The Effect of Geometry Modification on the Performance of Stretchable Wires

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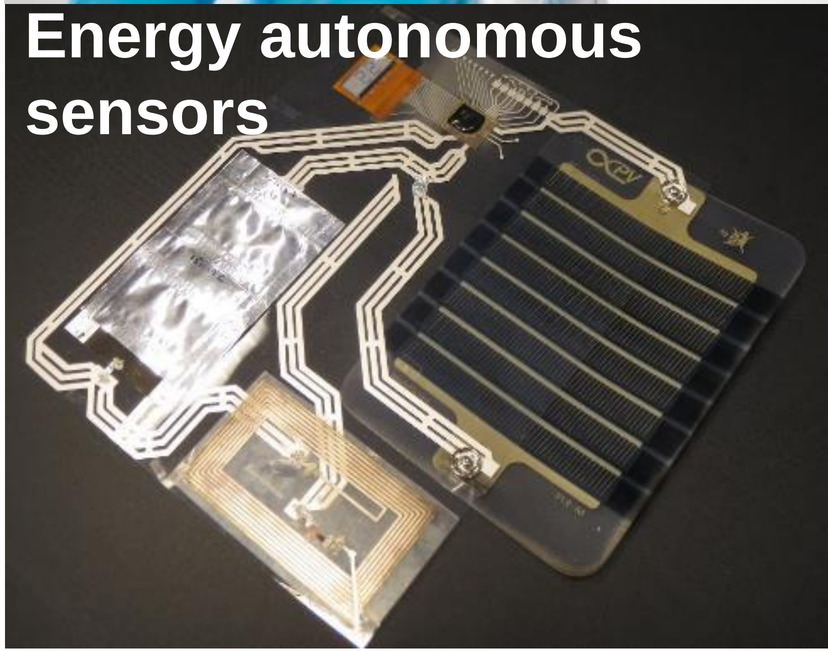
Tampere University,
Laboratory of Future Electronics

We perform research in novel materials, architectures and processes.

- We digitalize physical objects
- The focus is on Internet-of-Everything for **ambient intelligence** and **healthcare** application.

Research themes:
- Flexible/bendable/stretchable electronics
- Integration of printed and conventional electronics (hybrid printed electronics)
- Energy storage and harvesting
- Printed thin-film circuits and systems



Content

- Stretchable Electronics
  - Concept
  - Stretchable materials
  - Fabrication methods
  - Applications
- Stretchable silver interconnects
  - Materials and fabrication method
  - Characterization
  - Effect of conductor's geometry
- Effect of encapsulation layer and layout
- Summary

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Concept

- Stretchable electronics
  - Twistable
  - Expandable
  - Compressible
- Requirements
  - Light weight
  - Unobtrusiveness
  - Biocompatible
  - Maintain conductivity with receiver

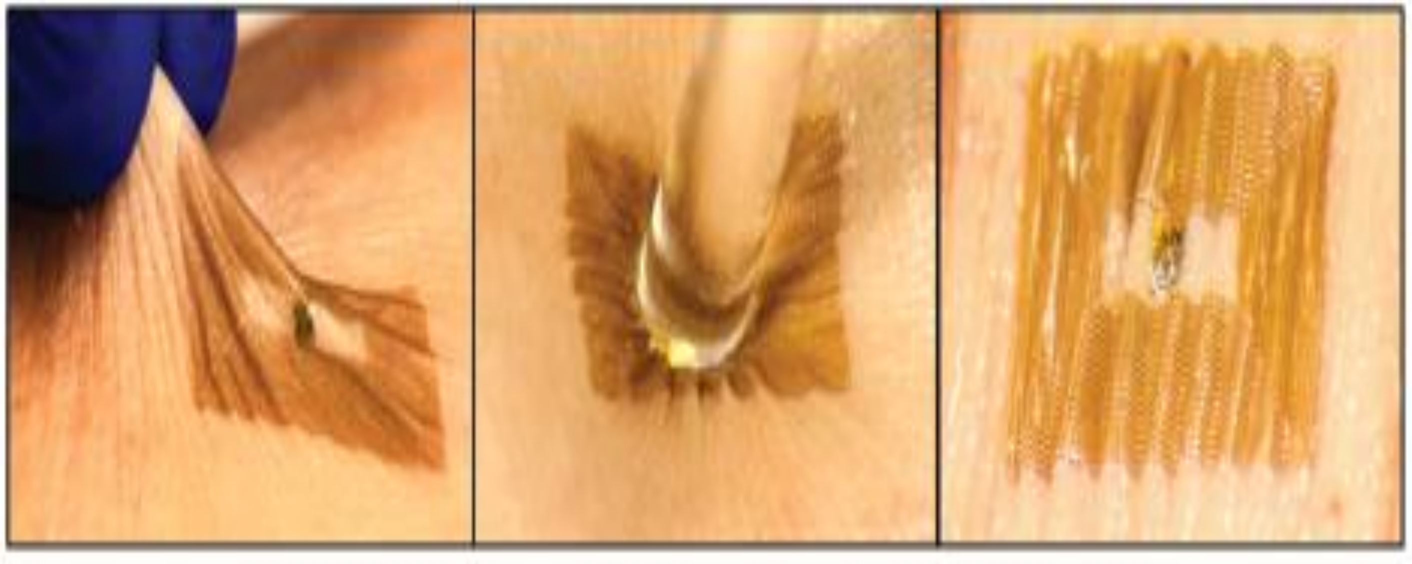

Fig.1 Deformability of epidermal device
Kim, J. et al. DOI:10.1002/smll.201402495

Stretchable materials

- Materials for substrates
  - Elastomers (highly elastic polymers)
  - Biodegradable substrates
- Materials for electrical conductivity
  - Metallic materials (metals, silicon)
  - Conductive polymers (PANI, PEDOT)
  - Nano-based materials (Metal Rubbers)
  - Nanowires (e.g. AgNWs, AuNWs, CuNWs, CNTs)

Design of stretchable devices

- Island-bridge configuration
  - Stretchable interconnects (Bridges)
  - Miniaturized rigid functional units (Islands)

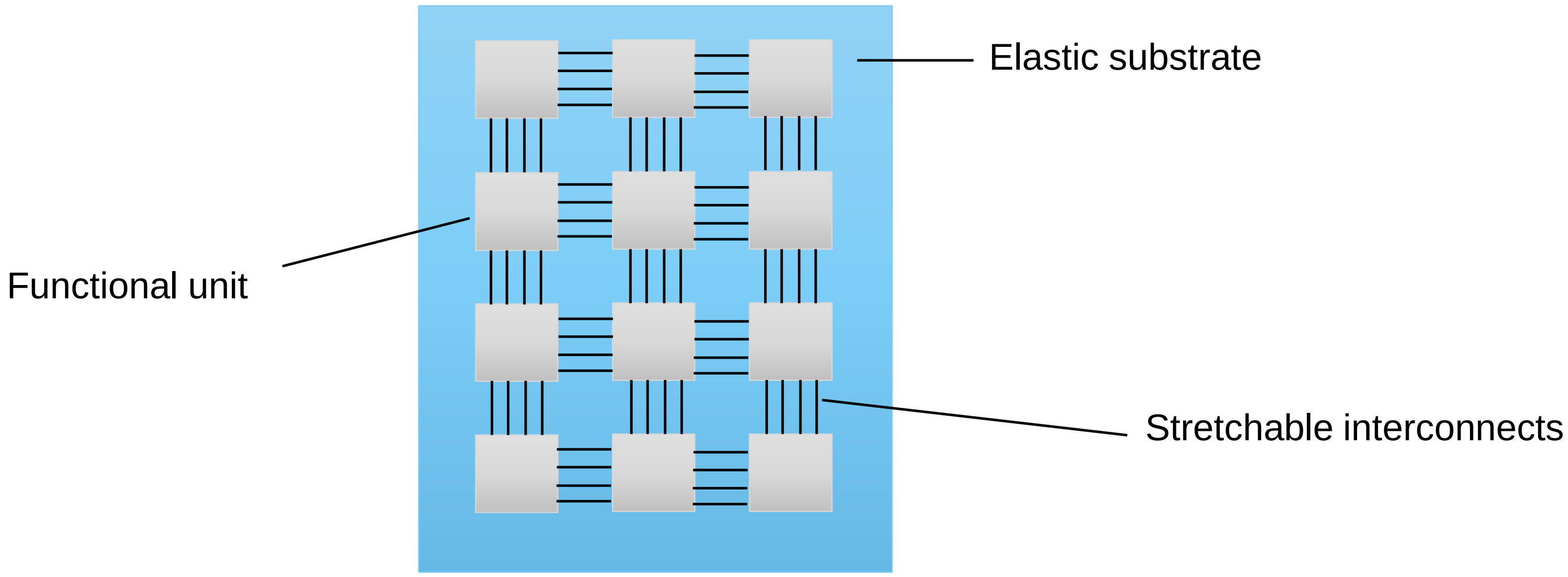

Fig.2 The concept of Island-Bridge

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Application

- Artificial E-skin
- Stretchable batteries
- Stretchable sensors
- Stretchable TFTs
- Personalized health system
- Epidermal devices
- Everyday tools
  (smart watches)

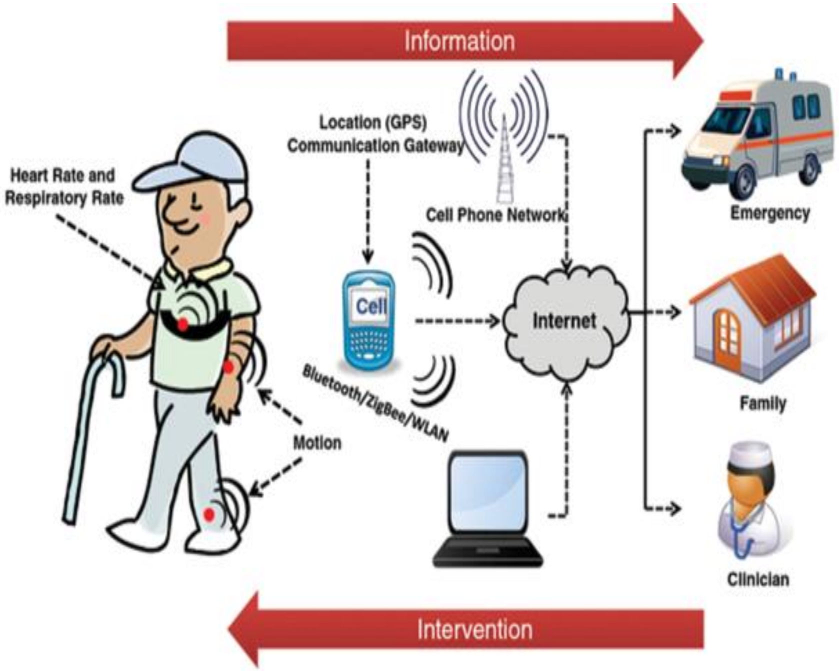


Fig.4 Schematic concept of remote health care system
M. Amjadi. et al. DOI: 10.1002/adfm.201504755

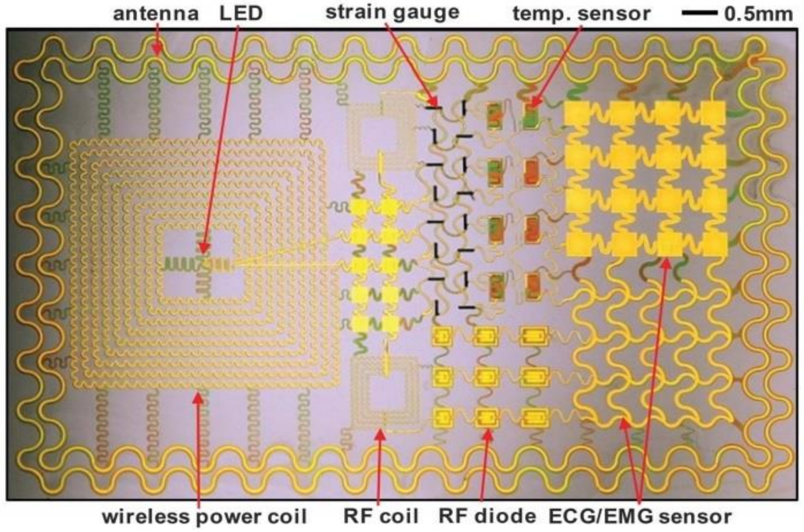


Fig. 5 Example of epidermal device mounted on a patient skin
J. Rogers. et al. DOI: 10.1126/science.1206157

Materials, Fabrication and Characterization

Materials

- Substrate: 50um TPU(EPUREX Platilon U4201)
- Ink: Conductive silver ink, ECM (CI-1036)
- Encapsulant: Same TPU, DI-7540 paste.

Fabrication

- TIC SCF-300 semi automatic screen printing machine, curing at 125 °C for 30 mins
- Heat-press machine (150C, 1min)

Characterization

- Electromechanical test
- Cyclic test

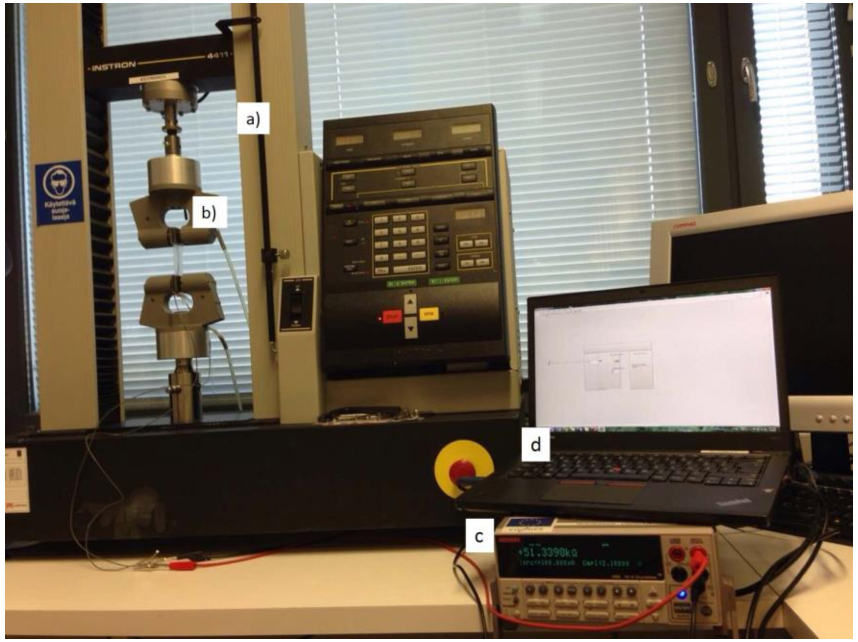


Fig.7 The measurement setup for electro-mechanical performance characterization. (a):Instron-4411 Universal Testing Machine, (b): sample kept by clamps, (c): Keithley 2425 sourcemeter, (d): LabVIEW software installed on laptop as the interface

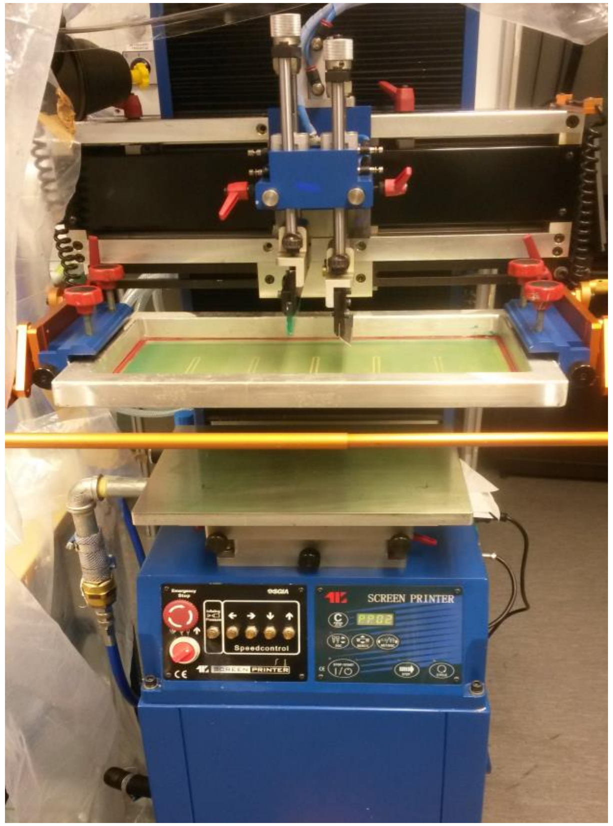


Fig.6 TIC SCF-300 semi automatic screen printing machine

How to retard failure of the conductors

- Material
    - Adoptable materials with deformation
    - Thicker material to locally increase the stiffness
- Geometry
    - Layouts to relief stress smoother with less stress concentration area
        - *Sacrificial zone*
- Protective coating
    - Encapsulants
    - Dielectric pastes

Stretchable interconnects

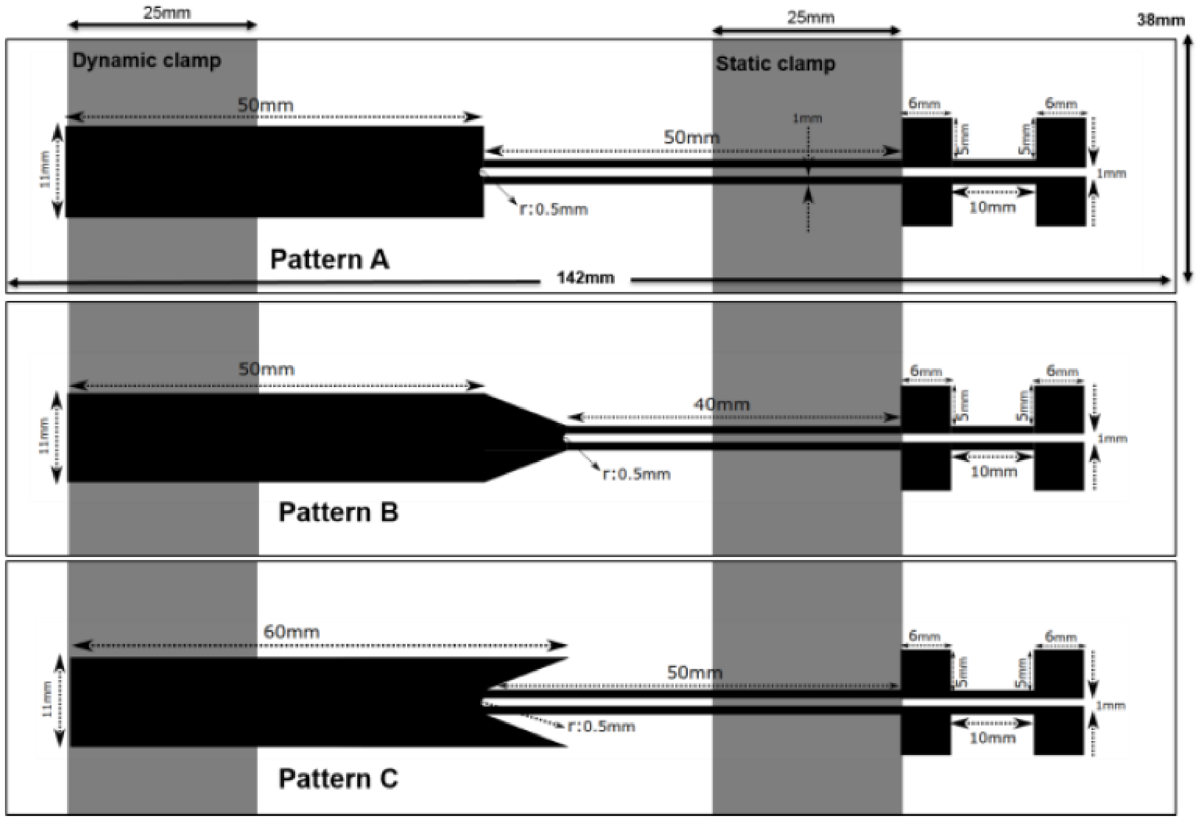


Fig.8 Pattern A, B and C: Schematic illustration of three different structural layout for the interconnects.

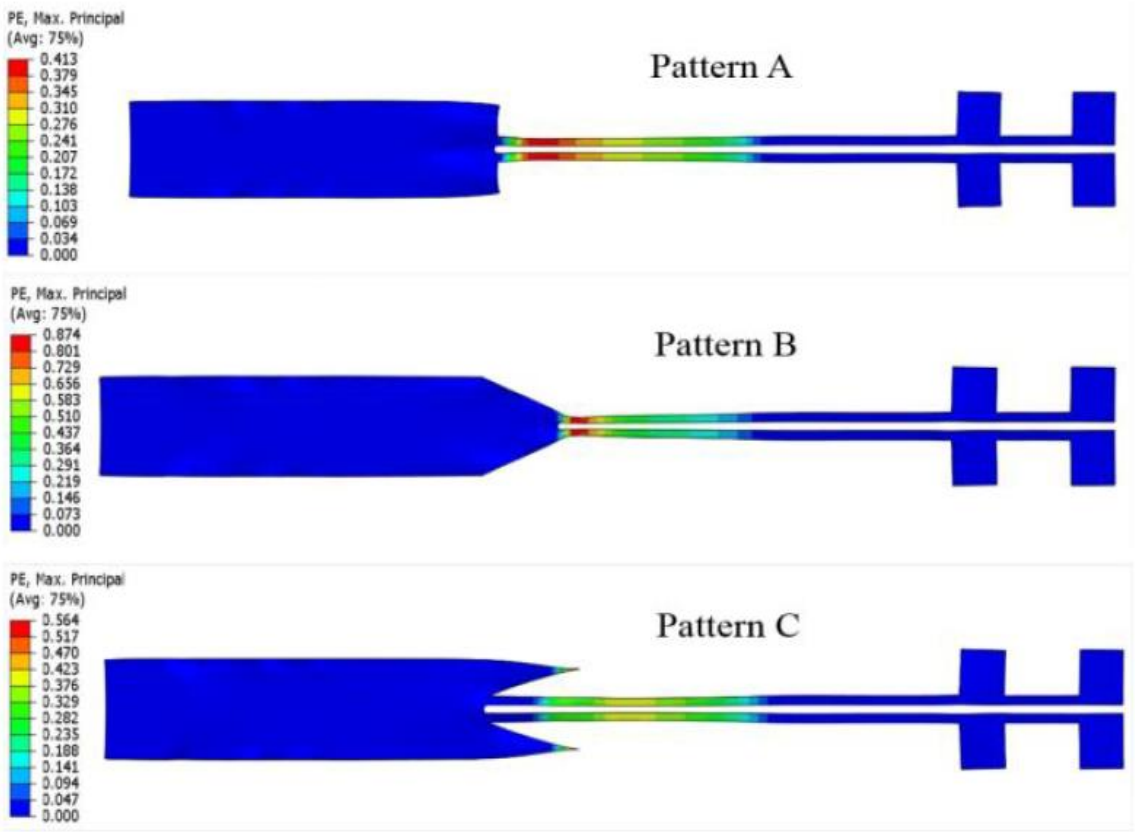


Fig.9 Plastic strain (PE) of 40% displacement for the designed patterns.

M. Mosallaei. et al. doi: 10.3390/mi9120645

Electromechanical and cyclic test

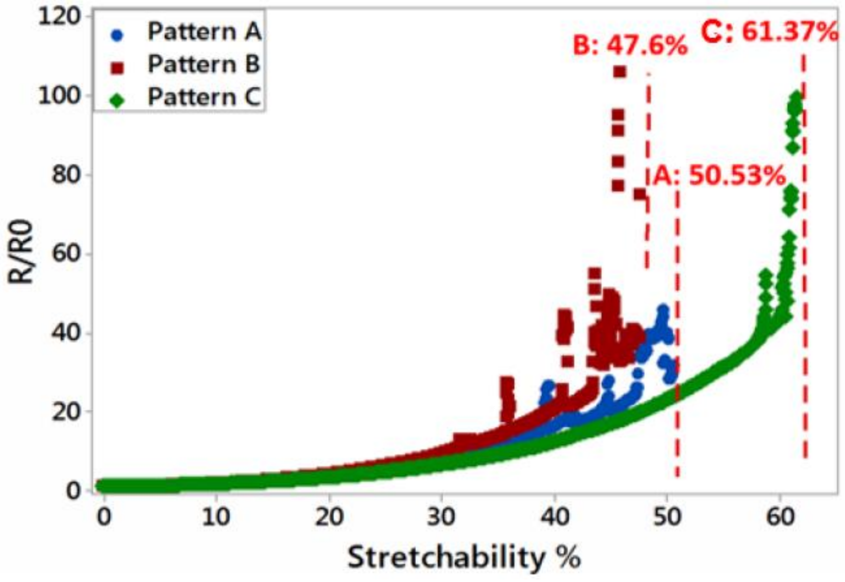


Fig.9 Comparison of the normalized resistances (R/R0) of typical performances of each pattern (The initial value for the resistance, R0 is 7 Ω).

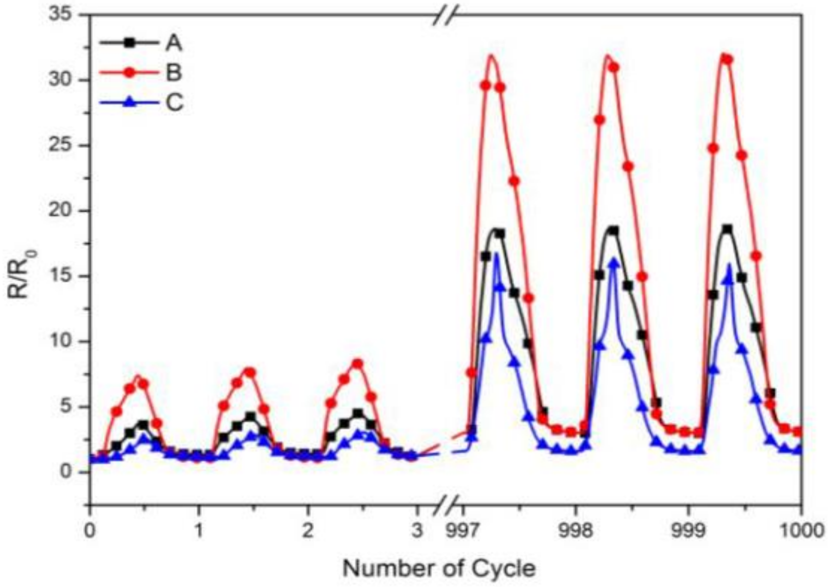


Fig.10 Developing of the normalized resistance for the first and last 3 cycles for patterns A, B, and C.

M. Mosallaei. et al. doi: 10.3390/mi9120645

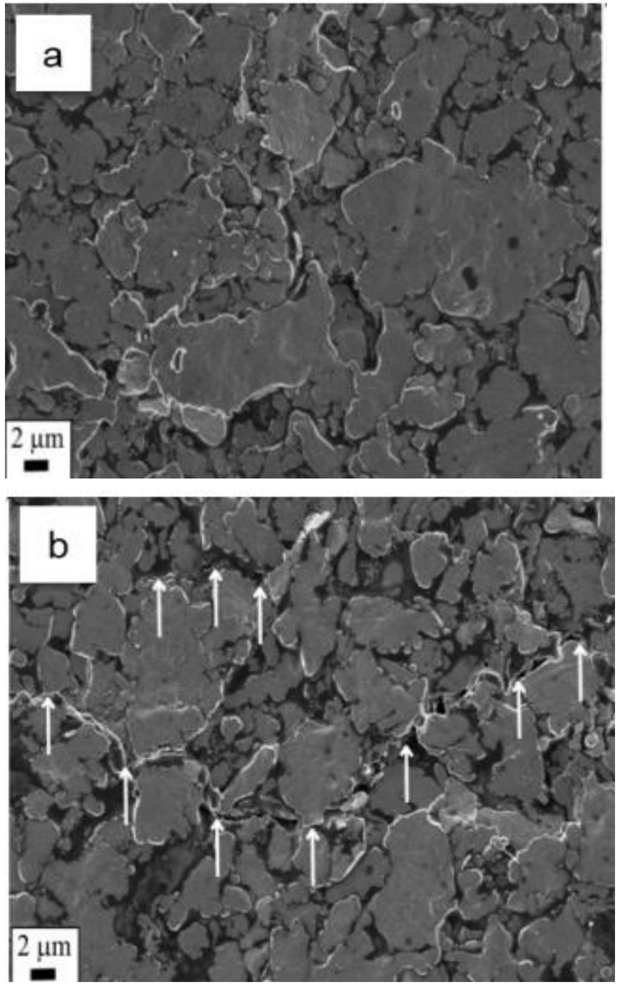
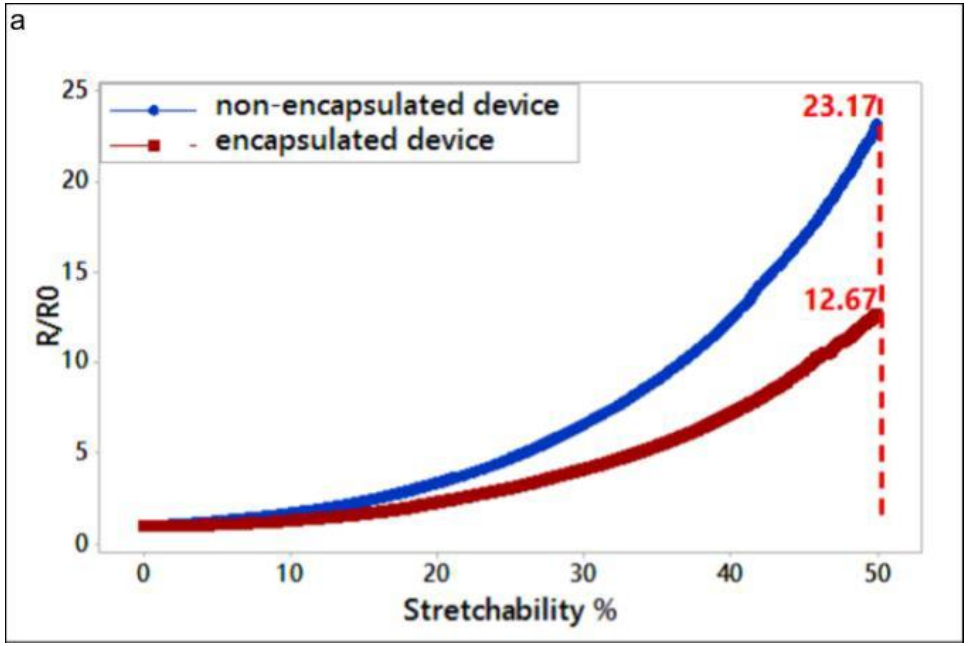


Fig.11 FESEM image from the surface of the printed conductive ink on the TPU substrate in relaxed form for (a) fresh sample, (b) sample after 1000 cycles,

Non-encapsulated Vs. Encapsulated



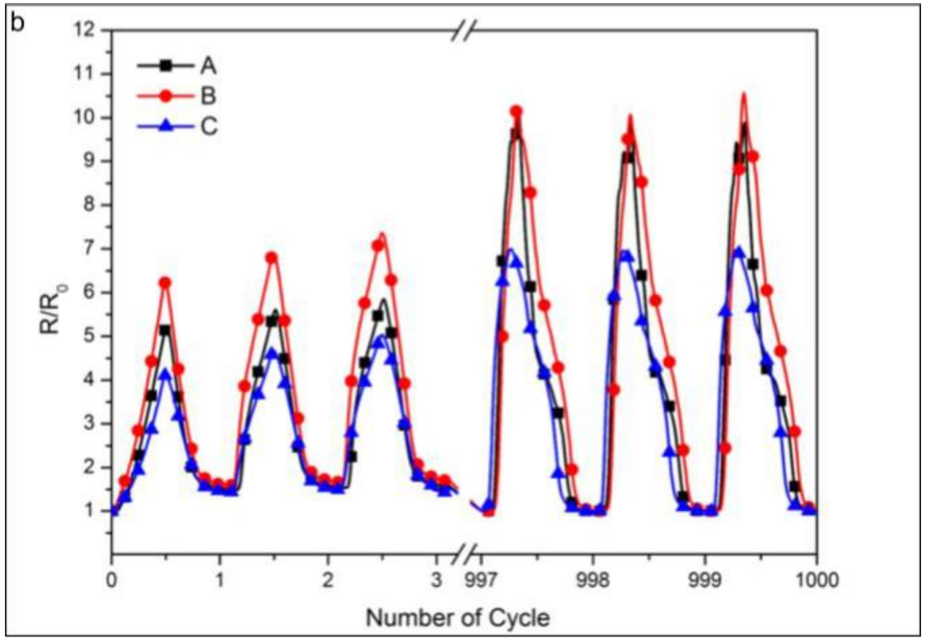


Fig12. (a) Normalized resistances of non-encapsulated and encapsulated interconnects with pattern C in stretching test (up to 50%). (b) Developing of the normalized resistance for the first and last 3 cycles for devices with patterns A, B, and C (with TPU encapsulating layer).

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Effect of encapsulation layer

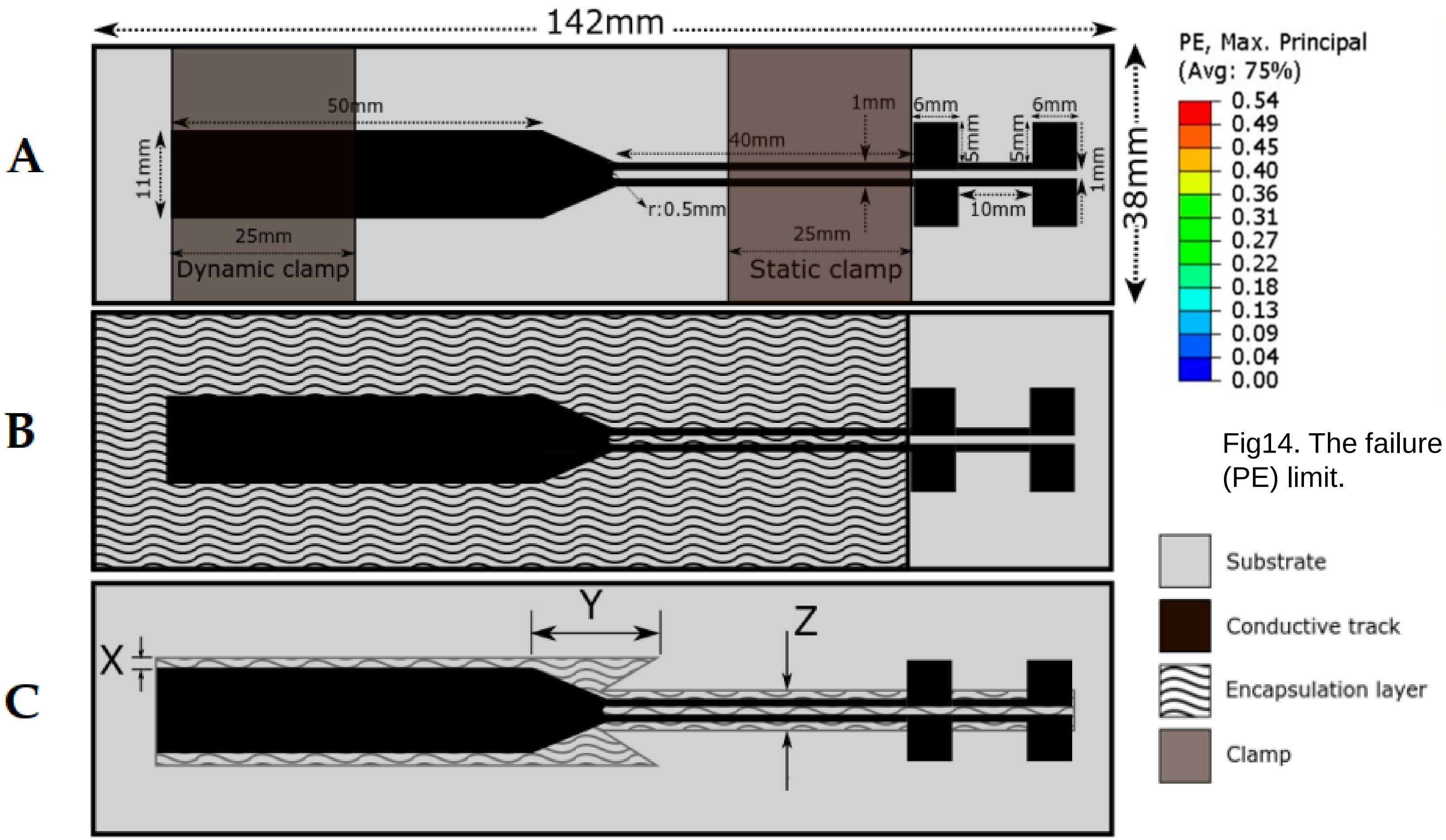

Fig13. A schematic of stretchable interconnects. The dimensions of the substrate, conductive track and clamps are the same for all cases. (A) a non-encapsulated sample (Set 1). (B) An entirely encapsulated sample (Set 3 and Set 5) (except for the pads used for electrical characterization)corresponding to Figure 2B,D. (C) A partially encapsulated sample (Set 2 and Set 4) (X, Y, and Z are offsets) corresponding to Figure 2A,C.

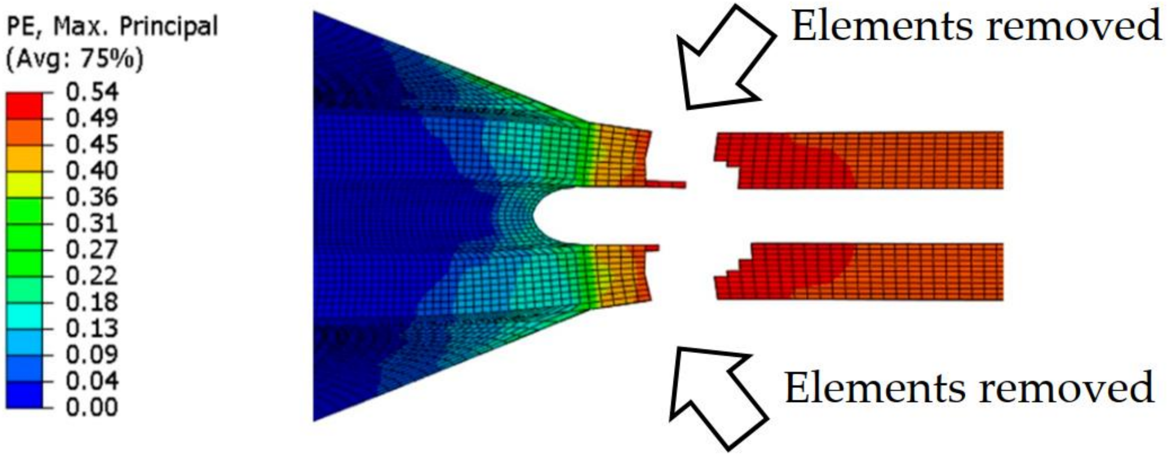

Fig14. The failure zone on the conductive track after the critical plastic strain (PE) limit.

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Single pull-up test

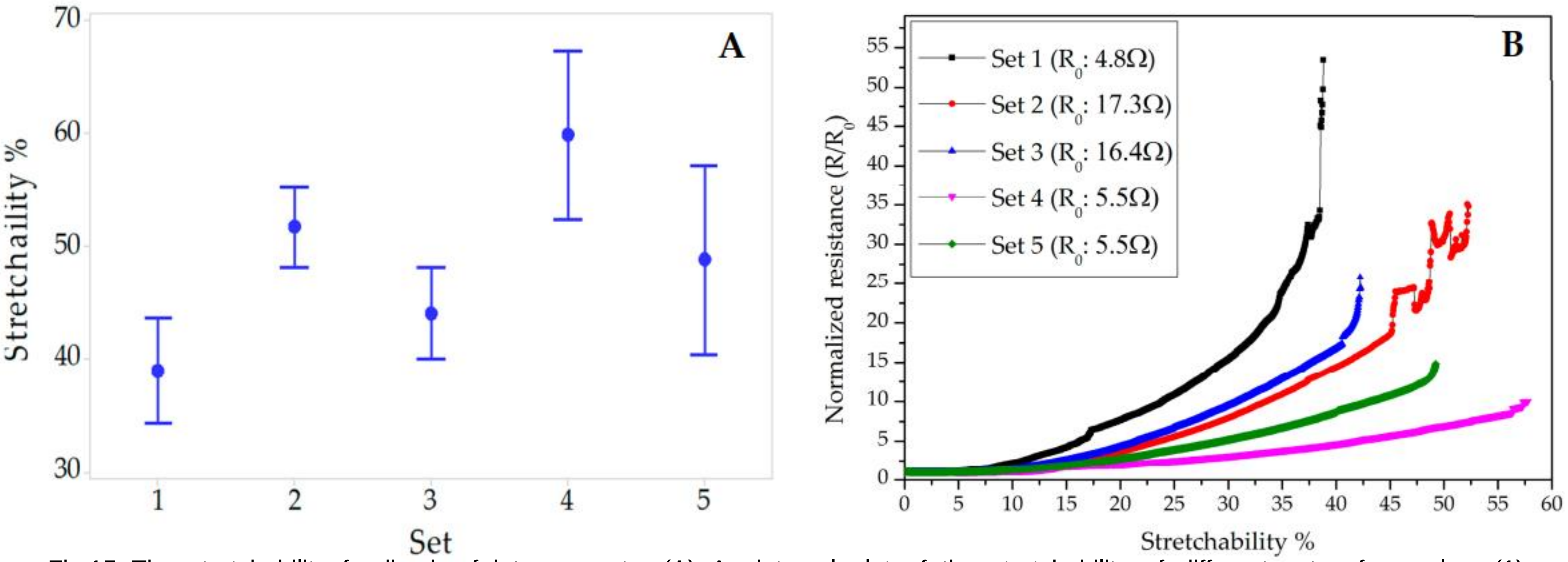

Fig.15 The stretchability feedback of interconnects. (A) An interval plot of the stretchability of different sets of samples: (1) non-encapsulated, (2) partially ink-encapsulated, (3) entirely ink-encapsulated, (4) partially TPU-encapsulated, and (5) entirely TPU-encapsulated; the mean values are 38.9%, 51.7%, 44.01%, 59.84%, and 48.81%, respectively. (B) Comparison of normalized resistances of a typical performance of each samples. Initial resistances (R0) are 4.8, 17.3, 16.4, 5.8, and 5.5 Ω for sets 1–5, respectively.

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Cyclic test

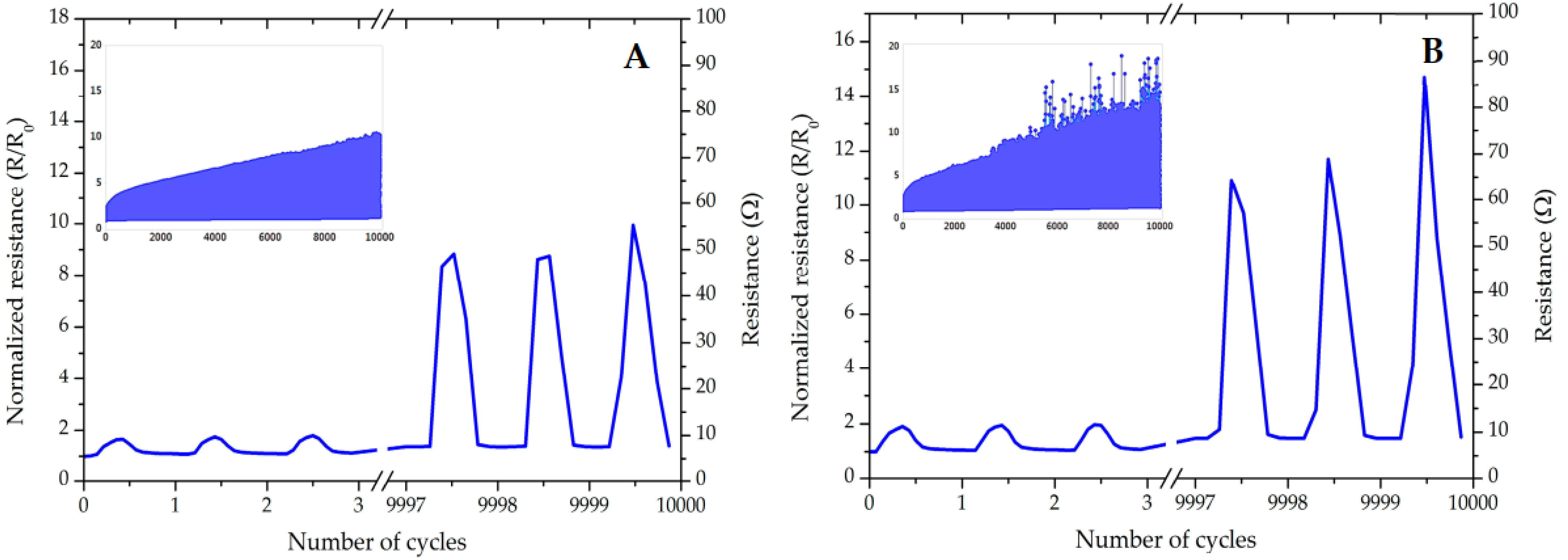

Fig.16 The resistances during 10,000 cycles at 10% stretching. (A) Partially TPU-covered, R0: 5.4 Ω. (B) Entirely TPU-covered, R0: 6.1 Ω. The insets are the overall trend during all the cycles.

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Summary

- Stretchable electronics have attracted a large amount of attention in the last few years, since they can bring freedom of design in a variety of applications.
- Health monitoring systems are among the most beneficial applications using the concept.
- Materials and geometry can clearly affect on functionalities of the soft devices.
- Stress distribution on substrate is important in delamination, crack initiation, and crack propagation on the conductive path when the device is subjected to stress, and these can lead to the early failure of the devices.
- Improvement of stretchability by sacrificial zone
- Encapsulation layer and layout can improve the functionality of stretchable wirings.
- Using less materials would be economically/environmentally beneficial in large area production.

Thank You for Your attention! Questions?