Self-Charging Energy Harvesting System for Wearables

Xia Liu, Juergen Brugger, Xiaohong Wang
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

Energy source

- Macro
  - Self-powered systems
  - Massive Energy harvesting

- Micro/nano
  - Pulse charging supply
  - Self-powered micro/nano systems

Microsensors or Microsystems

1. Automatic sensing
2. E-skin
3. Triboelectric generator
4. Graphene
5. Pulse charging supply
6. Self-powered systems
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

**Energy Harvester**
- Piezoelectric
- Electrostatic
- Electromagnetic
- Triboelectric
- Solar ...

**Route #1**
- Direct drive
  - LED, LCD... display
  - Calculator

**Route #2**
- Need of power control
  - Automatic control
  - Multiple devices

**Route #3**
- Need of energy storage
  - Standfree energy source
  - Micro/nano systems

**Electric-driving user**
- Sensor
- Actuator (Pacemaker...)
- Display (display)
- RF, wireless network
- Other electronic devices...

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Xia Liu, Self-Charging Energy Harvesting System for Wearables
Flexible energy harvesters are based upon the coupling of flexible electronics and piezoelectric, triboelectric, and hybrid nanogenerators.

State-of-the-art – automatic sensing

- Machine Learning
- Human-machine Interfacing
- Pattern Recognition
- Feedback System
- Big Data
- Data Transmission
- Control System
- Data Processing
- Artificial Intelligence
- Neural Interfacing
- Energy Management
- Biomedical Sensor
- Energy Harvester
- Humidity Sensor
- Supercapacitor
- Temperature Sensor
- Battery
- Security

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

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

- to find an effective and efficient power supply solution.

Energy input:
- instantaneous (pulse), hundreds of V voltage, μA-level current, MΩ or higher

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

User terminals:
- Sensors, electronic devices

Power management circuit:
- Interface circuit (inductor, capacitor, resistor, diode, amplifier, etc.)
- Generator
- Storage

- Objective: to find an effective and efficient power supply solution.

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

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of input voltage</td>
<td>1.8~8.0 V</td>
</tr>
<tr>
<td>Switch frequency</td>
<td>1 kHz</td>
</tr>
<tr>
<td>Load regulation</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Output voltage</td>
<td>1 V</td>
</tr>
<tr>
<td>Conversion efficiency</td>
<td>&gt; 85%</td>
</tr>
</tbody>
</table>

2019 Spring Meeting of the European Materials Research Society (E-MRS)
Flexible All-Solid-State Micro Supercapacitor

- Electrode: Interdigitated structure
- Electrode material: activated carbon
- Electrolyte: all-solid state, polyvinyl alcohol–phosphoric acid (PVA-H₃PO₄) polymer gel
- Substrate: parylene-C
Micro Supercapacitor – Design and fabrication

- Fabrication process:
  1. Spin coat parylene-C
  2. Micropattern Au electrode
  3. Micropattern SU-8 separator
  4. Peel off the structure
  5. Inject AC solution
  6. Drop coat PE electrolyte
Micro Supercapacitor – Structure result

① P/E polymer gel electrolyte
② AC electrodes
③ Parylene-C
④ SU-8 Separator
(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/cm².
(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
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
Strategy 1: transformer + bridge rectifier + capacitor

- $V_1 \ U=100 \ V$
- $T_{tr_1} \ T=40$
- $C_1 \ C=0.001 \ \mu F$
- $C_2 \ C=1000 \ \mu F$
- $C_3 \ C=0.01 \ \mu F$

Transient simulation
- Type=lin
- Start=0
- Stop=1s
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.
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.