Self-Assembly of Polypyrrole Micro-foam/Carbon Nanotube Composite Electrode for Flexible Supercapacitors

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Outline

- Introduction
- Motivation & Objectives
- Fabrication Technique
- Results & Discussion
- Conclusions

The Need of Flexible Energy Storage

Sensing

Transmission

Energy Storage Materials

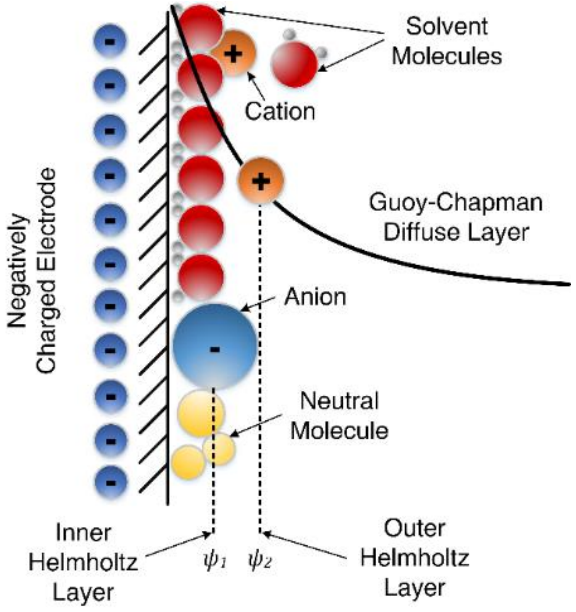
- Batteries
- Supercapacitors
- Hybrid Capacitors

Actuators

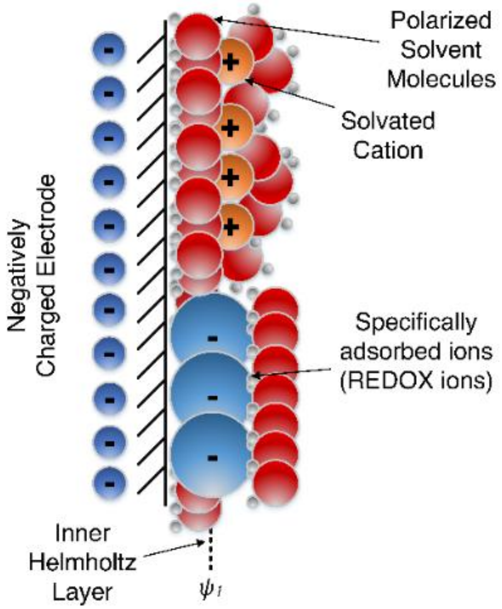
Display

Sources: Google Project Jacquard, Erogear, STMicroelectronics, Softrobotics

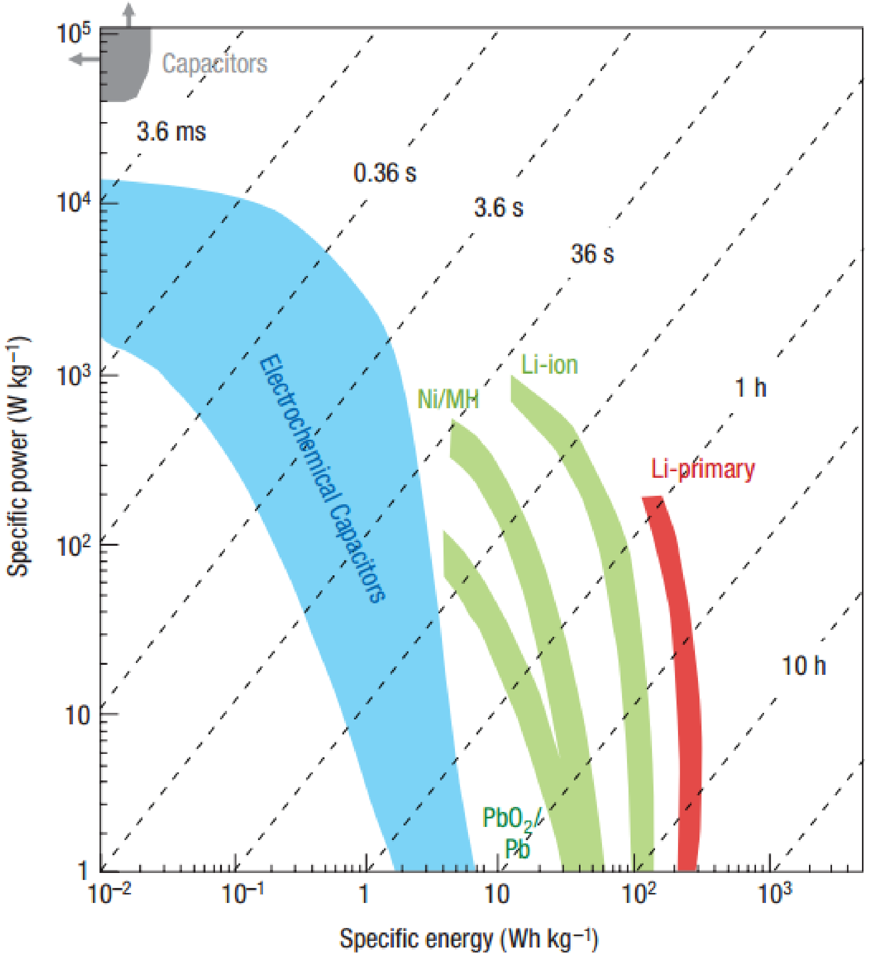
Introduction: Electrochemical Capacitors



General Representation of EDL Structure



General Representation of Pseudocapacitance Structure



Electrical Conductivity

Specific Surface Area

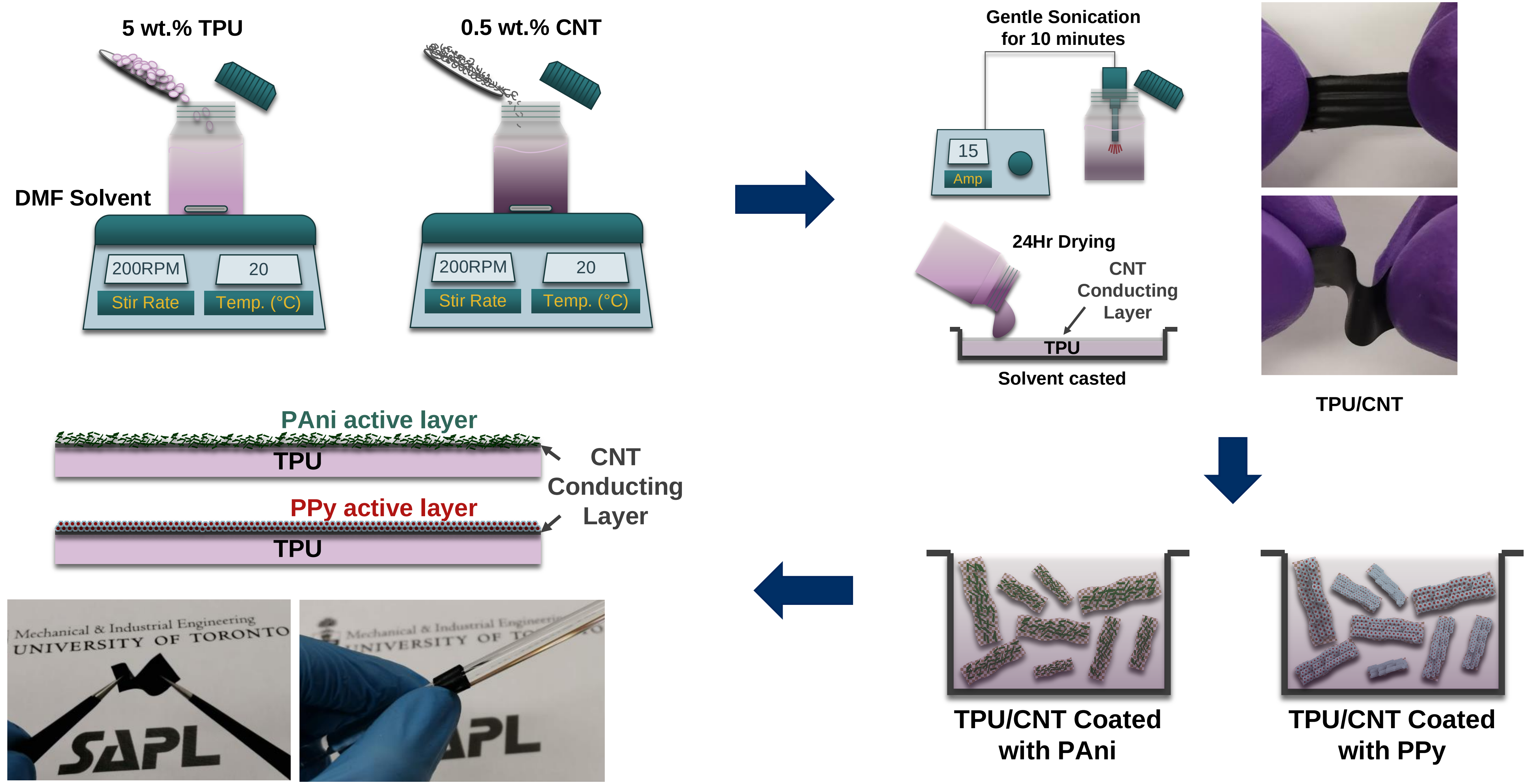
Specific Capacitance

Simon, P., & Gogotsi, Y. (2008). Materials for electrochemical capacitors. Nature Materials, 7(11), 845-854.

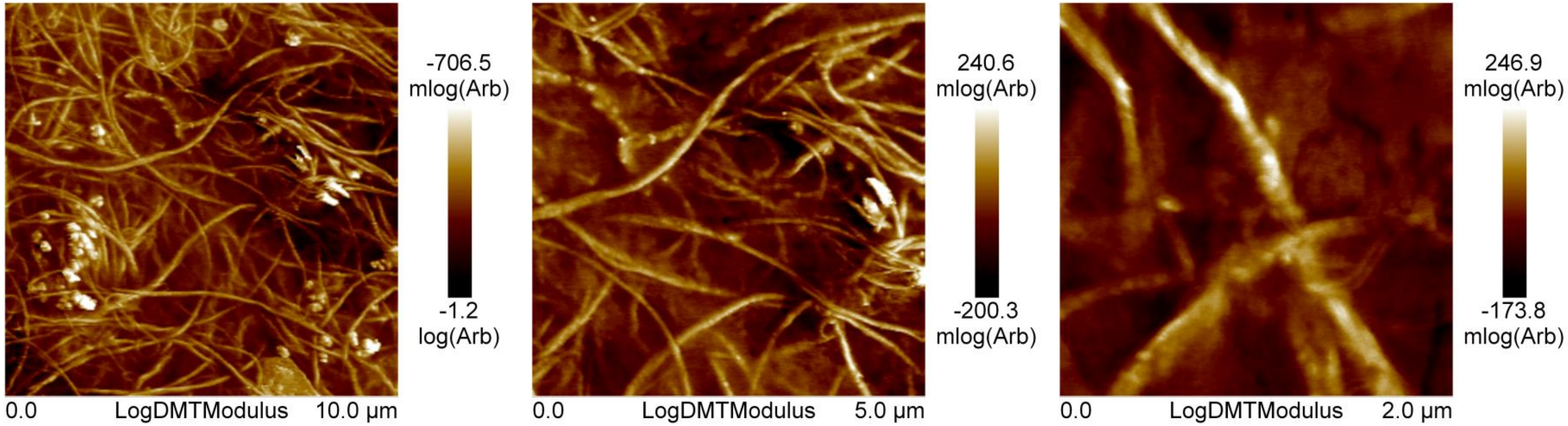
Gaps & Motivations

- Low energy densities with current textile energy storage devices, specifically ECs
- Excessive bending and stretching leading to pre-mature cell failure
- Lack of facile fabrication routes for microscale surface modification of EC textile electrodes
- Issues with electrode/electrolyte interfaces

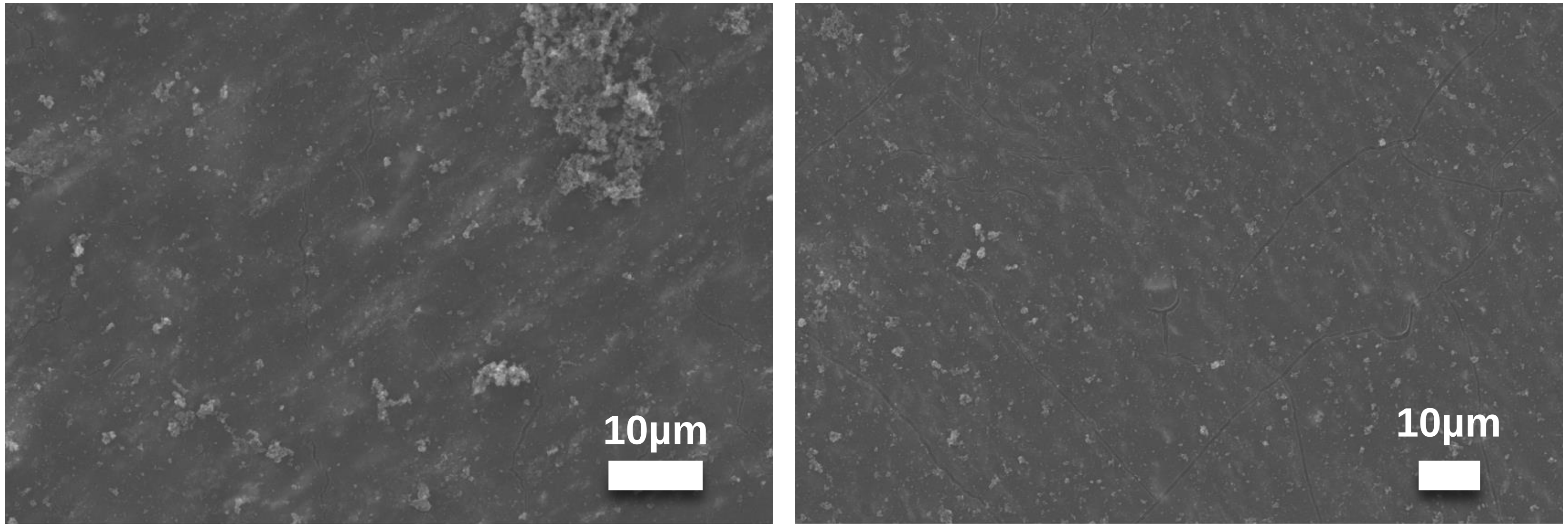
Fabrication: Multilayer Self-Assembly



Surface Morphology



- **TPU/CNT Surface**
- Increased surface roughness
- Conductive Layer ensures electron transfer



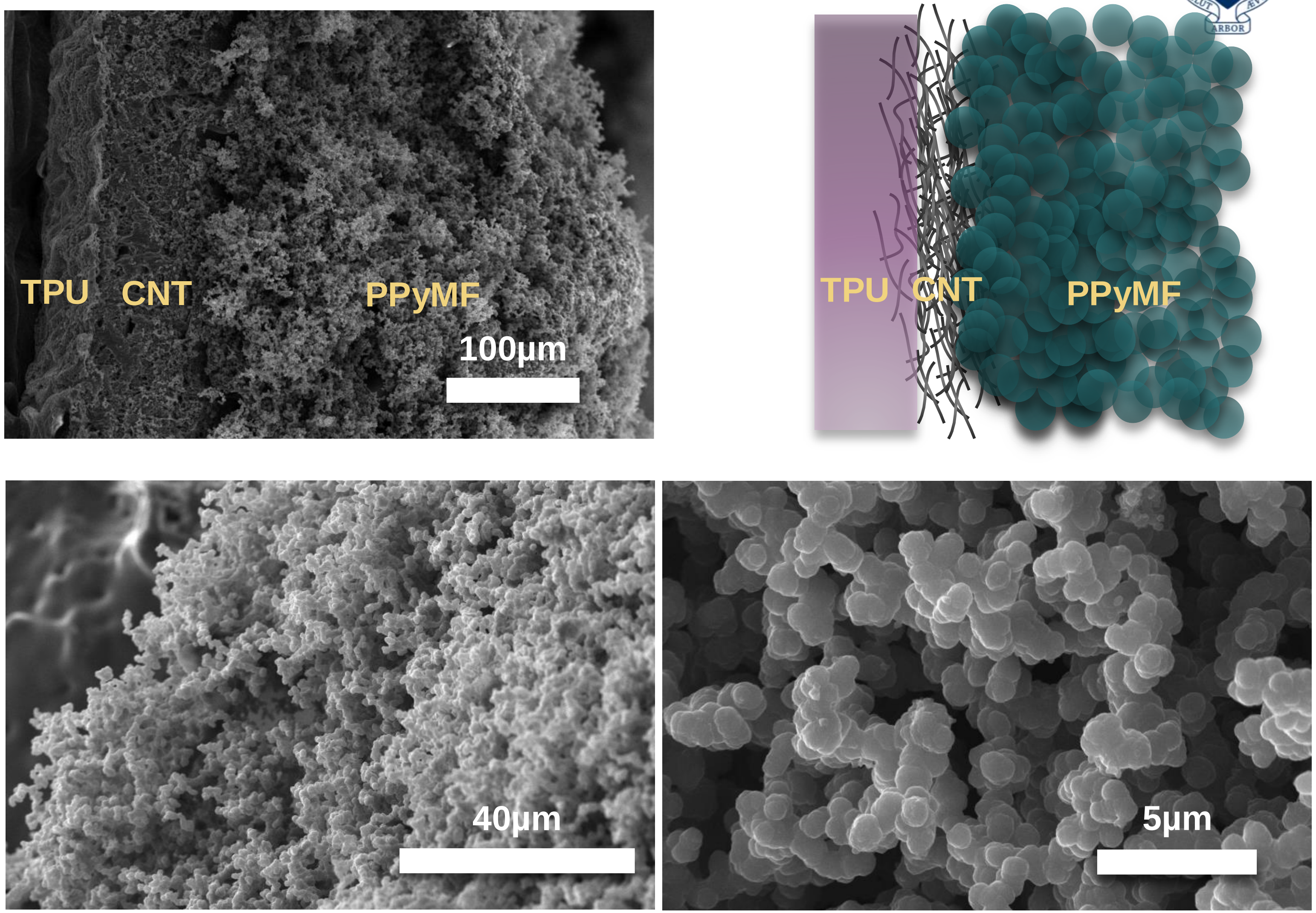
TPU/CNT/PAni Surface

- Flat morphology
- PAni did not form 3D porous structures
- Attributed to lack to incompatibility during polymerization

Multilayered TPU/CNT/PPyMF Structures

TPU/CNT/PPyMF Surface

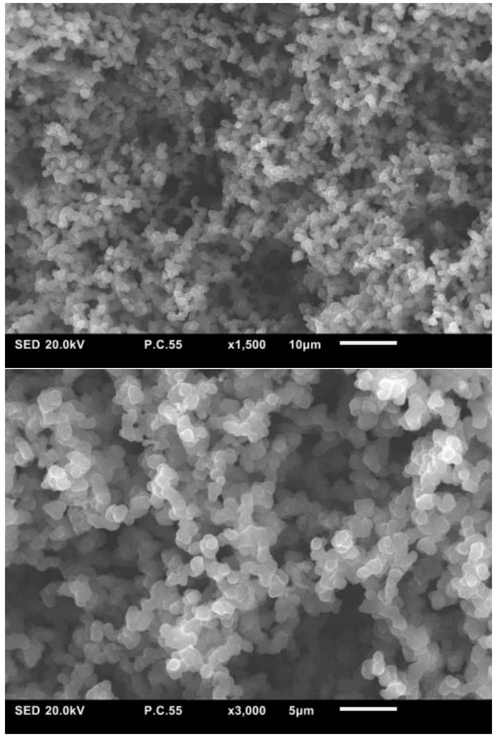
- Functionally graded morphology
- PPy microspheres formed 3D structures that facilitates electrolytic ion transfer
- Py monomer swelled TPU/CNT system during polymerization, allowing conductive polymer structures to adhere rightly on the flexible substrate

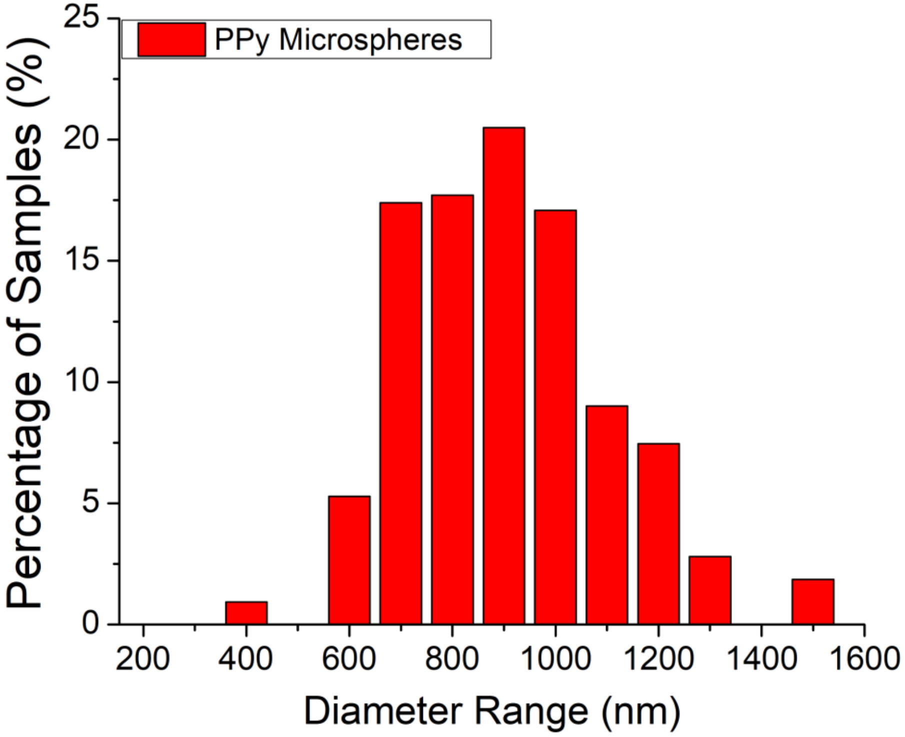


Multilayered TPU/CNT/PPyMF Structures

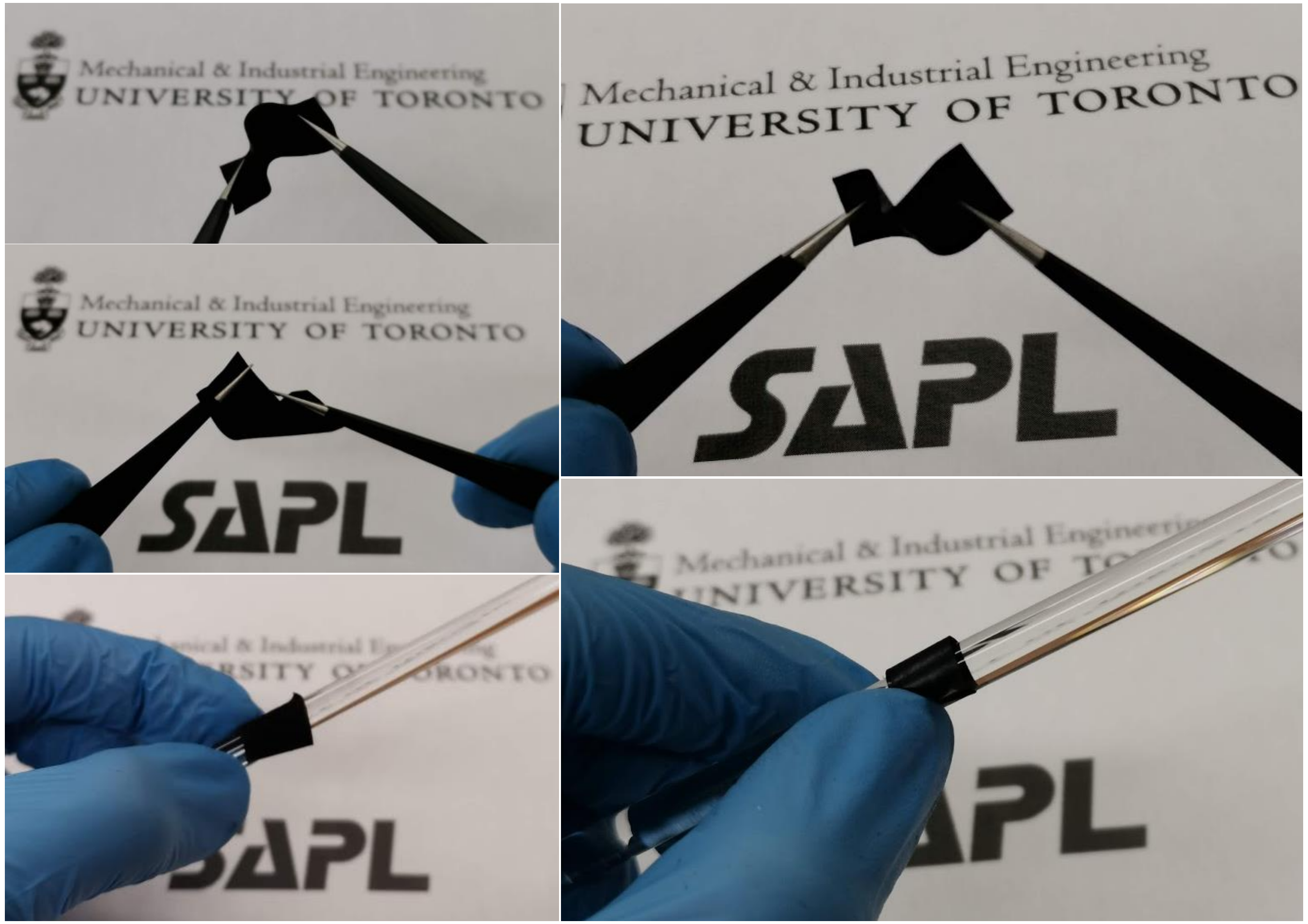
TPU/CNT/PPyMF Surface

- PPy Microspheres have diameters of about 851nm on average
- Active layer thickness is about 200-300µm
- Can be effectively tuned via changing self-assembly parameters





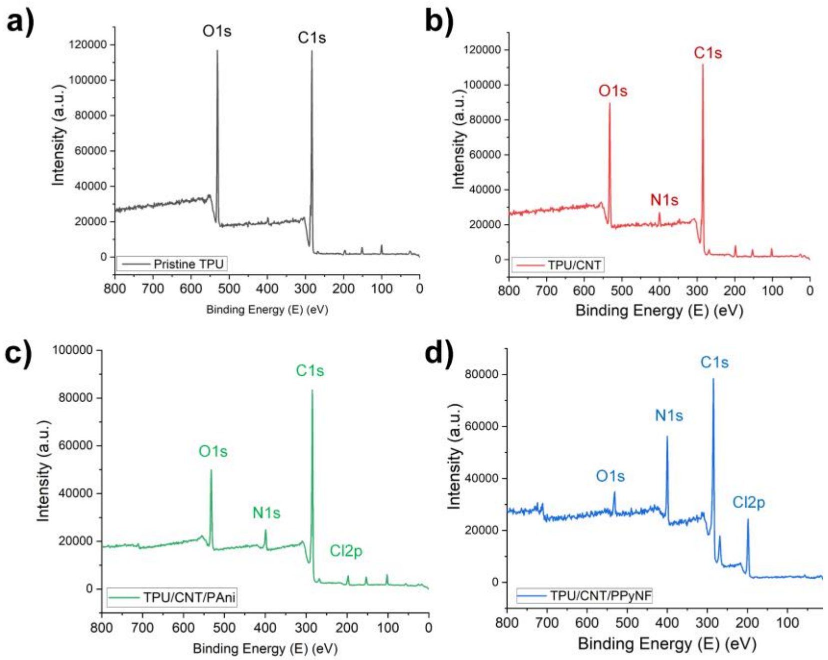
Electrode Flexibility



TPU/CNT/PPyMF **TPU/CNT/PAni**

- Both TPU/CNT/PPyMF and TPU/CNT/PAni electrodes experienced desirable flexibility during testing.
- No permanent deformation observed after repeated bending and flexing.

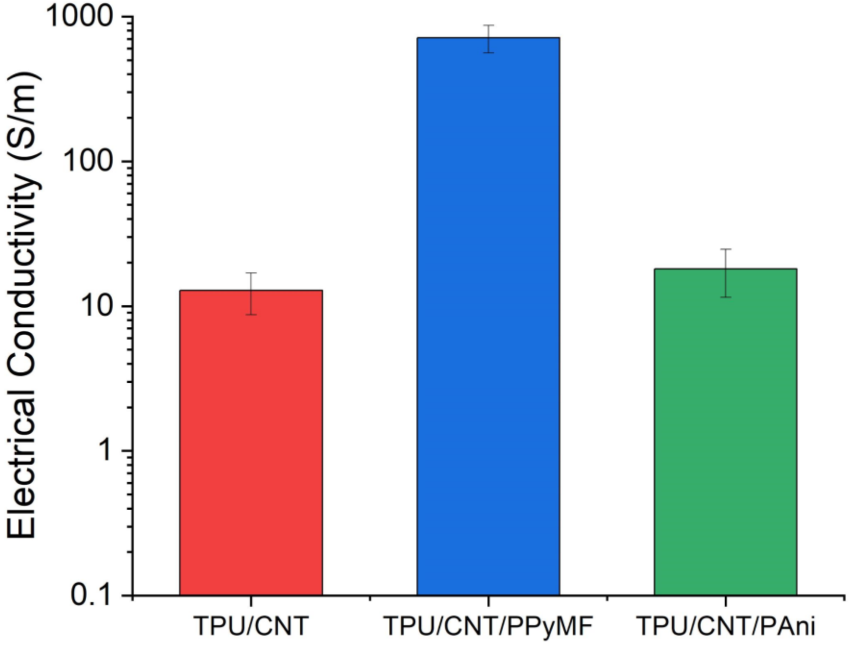
Electrical Conductivity and Surface Energy

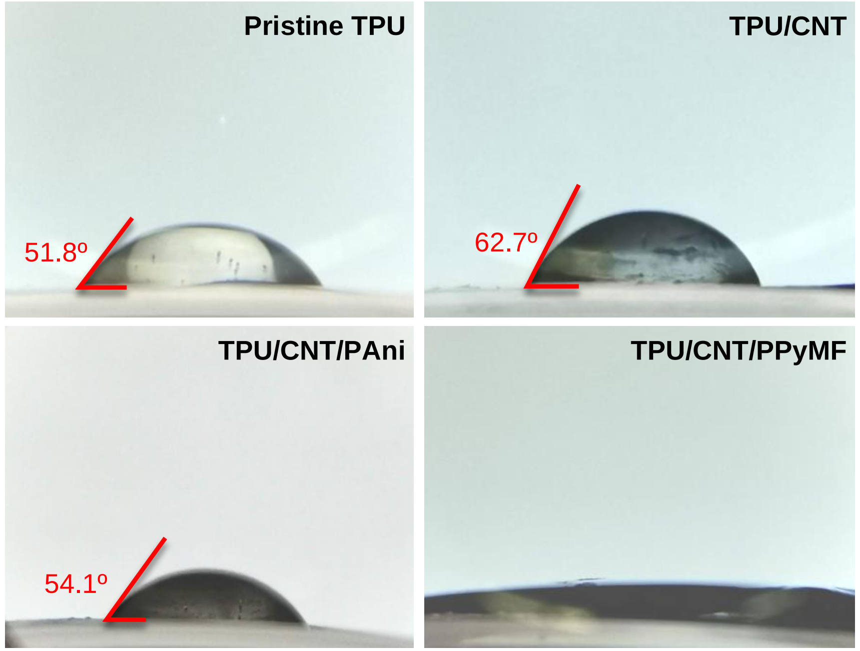


Sample Name	C1s (Atomic %)	N1s (Atomic %)	O1s (Atomic %)
Pristine TPU	71.86	1.98	23.37
TPU/CNT	72.73	3.04	19.62
TPU/CNT/PAni	75.55	6.92	13.16
TPU/CNT/PPyNF	70.03	16.32	4.86

- XPS was performed to confirm the material composition and to verify the growth of the conducting polymers on the surface.
- The increase in nitrogen content indicates successful polymerization since PAni and PPyNF contains nitrogen.
- For TPU/CNT/PAni, due to the lack of adherence of PAni on the surface of TPU/CNT, there was only a slight increase in carbon and nitrogen.
- On the other hand, TPU/CNT/PPyNF system showed a drastic increase in nitrogen content.

Electrical Conductivity and Surface Energy

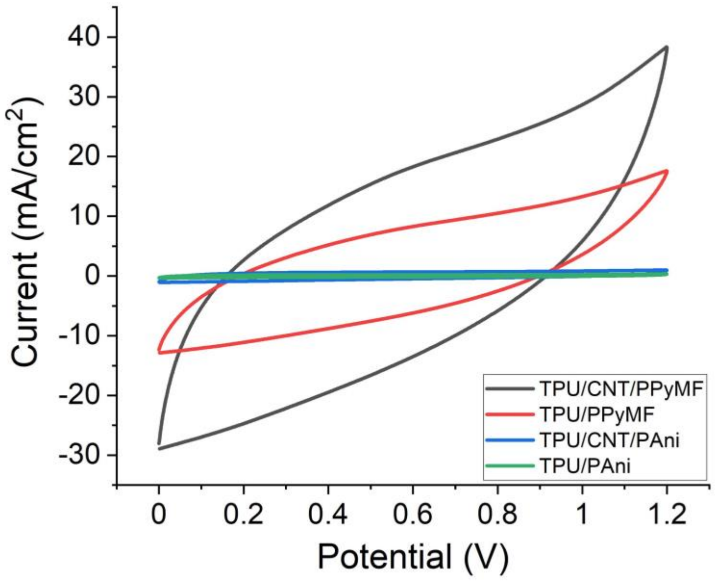


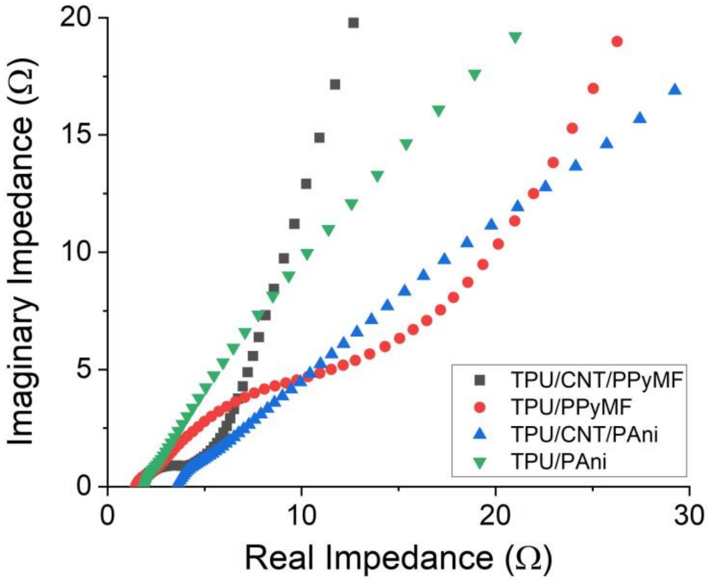


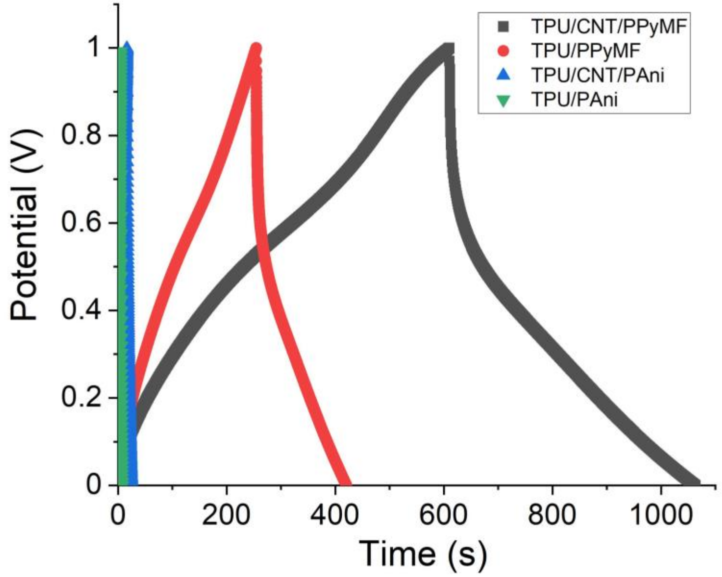
- Both TPU/CNT/PPyMF and TPU/CNT/PAni electrodes experienced an increase in electrical conductivity, however, due to the conductive polymer microsphere network formation, TPU/CNT/PPyMF has an electrical conductivity of 713.4 S/m on average.

- Water droplet test shows that the PPyMF structures are well structured to facility electrolytic ion transfer and would allow interactions with the entire internal surfaces.

Electrochemical Comparisons

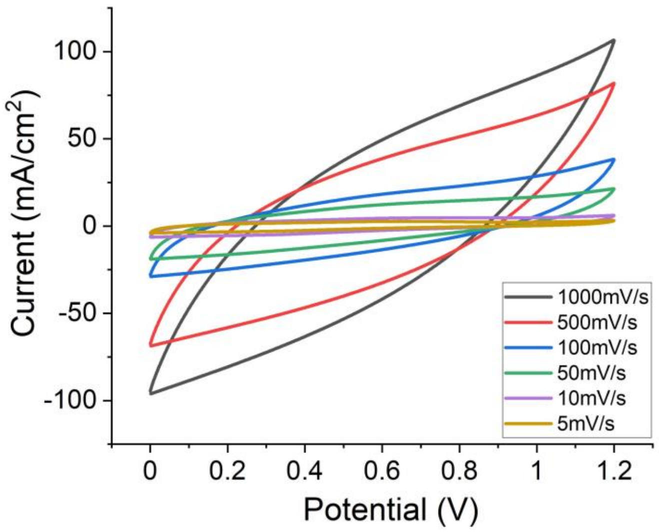


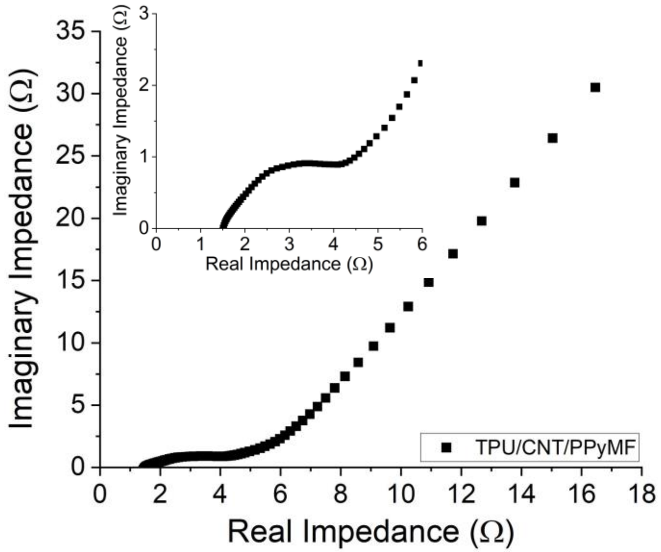


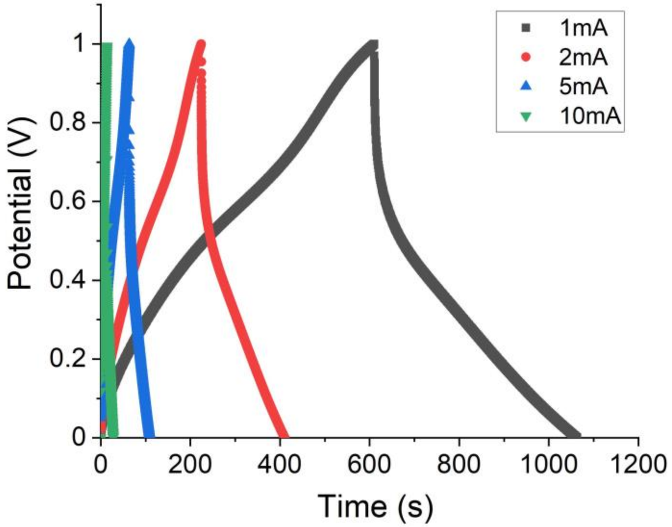


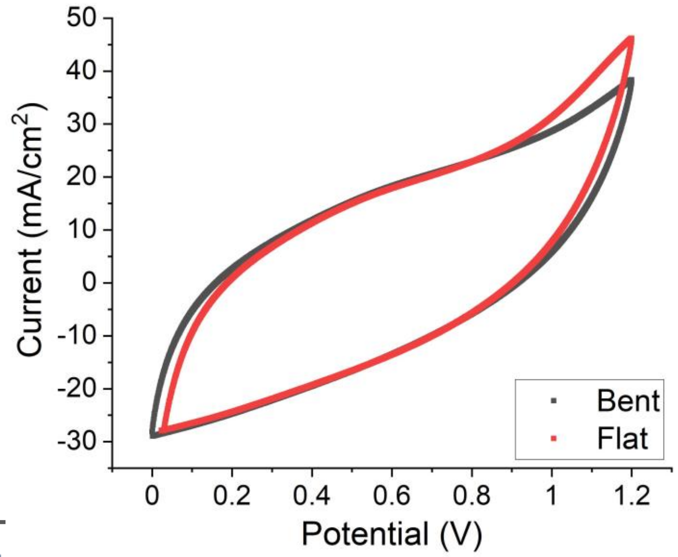
Both TPU/CNT/PPyMF and TPU/PPyMF electrodes offered an increase in the capacitance, however, it is shown that the addition of CNT layer contributed to more than 100% increase in the areal specific capacitance due to enhanced PPy growth and adhesion.

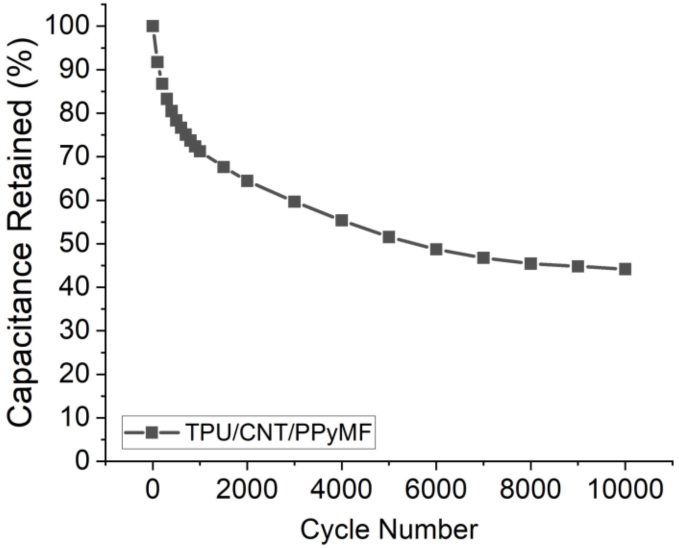
Electrochemical Analysis of TPU/CNT/PPyMF





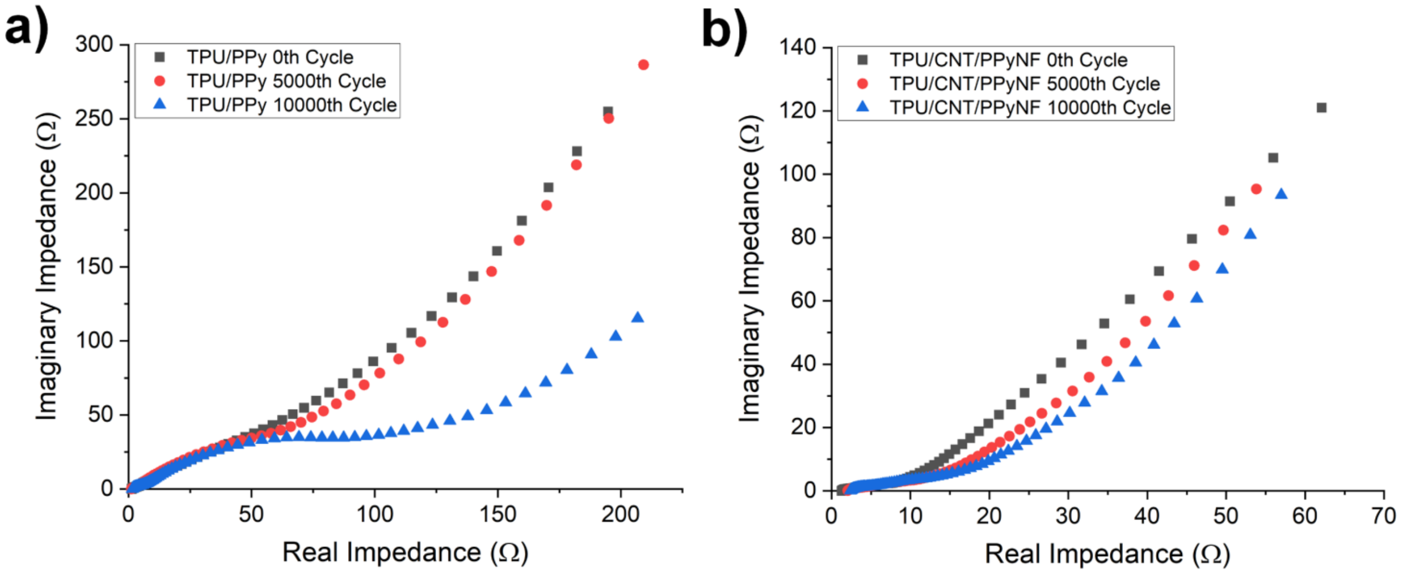






- Capacitance reached 712 mF/cm^2 at a scan rate of 5 mV/s
- Flexing showed minimal effect on capacitance
- Cycling degradation comparable to previous work

Electrochemical Analysis of TPU/CNT/PPyMF



- Throughout the cycling test, Nyquist plots for TPU/CNT/PPyNF stayed consistent during the cycling stability test, which is an indication that the interface between each layer was not substantially affected by the charging/discharging cycling.
- However, for the TPU/PPy samples, the charge transfer resistance at the electrode/electrolyte interface increased drastically, which may be attributed to the interfacial debonding between the PPy layer from the TPU surface.

Conclusions

- Methodology demonstrated a facile method to enhance electrode capacitance performance via microstructuring.
- Sandwiched flexible TPU/CNT/PPyMF structure achieved a specific capacitance of 712 mF/cm^2.
- Conductive CNT middle layer aided the charge transfer during fabrication and therefore improved the overall performance.
- Repeated bending and stretching showed minimal impact on performance.

Thank You for Your Attention!