Painotekniikoilla älykkyyttä kaikkialle

BioÄly-hanke, seminaari, 10.3.2020

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Kestävää kasvua ja työtä -ohjelma

Tampereen yliopisto

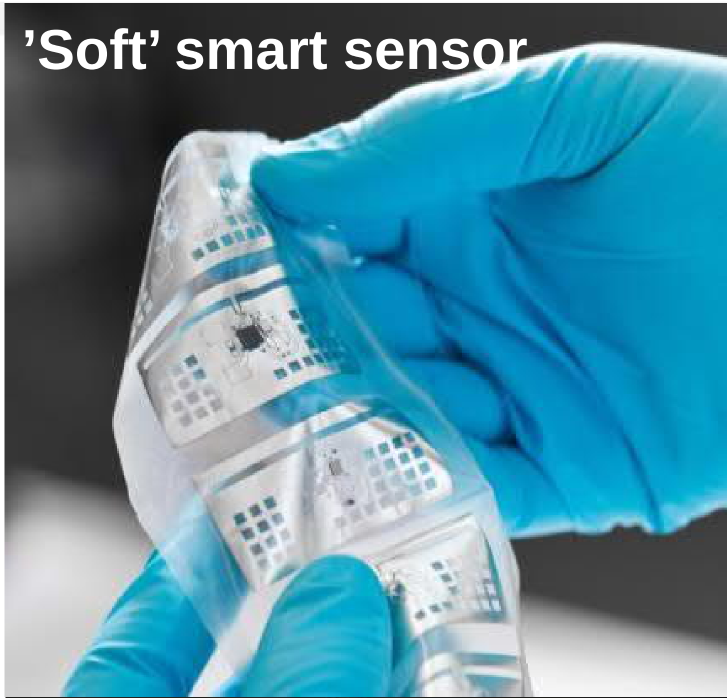
Vipuvoimaa EU:lta 2014–2020

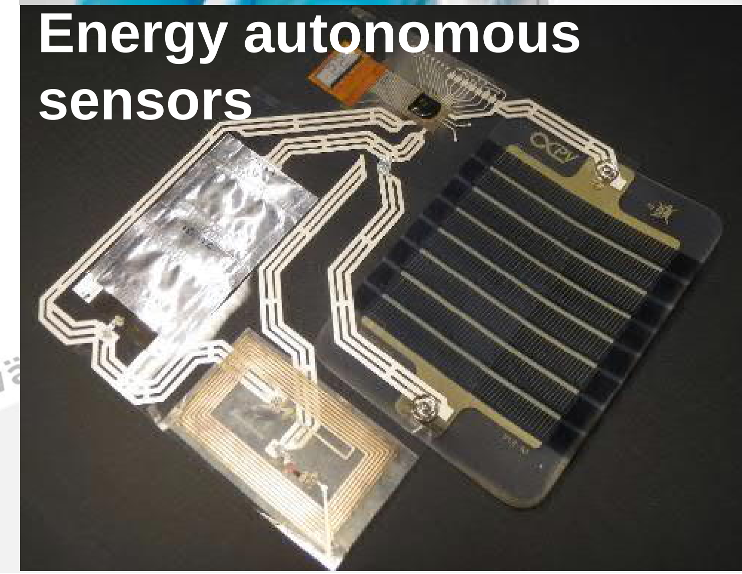
Euroopan unioni
Euroopan aluekehitysrahasto

research.tuni.fi/lfe

Laboratory for Future Electronics

- LFE investigates technologies and solutions related to **energy-autonomy** (storage and harvesting), **sensors**, conformable **wearable** electronics (soft/stretchable, on-skin, textile), and **hybrid system** integration.
- Strong emphasis is placed on scalable, low-cost manufacturing methods such as **printing** as well as their integration with more conventional component assembly methods.
- LFE explores new device and circuit approaches based on printable organic and metal oxide semiconductors.





Outline

- Internet-of-Everything
- Printed Electronics
- Stick-it-on-Device
- Research examples
- LFE infrastructure and on-going research

Kestävää kasvua ja työtä -ohjelma

Vipuvoimaa EU:lta 2014–2020

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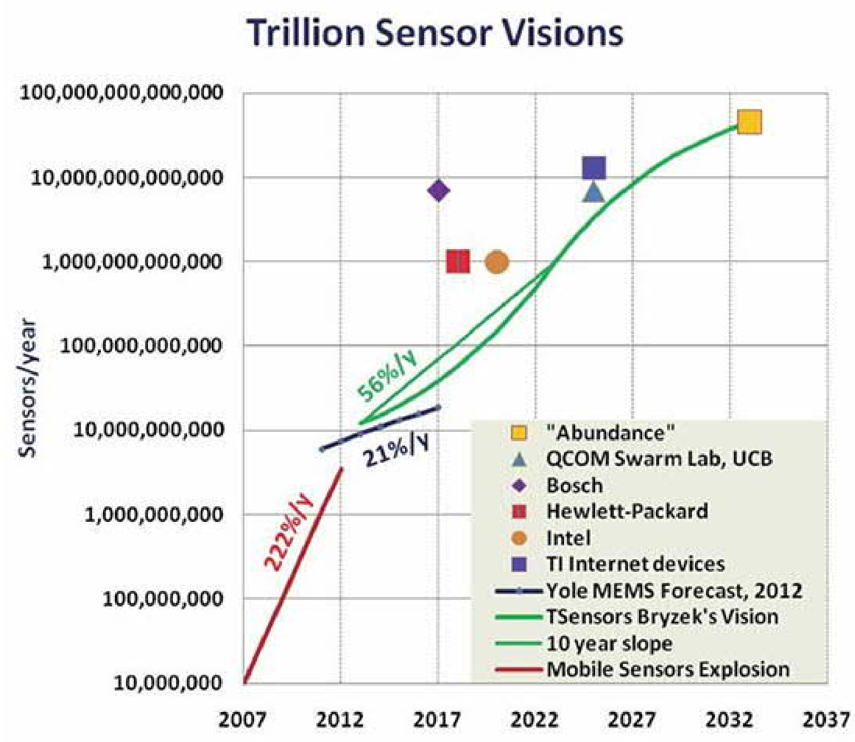
Trillion sensor vision

- Billions (and potentially trillions) of MCUs are needed every year.
- World's annual manufacturing rate of MCUs is around tens of billion pieces.
- **Paradigm shift in manufacturing is needed**



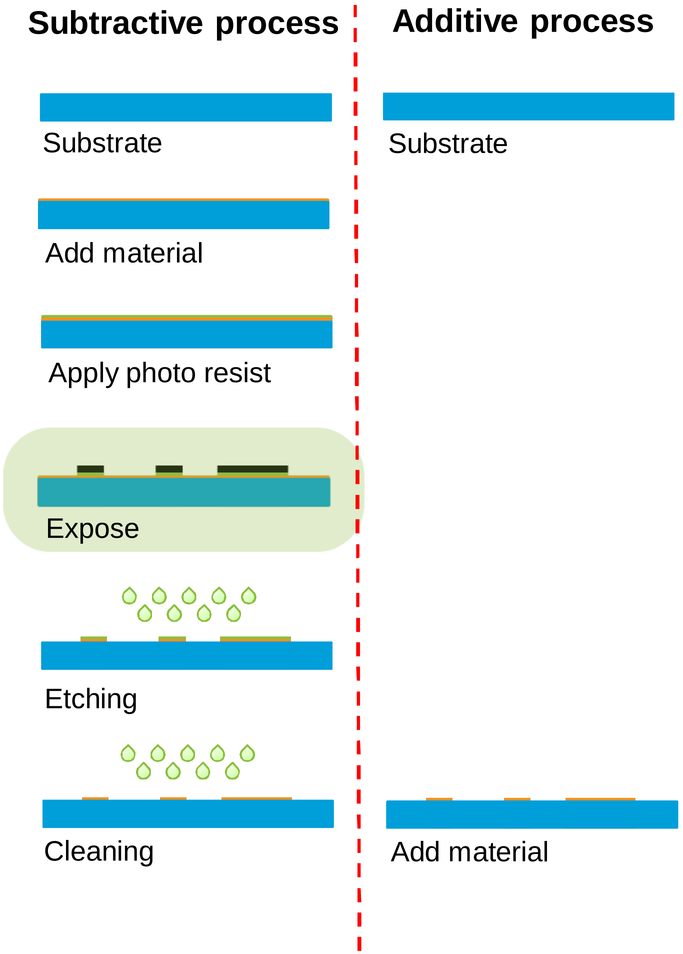
Source: Thin Film Electronics

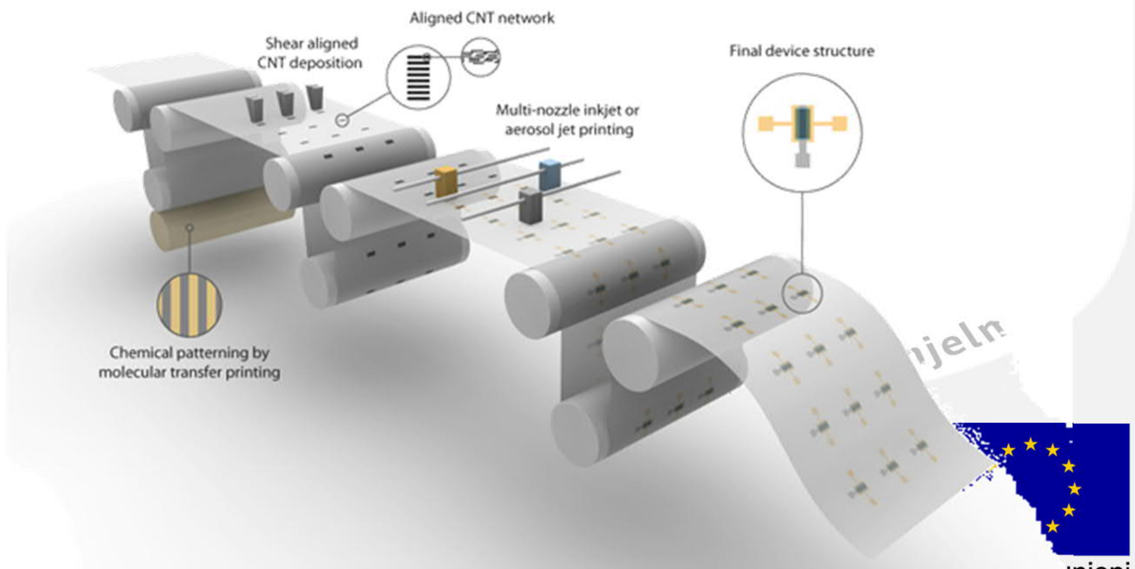
Source: FuturistSpeakers.com

Printed electronics

"Instead of printing graphic arts inks, families of electrically functional electronic or optical inks are used to print active or passive devices, such as thin film transistors or resistors"

- Additive => *less material waste*
- No etching => less harsh chemicals
- Less process steps => *simplified process*





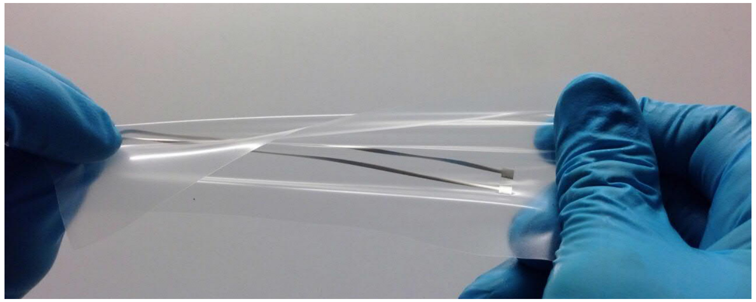
Printed Electronics Processing Concept (Grant Illustration)
From Dr. C. Daniel Frisbie at the University of Minnesota.

Printed Electronics

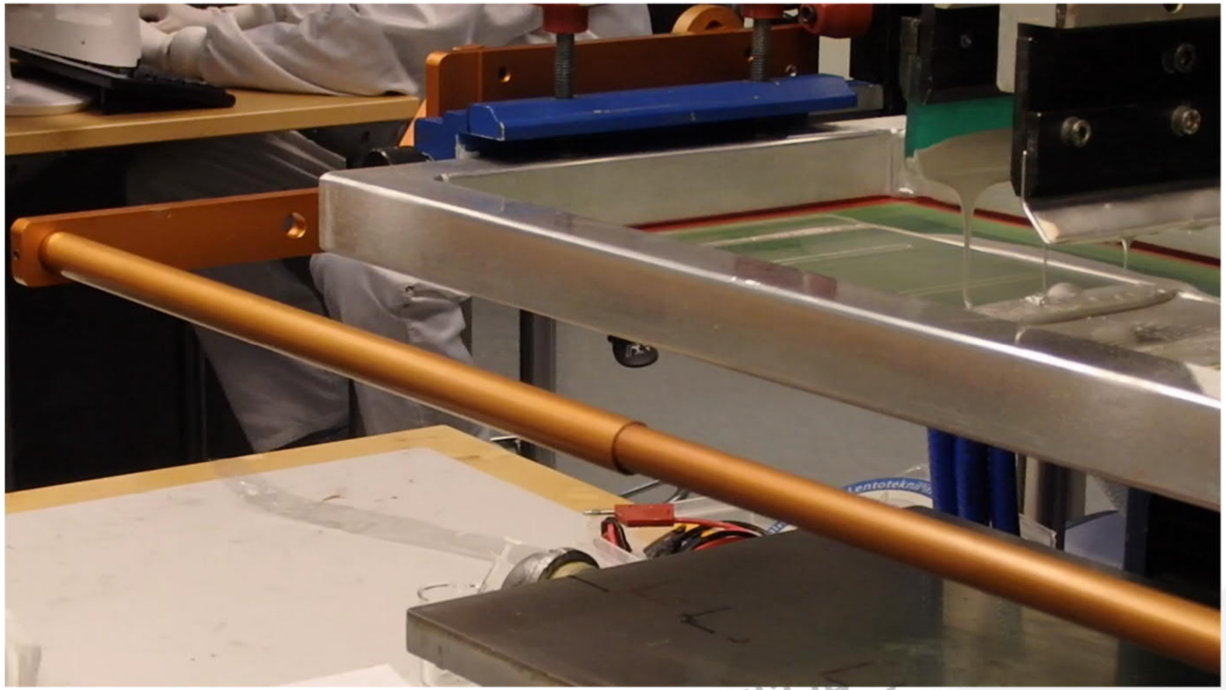
Main advantages:

- Simplified process
- Large-area
- Cost-effective

Inks

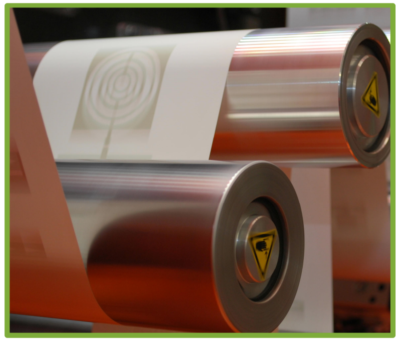
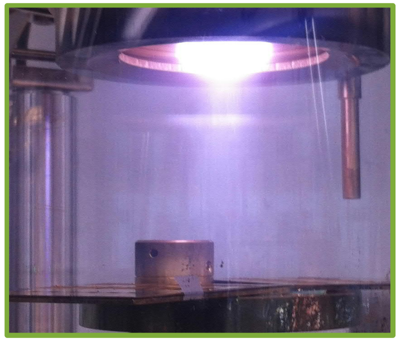
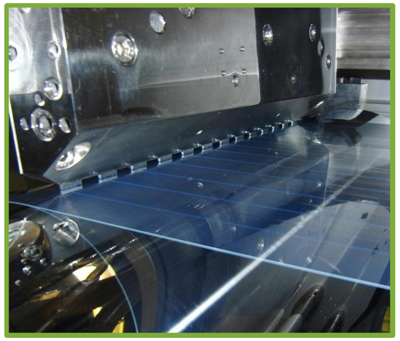


Thin foils



Printing technologies

Large Area Printing & Patterning Techniques

High volume printing processes	Digital patterning processes	Further patterning & deposition processes	Solution coating processes
			
• Gravure • Flexography • Offset • Lithography	• Inkjet printing • Aerosol jet printing • Laser transfer & machining • Micro-plasma printing • Syringe deposition • Xerography	• Vapor phase deposition • Soft & large area lithography • Nano-imprint lithography • Pad printing • Wetting/dewetting • Hot stamping	• Slot-die coating • Wire bar coating • Curtain coating

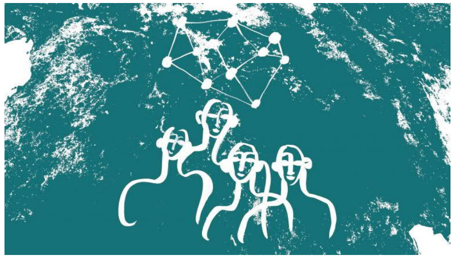
https://nakedapproach.fi/

Stick-it-on-Devices ”sticker computer”

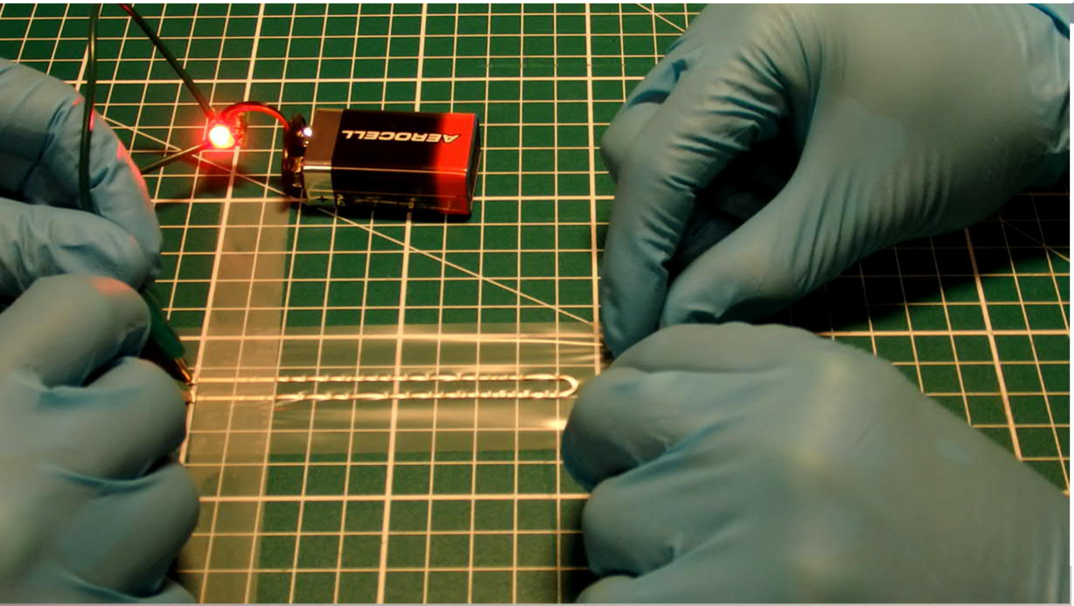
Turn ”**old world**” objects to ***smart devices***

Mass manufacturable	• billions of components and devices will be needed in the future (i.e.”trillion sensor visions”) • produced via low cost manufacturing processes
Form factor	• easy embedding into old world objects • concepts like “sticker computing”
Self-powering	• all units will operate on the basis of harvested energy • Either shared or self gathered from renewable source
Connectivity	• new connectivity technologies are needed to reach the peripheral “zero-resource” devices
Function	• each device should increase the “functional potential” of the environment – e.g. utilizing: sensing, actuating, computing, or connecting functions.

The Nordic Digital Promise: Four Theses on a Hyperconnected Society



On the Road to Digital Paradise



Example: Form factor

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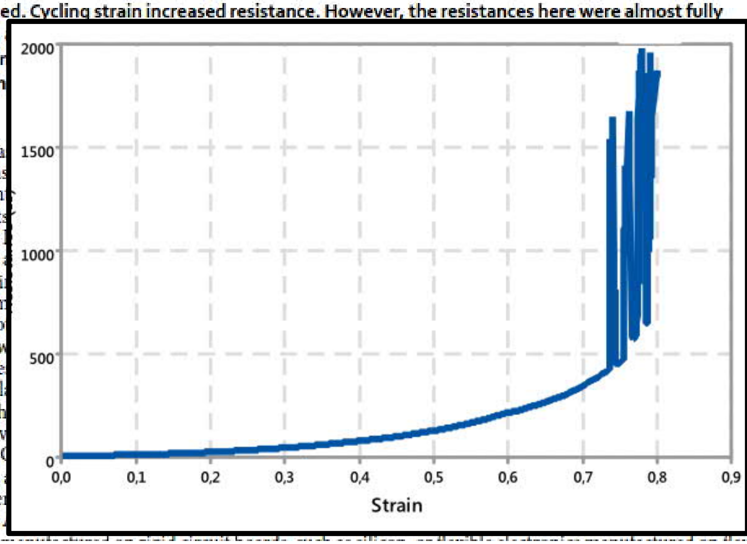
Screen-Printing Fabrication and Characterization of Stretchable Electronics

Received: 21 December 2015
Accepted: 22 April 2016
Published: 13 May 2016

Jari Suikkola, Toni Björninen, Mahmoud Mosallaei, Timo Kankkunen, Pekka Iso-Ketola, Leena Ukkonen, Jukka Vanhala & Matti Mäntysalo

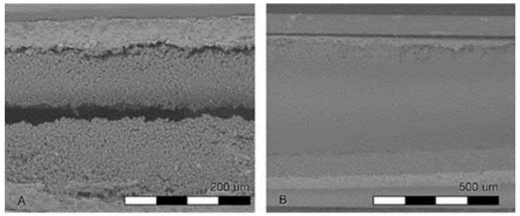
This article focuses on the fabrication and characterization of stretchable interconnects for wearable electronics applications. Interconnects were screen-printed with a stretchable silver-polymer composite ink on 50-µm thick thermoplastic polyurethane. The initial sheet resistances of the manufactured interconnects were an average of 36.2 mΩ/□, and half the manufactured samples withstood single strains of up to 74%. The strain proportionality of resistance is discussed, and a regression model is introduced. Cycling strain increased resistance. However, the resistances here were almost fully reversible, … cyclic strain… …y application…

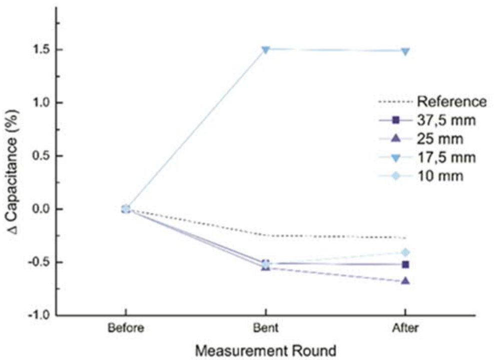


- Silver flakes: ~36 mΩ/□
- Single pull strain: 74%
- R(ε: 10%) ~ 2 x R_0
- R(ε: 20%) ~ 4 x R_0
- Up to 1 000 cycles (20%)

Supercapacitors for non-toxic energy storage

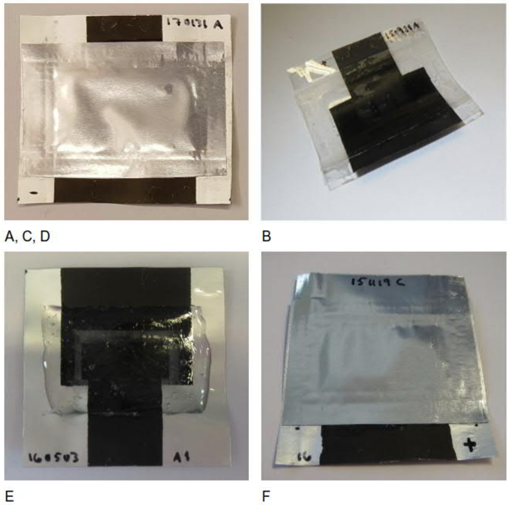
Non-toxic gelatin electrolyte





A. Railanmaa et al., Appl. Phys. A, in press

Monolithic supercaps

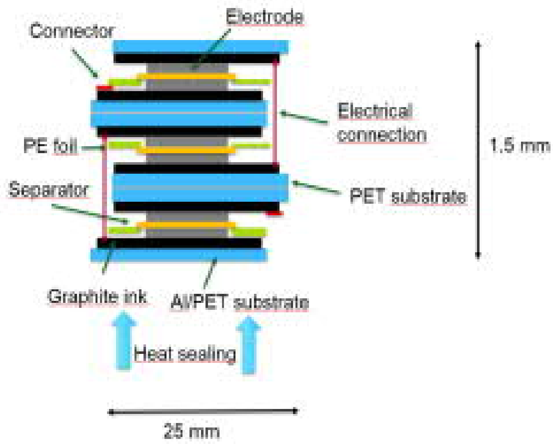


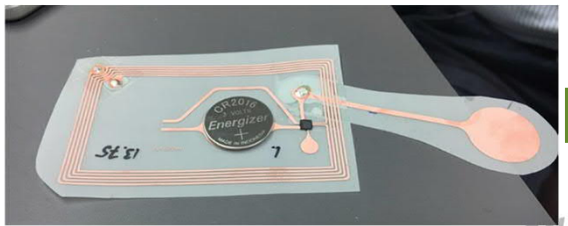
J. Keskinen et al., *J. Energy Storage* **16**, 243 (2018)

- Non-toxic materials: graphite, activated carbon, chitosan, paper, water, table salt
- Bill of materials few cents/device
- Fabrication by screen or stencil printing, bar coating
- Can hold energy for up to a month with barrier film

Example: Self-powering

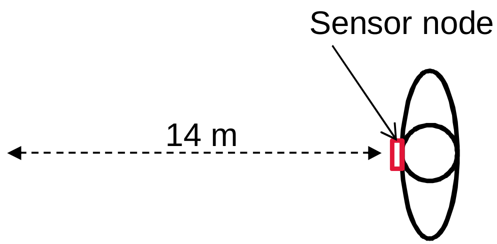
- Joint demonstrator with Confidex
- Commercial wireless temperature tracker was modified to replace coin cell with OPV module and printed supercap module
- OPV and supercaps fit within NFC read antenna and did not significantly affect reading
- Indoor light sufficient to power device and charge supercap, and supercap can power device for 18 hours in dark
- Best Poster award at InnoLAE2019 conference

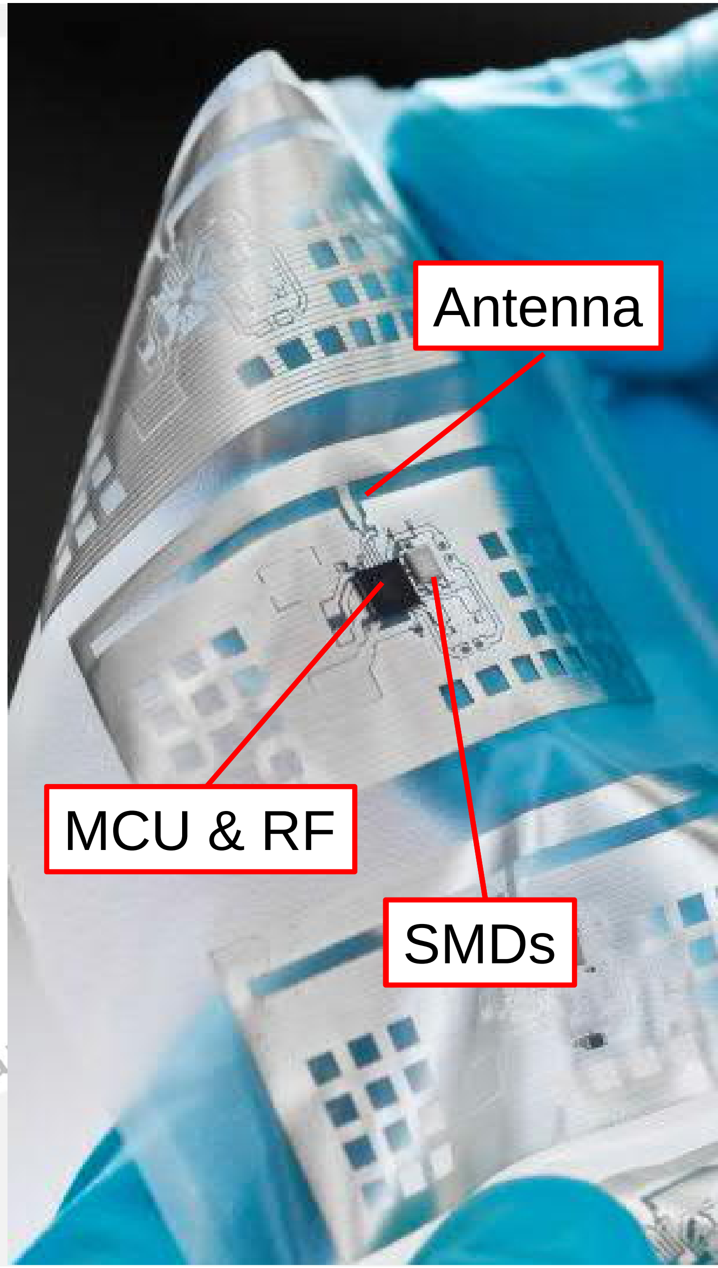




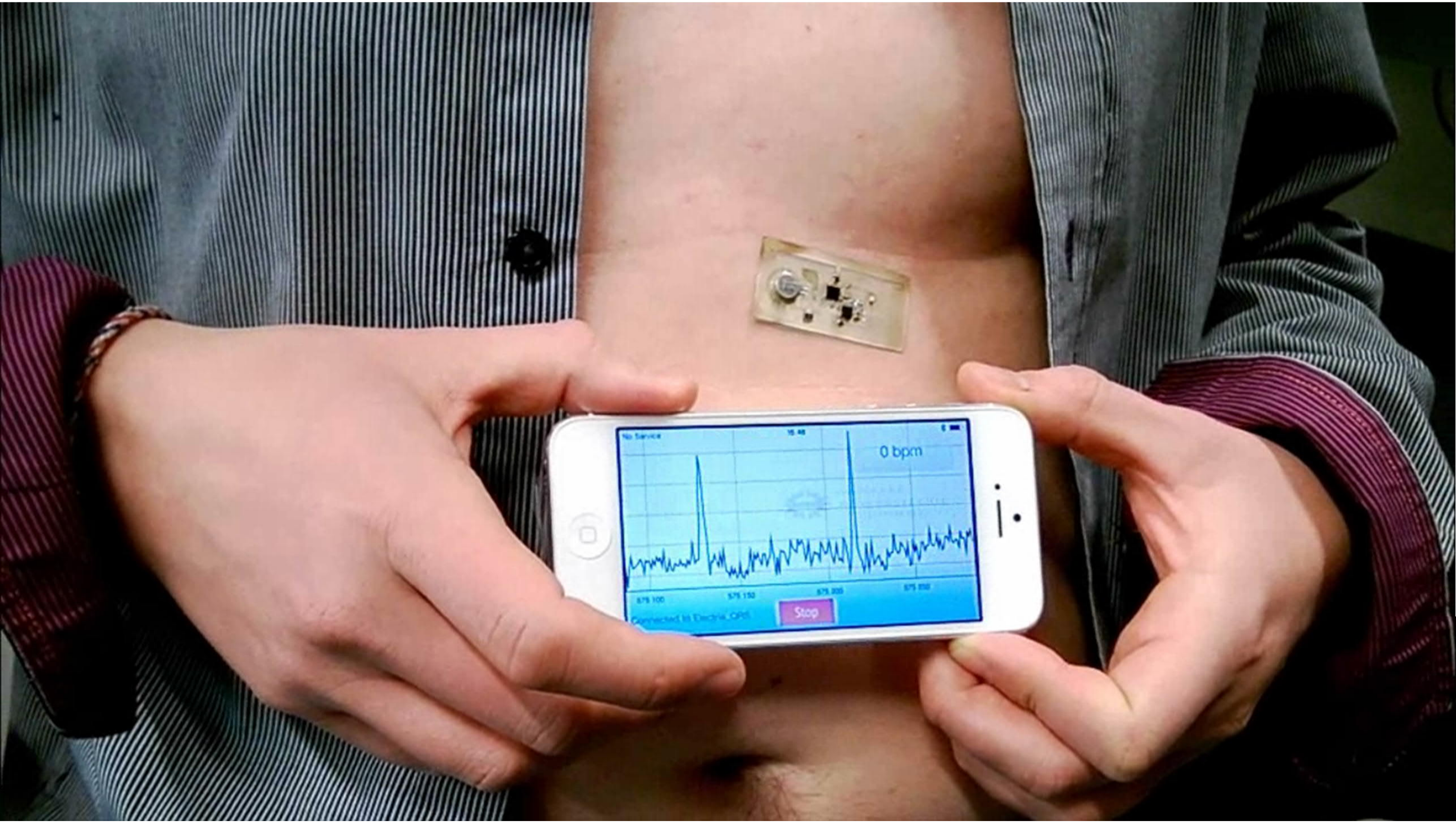
Example: Connectivity

- Band-aid like sensor attached directly on the body
  - 14 m reading distance (P_{TX} @ 0 dBm)
- Commercial NRF51822 (SoC) from Nordic Semi (WLCSP package)
  - Bluetooth low-energy
  - A/D converters
- In addition, there are the
  - Antenna (printed),
  - Amplifier and discrete components
  - Gel-electrodes for measuring the ECG signal.





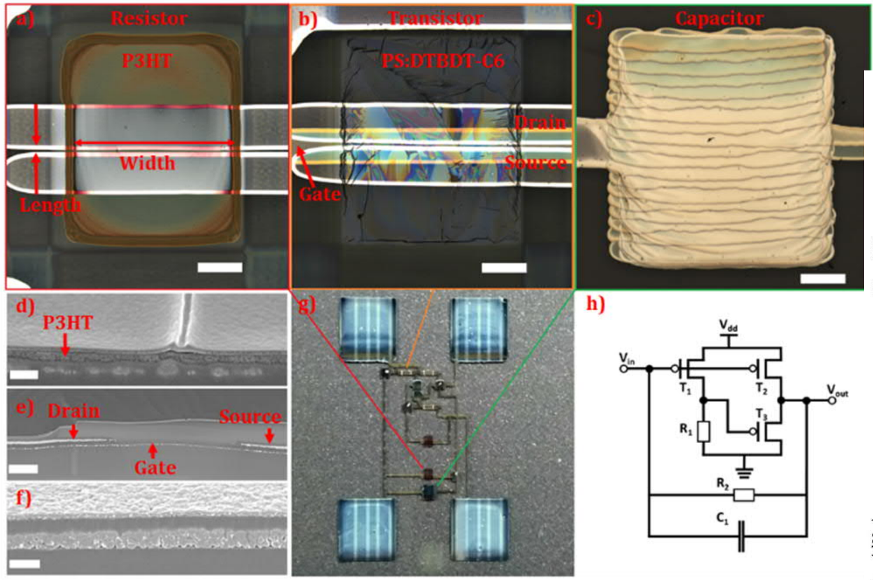
Sillanpää, et al.,, ESTC, 2014

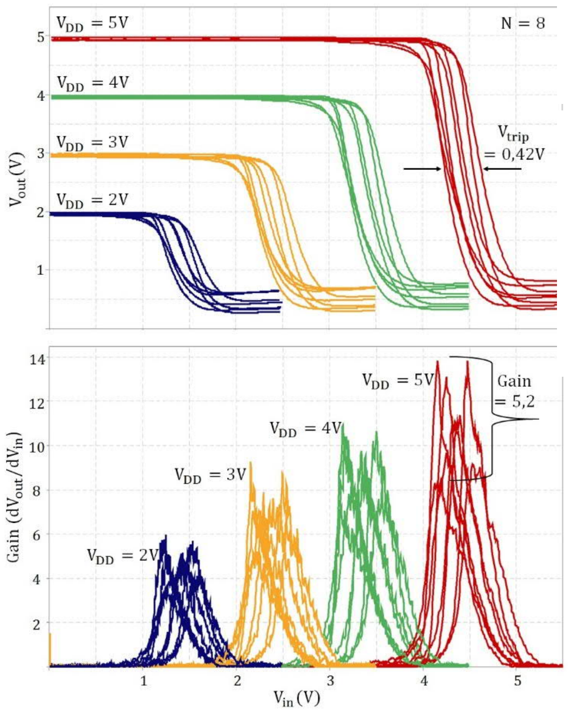

No Service
0 bpm
Stop

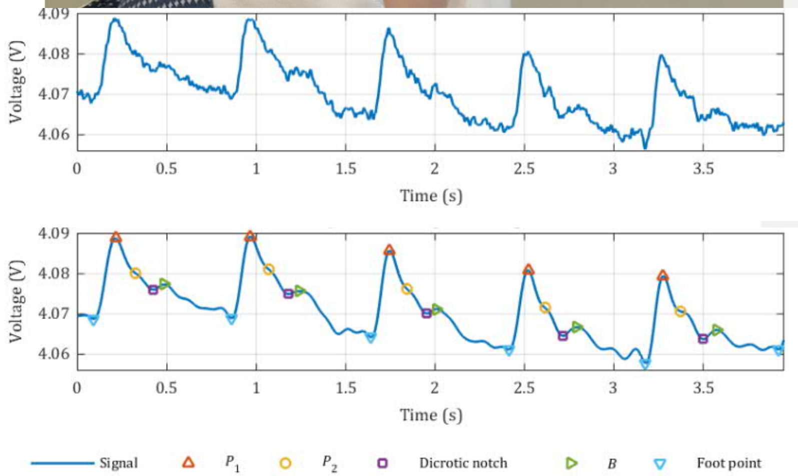
Laurila, et al., J-EDS, DOI: 10.1109/JEDS.2019.2915028

Example: Thin film circuitry

Collaboration between Tampere University, Tampere University Hospital and Yamagata University (Prof. Tokito)





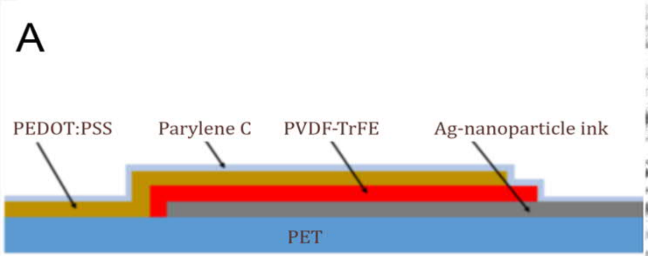


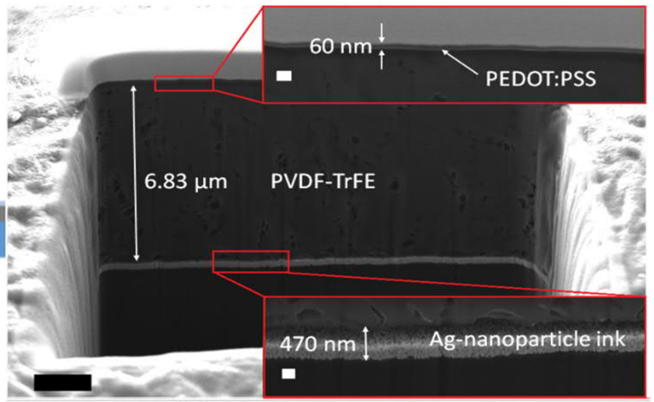
Substrate: parylene
Conductors: NPS-JL
Semiconductor: PS:DTBDT-C6
Resistor: P3HT

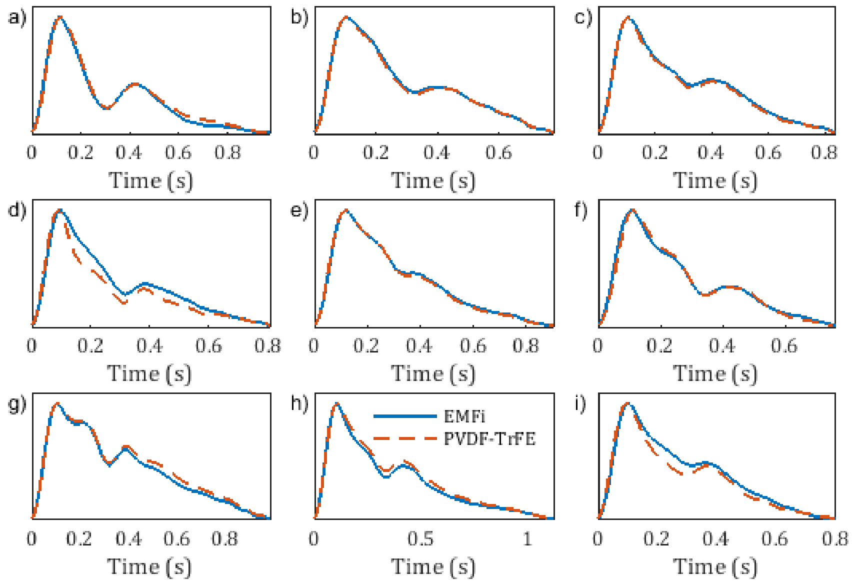
Parameter (n=25)	Average	Std. dev
RI, sensor	0.388	0.031
RI, output	0.404	0.044
rAIx, sensor	0.615	0.045
rAIx, output	0.626	0.057

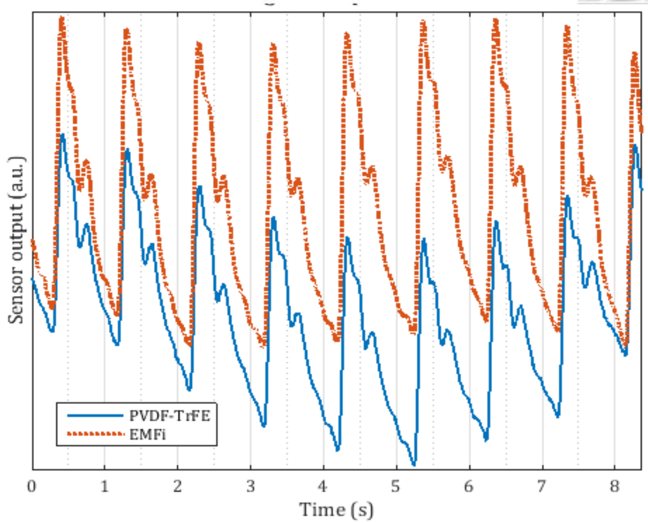
M.-M. Laurila, et al., DOI: 10.1109/JSEN.2019.2934943

Example: Pressure sensor









N=22	BA-ratio	CCC	Pearson's correlation
rAIx	0.195	0.761	0.817
RI	0.225	0.575	0.664
SI	0.067	0.941	0.950

Vipuvoimaa EU:lta 2014–2020

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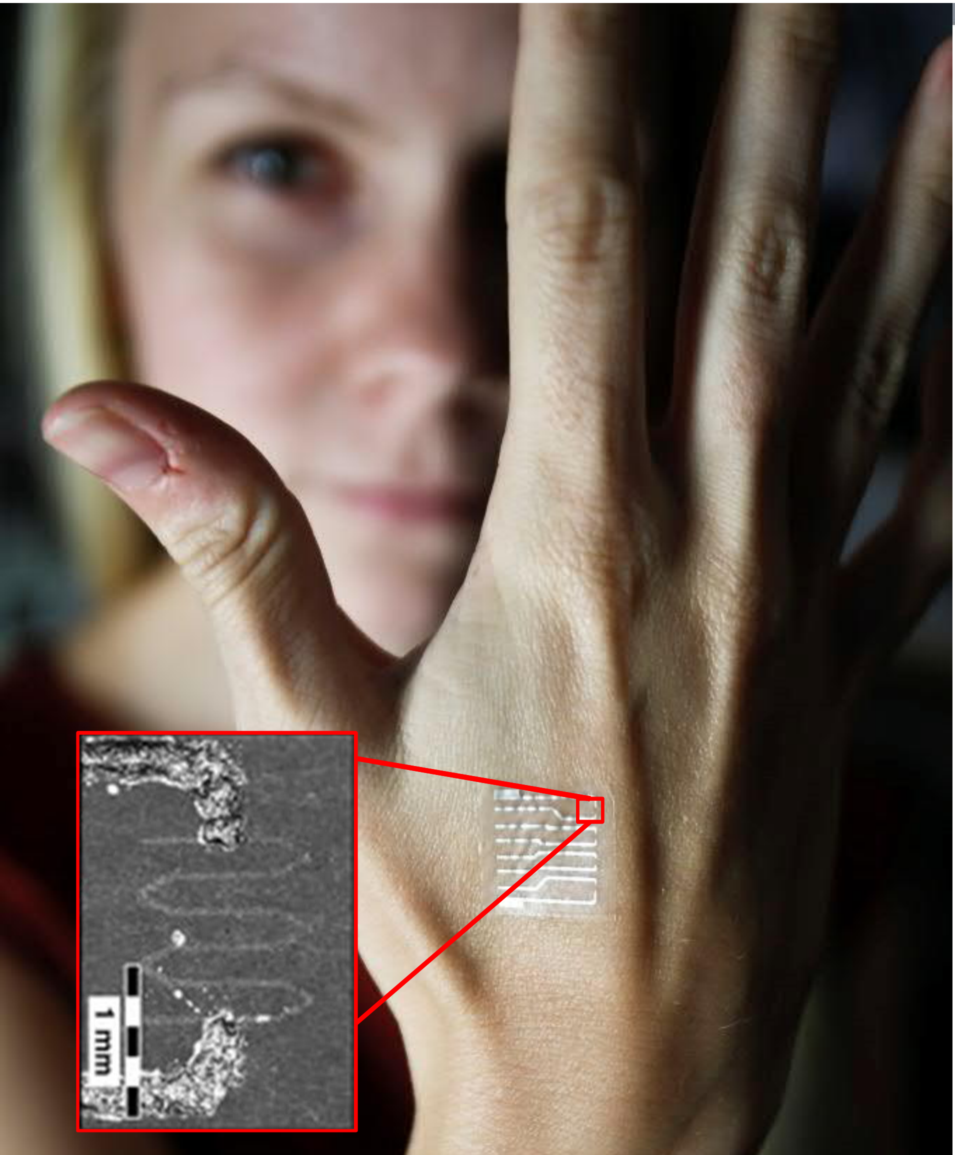
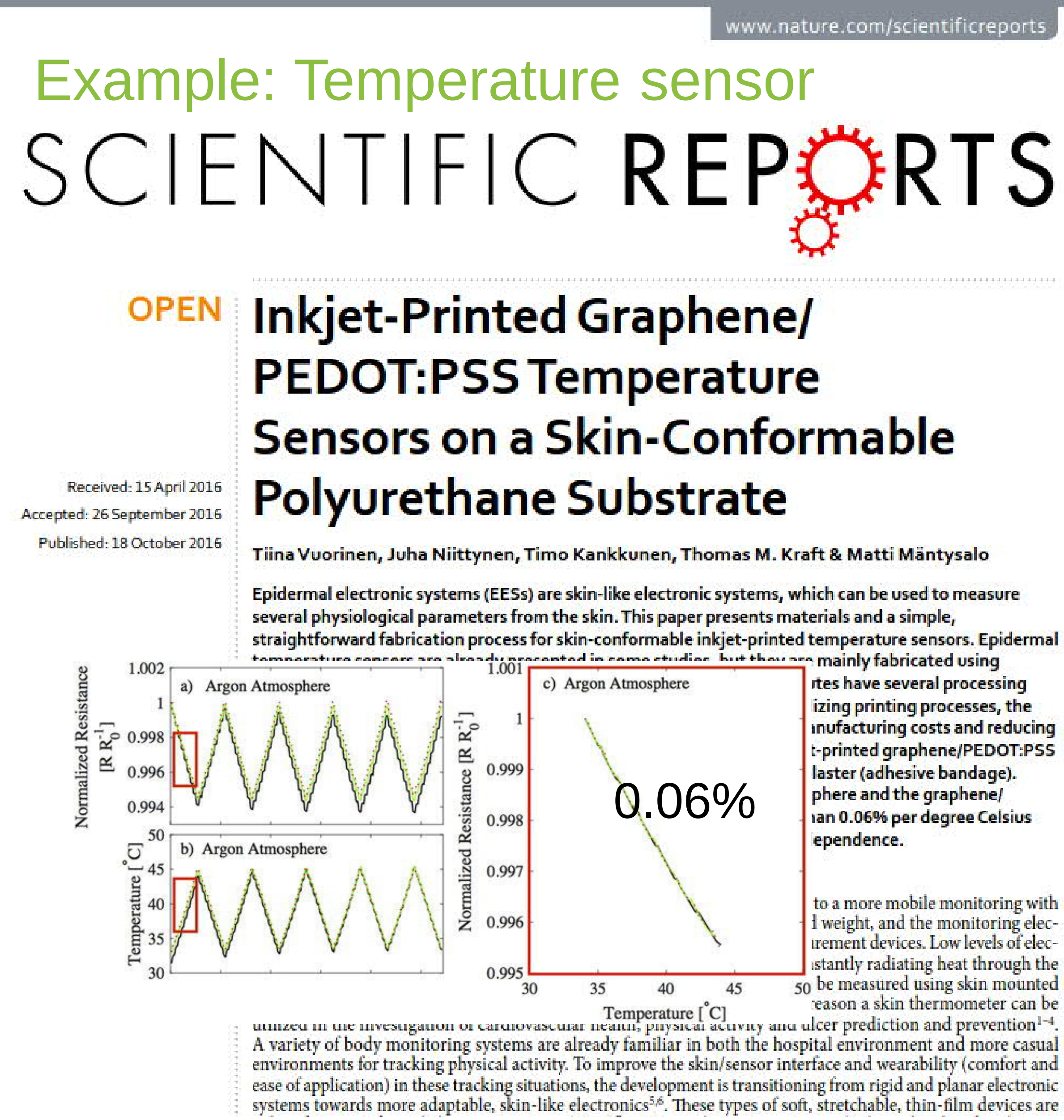
Example: Temperature sensor





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Accepted: 26 September 2016
Published: 18 October 2016

Inkjet-Printed Graphene/ PEDOT:PSS Temperature Sensors on a Skin-Conformable Polyurethane Substrate

Tiina Vuorinen, Juha Niittynen, Timo Kankkunen, Thomas M. Kraft & Matti Mäntysalo

Epidermal electronic systems (EESs) are skin-like electronic systems, which can be used to measure several physiological parameters from the skin. This paper presents materials and a simple, straightforward fabrication process for skin-conformable inkjet-printed temperature sensors. Epidermal
mainly fabricated using
ıtes have several processing
lizing printing processes, the
ınufacturing costs and reducing
t-printed graphene/PEDOT:PSS
laster (adhesive bandage).
phere and the graphene/
ıan 0.06% per degree Celsius
lependence.

to a more mobile monitoring with
d weight, and the monitoring elec-
ırement devices. Low levels of elec-
ıstantly radiating heat through the
be measured using skin mounted
reason a skin thermometer can be
utilized in the investigation of cardiovascular health, physical activity and ulcer prediction and prevention[1–4]. A variety of body monitoring systems are already familiar in both the hospital environment and more casual environments for tracking physical activity. To improve the skin/sensor interface and wearability (comfort and ease of application) in these tracking situations, the development is transitioning from rigid and planar electronic systems towards more adaptable, skin-like electronics[5,6]. These types of soft, stretchable, thin-film devices are

T. Vuorinen, DOI: 10.1038/srep35289

Contact: Dr. Jari Keskinen, Staff Scientist
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research.tuni.fi/lfe

LFE infrastucture

250 m2 Lab space
60 m2 Clean-room
PrintLab
Thin-film fabrication

Inkjet (with NIR and UV post processing), Modular printing system (gravure/flexo/rotary screen/wet and dry lamination / online annealing), screen printer, high-resolution inkjet

Inert glovebox-system including evaporator (thermal, e-beam), probe station, spin-coating, vacuum hot-plate, inkjet, ALD

LFE On-going projects

Academy of Finland

- HiFlex (Academy of Finland, 2017-2021) – high speed solution processed circuitry for wireless communication, based on tunnel diodes and transistors
- LightningSense (Academy of Finland, 2018-2021, with TAU Chemistry and Aalto Microelectronics) – energy autonomous wireless sensor node with printed light harvesters (lead-free perovskites) and energy storage (supercapacitors)
- VBA (AoF, 2017-2021) Vascular Biomechanics Assessment using printed soft electronics and advanced signal processing
- PII (AoF-FIRI, 2019-2021), Printed Intelligence Infrastructure
- EpiPrint (AoF Research fellow) – Development of epidermal electronics using nano-materials and advanced printing technologies 9/2015-8/2020

Business Finland:

- Elastronics (BF co-innovation, 9/2018-8/2020) printed stretchable hybrid electronics for wearables
- ECOtronics (BF co-innovation, 10/2019-9/2021) sustainable electronics and optics

European Union

- Smart2Go (EU H2020, 2019 – 2021, coordinator Fraunhofer) – smart and flexible energy supply platform for wearable electronics
- Charisma (EU Marie Curie ITN, 2019 – 2022) – engineering chemical irreversibility to prototype responsive smart labels
- BioÄly (EAKR EU-regional funding, 2018-2020), sustainable biodegradable materials
- InCOmESS (EU H2020, 2020-2023) - INnovative polymer-based COmposite systeMs for high-efficient Energy Scavenging and Storage

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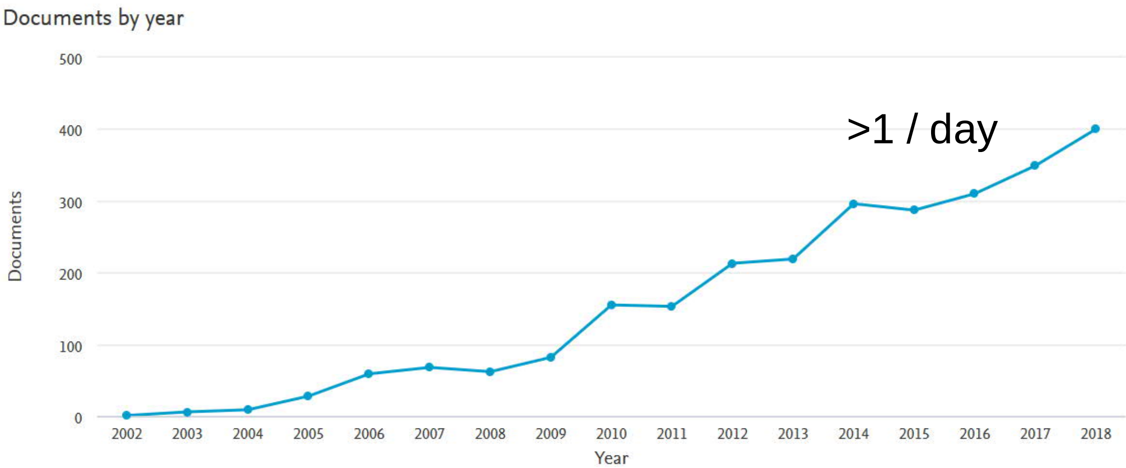
Scopus analysis 4.11.2019
”Printed electronics” in ABS-KEY-TITLE

”Printed electronics” research articles



>1 article per day (400/year)
Approx 2700 articles from 2002
Finland is top 7
Tampere in top 2