EPFL

Self-Charging Energy Harvesting System for Wearables

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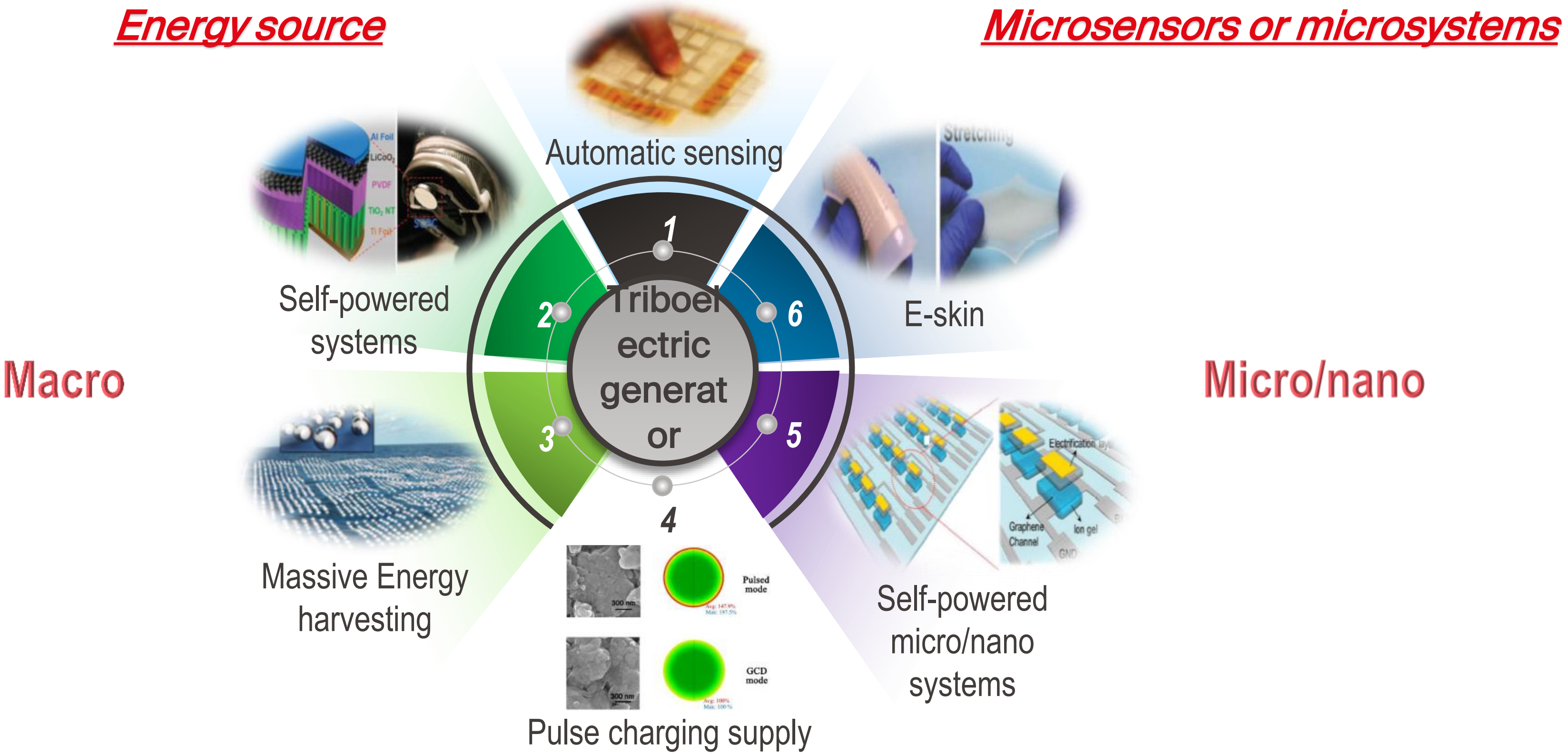
Outline

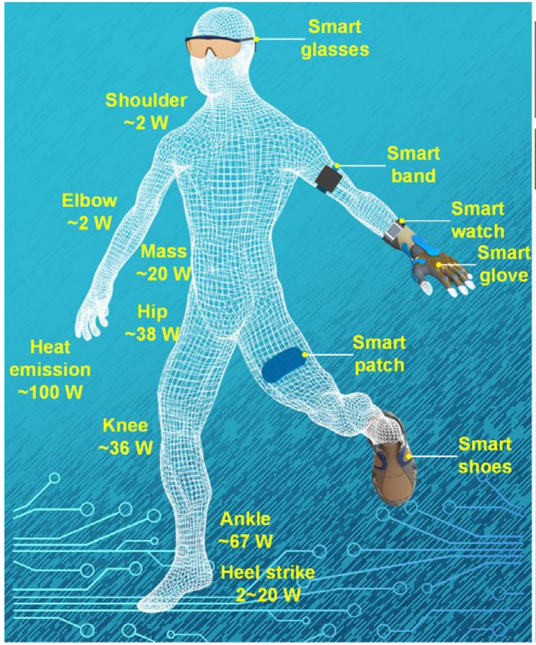
- Introduction about energy harvesting
- State-of-the-art research
- Objective of our research
- Diagram of our research
  - Electrostatic energy harvester
  - Micro supercapacitor
  - The management integrated circuit
  - Testing result of the microsystem
- Summary

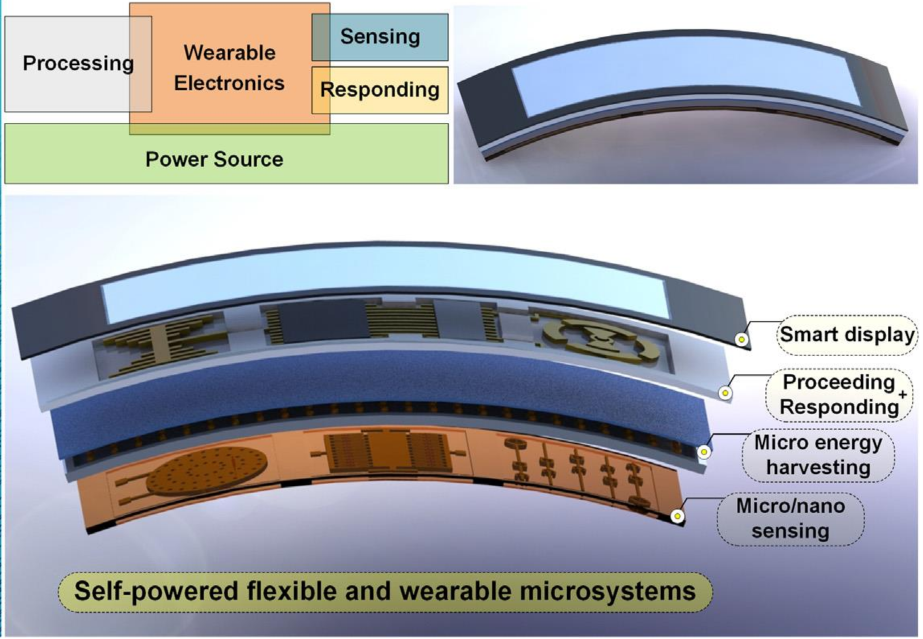
Introduction – Applications of Energy Harvesting



Introduction – Self-charging sensing microsystems

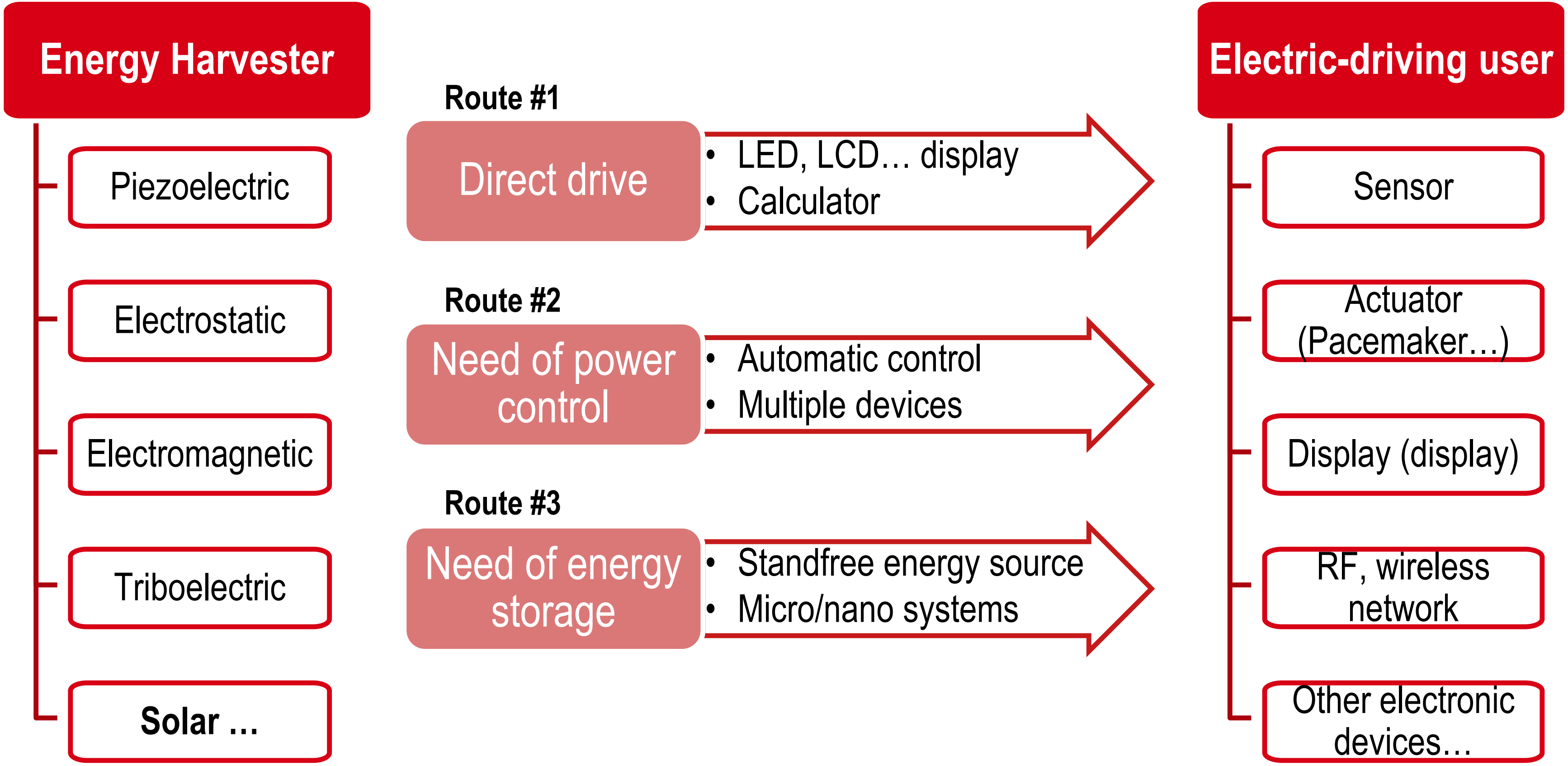
- Micro power energy source



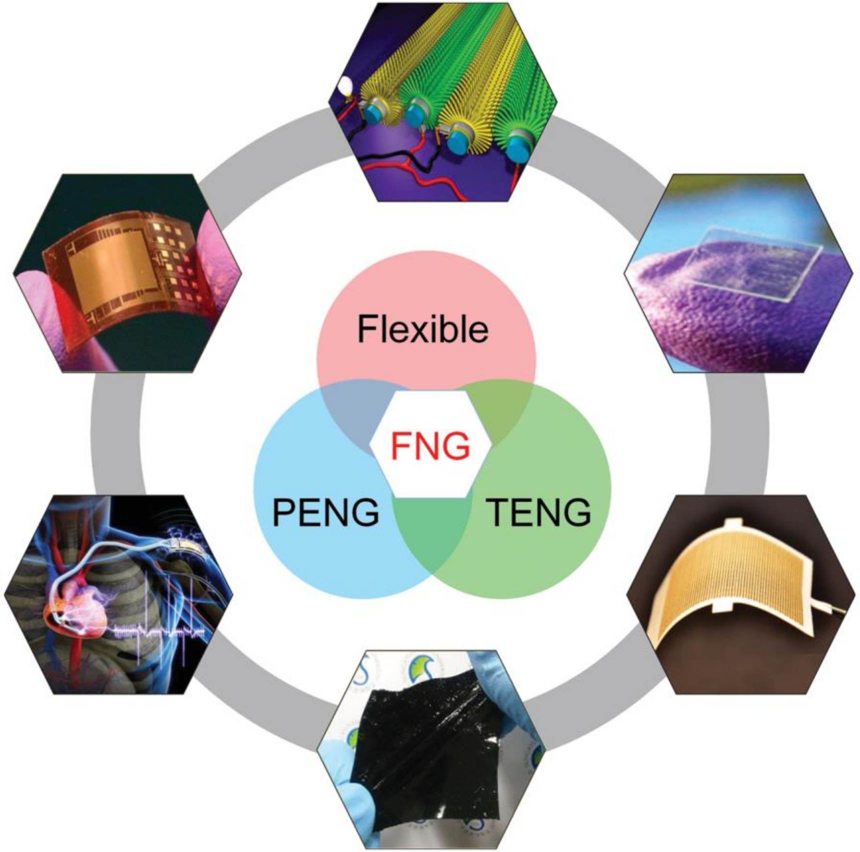


Xiao-Sheng Zhang, Mengdi Han, Beomjoon Kim, Jing-Fu Bao, Juergen Brugger, Haixia Zhang, Nano Energy 47 (2018) 410–426

Introduction – Diagram of self-charging sensing microsystems



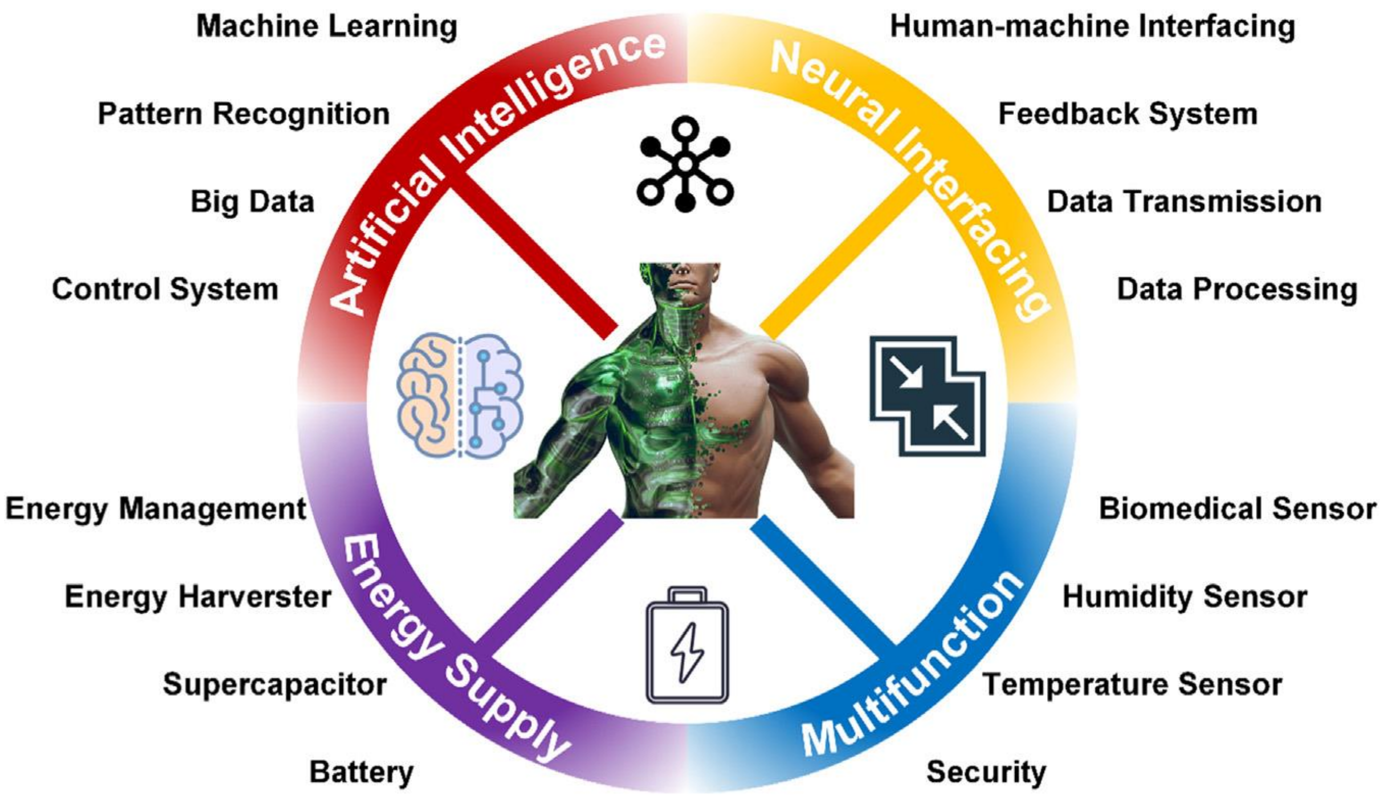
State-of-the-art – micro power source



Flexible energy harvesters are based upon the **coupling of flexible electronics and piezoelectric, triboelectric, and hybrid nanogenerators**.

Feng Ru Fan , Wei Tang , and Zhong Lin Wang, Adv. Mater. 2016, 28, 4283–4305

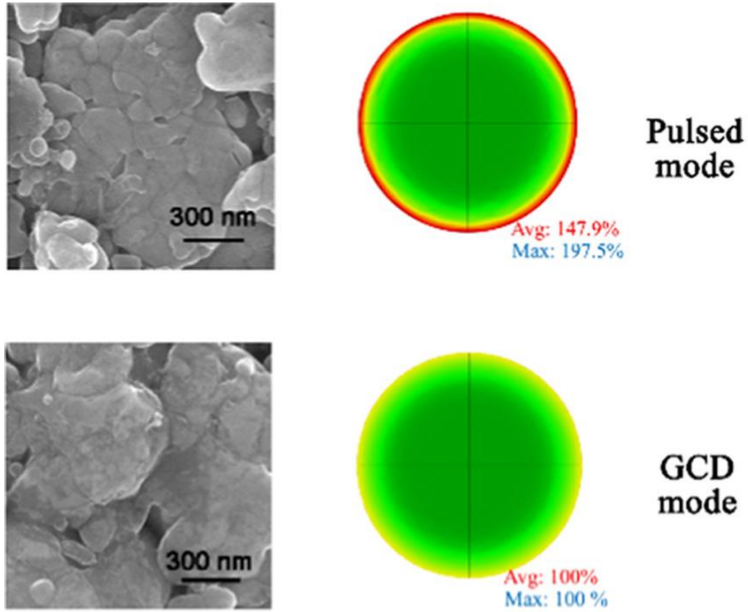
State-of-the-art – automatic sensing

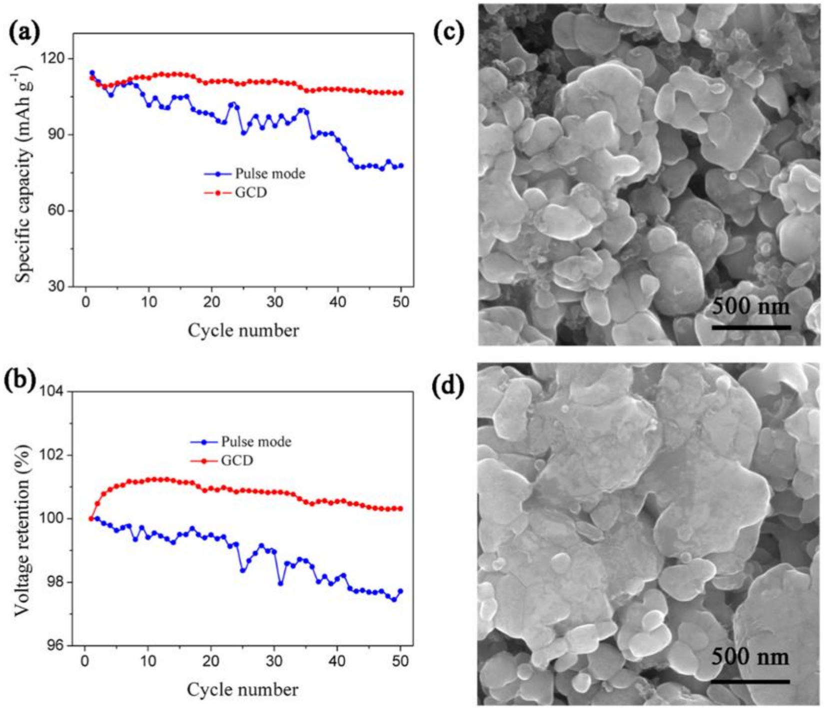


Haotian Chen, Yu Song, Xiaoliang Cheng, Haixia Zhang, Nano Energy 56 (2019) 252–268

State-of-the-art – other applications

- Pulse charging supply





Shaoqing Li, Qiang Wu, Dan Zhang, Zhongsheng Liu, Yi He, Zhong Lin Wang, hunwen Sun, Nano Energy 56 (2019) 555–562

Objective of the research

User terminals

Generator → **Interface circuit** (inductor, capacitor, resistor, diode, amplifier, etc.) → Storage → Sensors, electronic devices

- Instantaneous (pulse)
- V: AC, 1 ~1000 V
- I: few uA
- Impedance: MΩ

Power management circuit

- Voltage: DC, few V
- Impedance: kΩ

Energy input

- instantaneous (pulse), hundreds of V voltage, uA-level current, MΩ or higer

Energy output for charging the storage device

- Few V voltage (<3V for MSC)
- <kΩ impedance

Function of the interface circuit

- manage the electric energy of the generator and transfer to the storage device

Objective of the research:

to find an effective and efficient power supply solution.

Diagram of the research

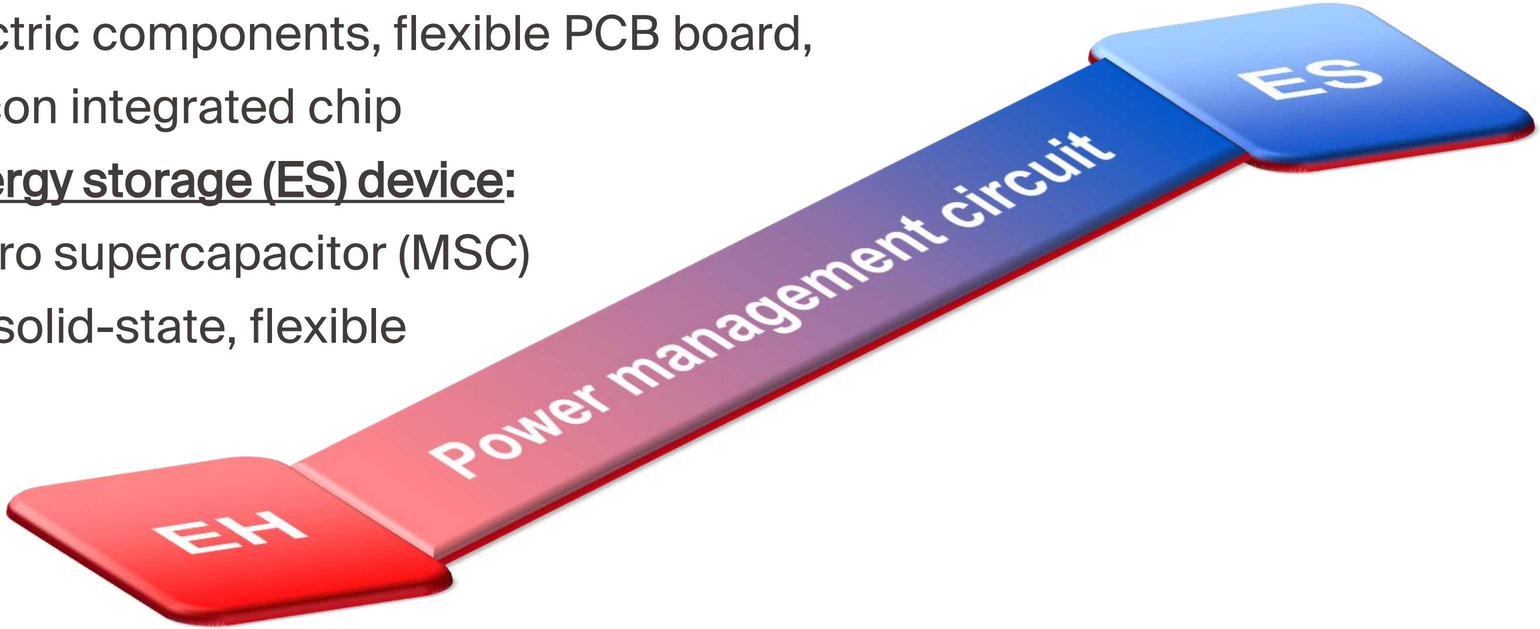
- Energy harvesting (EH) device: Electrostatic Energy Harvester
- Power management circuit:

  electric components, flexible PCB board,

  silicon integrated chip
- Energy storage (ES) device:

  Micro supercapacitor (MSC)

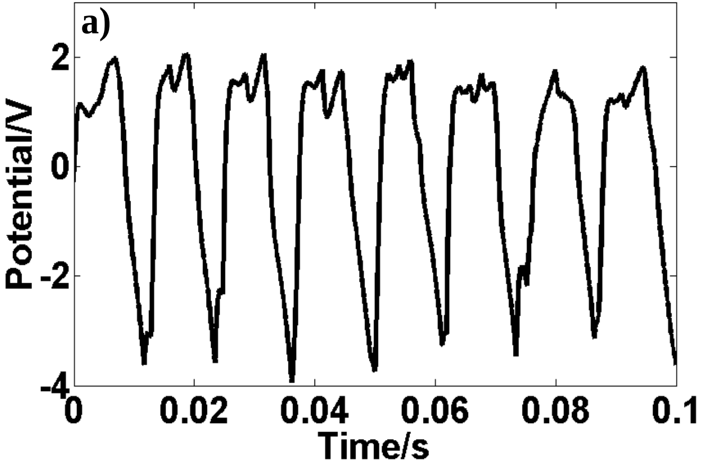
  All-solid-state, flexible



Electrostatic Energy Harvester

- Act like electrified triboelectric generator
- the output voltage peak of the harvester varies with vibration amplitude and frequency
- Vibration source: an exciter

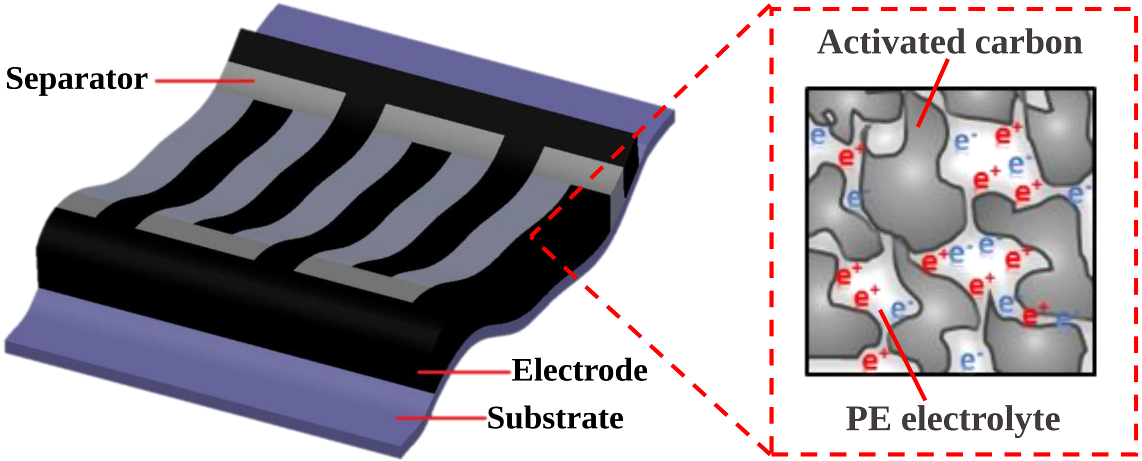
80Hz

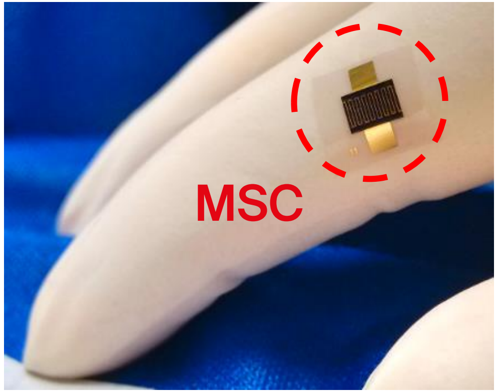


Indicator	Value
Range of input voltage	1.8~8.0 V
Switch frequency	1 kHz
Load regulation	< 1%
Output voltage	1 V
Conversion efficiency	> 85%

Flexible All-Solid-State Micro Supercapacitor

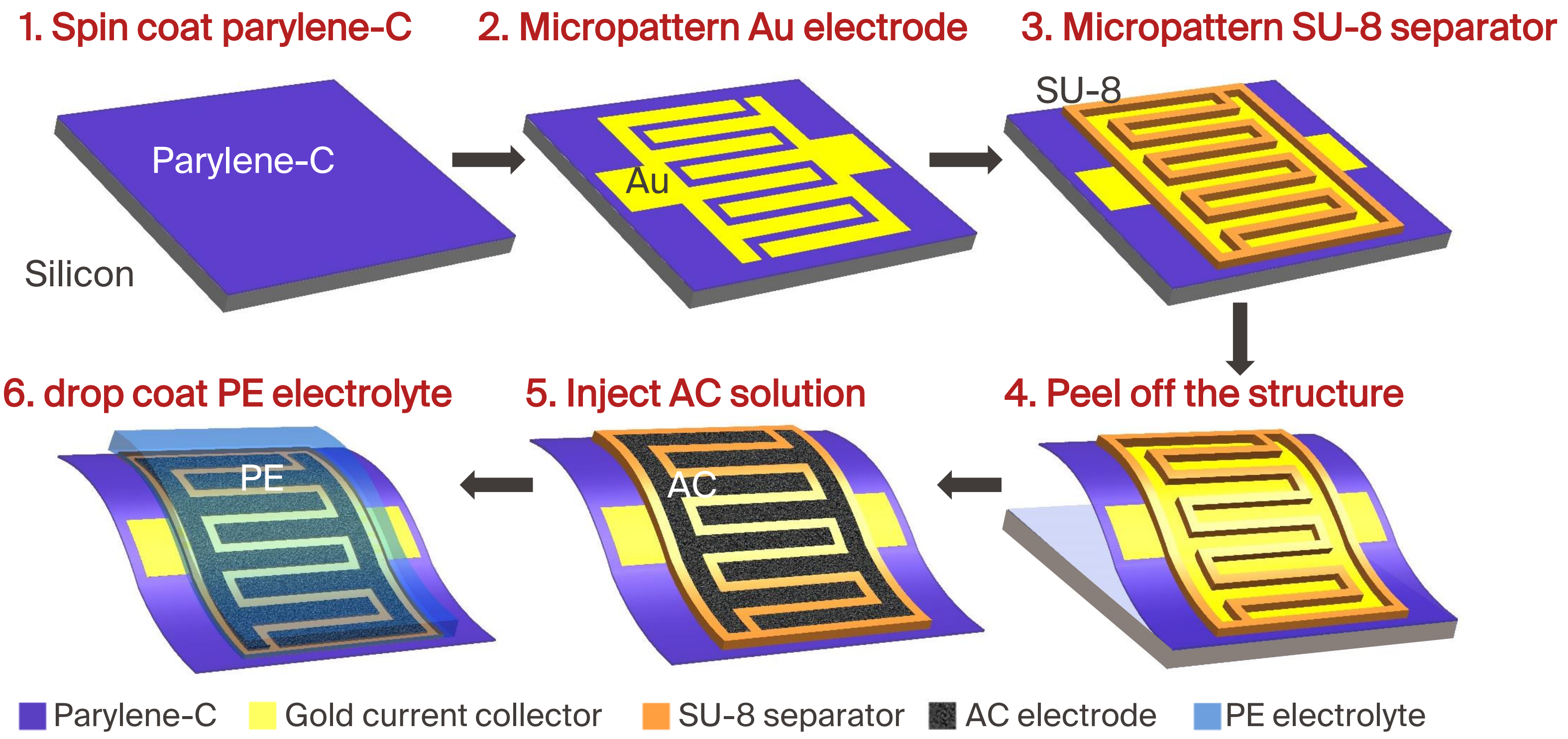
- Electrode: Interdigitated structure
- Electrode material: activated carbon
- Electrolyte: all-solid state, polyvinyl alcohol–phosphoric acid (PVA-H_3PO_4) polymer gel
- Substrate: parylene-C



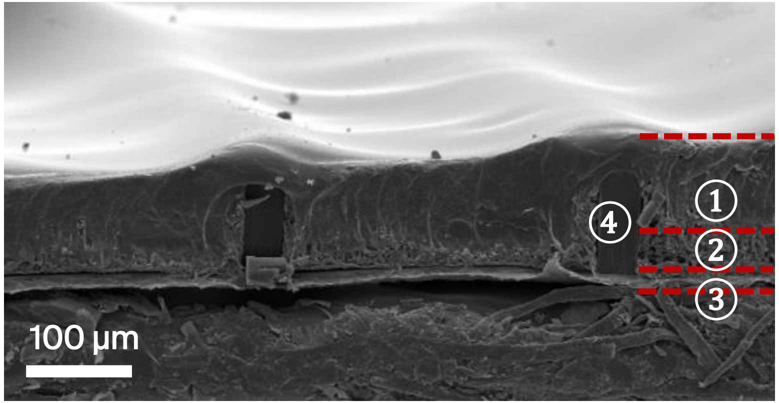


Micro Supercapacitor – Design and fabrication

- <u>Fabrication process:</u>



Micro Supercapacitor – Structure result

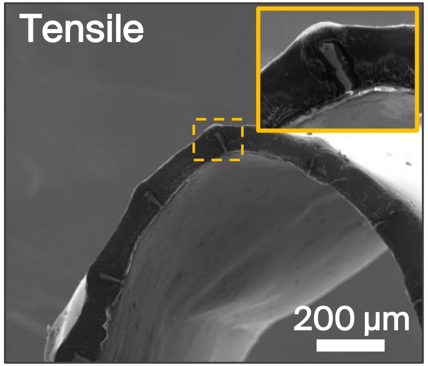


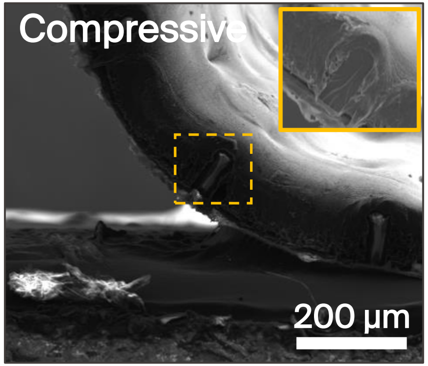
① P/E polymer gel electrolyte

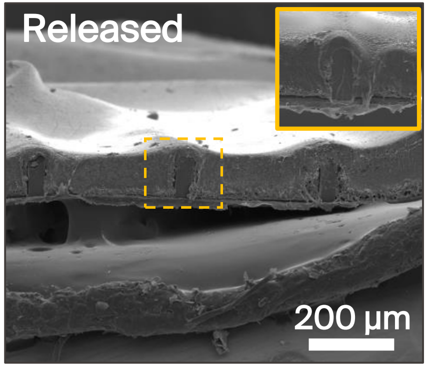
② AC electrodes

③ Parylene-C

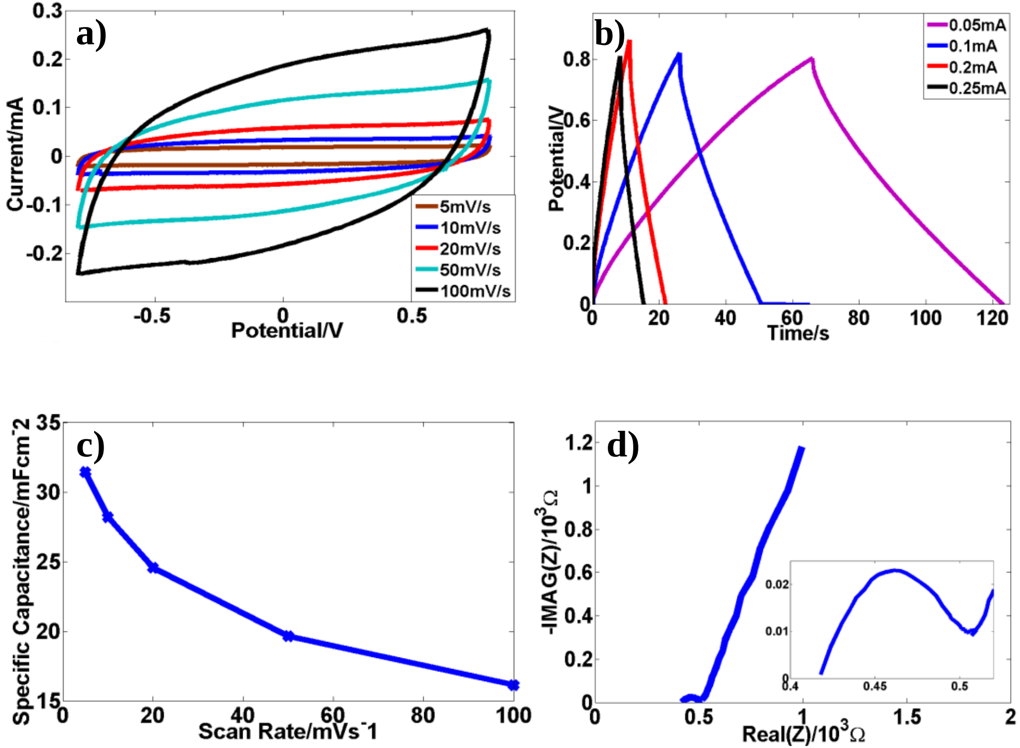
④ SU-8 Separator





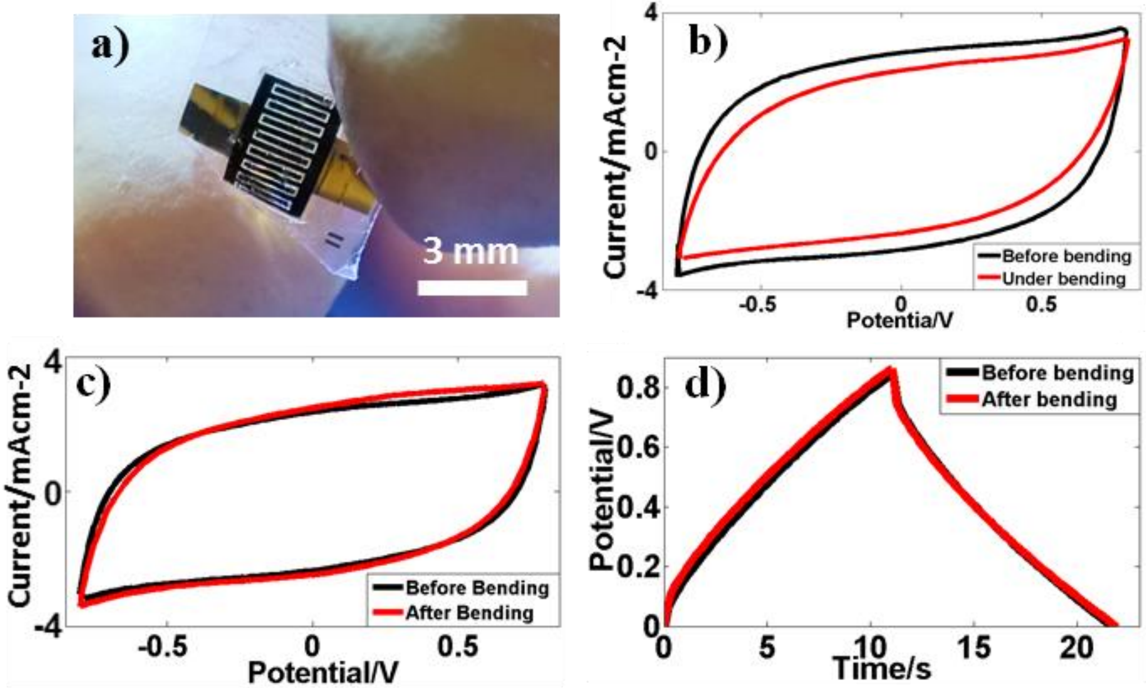


Micro Supercapacitor – Performance result



- (a) I-V curves at different scan rate (5~100mV/s)
- (b) Charging/discharging curves at different constant current
- (c) C-V curve: the specific capacitance ranges from 15.35 to 31 mF/cm^2.
- (d) EIS of the device, the testing frequency range: 0.1 to 100k Hz

Micro Supercapacitor – Performance result



(a) The MSC device under bending
(b) I-V curves w/ and w/o bending
(c) I-V curves before and after bending (40 cycles)
(d) Charging/discharging curves before and after bending

Power Management Circuit – Configuration

- There are mainly three components.
  - AC-AC converter: tremendously boost the output current at the expense of the output voltage
  - AC-DC converter: convert the AC signal to DC signal for next energy storage
  - Energy storage (temporary): store the electrical energy in a storage device, such as capacitor, inductor

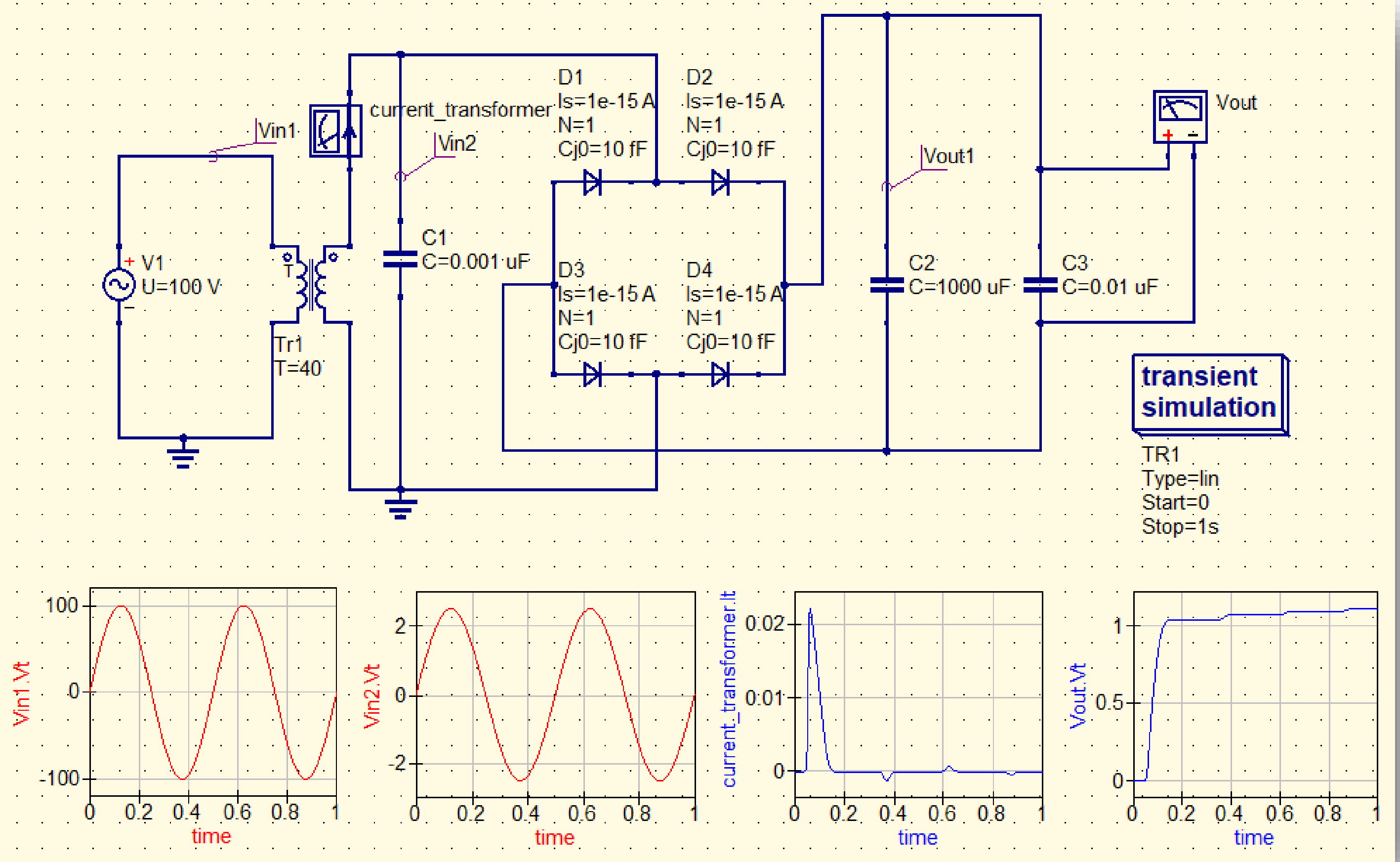
AC-AC converter → **AC-DC converter** → **Energy storage (temporary)**

AC-AC converter:
- Transformer
- Boost-buck converter

AC-DC converter:
- High-voltage diode
- Bridge rectifier

Energy storage (temporary):
- Capacitor
- Inductor
- Inductor-capacitor oscillating

Strategy 1: transformer + bridge rectifier + capacitor



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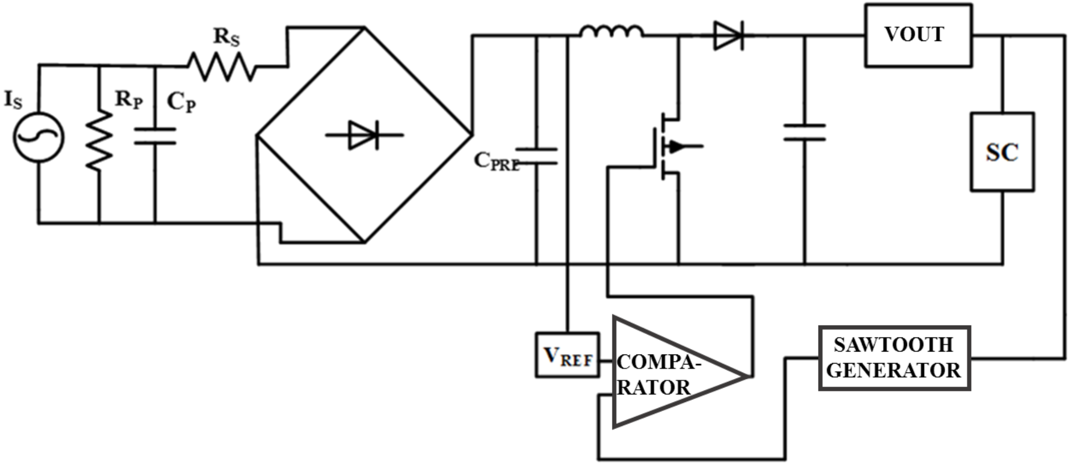
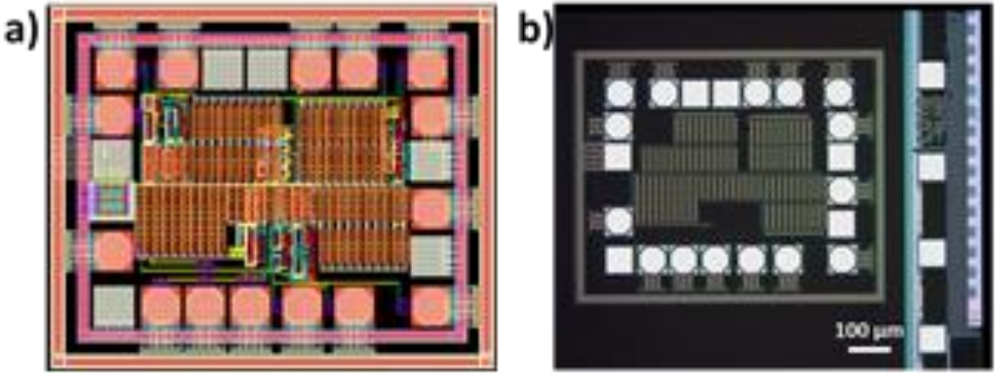
Management Integrated Circuit – Design and Fabrication



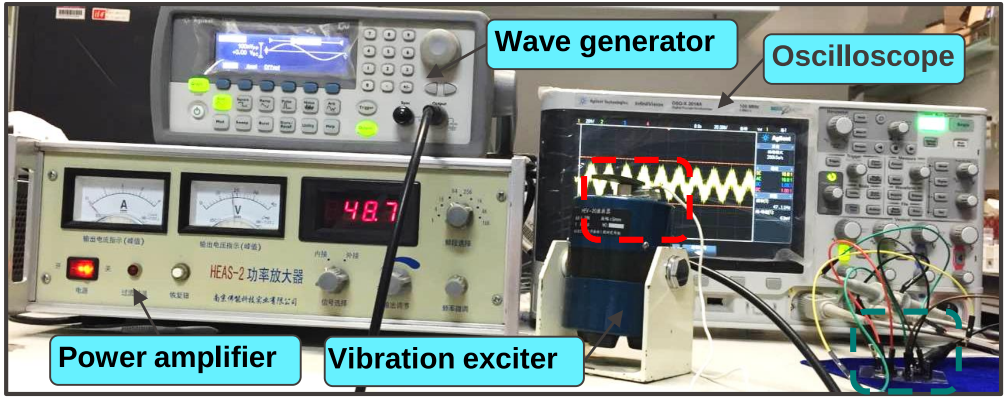
Strategy 2:
boost-buck converter +
bridge rectifier + capacitor

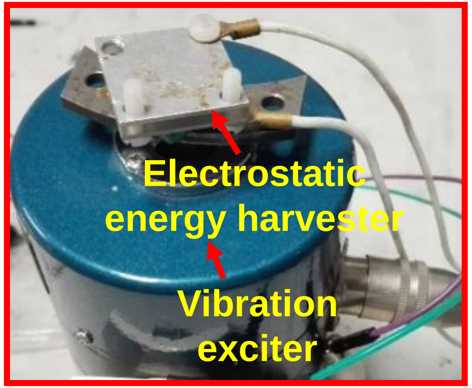


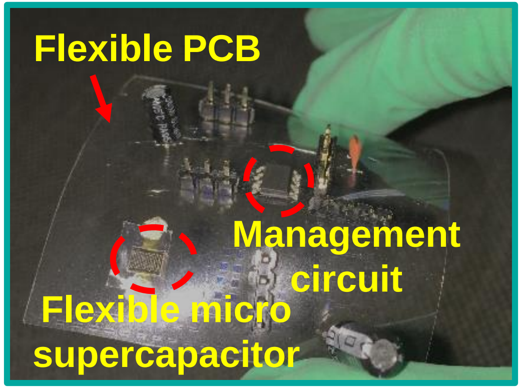
(a) The layout of the management circuit,
(b) The digital photograph of the management circuit.

- 2019 Spring Meeting of the European Materials Research Society (E-MRS)

Self-Charging microsystem – Testing Result

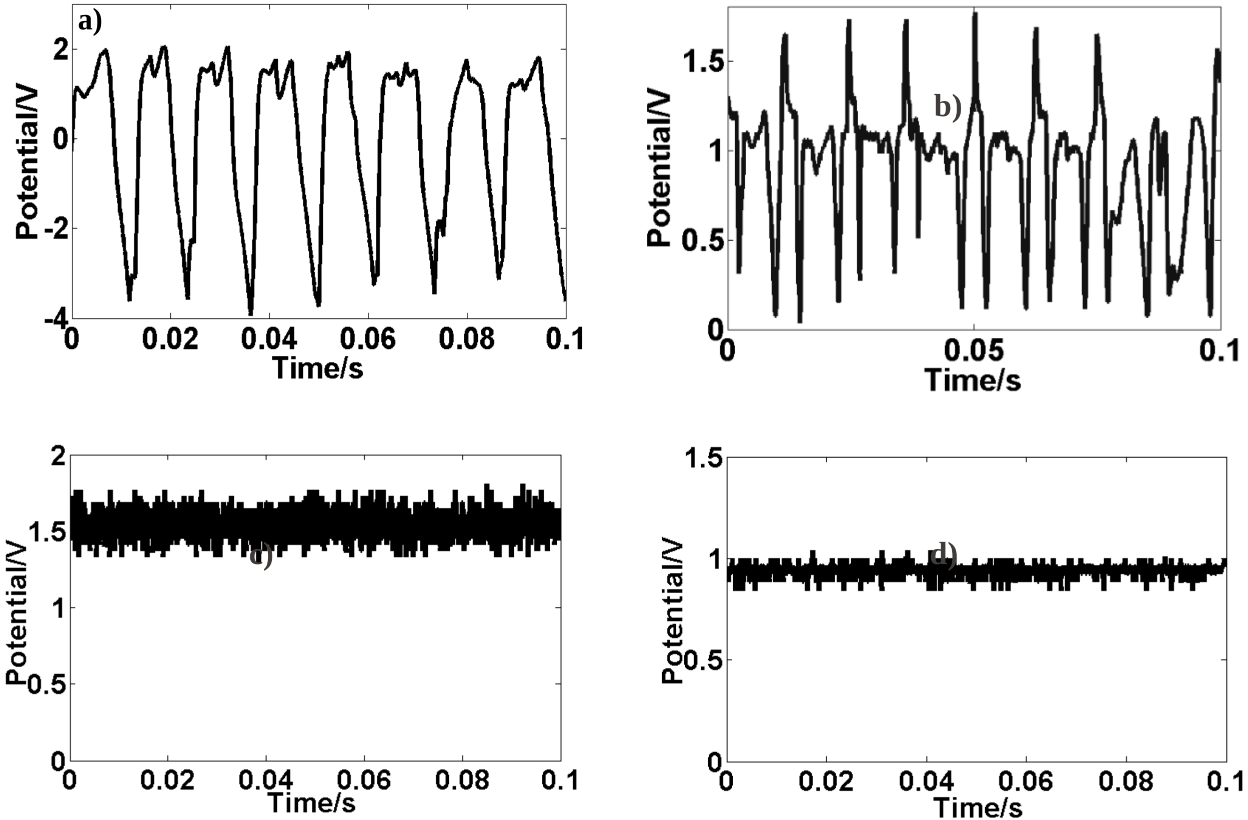






- Power amplifier and wave generator to make the exciter to vibrate.
- Oscilloscope for output voltage measurement.
- MSC is mounted on the flexible PCB board.

Self-Charging microsystem – Testing Result

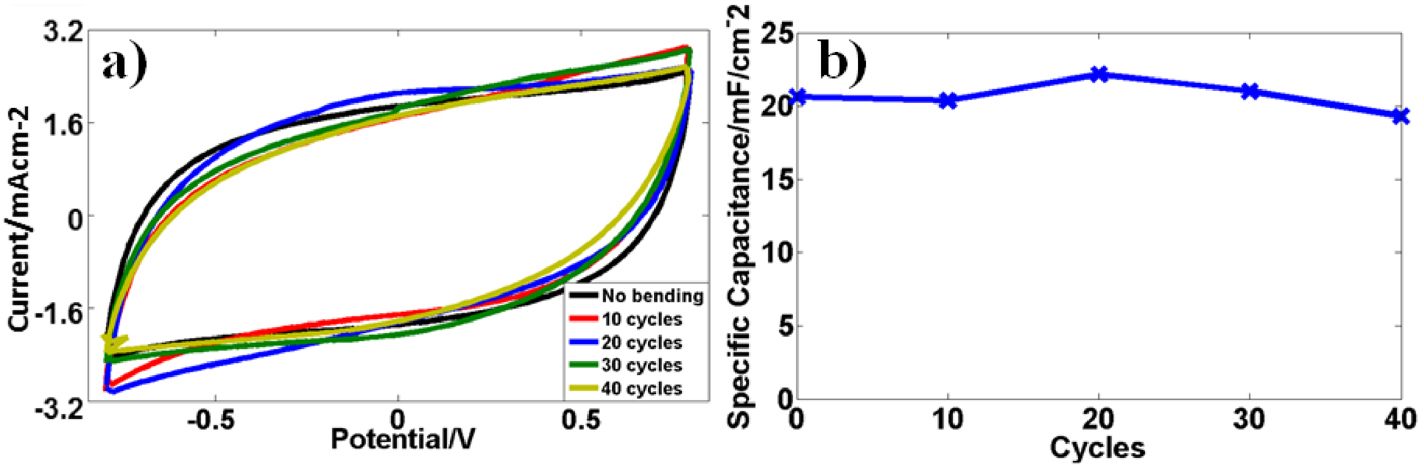


(a) Output signal of the electrostatic energy harvester
(b) Signal from the DC converter
(c) Output signal from the DC-DC module in Boost-Buck converter
(d) Output signal of about 1 V from the capacitor

Summary

- The energy harvested from the electrostatic energy harvester was successfully stored in the micro supercapacitor through the energy management circuit.
- The flexible all-solid-state micro supercapacitor has good mechanical stability and expected performance.
- The self-charging energy harvesting system demonstrates good potential as power supply for wearable electronics.
- Future work:
  - Higher integration, higher energy conversion efficiency, flexible triboelectric generator

Thank you for your attention.



- Comparison between the CV curves before and after 10, 20, 30, and 40 bending cycles at the same scan rate of 100 mV/s, b) calculated specific capacitance of the prototype as a function of bending cycles.