Sensor devices for smart and wearable electronics

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SAINT SKKU Advanced Institute of Nanotechnology

SAIHST Samsung Advanced Institute for Health Sciences and Technology

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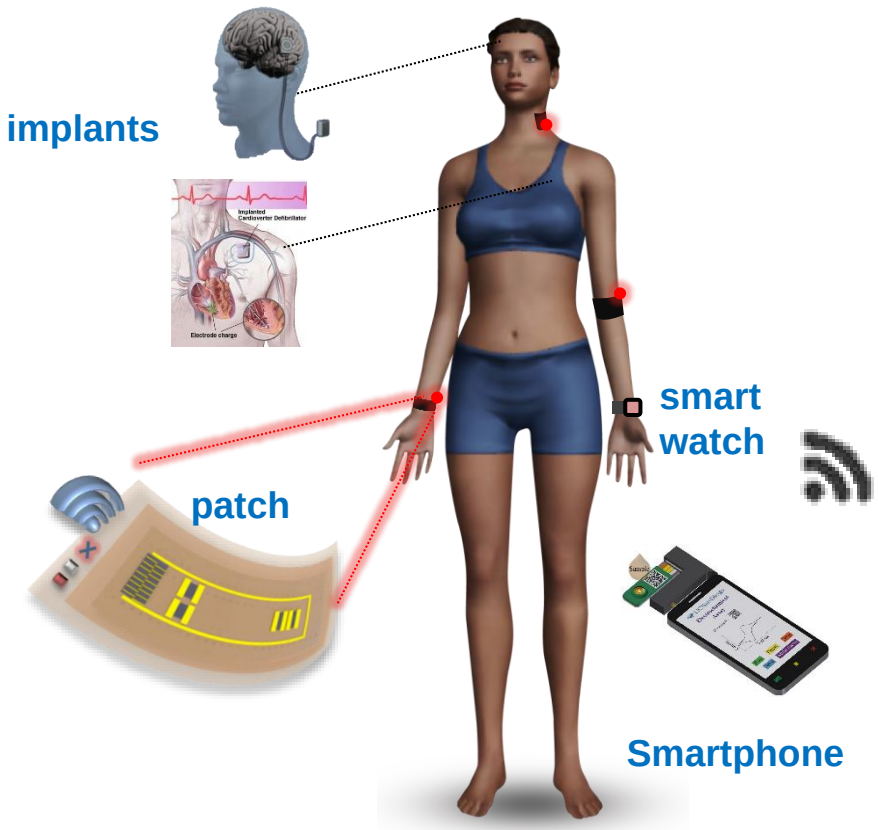
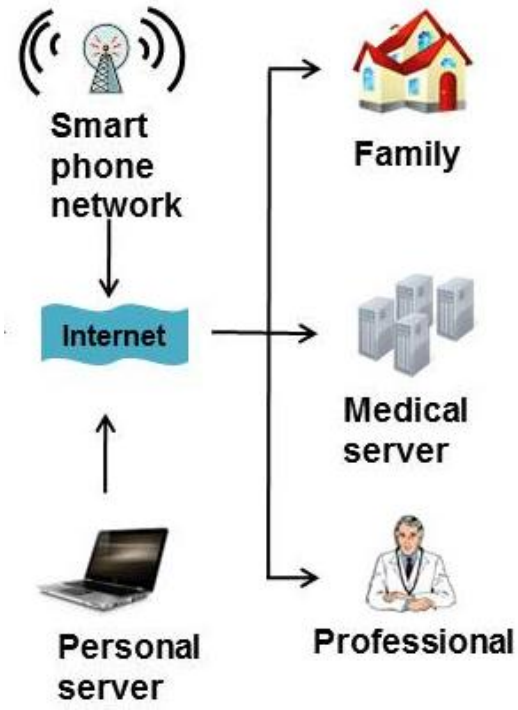
IOT in smart healthcare





- preventive medicine
- diagnostics
- prognostics
- rehabilitation
- therapy

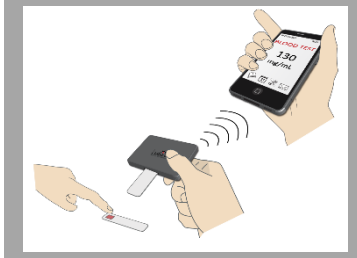
IOT-enabled sensor systems which can monitor physiological and clinical parameters are promising for smart healthcare.

IOT-enabled sensor systems for smart healthcare

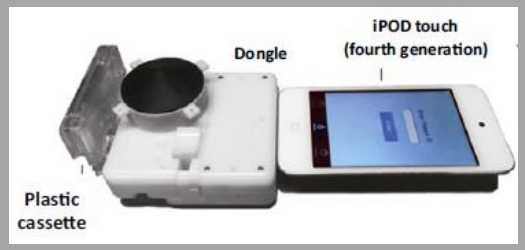
mPOCT

Wearables

Standalone



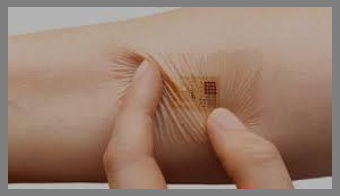
Smartphone-integrated



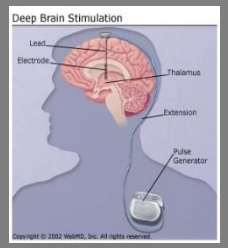
dressable

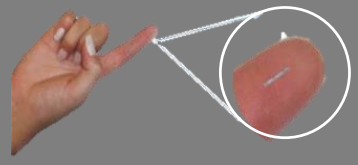
accessary

skin-attachable



implantable





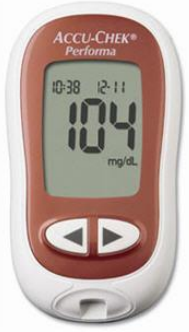
UNOBTRUSIVE

Mobile point-of-care testing (mPOCT) systems

Portable PoCTs : limits in connectivity and personalization

iSTAT
Abbott Labs

Blood analyzer
Alere



Accu-Check
Roche

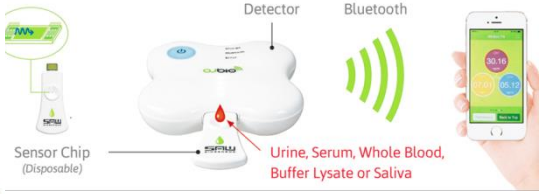
Coagucheck
Roche

Stratus troponin analyzer
Siemens

mPOCTs : advantage in connectivity (spatiotemporal mapping, epidemic demography, preventive healthcare) but limit of low accuracy and no standardization

Glucometer
iHealth

LFA reader
CELLMIC



SAW biosensor
OJbio

Heart monitor(ECG)
Alivecor

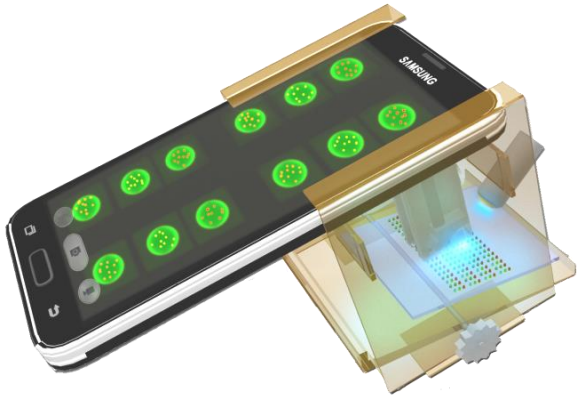
Fluorescence imaging-based high accuracy bioassay for mPOCT

Fluorescence spectrophotometer

Agilent

Hamamtsu

PMT



Smartphone

CMOS Image Sensor (CIS)

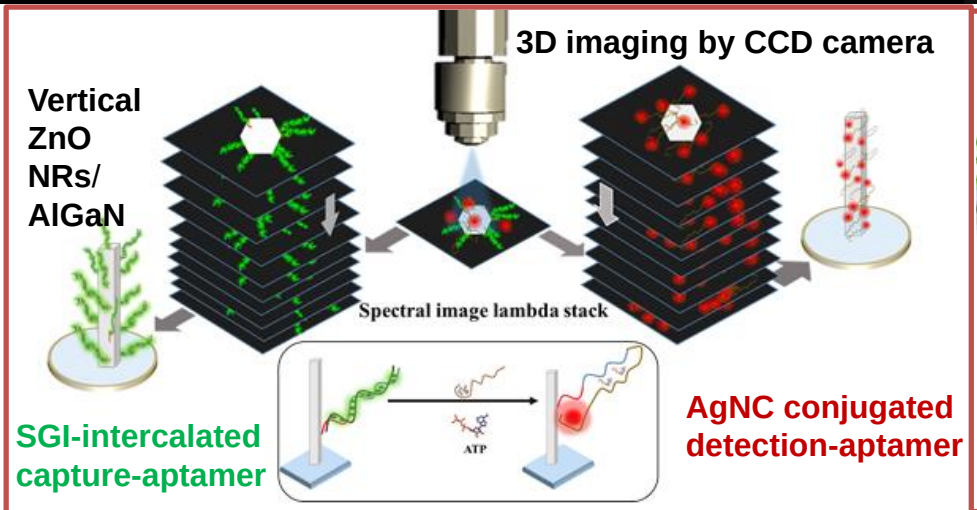
Rough exposure time control / low SNR

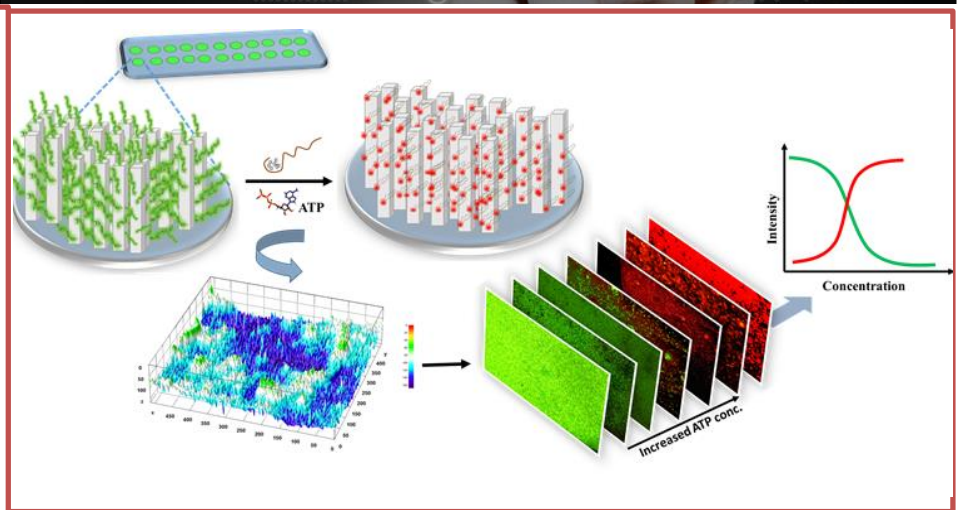
Issue : Low Accuracy

False-negatives/
False-positives ↓

specificity & selectivity ↑

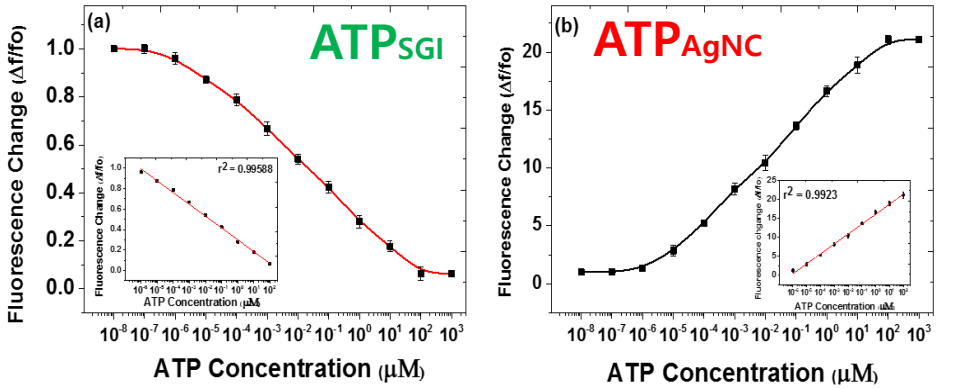
Fluorescence imaging-based 'seesawed' high-accuracy detection of biomolecules

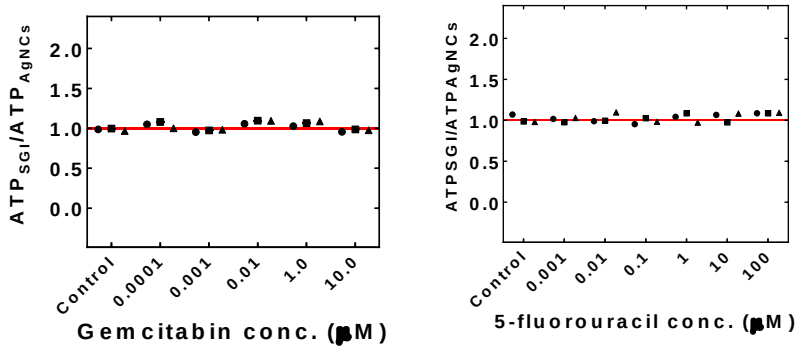




ZnO NR-enhanced fluorescence (FRET), Quantitative 3D quantification → SNR ↑

"Seesawed ratio" of red and green fluorescence ~ 1 during cellular ATP



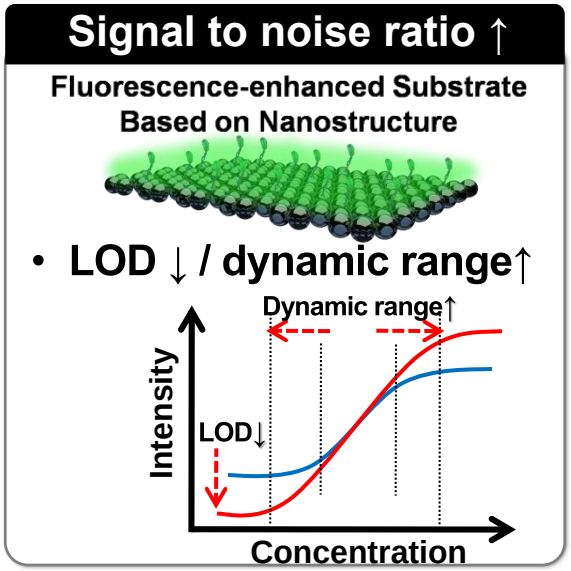


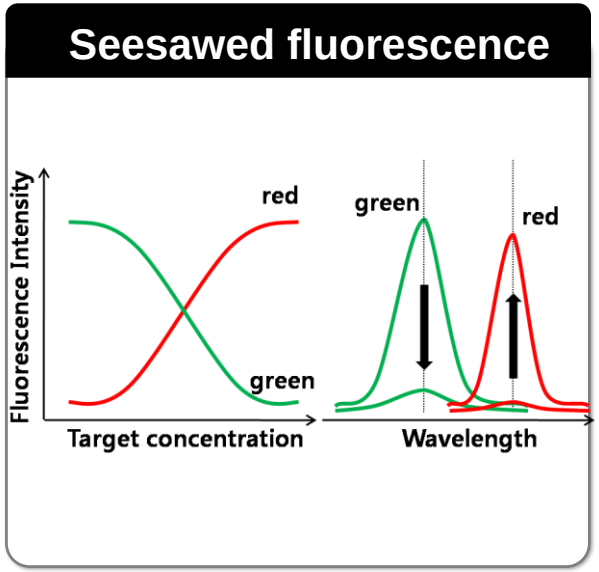
Minimize false-negatives : sensitivity ↑

Minimize false-positives : selectivity ↑

S. Shrivastava et al., Biosensors and Bioelectronics, 90(2017) , 450

Smartphone imaging-based fluorescence detection for high accuracy bioassays





False-negatives ↓

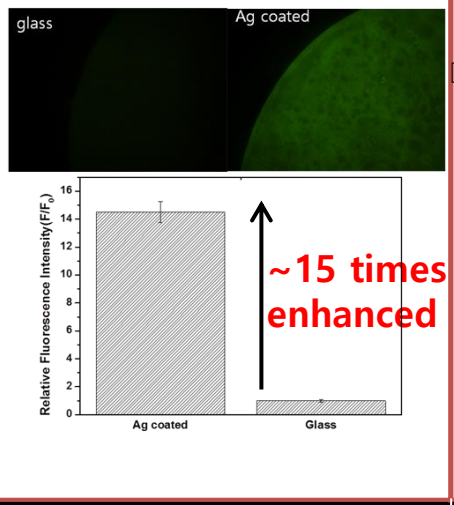
Sensitivity ↑

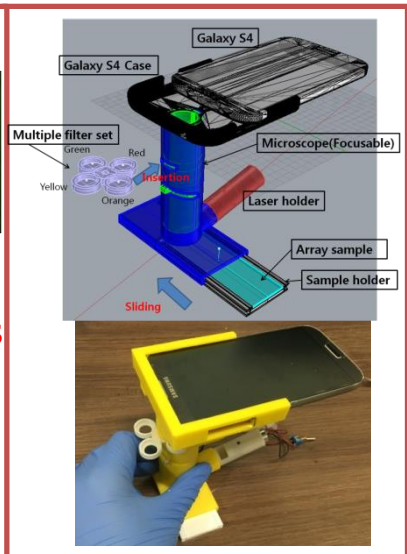
False-positives ↓

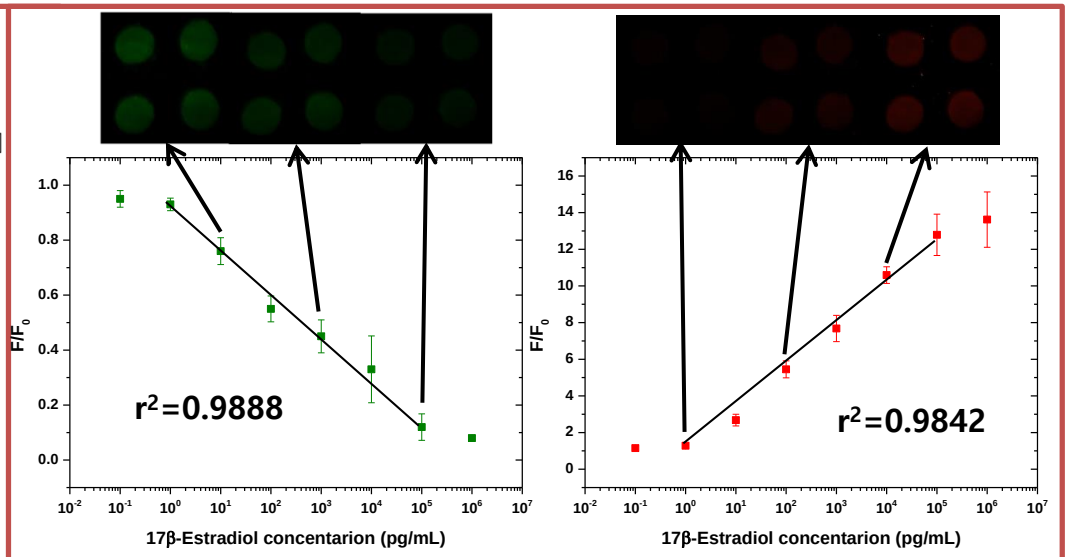
Selectivity ↑

W. Lee et al., Biosensors and Bioelectronics, 94(2017) , 643

Smartphone imaging-based fluorescence detection for high accuracy bioassays



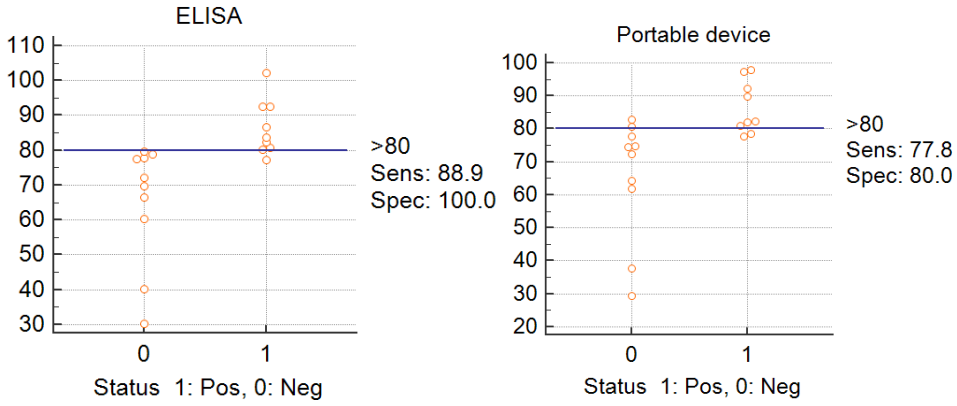


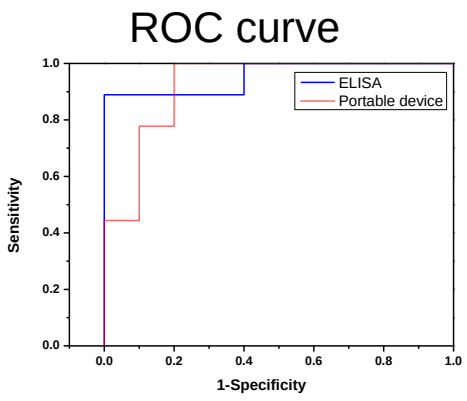


MEF(Ag)→SNR ↑

Prototyping of using 3D printing

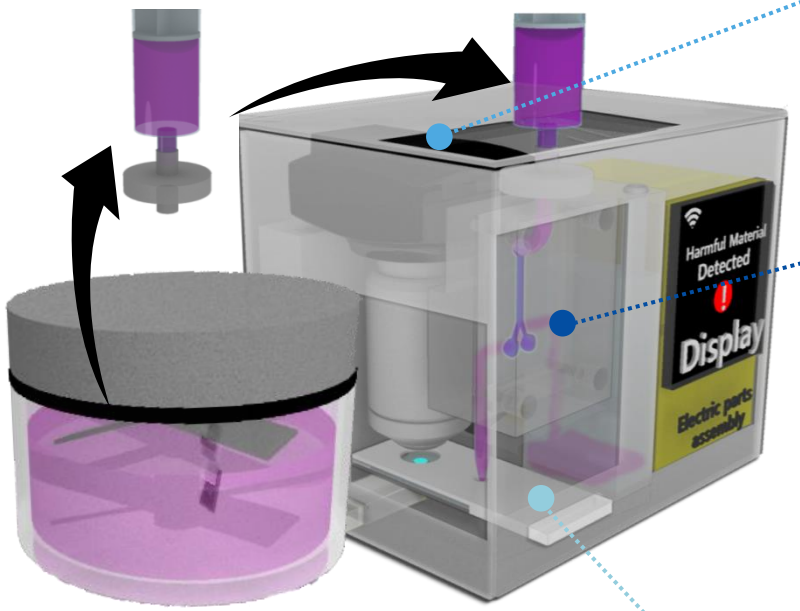
Calibration curve for 17β-estradiol with smartphone fluorescence microscope





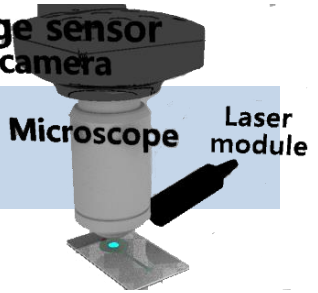
Statistical accuracy test of target analyte spiked wastewater	Area under ROC curve
ELISA	0.956
Mobile biosensor	0.922

Fluorescence imaging-based on-the-spot detection system for food safety

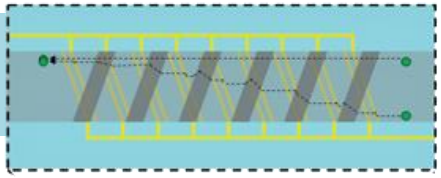


IOT-enabled system

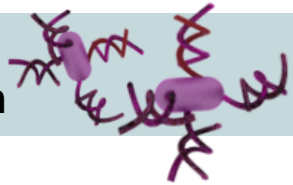
Fluorescence imaging based biosensing

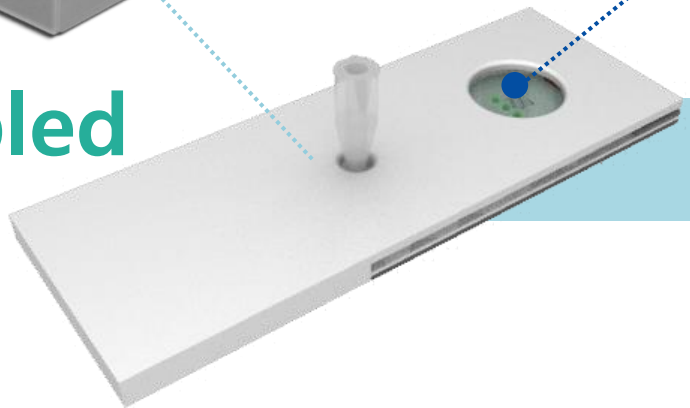


Bacteria separator/concentrator



Probes for bacterial, pesticide and toxin





Cartridge integrated with MEF substrate

Why skin-attachable sensor patches?

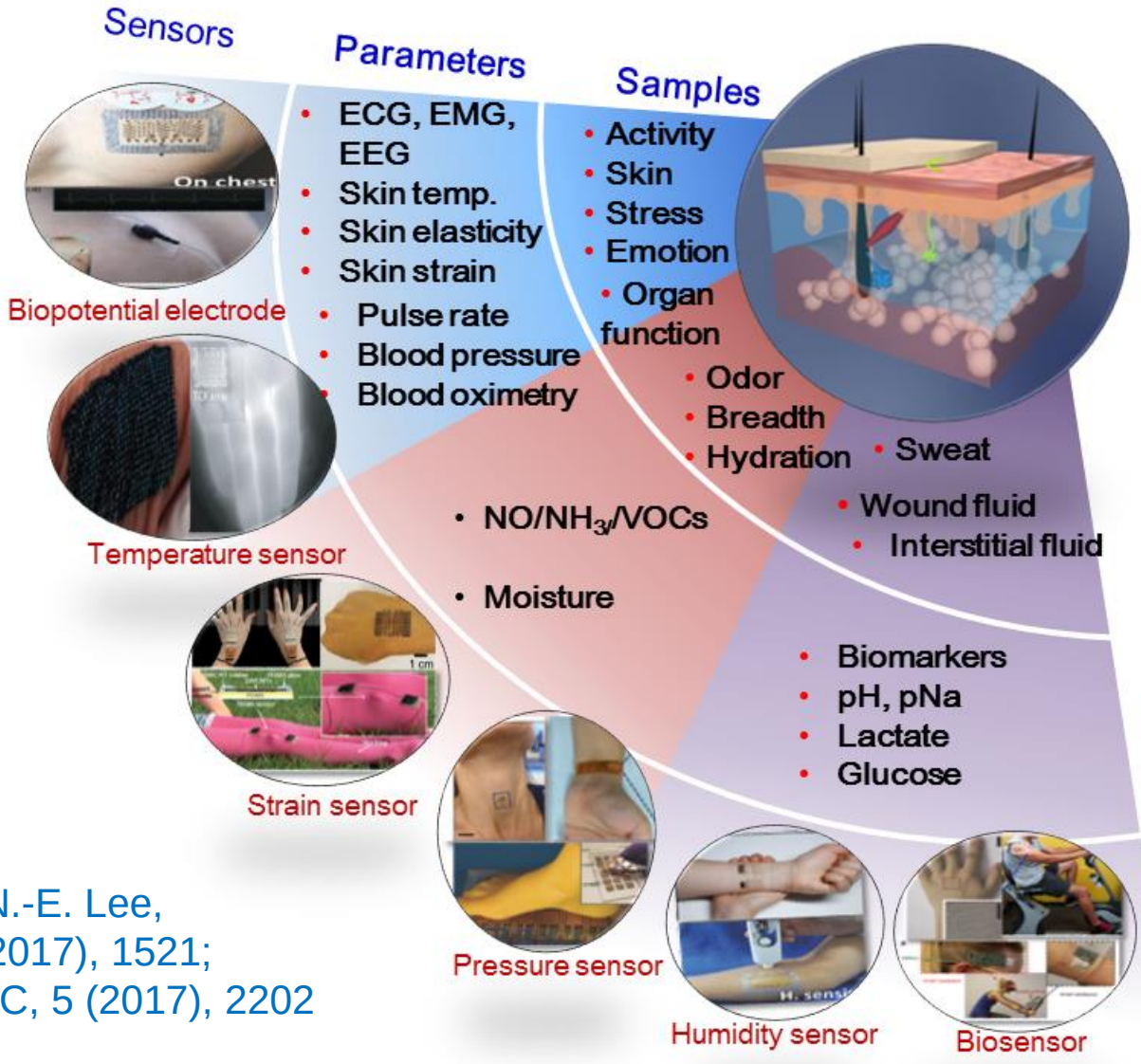
Accessary : non-invasive but limit in unobtrusive monitoring

Patch: non-invasive and unobtrusive monitoring, high SNR due to conformal contact with skin

Biostamp
MC10

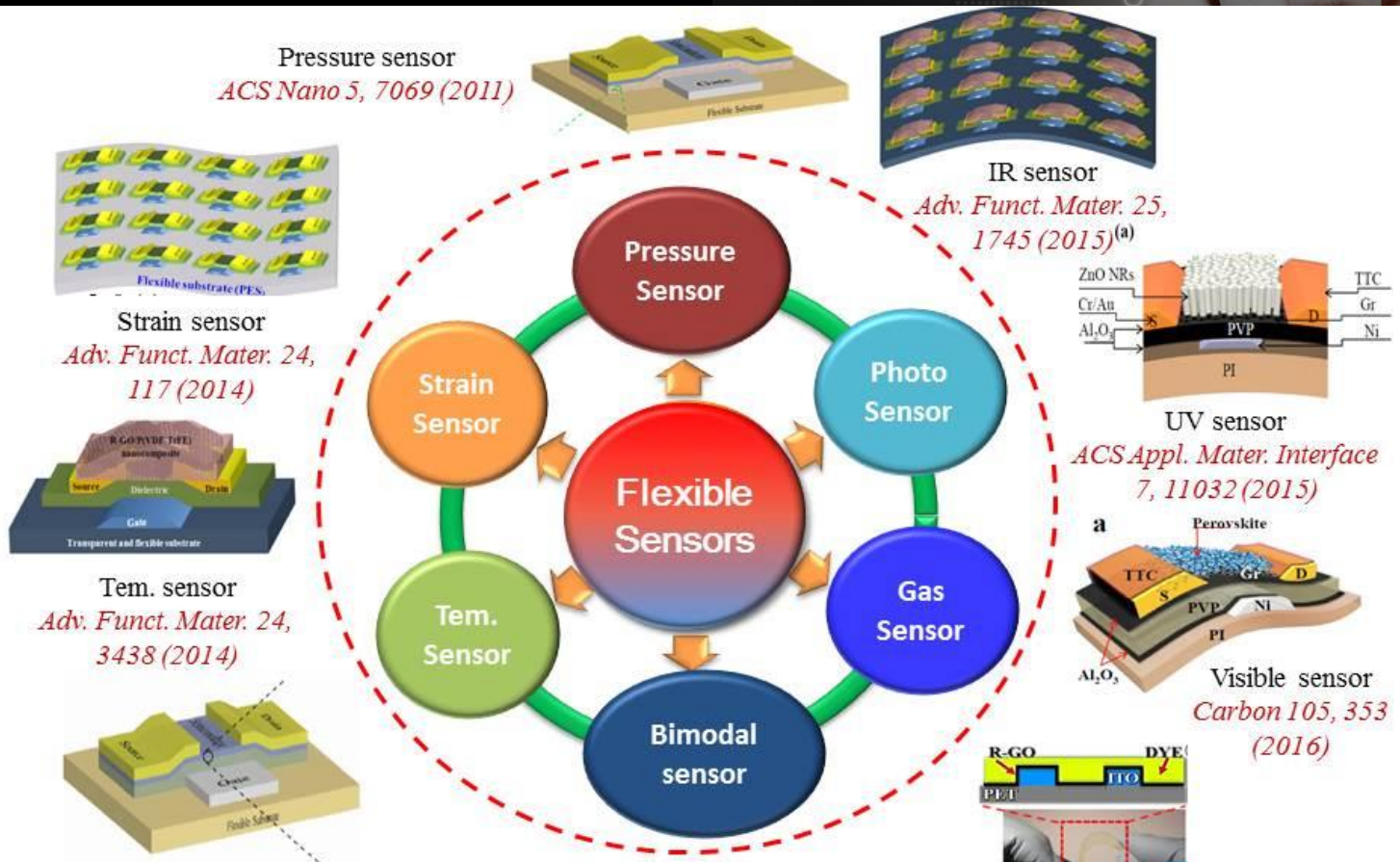
S-patch
Samsung

What can be measured by skin-attachable sensor patches?



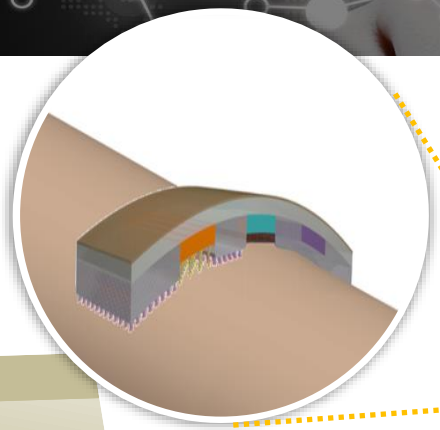
T.Q. Trung and N.-E. Lee,
Adv. Mater. 29 (2017), 1521;
J. Mater. Chem. C, 5 (2017), 2202

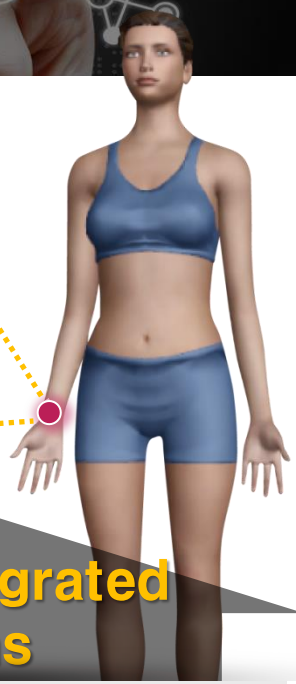
Flexible sensors for skin-attachable patches by our group



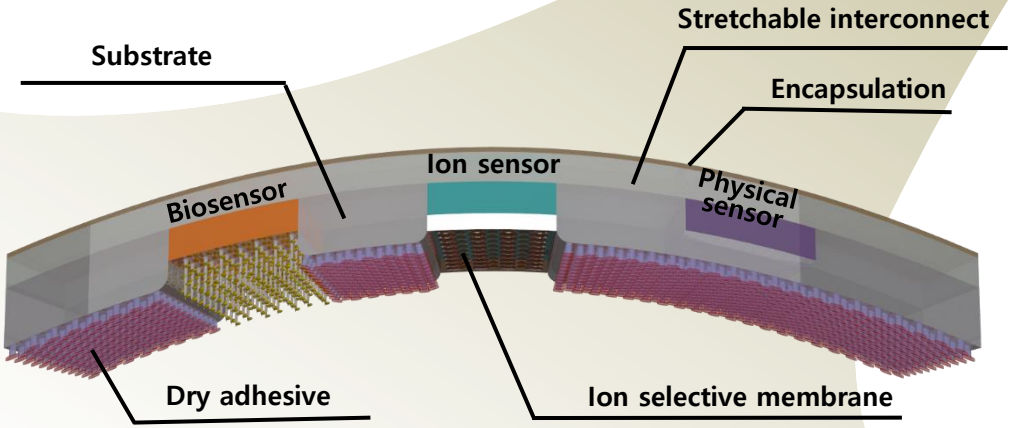
Stretchable sensors for skin-attachable patches

Materials	Stretchable sensing materials, electrochemical electrodes, dry biopotential electrodes
Device	Stretchable sensors, energy harvesters, energy storage devices
Packaging	Substrate, dry adhesives, interconnect, encapsulation





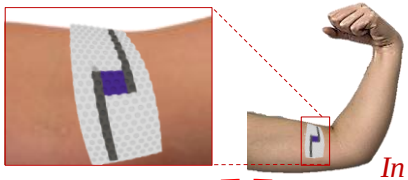
Stretchable materials & devices



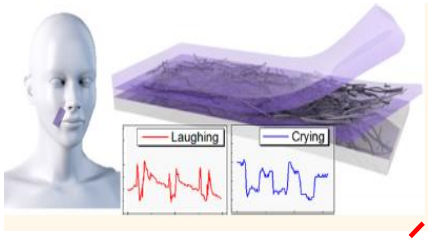
Sensor-integrated systems

Integration	Sensor array, integration of sensors, power, and MCU
S/W	Signal processing, data transmission, apps, big data
Clinical	New applications, clinical evaluation, service

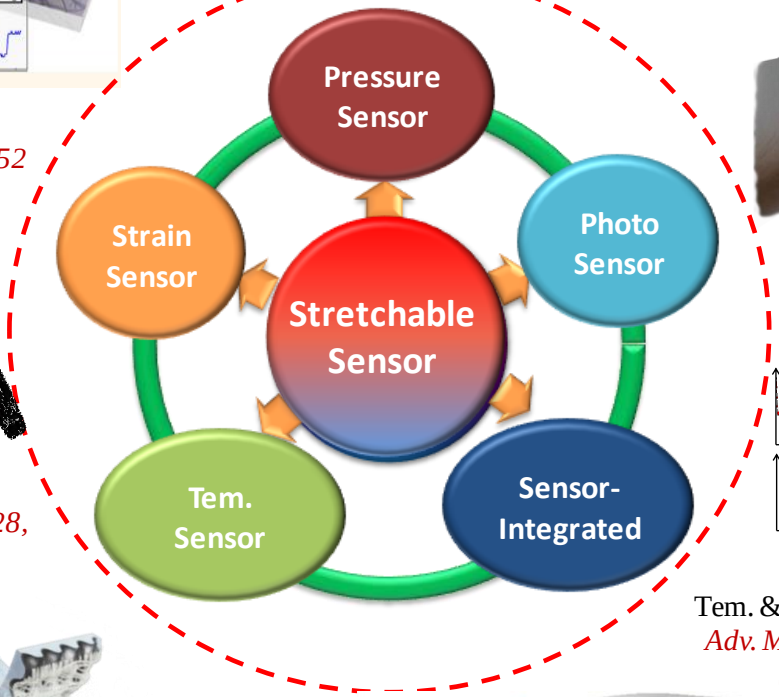
Stretchable physical sensors for skin-attachable patches

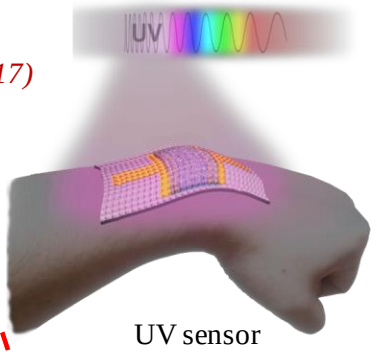


Pressure sensor
In preparation (2017)



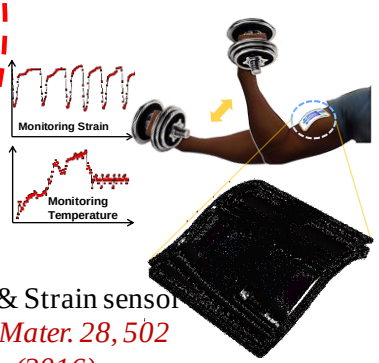
Strain sensor
ACS Nano , 11, 6252 (2015)





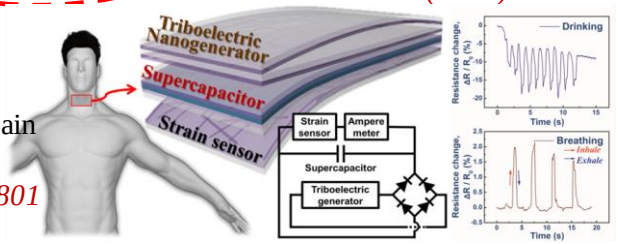
UV sensor
In preparation (2017)

Tem. sensor
Adv. Funct. Mater. 28, 502 (2016)



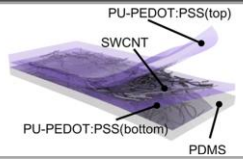
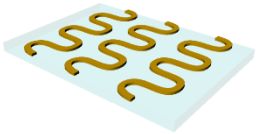
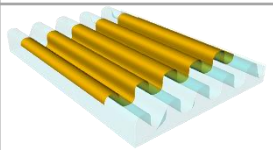
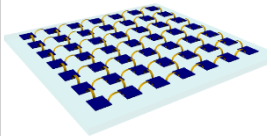
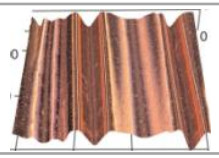
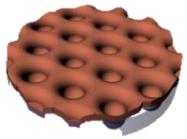
Tem. & Strain sensor
Adv. Mater. 28, 502 (2016)

Nano Generator
In preparation (2017)



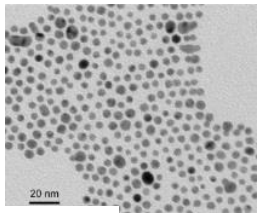
Self-Power Strain sensor
ACS Nano 9, 8801 (2015)

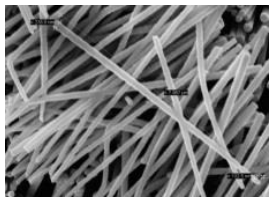
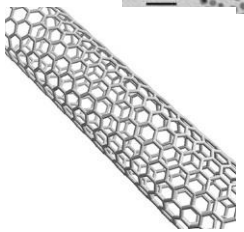
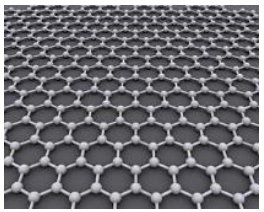
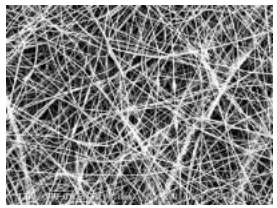
Approaches for stretchability

Materials	Strategies	Designs	Process methods	Stretchable direction
Intrinsically stretchable components	Using intrinsically stretchable materials	 **Elastomeric nanocomposites**	Spin-coating, printing, spraying *ACS Nano* **2015**, *9*, 6252	Omni-direction
Geometric engineering of flexible materials	In-plane, geometric engineering	 Serpentine routing	Patterning *Appl. Phys. Lett.* **2014**, *104*, 021908	Uniaxial
	Out-of-plane, geometric engineering	 Wavy structure	Pre-stretching and release *J. Vac. Sci. Technol. A* **2009**, *27*, L9	Uniaxial, Biaxial
		 Island-bridge	Transfer printing *IEEE Trans. Compon. Packag. Manuf. Technol.* **2015**, *PP*, 1	Biaxial
		 Imperceptible	Transfer on pre-strained ultrathin substrate *Adv. Mater.* **2015**, *27*, 34	Unixial
	Out-of-plane, 3D structuring	 Bio-mimicking	Soft lithography *Adv. Sci.* **2015**, *2*, n/a	Multi-direction, but not fully stretchable
		 **Microstructrured pattern**	Soft lithography spin coating, printing, spraying	Omni-direction

Approach 1: Intrinsically stretchable elastomeric nanocomposites

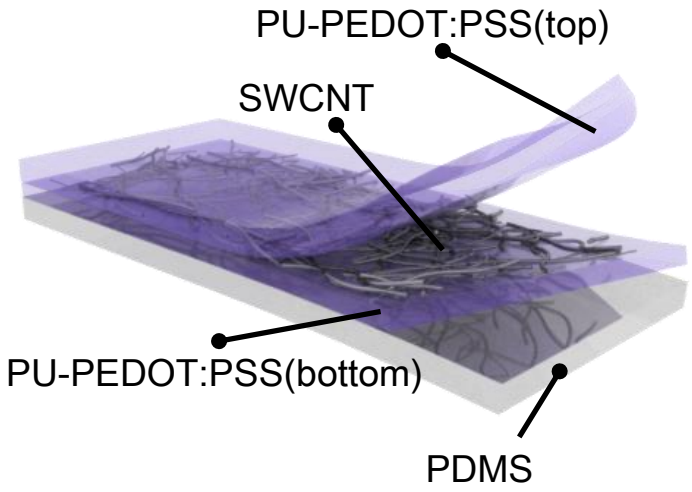
Nanomaterials

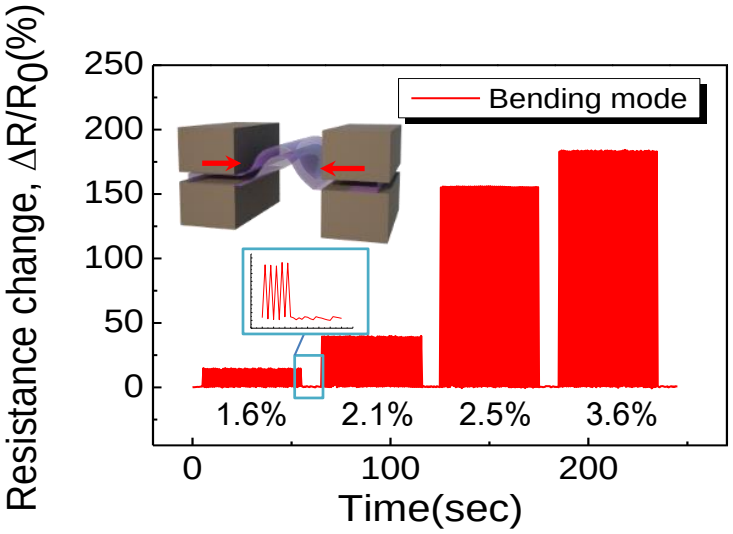


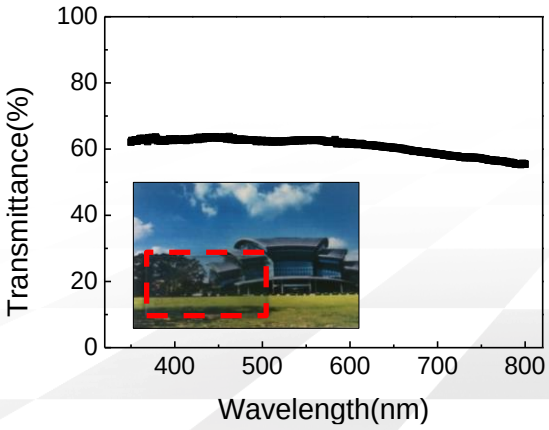





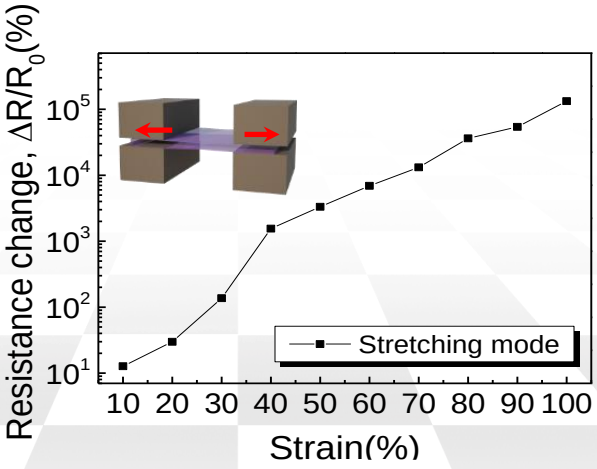
piezoelectric
pyroelectric
piezoresitive
chemresistive
thermoresistive
photoresponsive
electroactive

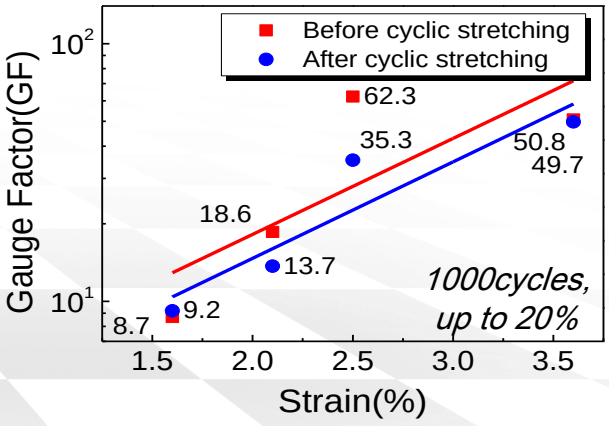
Stretchable, transparent and ultrasensitive strain sensor for emotion detection





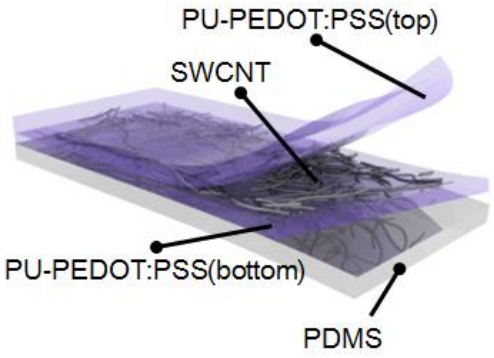


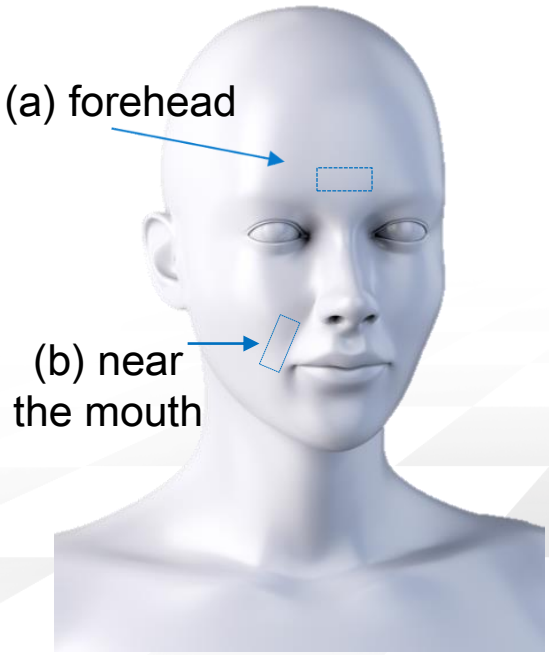


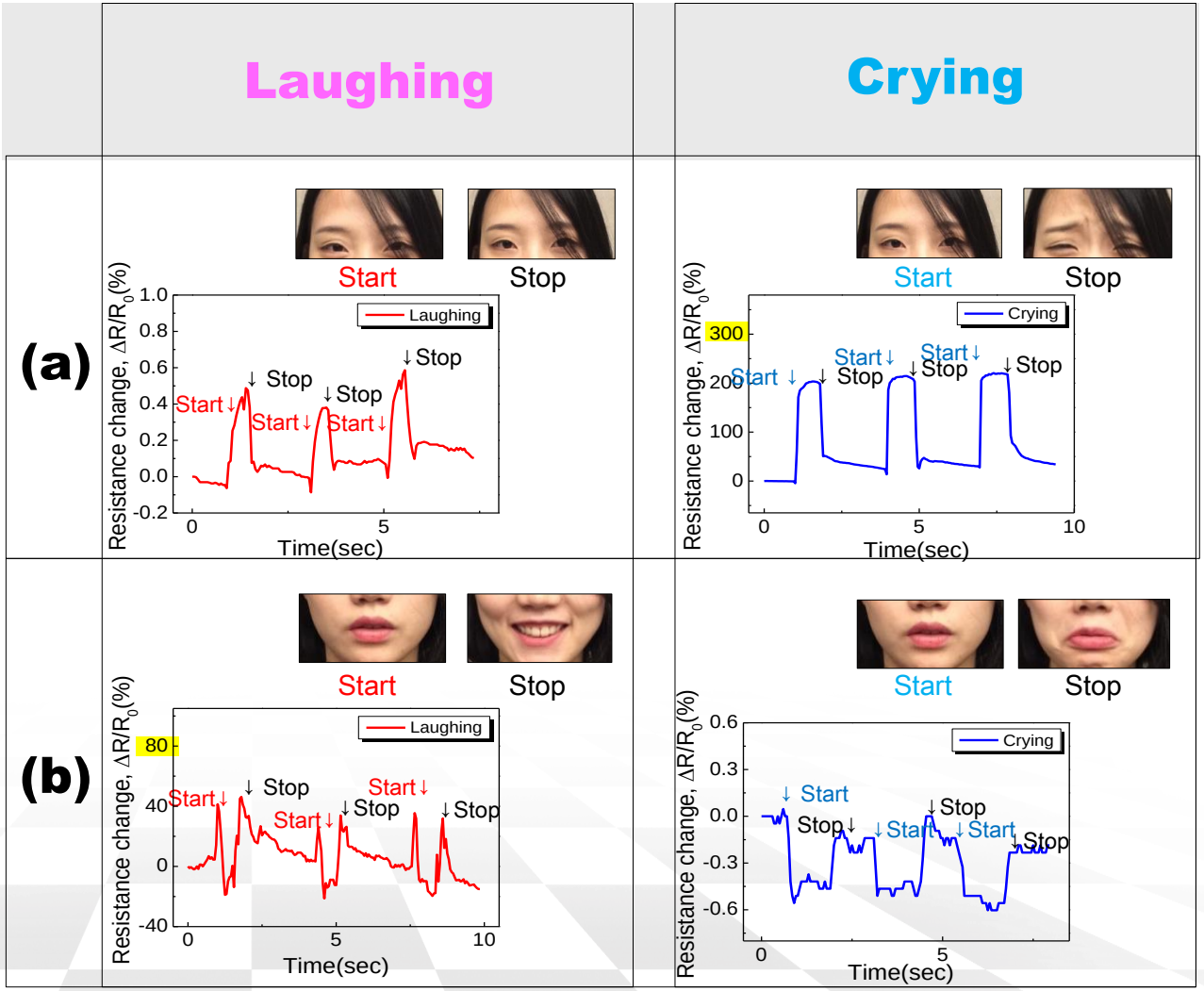


Roh et al., ACS Nano 11 (2015) 6252

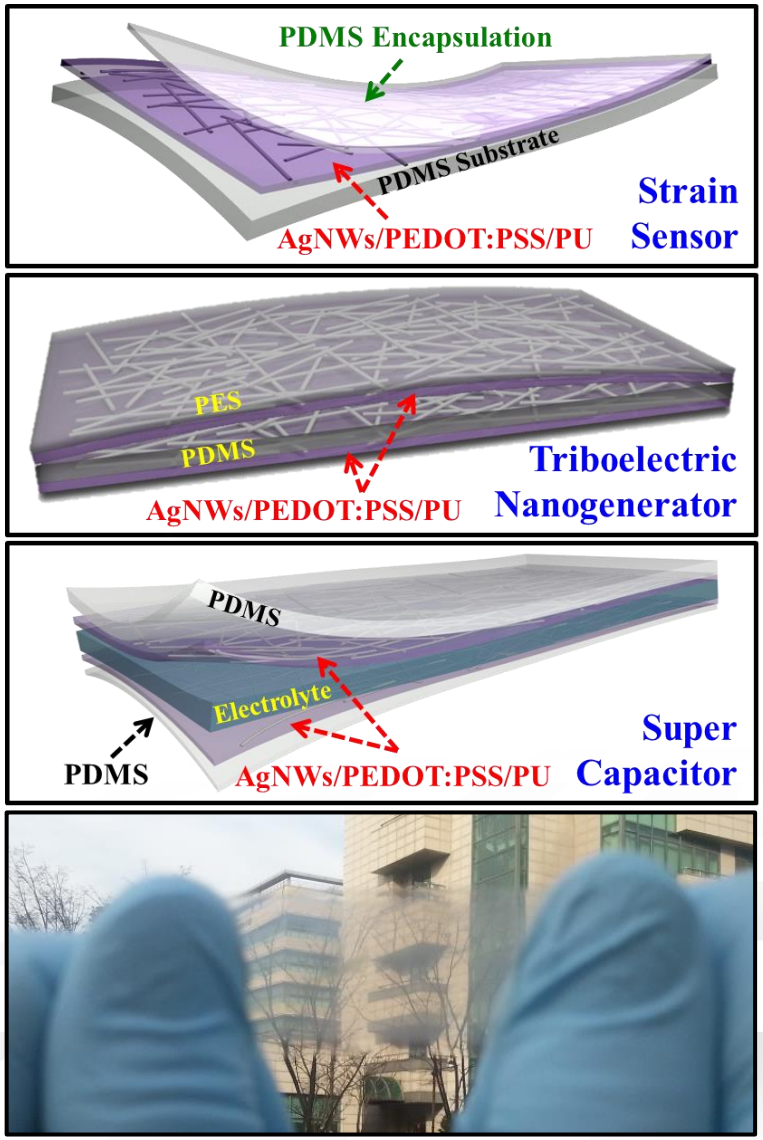
Stretchable, transparent and ultrasensitive strain sensor for emotion detection



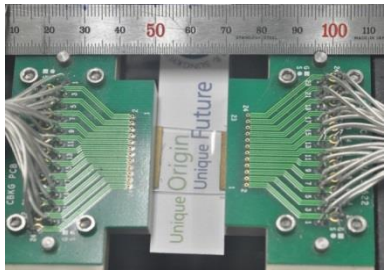




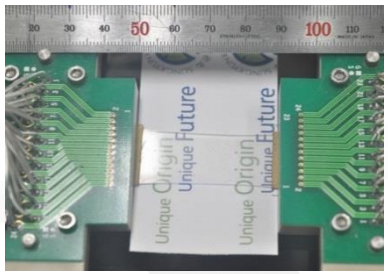
Stretchable, transparent, ultrasensitive, self-powered strain sensor for activity monitoring



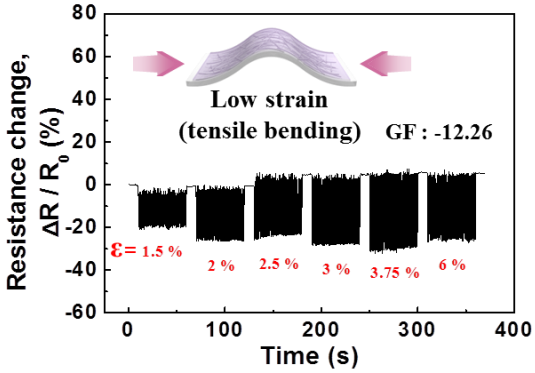
Evaluation

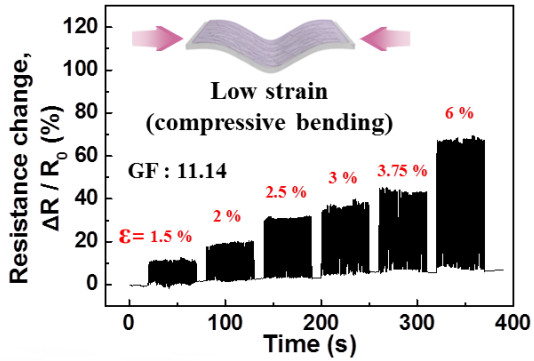


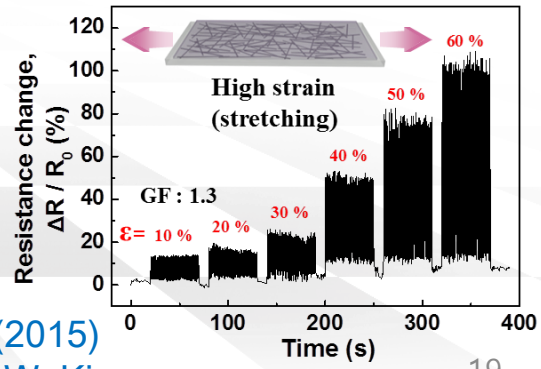
Strain : 0 %



Strain : 100 %

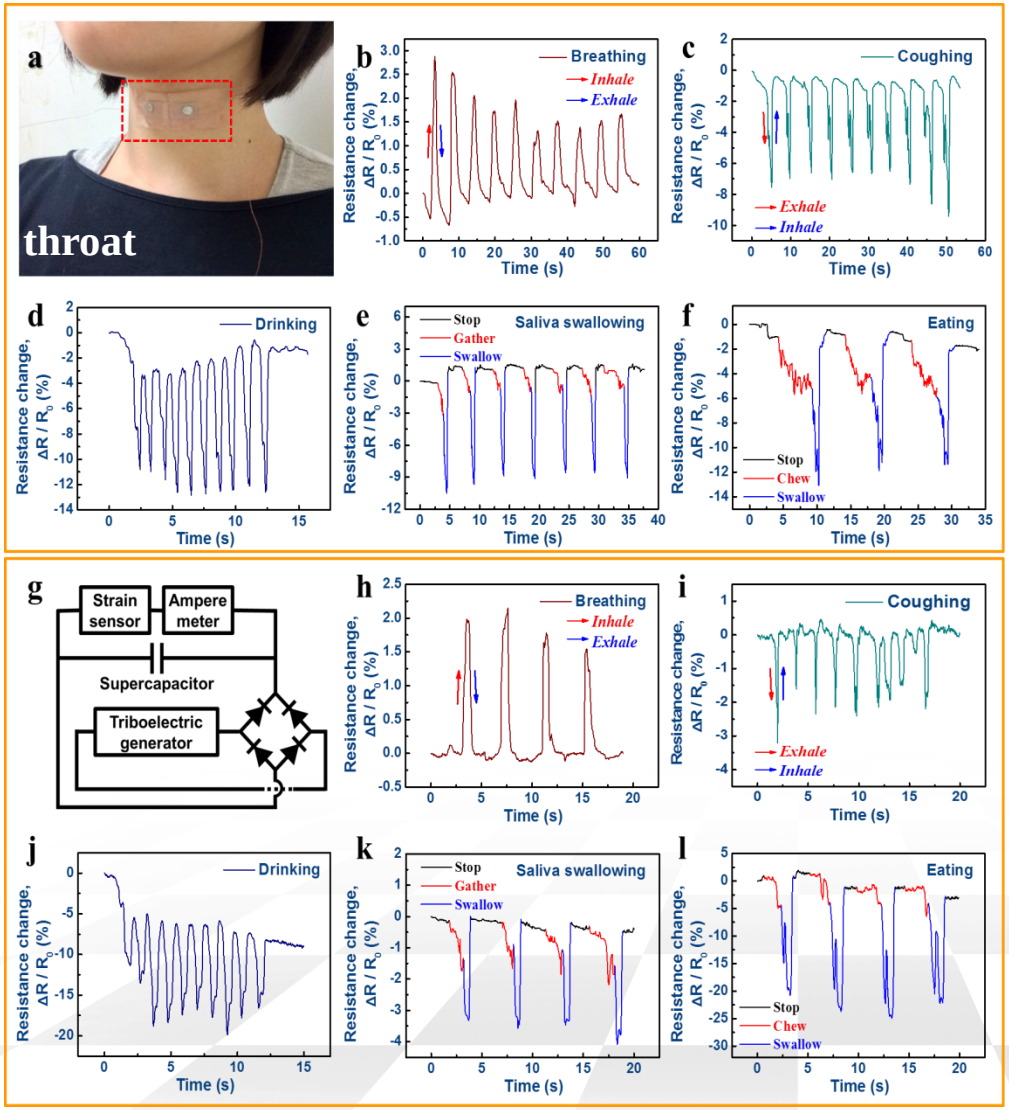


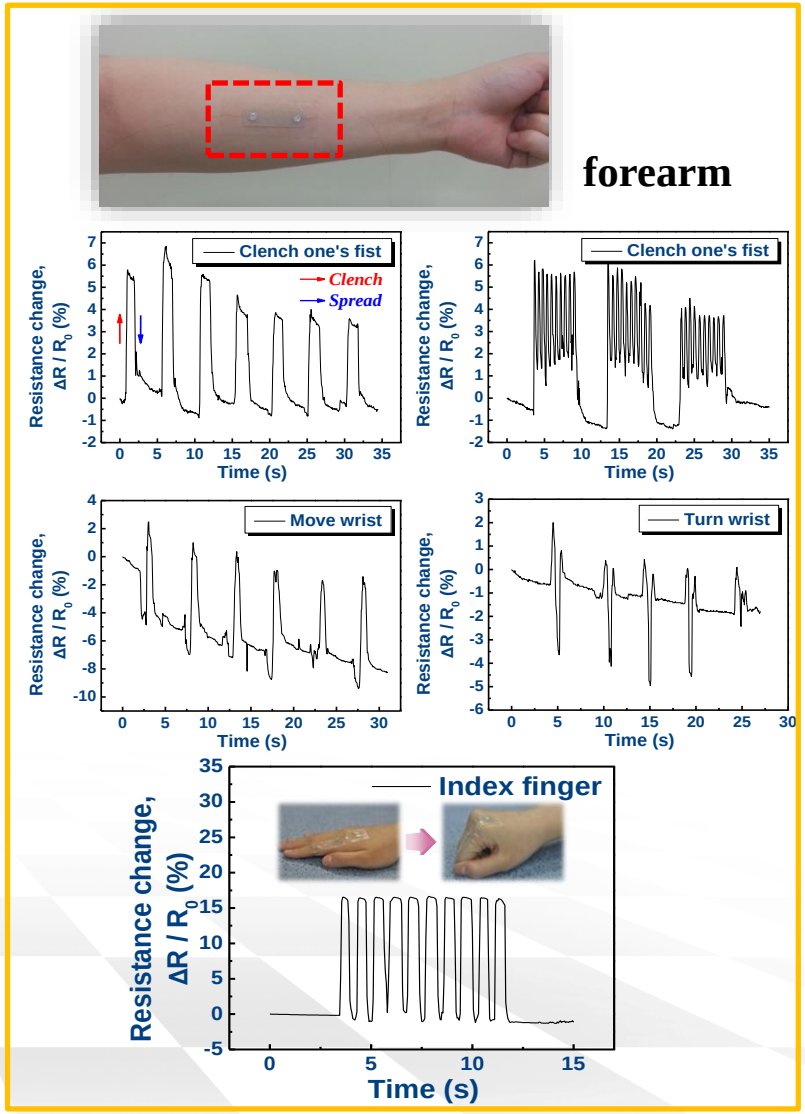




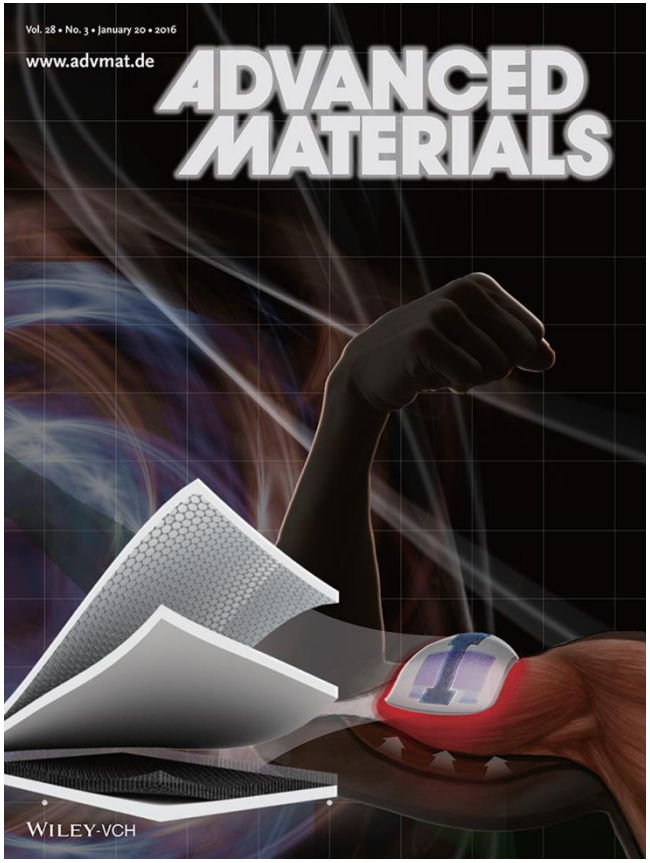
Hwang et al., ACS Nano 9 (2015) 8801, collaboration w/ prof. S.W. Kim

Stretchable, transparent, ultrasensitive, self-powered strain sensor for activity monitoring

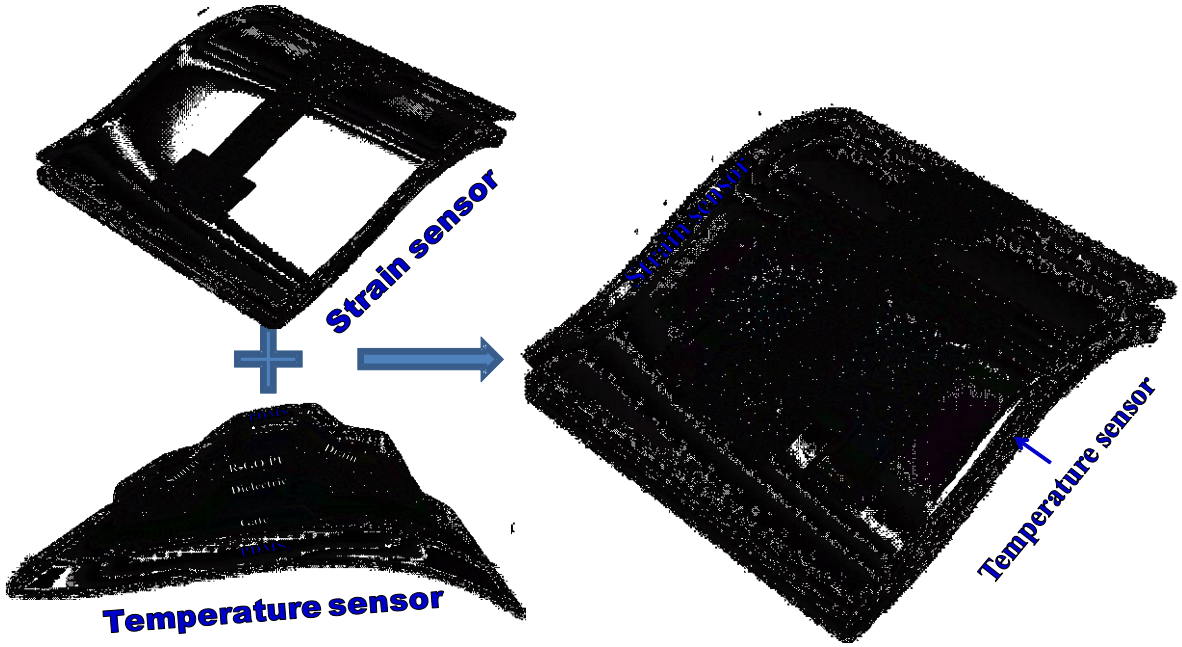




All-elastomeric transparent and stretchable multi-sensors for activity monitoring



AgNWs/PEDOT:PSS-PU resistor

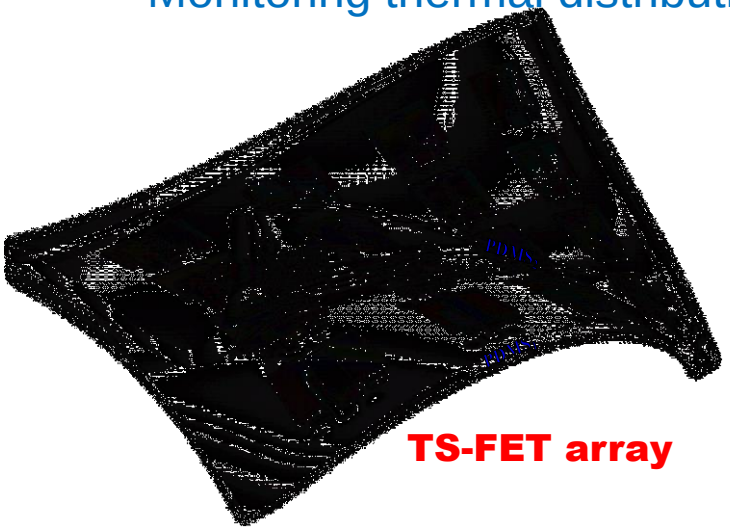


Reduced graphene oxide-PU channel, PU gate dielectric and PEDOT:PSS-PU electrode

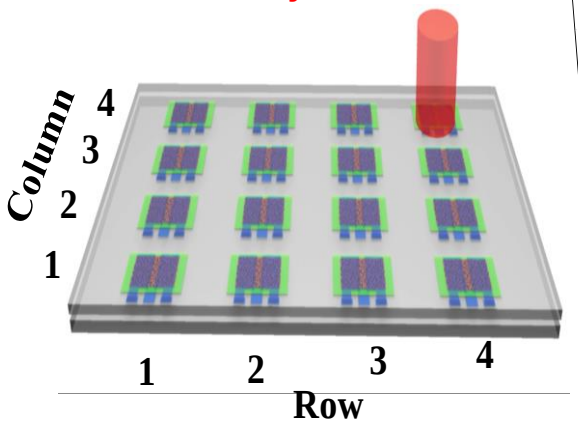
Trung et al., Adv. Mater., 28(2016) 502

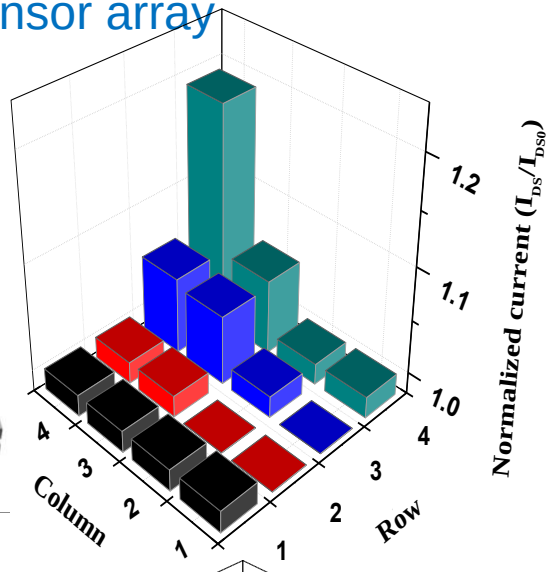
All-elastomeric transparent and stretchable multi-sensors for activity monitoring

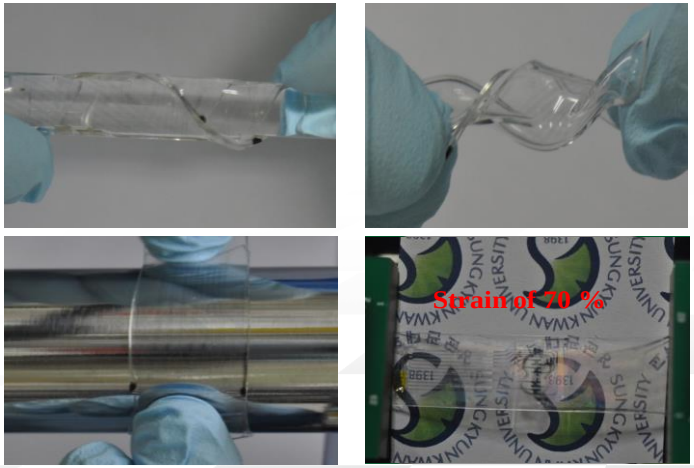
Monitoring thermal distribution by FET temperature sensor array

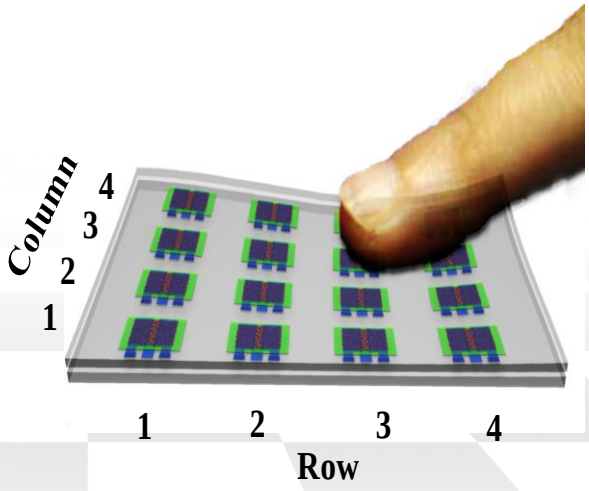


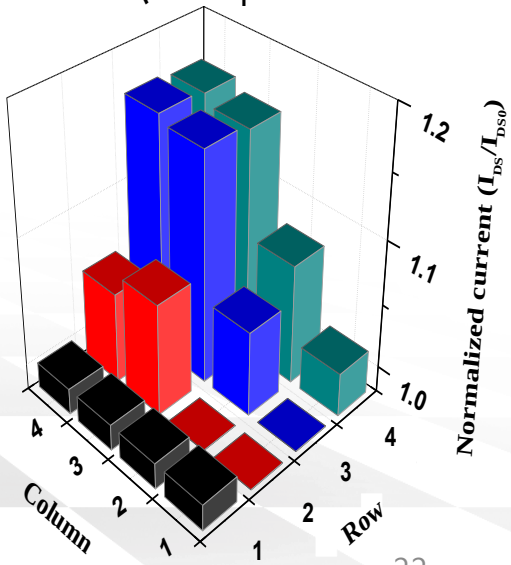
Hot object





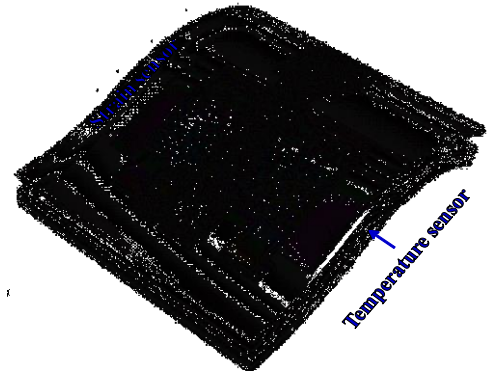


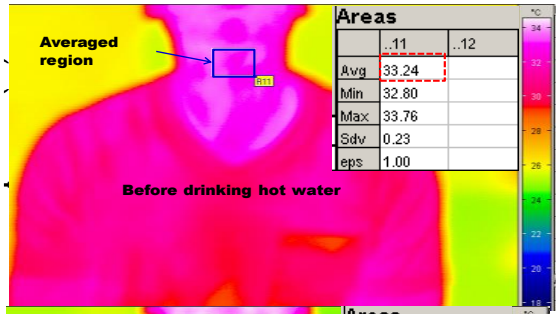


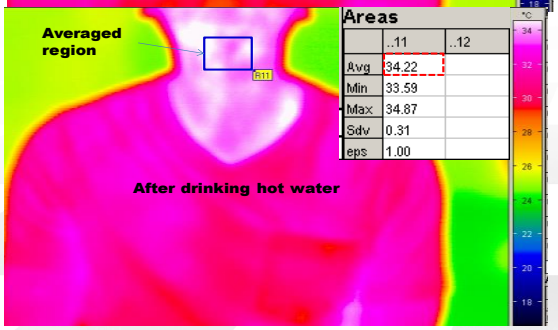


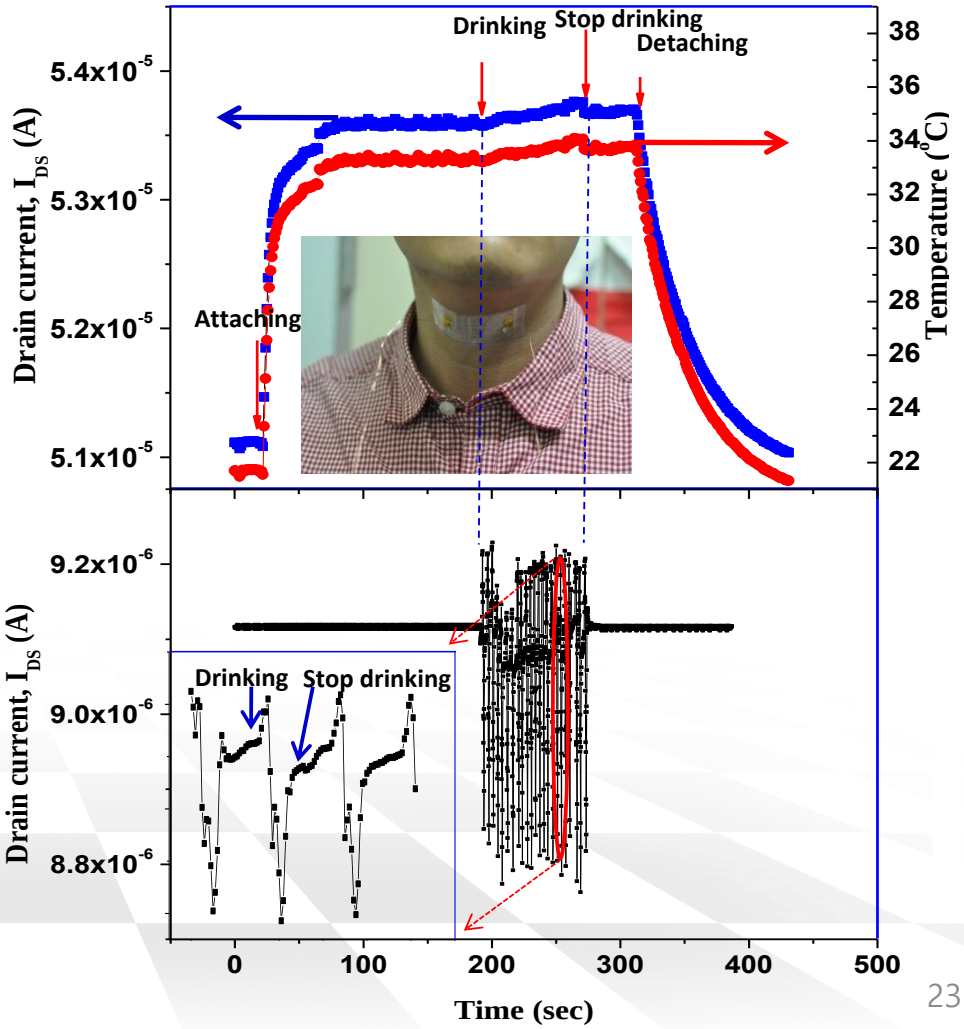
All-elastomeric transparent and stretchable multi-sensors for activity monitoring

Simultaneous monitoring skin temperature and muscle movement during drinking hot water



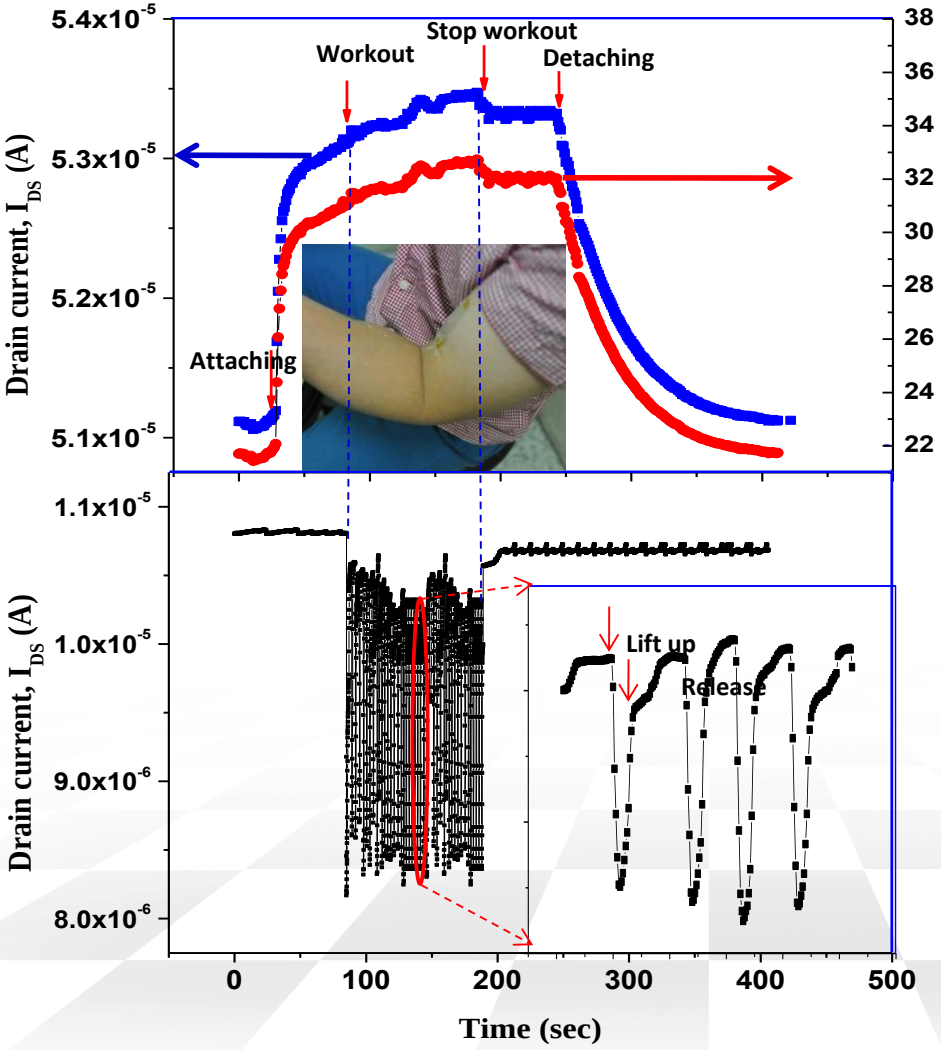


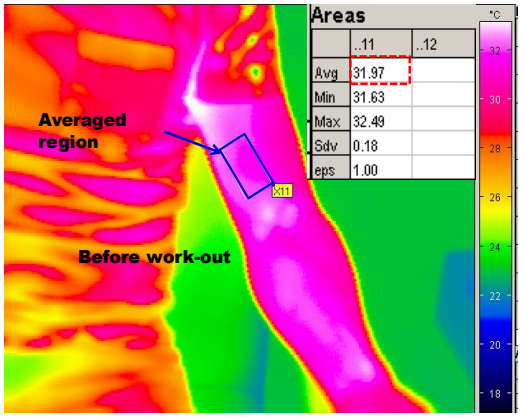


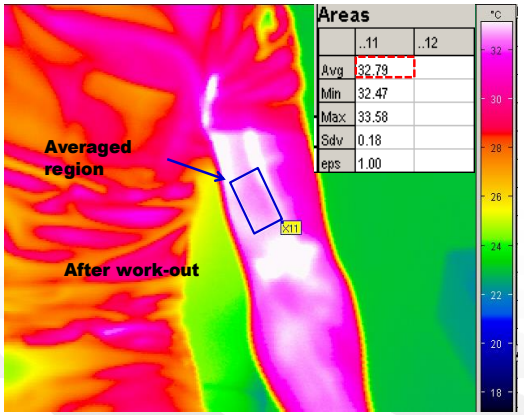


All-elastomeric transparent and stretchable multi-sensors for activity monitoring

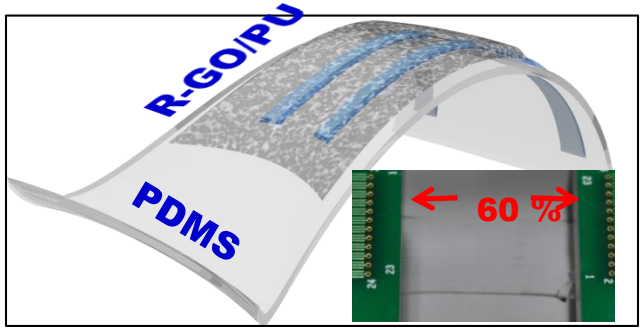
Simultaneous monitoring skin temperature and muscle movement during workout



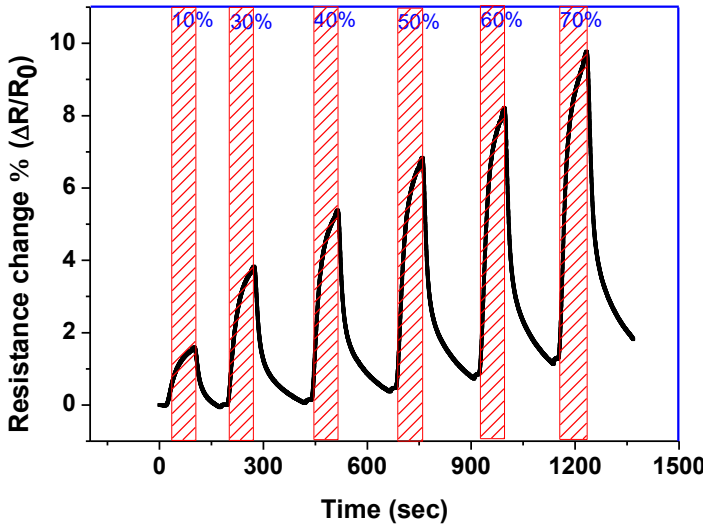




Stretchable transparent humidity sensor for hydration monitoring



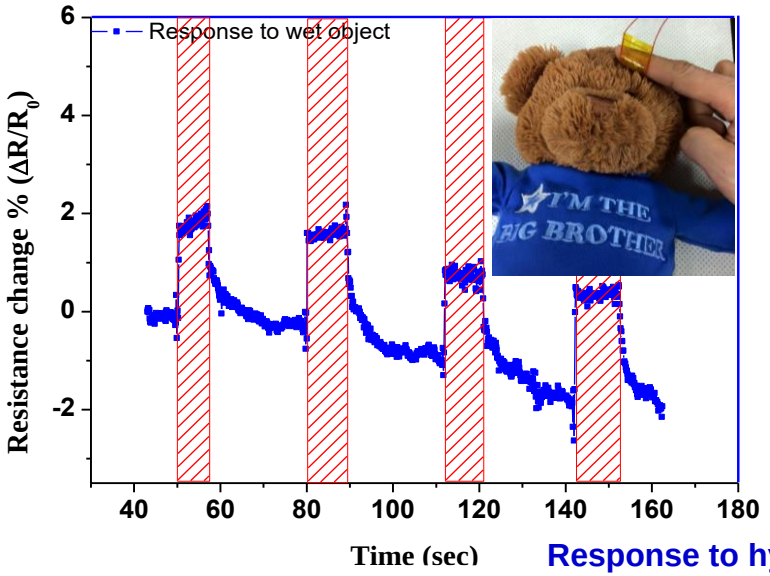
Response to humidity (10 % - 70 %)



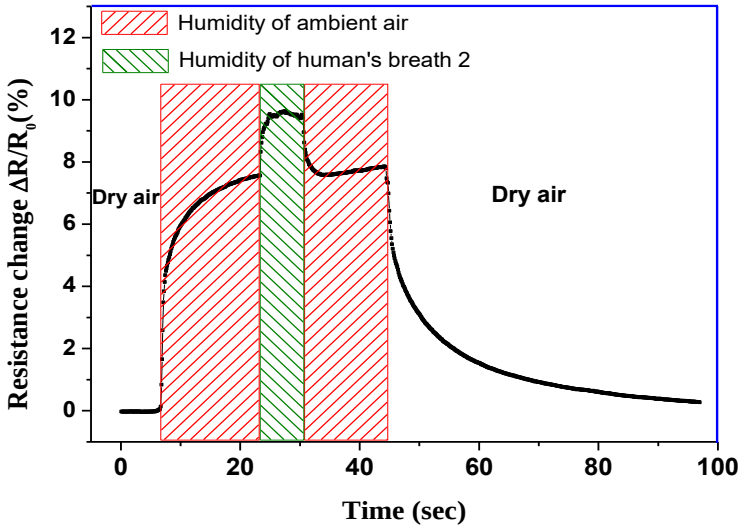
Trung et al., Nano Research, online

Stretchable transparent humidity sensor for hydration monitoring

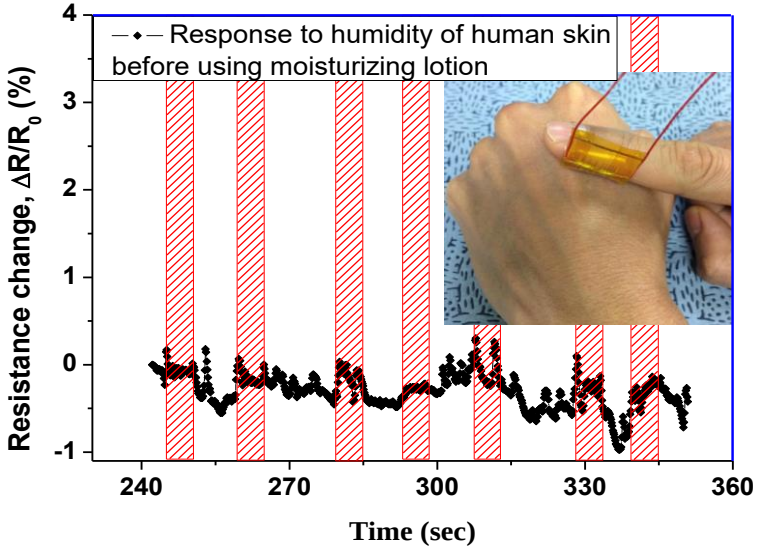
Response to humidity of wet object

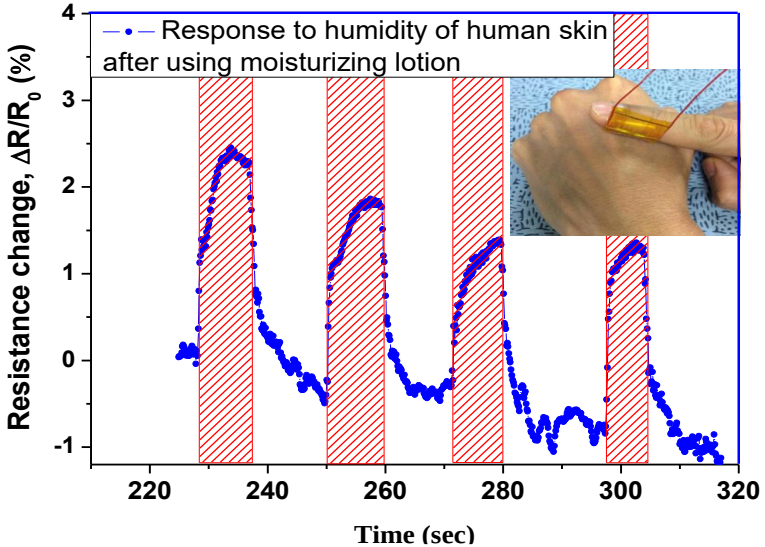


Response to humidity of human breath



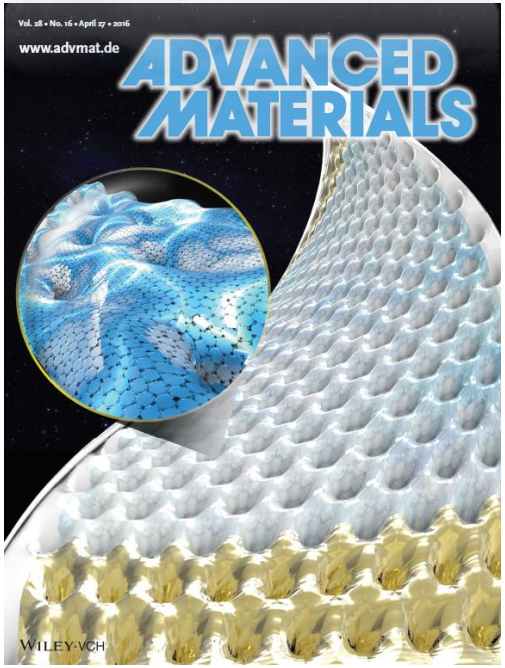
Response to hydration of human skin

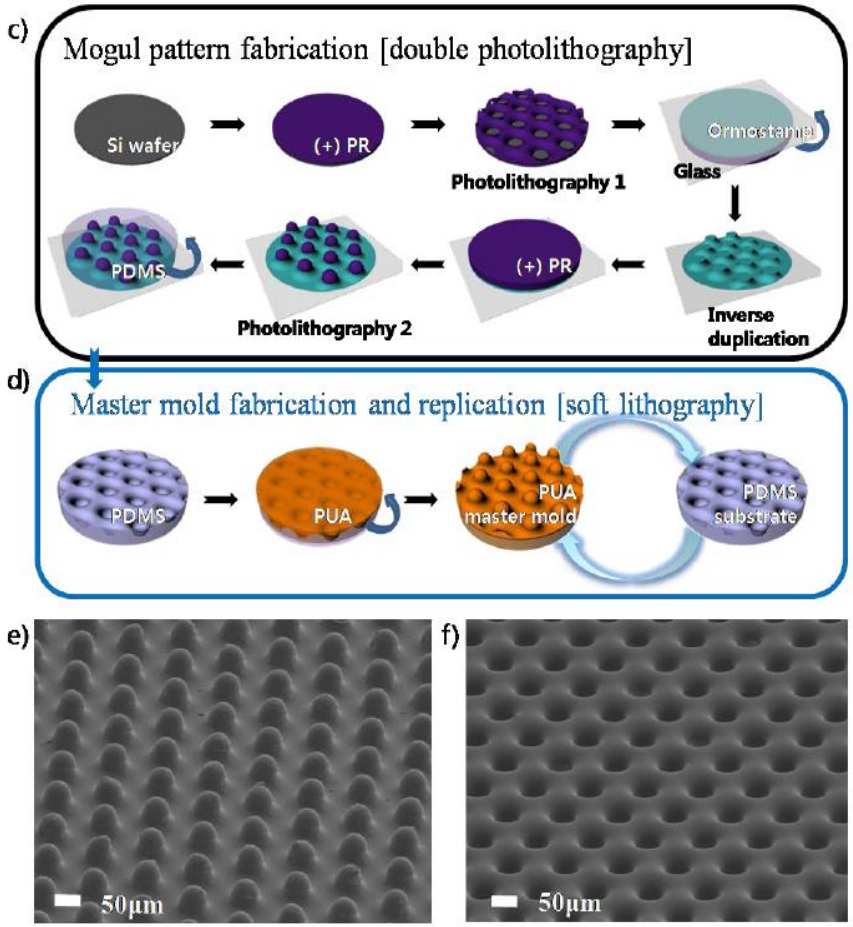




Approach 2: Mogul-patterned elastomeric substrate

An omnidirectionally stretchable substrate for structural engineering

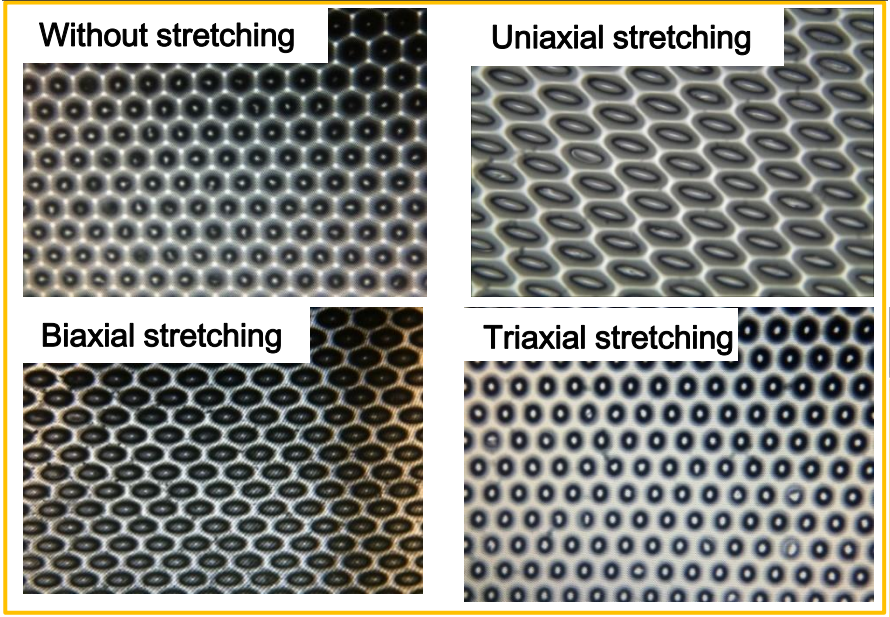




H.B. Lee et al., Adv. Mater., 28 (2016) 3086

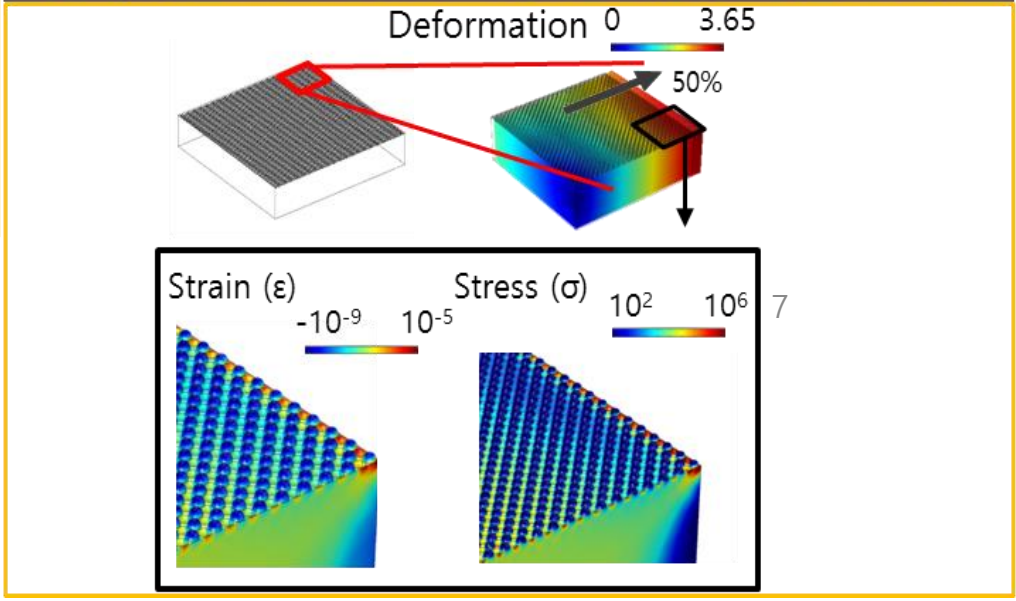
Approach 2: Mogul-patterned elastomeric substrate

Optical image depending on stretching direction



Omniaxially stretchable

Computer simulation for deformation, strain, and stress



Small tensile on bumps and valleys under elongation

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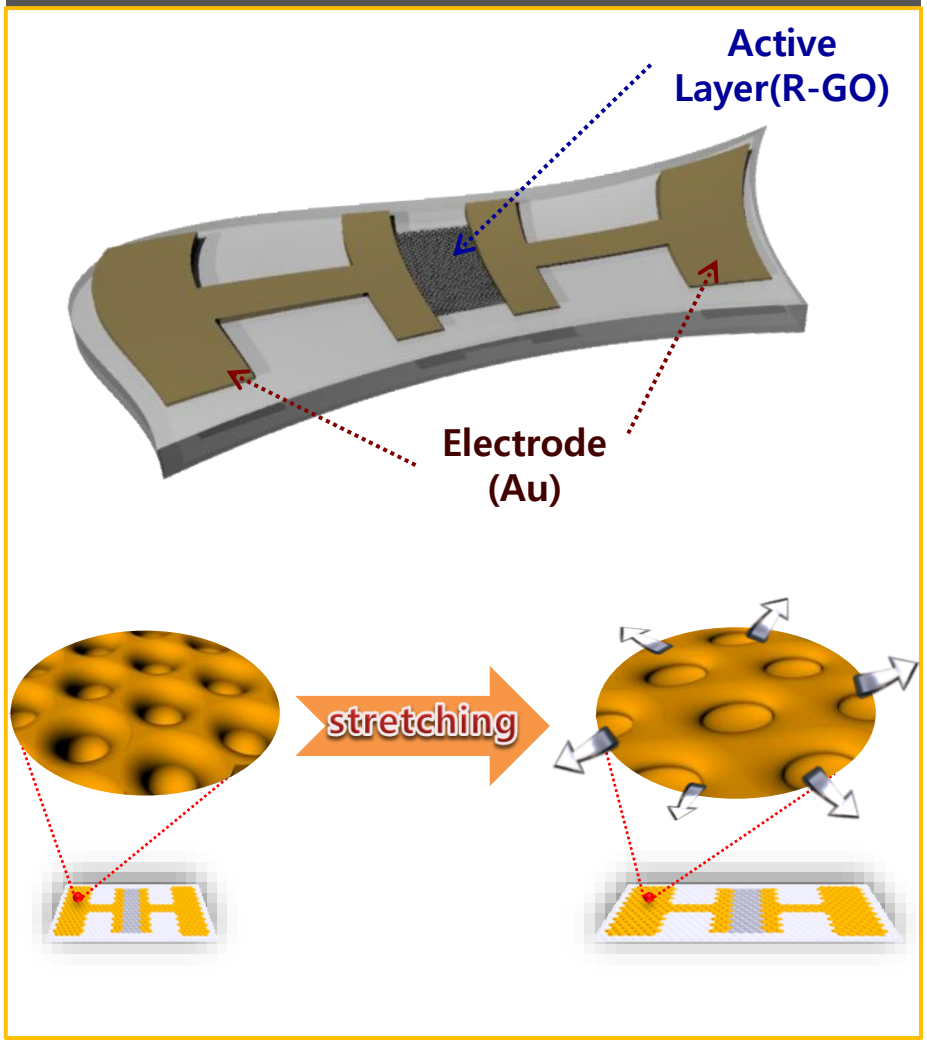
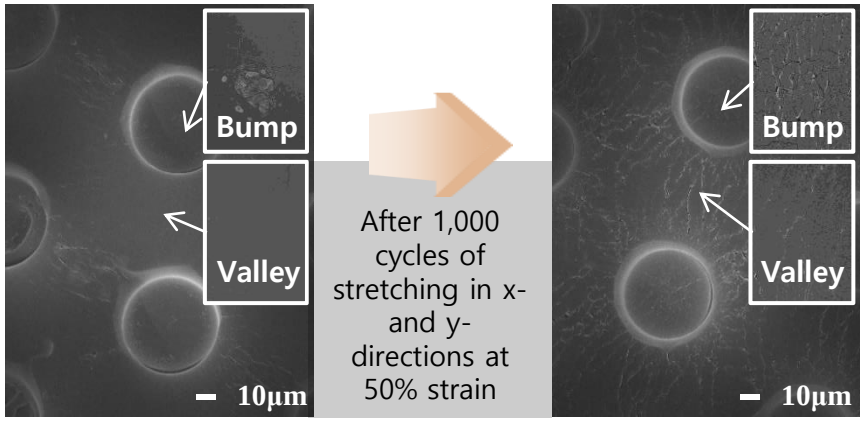
Omniaxially stretchable RGO gas sensor on mogul-patterned elastomeric substrate

Structure



Stability of Au electrode (70nm)



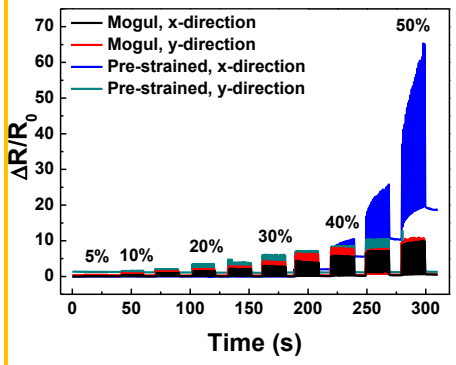
H.B. Lee et al., Adv. Mater., 28 (2016) 3086

Omniaxially stretchable RGO gas sensor on mogul-patterned elastomeric substrate

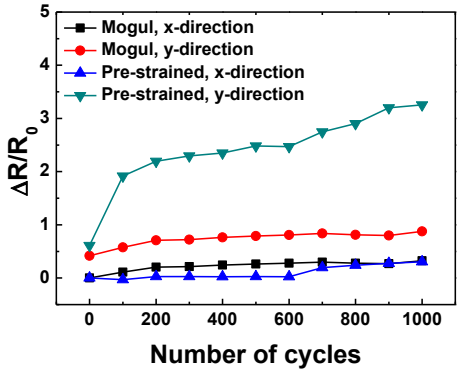
Investigatiion of electrical stability

Electrical stability of Au electrode

[Dynamic test]

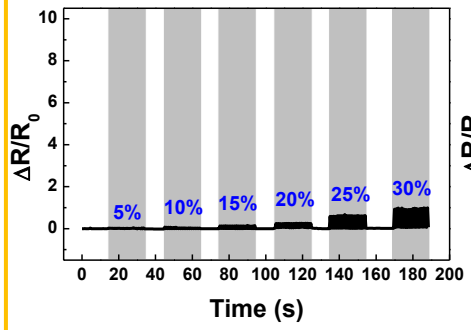


[Cyclic test]

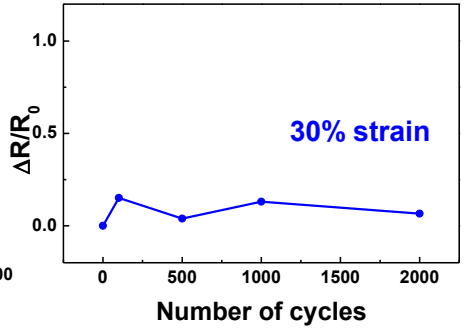


Electrical stability of chemical sensor

[Dynamic test]

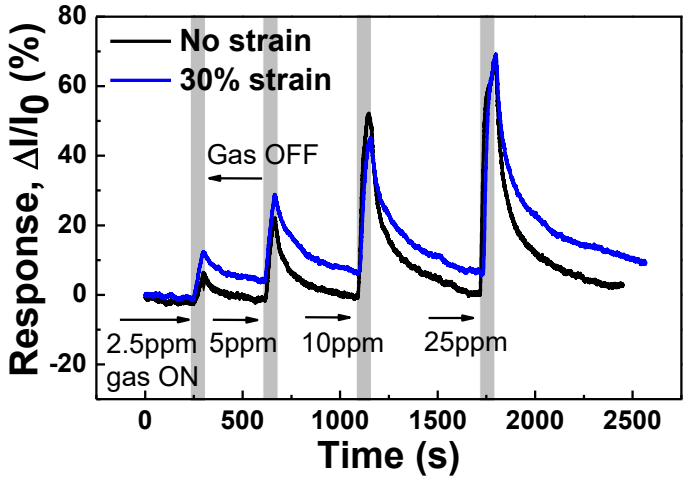


[Cyclic test]



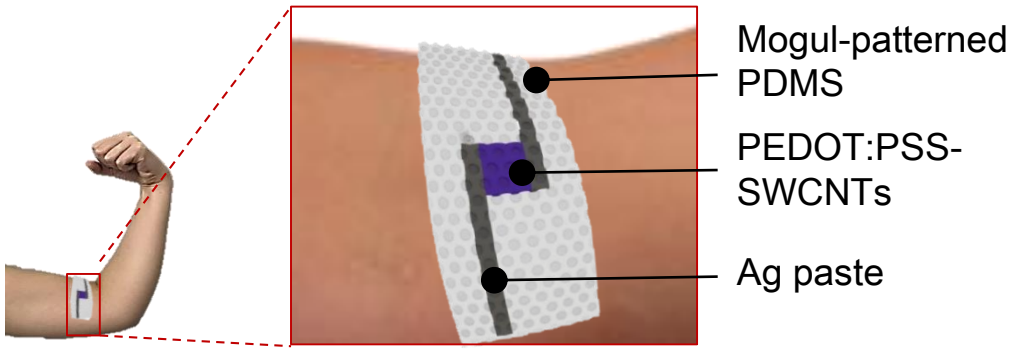
NO_2 sesning

Under stretched condition



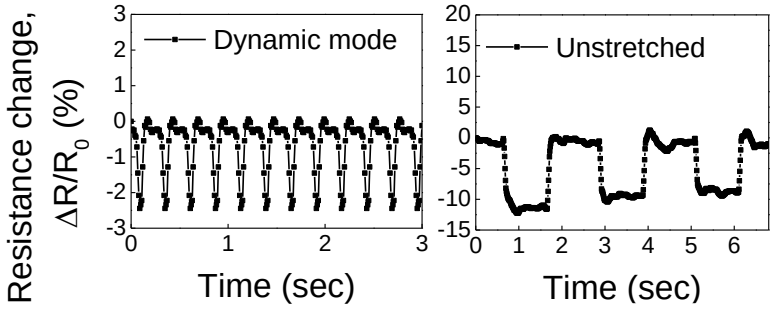
Omaniaxially stretchable piezoresistive pressure sensor on mogul-patterned substrate

Device Structure

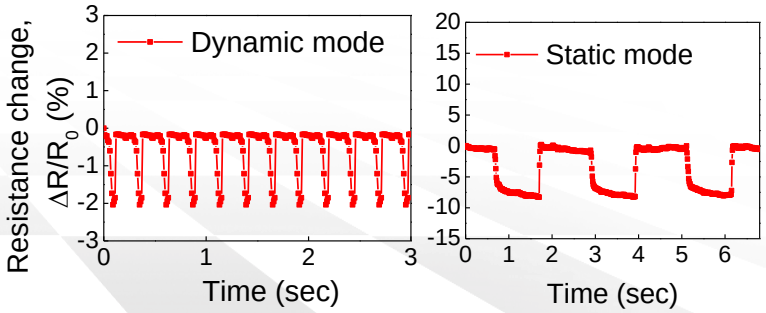


Pressure responsivity

✓ Unstretched state

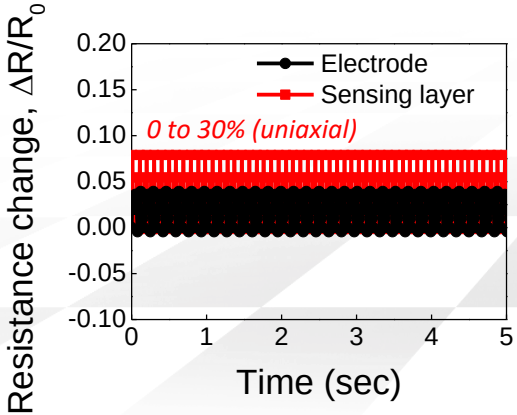


✓ Under 30% stretching state

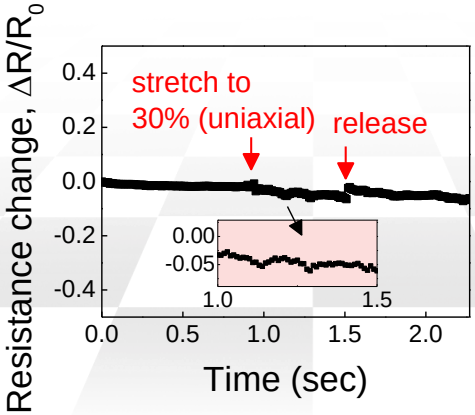


Stability under stretching

✓ Materials stability under stretching



✓ Device stability under stretching

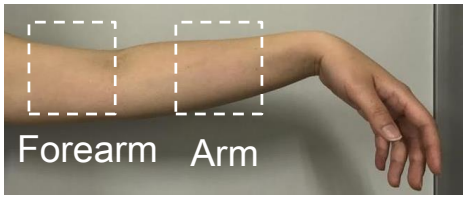


Roh et al., Adv. Mater., in press.

Omniaxially stretchable piezoresistive pressure sensor on mogul-patterned substrate

Demonstration : Tremor detection

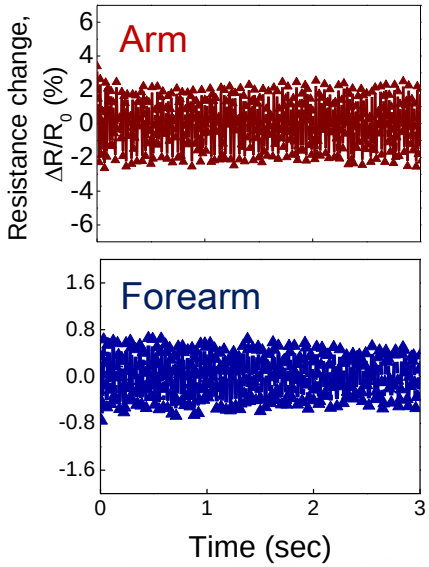
✓ Skin area



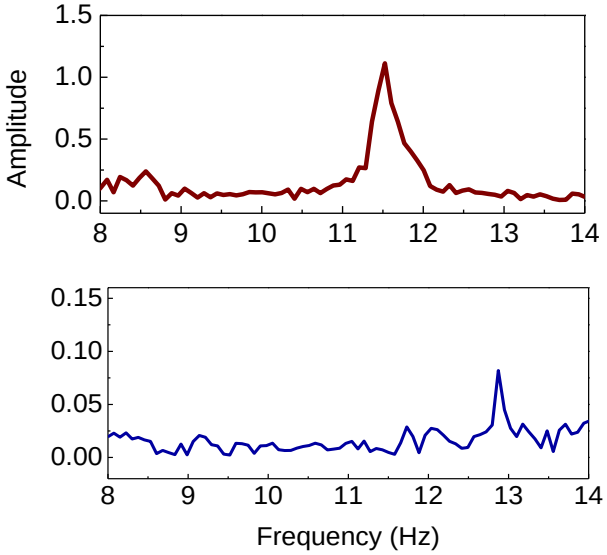
✓ Demonstration setup

Experimental mixer for vibration

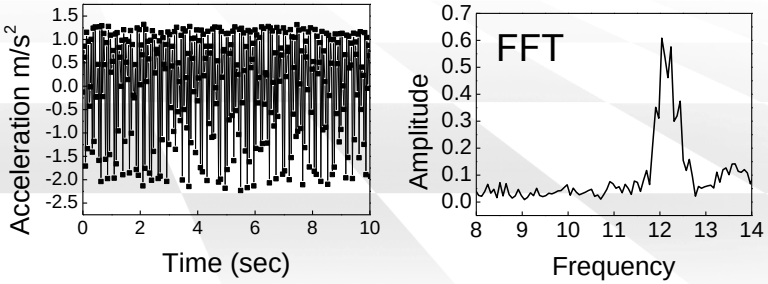
✓ Vibration detection using the device



✓ FFT (fast Fourier transform)

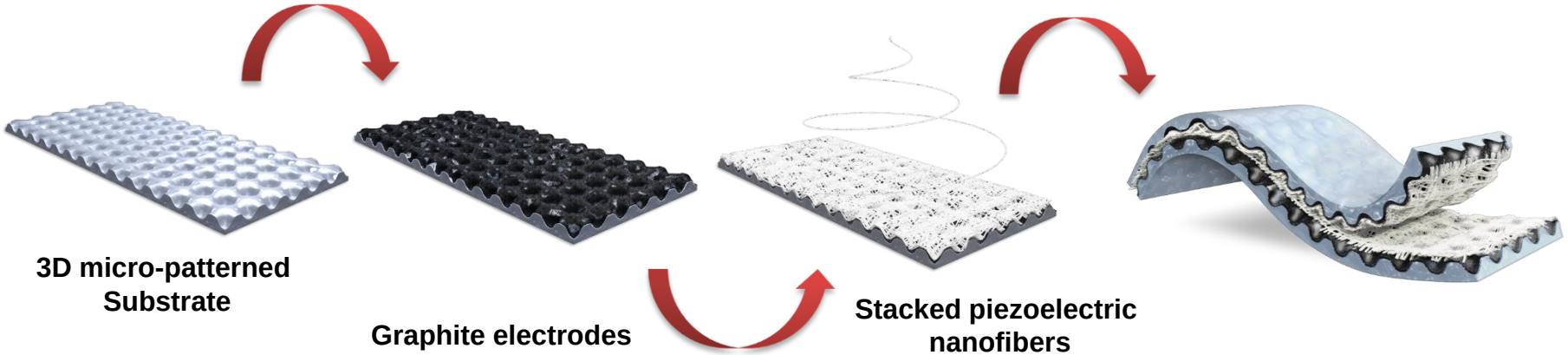


✓ Vibration detection using the accelerometer in smartphone



Omniaxially stretchable self-powered piezoelectric device

Stacked mat of BT NPs-PU nanocomposite and P9VDF-TrFE) nanofibers on stress-relieving mogul-patterned elastomeric substrate



3D micro-patterned Substrate

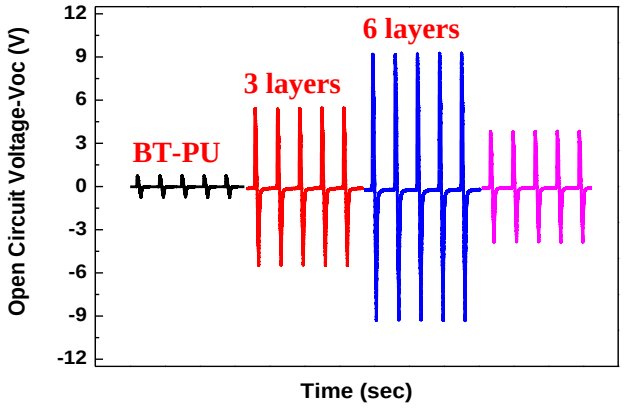
Graphite electrodes

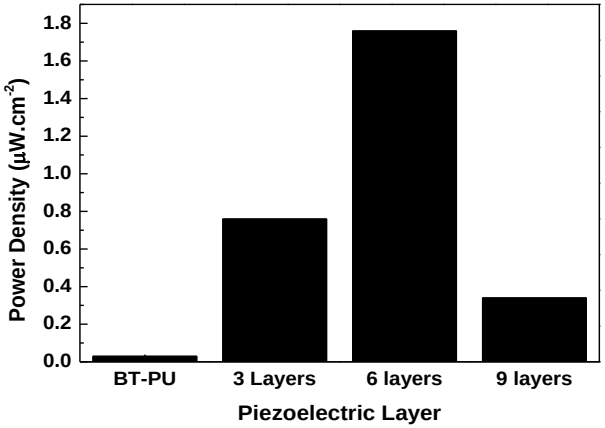
Stacked piezoelectric nanofibers

Stretchable self-powered sensor

Output during stretching

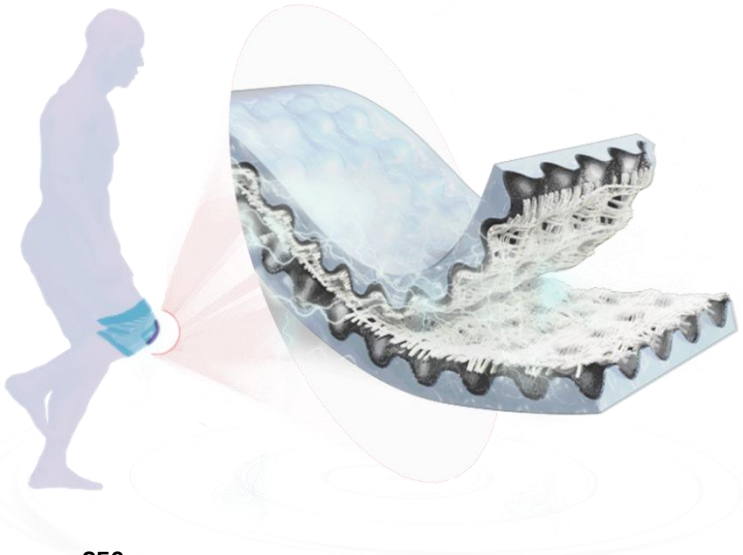
Output power at 40% stretching

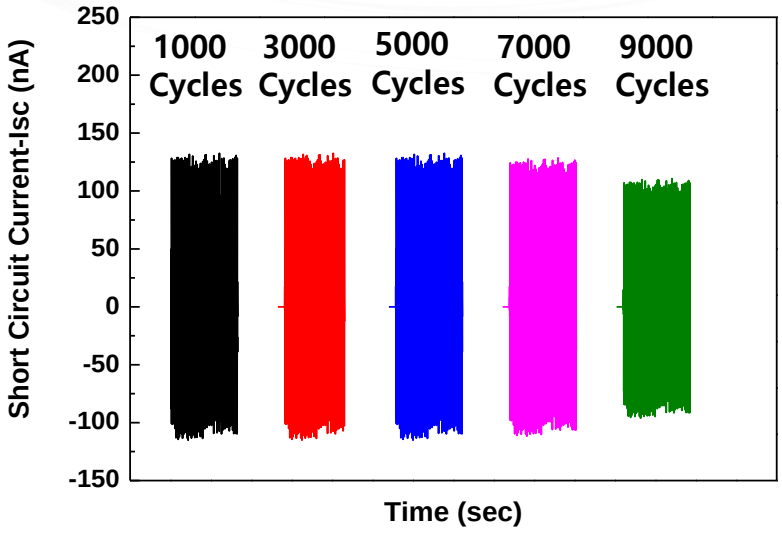




S. Siddiqui et al., Adv. Energy. Mater. In press

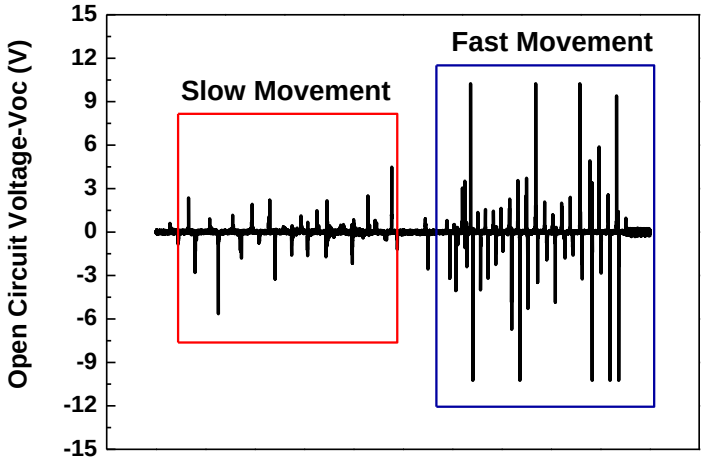
Omniaxially stretchable self-powered piezoelectric device



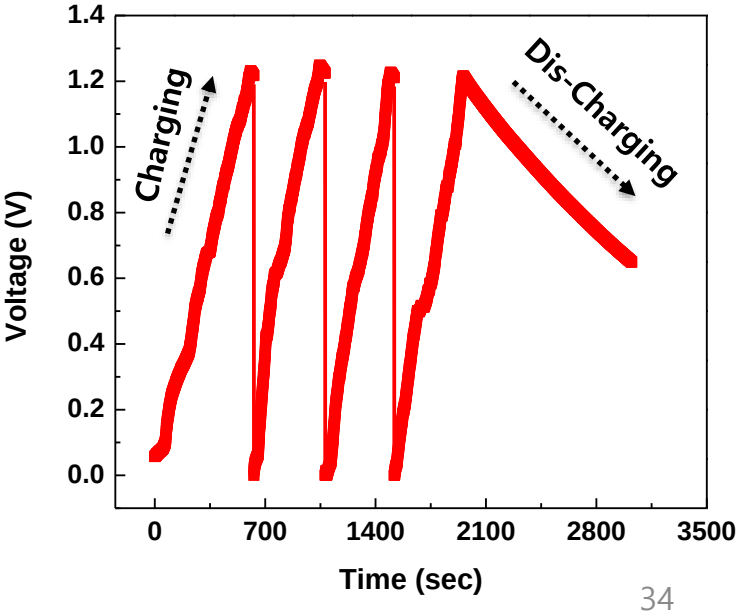


Stability at 30% stretching strain

Walking Pattern Detection

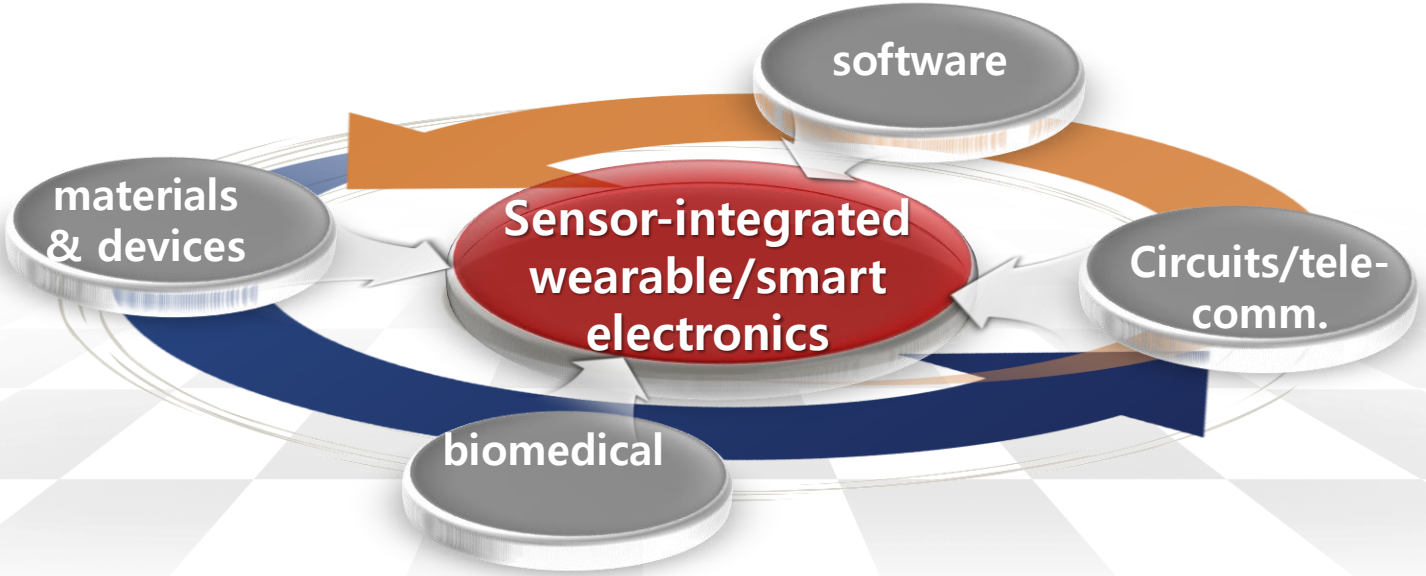


Charge Storage during walking



Perspectives

- Efforts toward the improvement of stability and reliability of the sensing nano-materials are required for real applications.
- Sensor-integrated systems by combining MCU, communication, energy and sample handling devices need to be developed by considering the specific service needs.
- Collaborative research is essential for success.



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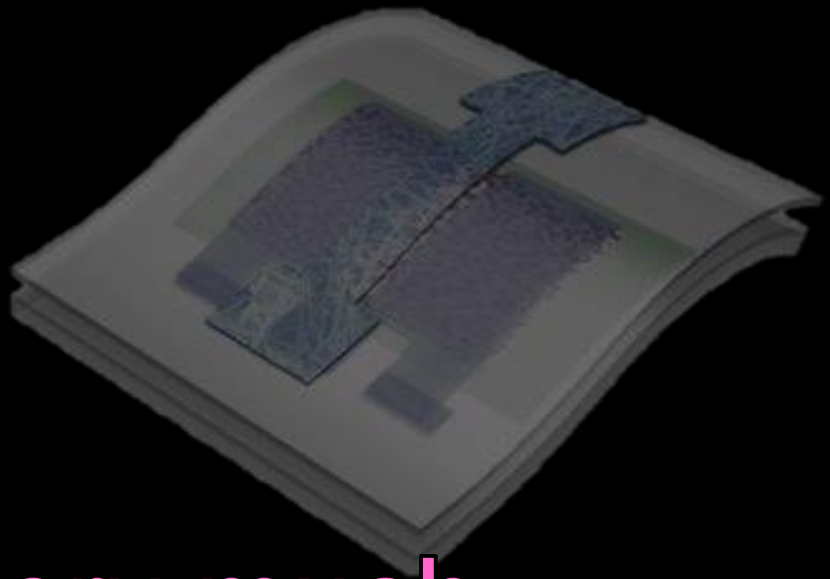

Thank you very much.