Printed electronic interconnection techniques

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Printed Electronics Limited (PEL) General Overview

- PEL was founded in 2006 – idea formed within a conventional PCB manufacturing business
  - Founders Dr Steve Jones, Dr Neil Chilton
  - Team of 11– PhD, MSc and BSc level
- **PEL** is an **integration**, **process**, materials and **product development company**
  - product development for clients: prototype through to production quantities. Includes system development with partners.
- PEL Consultancy and Training courses:
  Printed Electronics & Inkjet Electronics and Integration
- Inkjet-electronics and material deposition expertise:
  - Direct circuit printing, Material deposition, Composite device fabrication
- Partnership with Invotec Circuits, the UK's largest manufacturer of PCBs.
- Offices in Tamworth and Cambridge UK

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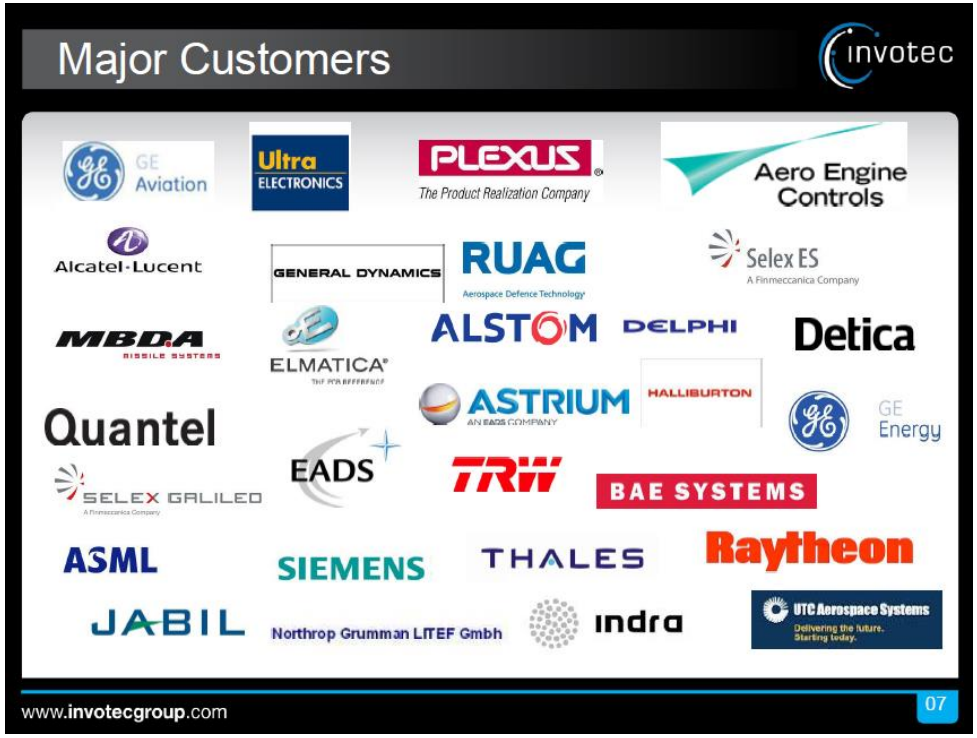
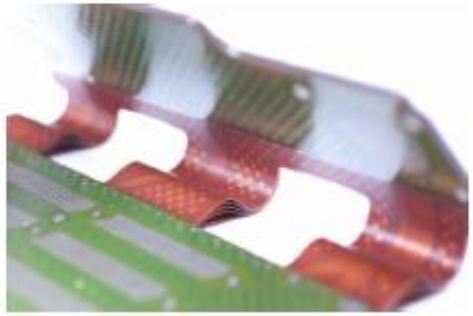
PCB Partnership - Invotec Group

- PEL is an independent company that operates in its own lab and office space within Invotec's manufacturing site:
  - Invotec are the UK's leading technology PCB and interconnect company; in continuous operation since 1986
  - A focus on challenging leading edge products
  - High technical capability – Invotec are ESA approved





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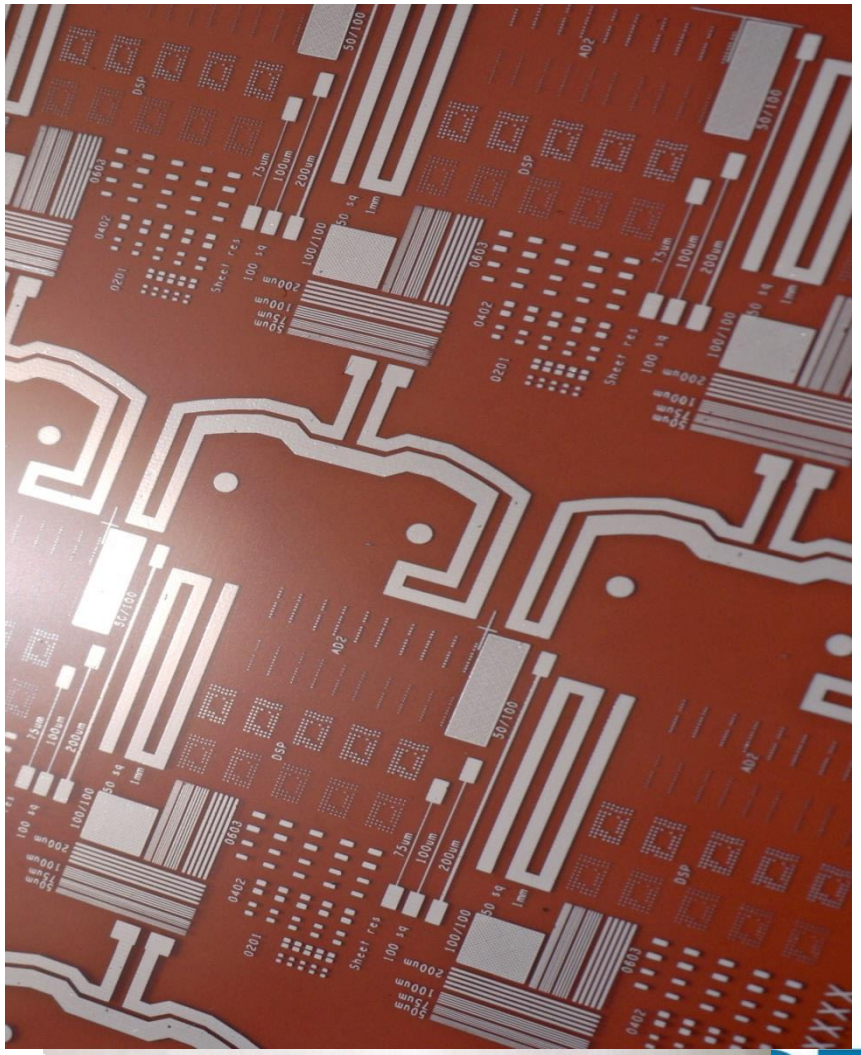
PEL's main application areas

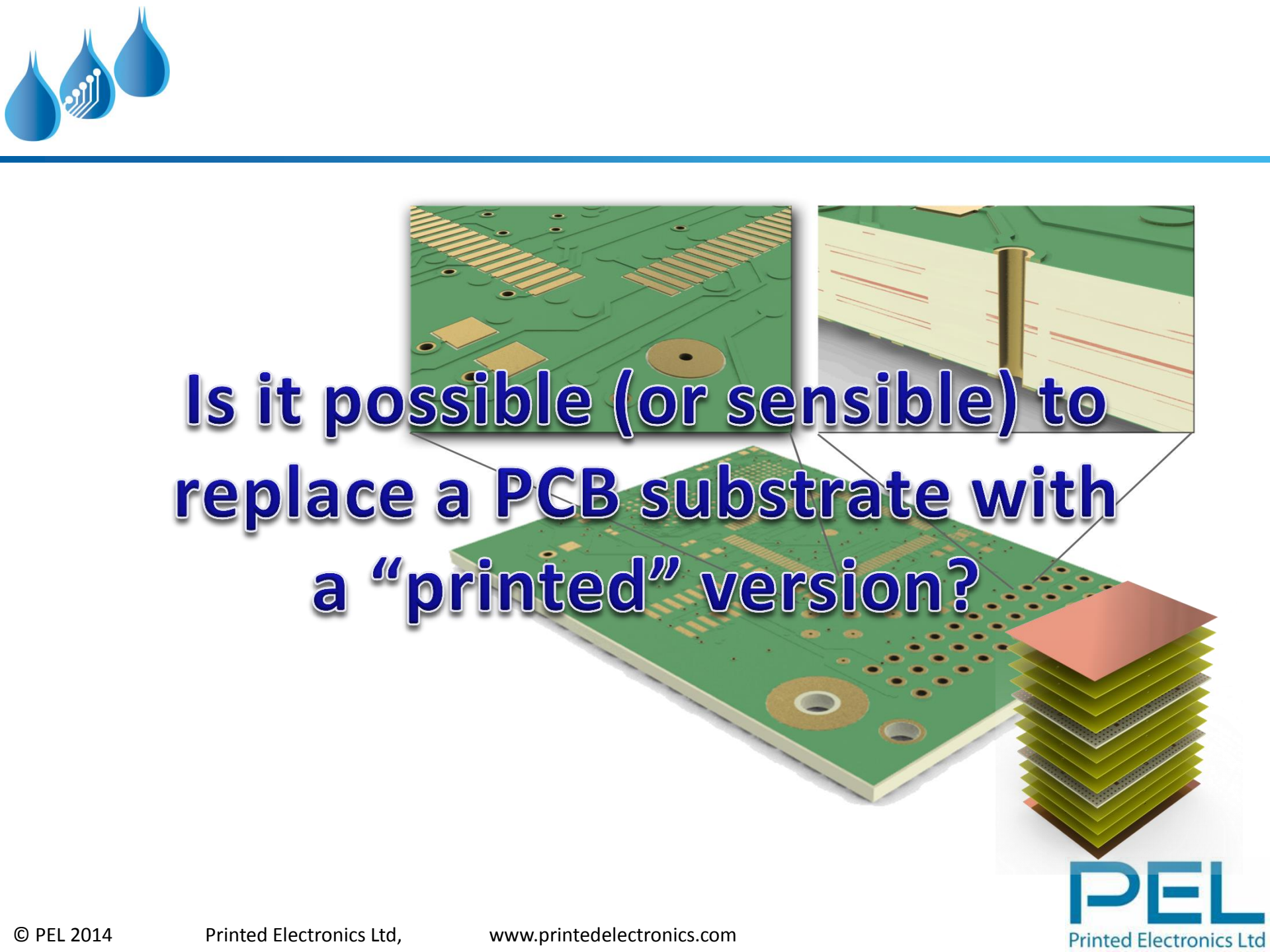
Circuit Interconnect and Integration	Smart Packaging	Sensors and Medical
High Value, Unique function	R&D for Defence/Aero	Wearable

Printed Interconnects

- Much of the work that PEL undertakes is related to printing interconnects: the conductive lines that form the circuits, antennae, passive components etc

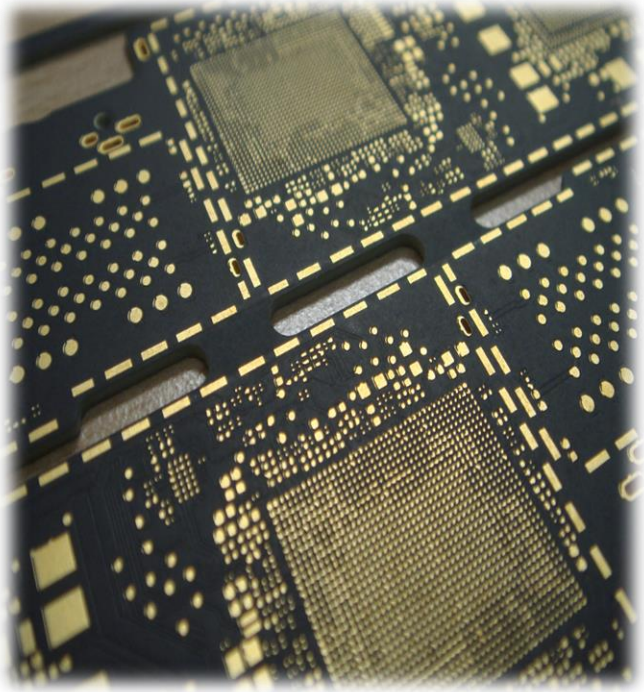
- “Printed Interconnects” are not new, every PCB (Printed Circuit Board) on the planet has them – but the entrenched technology uses lithography, subtractive etching and chemical plating




Is it possible (or sensible) to replace a PCB substrate with a “printed” version?

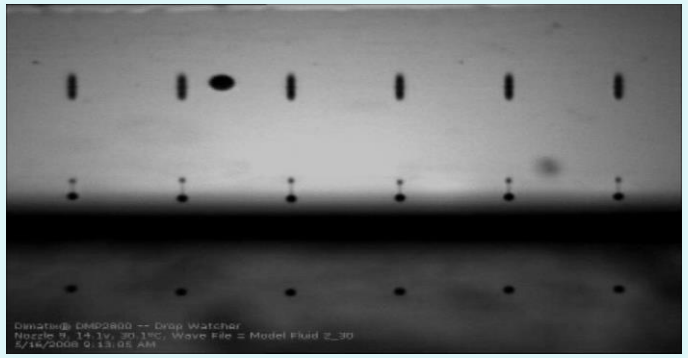
i.e. comparing…

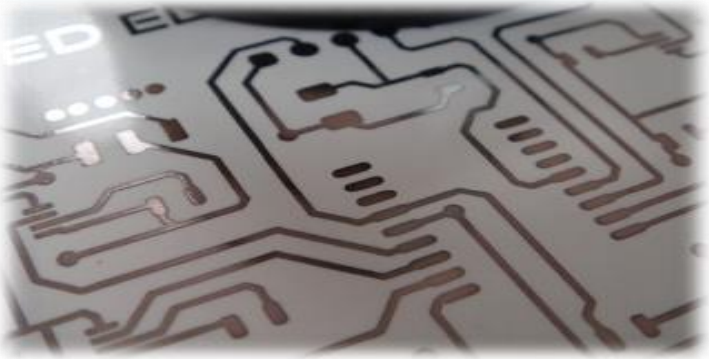
- PCB
  - high reliability multilayer



VS.

- Printed interconnect:
  - Inkjet printed silver on paper





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Low cost nano-metal printer

- PEL starter system for inkjet evaluation purposes
- Specialist nano inks available
- Print silver, copper, gold etc using nano inks

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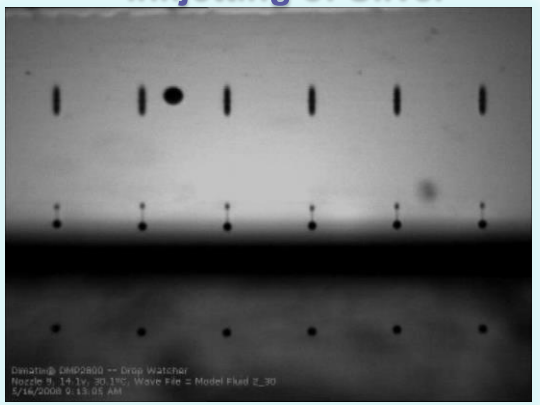
Desktop Printing of
Room Temp Cure Ag nano ink

Inkjet-Printed circuits and antennas

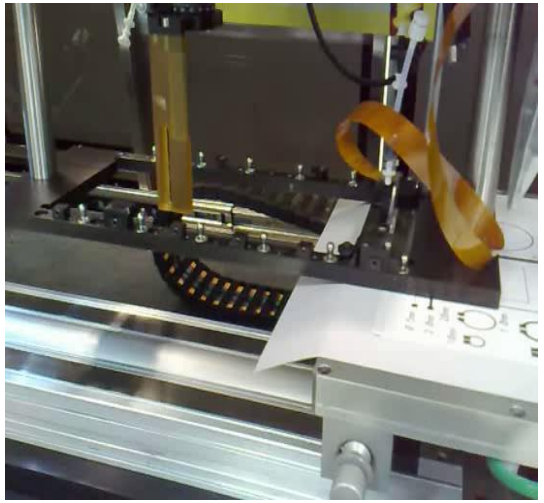
Process time < one hour

Inkjetting of Silver



Cu test circuit

Ag circuit on paper



Fabric antenna

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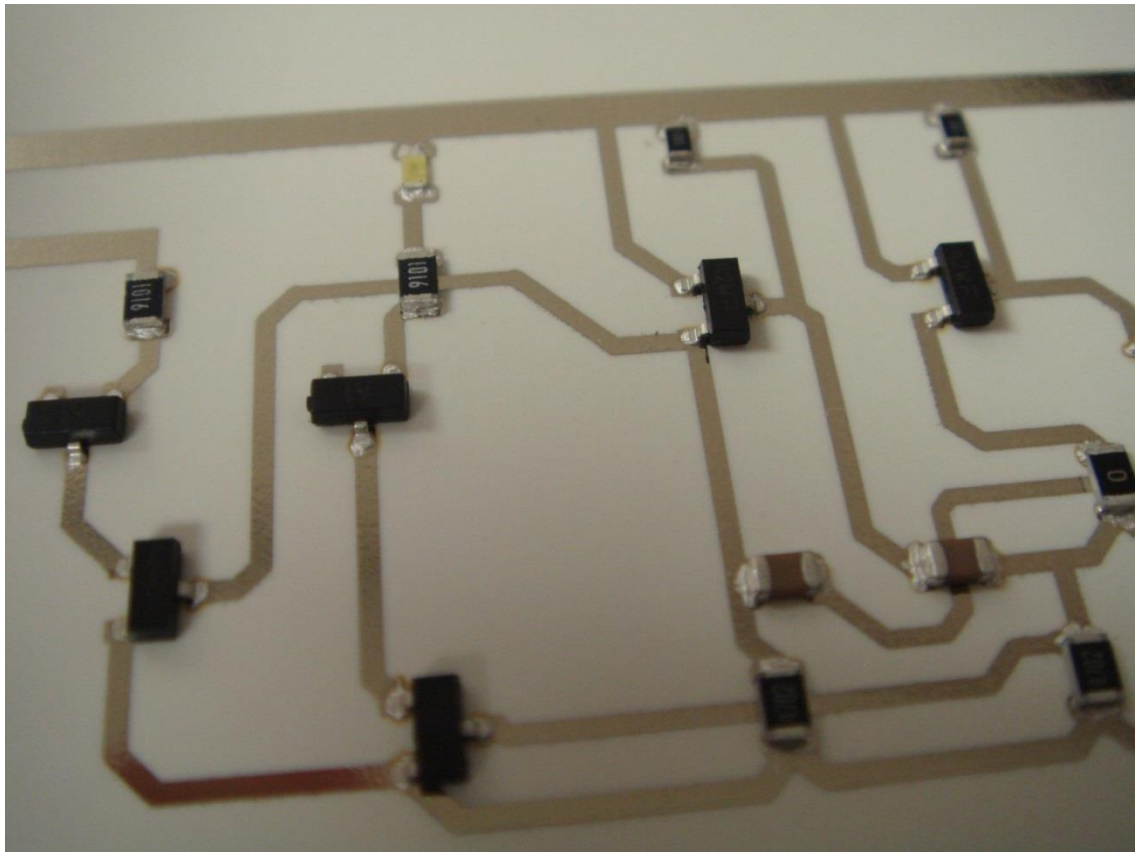
Useful for Rapid Prototyping

- Inkjet printed circuitry
  - Manufactured in less than 5 minutes
- SMT placement
  - ~minutes to complete
  - Using conductive epoxy (not solder)
- Pictured design Included

  (not shown):
  - Printed switch
  - Printed Battery
  - OLED
- **Design to Manufactured Product ~hour**



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Inkjet Printed Circuitry

Benefits

- **Tool-less** – rapid prototyping
  - CAM to Print in seconds
  - **Ultra fast manufacturing lead-time**
- **Adaptive – every part can be different**.
- Batch and security markers can all be added to the part *during print*
- (Single layer) **Printing straightforward**
- **Compatible with R2R**
- **High speed print** (~m/s), capable of very high volume.
- **Compatible with thin substrates (all automated handling)**
- **Low temperature** (energy) **processing**
- Can use **low cost substrates** (paper and plastics)

Problems

- **Conductor height: thin** – usually less than 1um.
  - Suitable only for Low Power Electronics
  - **Lower reliability**
- ***Fine Line Printed features** are **challenging***
  - Dimensions >> equivalent in lithography
- **Multilayer printing** is substantially more **difficult** than single layer
- Nano **materials** (inks) are **expensive** (thousands of $ / litre)
- Inkjet is inherently **less reliable than lithography**
  - Nozzles will block or misfire
  - Need inline scanning

A focus on areas that may be beneficial to ESA applications

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Reel to Reel (R2R) for long circuits

Highest Potential Areas for P.E.

- Very long circuits
- Non contact
- 3D
- Others…

- Using R2R process – very long circuits
- Not limited by conventional panel dimensions

- Sensors, cable printing etc

Can be reel-to-reel printed at km lengths – e.g. **CIT process** (**www.inkjetflex.com**)

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Non-Contact Printing

e.g. Inkjet-printed metallic circuits

Highest Potential Areas for P.E.

- Very long circuits
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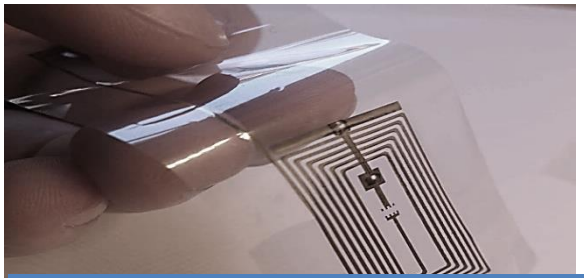
- Others…

- **Thin substrates (as thin as 12um) have been printed successfully.**
- **Make use of both surfaces: print on 2 sizes of material**
- **Very lightweight**



Material	Teijin Films
Thickness	12 micron
Tensile	310 Mpa
	.5% at 200C
	hin (dependent on retreatment)

Property	Test Method	Unit	PEN	PI	PEI	PPS	PET
Tensile strength	JIS C-2318	MPa	280	280	110	220	230
Tensile elongation	JIS C-2318	%	90	80	80	60	120
Continuous use temperature (mechanical)	UL-746B	deg C	160	200	170	180	105
Continuous use temperature (electrical)	UL-746B	deg C	180	240	180	180	105
Glass transition temperature (film)	deg C	155	-	212	90	110	
TDFJ method by DMA							
Melting point	DSC	deg C	269	-	-	285	258
Dielectric breakdown voltage	JIS C-2318	kv/mm	300	280	140	320	280
Dielectric constant	JIS C-2318	-	2.9	3.3	3.2	2.8	3.1
Water absorption	TDFJ method	%	0.3	1.3	0.3	0.02	0.4
Density	JIS C-2151	g/cm3	1.36	1.43	1.27	1.35	1.4
Flammability	UL-94		VTM-2	V-0	V-0	VTM-0	VTM-2

http://www.teijindupontfilms.jp/english/product/hi_film.html

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Ultra-fine-line features (~1um)

Highest Potential Areas for P.E.

- Very long circuits
- Non contact
- 3D
- Other…

SIJ – Super InkJet

Note - PEL represent SIJ

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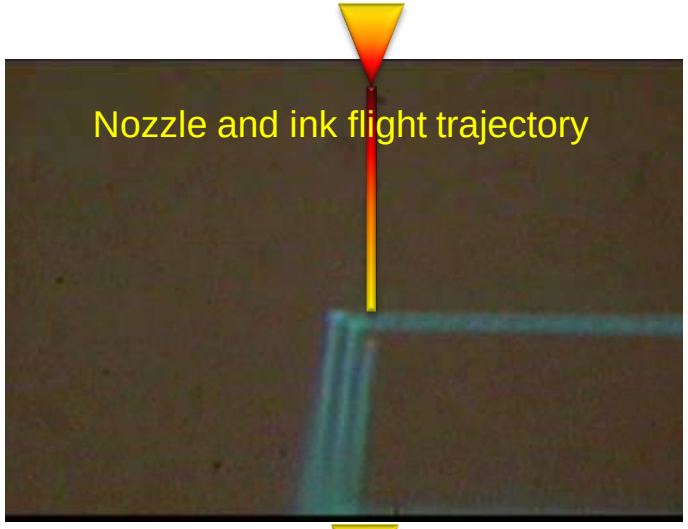
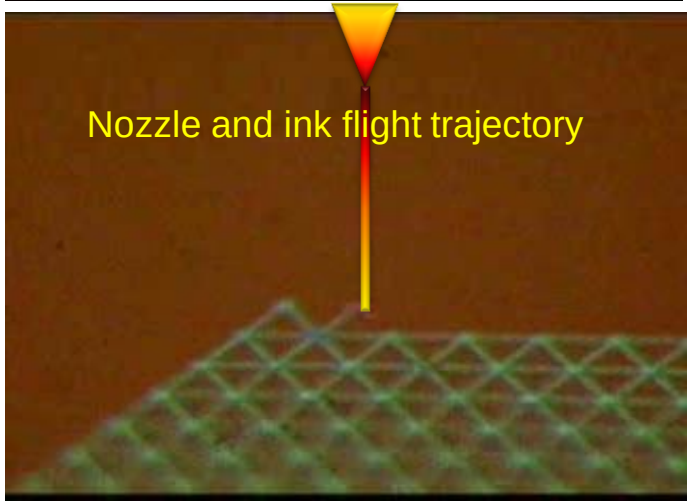




- Fixed single nozzle printer
- 5um line – real time printing

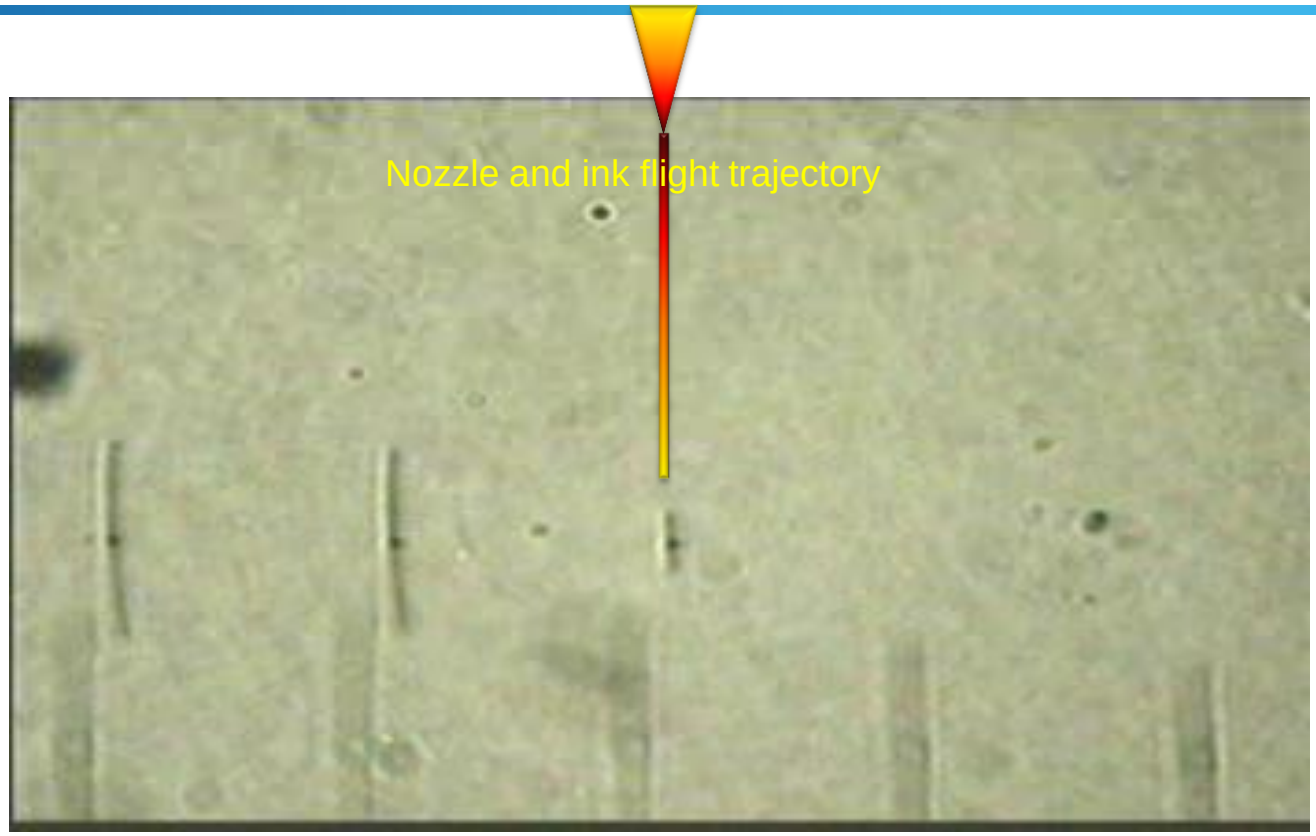
- 3um line on 15um pitch – real time video of printing

SIJ – Super InkJet

Note - PEL represent SIJ

Highest Potential Areas for P.E.

- Very long circuits
- Non contact
- 3D (2.5D)
- Other…



- Directly printed ***5 micron*** width towers of metallic silver with aspect ratio > 50:1

Printing onto 3D objects

Highest Potential Areas for P.E.

- Very long circuits
- Non contact
- 3D
- Others…

PEL-developed proof of concept inkjet printing system for curved surfaces.

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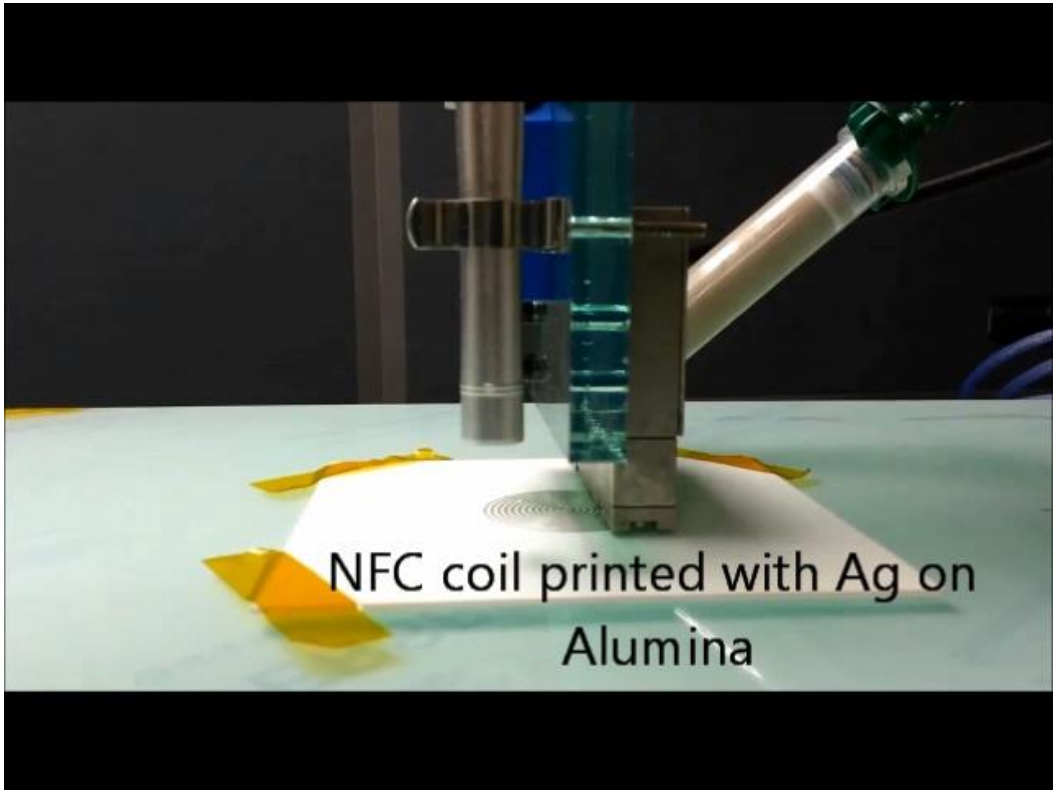
3D Circuit Printing

Highest Potential Areas for P.E.

- Very long circuits
- Non contact
- 3D
- Others…

- Four axis system to digitally print onto curved surfaces
- Printed cones, bottles and cylinders
- Digitally prints high viscosity inks (e.g. as per screen printing).



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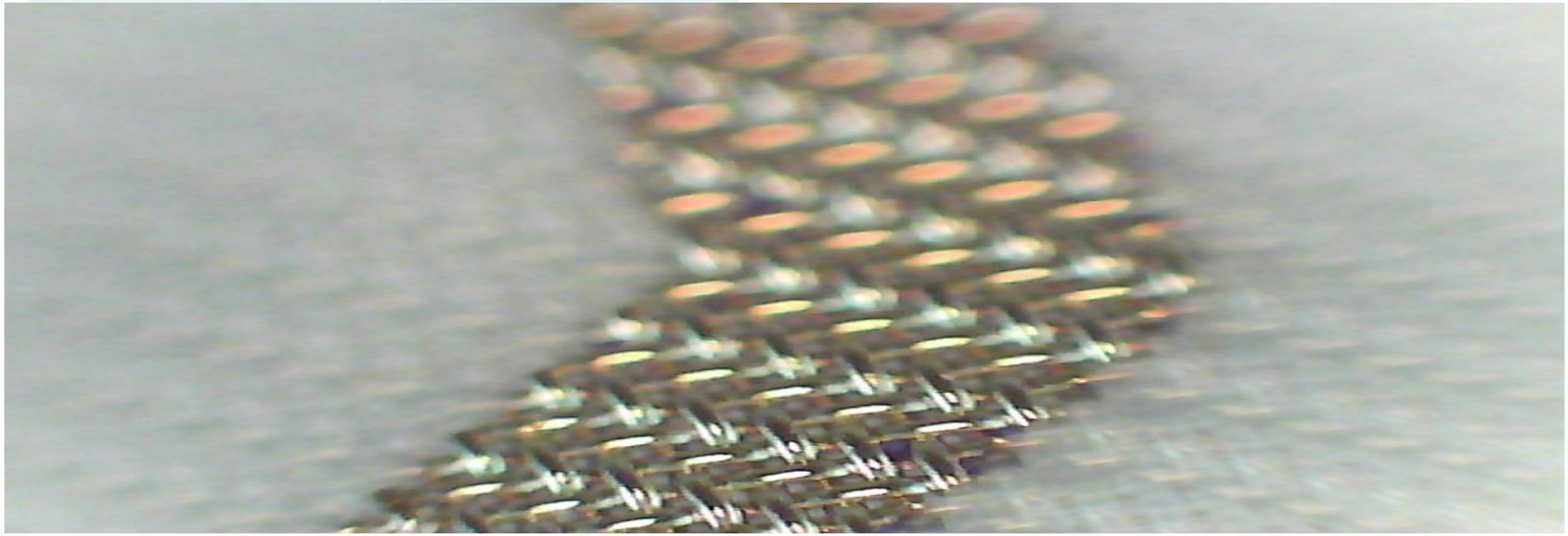
Interconnects using Fabric

- For lightweight & robust wearable applications PEL are partnered with NEL Ltd (UK) to utilise their Neltex® material range with PEL's printed electronic interconnects.

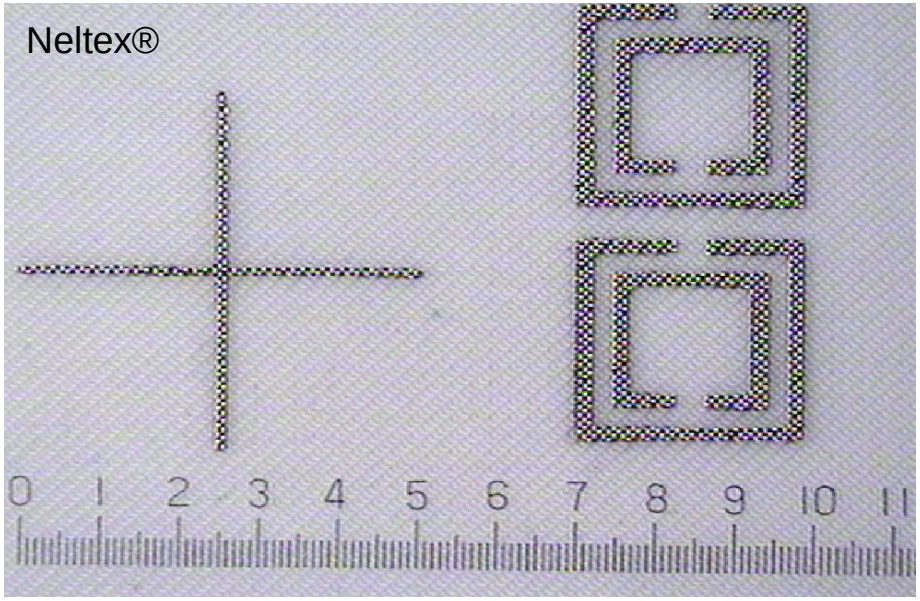
Lightweight and foldable

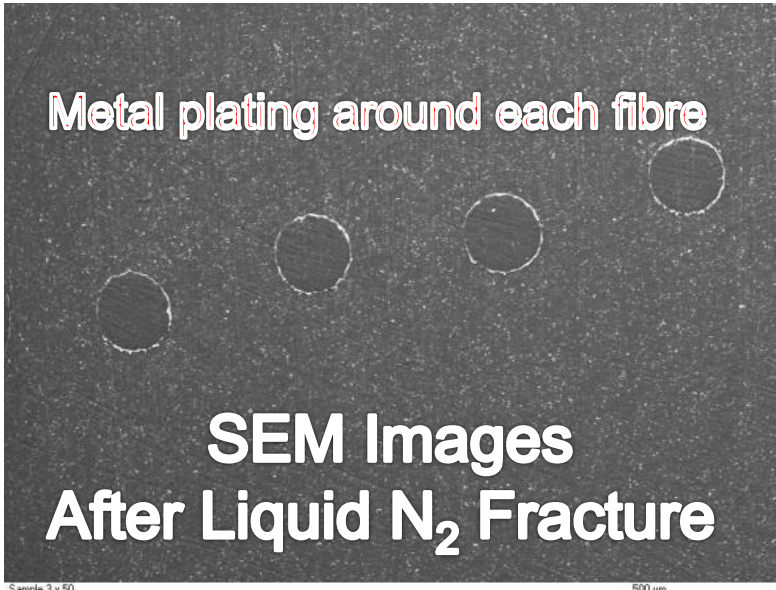
Feature	Value
Weight per m^{-2}	62g (70um thick)
Resistance of trace (Ohms per Sq)	~30mOhm/square
Thread filaments	165 / cm

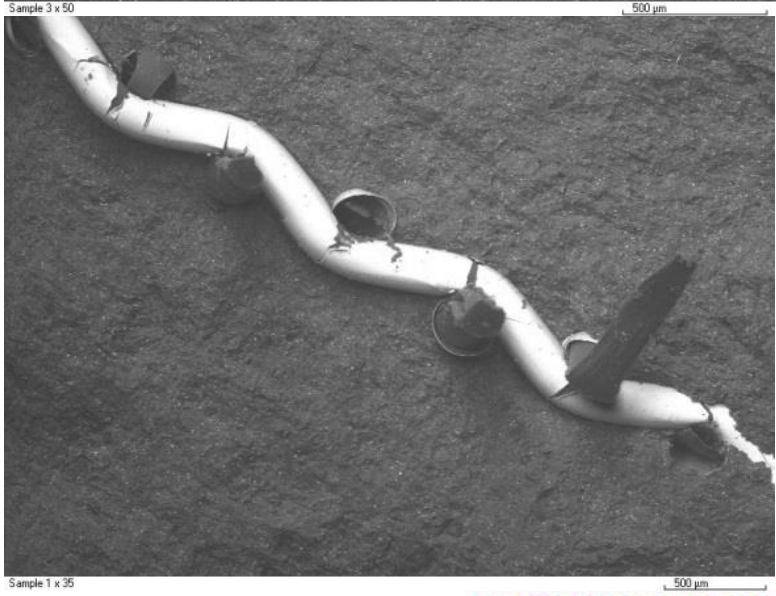
Breaking Test (Tensile Strength) :
Warp direction --- per 5cm strip minimum 26kg
Weft direction --- per 5cm strip minimum 26kg
- Breaking strength of unplated fibre 130Mpa



Neltex structure





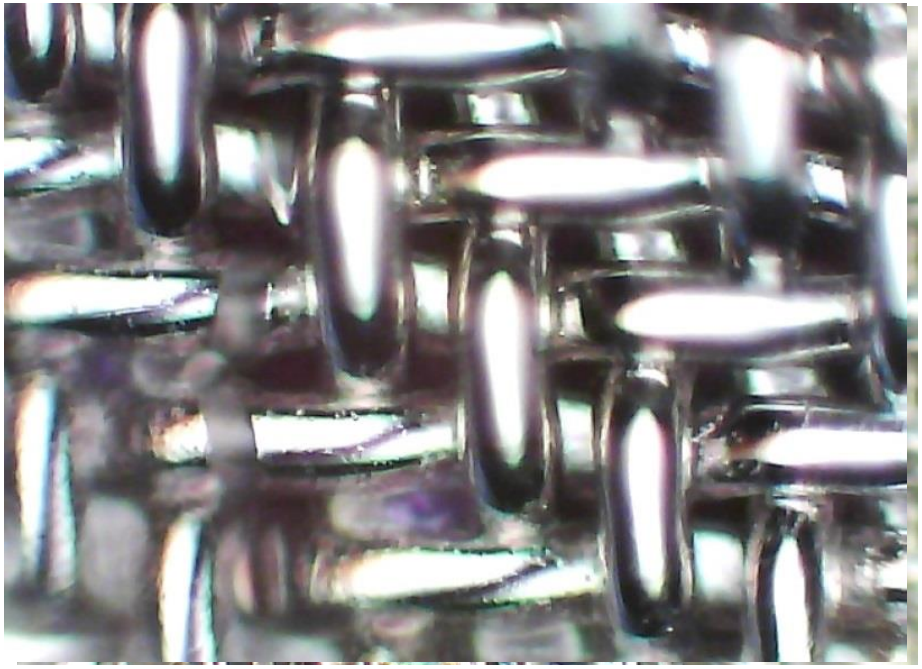


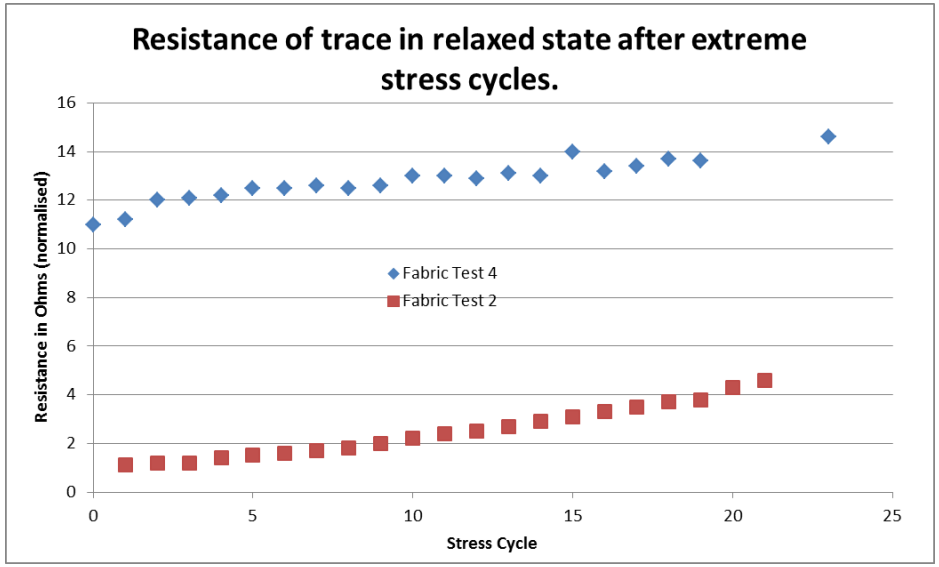
- Each fibre of the weave is plated and fully encapsulated with metal (Ni, Ag, Cu etc)
- It can be folded and repeatedly stressed with relatively low change in resistance.

Severe stress testing

- Possible application - foldable and extensible antenna

Resistance vs load
(after severe tests)





Testing to near failure results in breakage of some of the plating **around** the fibres in the weave but the elastic fibres remain connected.

Therefore when the material relaxes again resistance falls back to a useable value (*for wearable applications at least*)

Summary

- Printed Electronics (*the field* as well as *the company*) relies on good collaboration. PEL welcomes the opportunity to collaborate in this area.

- Printed electronics calls for multiple deposition (printing) methods.
  - Inkjet, femto-litre deposition (Super Inkjet), Drop on demand nozzle dispensing, screen, R2R etc

- Done correctly, printed methods can add electronic function to objects where conventional electronics could not.

Conclusion

- Printed Electronics is **absolutely not** a replacement for conventional electronics: It is not generally robust enough – especially for ultra-high reliability applications such as ESA topics.
- However there are areas where the benefit of being able to digitally print very long circuits on lightweight substrates may be useful.
- Where weight and robustness is crucial, e.g for origami or folding electronics, the use of fabrics together with flexible connections may be useful for the space industry.
- Printed interconnects at 1um level in 2D and 3D (e.g. SIJ) may be potentially used for attachment and novel electronics.

- Please remember that this is very early and further work would be required to determine robustness criteria for these materials and methods.

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Thank you
&
Questions