Mechanical Energy Harvesting – A Pocket Power Plant

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European Research Council
Established by the European Commission

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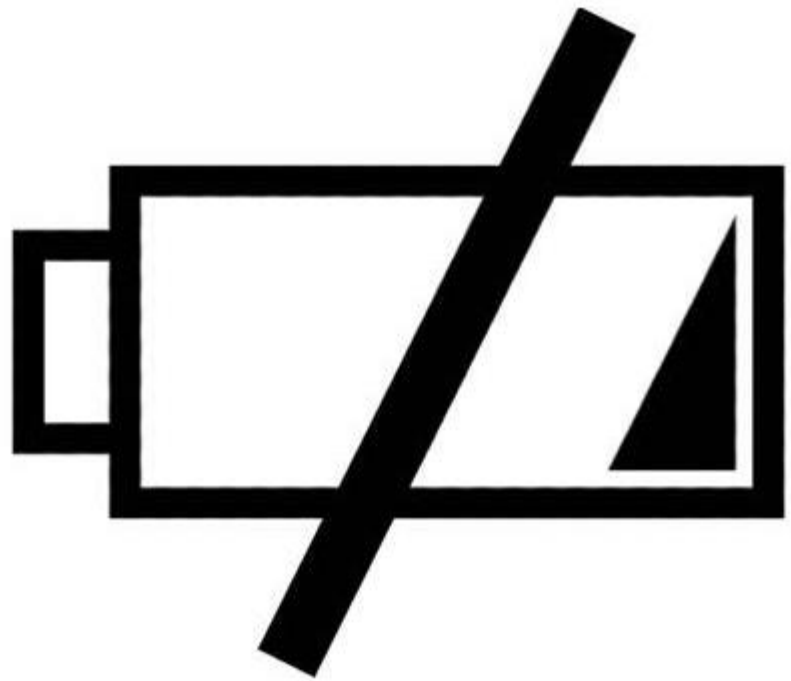
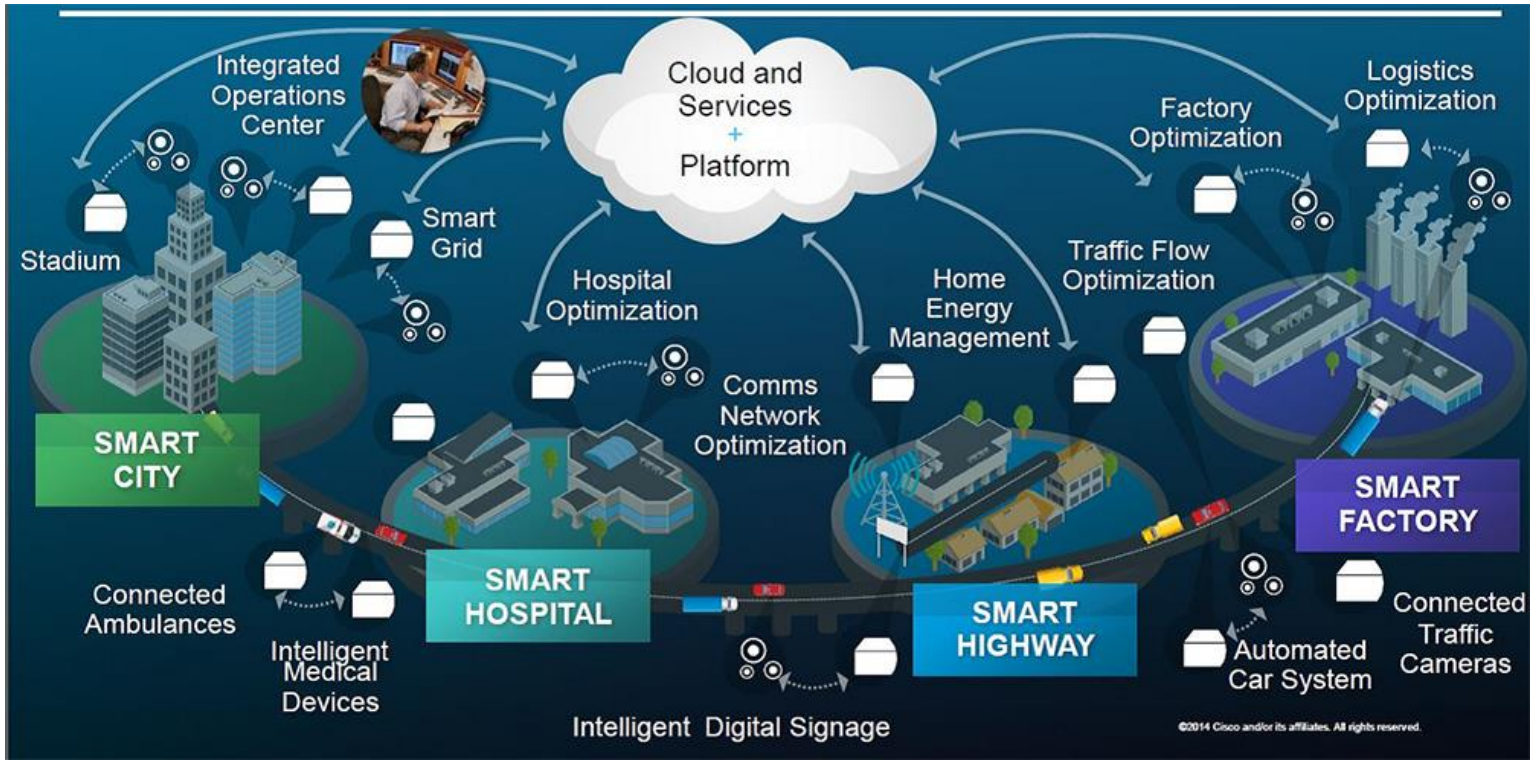
Nanogenerators & Sensors

- Polymer-based piezoelectric, triboelectric & thermoelectric materials & devices
- Flexible / printed / stretchable electronics
- Advanced nano-characterization: Scanning Probe Microscopy



Wireless Sensors & the Internet of Things



Source: Cisco (Smart Cities)

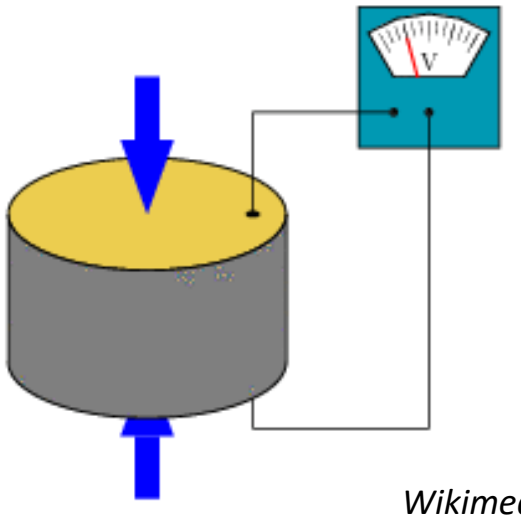
How do we power the Internet of Things?

Image from http://hi-globe.com/

Piezoelectric Materials

The Greek word “*piezo*” or “*piezen*” means to squeeze or press

Piezoelectric materials produce electricity under an applied stress/strain.
They can also change shape when a voltage is applied across them



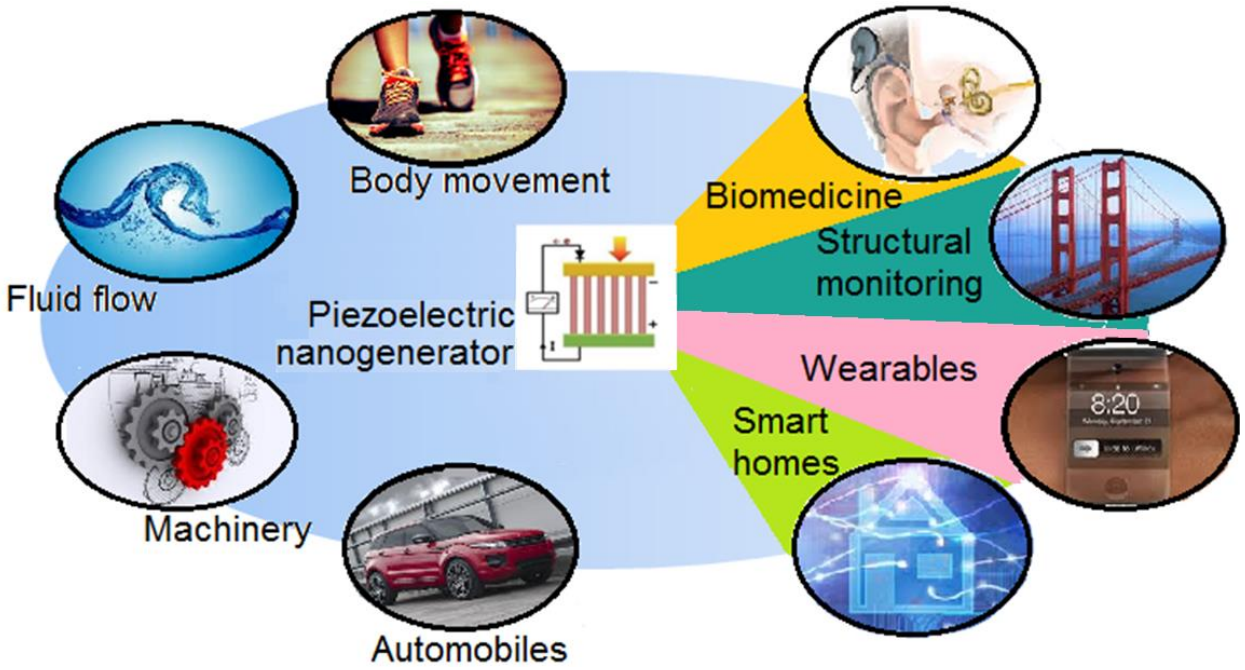
Wikimedia commons

Motivation

Energy harvesting from ambient sources for **self-powered** micro/nanoelectronic devices – *Vibrational energy harvesting*

Traditional power sources such as batteries need replacing/recharging, do not scale with size.

Ambient vibrations
0.01 – 10 mW/cm^3

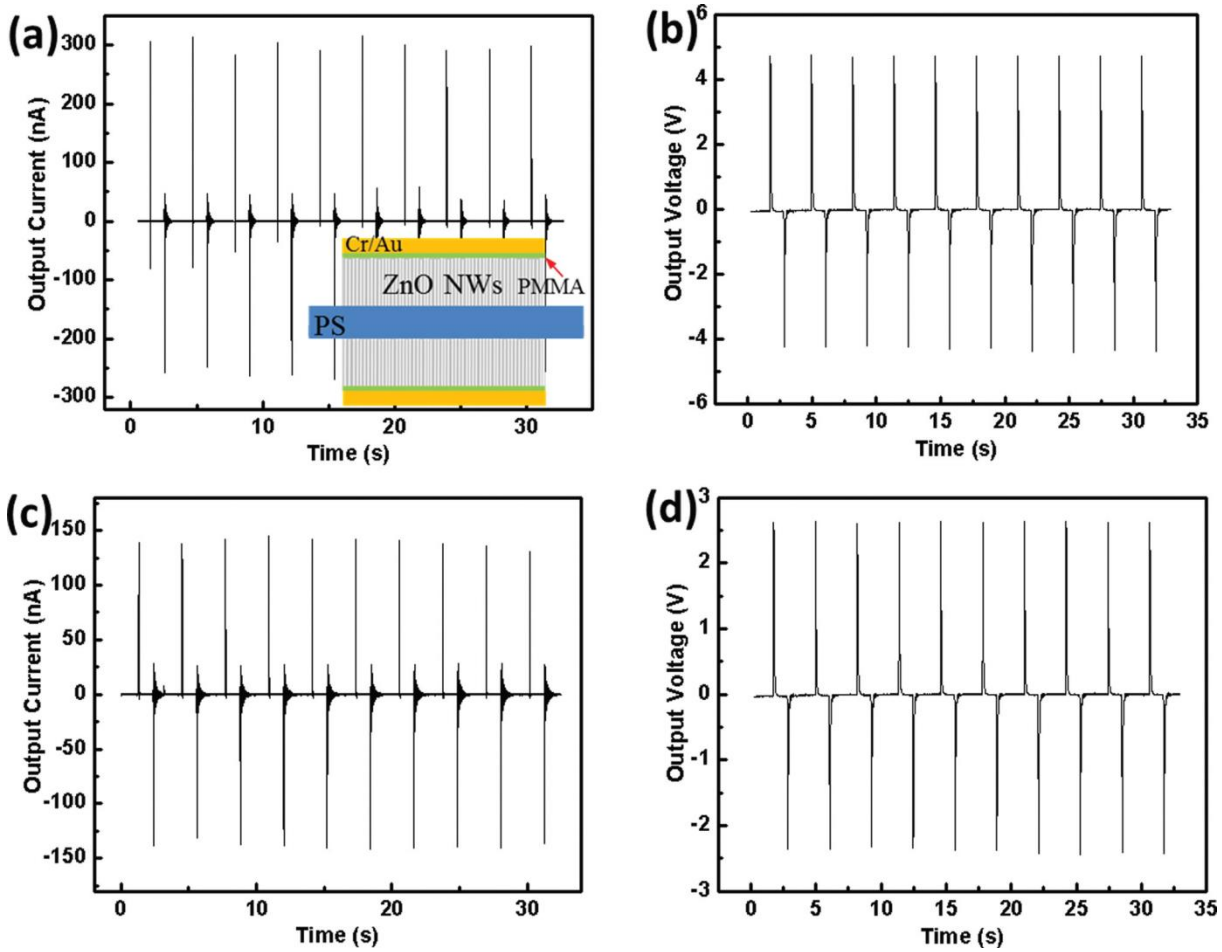


Devices
100 nW – 1mW

Piezoelectric Materials

Mechanical Energy ⟷ Electrical Energy

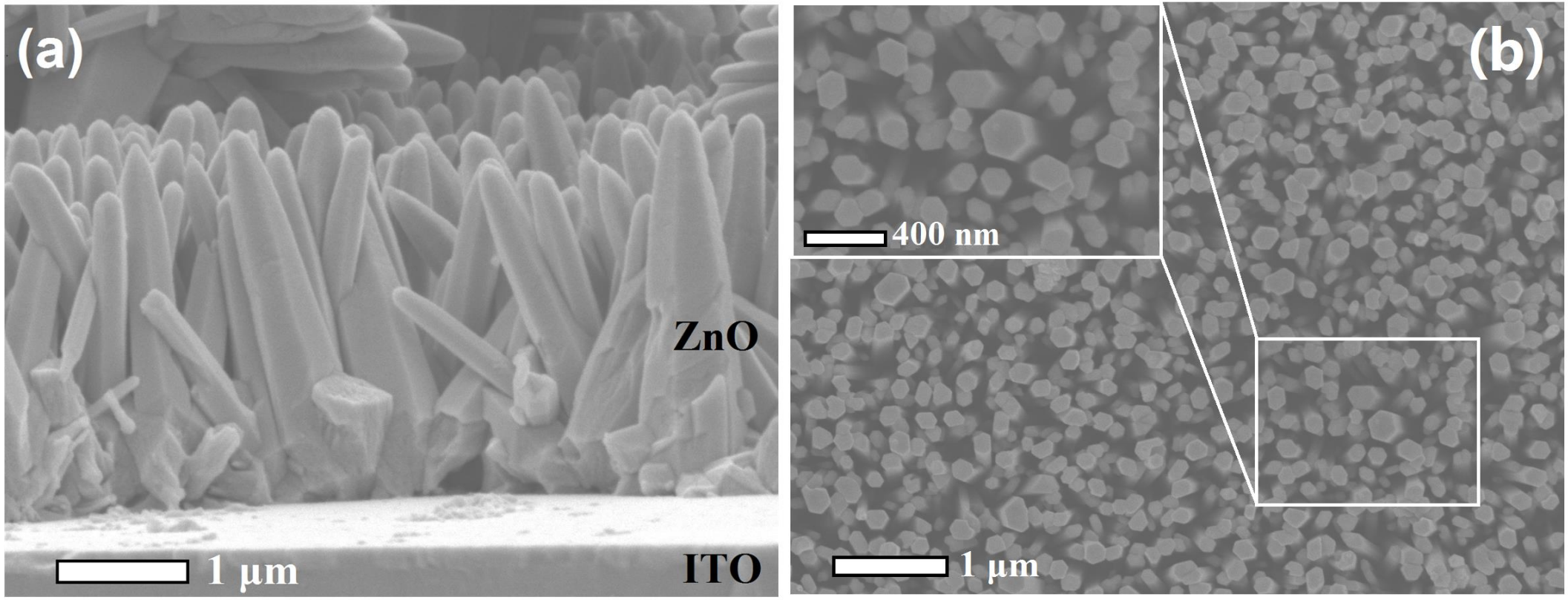
NG based on ZnO arrays



Adv. Mater. **2012**, *24*, 110–114

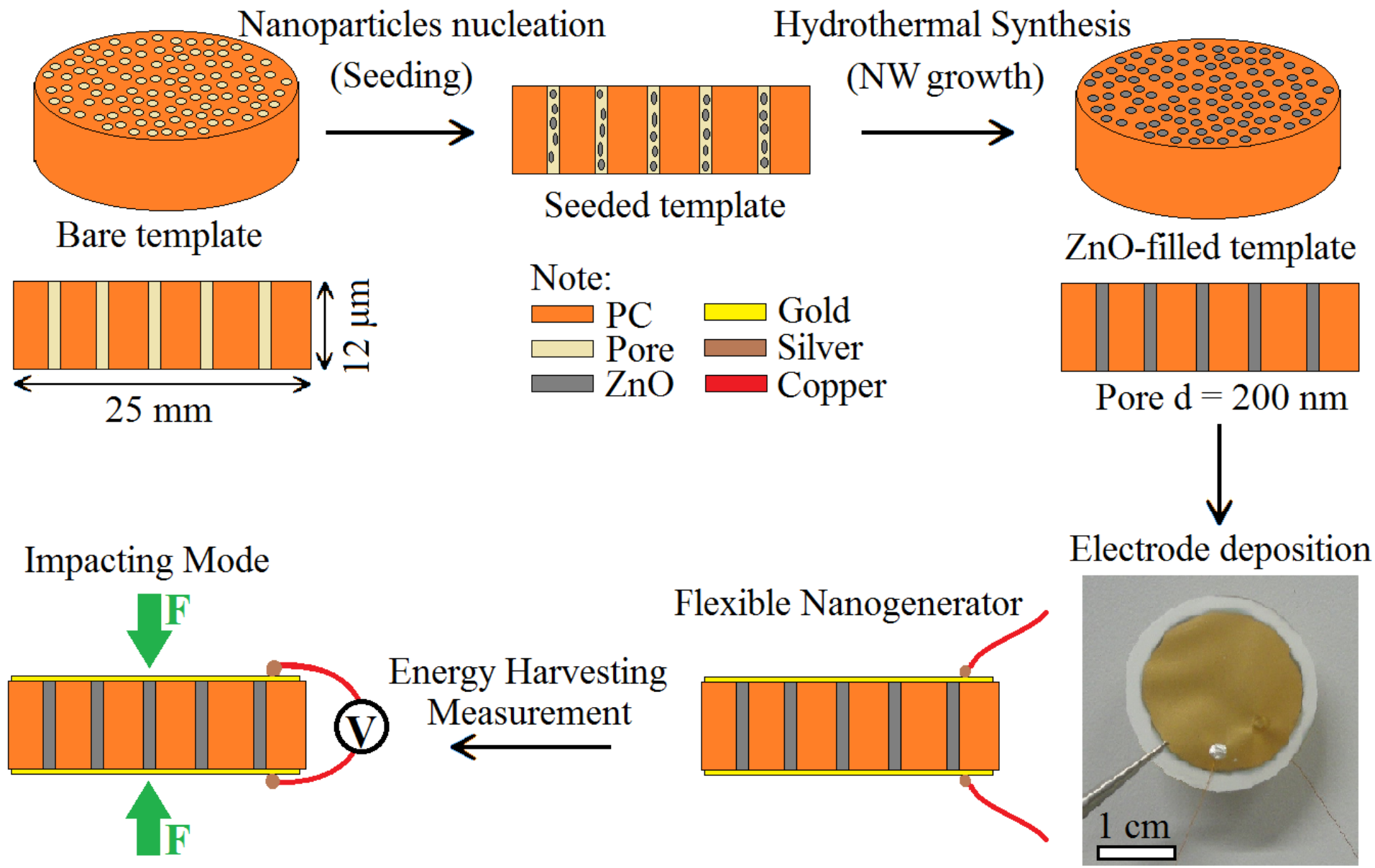
Performance degrades on exposure to air.
Surface passivation required

Hydrothermal synthesis of Zinc Oxide

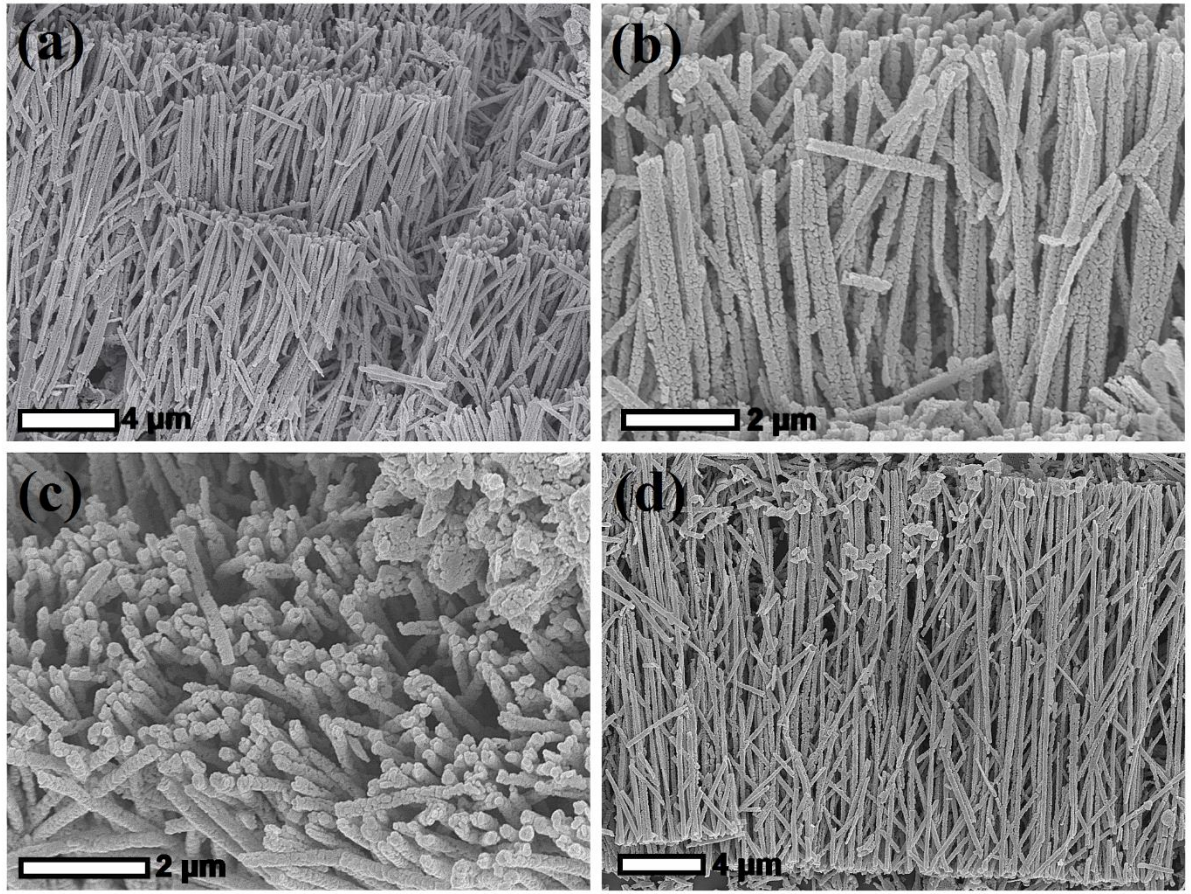


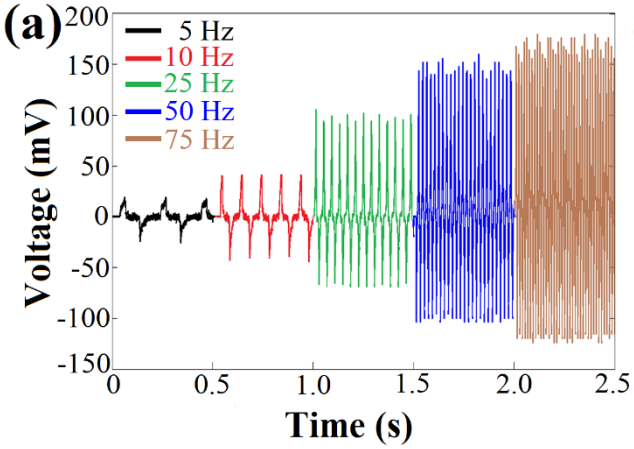
$$Zn^{2+} + 2OH^- \leftrightarrow Zn(OH)_2 \rightarrow ZnO + H_2O$$

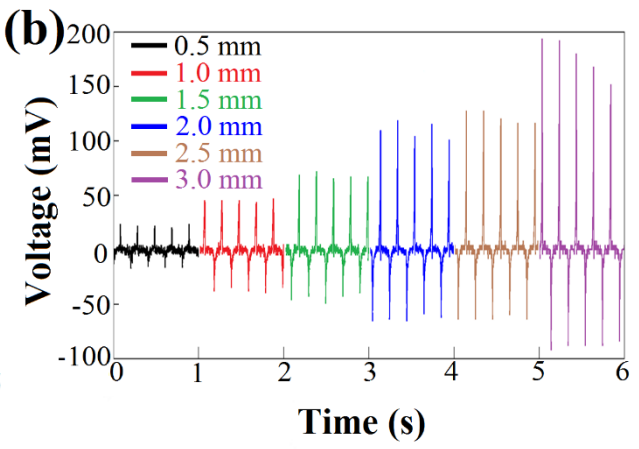
Zinc Oxide – Polycarbonate nanocomposite

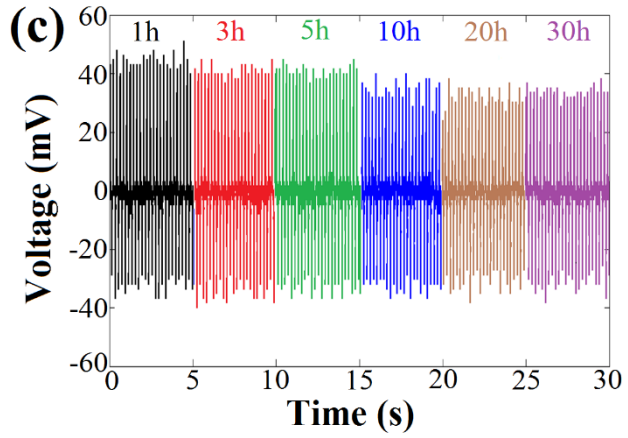


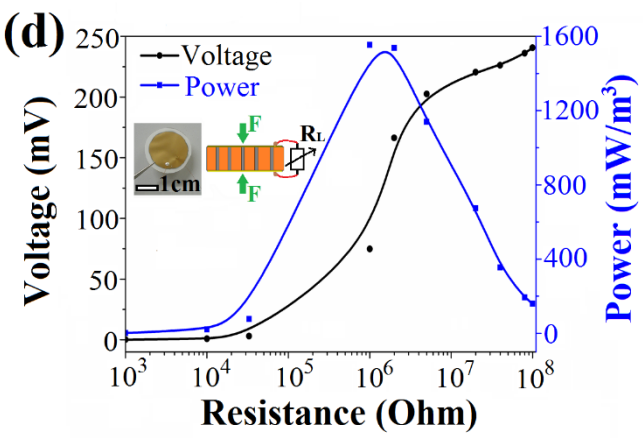
ZnO– PC nanocomposite – Hydrothermal synthesis







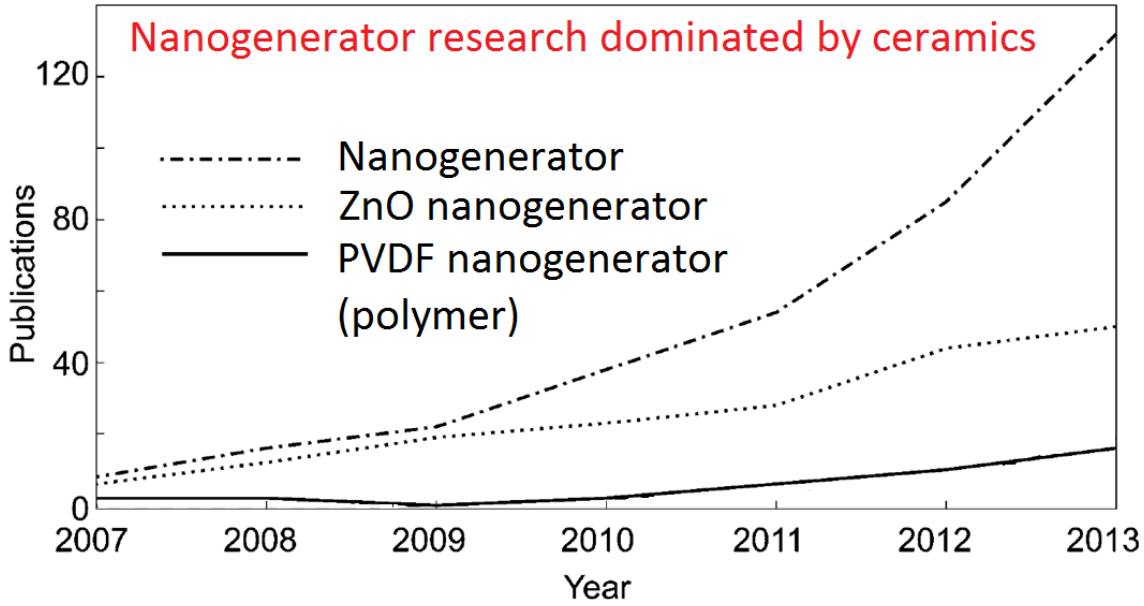




CO, PESJ, AD, FLB, RAW S-L.S & SK-N (*ACS Applied Materials & Interfaces*, 2016)

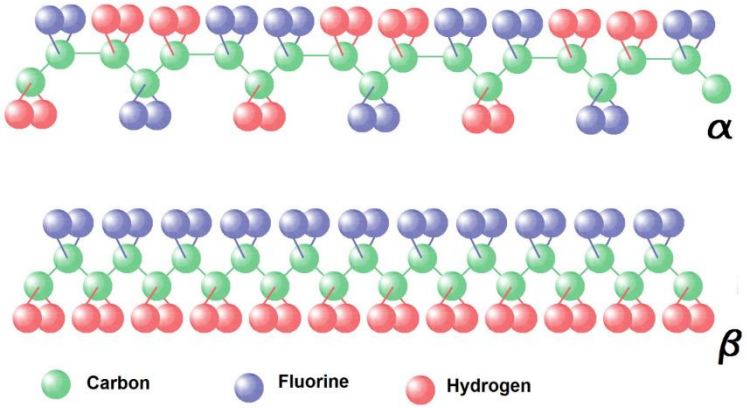
Polymer nanogenerators

- ✓ Flexible
- ✓ Robust
- ✓ Cheap
- ✓ Easy to fabricate
- ✓ Lead-free
- ✓ Biocompatible
- ✓ Acoustic impedance matching
- ✗ Low piezoelectric constant



SC, RAW & SK-N, *Mater. Sci. & Technol.* (2014)
Invited Review, focus issue on "Smart Materials"

Field limited to Poly-vinlyidene fluoride (PVDF)

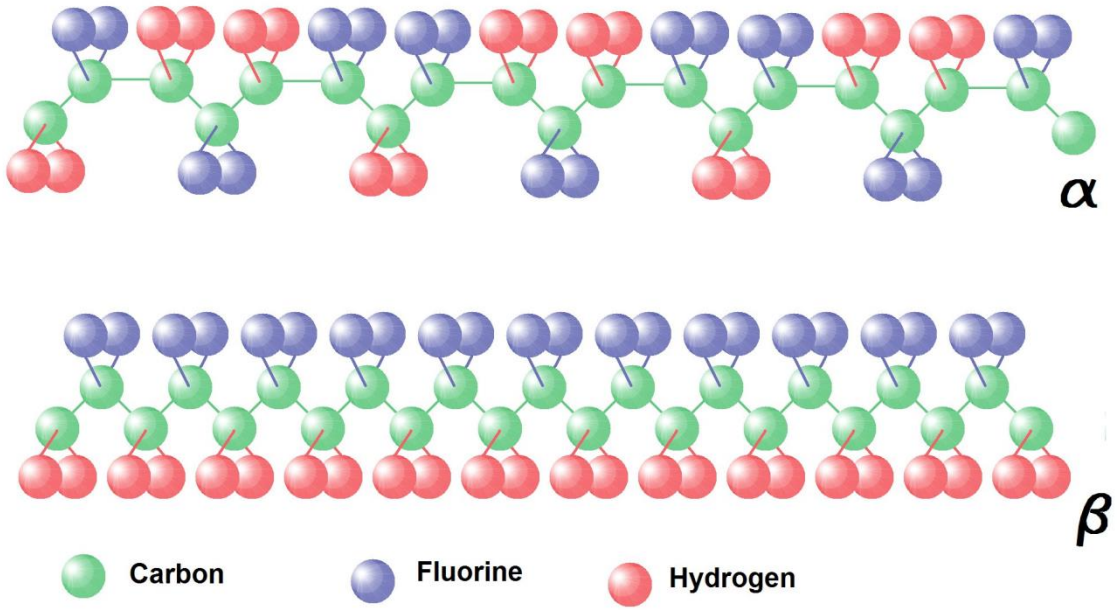


Way forward : Polymer-Ceramic composites!

SC & SK-N, *Nanotechnology* (2015)

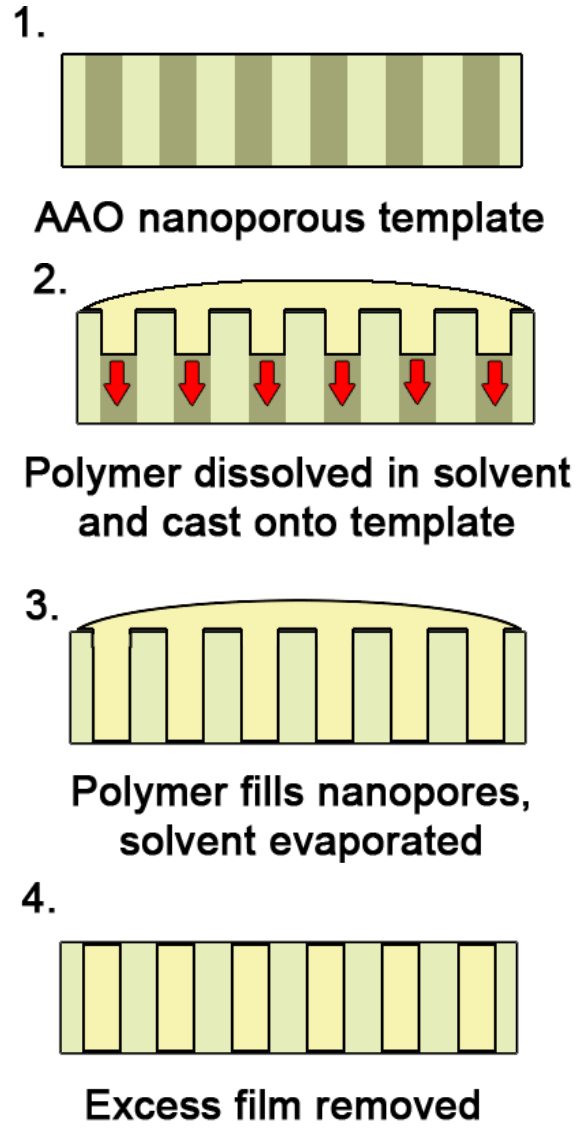
Piezoelectric Polymer

- Flexible and light
- Ease of fabrication
- Cost-effective
- Lead free



Poly-vinlyidene fluoride (PVDF)

Template Wetting



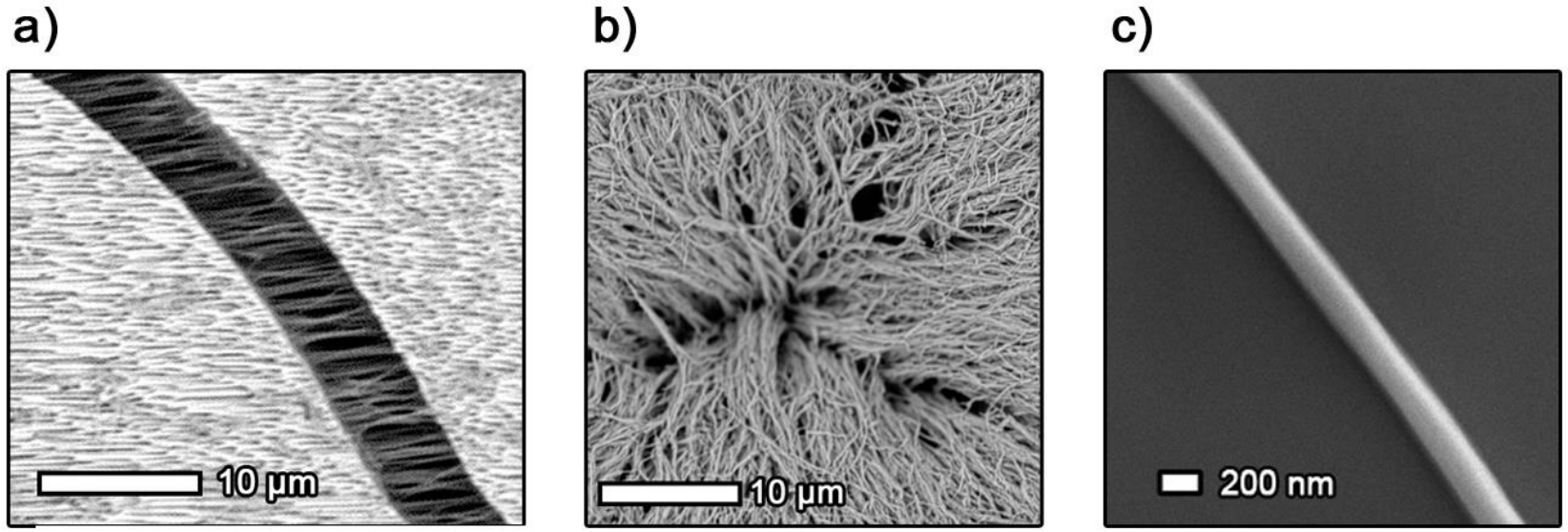
- Simple
- Scalable
- Versatile

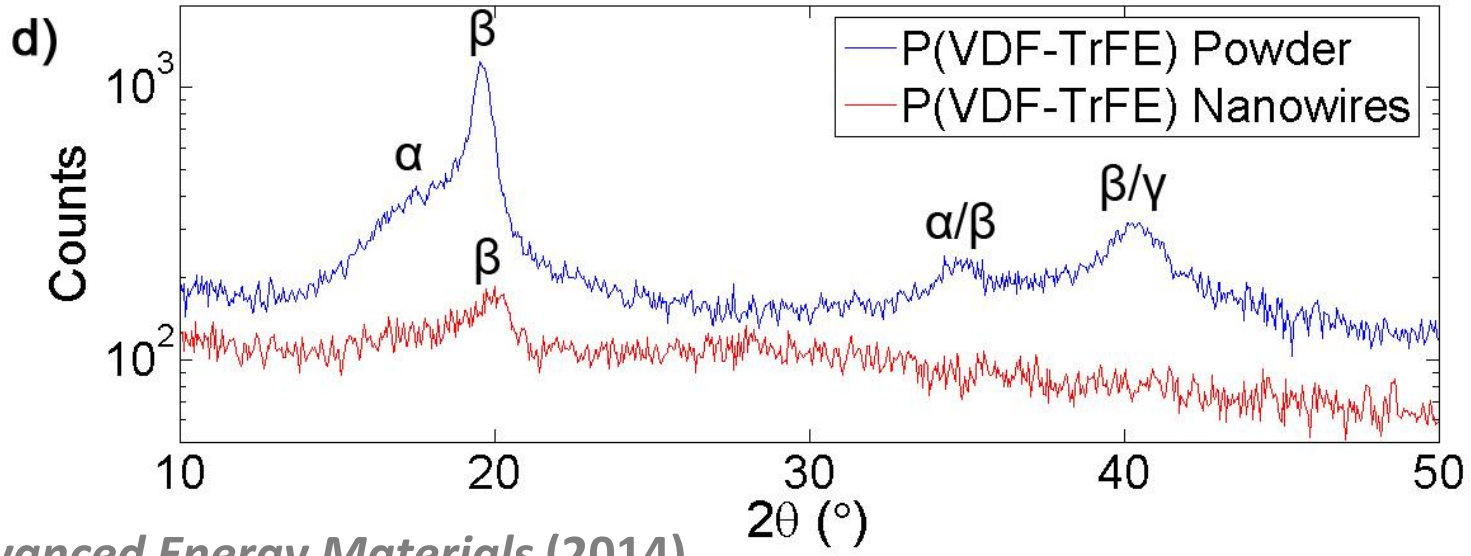
- Can form nanotubes or nanowires
- Can change dimensions with different templates

After forming nanowires inside template:

- Can coat template surfaces in metal to make simple devices
- Can dissolve template to release nanowires into solution

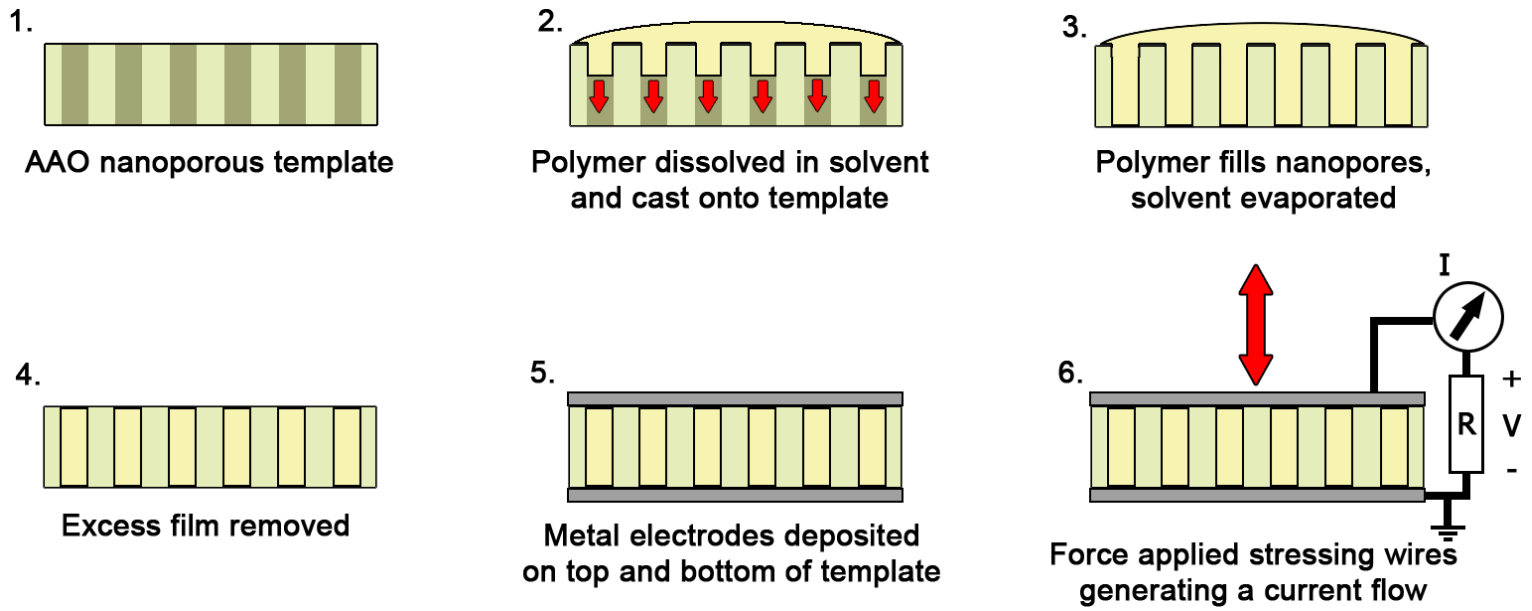
Template-grown P(VDF-TrFE) Nanowires





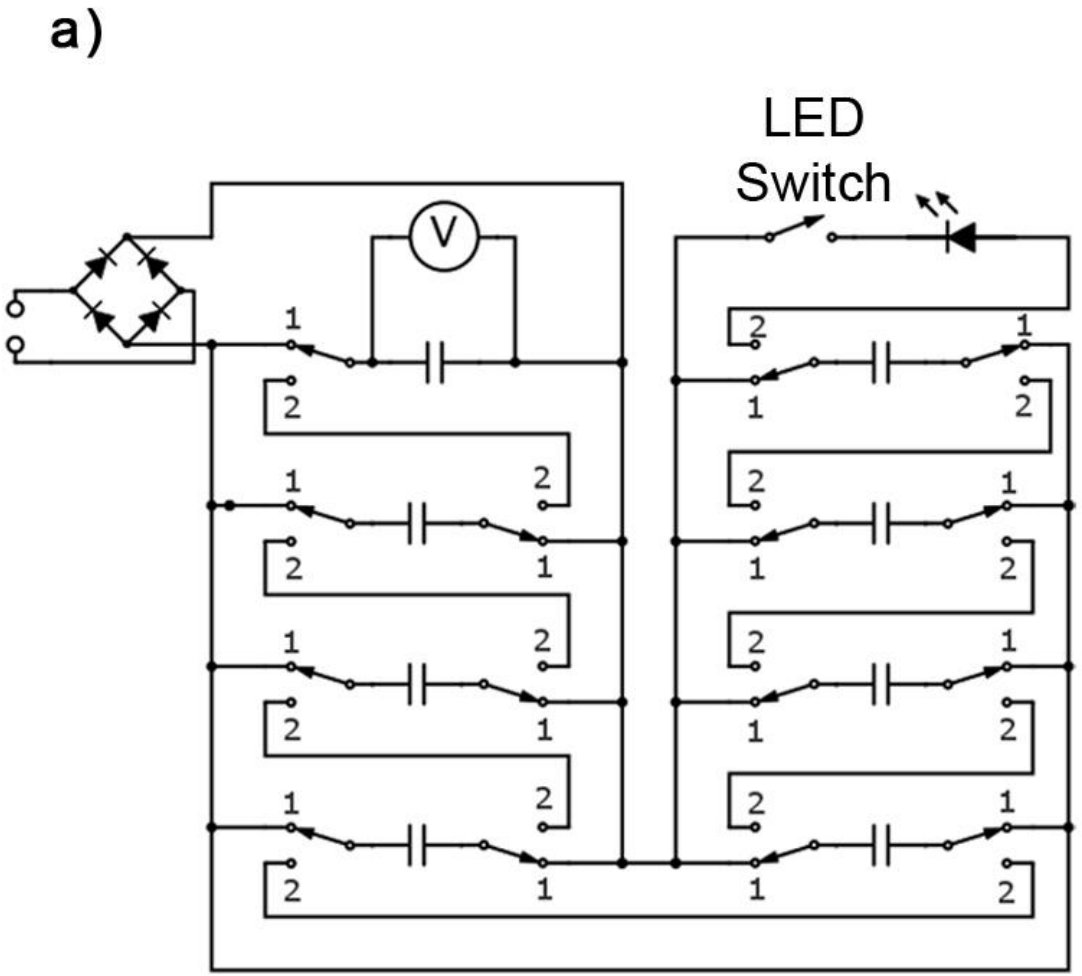
RAW, VN & SK-N, *Advanced Energy Materials* (2014)

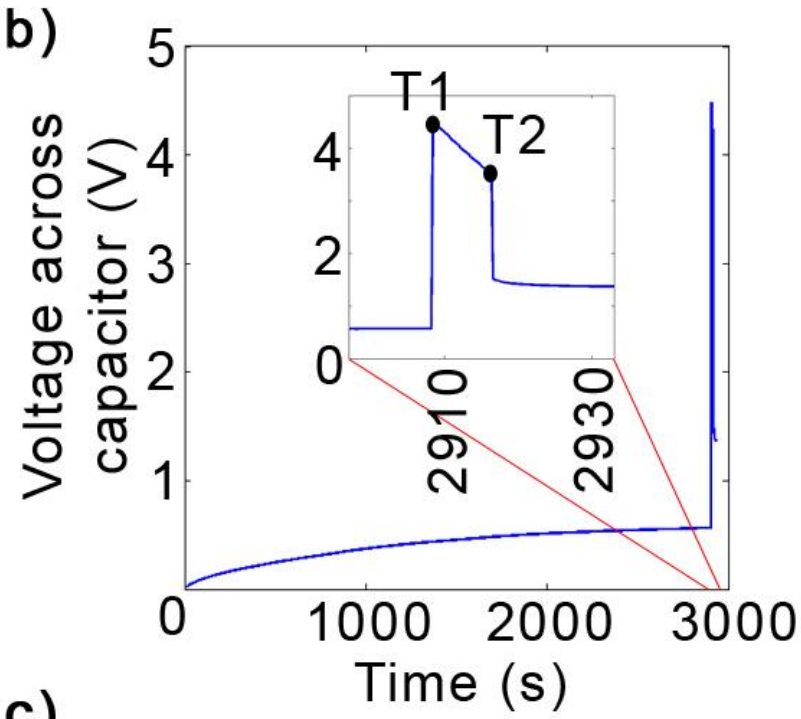
Fabrication of an energy harvesting device



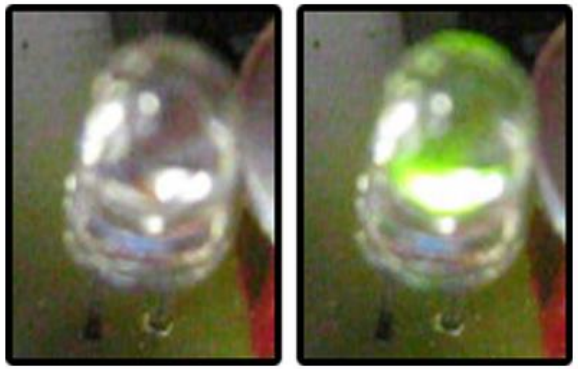
Device comprises 10^{10} aligned nanowires in circle of diameter 1cm

Lighting an LED with a polymer nanogenerator



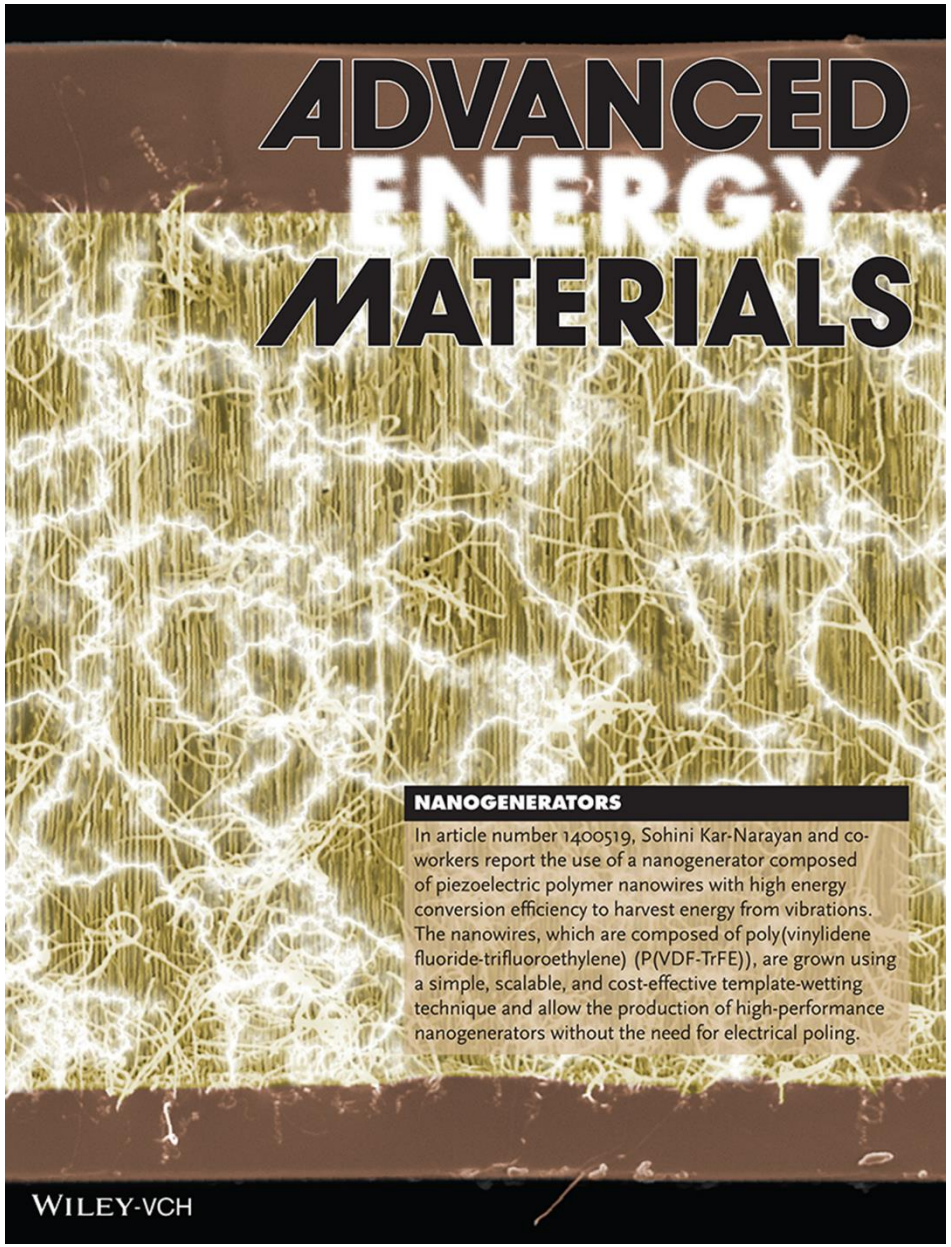


c)



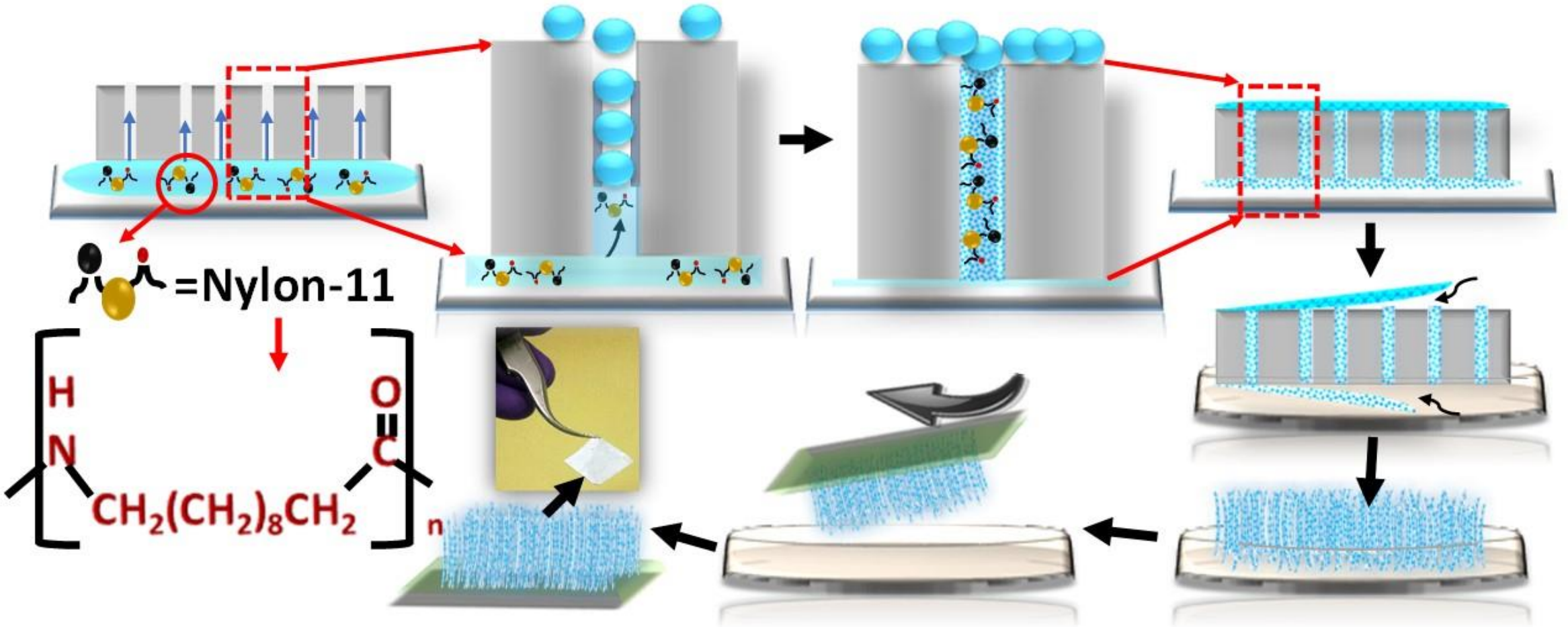
RAW, VN & SK-N, *Advanced Energy Materials* (2014)

Key findings



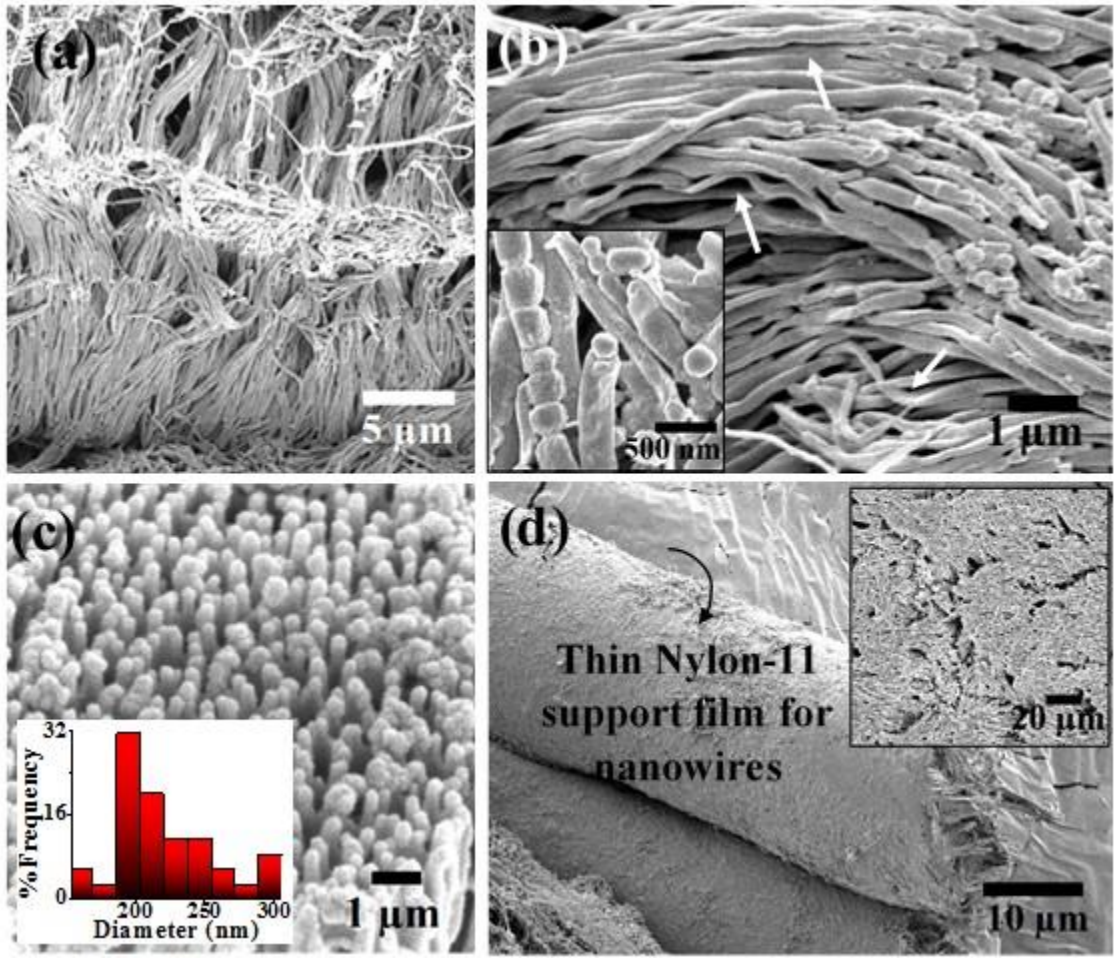
- Energy conversion efficiency 11%
- **Self-poled**
- **Scalable**
- Power density improved by stacking
- Device efficiency ~ 0.2%
- **Good Fatigue Performance**

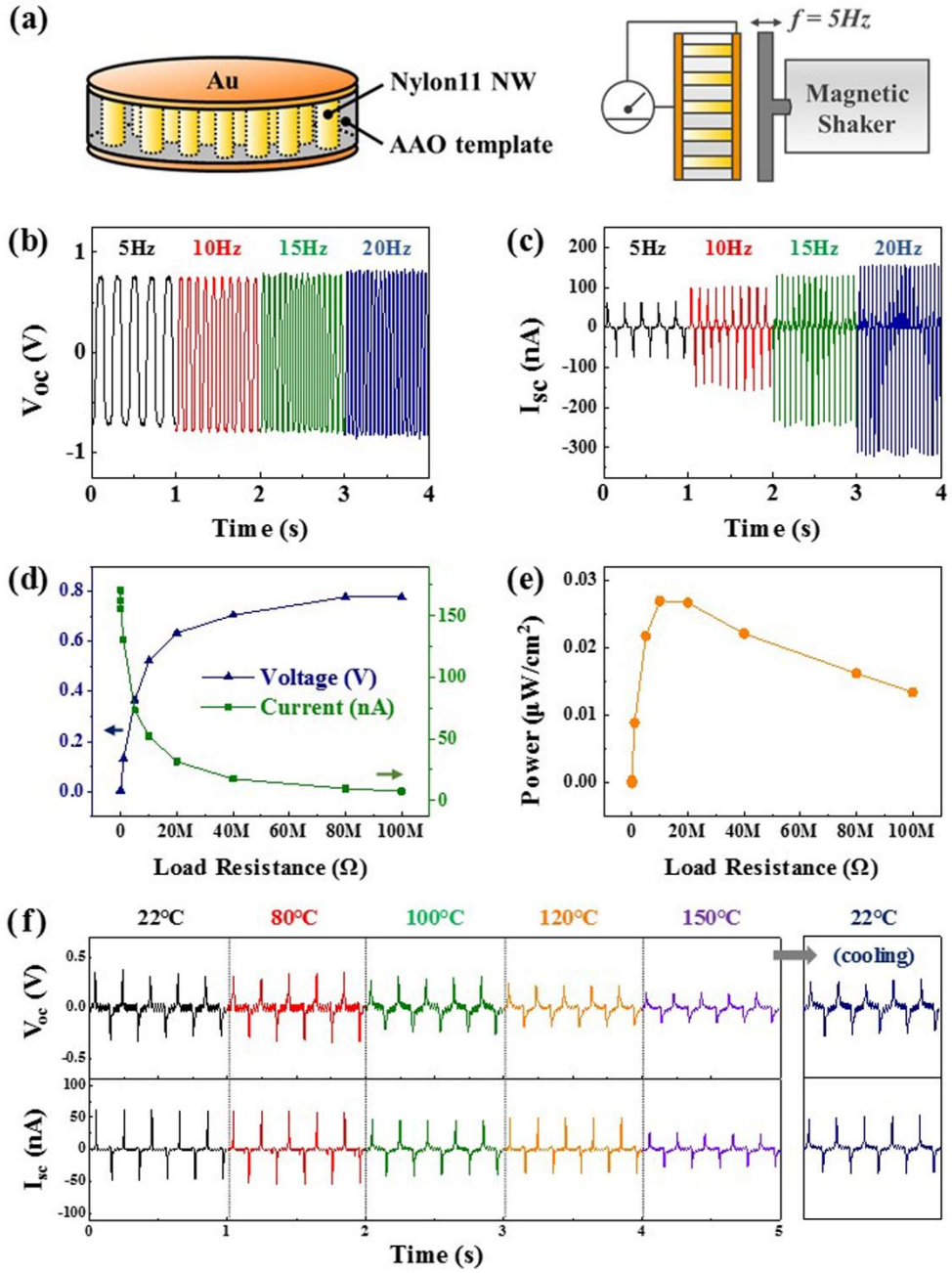
Self-poling in Template-grown Nylon Nanowires?



AD, YSC, EC, CO & SK-N, *Advanced Functional Materials* (2017)

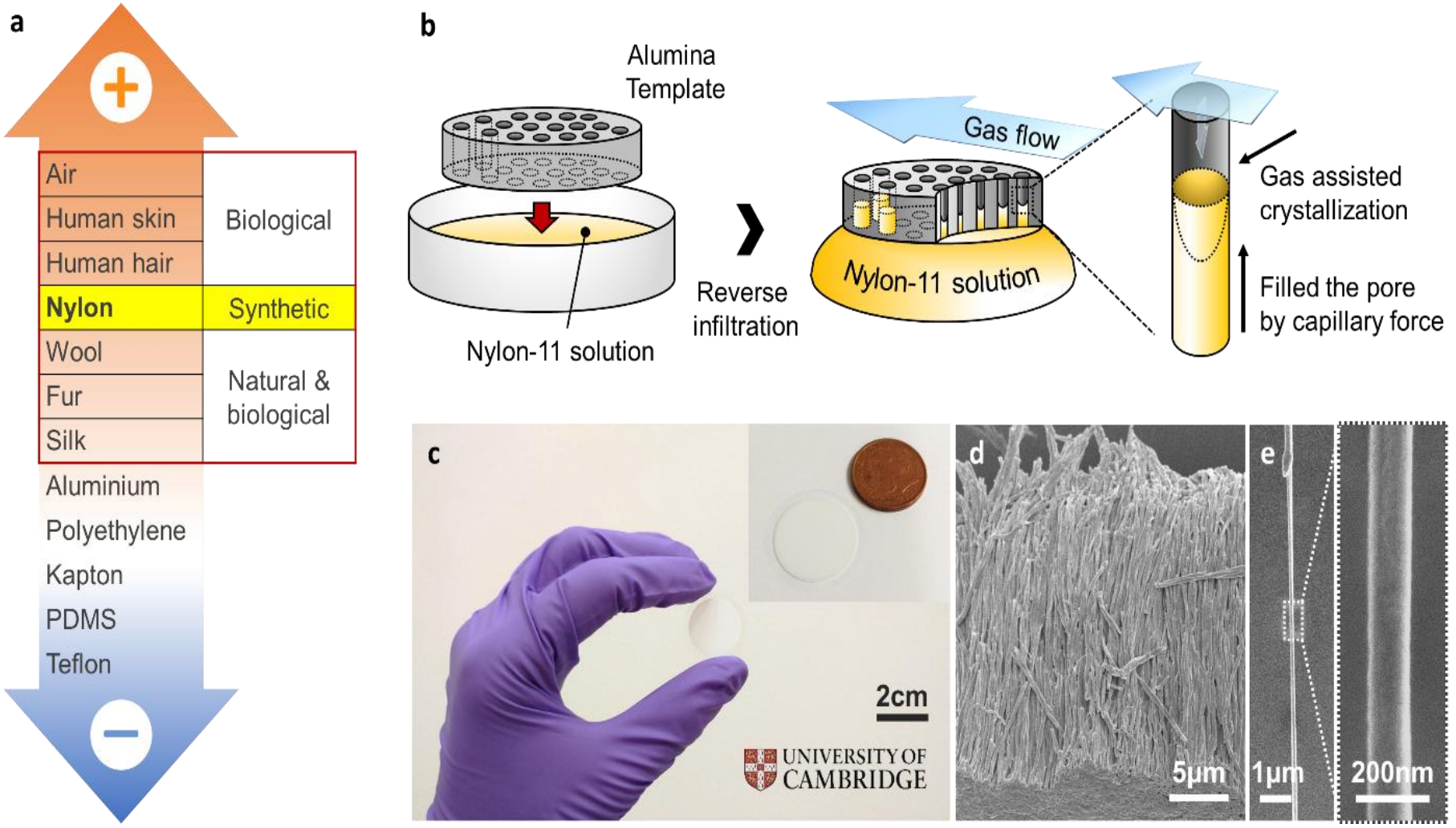
High-Temperature stability in Template-grown Nylon Nanowires?





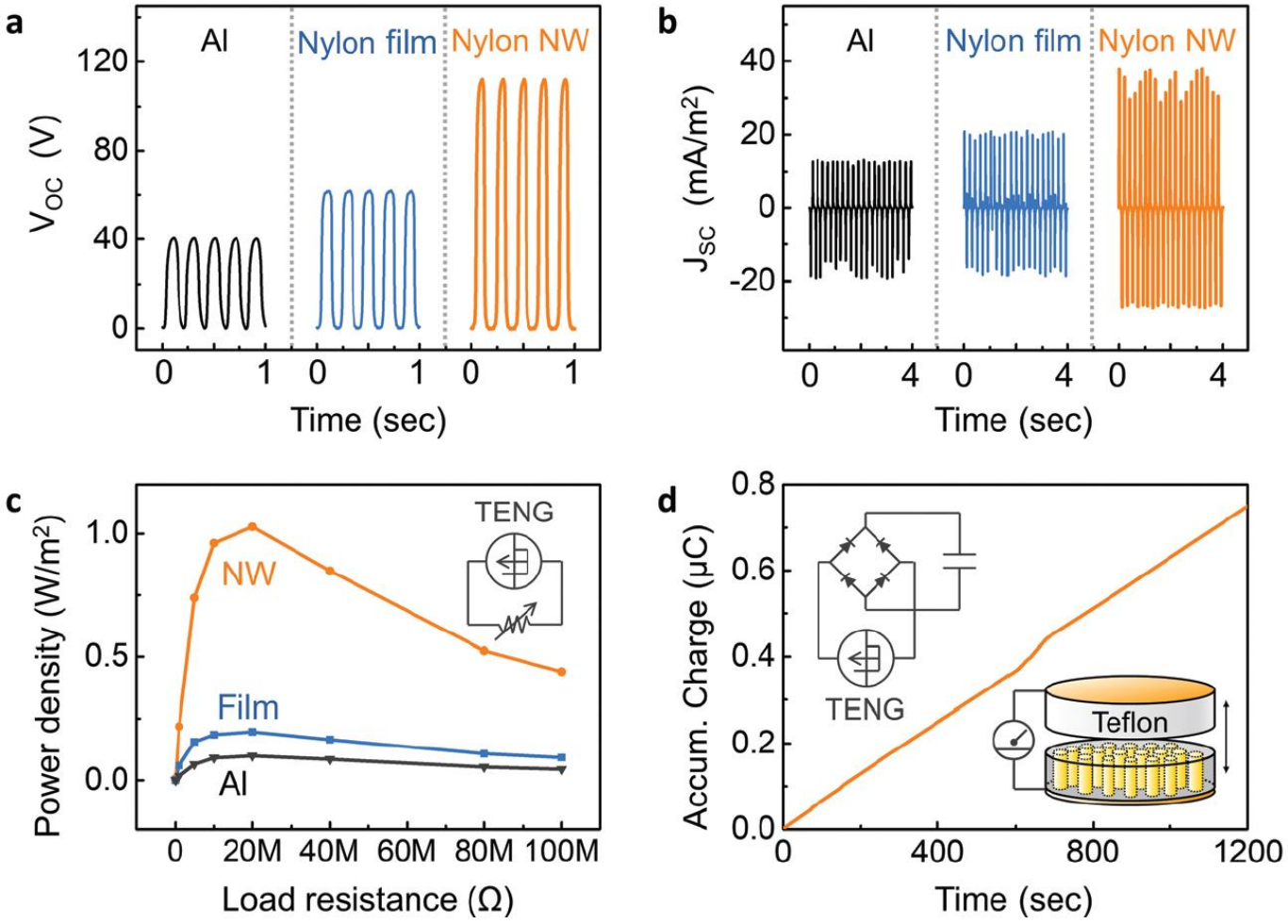
AD, YSC, EC, CO & SK-N,
***Advanced Functional Materials* (2017)**

Nylon-11 as a triboelectric material



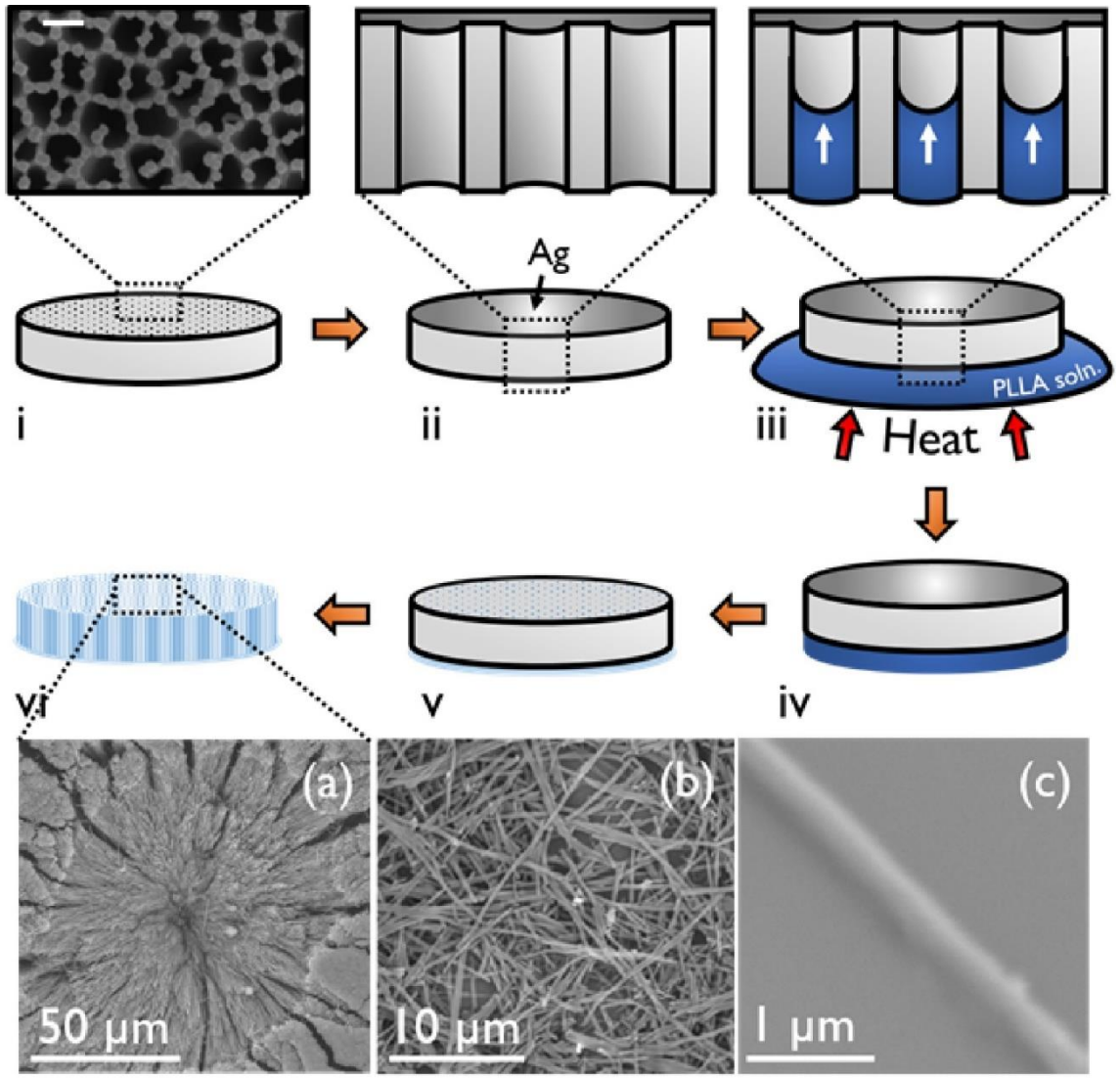
SK-N group, *Energy & Environmental Science* 2017 (Publisher's Pick "HOT articles")

Nylon-11 nanowires for triboelectric energy harvesting

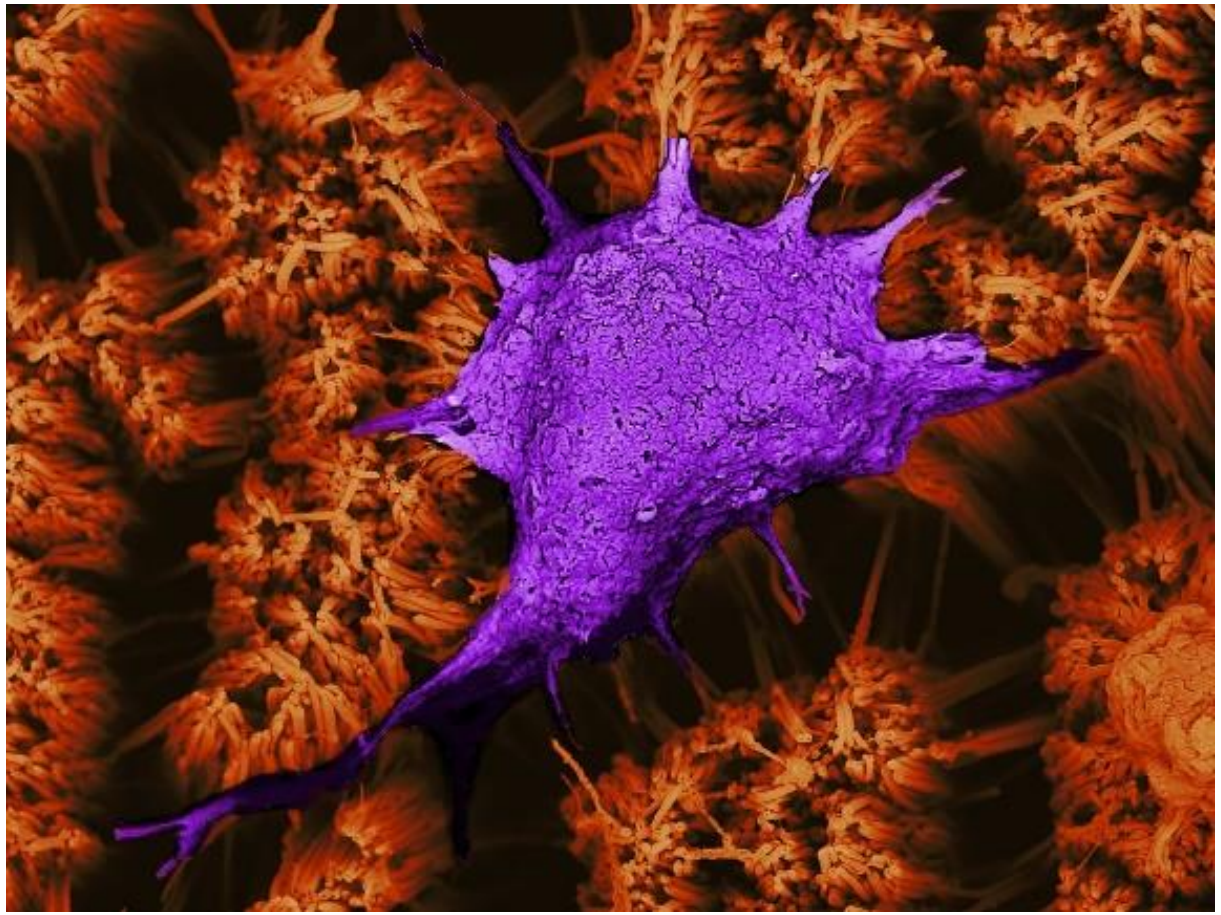


SK-N group, *Energy & Environmental Science* 2017 (Publisher's Pick "HOT articles")

Bio-inspired piezoelectric materials



MS, YC, QJ & SK-N, *APL Materials* (2017)

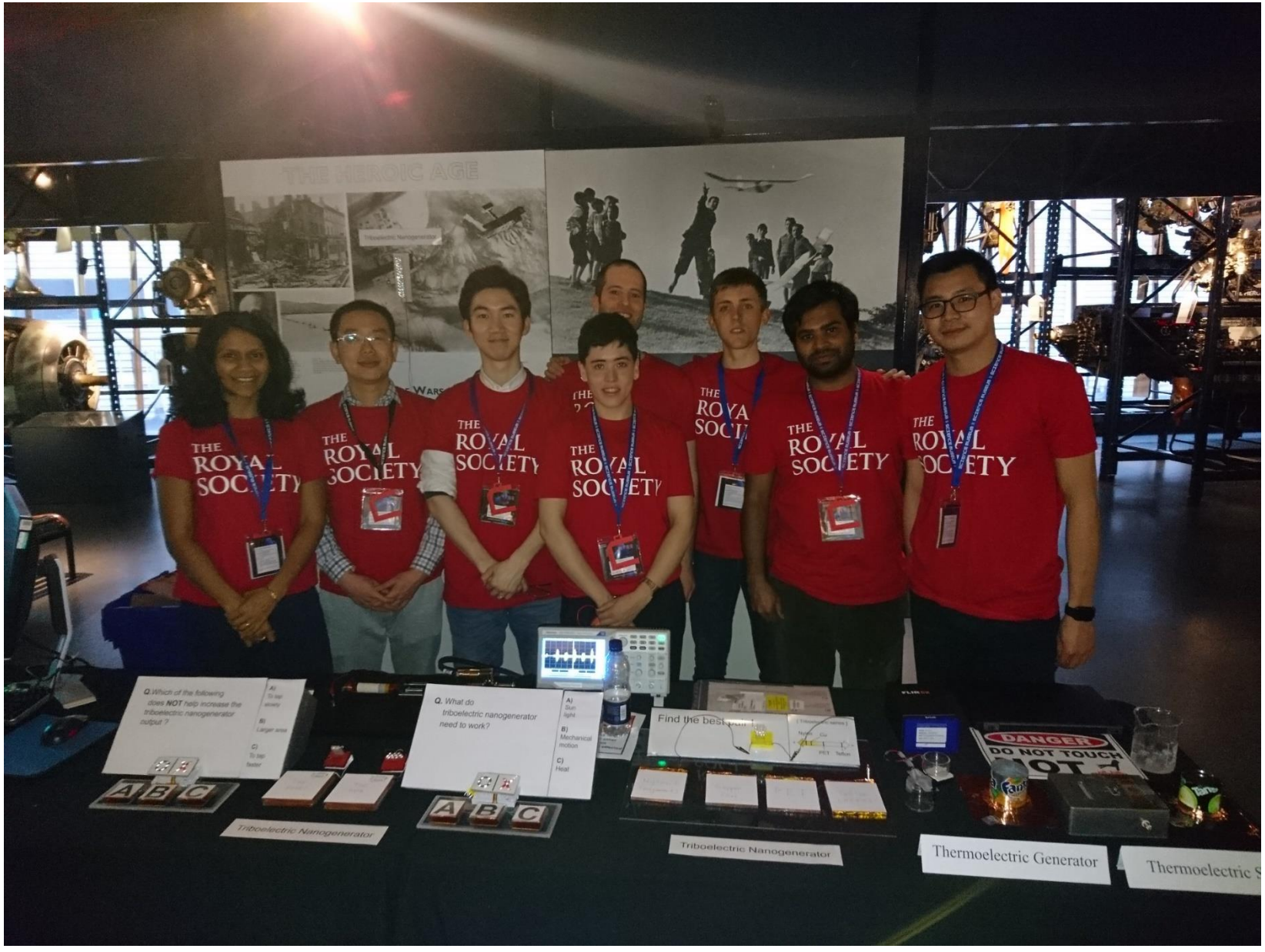


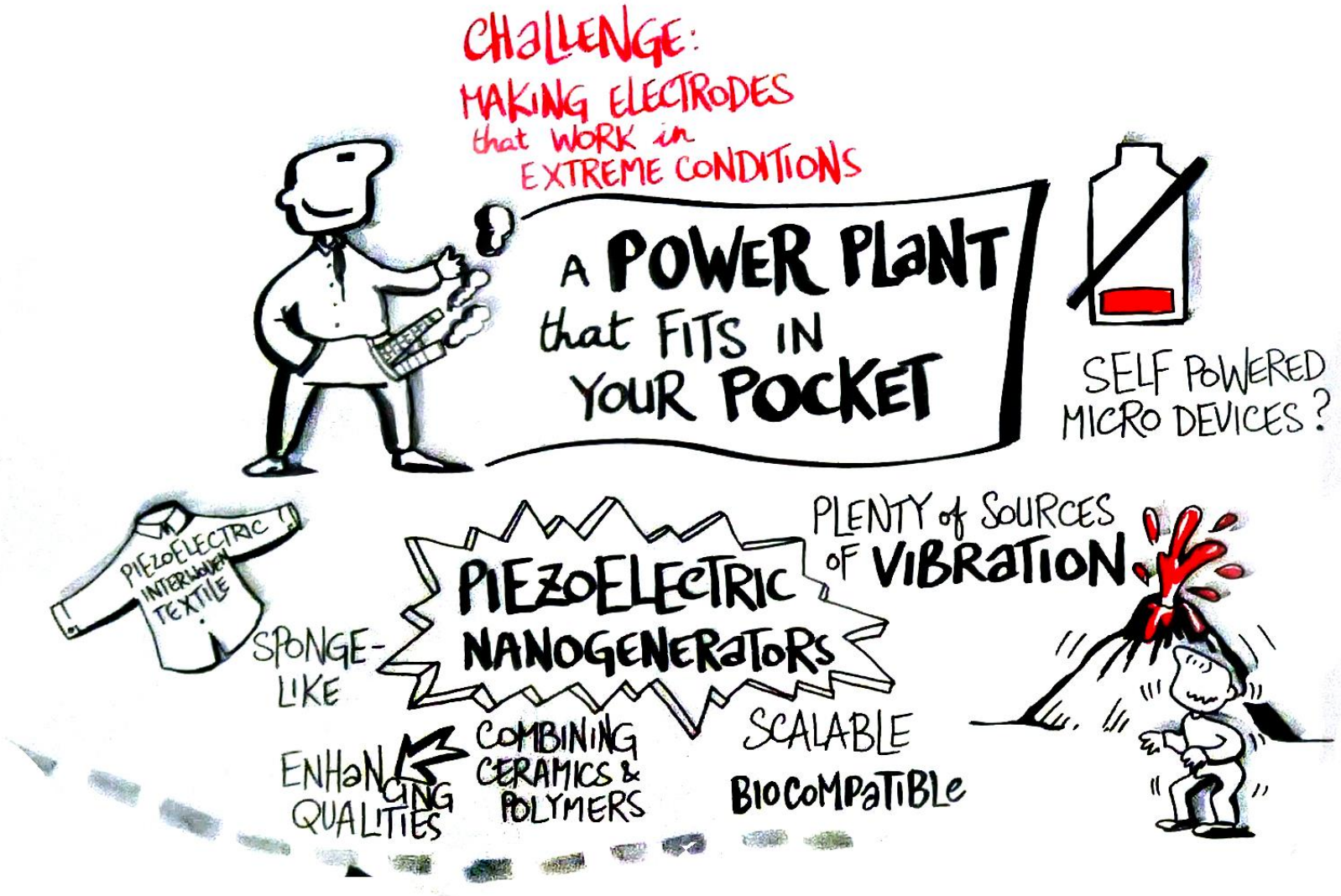
Poly-l-lactic acid nanowires for applications in bio-sensing and mechanobiology

The big picture

- **Sustainability** : wireless sensors and IoT provide a route for better energy and resource management, infrastructure maintenance, safety.
- **Health and well-being** : Reducing the burden on healthcare systems, especially in the context of elderly care.
- Key enabling technology with implications for **robotics**, **biomedicine**, **ICT**.
- Integration with other renewable energy technologies for fully **autonomous devices.**
- **Flexible and stretchable** electronics for integration into clothing, or on skin.

Royal Society Science Museum Lates Event 2017 : **Pocket Power Plant**





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- Dr Yonatan Calahorra
- Dr Qingshen Jing
- Dr Abhijeet Sangle

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- Yuning Zhou (MPhil, Materials)
- Evie Chalmers (Part III Materials)
- Nick Hardingham (Part III Materials)

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