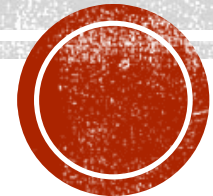


# STANDALONE STRETCHABLE DEVICE PLATFORM FOR HUMAN HEALTH MONITORING



**Larry Cheng**, Associate Professor at Penn State

Huanyu.Cheng@psu.edu



DUE 2000725

This webinar is hosted by:



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**CENTER FOR NANOTECHNOLOGY  
EDUCATION AND UTILIZATION**

## Host



**Zac Gray**  
*Managing Director*  
NACK Center / CNEU

## Co-host



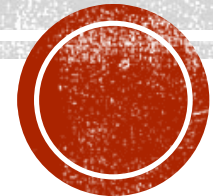
**Vishal Saravade**  
*Assistant Teaching*  
*Professor*  
CNEU

## Presenter



**Huanyu "Larry" Cheng**  
*James L. Henderson, Jr.*  
*Memorial Associate*  
*Professor of Engineering*  
*Science and Mechanics*  
Penn State

# STANDALONE STRETCHABLE DEVICE PLATFORM FOR HUMAN HEALTH MONITORING



**Larry Cheng**, Associate Professor at Penn State

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# ACKNOWLEDGEMENTS



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National Institute  
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National Heart, Lung,  
and Blood Institute

National Institute of  
Biomedical Imaging  
and Bioengineering



Howard Hughes  
Medical Institute



# SOFT APPROACH TO ELECTRONICS



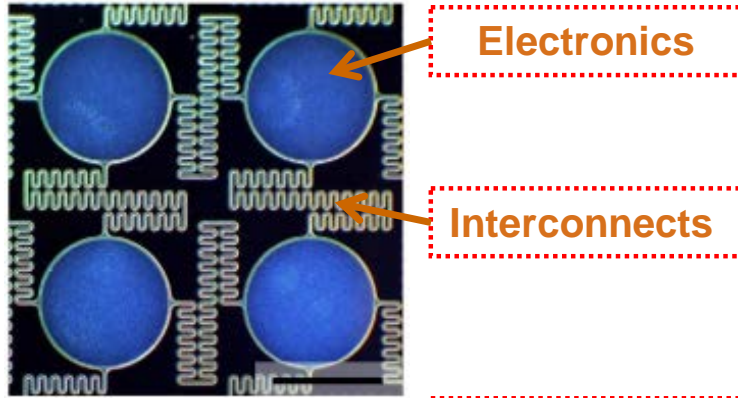
The Persistence of Memory, Salvador Dalí, 1931

# DEVICE-INTERCONNECT DESIGN

## Microscale stretchable battery :

- >300% biaxially, little loss over cycles

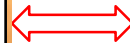
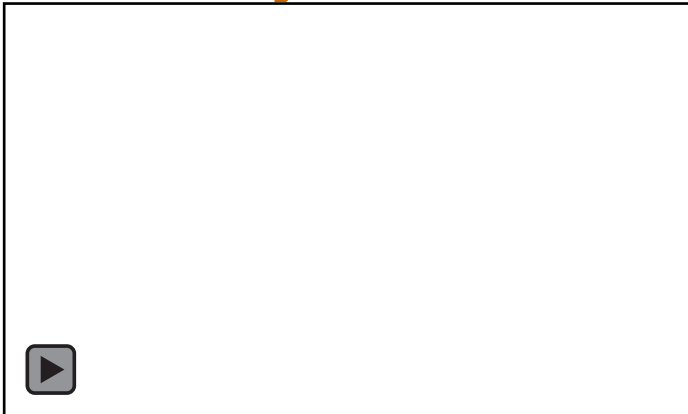
TOP VIEW



SIDE VIEW



## Mechanically robust construction for repeatable use:



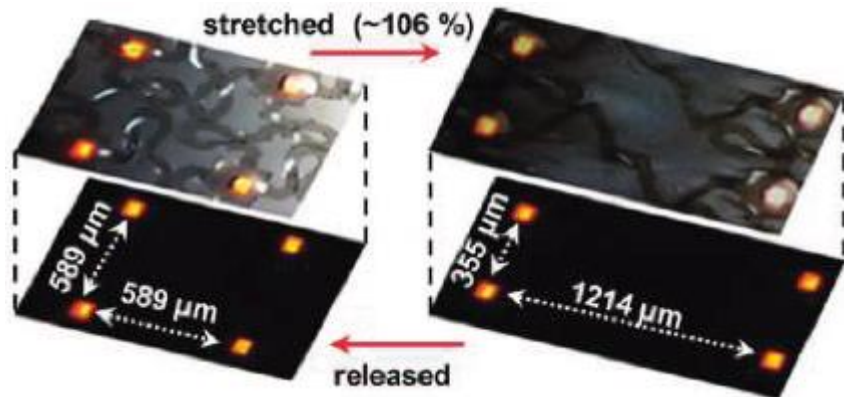
### Bi-layer substrate

- **Top:** soft -> stretchable
- **Bottom:** stiff -> high strength

*Nat. Commun.* 4, 1543 (2013)  
*Adv. Mater.* 25, 6839 (2013)

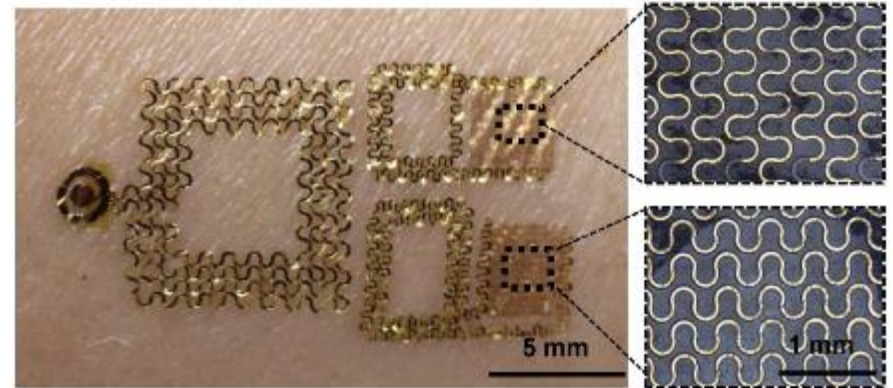
# VARIOUS STRETCHABLE SENSORS

## Stretchable LEDs



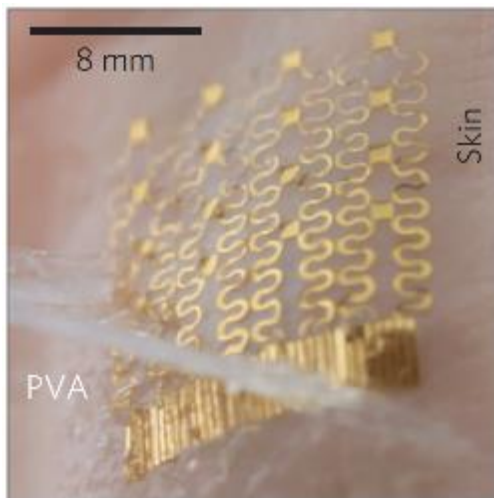
*Nano Lett.* 11, 3881 (2011)

## Hydration and strain



*Adv. Funct. Mater.* 24, 3846 (2014)

## Temperature sensors



*Nat. Mater.* 12, 938 (2013)

## Fingertip electrode



*Nanotechnology* 23, 344004 (2012)

## Near field communication

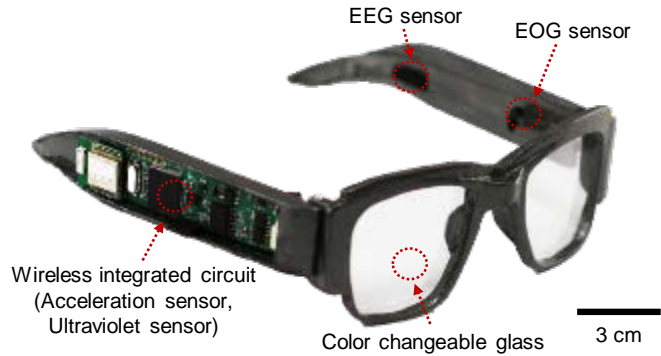


*Small* 11, 906 (2015)



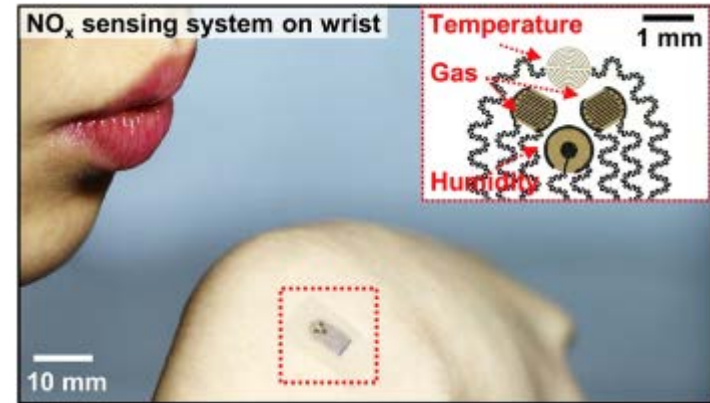
# INTEGRATED SYSTEM

## Smart electronic eyeglasses



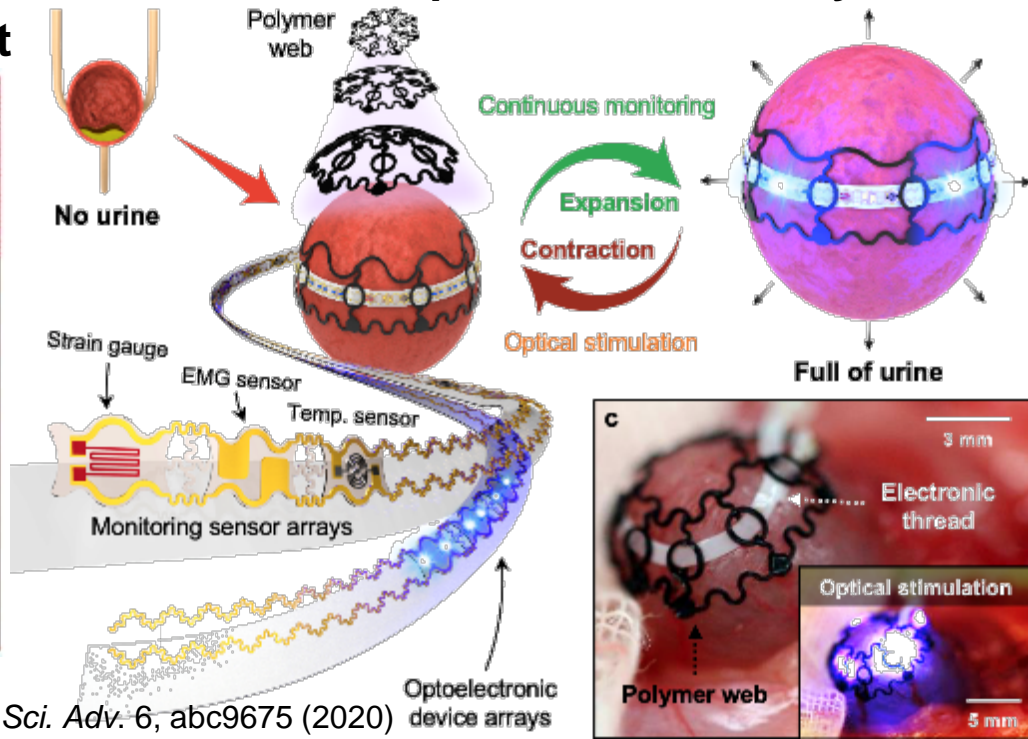
*ACS Appl. Mater. Interfaces* 12, 21424 (2020)

## NO<sub>x</sub> gas sensor



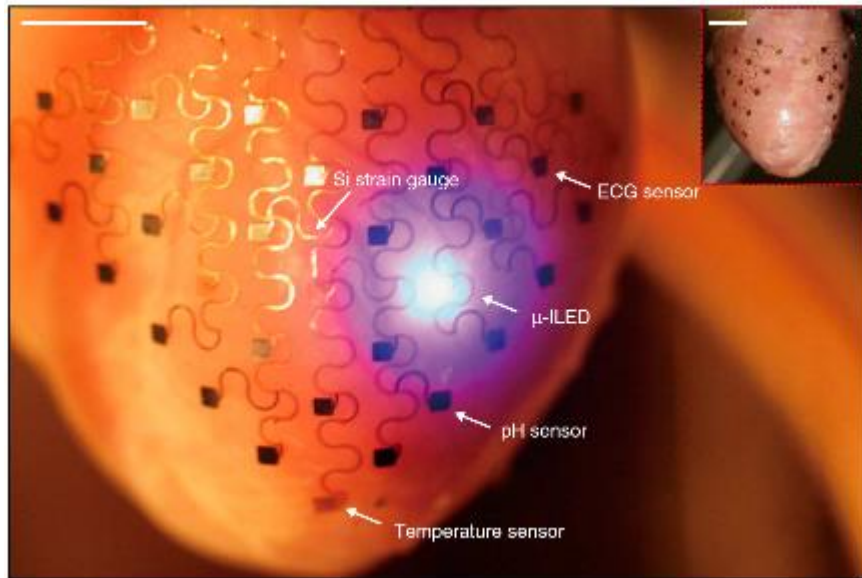
*NPG Asia Mater.* 12, 17 (2020)

## Bioelectronic complex on the urinary bladder



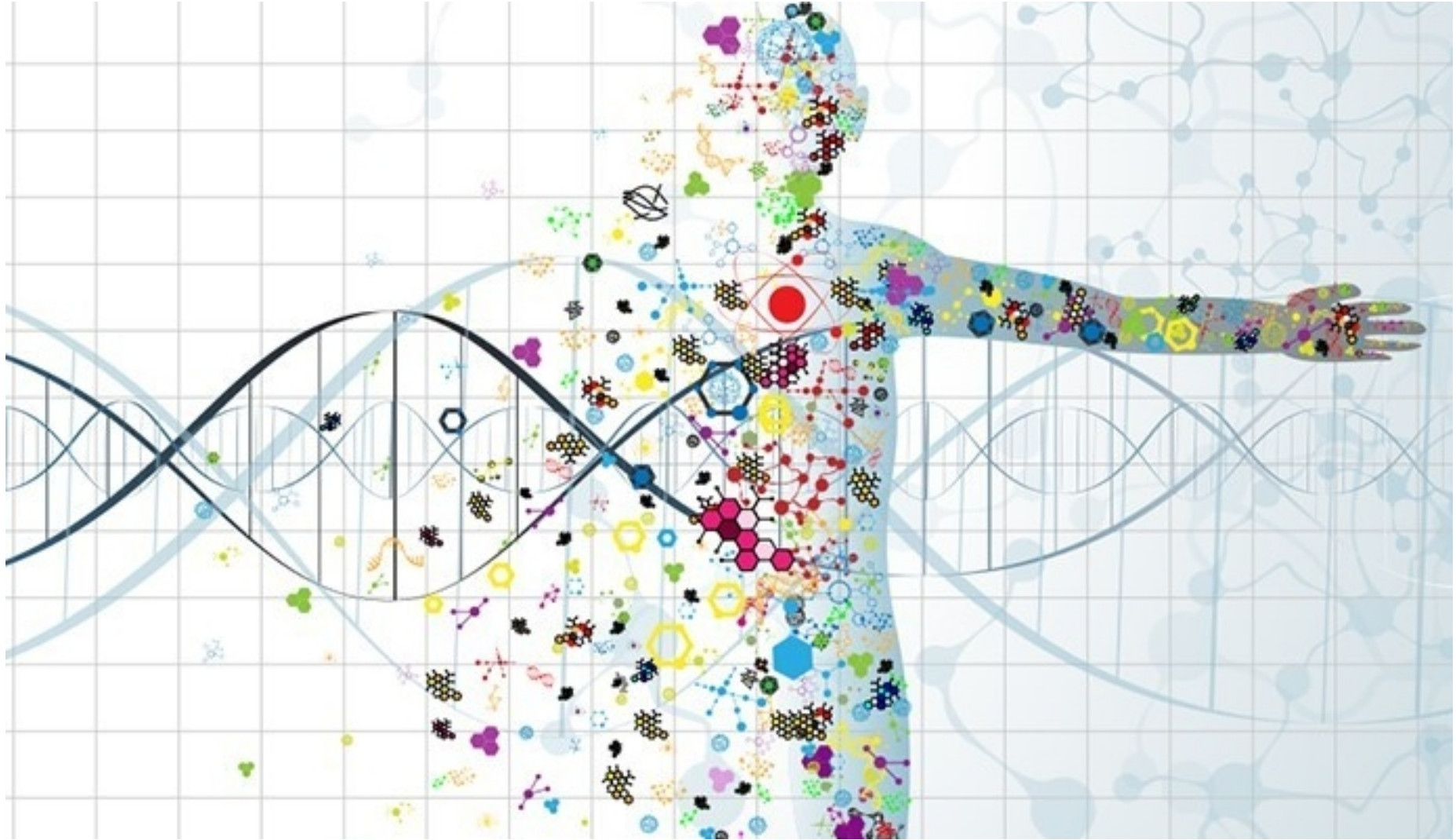
*Sci. Adv.* 6, abc9675 (2020)

## 3D integumentary membrane on heart



*Nat. Commun.* 5, 3329 (2014)

# PRECISION MEDICINE AND HEALTHY AGING

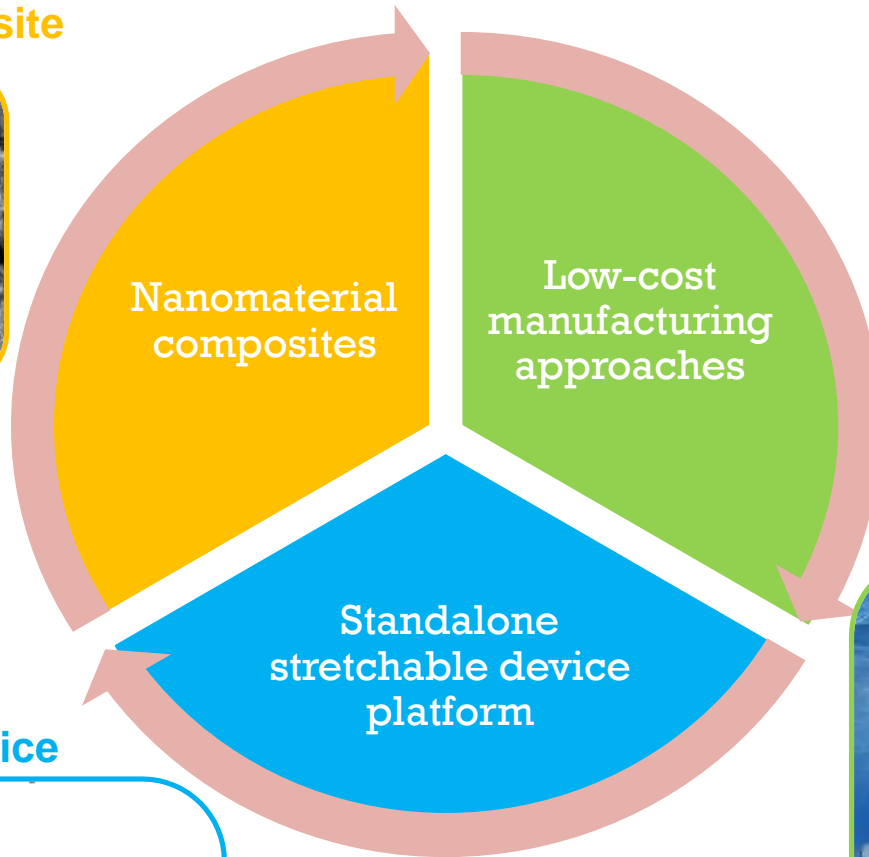
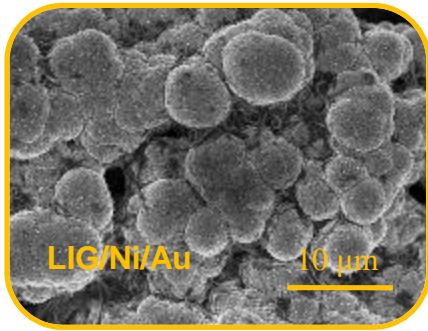


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# RESEARCH THRUSTS

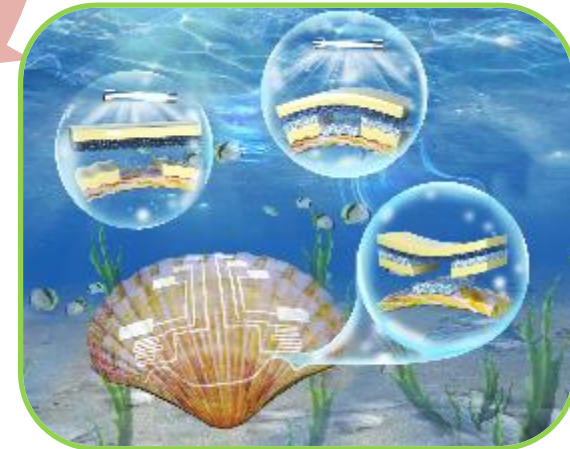
## Nanomaterial composite



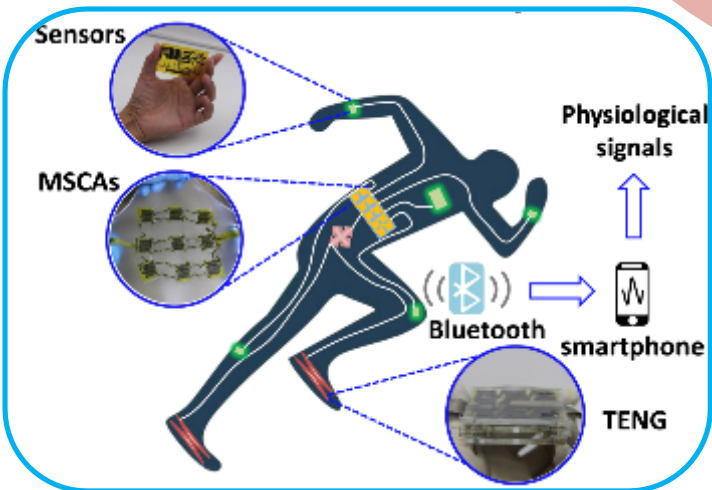
## Body area network



## 3D freeform fabrication



## Standalone device



# STRETCHABLE GAS SENSORS

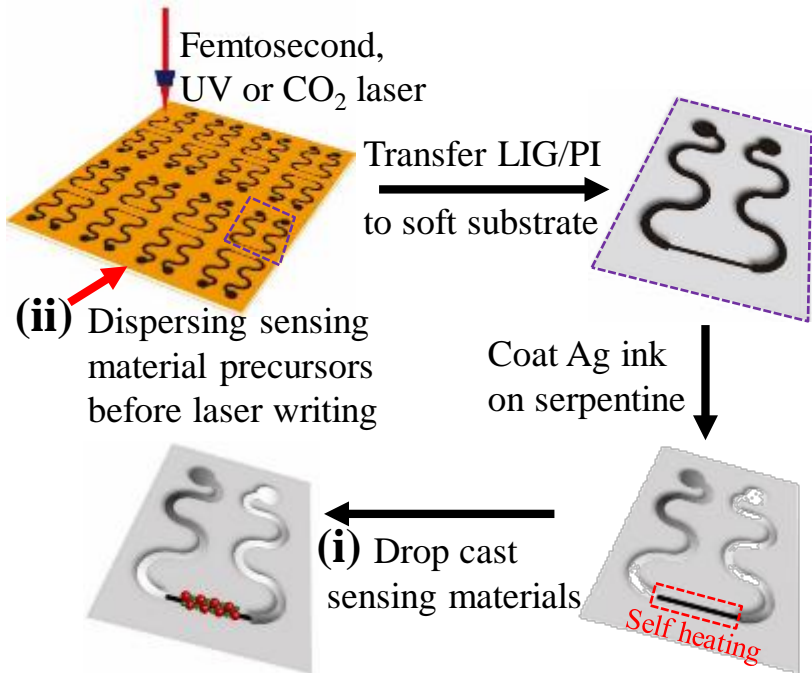


## Application:

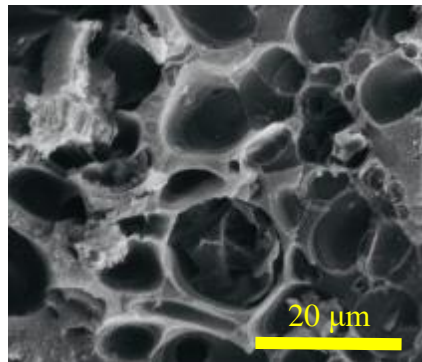
- Health biomarker
- Industry safety
- Environmental monitoring
- Military countermeasures

*Trends Analyt. Chem.* 133, 116085 (2020)

# LIG SENSING PLATFORM



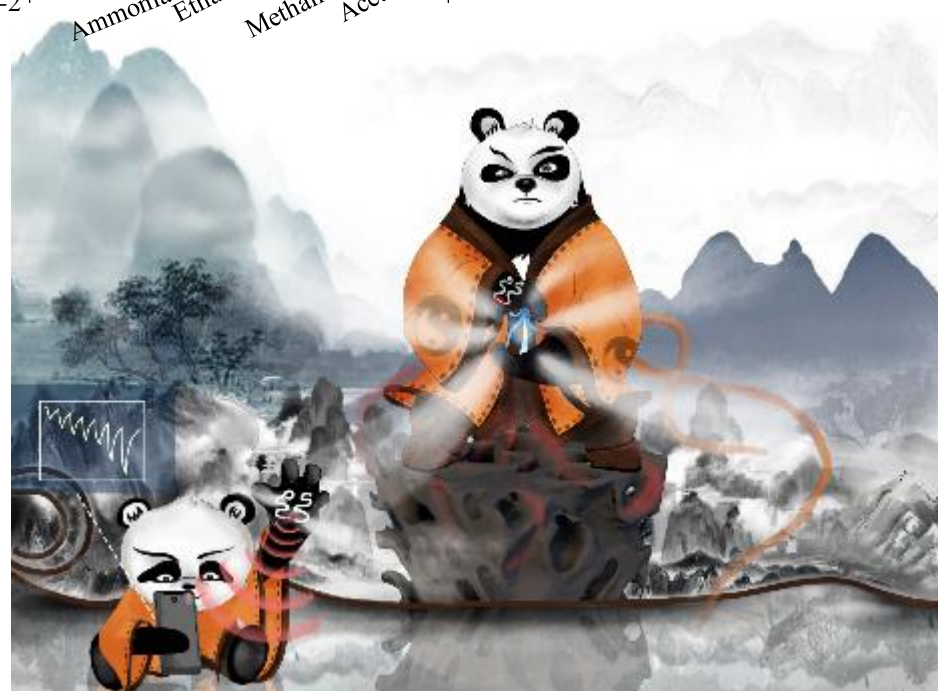
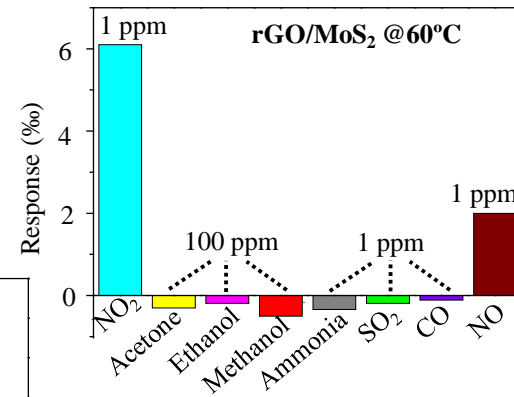
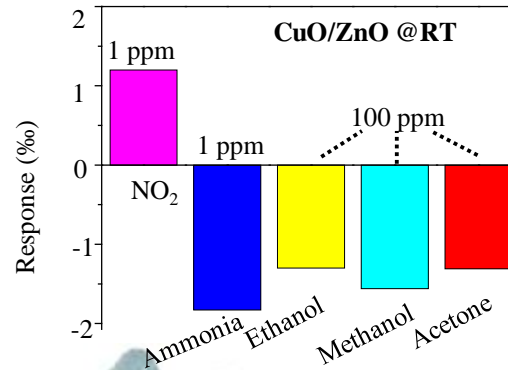
**Porous LIG**



**Skin-conforming**

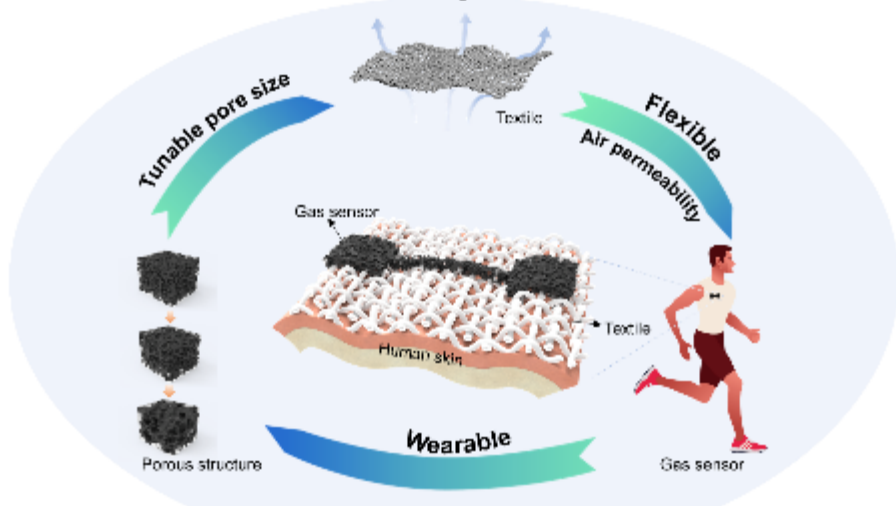


## Varying gas specificity for combinatorial sensing



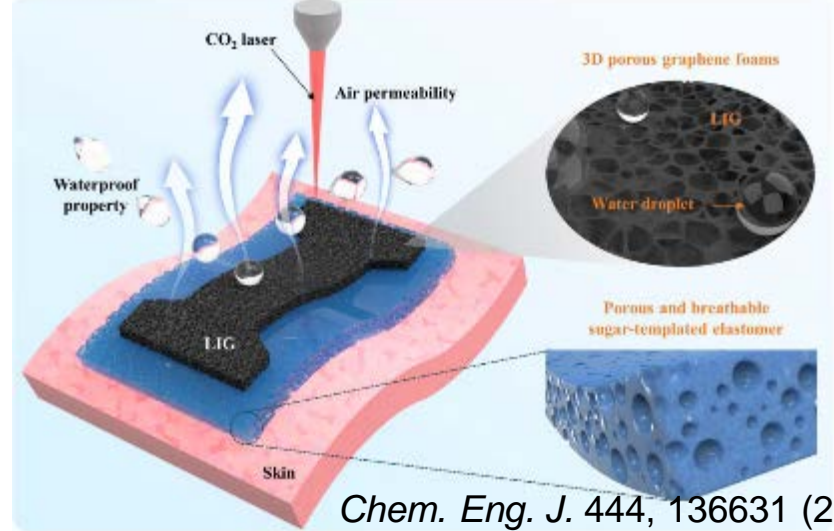
# LIG FUNCTIONAL COMPOSITES

Breathable gas sensor



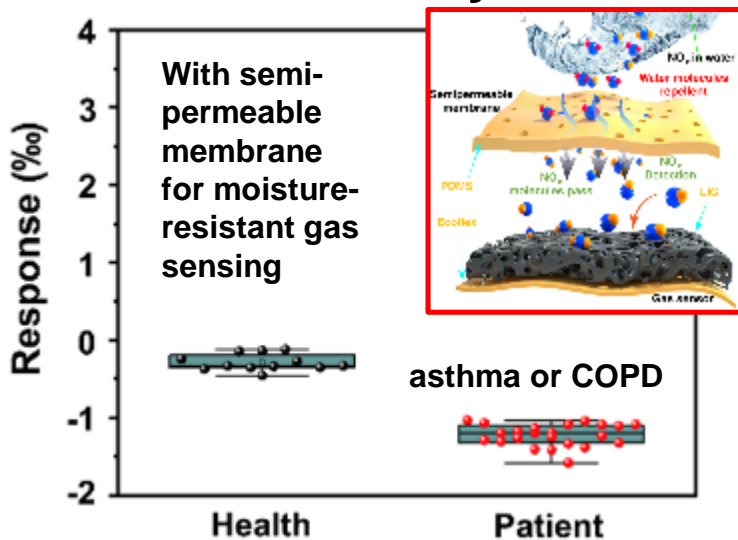
ACS Appl. Mater. Interfaces 14, 17818 (2022)

Dual-mode for T and subtle motion



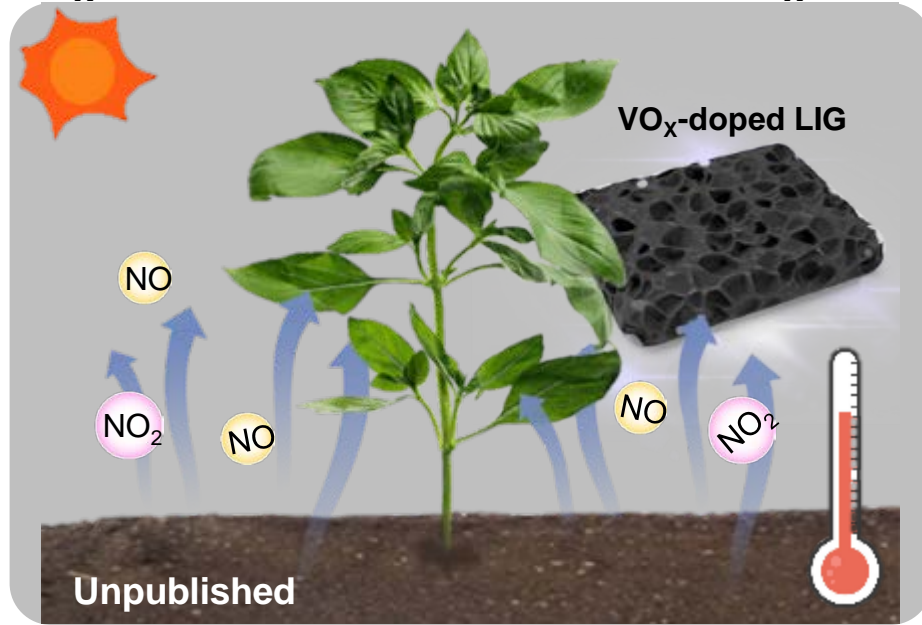
Chem. Eng. J. 444, 136631 (2022)

## Breath analysis

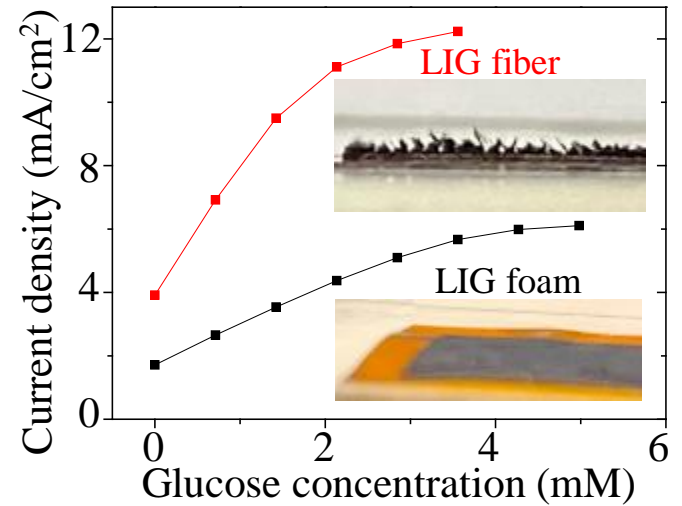
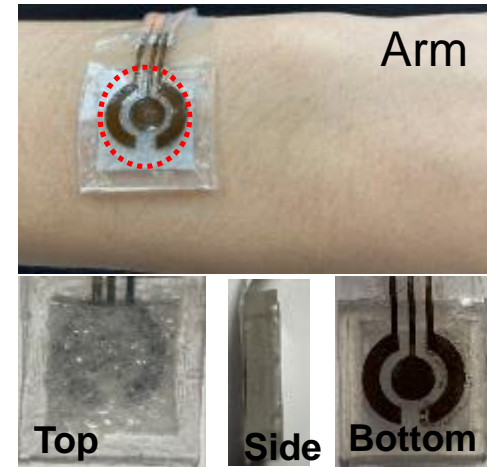
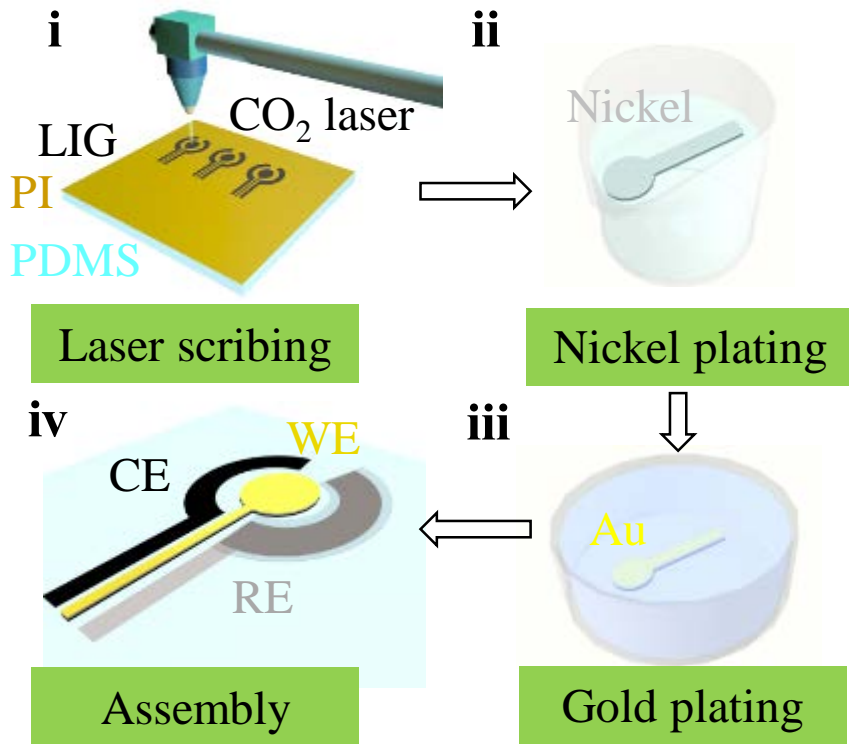


Microsyst. Nanoeng. 8, 78 (2022)

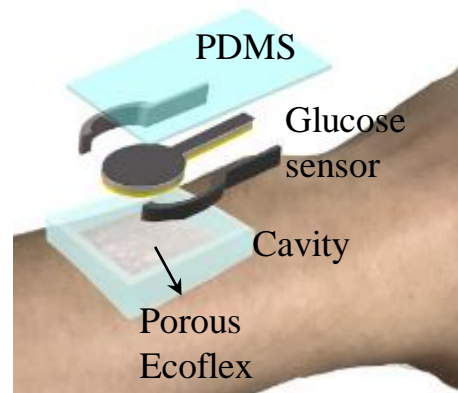
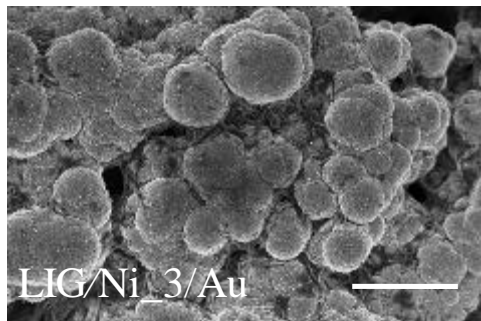
## VO<sub>x</sub>-doped LIG to decouple NO<sub>x</sub> and T



# LIG GLUCOSE SENSOR

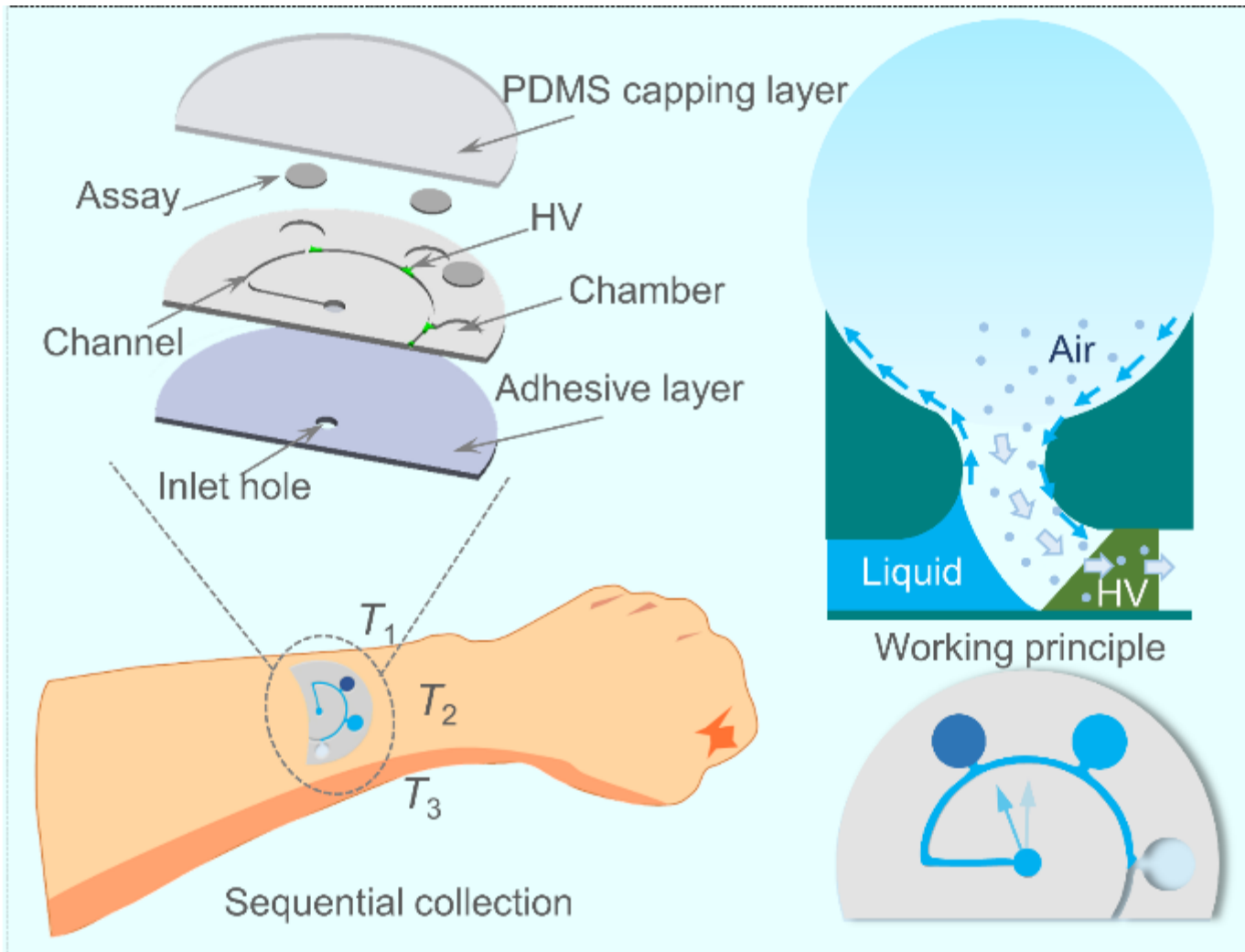


*Biosensors and Bioelectronics* 193, 113606 (2021)



# SOFT MICROFLUIDIC DEVICES

## One-opening chambers and hydrophobic valves (HV)



Lab Chip 20, 2635 (2020) (Cover)



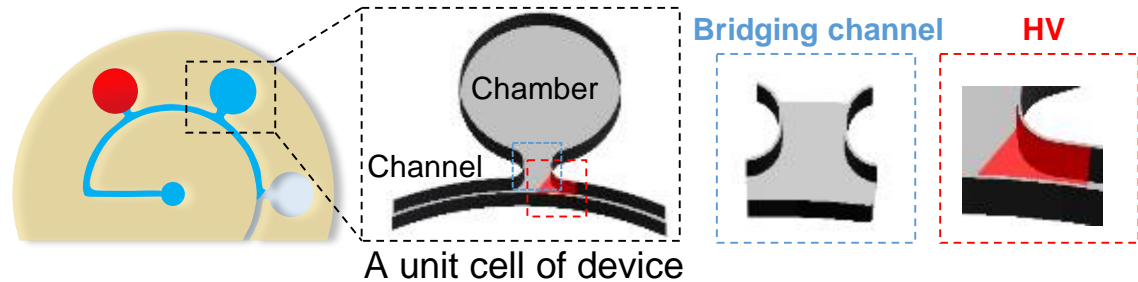
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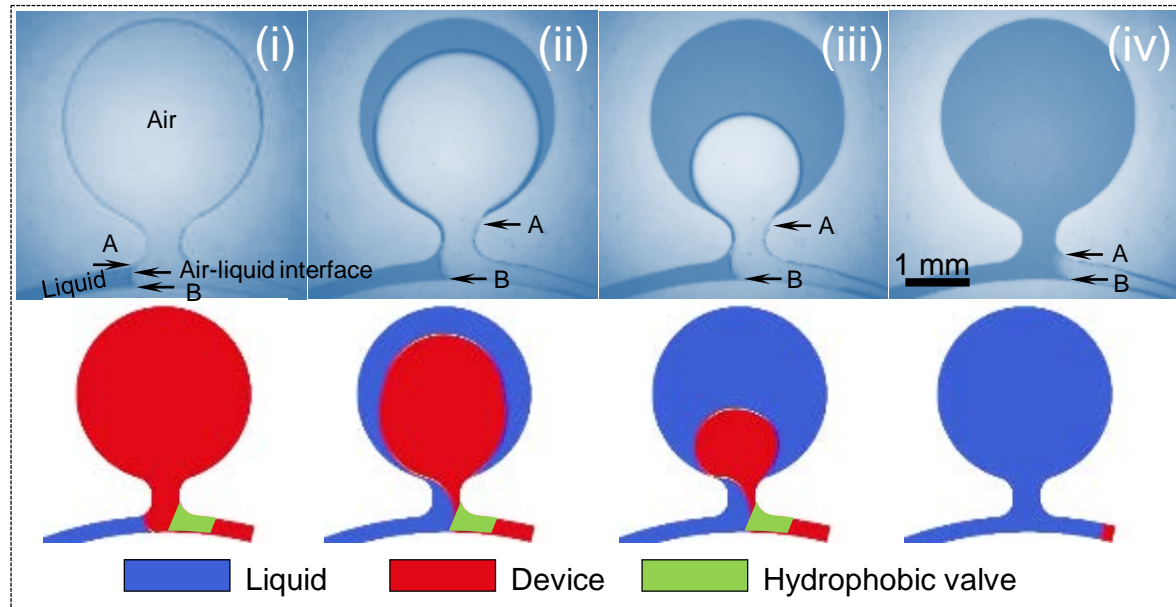
# SOFT MICROFLUIDIC DEVICES

Design



## Hydrodynamic flow process

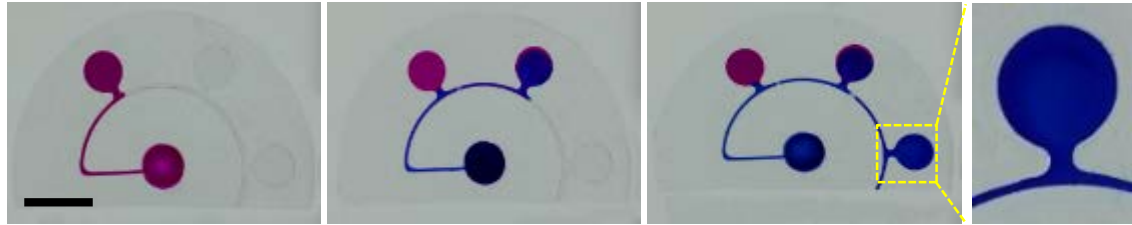
Experiment



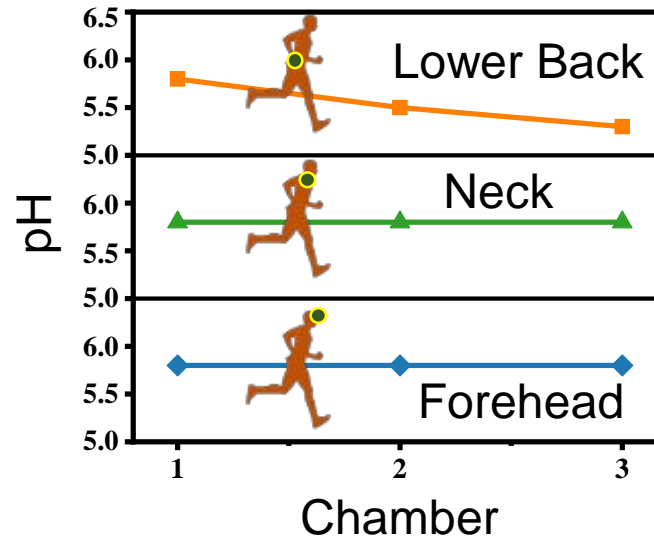
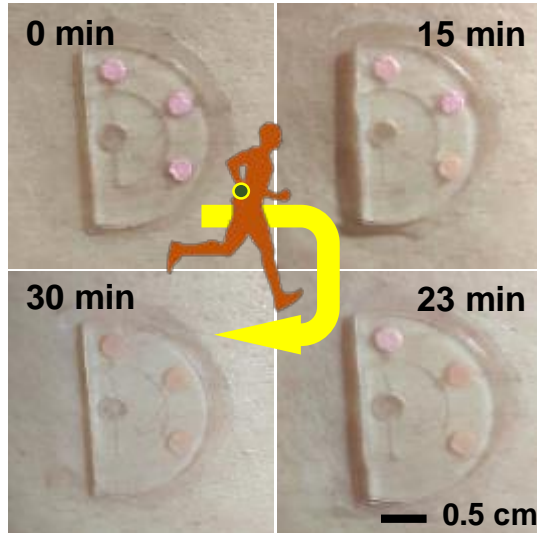
Simulation

# SOFT MICROFLUIDIC DEVICES

Functional demonstrations with two colors of water



Sequential measurement of sweat pH values



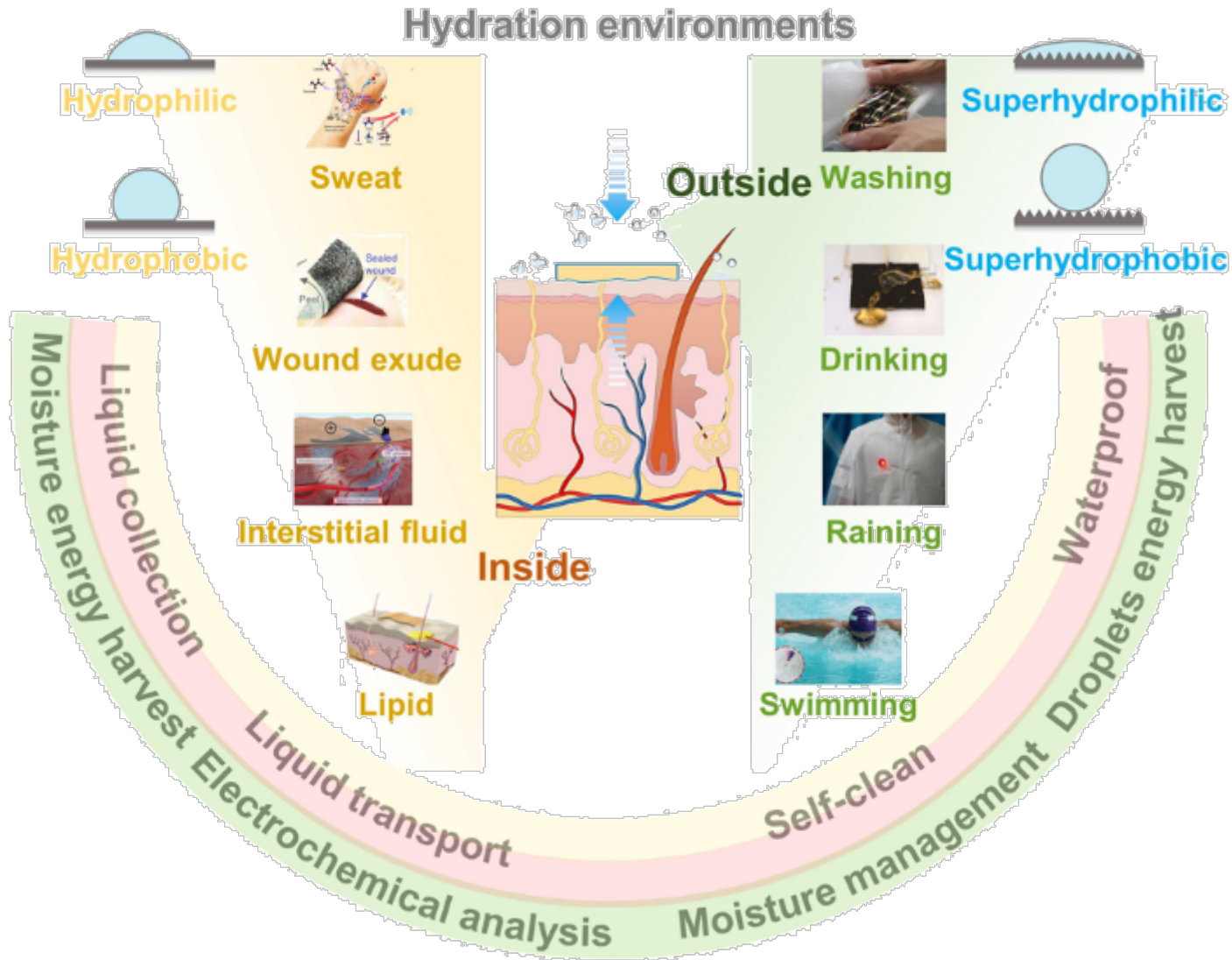
Lab Chip 20, 2635 (2020) (Cover)

# SOFT MICROFLUIDIC DEVICES



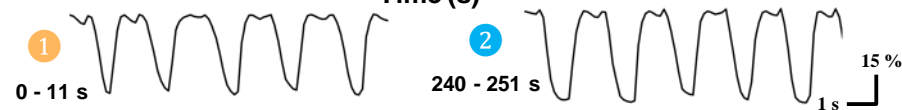
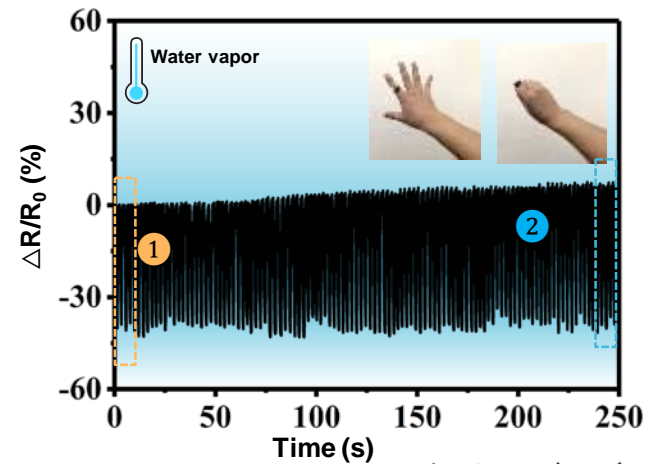
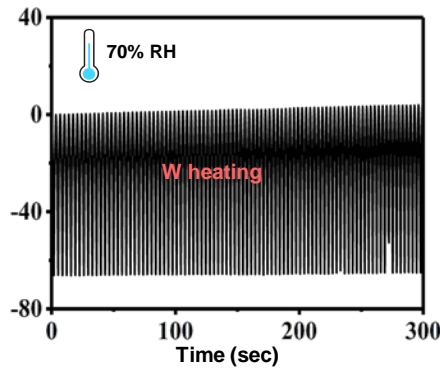
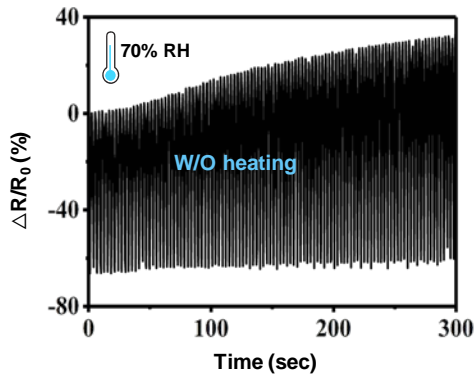
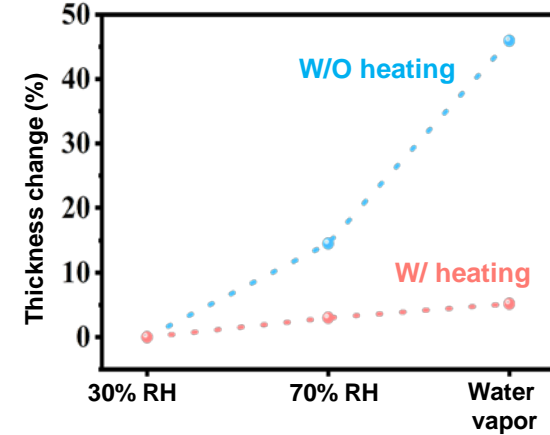
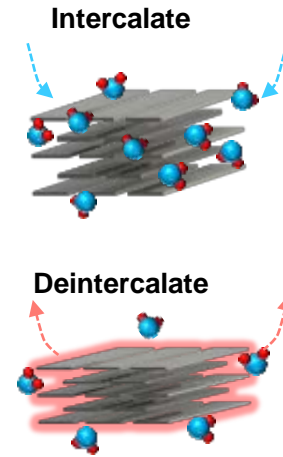
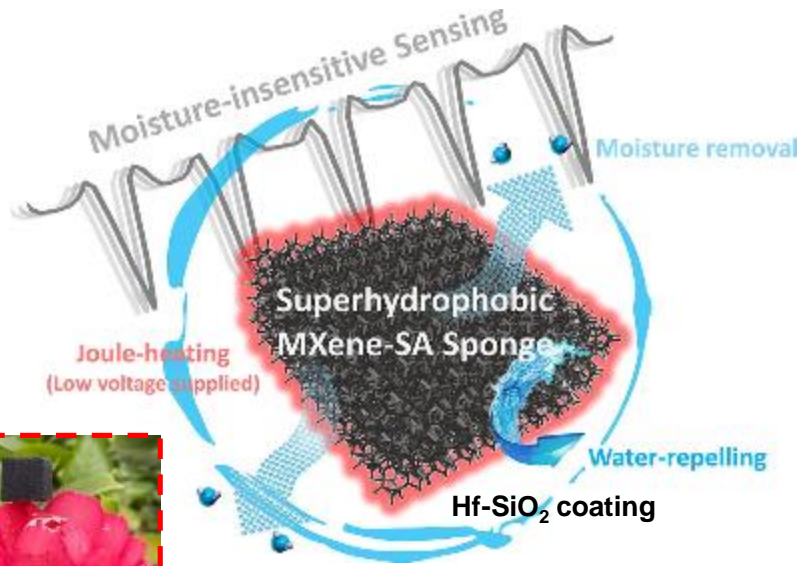
Lab Chip 20, 2635 (2020) (Cover)

# SURFACE WETTABILITY DESIGN



# SUSTAINED SUPERHYDROPHOBICITY

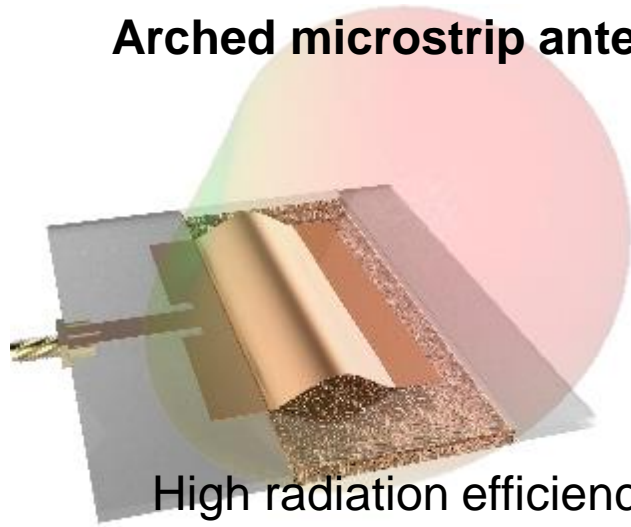
## MXene-sodium alginate sponge



Chemical Engineering Journal 432, 134370 (2022)

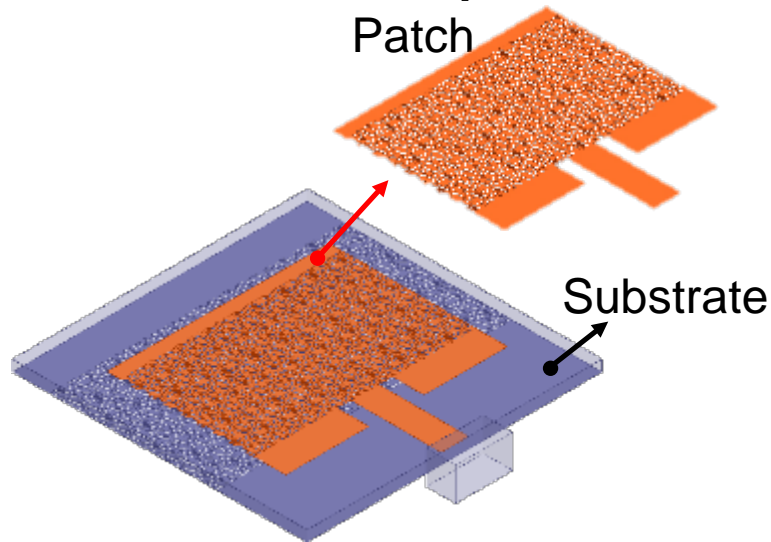
# STRETCHABLE METAL ANTENNA

## Arched microstrip antenna



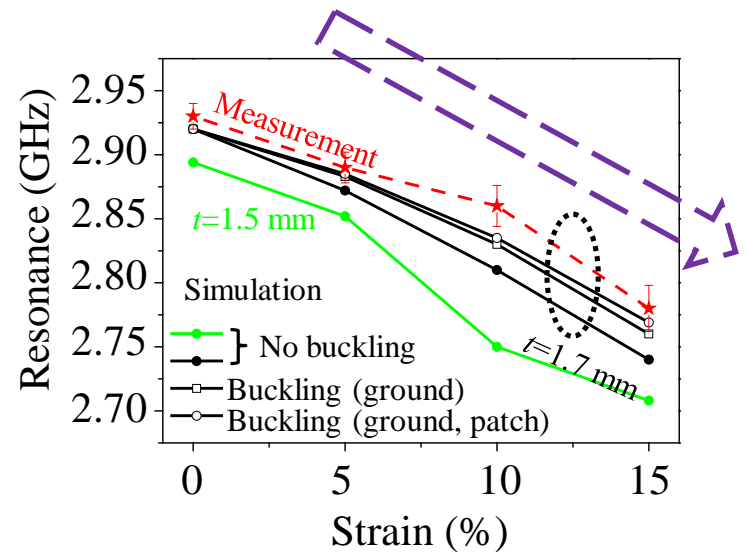
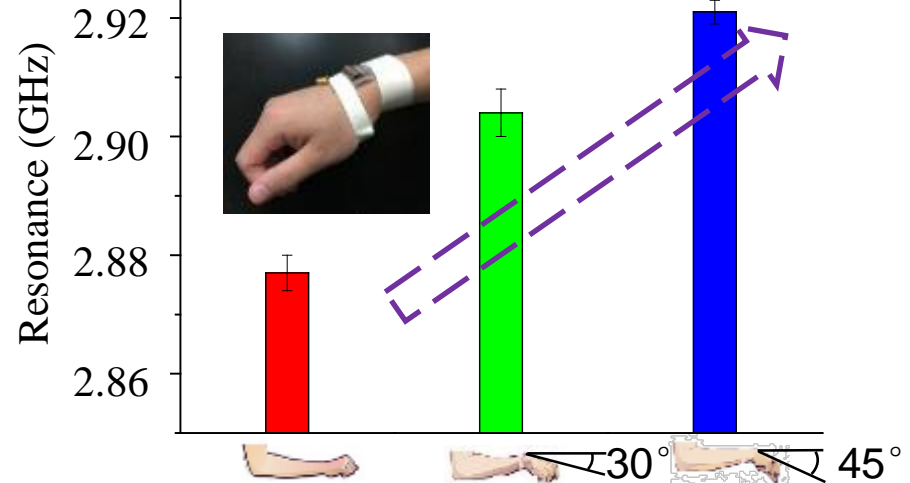
High radiation efficiency of 87 %

## Meshed microstrip antenna

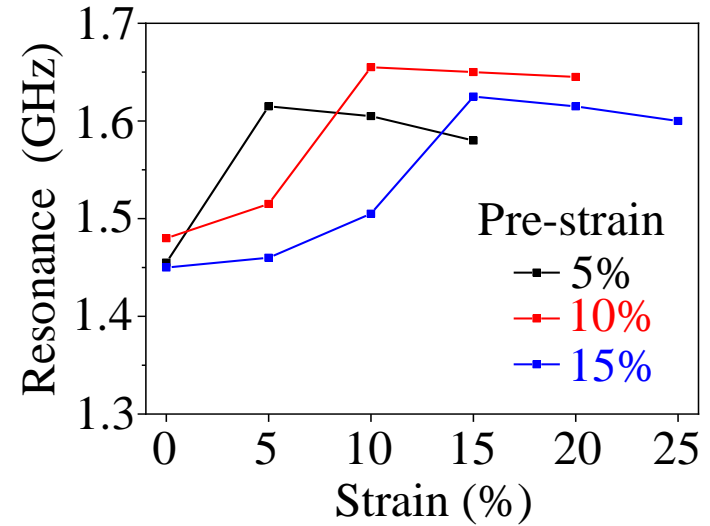
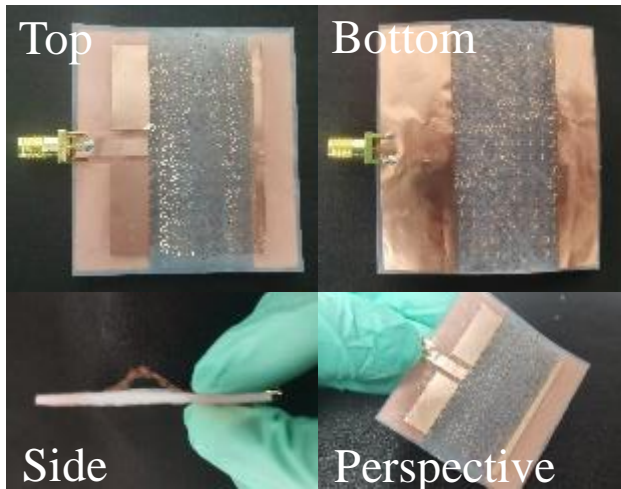


ACS Appl. Mater. Interfaces 11, 8867 (2019)

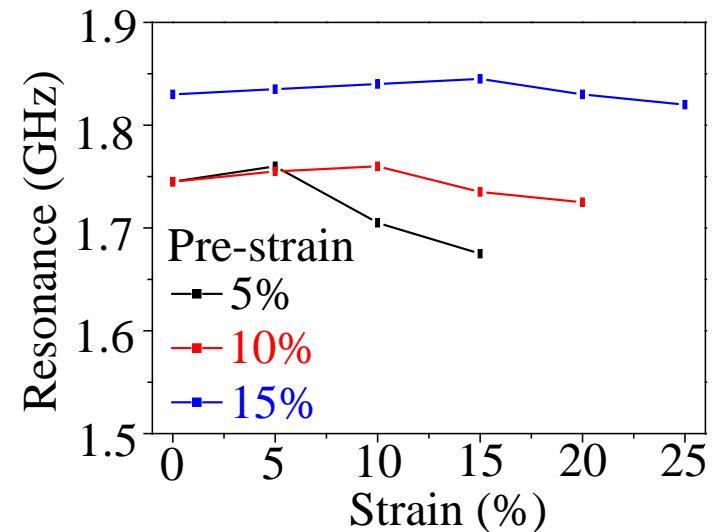
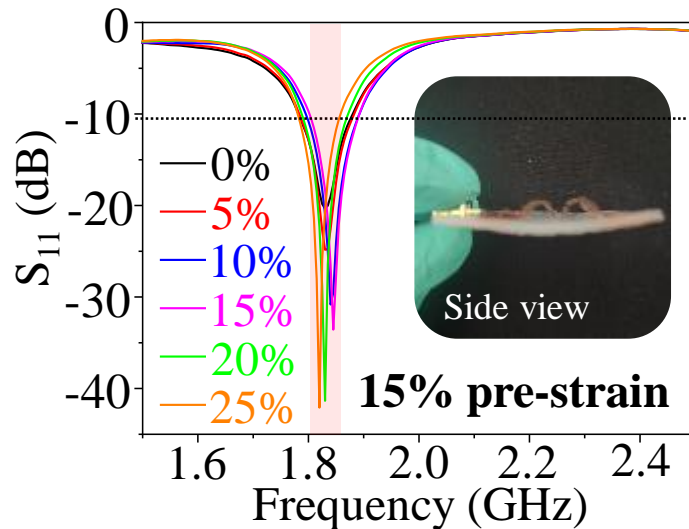
## Wireless motion detection



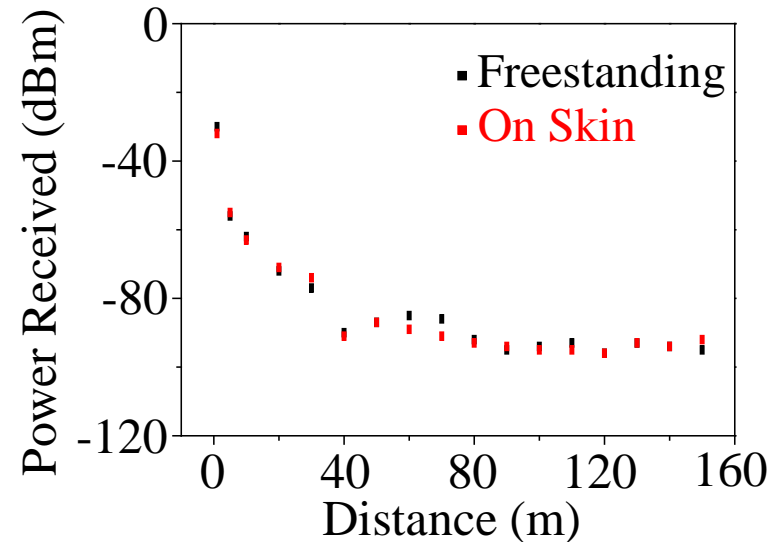
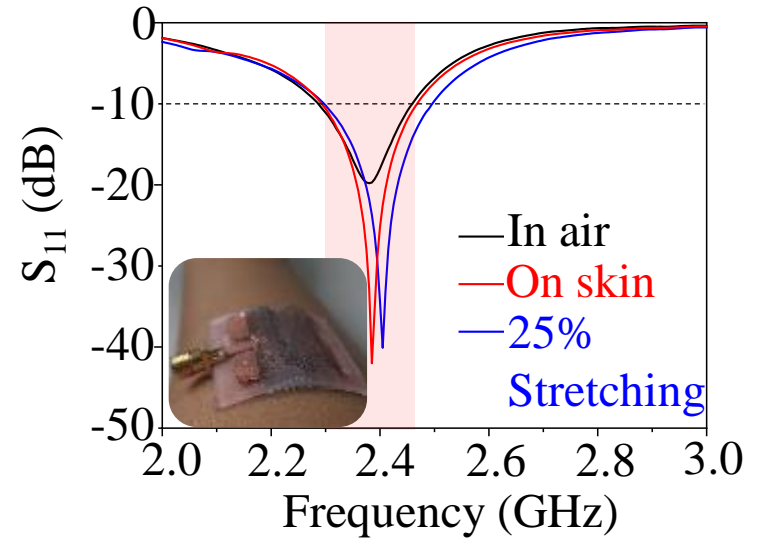
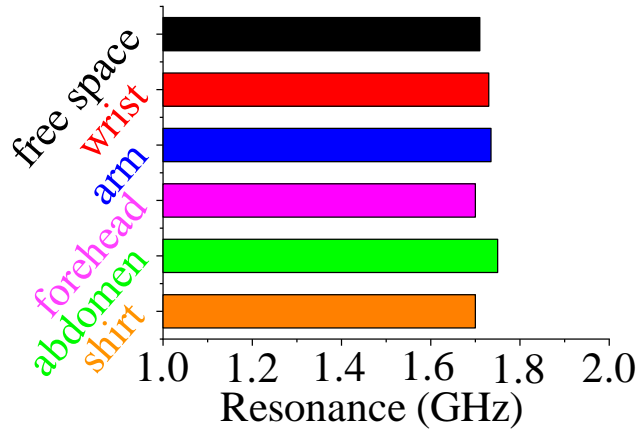
# STRAIN-INSENSITIVE ANTENNAS



## Hierarchical structured



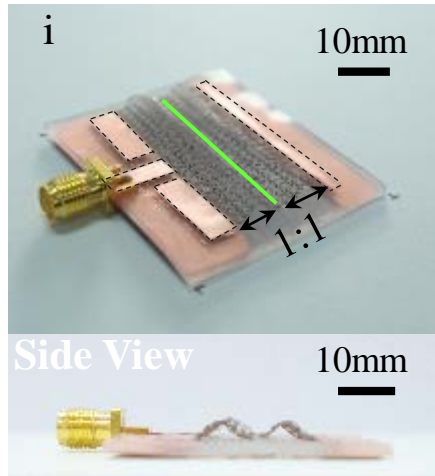
# ON-BODY COMMUNICATION



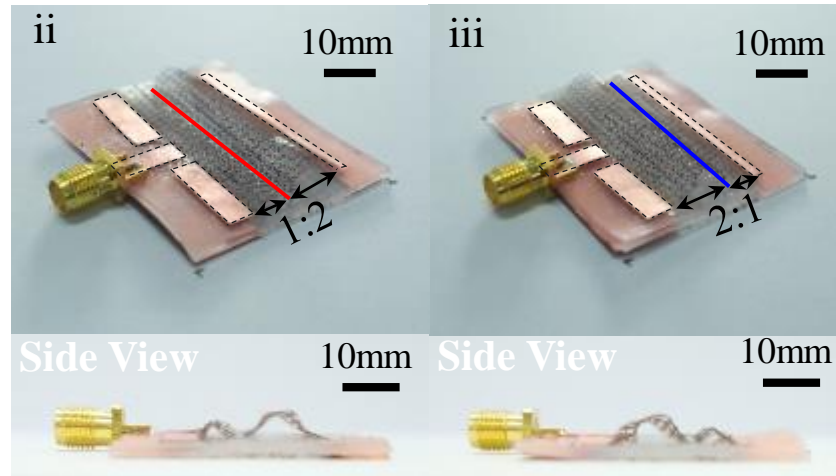


# ASYMMETRIC 3D MICROSTRIP ANTENNA

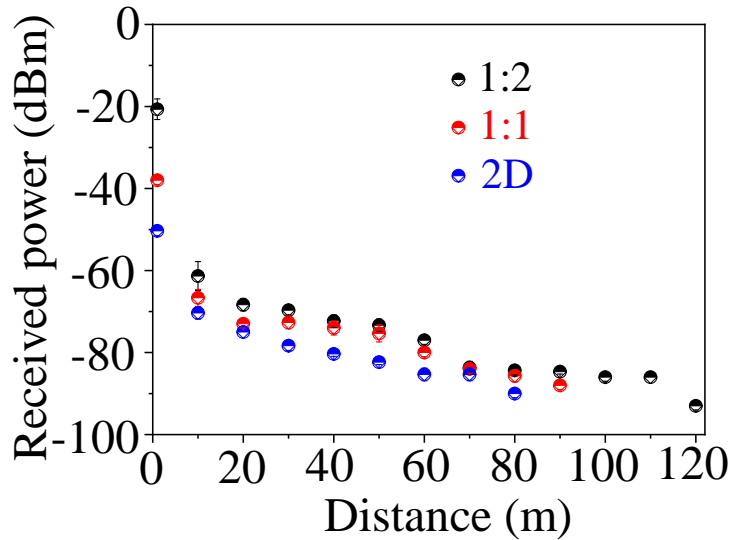
Symmetric



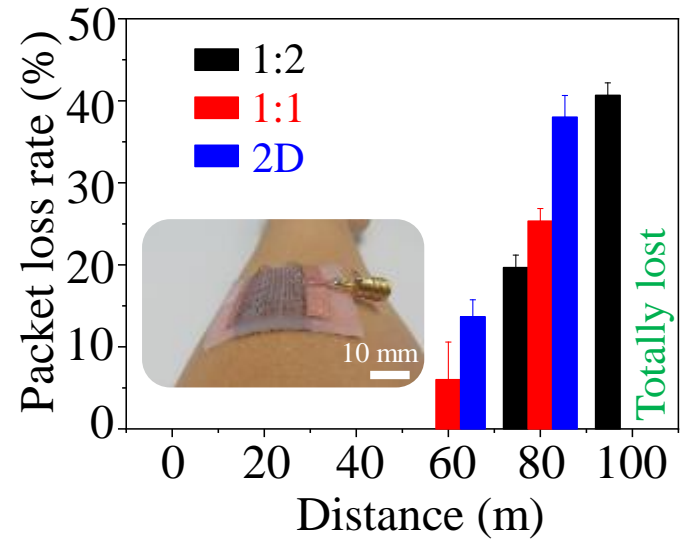
Asymmetric



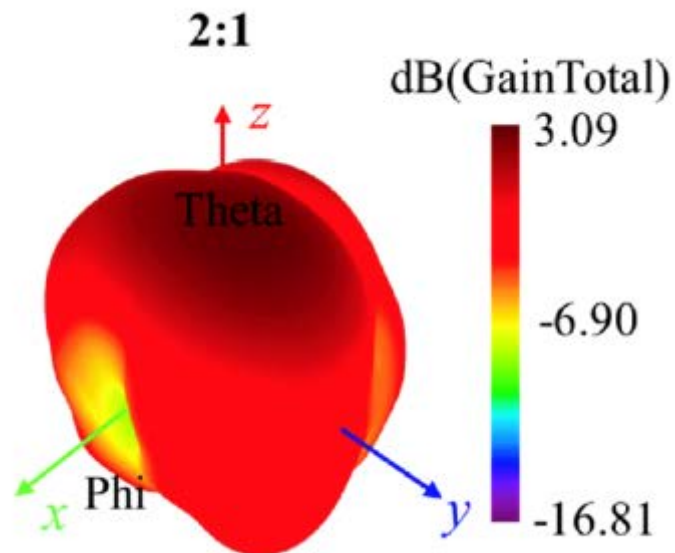
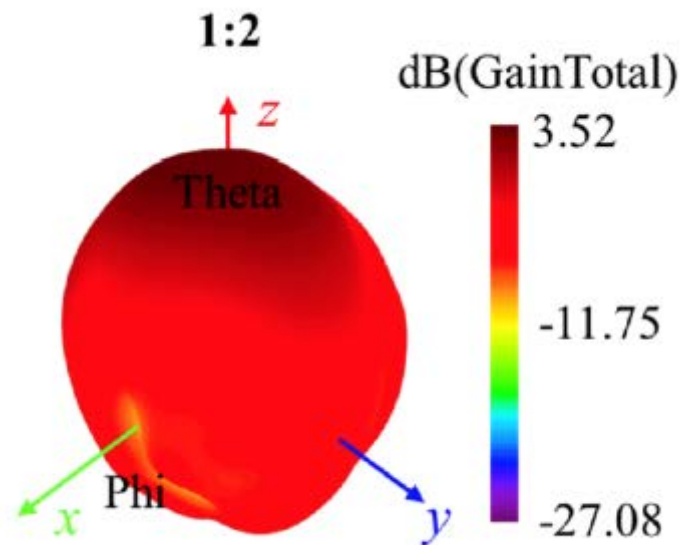
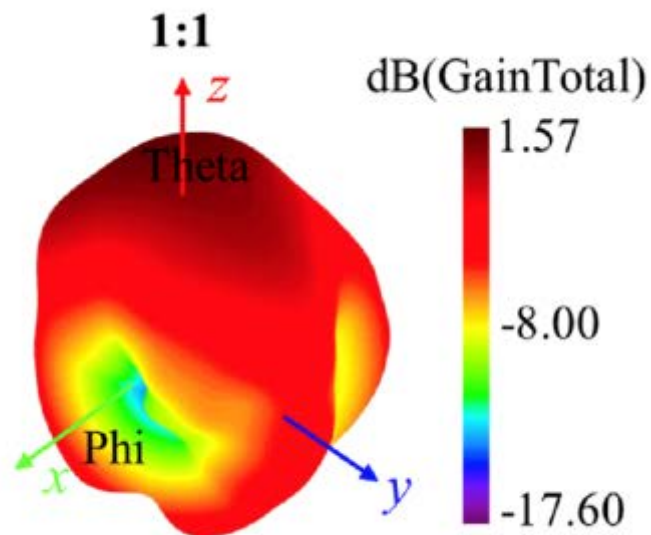
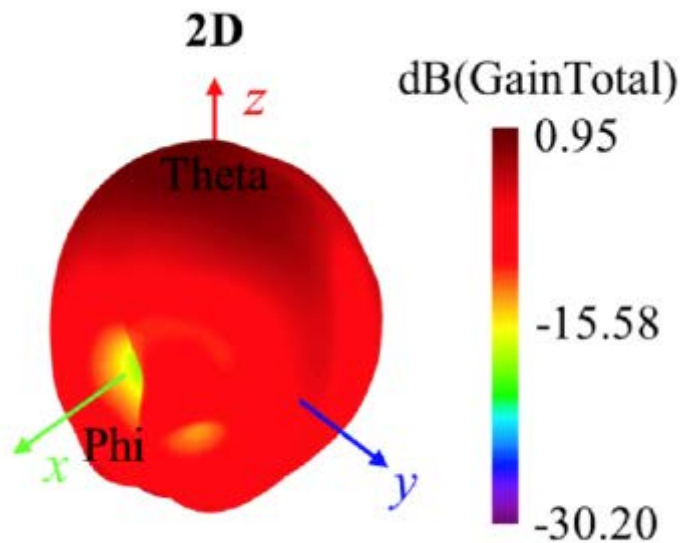
Average receiving power



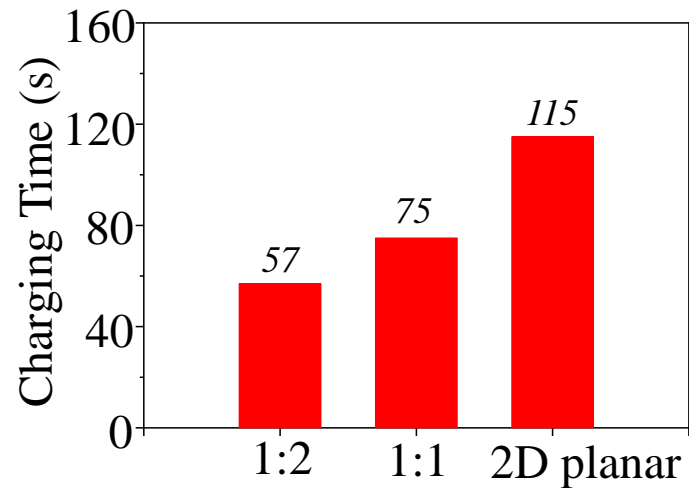
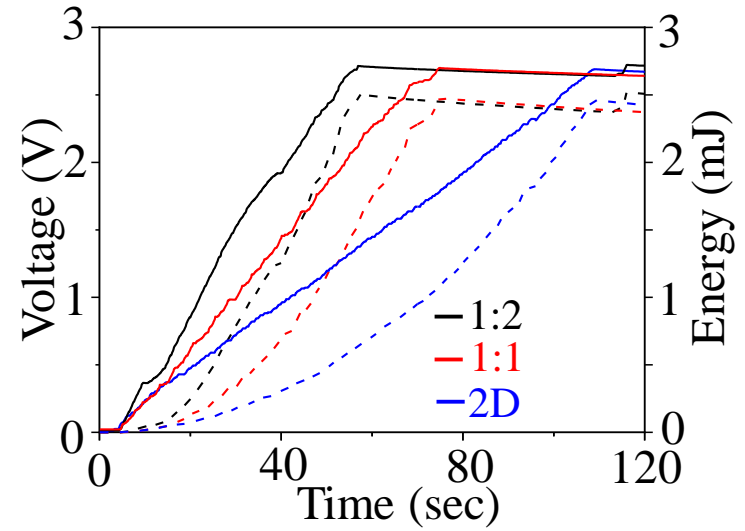
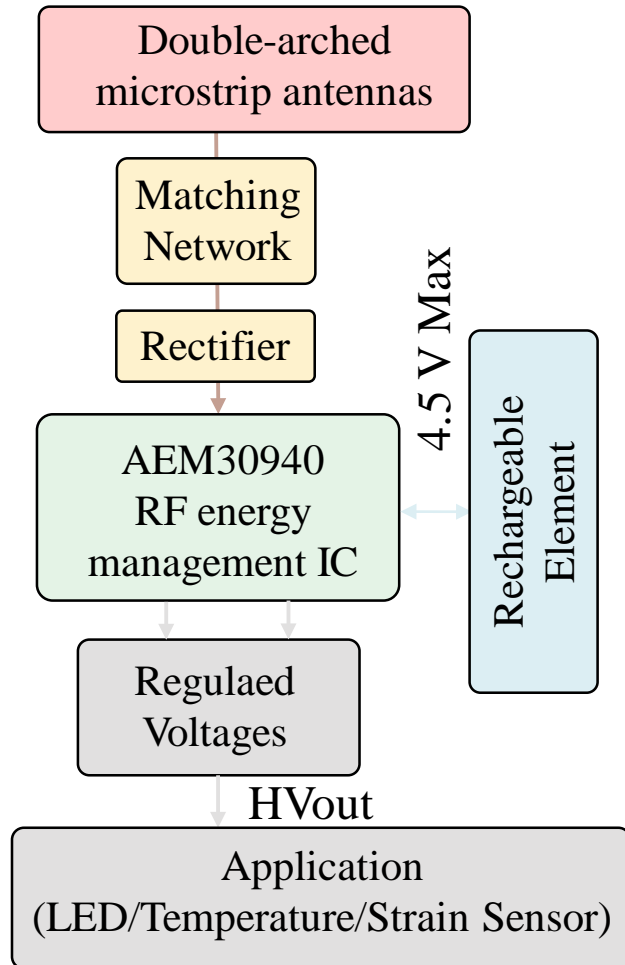
Data packet loss rates



# ENHANCED GAIN AND RADIATION

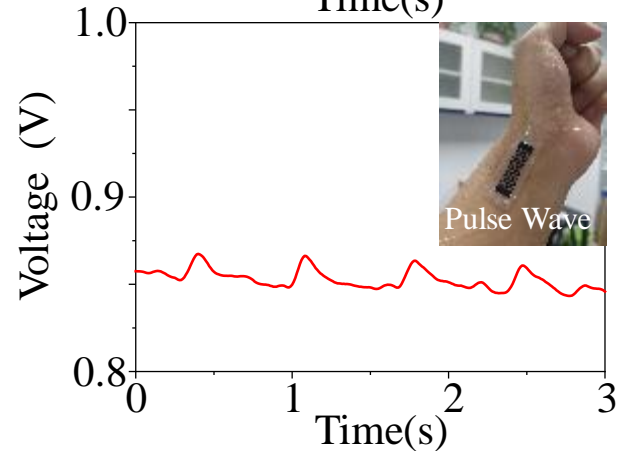
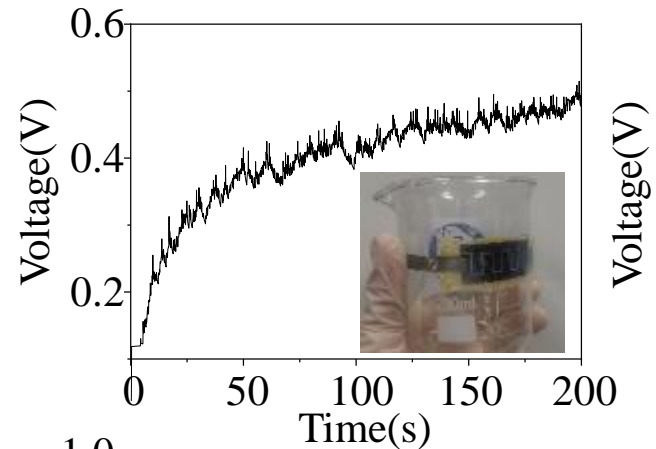
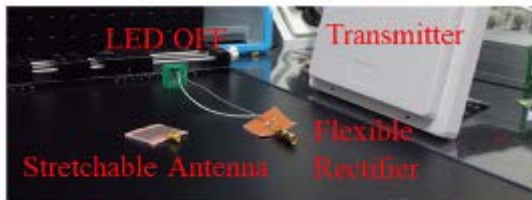
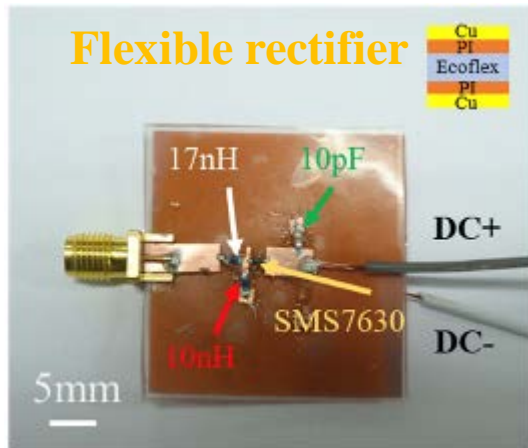
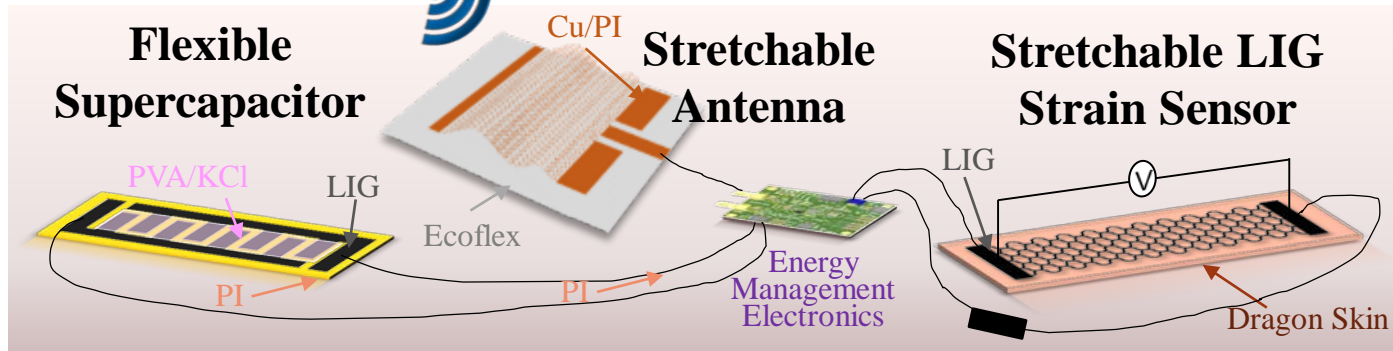


# RF ENERGY HARVESTING



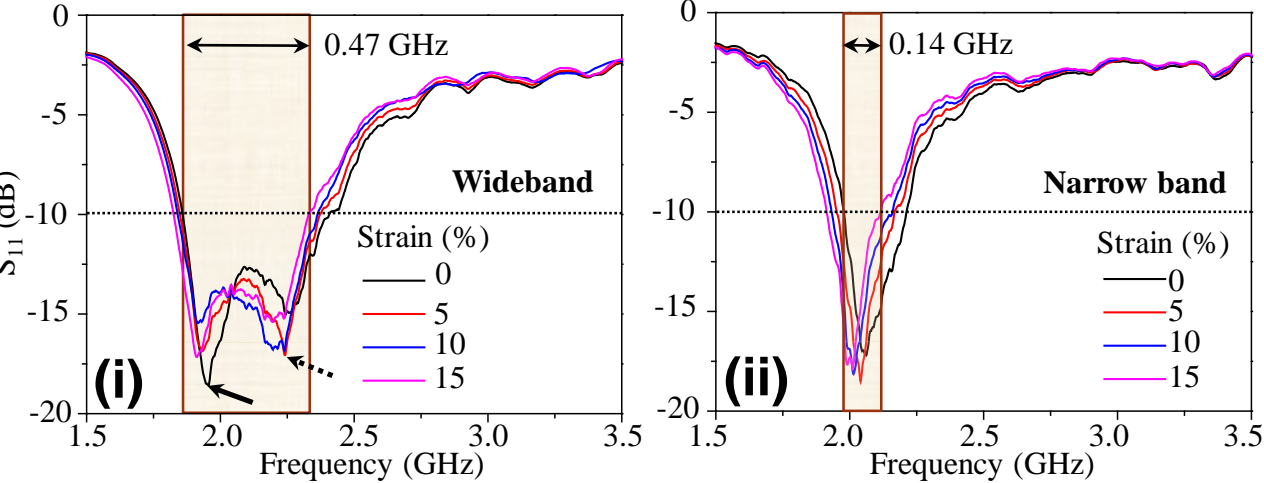
# RF ENERGY HARVESTING

2.4GHz RF Source

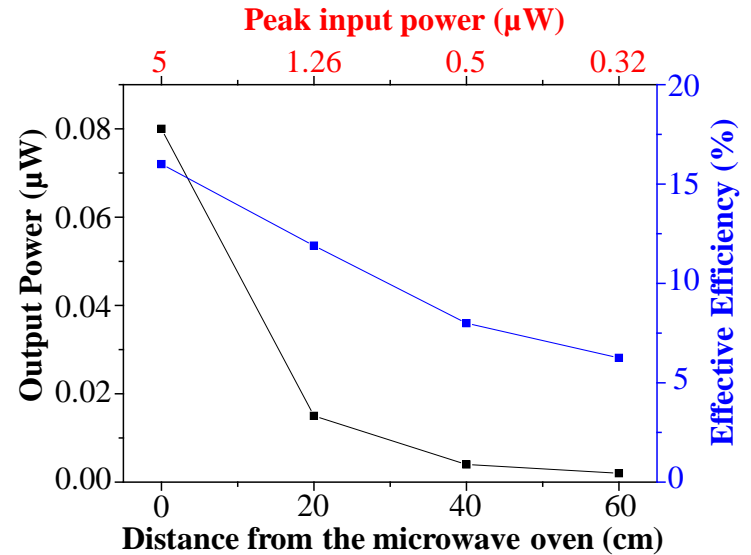
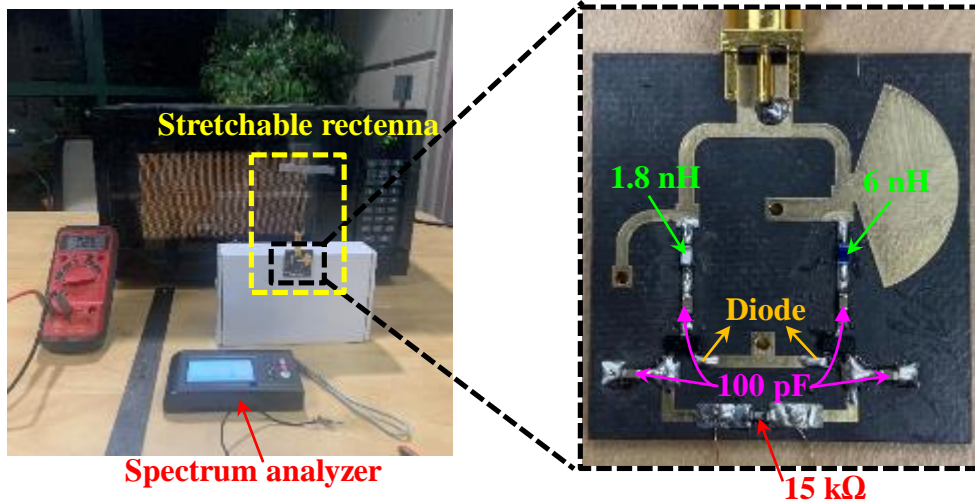
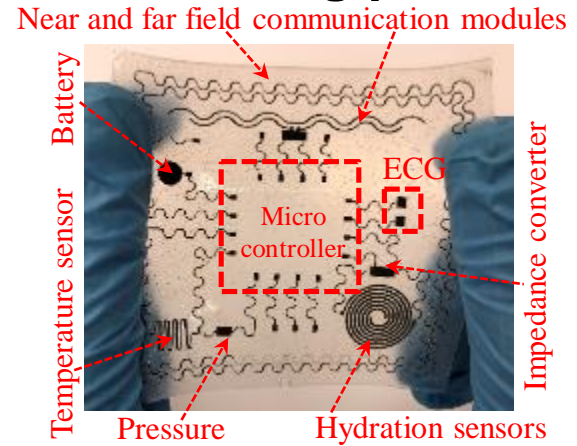


# STRETCHABLE WIDEBAND RECTENNA

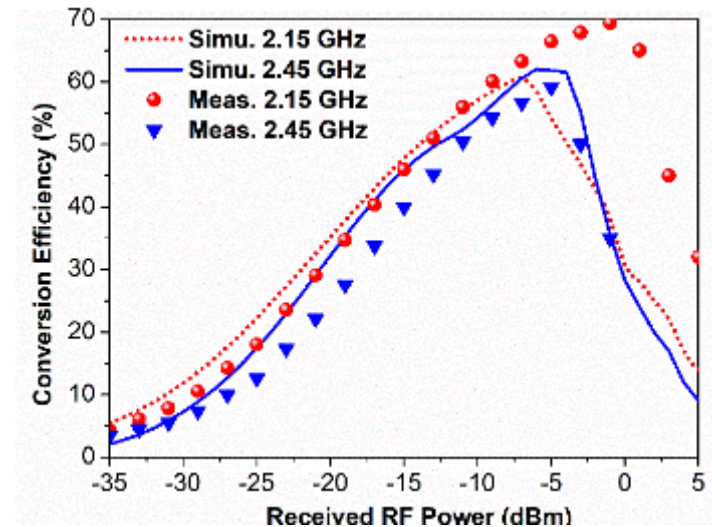
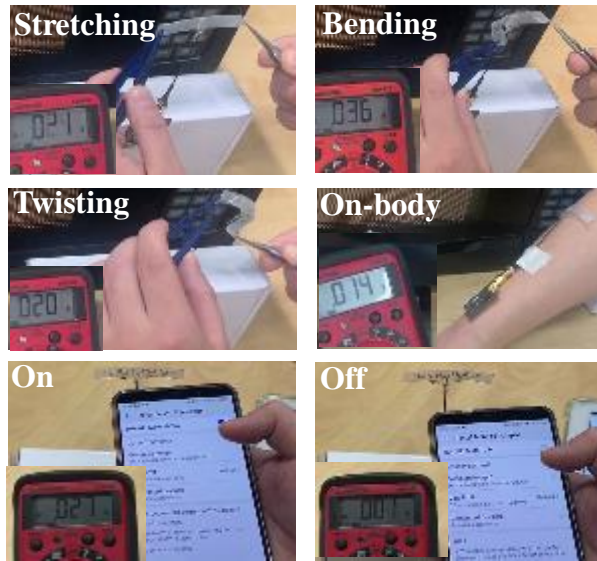
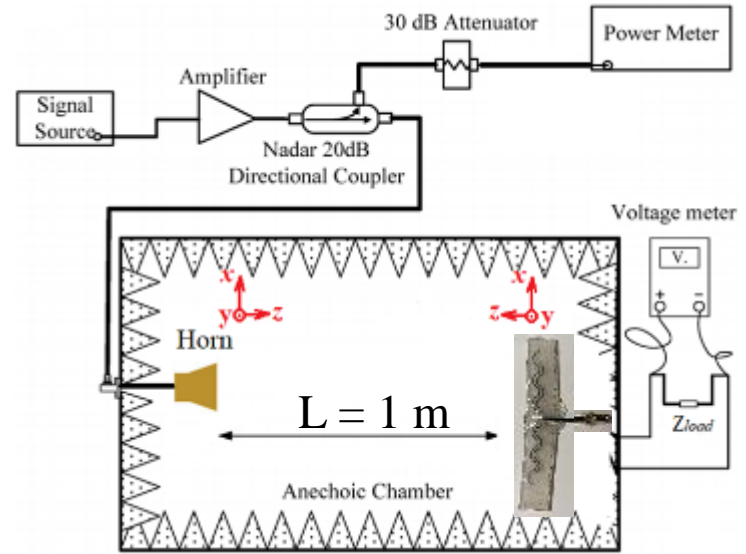
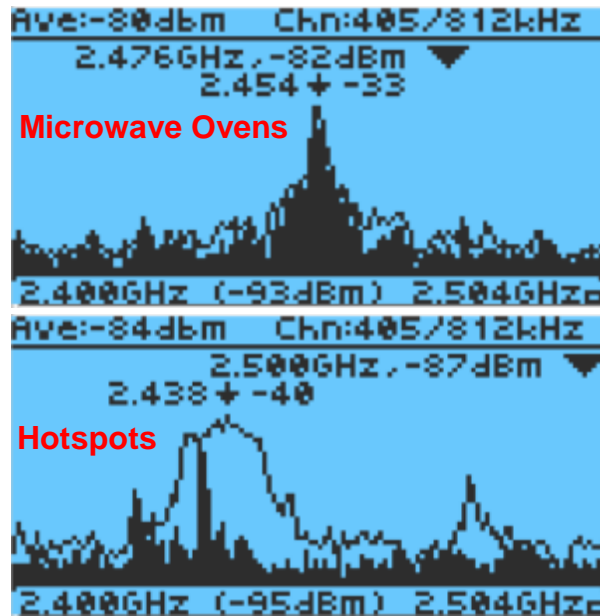
## Wide bandwidth stretchable antenna



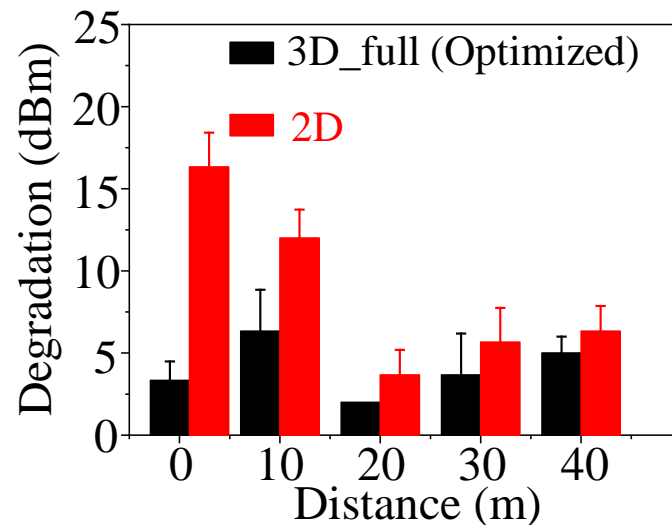
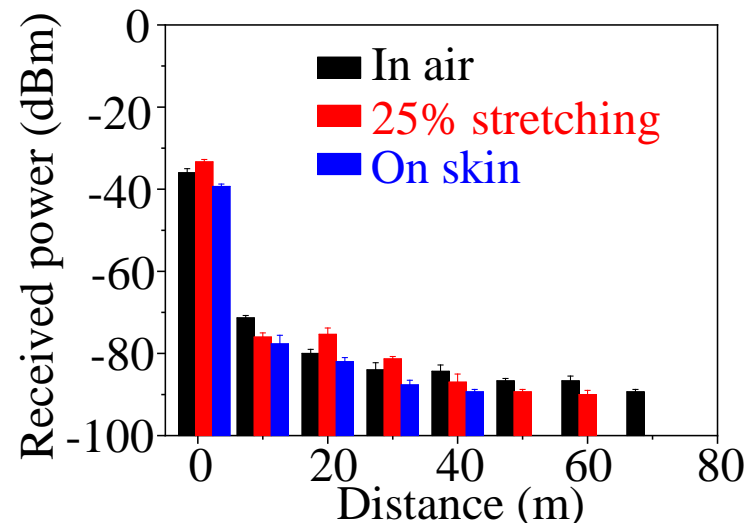
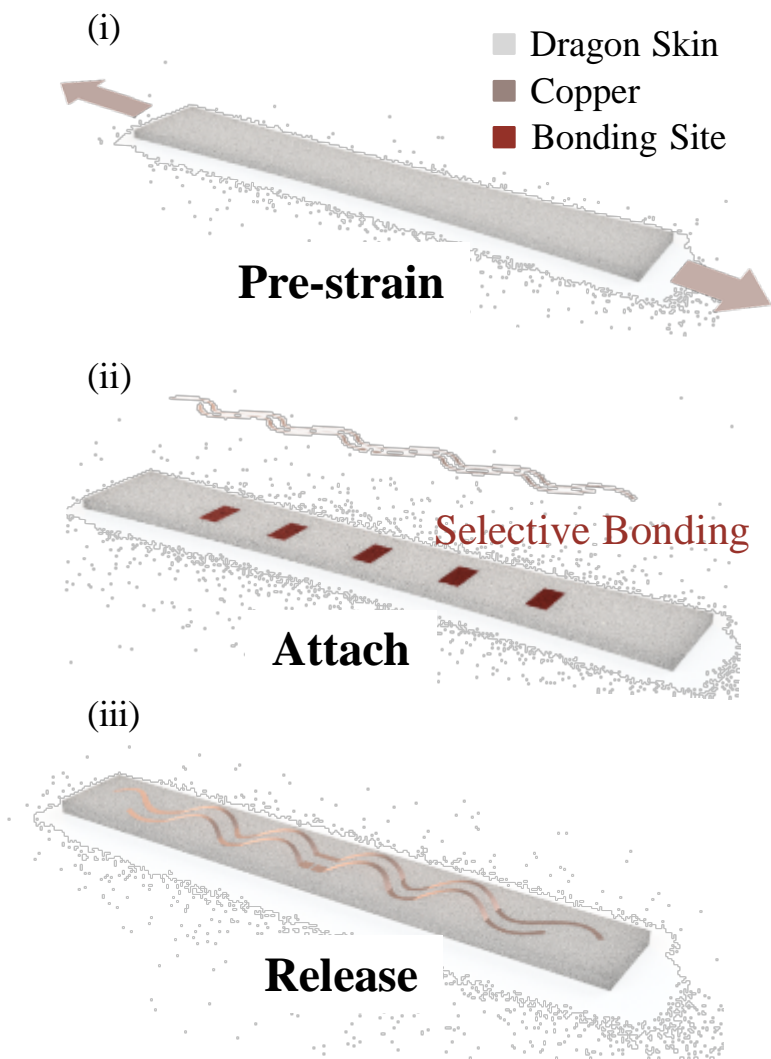
## All-LIG sensing platform



# RF ENERGY HARVESTING



# RF ENERGY HARVESTING





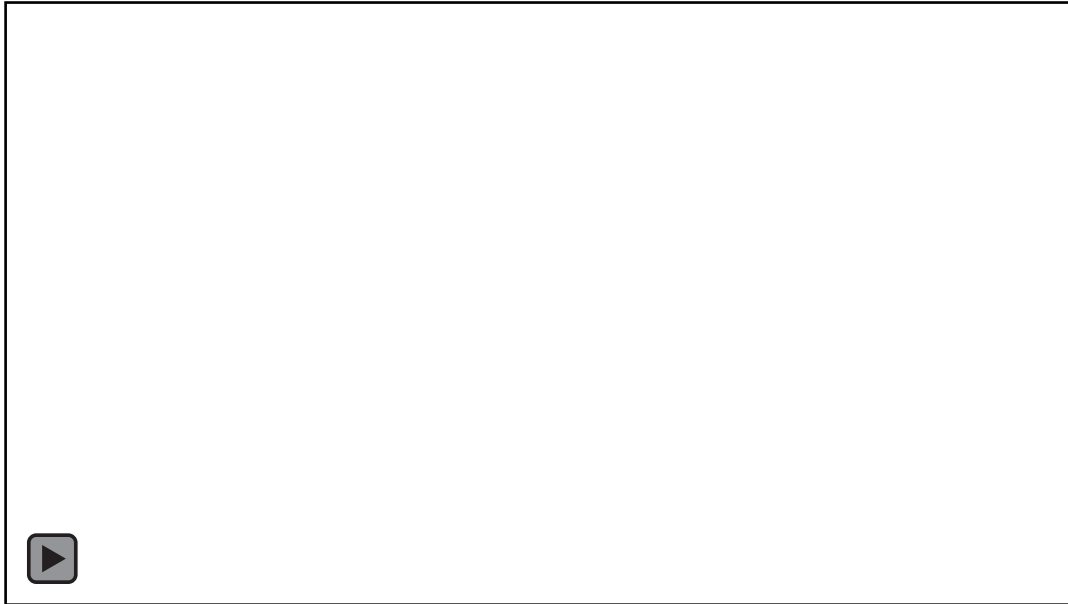
**Questions?**



# ELECTRONICS THAT DISSOLVE

- **Substrate:** Silk (FDA approved), PLGA
- **Interconnects:** Mg, Fe, Zn, W
- **Electronic components:** Si, SiO<sub>2</sub>

## Transient Electronics



**Mg ~ 100  $\mu$ g, Si ~ 3  $\mu$ g**

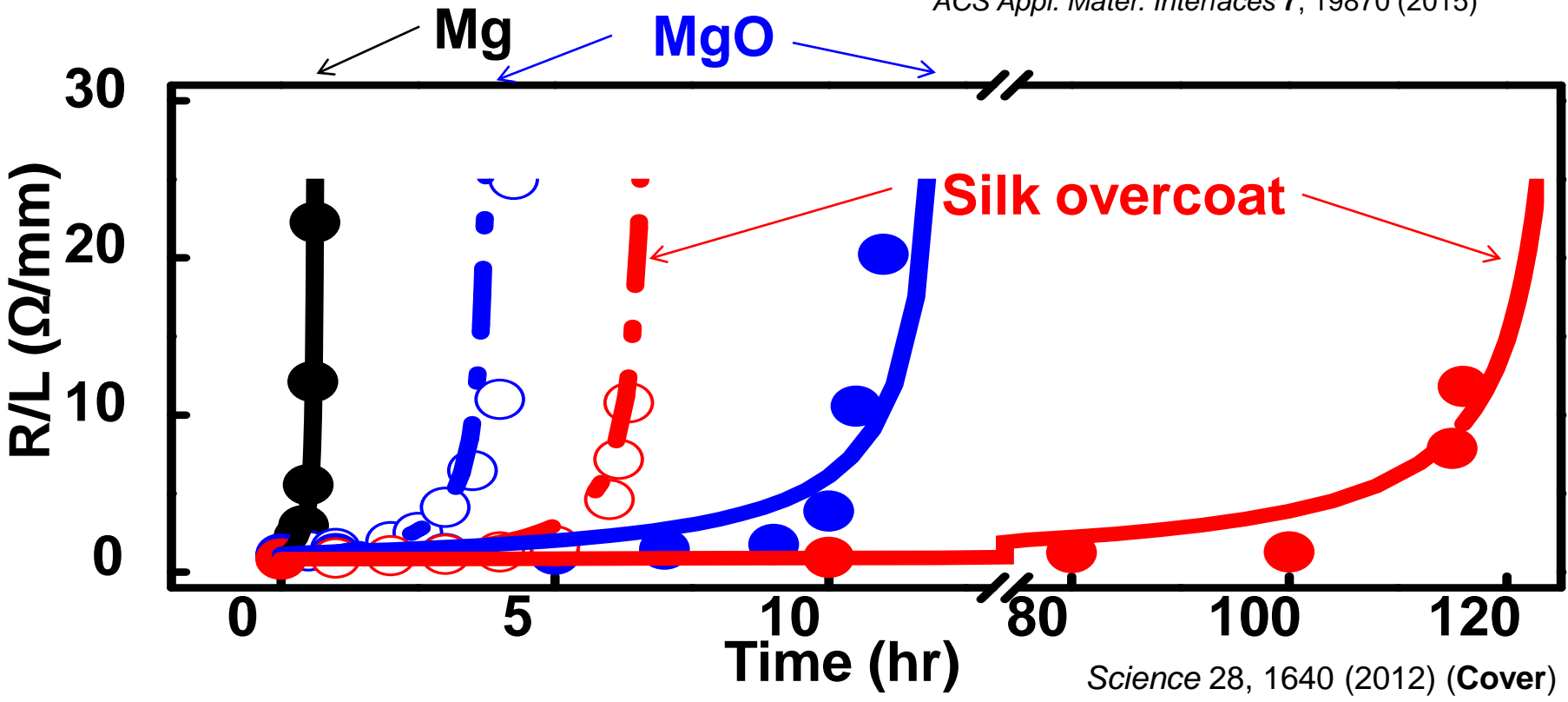
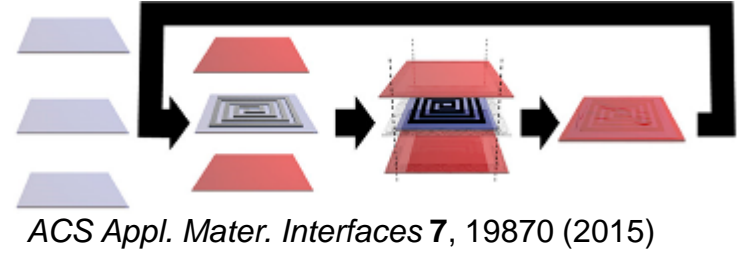
## Rec. Daily Intake



**Mg ~ 300 mg, Si ~ 10 mg**

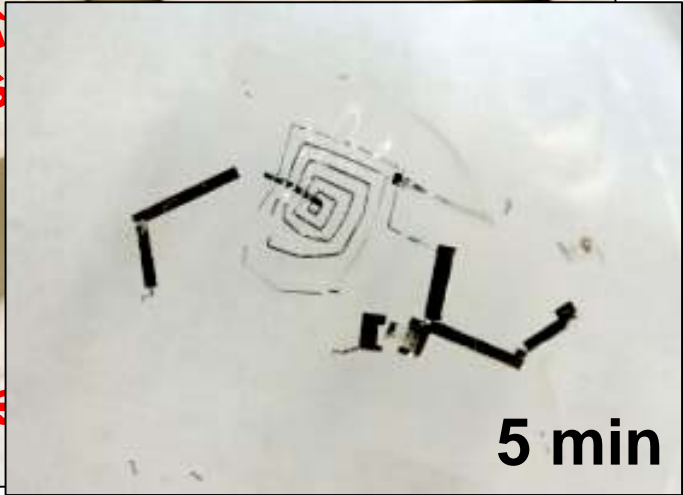
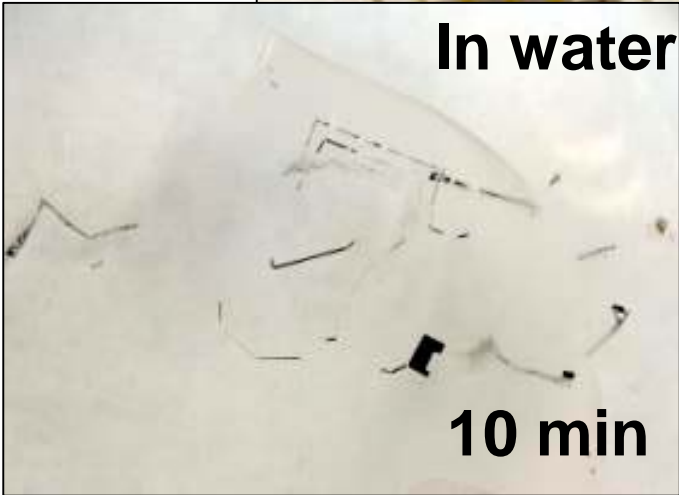
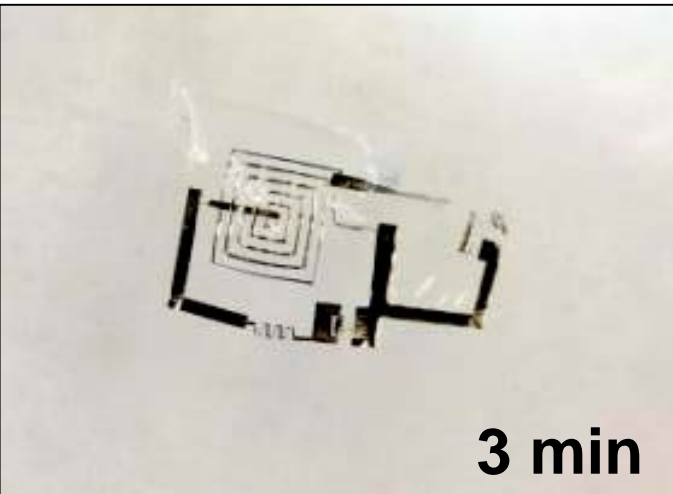
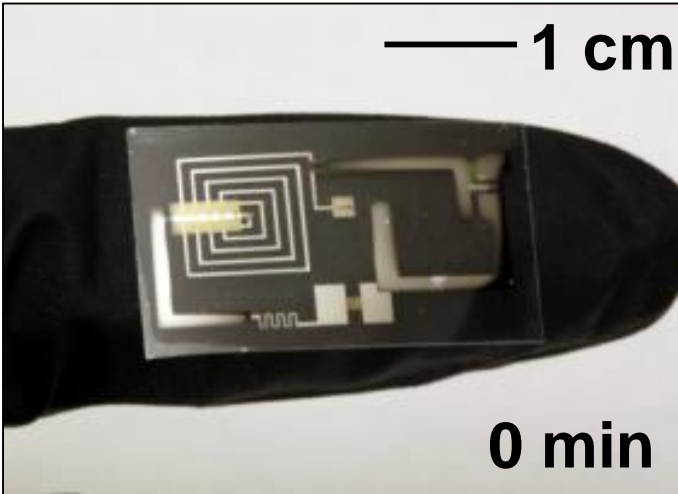
# ENGINEERED LIFETIME

- MgO: thickness control
- Silk: tunable dissolution



Science 28, 1640 (2012) (Cover)

# SYSTEM LEVEL DEVICE



MgO capacitor

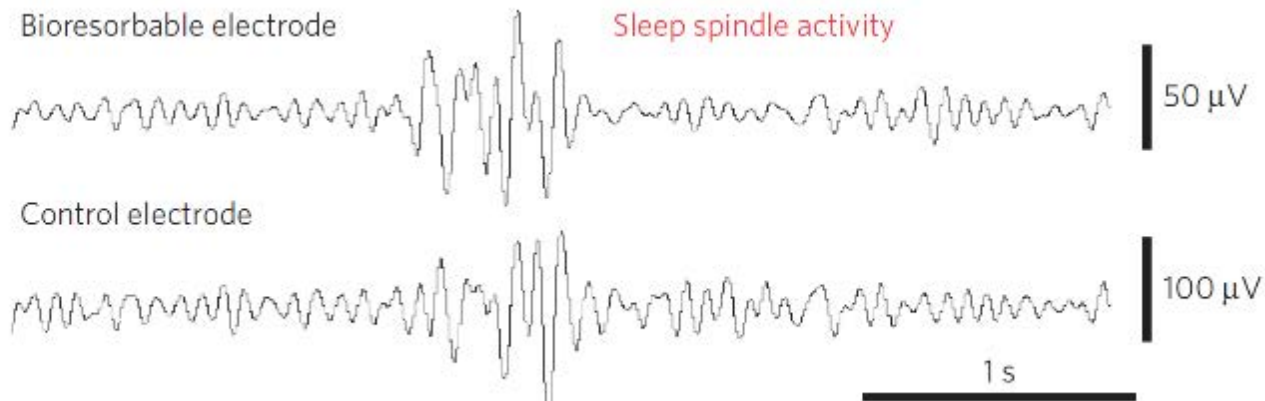
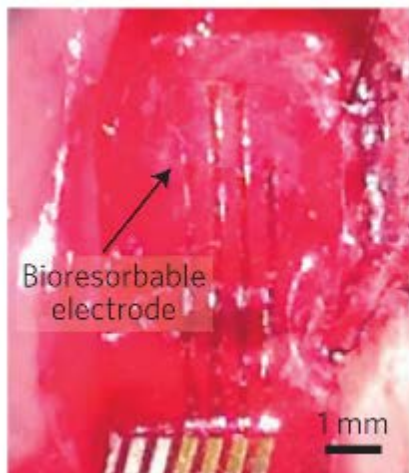
Mg resist

These labels are in red text with arrows pointing to specific components in the device images.

Science, 2012, 28, 1640 (Cover)

# TRANSIENT IMPLANTABLE DEVICES

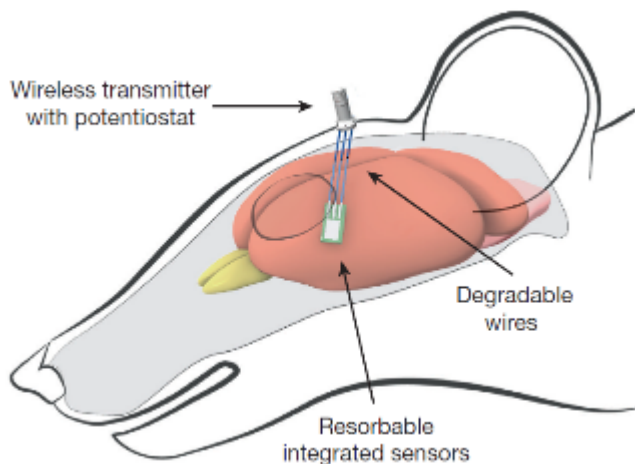
## Cerebral cortex spatiotemporal mapping



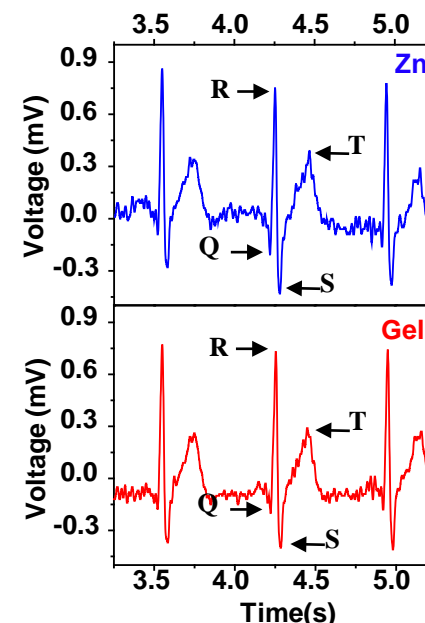
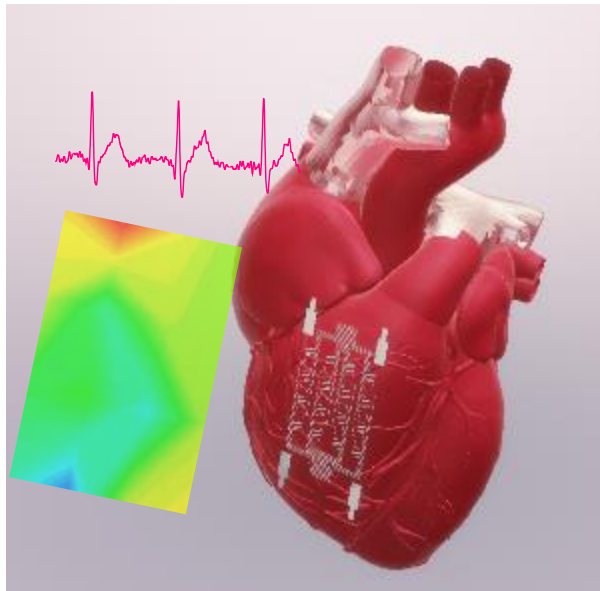
*Nat. Mater.* 15, 782 (2016)

## Low-cost transient sensors

### Brain monitor



*Nature*, 2016, 530, 71

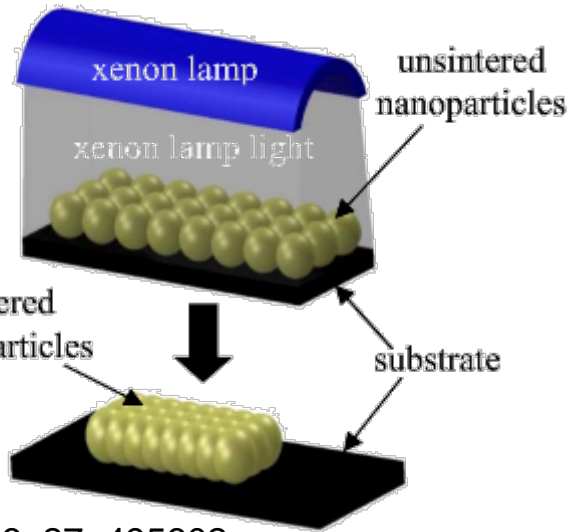


*ACS Appl. Mater. Interfaces* 10, 36664 (2018)

# LARGE SCALE AM W/ XENON FLASH

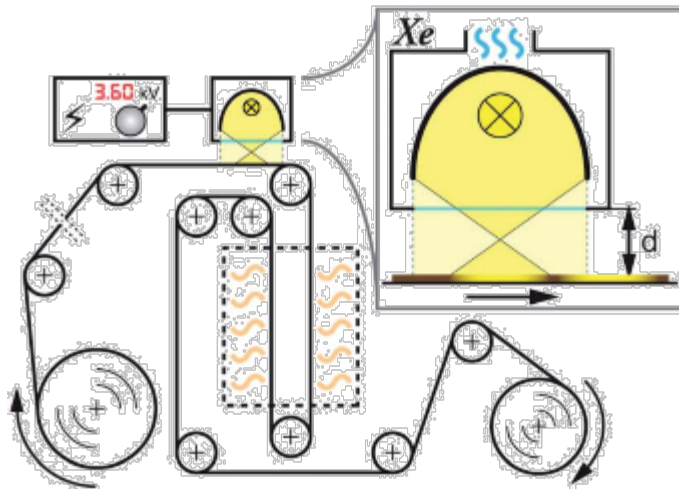
**Intense pulsed light sintering**

Fast and high energy (1000J within ms)



*Nanotechnology*, 2016, 27, 495602

**Large-scale, Roll-to-Roll**

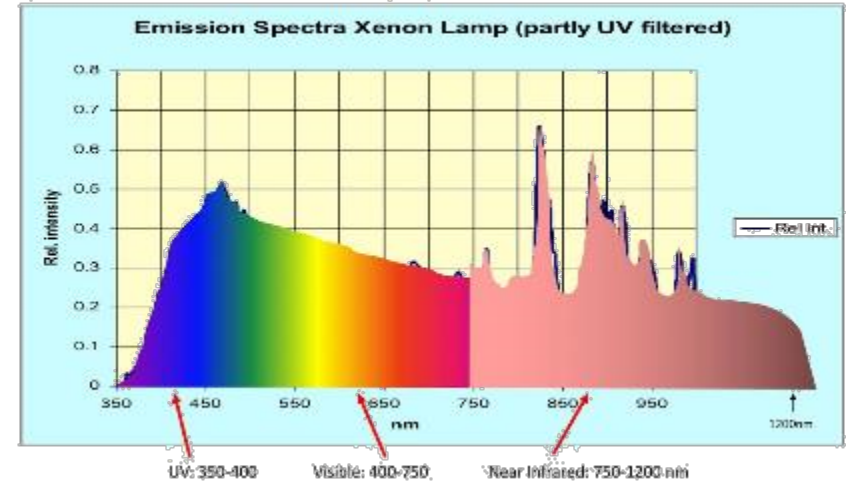


*J. Mater. Chem.*, 2012, 22, 15683



**Broad output spectra**

IPL flashlamp spectra Unfiltered



**Wide range of materials**

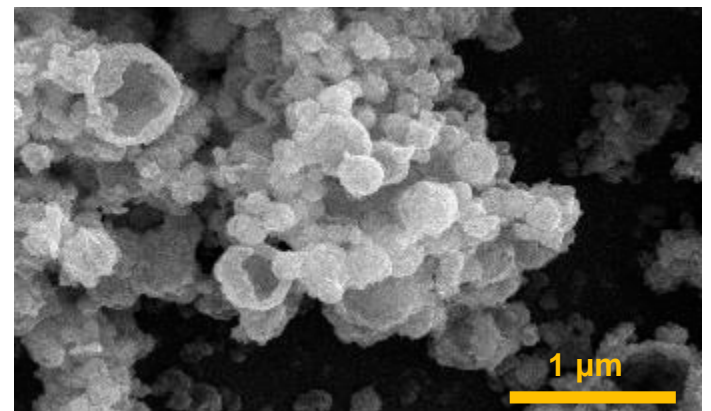
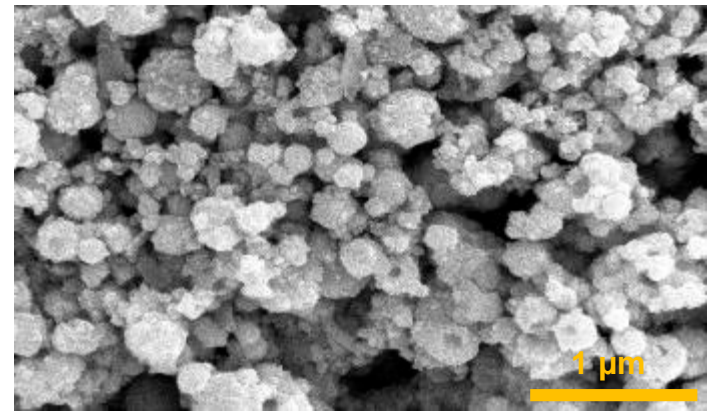
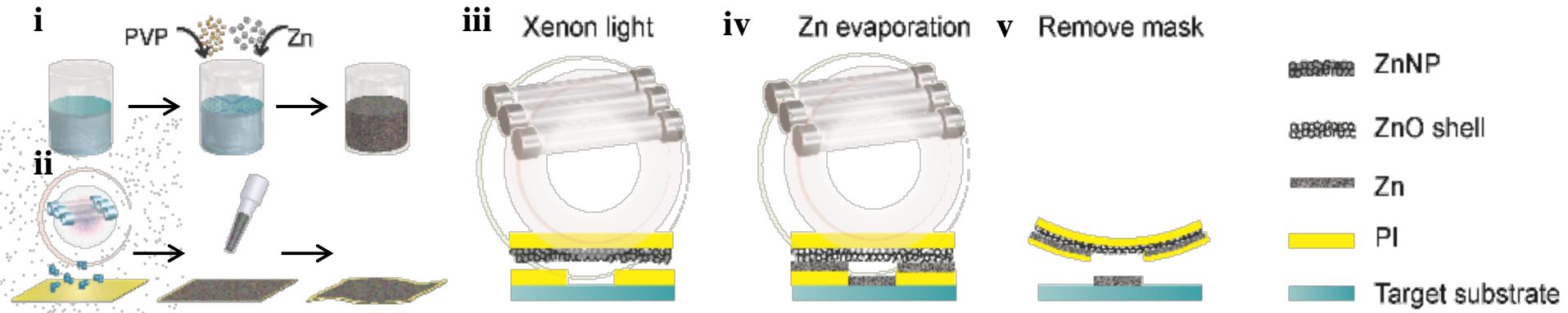
- Conductors (Zn NPs, Ag NPs/NWs/film, Au, Cu)
- Semiconductors (indium gallium zinc oxide, IGZO;  $\text{Cu}_2\text{ZnSnS}_4$ , CZTS)

On diverse substrates (glass, plastic, polymer)



*Small*, 2017, 13, 1700065

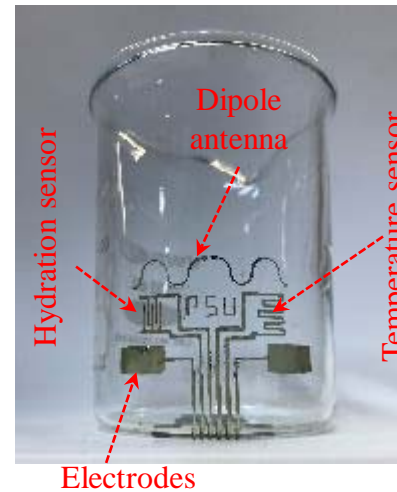
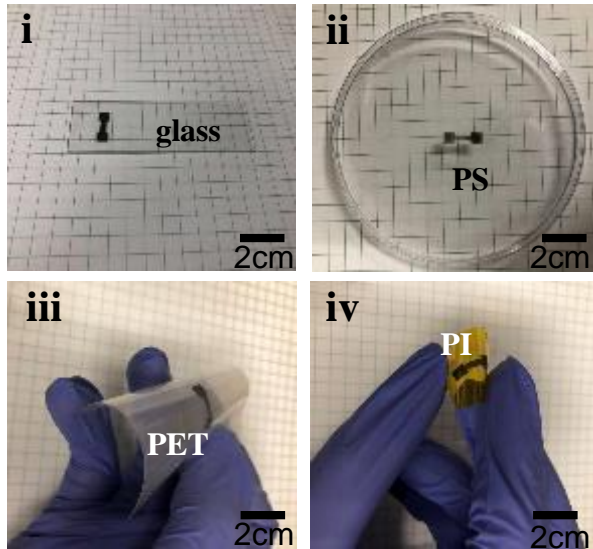
# 3D BIODEGRADABLE SENSORS



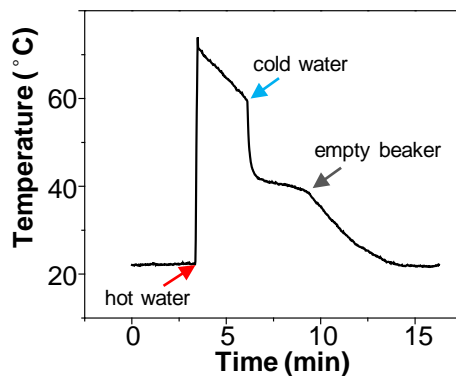
*Materials Today* 50, 24-34 (2021) (Front Cover)

# 3D BIODEGRADABLE SENSORS

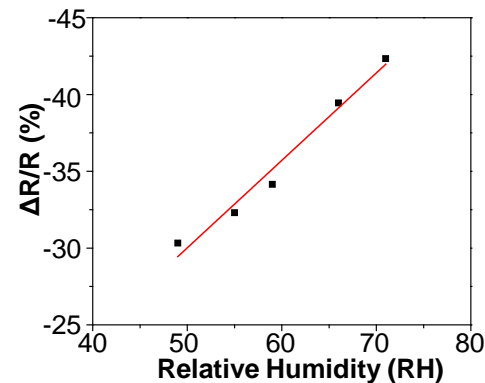
## Smart Internet-of-Things (IoT)



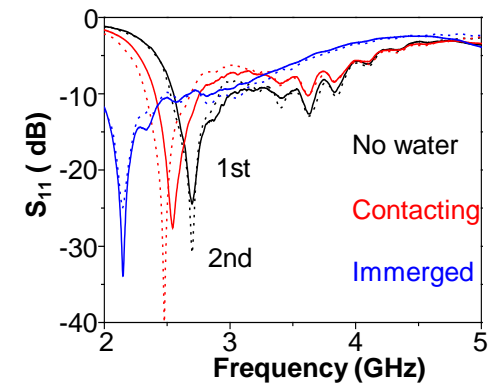
### Temperature sensor



### Humidity sensor

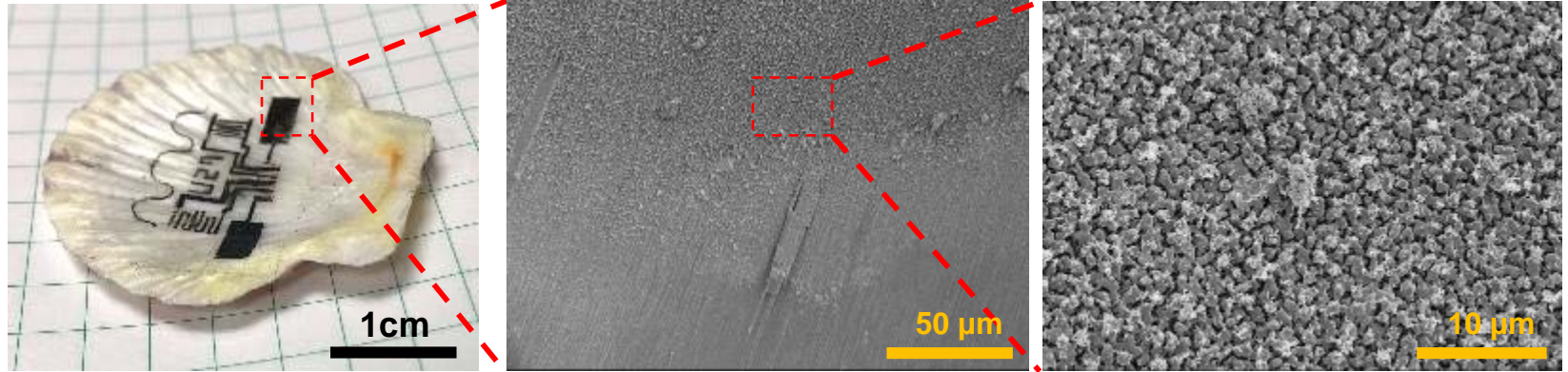


### Dipole antenna

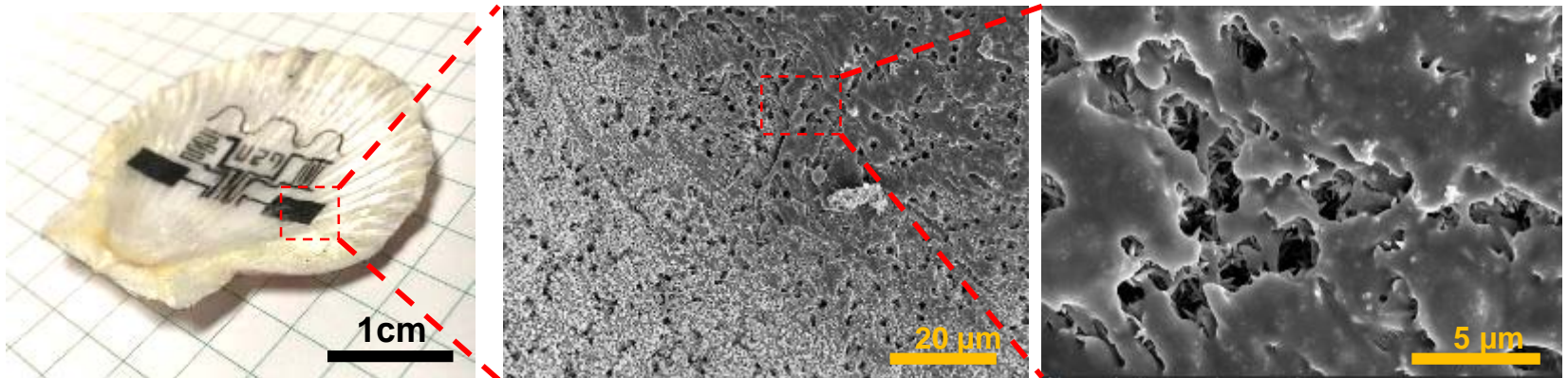


# CIRCUITS ON COMPLEX SEASHELL

## Zn layer patterned on the seashell

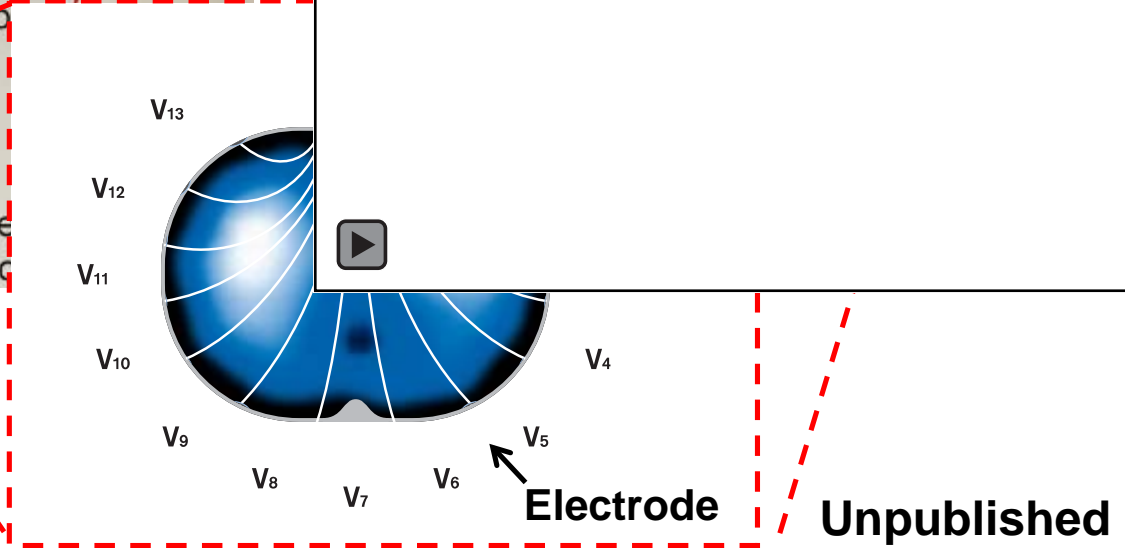
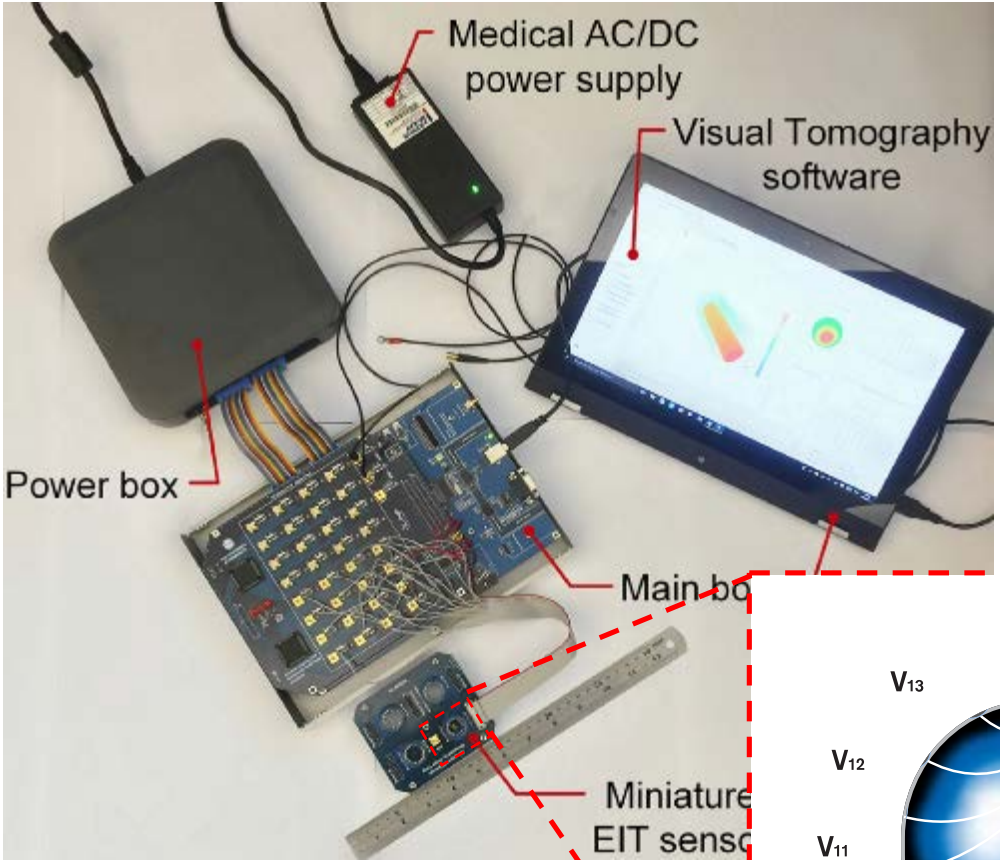


## Ag layer on the seashell by a single-replacement reaction

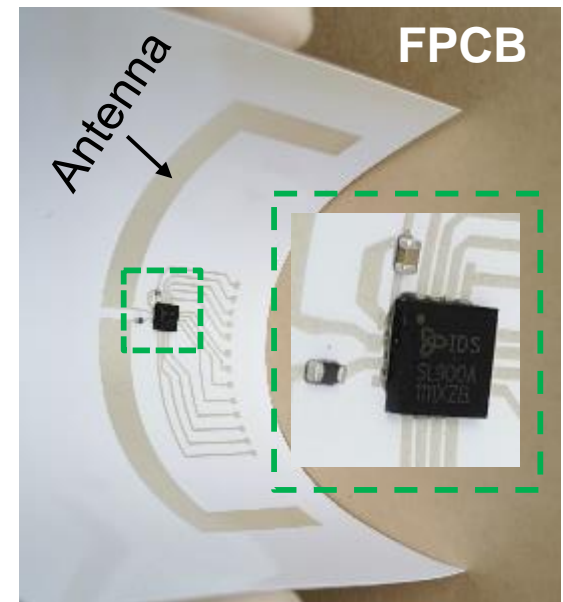
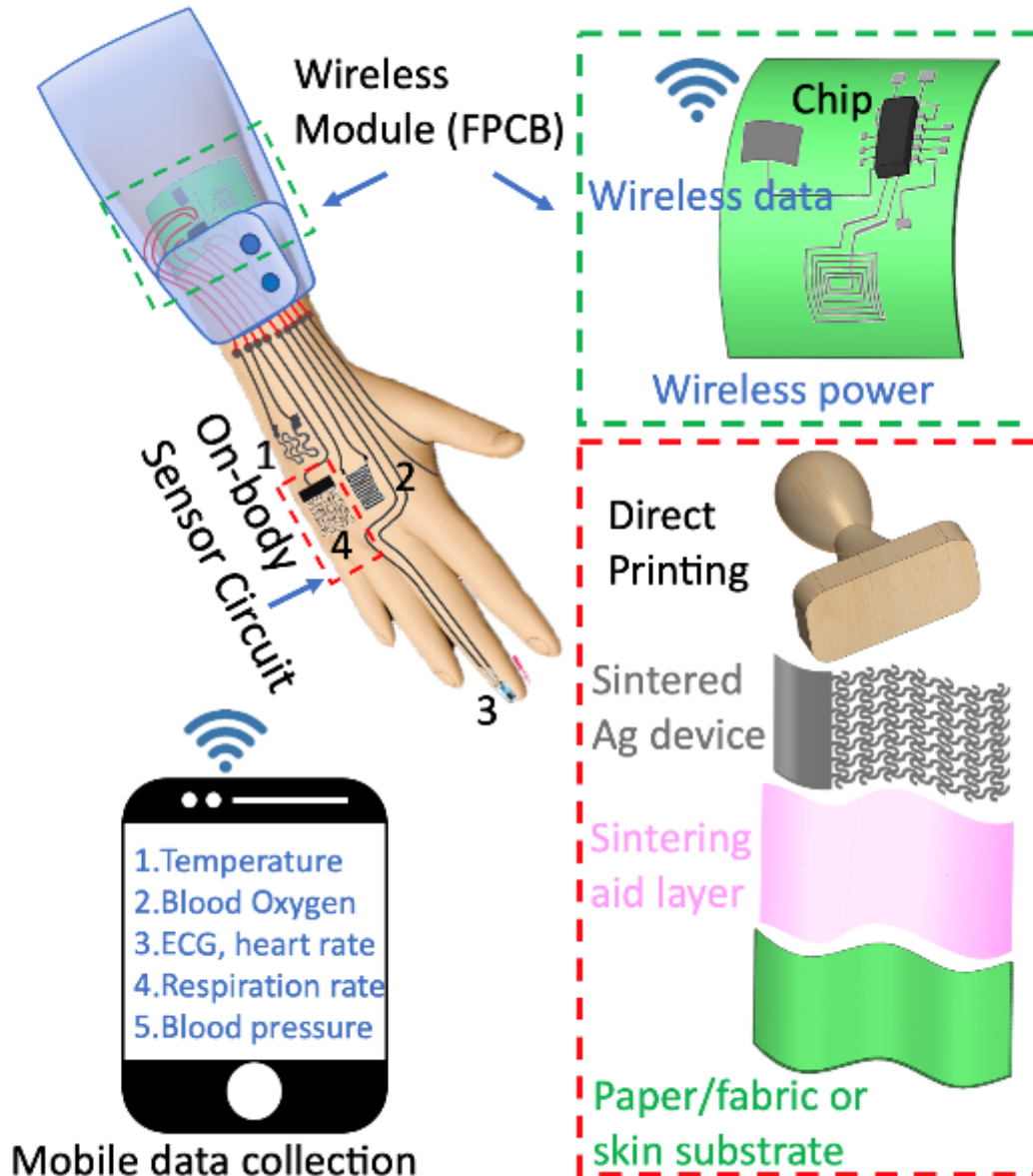




# ELECTRICAL IMPEDANCE TOMOGRAPHY



# BODY AREA SENSOR NETWORK

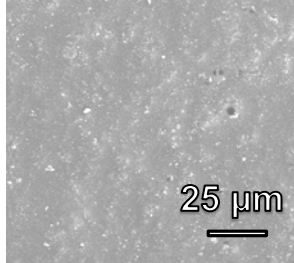
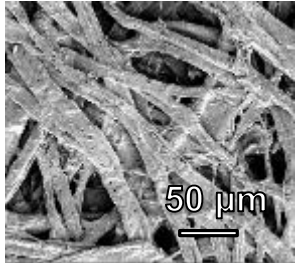


# SIMPLE FABRICATION PROCESS

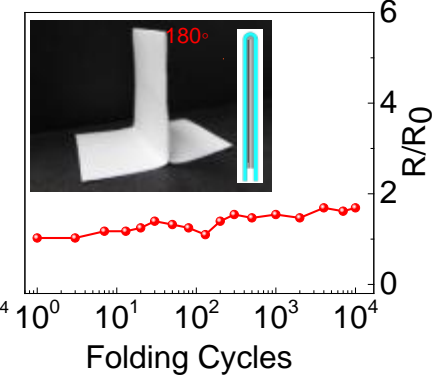
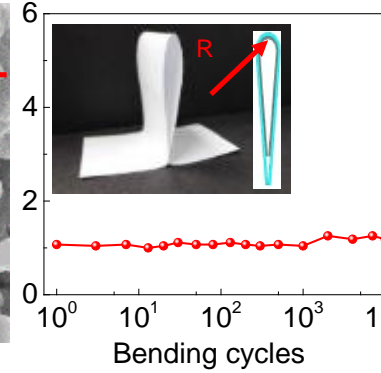
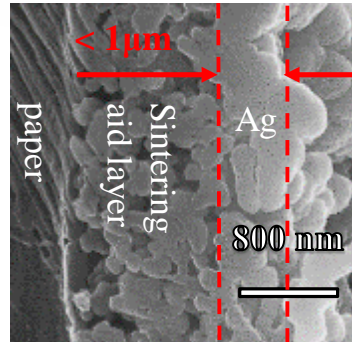
## Reduced roughness

Before

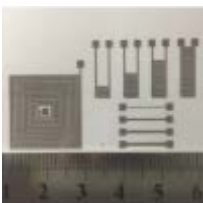
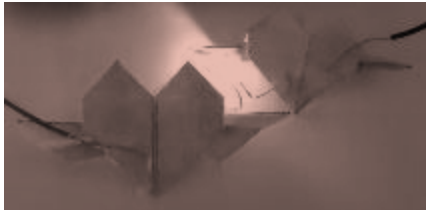
After  
sintering aid layer



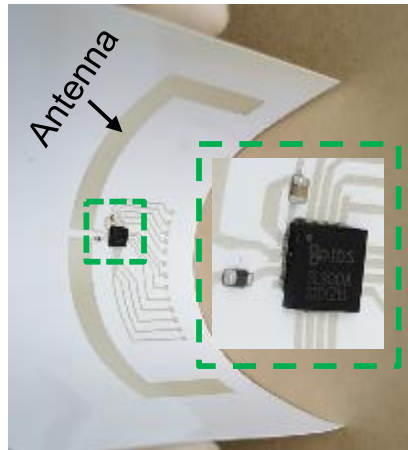
## Interfacial sintering at room temperature



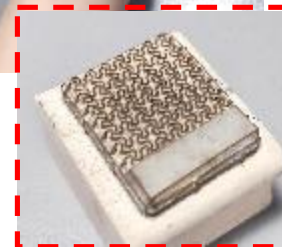
## 3D origami paper structures



Flexible printed  
circuit board (FPCB)



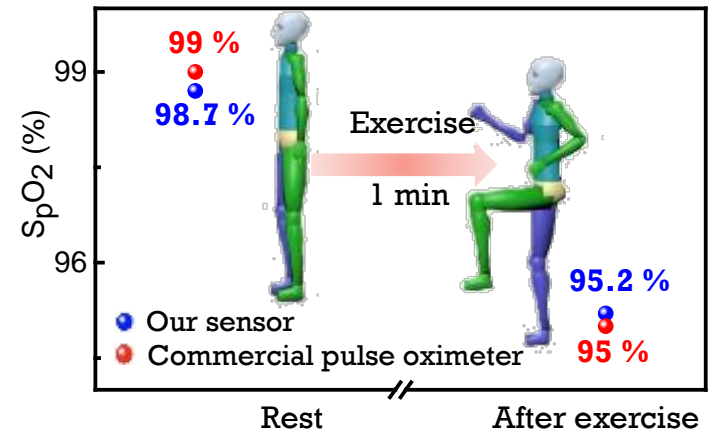
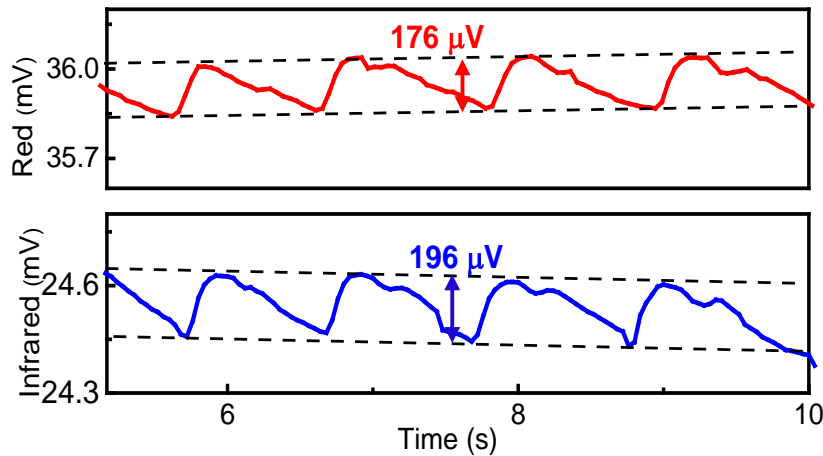
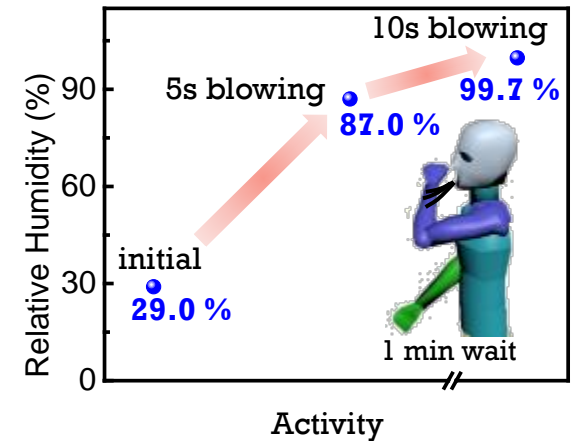
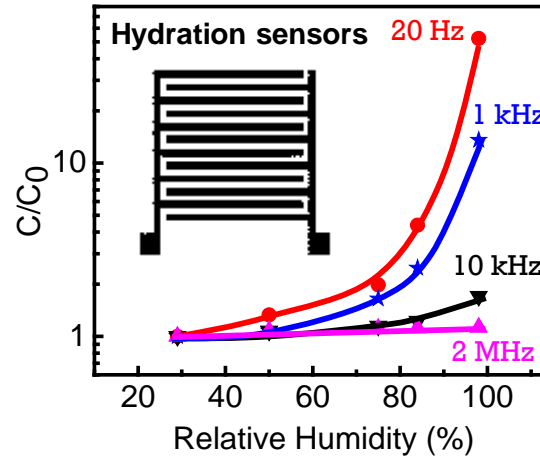
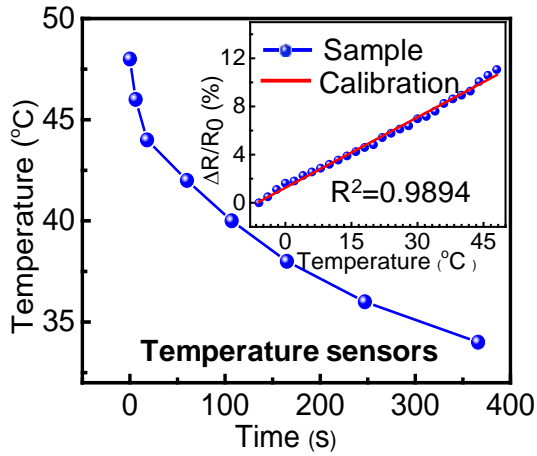
## Stamping on the textured skin surface



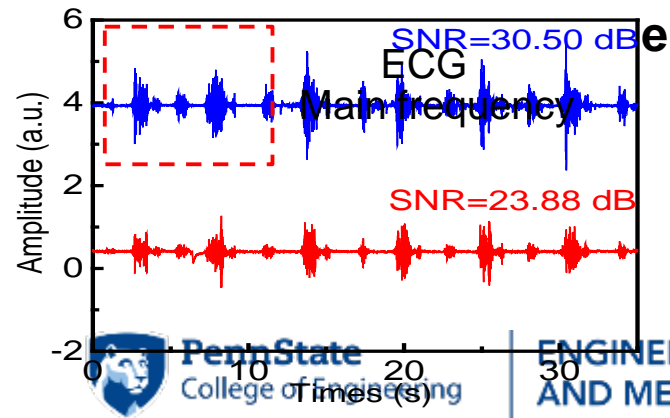
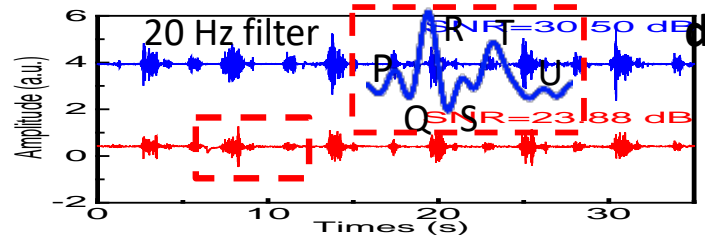
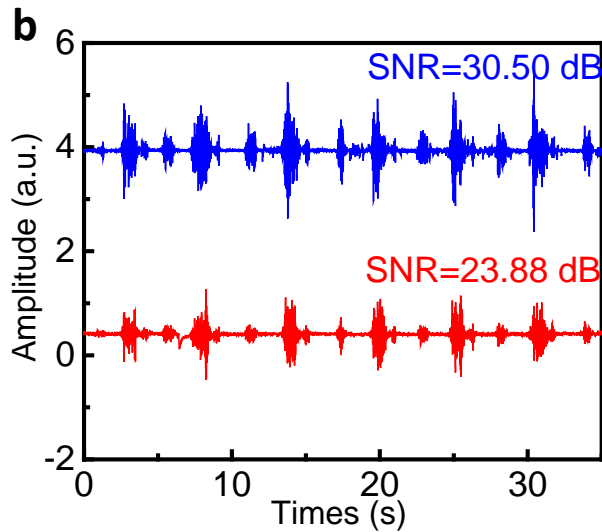
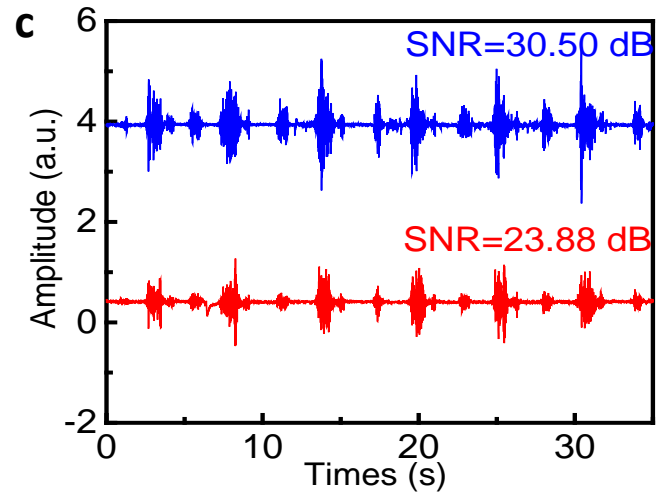
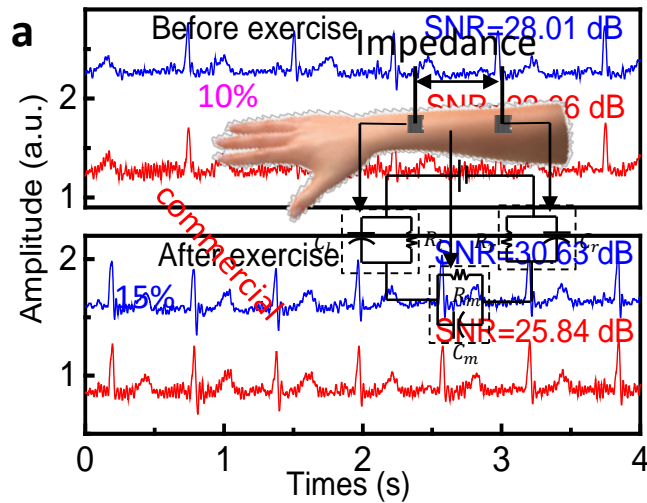
Drying with  
hairdryer



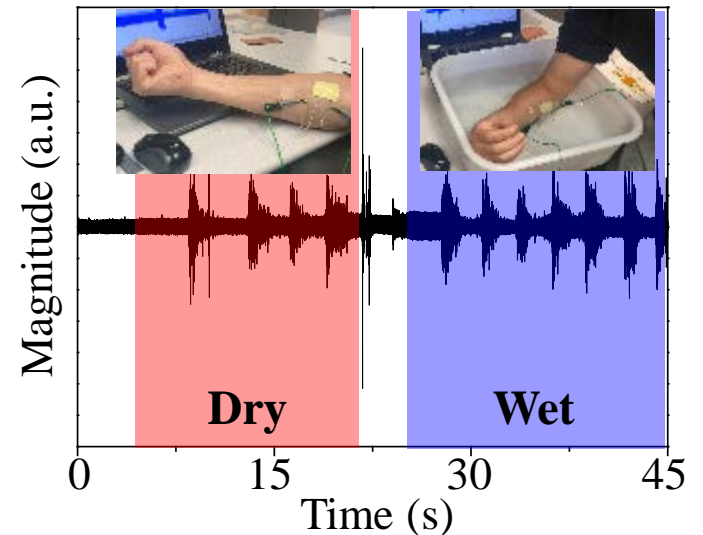
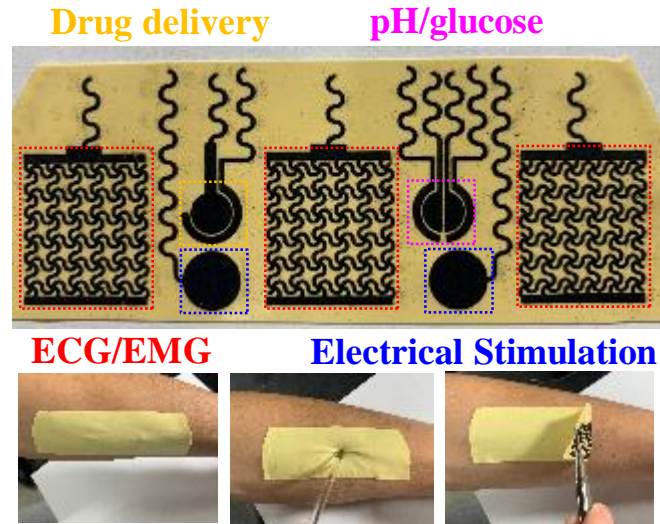
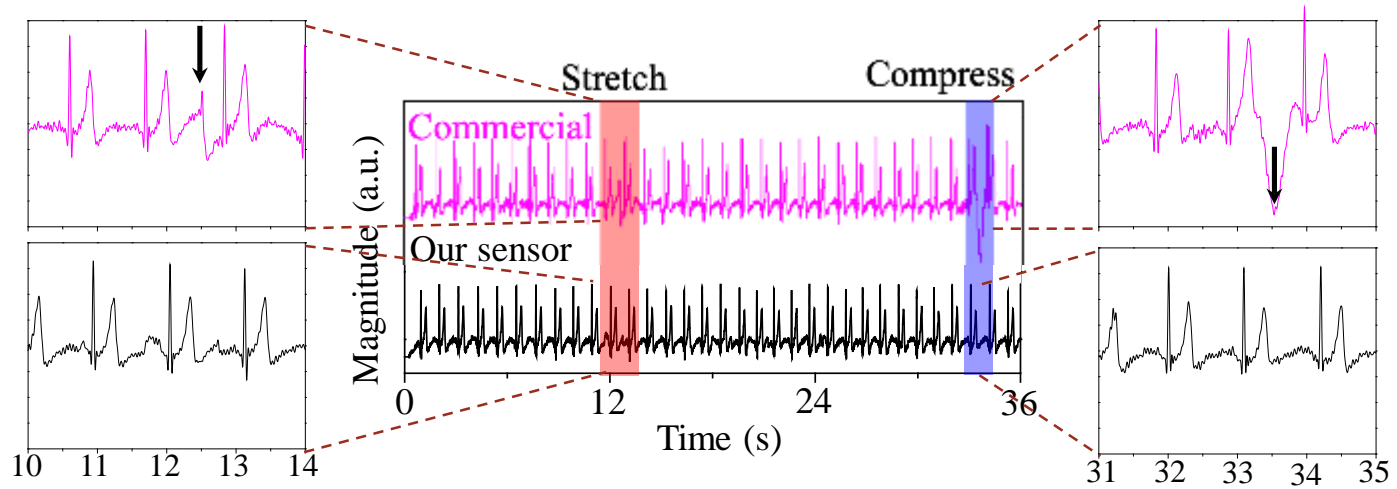
# ON-BODY SENSORS



# ENHANCED CONTACT QUALITY



# MOTION ARTIFACT-FREE SENSING

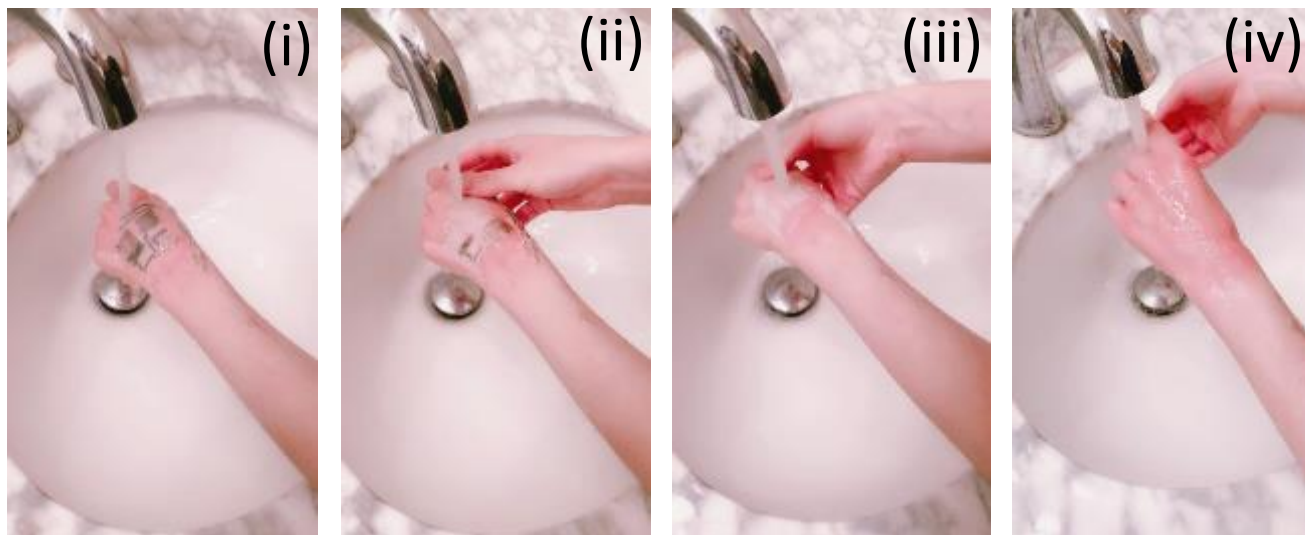


Unpublished

# EASY REMOVAL OF SENSORS



Removal of the device from the skin in warm water flow



# FUTURE PERSPECTIVE



**Wireless  
Self-powered**

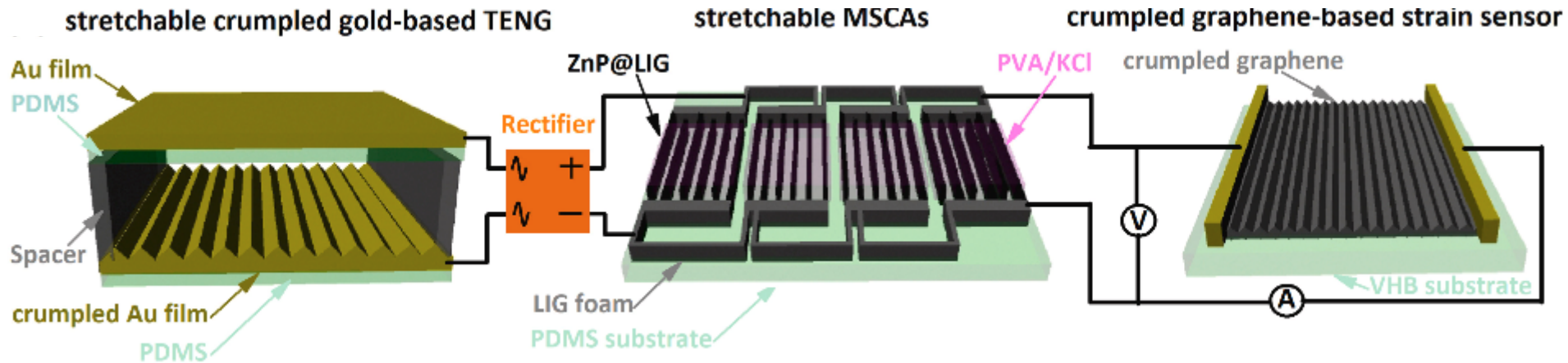


# SELF-POWERED STRETCHABLES

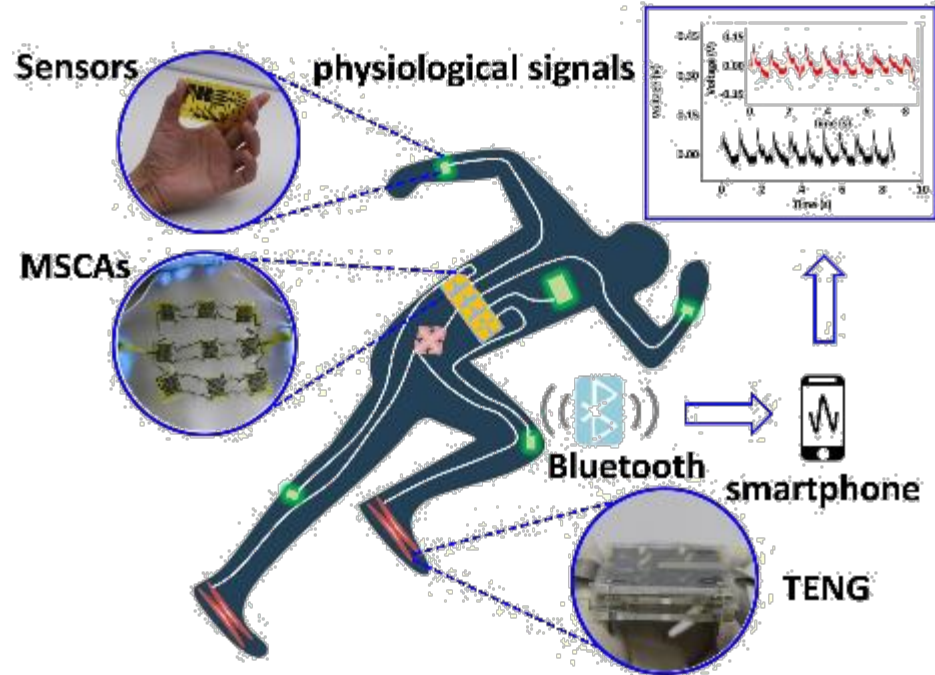
## Stretchable ZnP@LIG supercapacitor



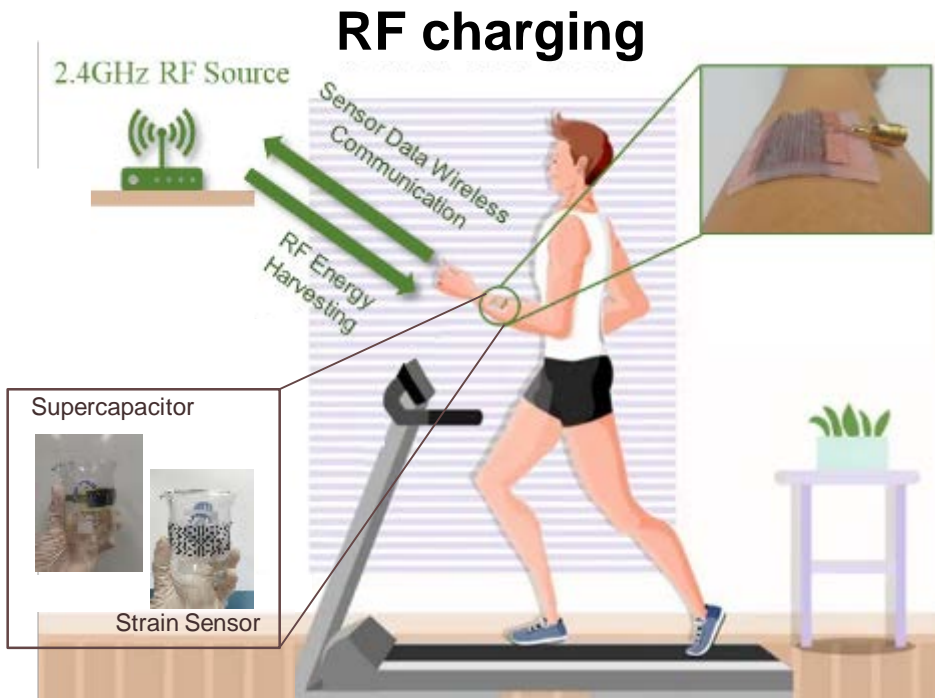
*Nano Energy* 81, 105609 (2021)



# STANDALONE STRETCHABLE SYS.

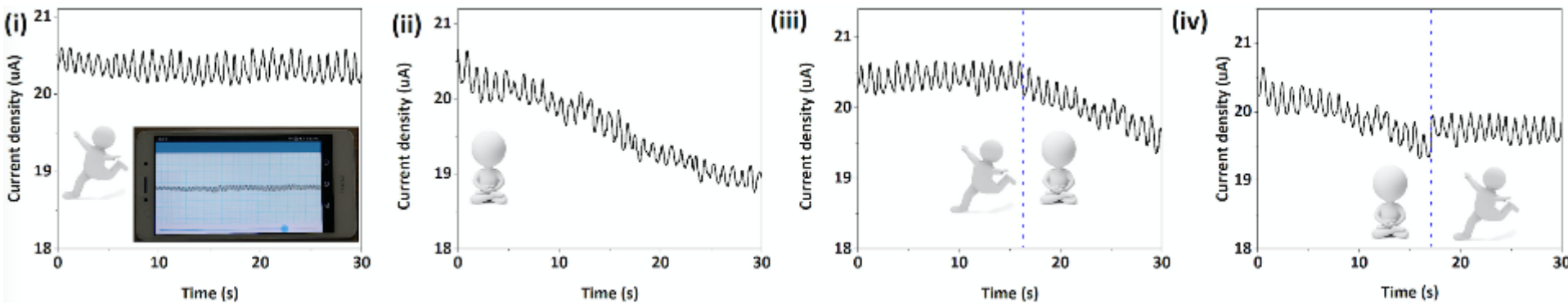


*Appl. Phys. Rev.* 9, 011413 (2022), **Cover**



*Nano Energy* 96, 107069 (2022)

## Pulse sensor powered by the self-charging units

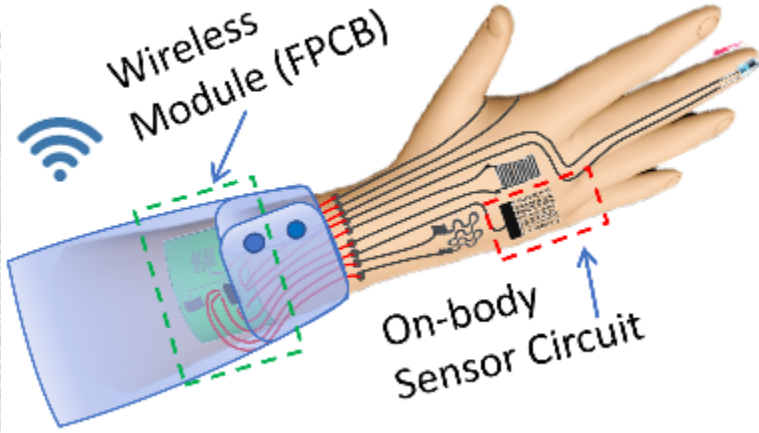


# THANK YOU FOR YOUR ATTENTION!

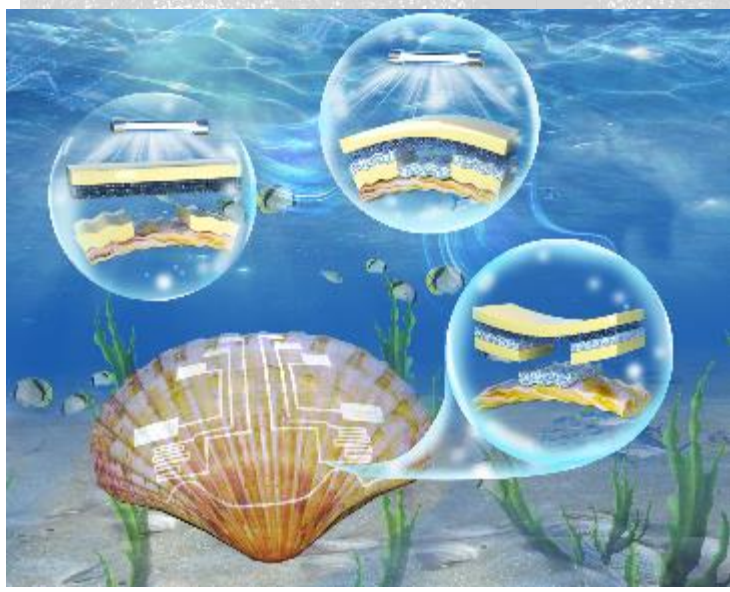
LIG composites



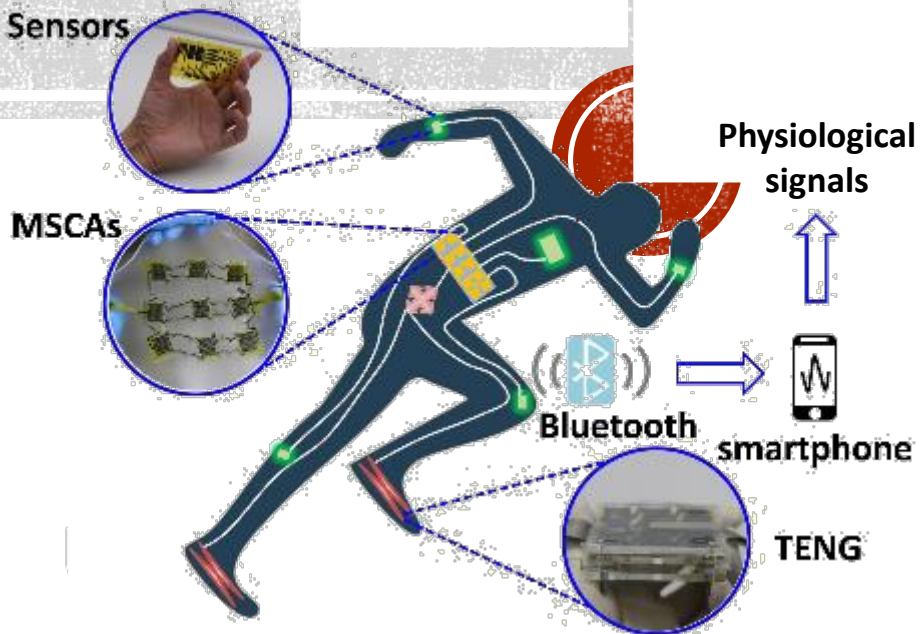
Body area sensor network



3D freeform fabrication



Standalone stretchable platform





Questions?

Thank you for  
attending!

We would love your  
feedback



This webinar recording will be found at:

<https://www.cneu.psu.edu/webinars/>

<https://www.youtube.com/@nano4me>