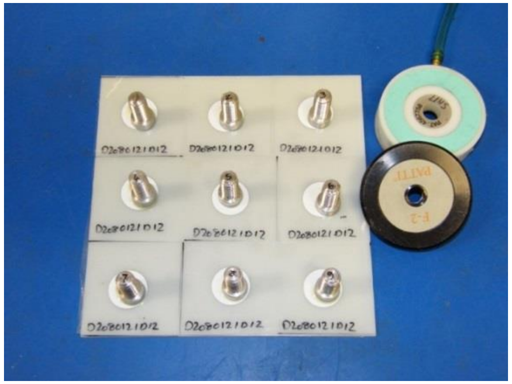
Stub

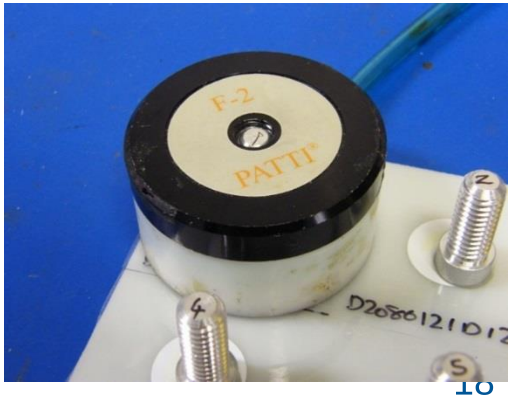
Printed track area

Adhesive

Substrate





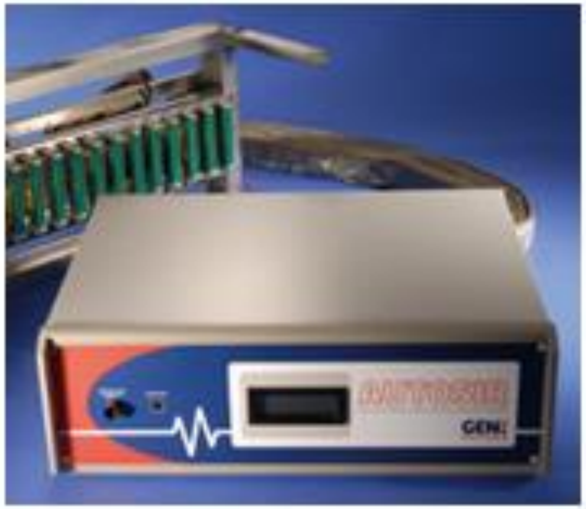


SIR testing of wearables

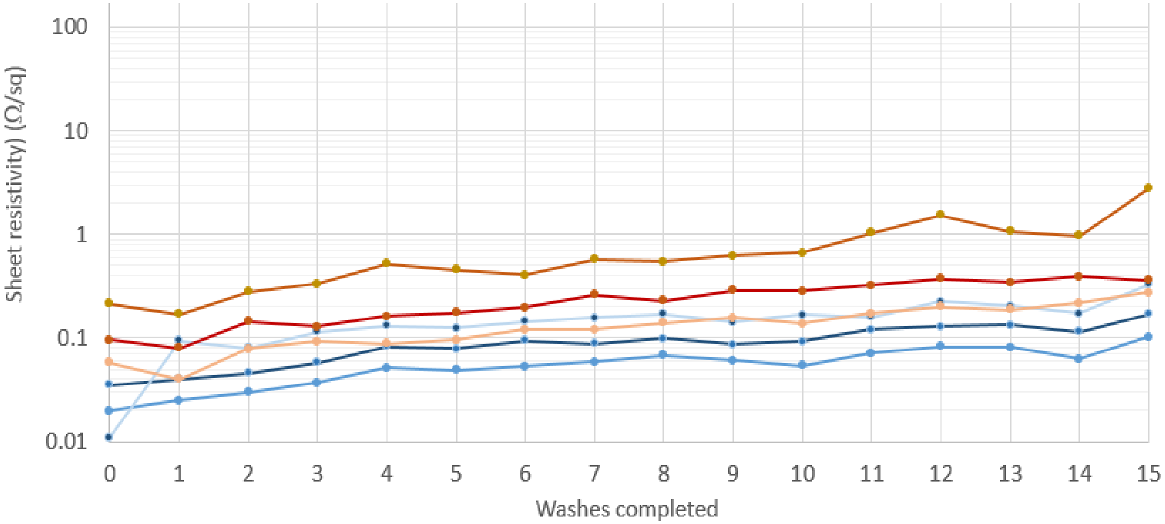
- SIR testing involves bias, moisture and contaminants (flux)

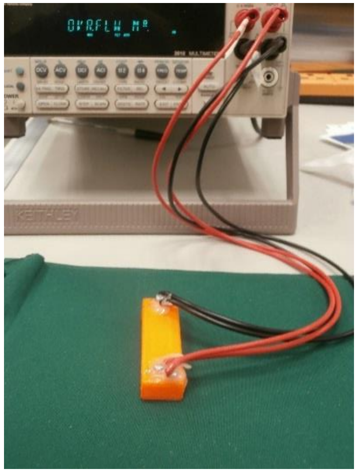
- should this contaminant be:
  - sweat
  - detergents
  - shampoo

- AutoSIR



Washing machine tests

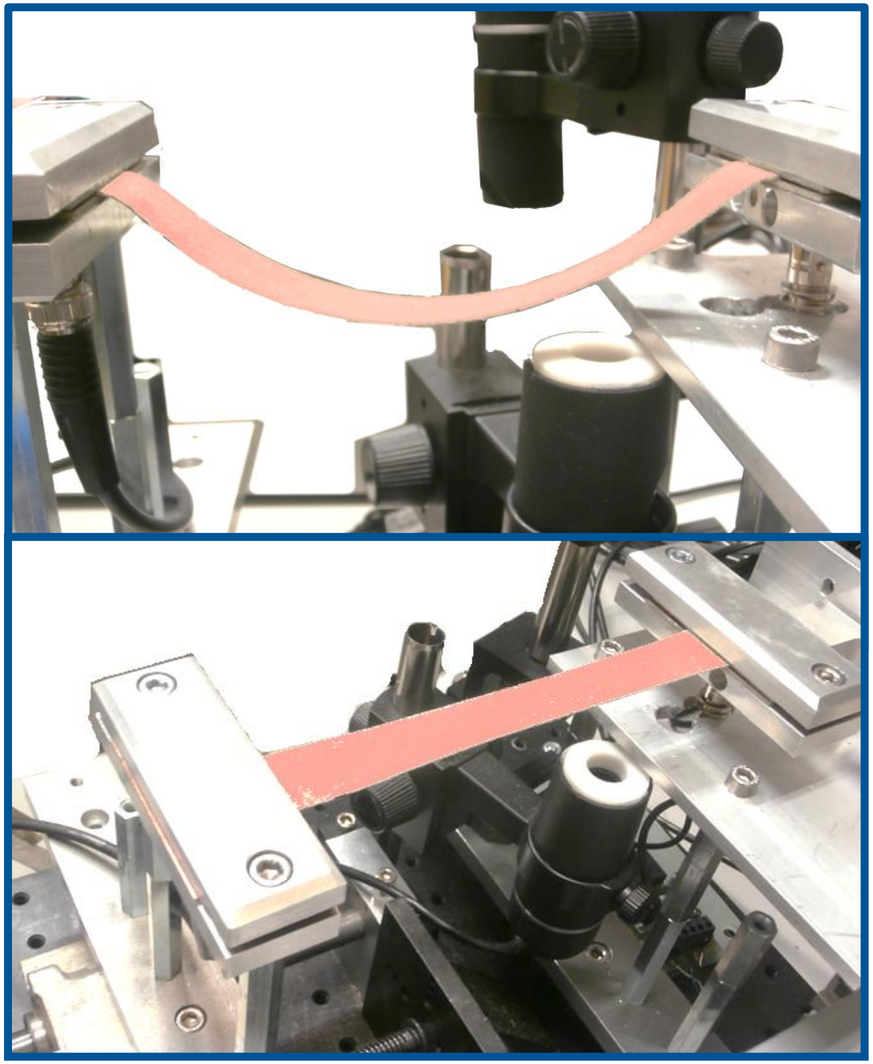




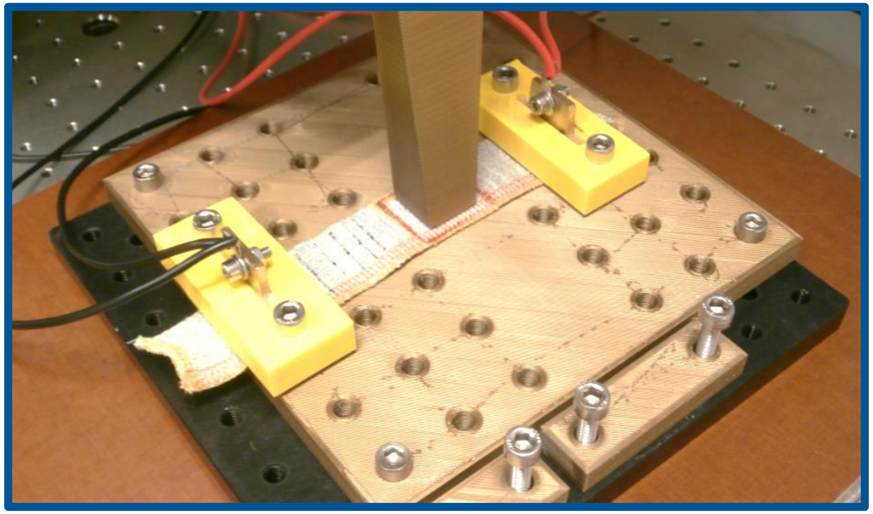
- Four-point probe measure sheet resistivity
- Wash 30 ºC (37 ml non-bio detergent), dry 65 ºC oven and measure change in resistivity

Fabric, Flexible and Stretchable Sensors: Testing Rigs

Stretch Test



Strain Test



- Ongoing work:
  Developing stretch sensor platform to understand effect of applied load on performance

Protection

- Coatings – conventional coatings, nano-coatings, etc.
  - Most testing is done on new coatings
  - Knowledge gap – how good are coatings that have been in the field for *x* years?

  - Evaluation methods:
    - Repeat SIR/mechanical/other tests as performed on new coating
    - Chemical analysis – FTIR and other spectroscopic analysis

Conclusions

- Materials used are typically not suitable to high temperature and hence we cannot use significantly higher temperatures to accelerate failure mechanisms

- Harsh environments for wearable electronics are different to conventional electronics
  - → introduces new failure mechanisms
  - → particularly harsh with regards in electrochemical and mechanical aspects

- New test methods need to be developed. These will need to be combinatorial to mimic realistic end usage.

Questions

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