

# Soft Electronics for the Human Body

---

1) Epidermal Electronics

2) Biodegradable Electronics

***John A. Rogers -- University of Illinois at Urbana/Champaign  
Departments of Materials Science and Engineering,  
Electrical and Computer Engineering, Bioengineering  
Mechanical Science and Engineering, and Chemistry  
Beckman Institute for Advanced Science and Technology  
Seitz Materials Research Laboratory***

Contact: [jrogers@illinois.edu](mailto:jrogers@illinois.edu); (217) 244-4979; <http://rogers.mse.uiuc.edu/>

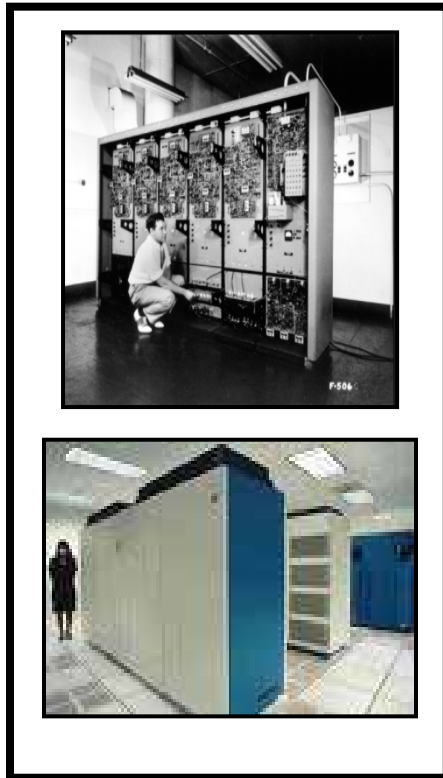
# The Dominant Future for Electronics: *Smaller, Faster, Cheaper*

Past



Present

Future



***Industrial***



***Personal***



***Smaller, Faster  
Cheaper***

# An Alternative Future for Electronics: *Stretchy, Curvy, Bio-Integrated*

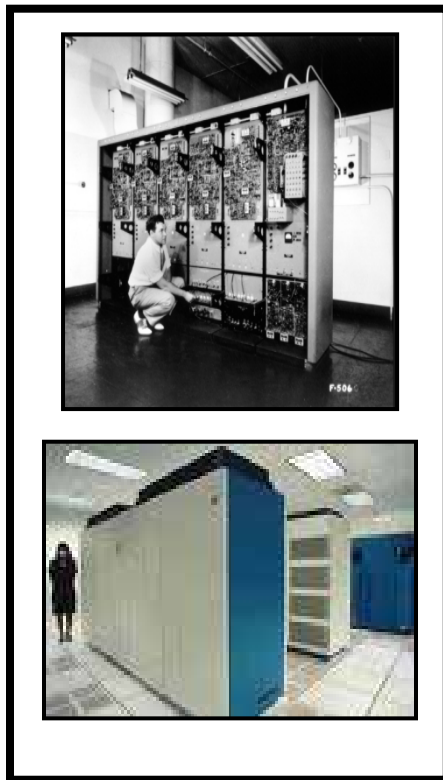
Past



Present



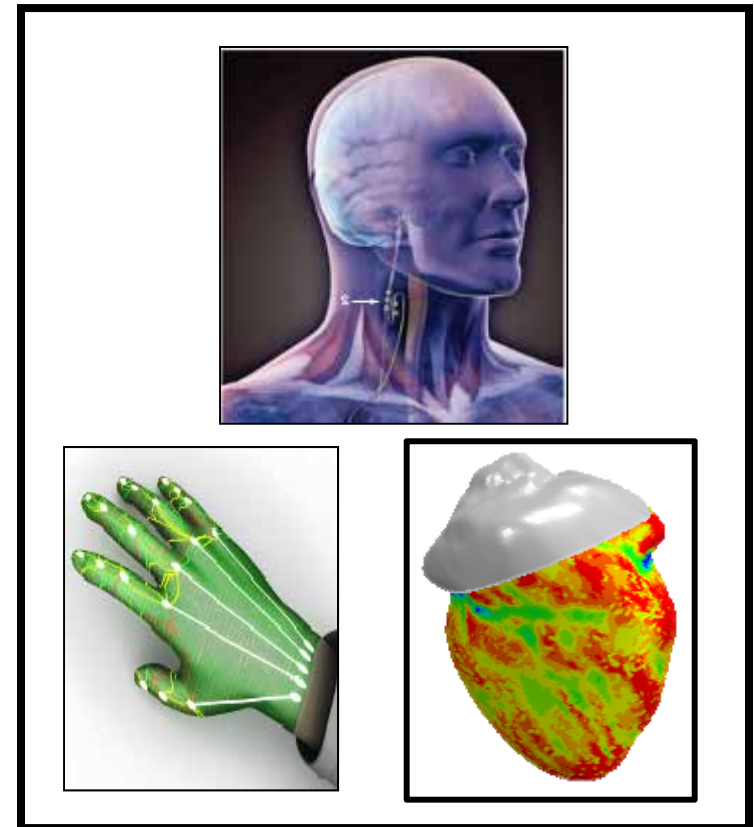
Future



***Industrial***



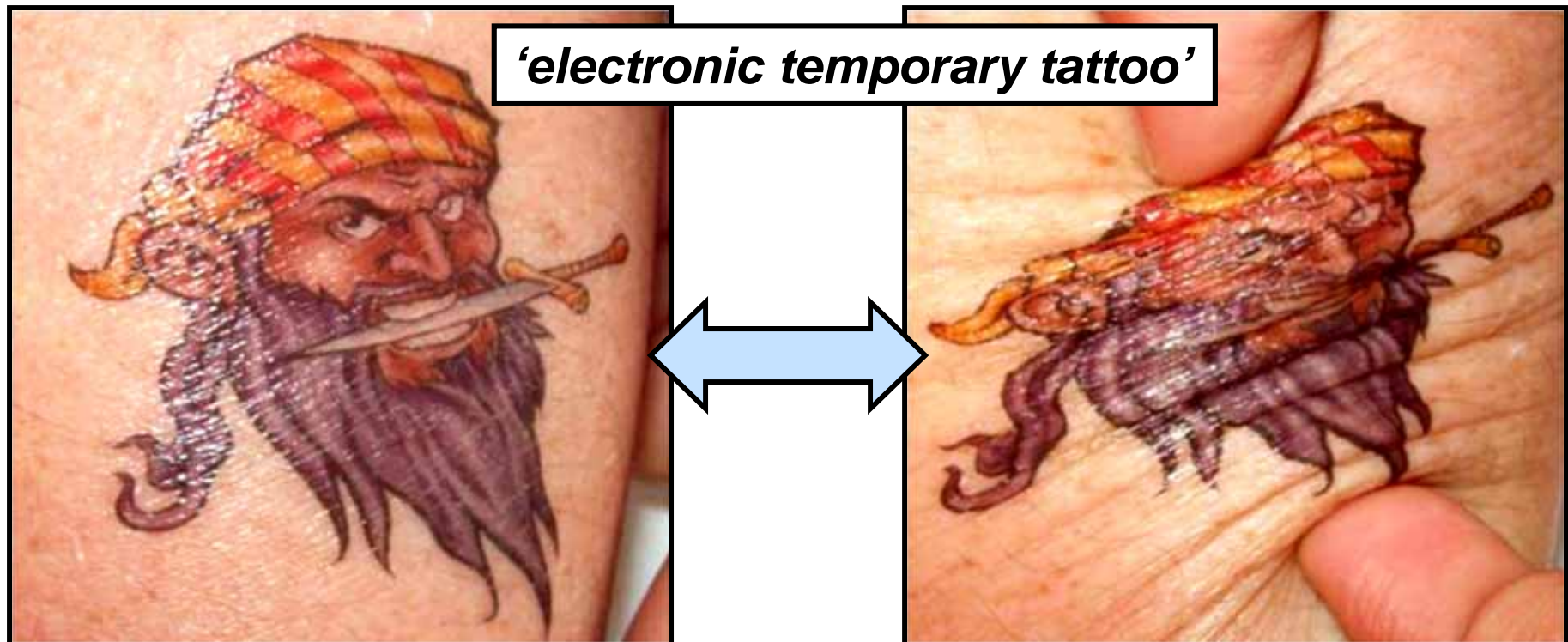
***Personal***

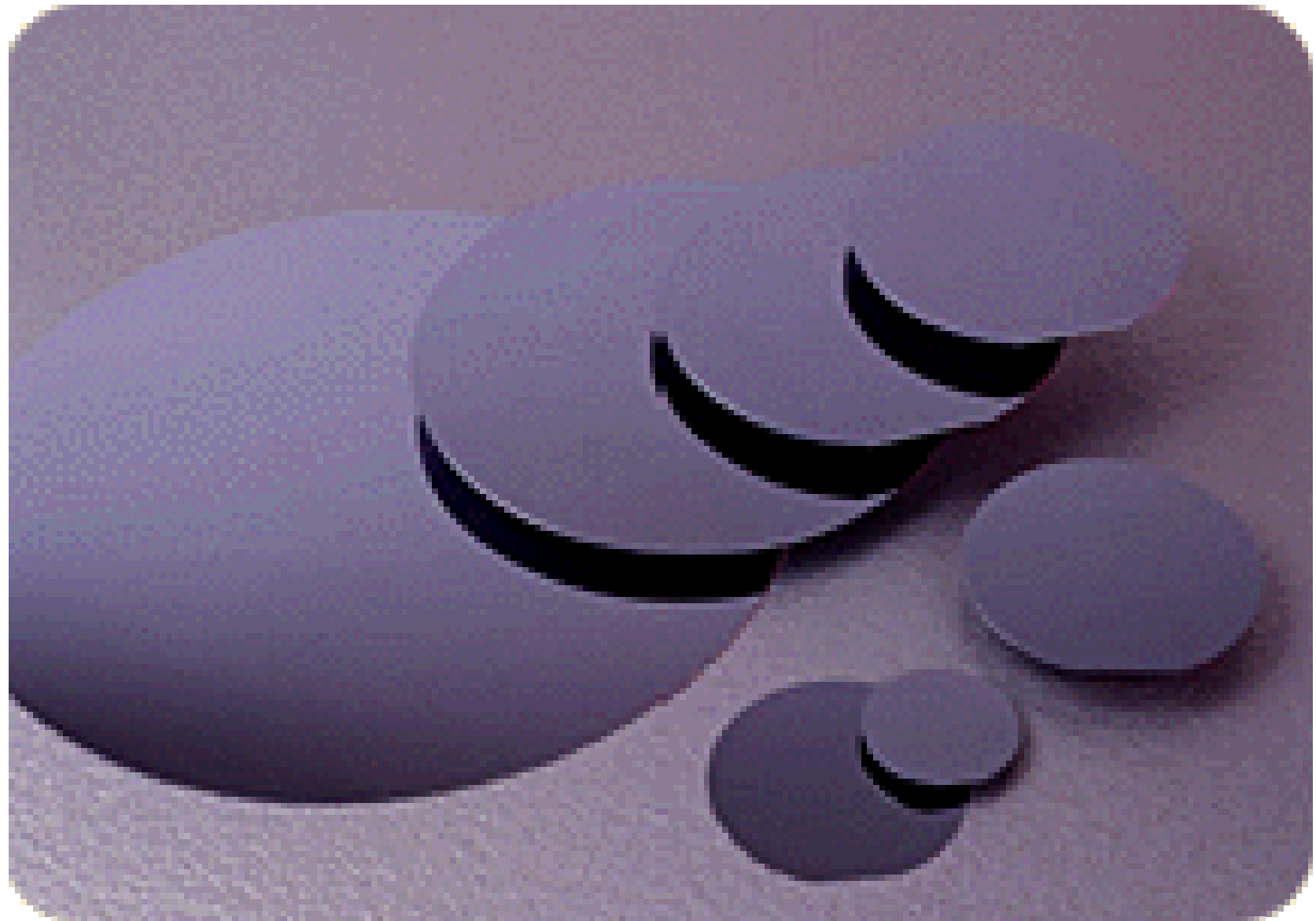


***Bio-Integrated***

## New Concept: 'Epidermal' Electronics

- 1) Ultra-thin ( $\sim 5 \mu\text{m}$ ), ultra-light ( $\sim 1 \text{ mg/cm}^2$ )
- 2) Ultra-low modulus ( $\sim 5 \text{ kPa}$ ), stretchable (30%)
- 3) Air/water permeable; waterproof

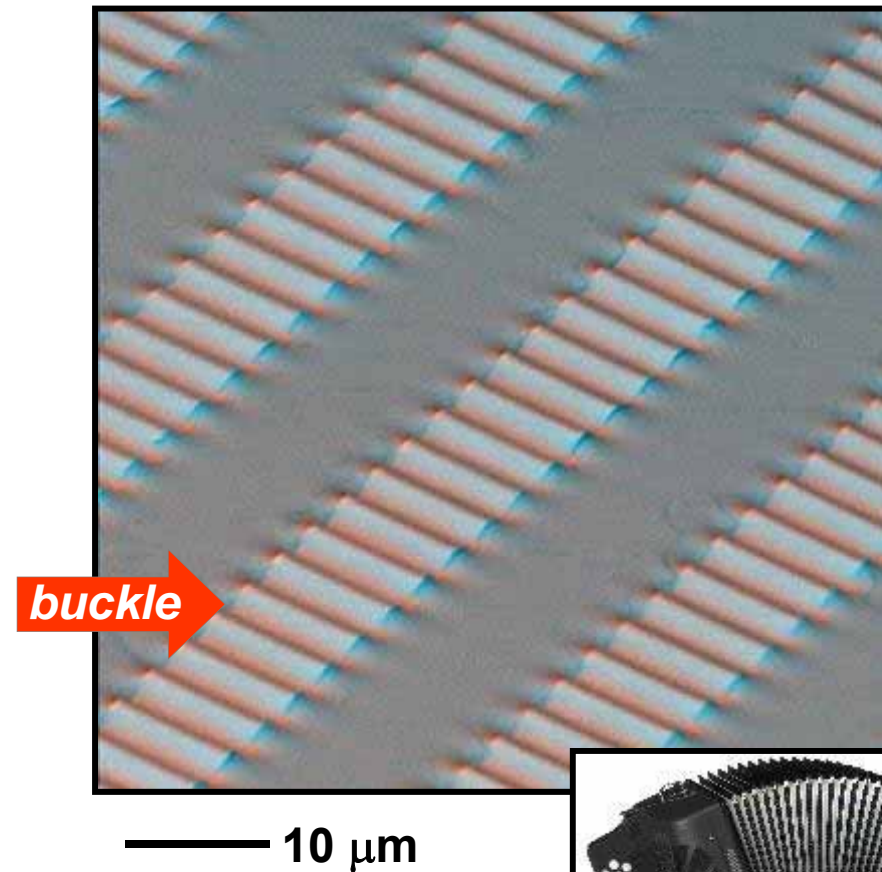
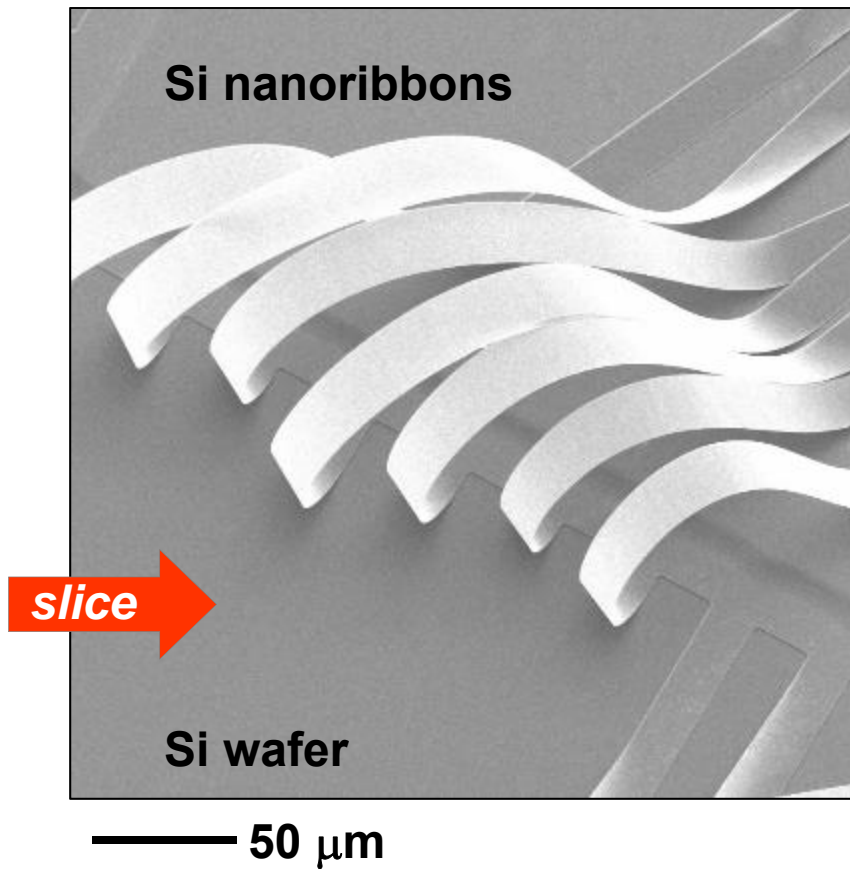






## Stretchable Silicon

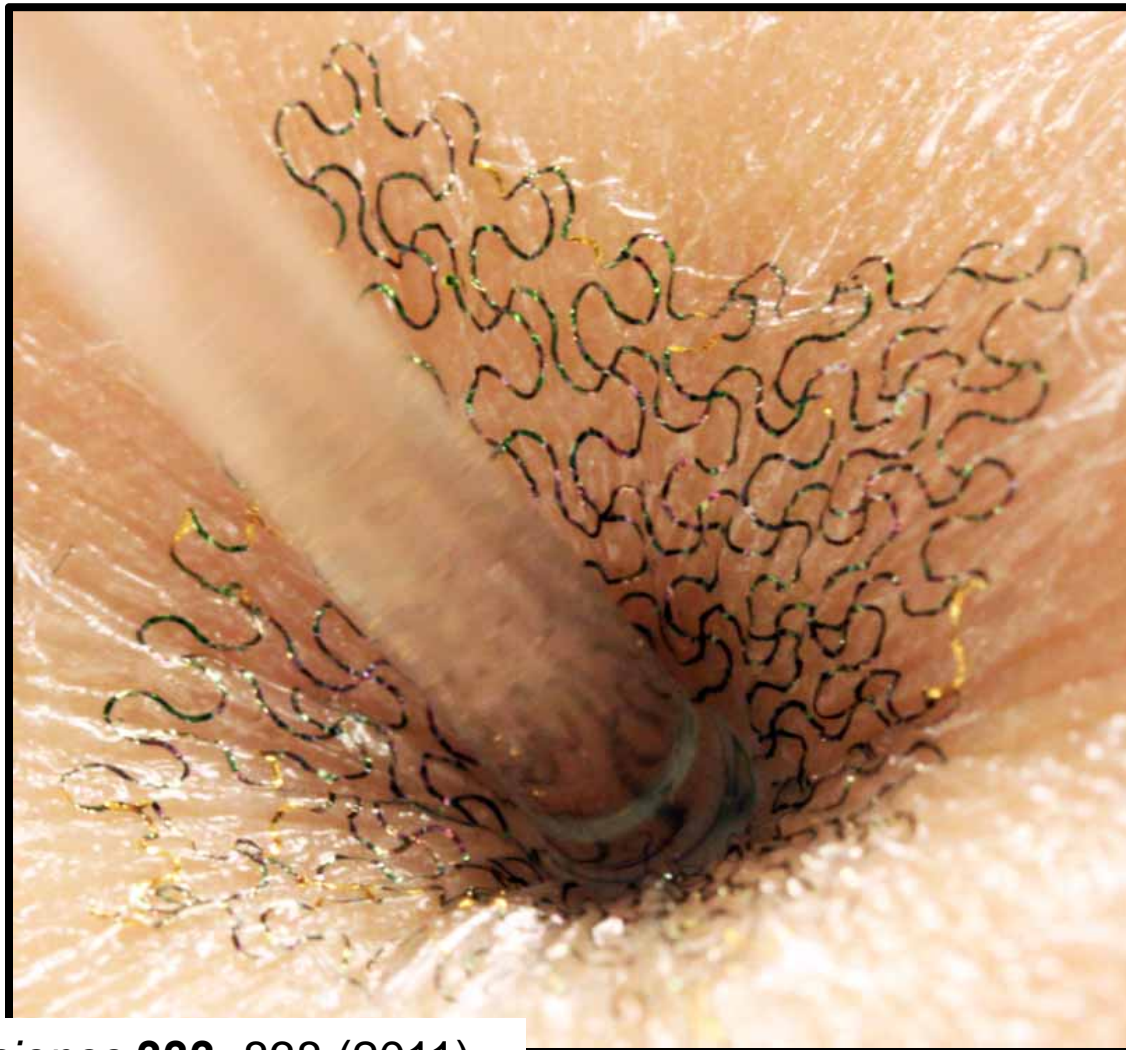
(1): Thin -- *Flexible* → (2): Wavy -- *Stretchable*



*Science* **311**, 208 (2006); *PNAS* **104**, 15607 (2007).

## Epidermal Electronics on Skin, and Free-Standing

### Skin Mounted, Deformed



*Science* **333**, 838 (2011).

### Free Standing



— 3 mm





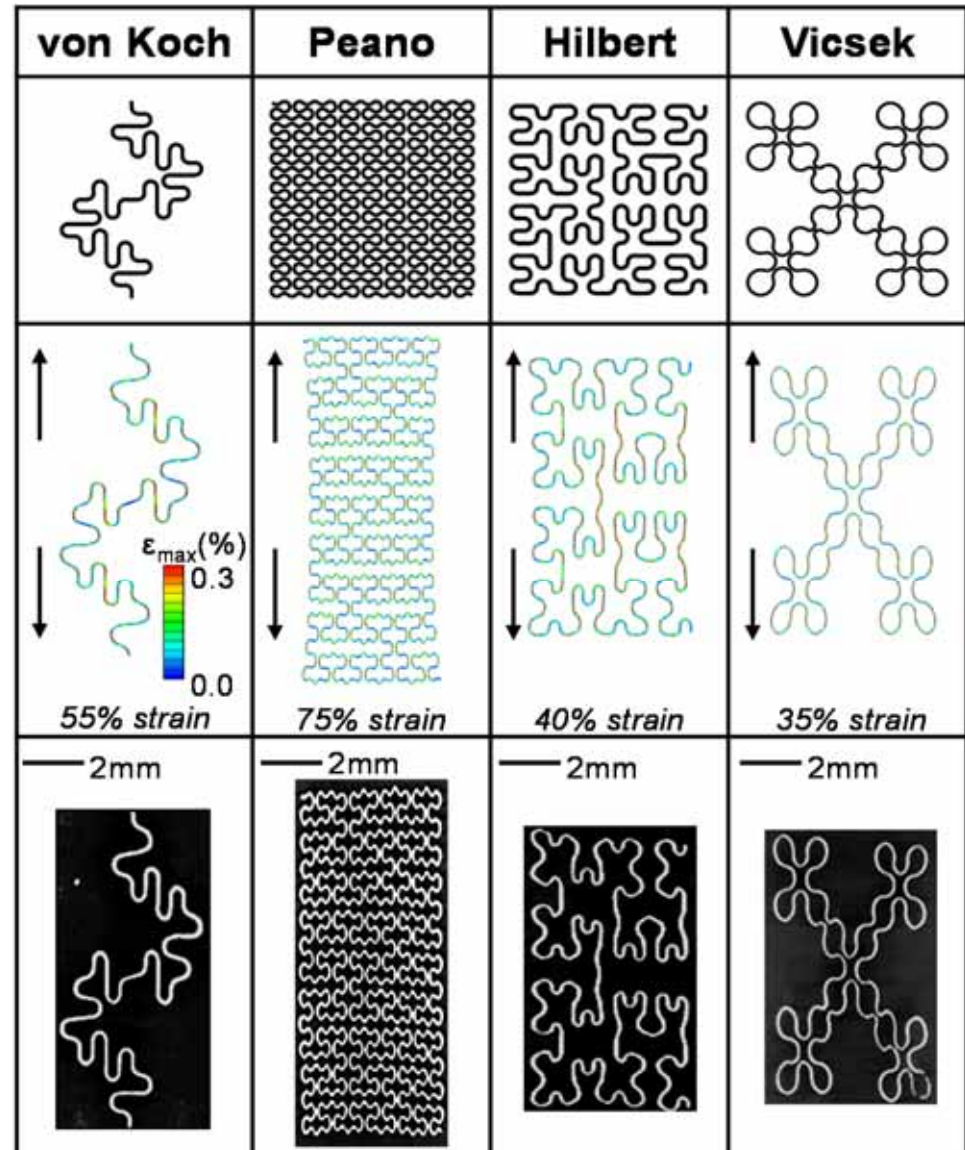
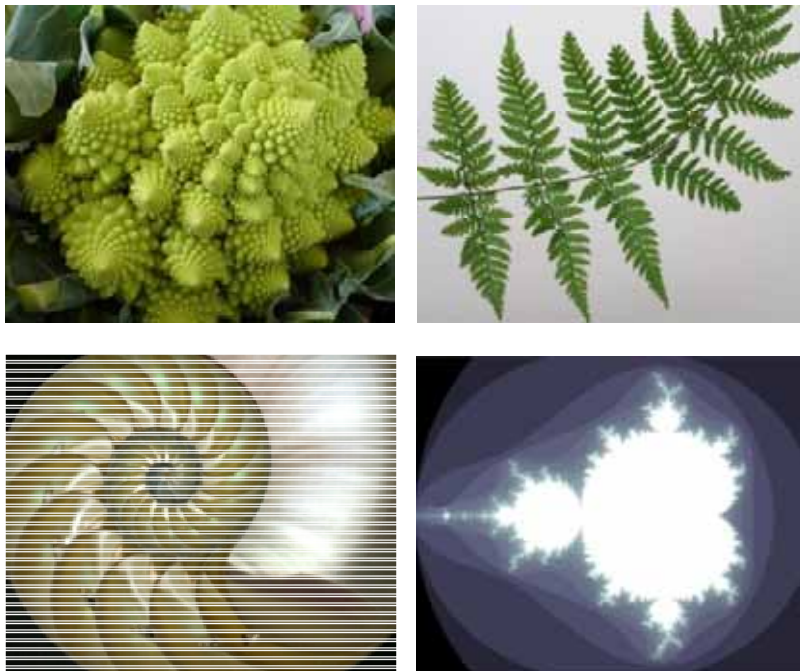
1.0kV 8.3mm x100 SE(M)

500um



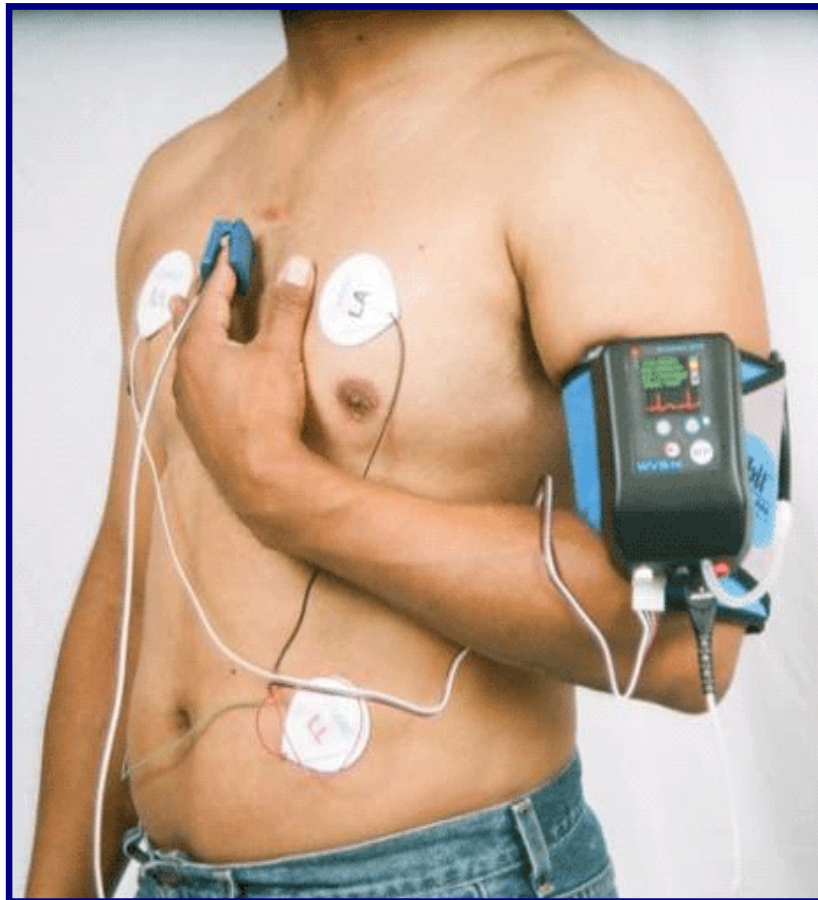
# Fractal Layouts – Natural and Engineered Systems

Fractals are a class of geometries defined by self-similarity

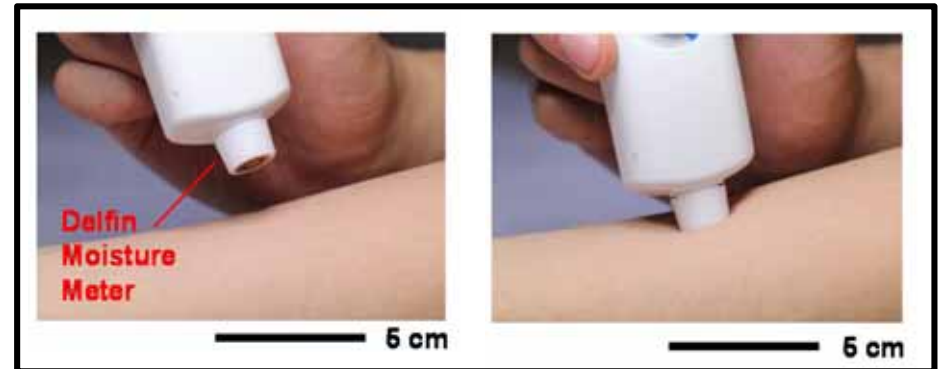


# Clinical Standard Measurements Through The Skin

## Electrocardiography



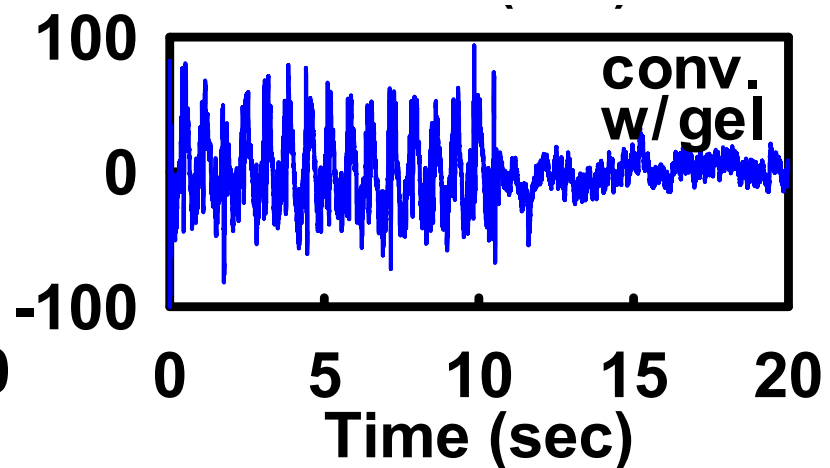
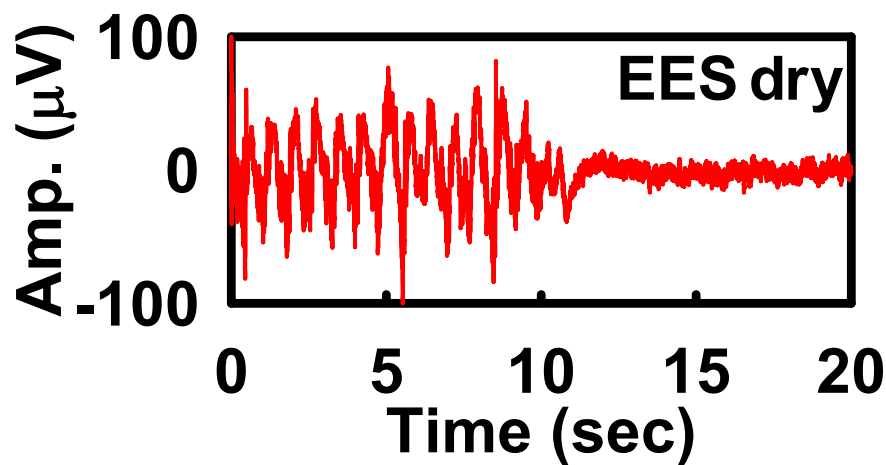
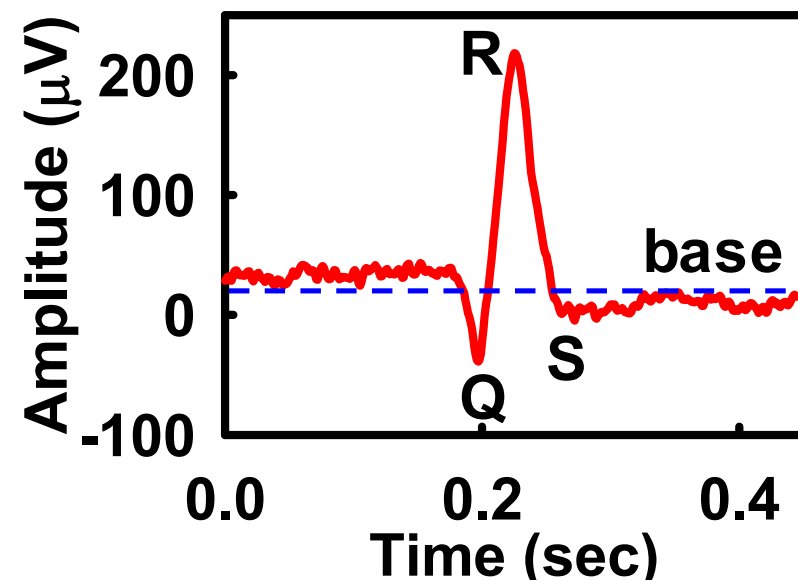
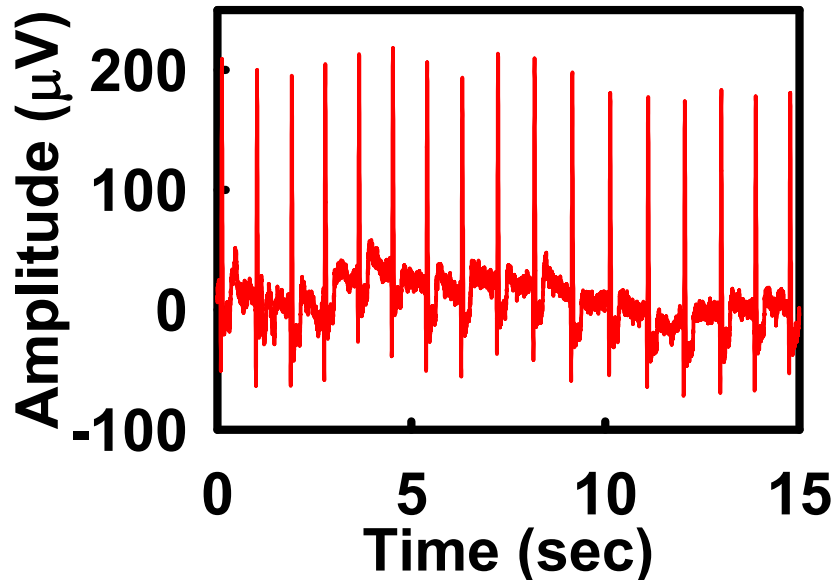
## Hydration



## Tonometry (pressure)

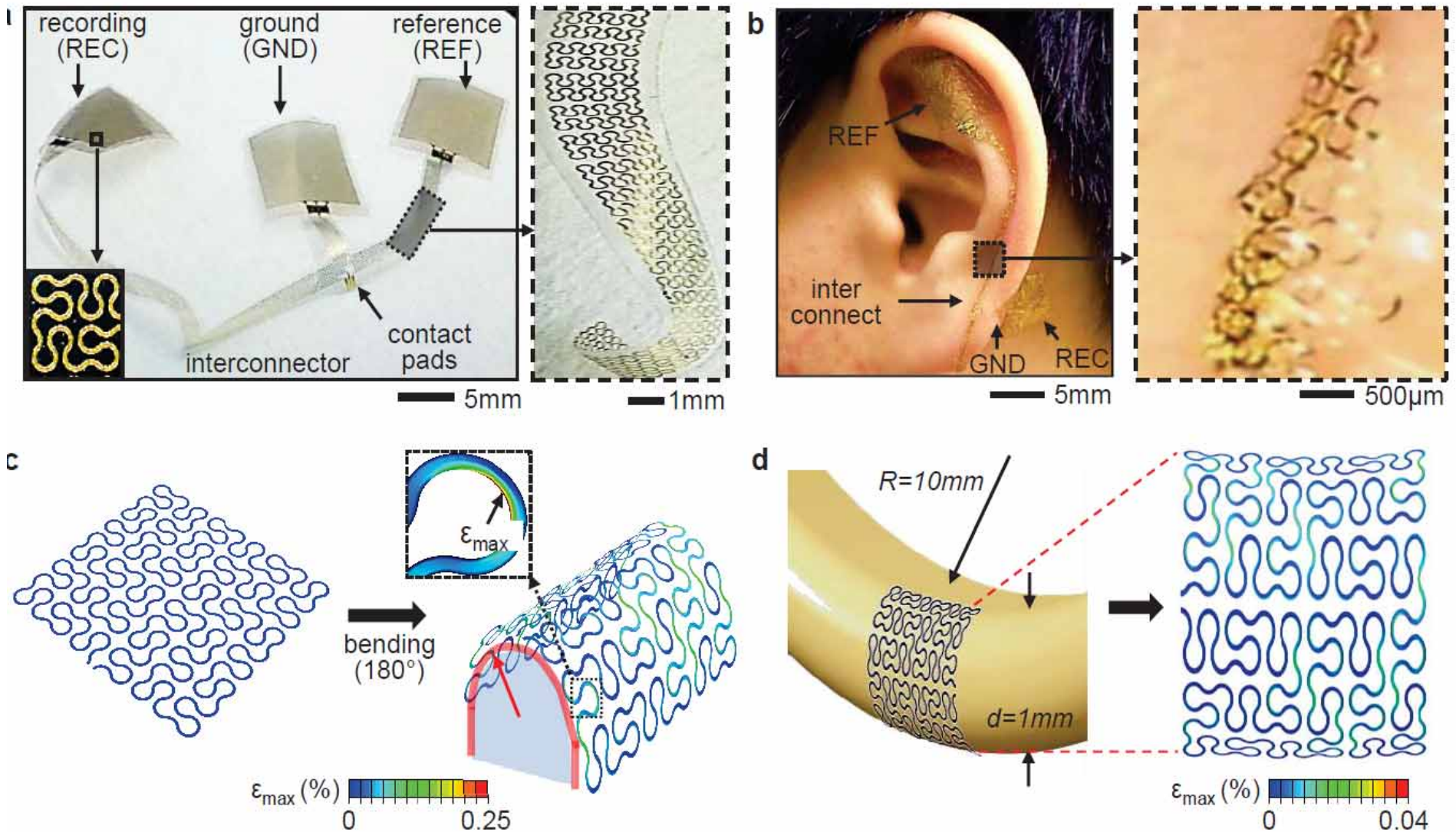


# Measuring EKG, Forearm EMG via EES (w/ Coleman)



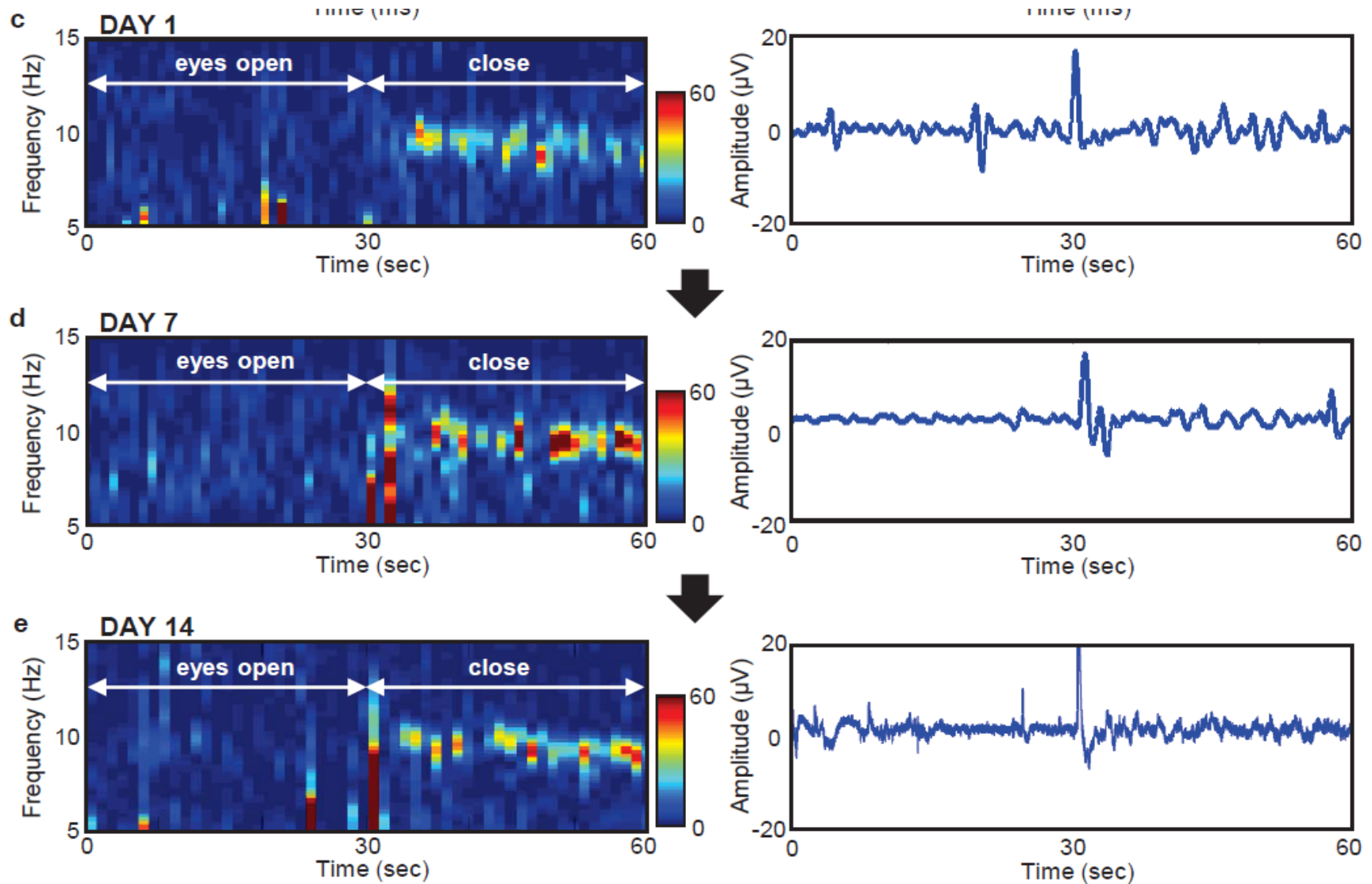


# Epidermal Electronics for the Auricle -- EEG



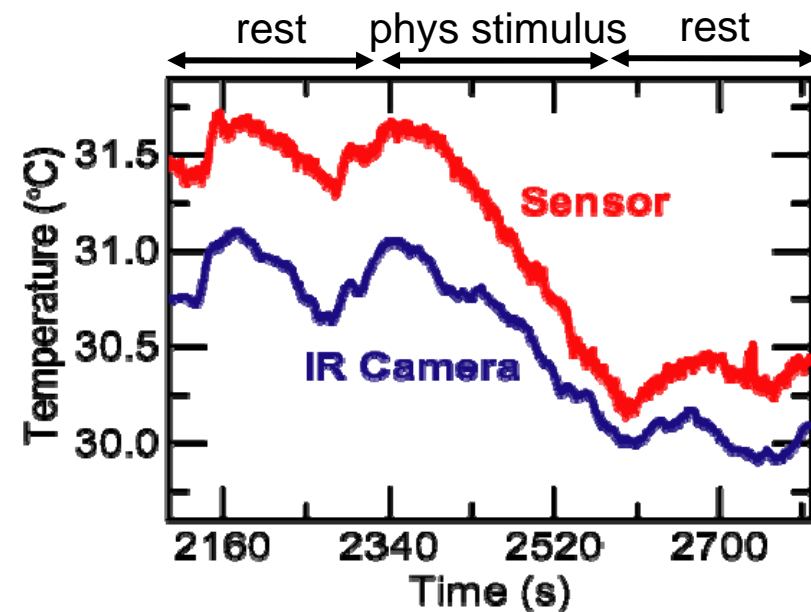
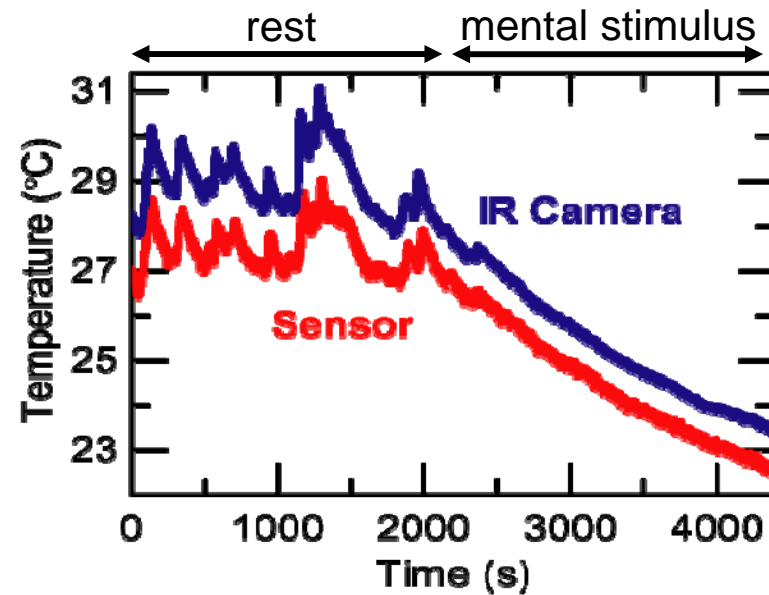
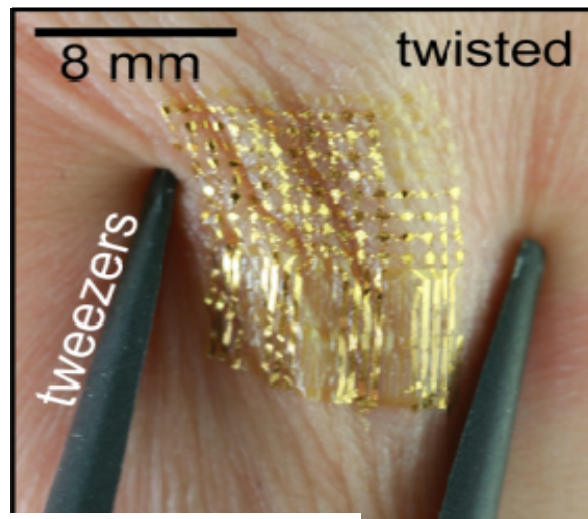
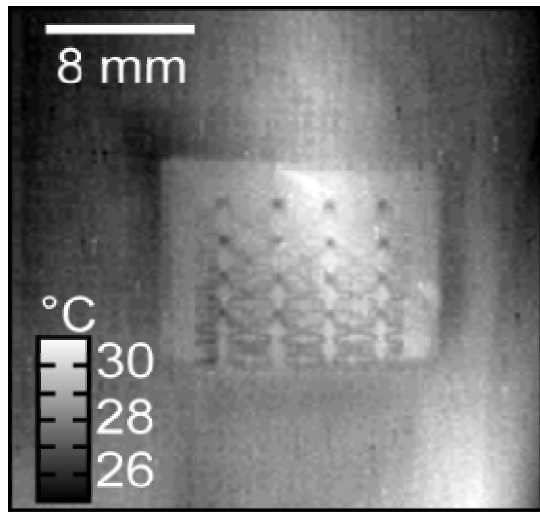
PNAS 112, 3920 (2015).

# Persistent EEG for BMI



PNAS 112, 3920 (2015).

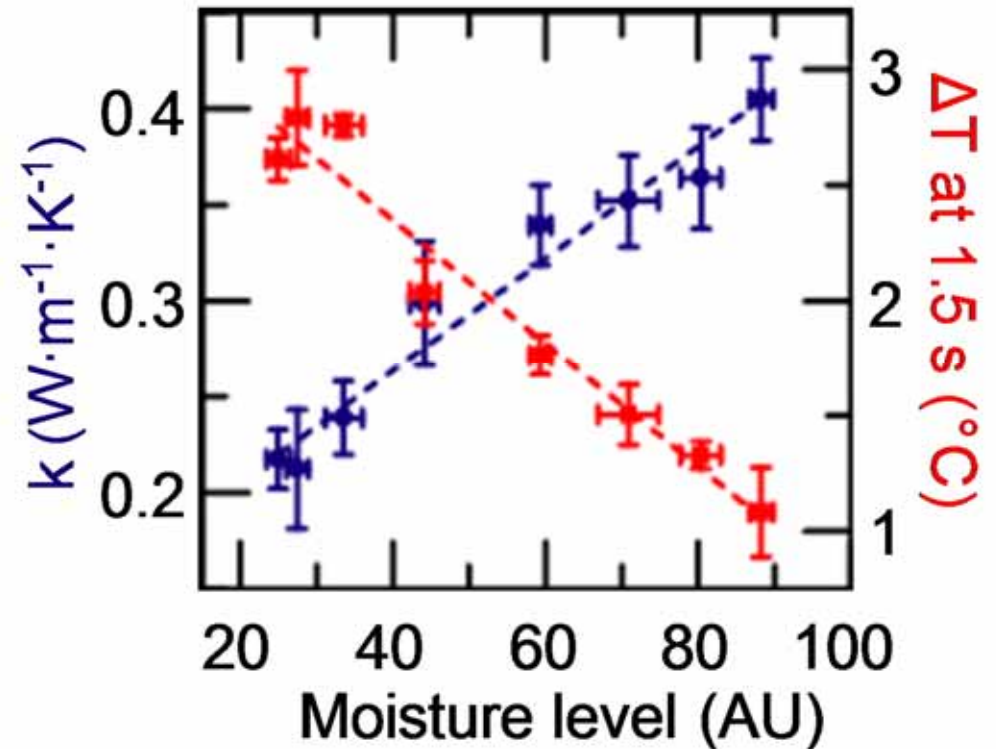
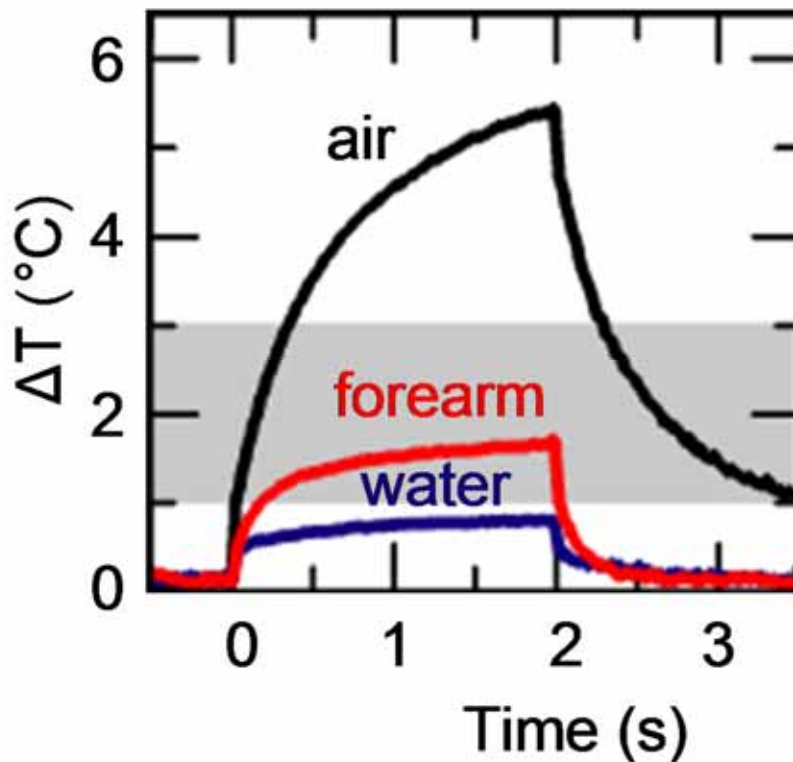
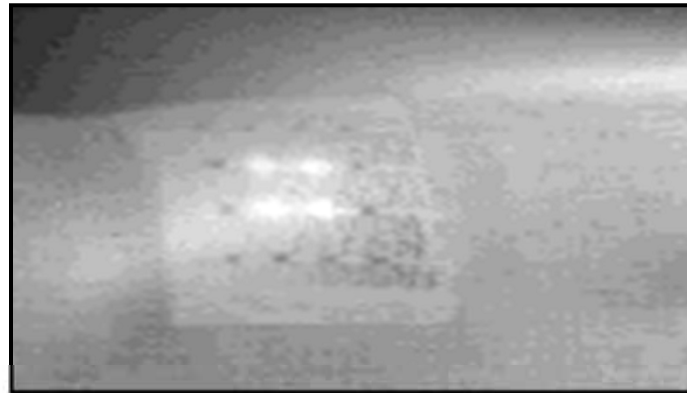
# Precision Skin Temperature via Epidermal Electr.



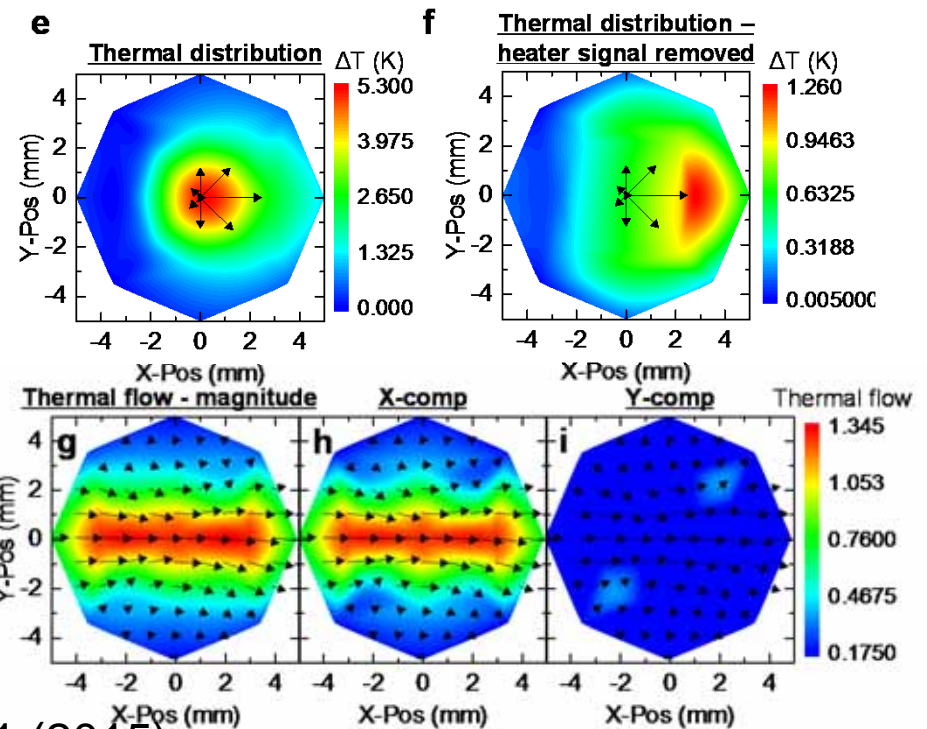
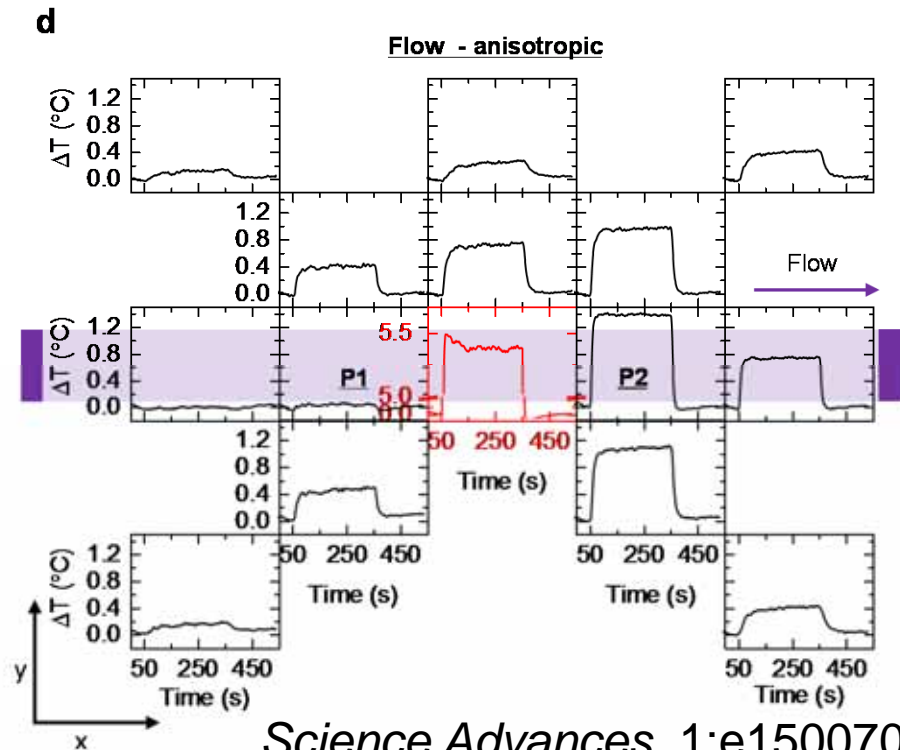
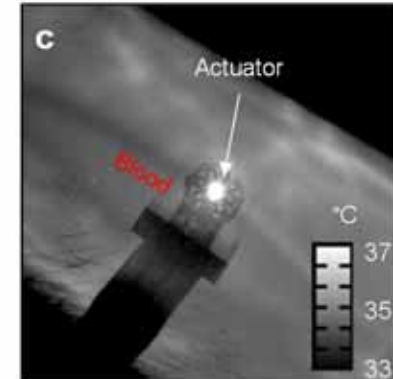
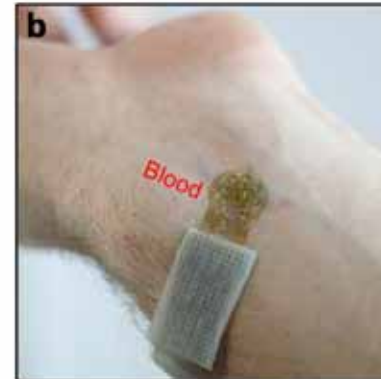
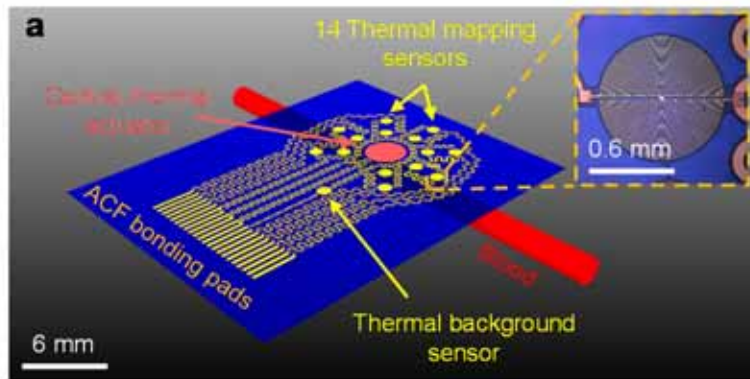


# Delivery of Heat -- Meas of Thermal Conductivity

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

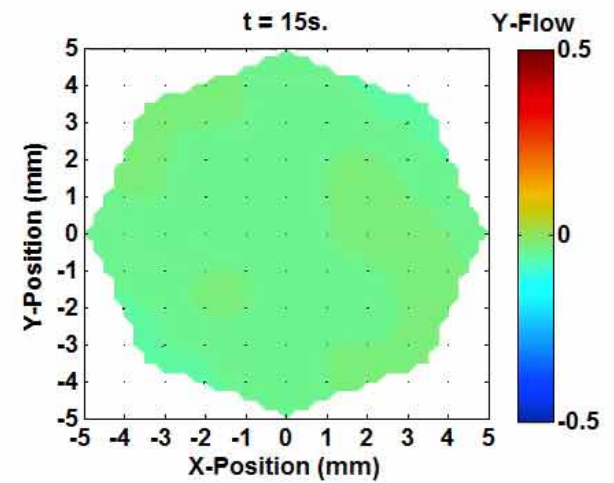
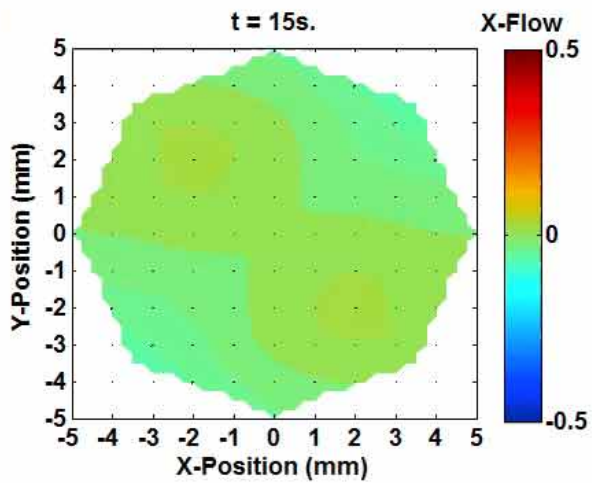
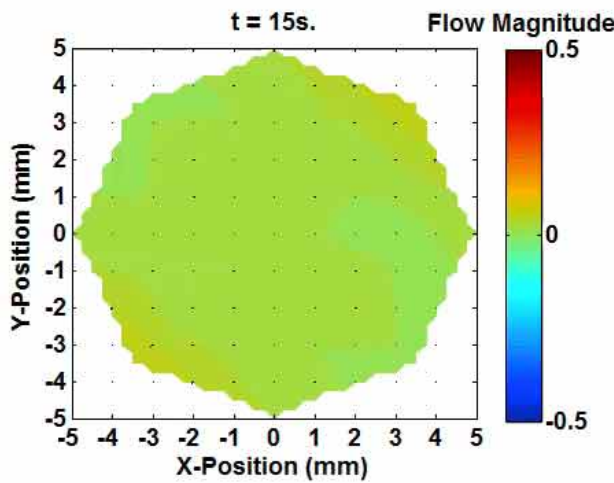
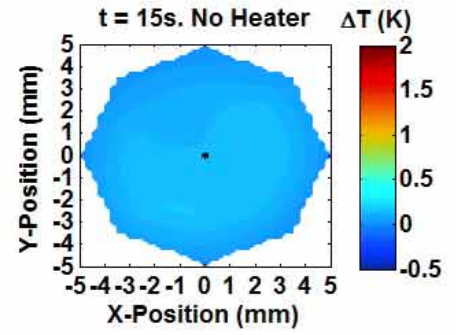
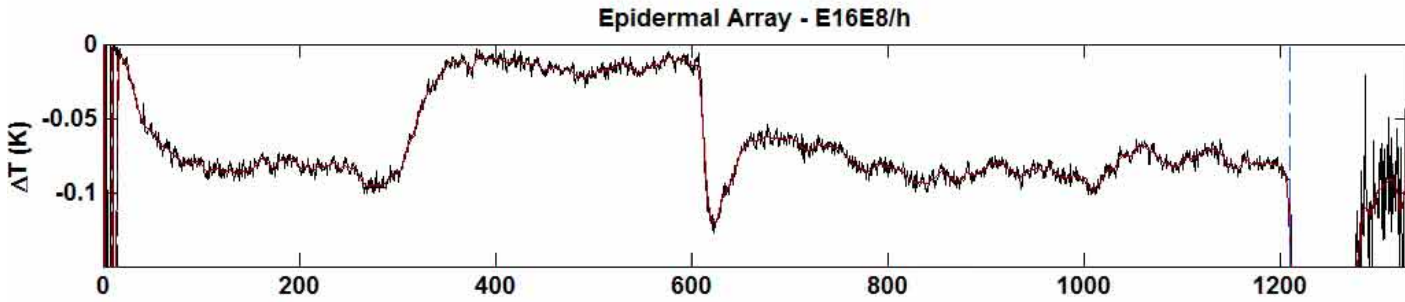
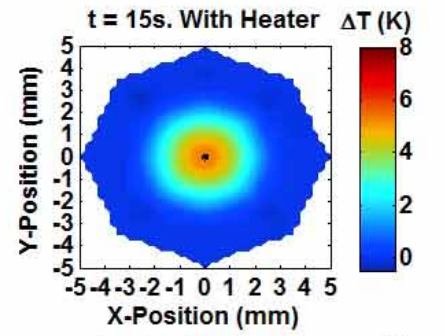
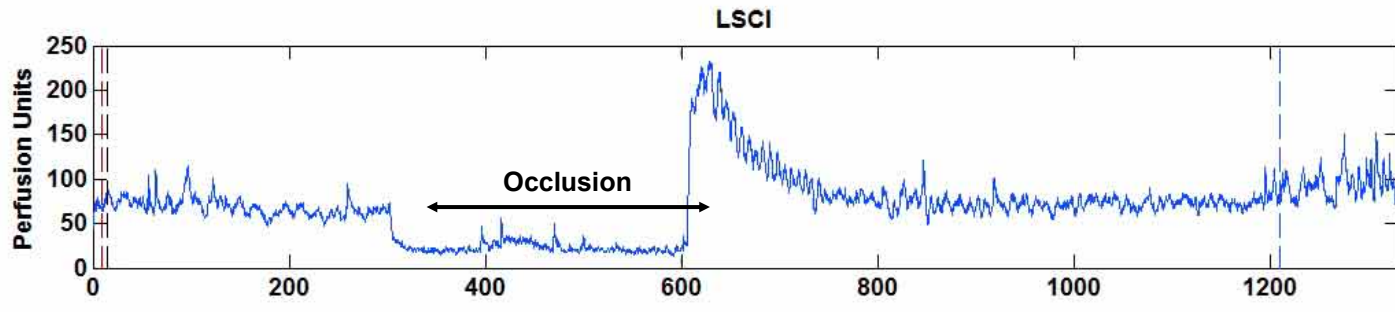


# Thermal Actuators/Sensors for Blood Flow Measurement



*Science Advances*, 1:e1500701 (2015).

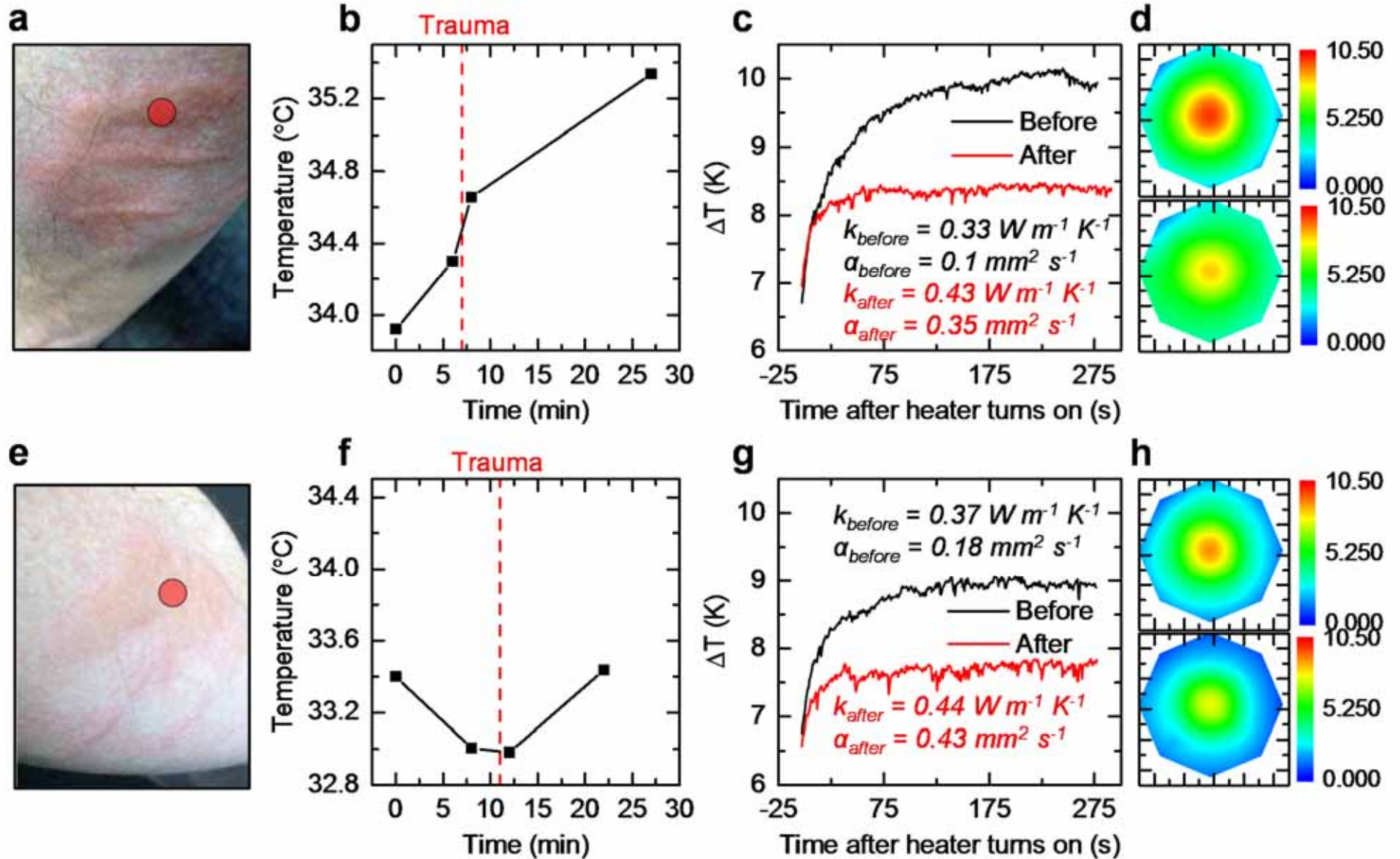
# Occlusion and Reperfusion



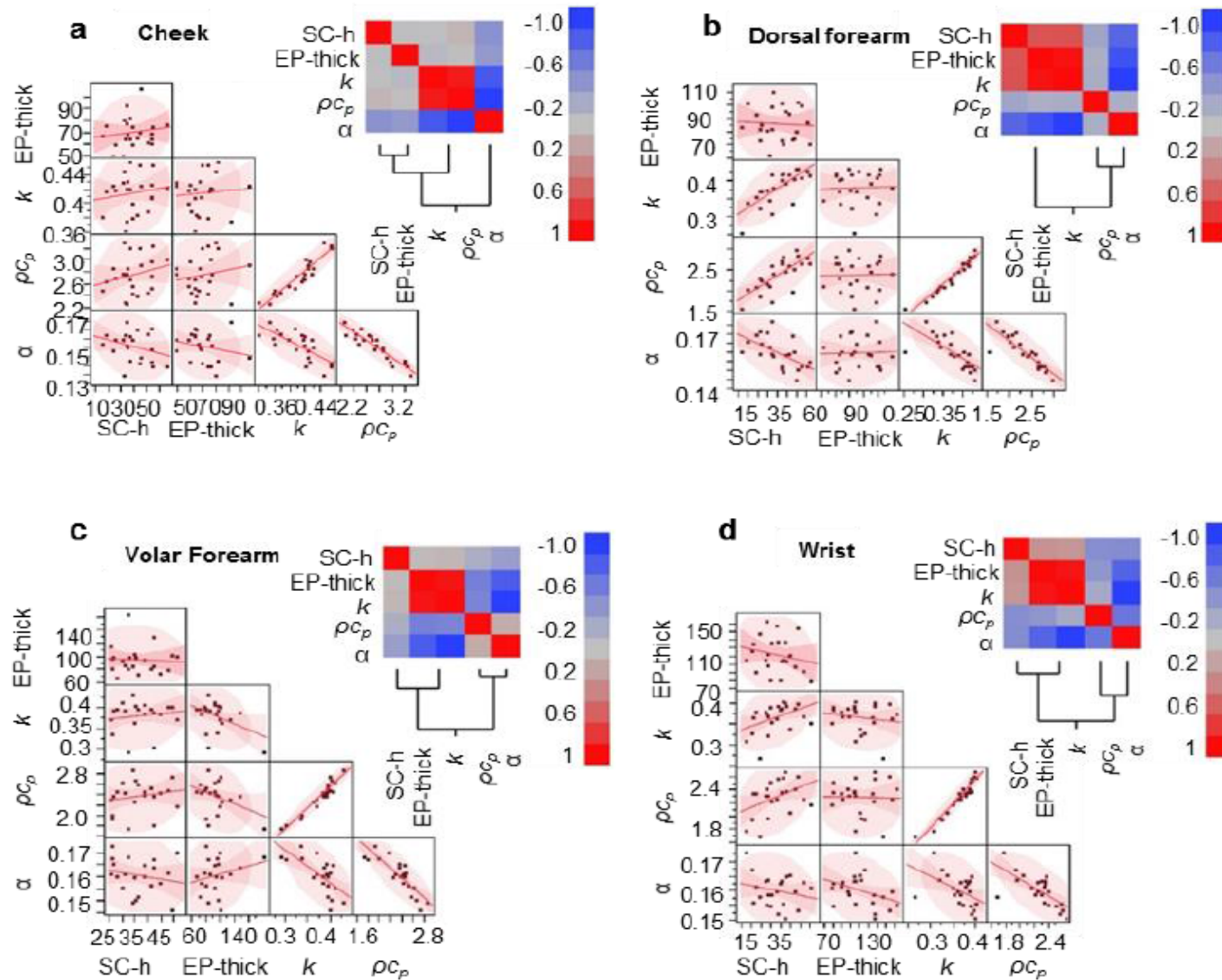
Science Advances, 1:e1500701 (2015).



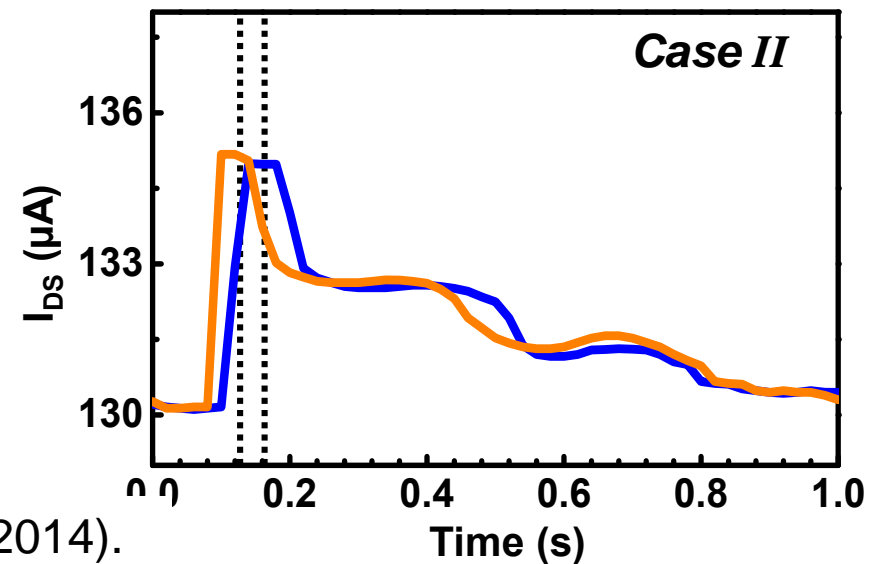
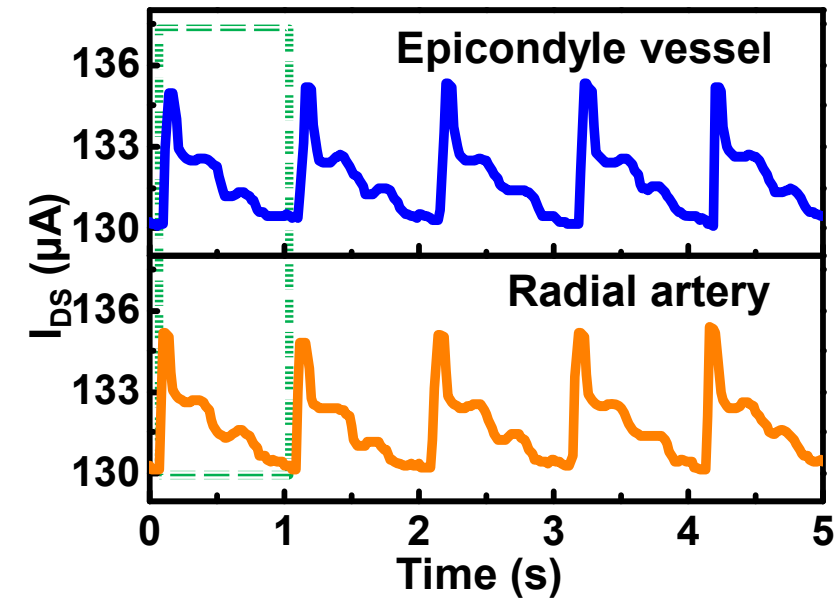
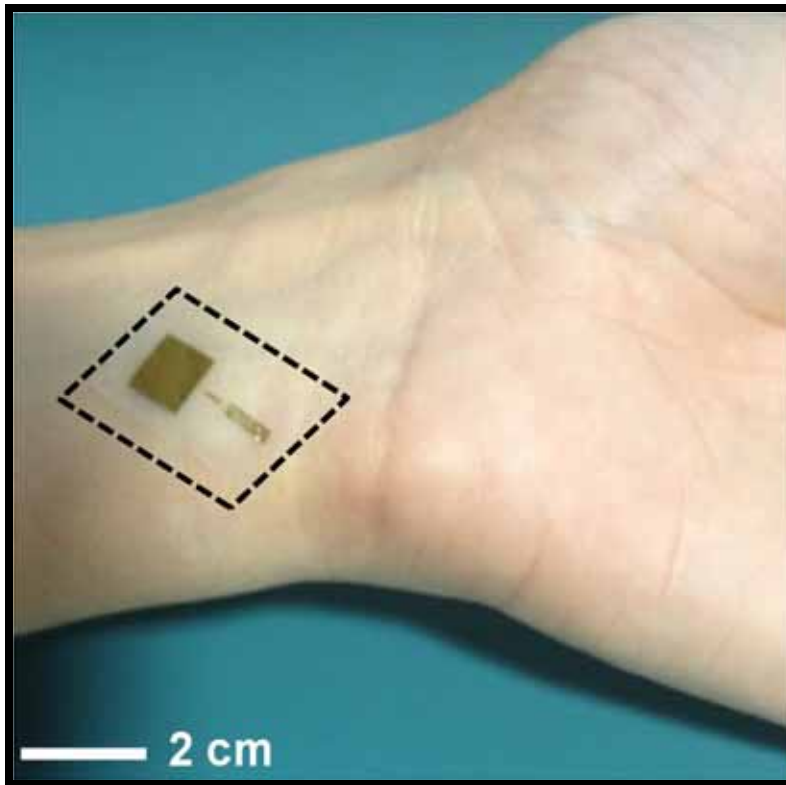
# Characterization of Dermatographic Urticaria



# Clinical Studies With Loreal

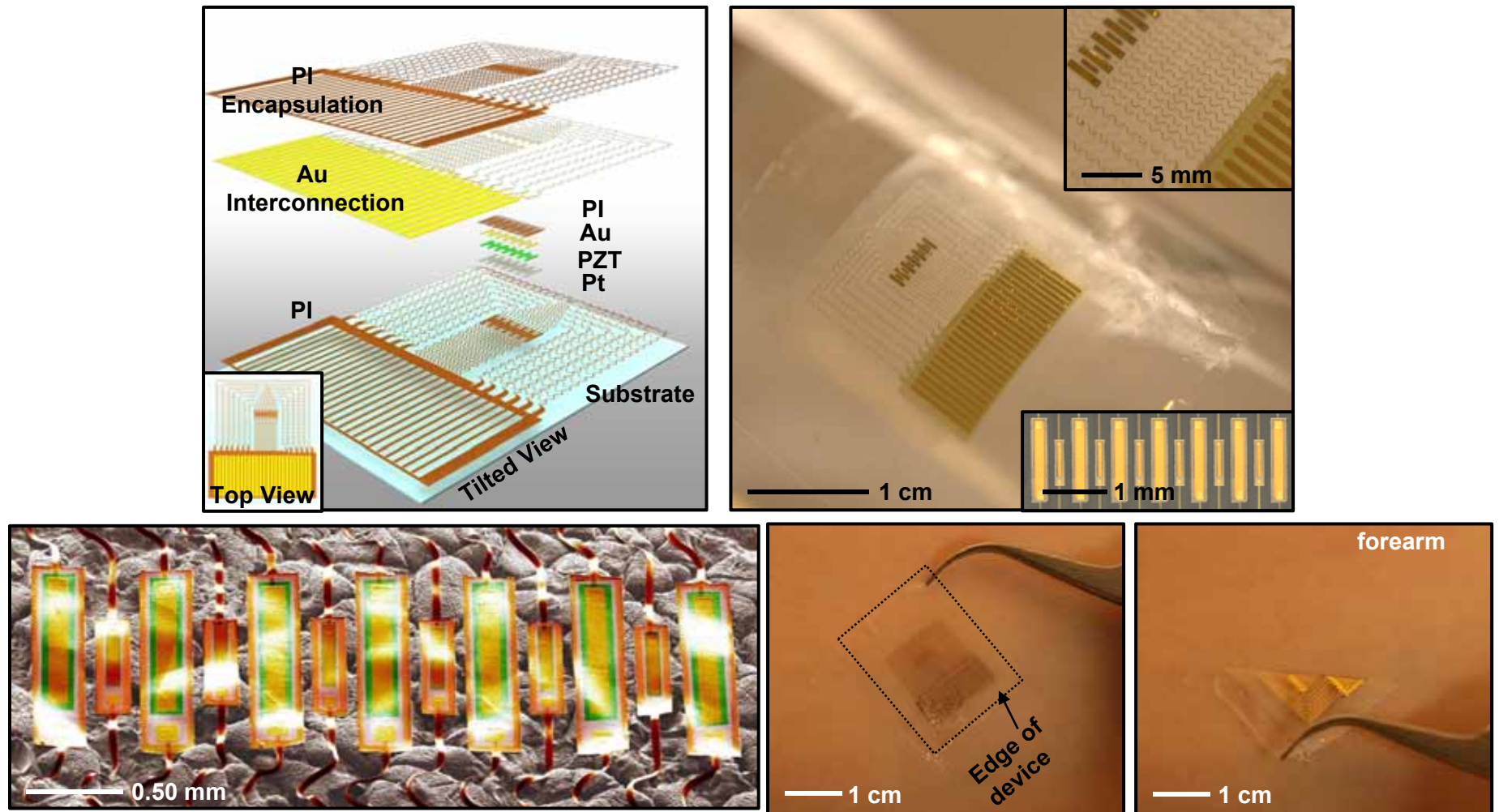


# Measurement of Arterial Blood Pressure Waves

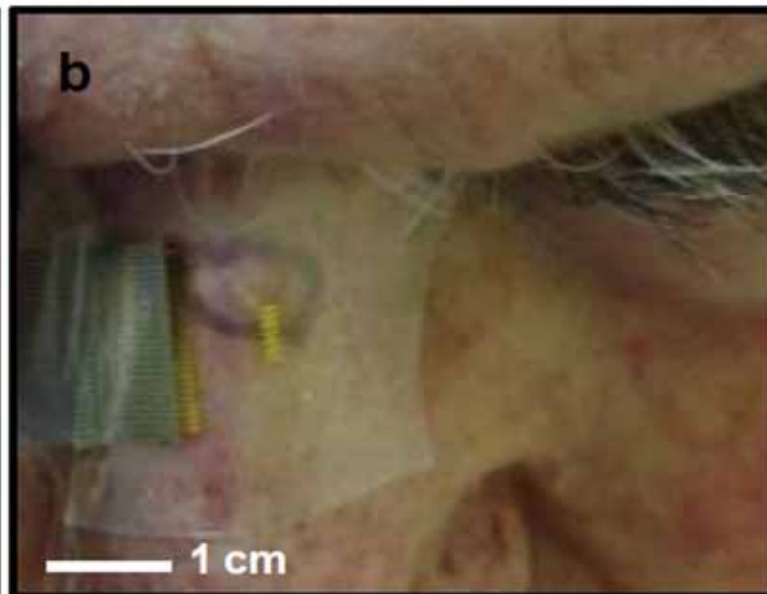
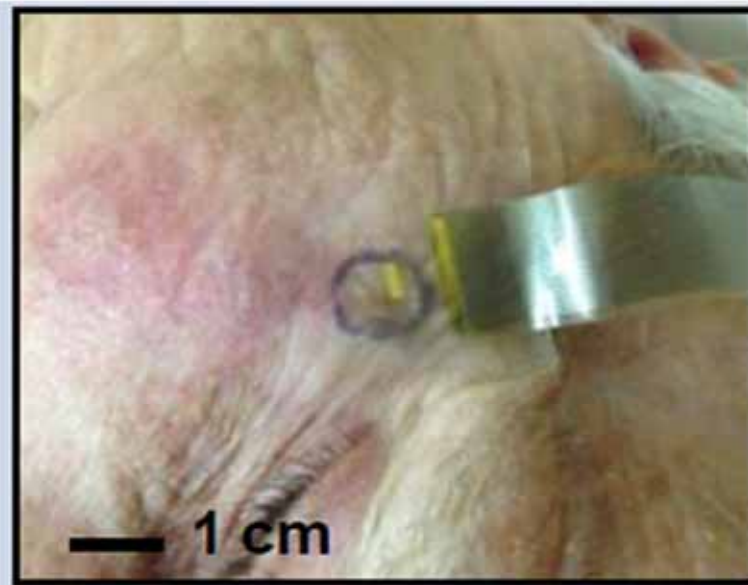




# Epidermal PZT Actuators/Sensors for Modulus Measurement



## Clinical Study Involving 32 Volunteers



## Standard Clinical Tools – Hard, Cold, Rigid





# Neonatal Intensive Care

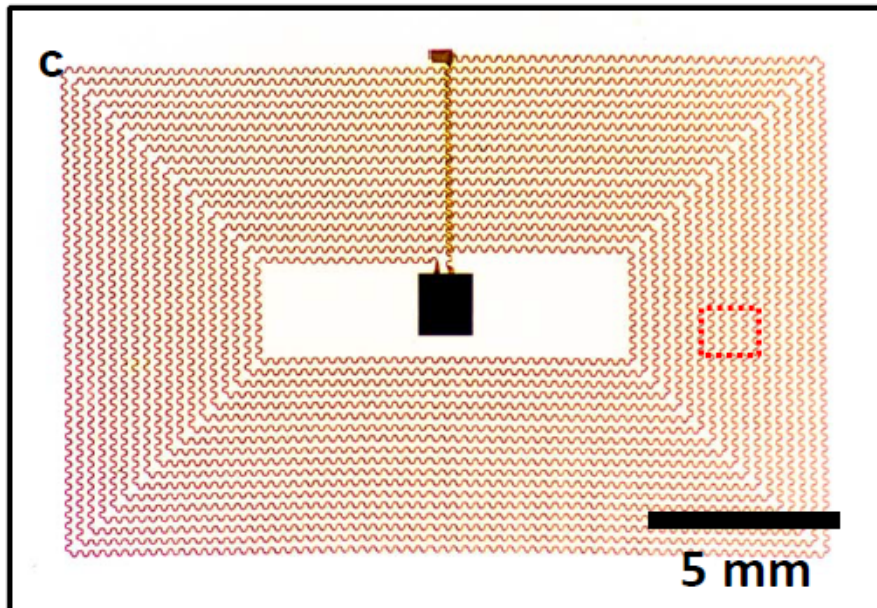
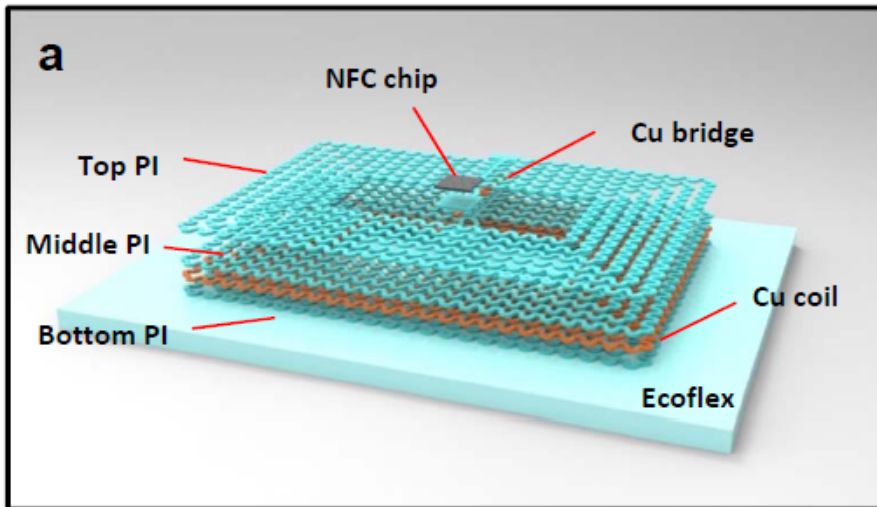
**Current**



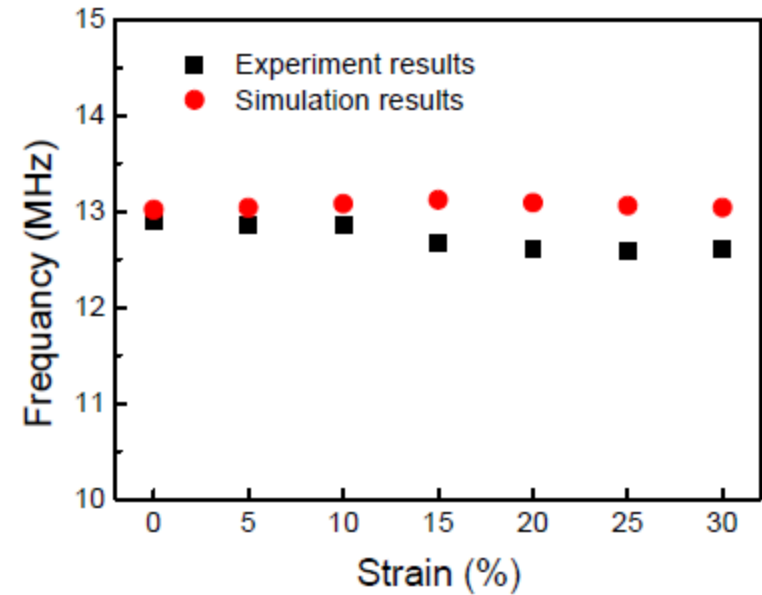
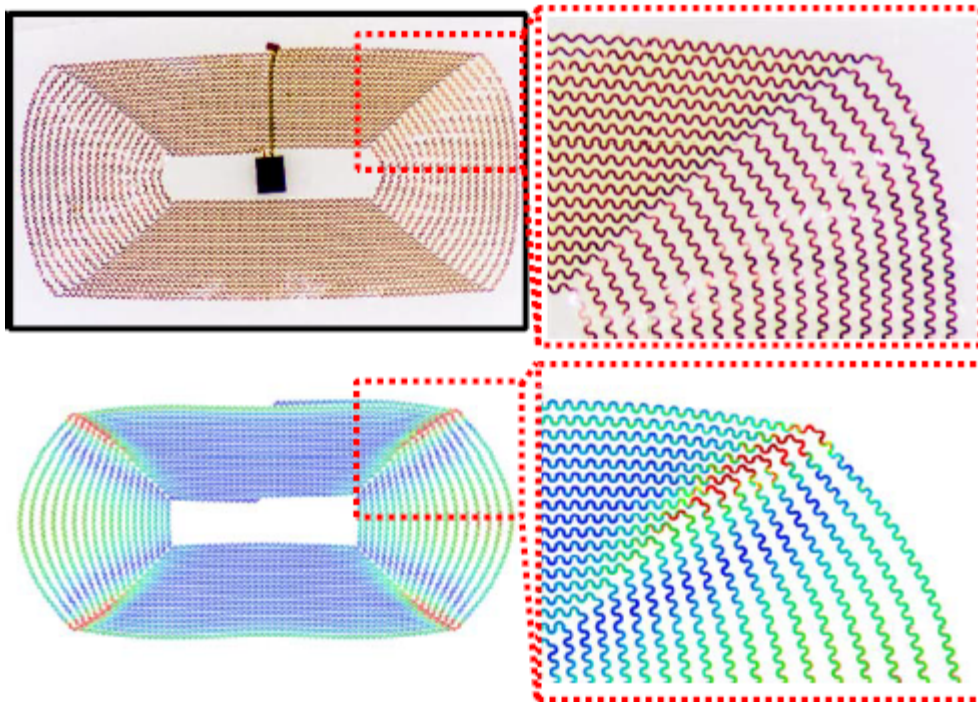
*Future*



# Wireless, Electronic Data Tattoo



# Multiphysics Modeling: Mechanics and EM



Small 11, 906 (2015).

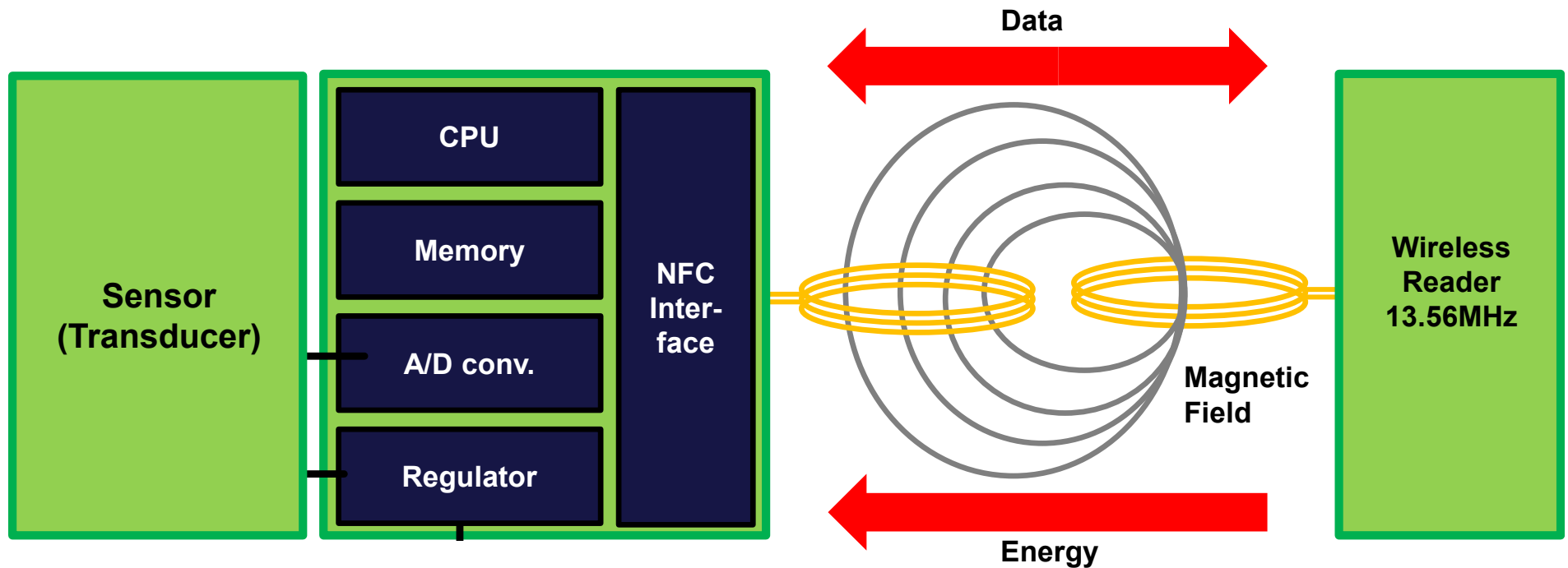


## Wireless, Electronic Data Tattoo



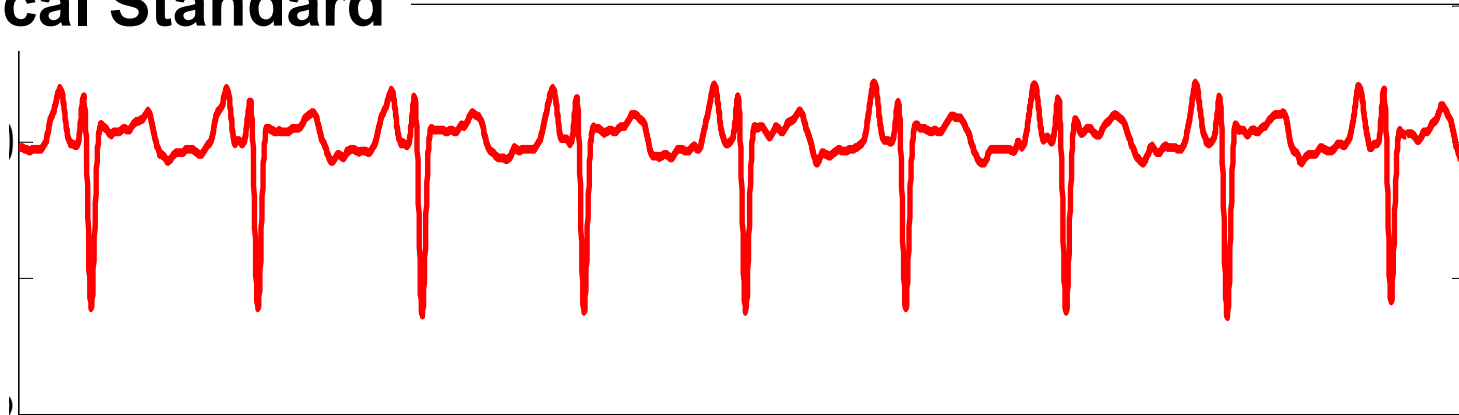
*Small 11, 906 (2015).*

# NFC System Architecture

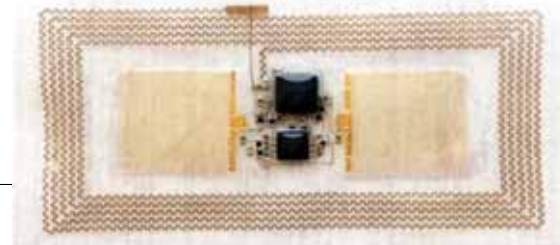
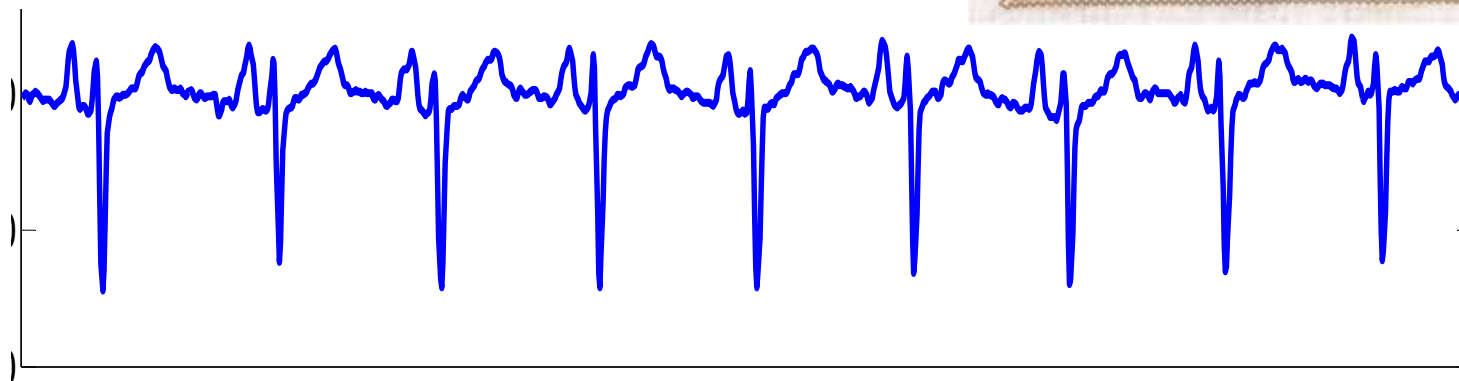


# Wireless ECG Data, Comparison to Clinical Standards

## Clinical Standard



## Epidermal



*unpublished*





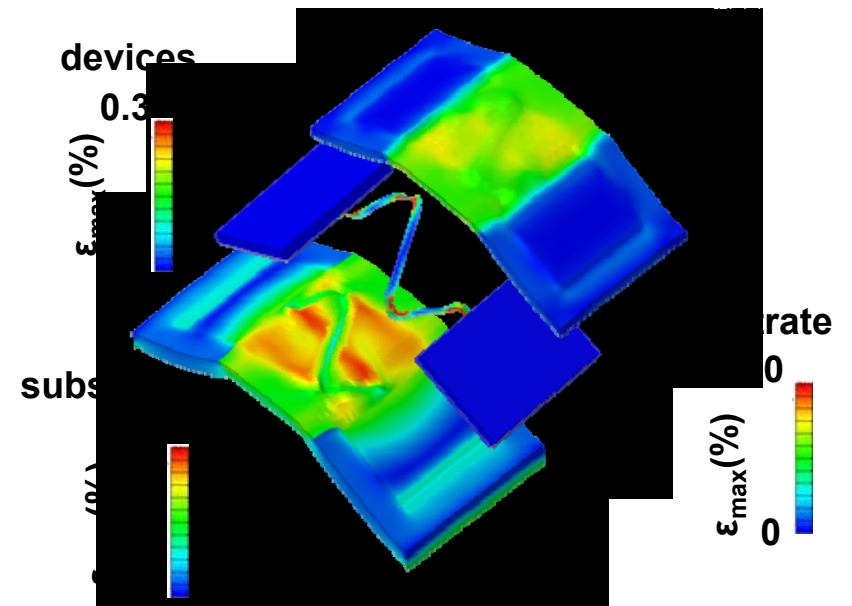
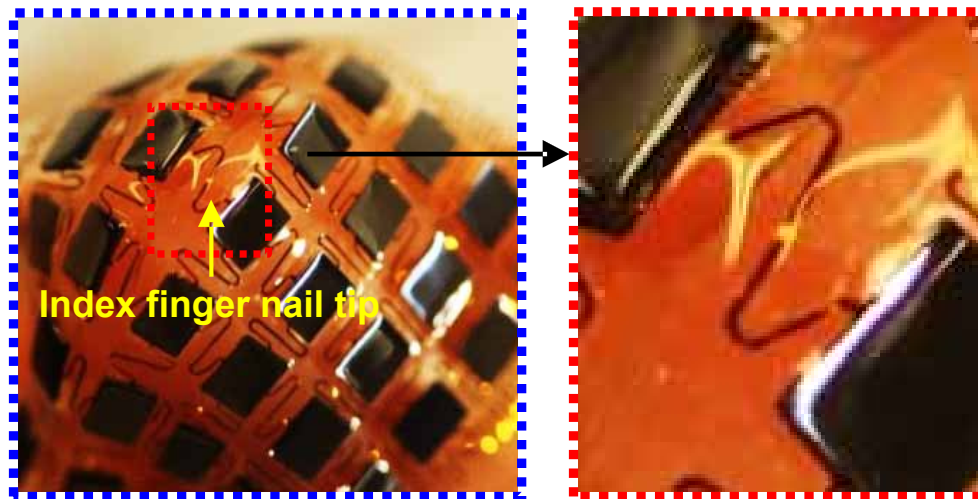
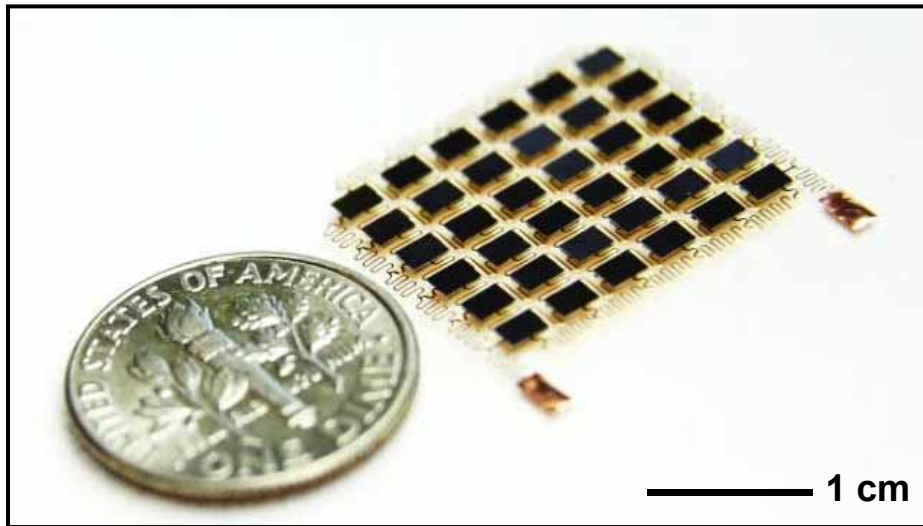
*unpublished*

## Long Range (~1 m) Operation, On-Board Data Analytics



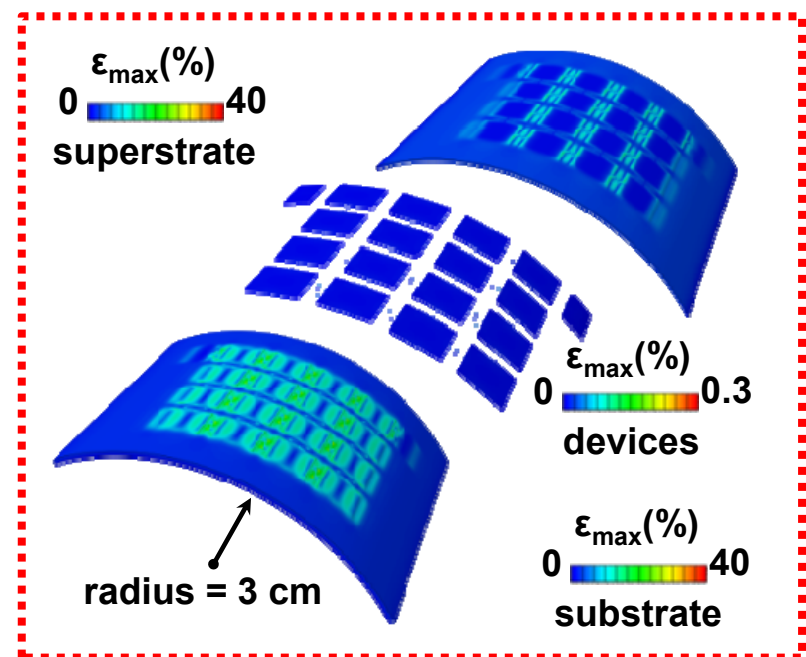
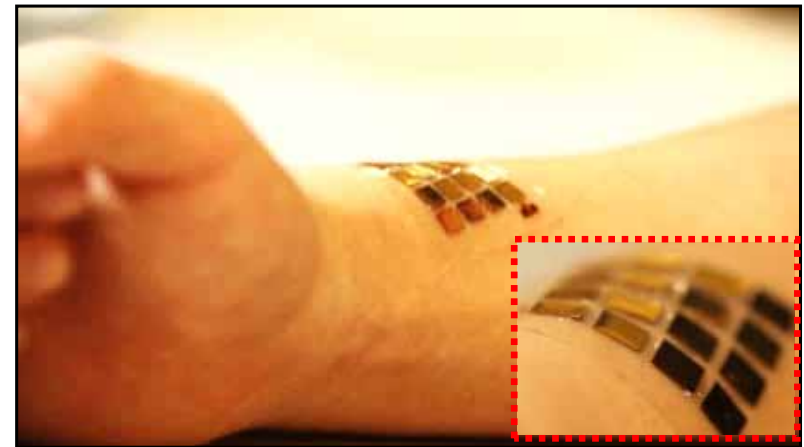
*unpublished*

# Arrays of Chip Scale Batteries



unpubl.

# Mounting, Deformation on Skin

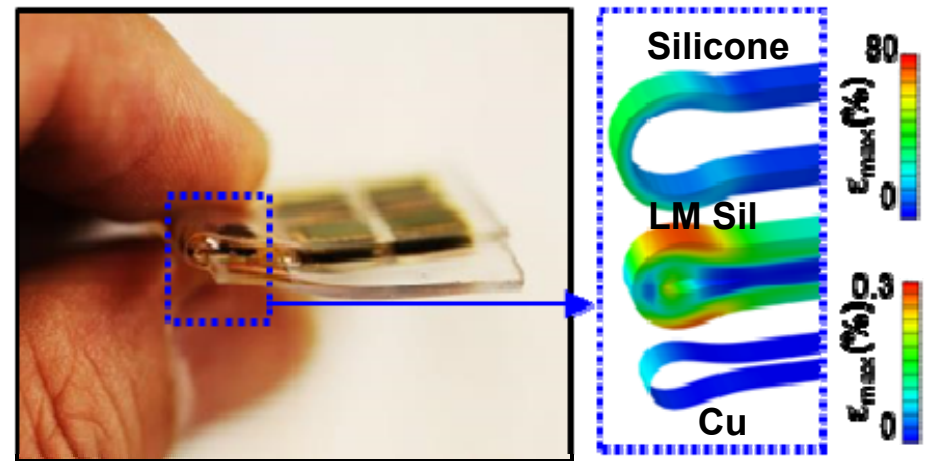
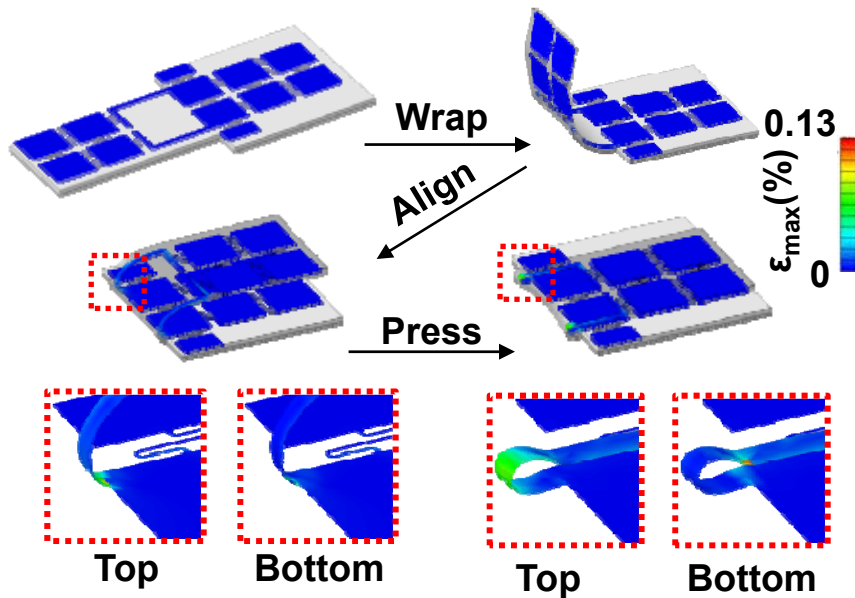
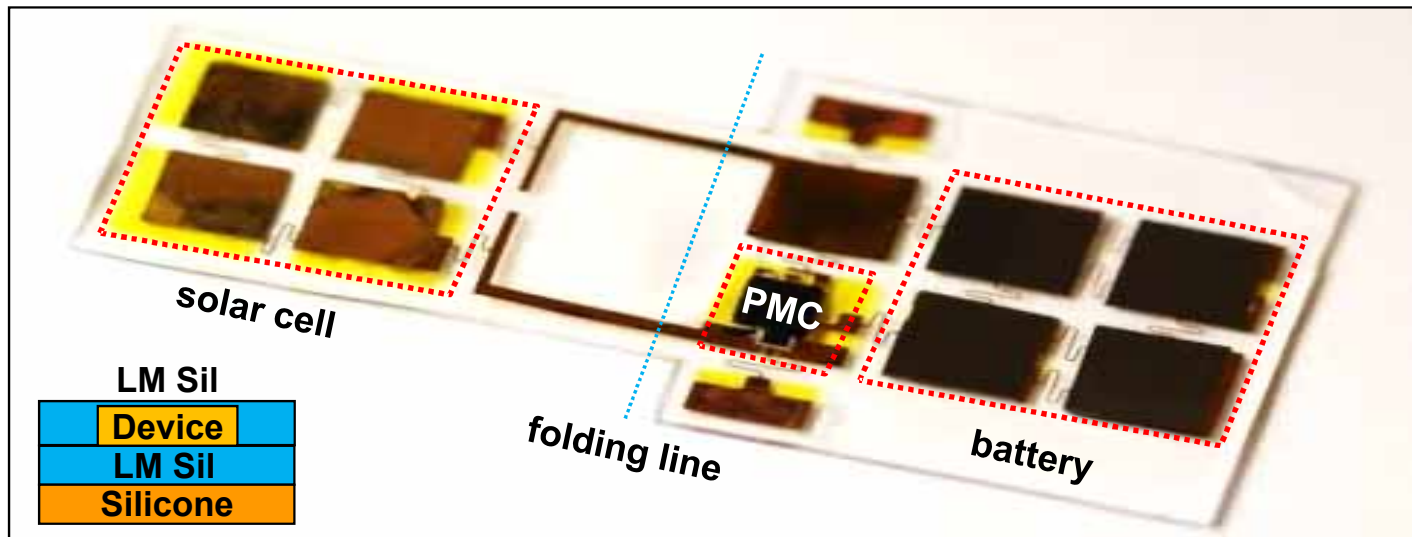


**Bending, Twisting, Pinching, Stretching**

*unpubl.*

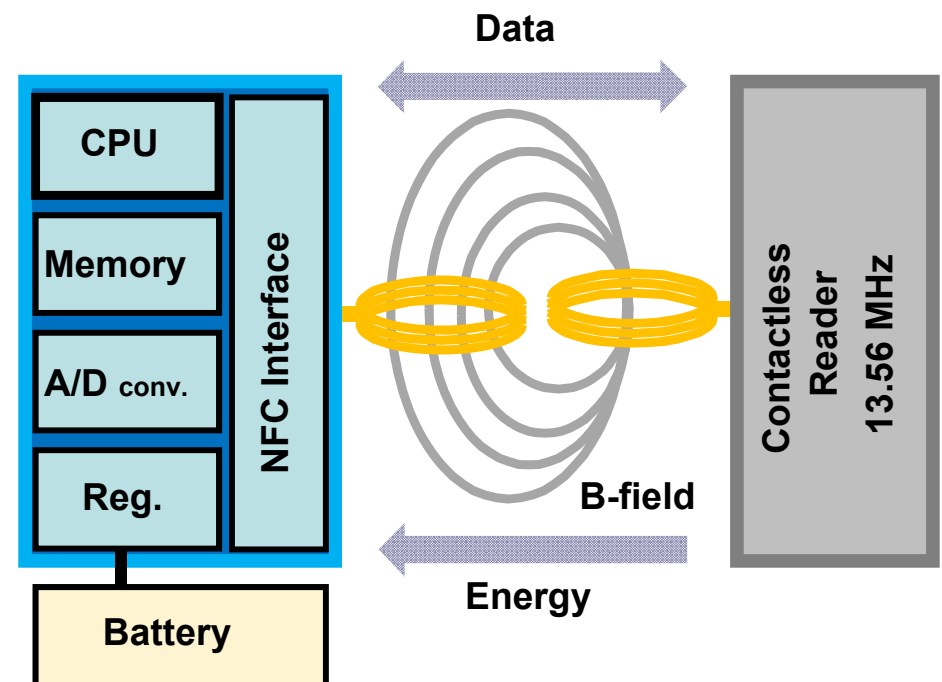
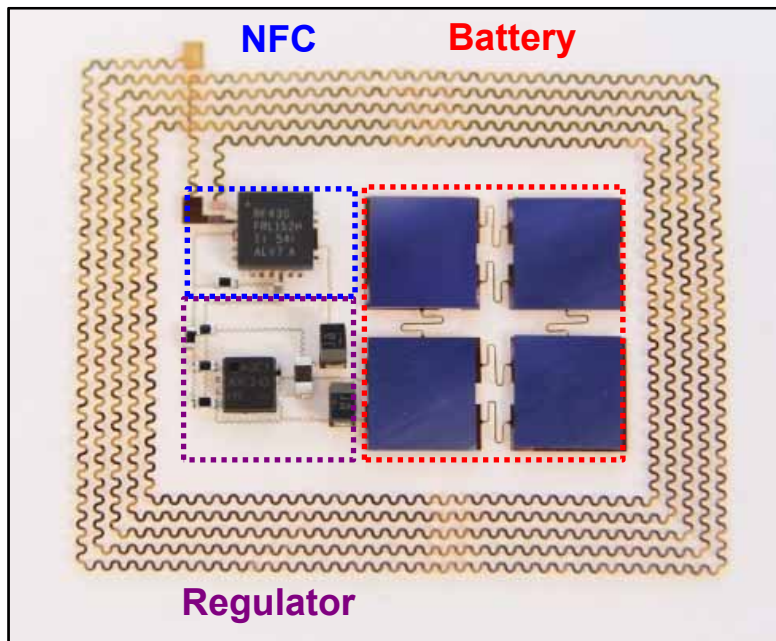


# Compact Integration by Folding

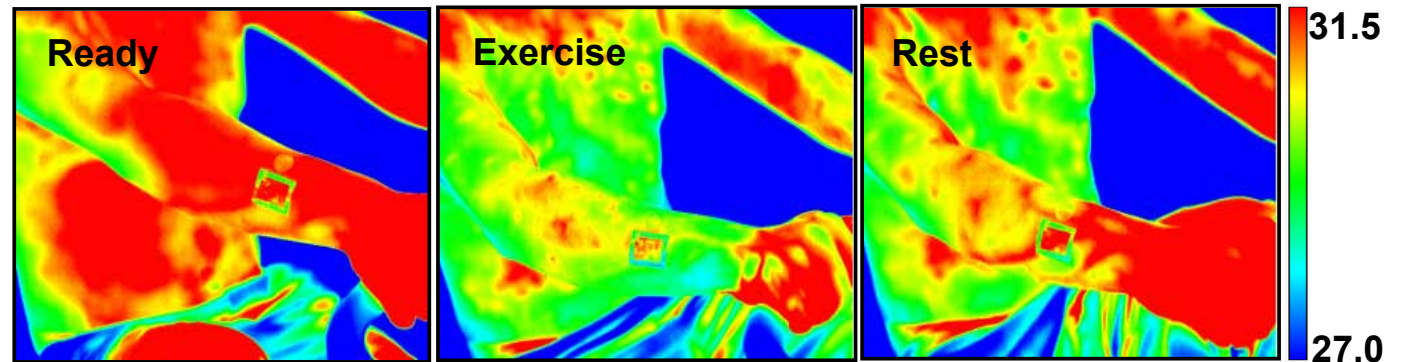
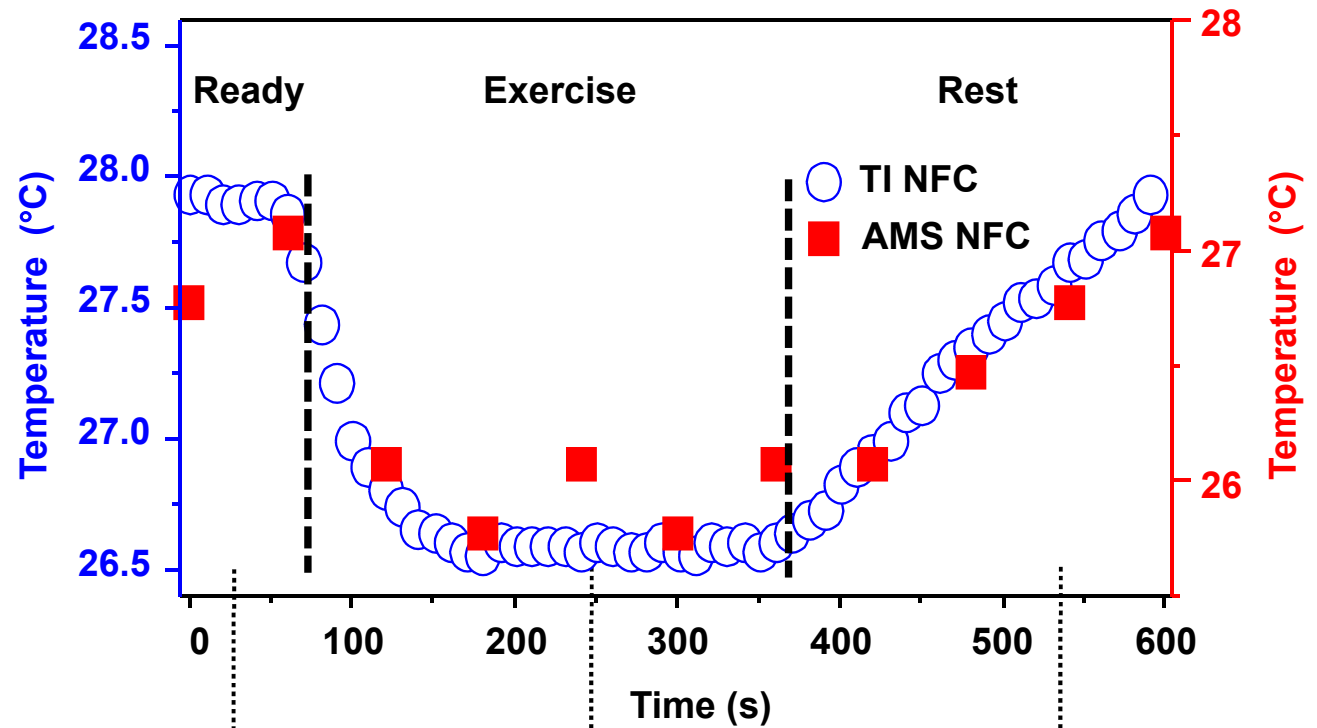


*unpubl.*

# Stretchable NFC Temperature Sensor w/ Battery



# Temperature Data-Logging + Wireless Readout



unpubl.



## Pipeline: WiSP™



Real time ECG and heart rate logging in ultra-thin sticker form factor for clinical monitoring, neuromarketing and sports applications.



## Commercial Activities – MC10, Reebok, L’Oreal

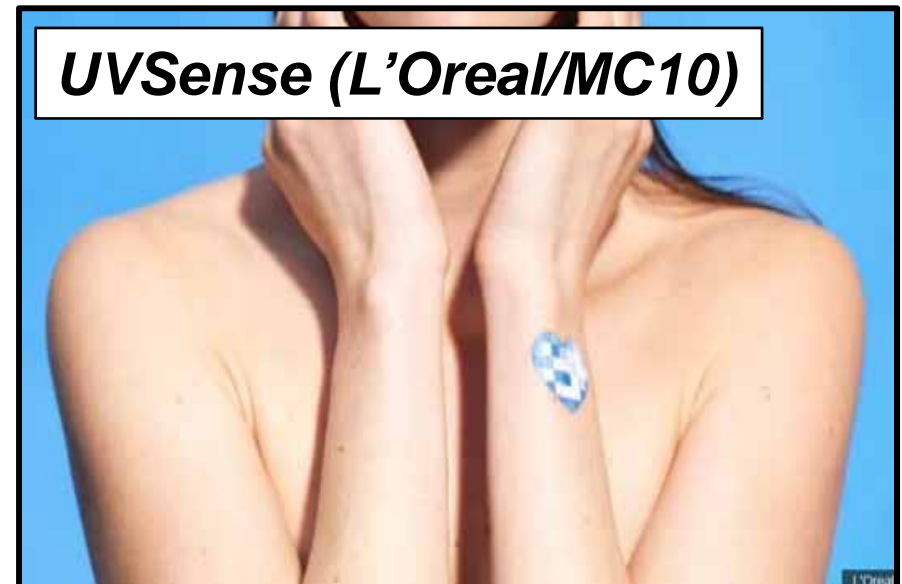
**CheckLight (Reebok/MC10)**



**Biostamp (MC10)**



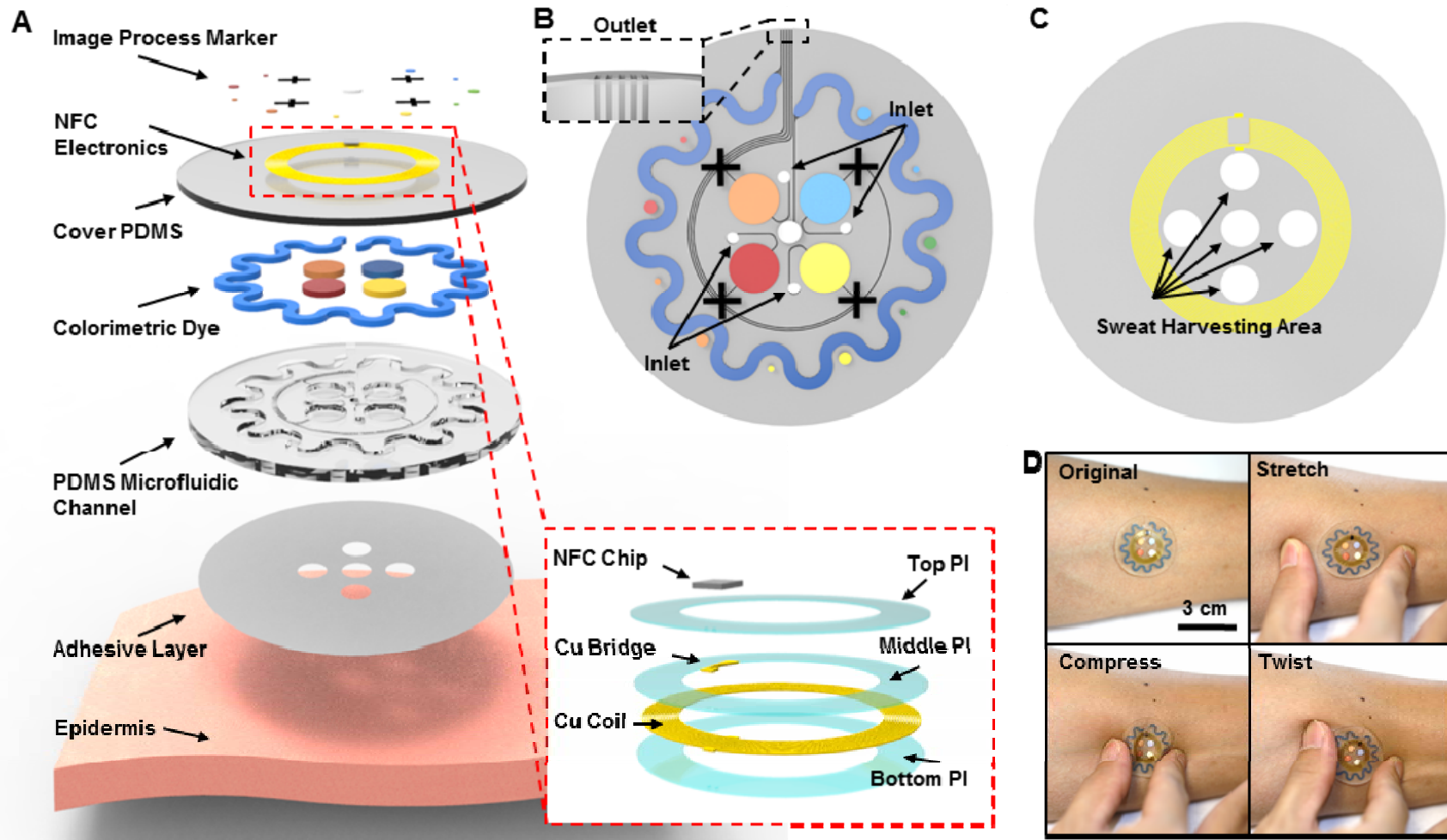
**UVSense (L’Oreal/MC10)**





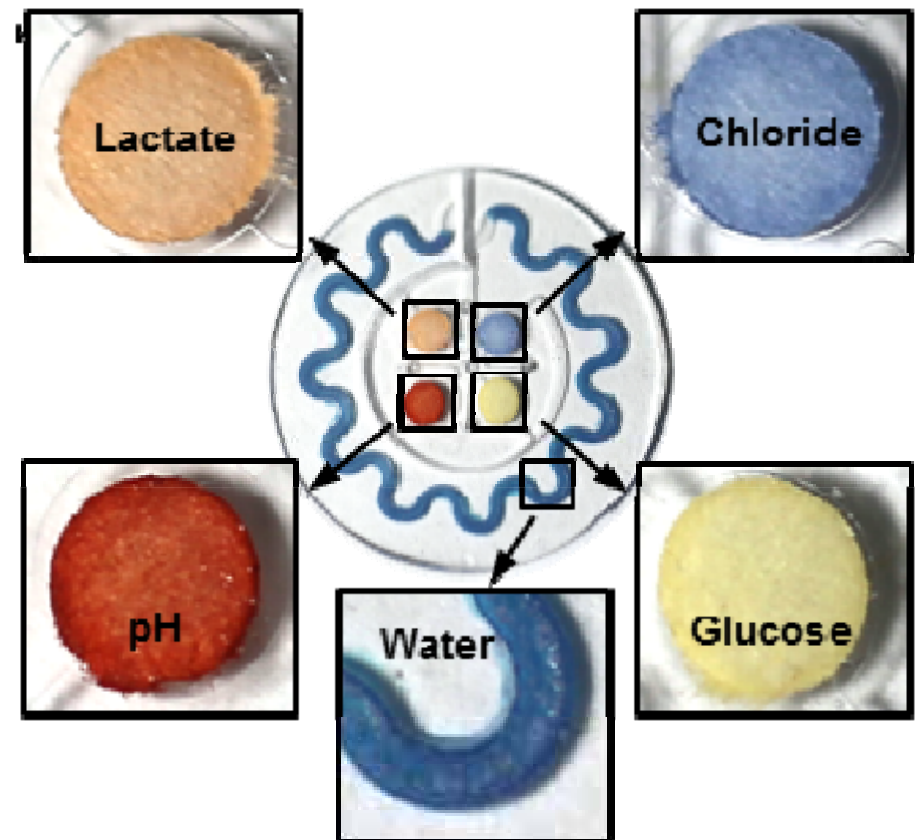
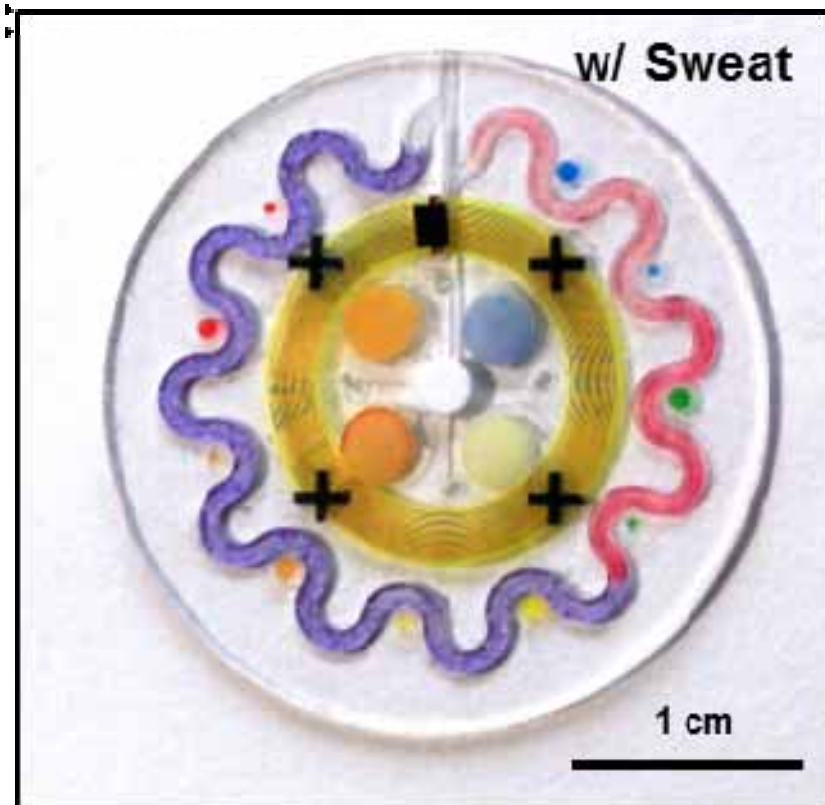


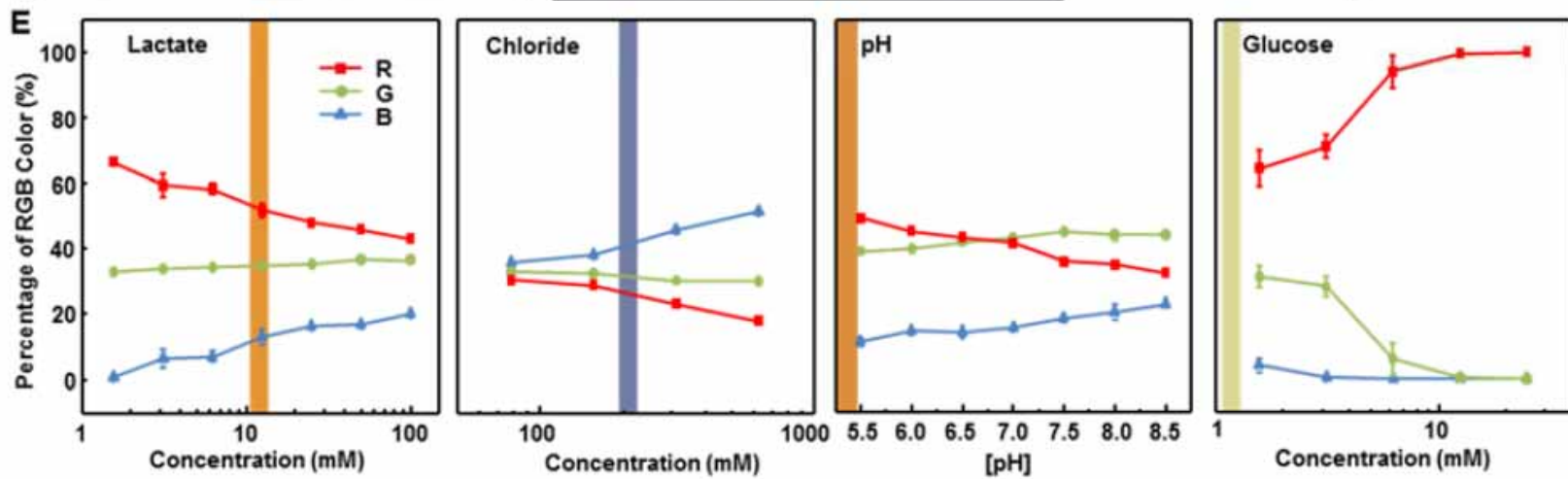
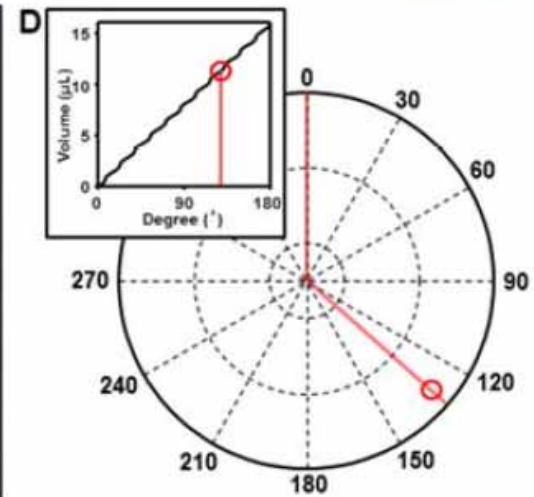
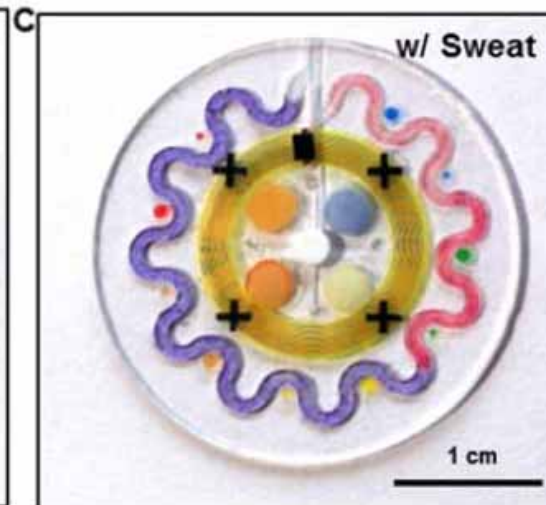
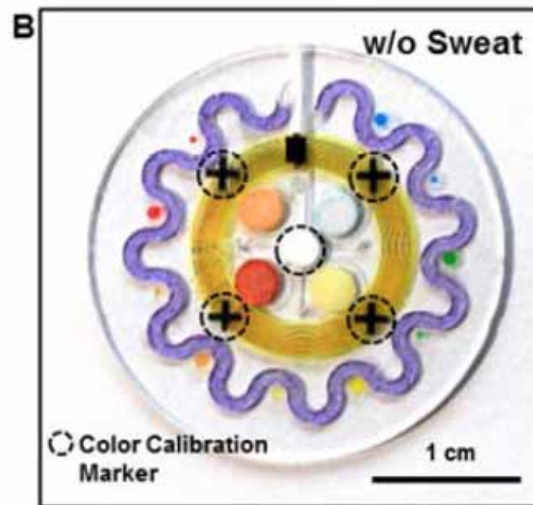
# Epidermal Microfluidics, and Sweat Analytics



*In revision, Science Translational Medicine*

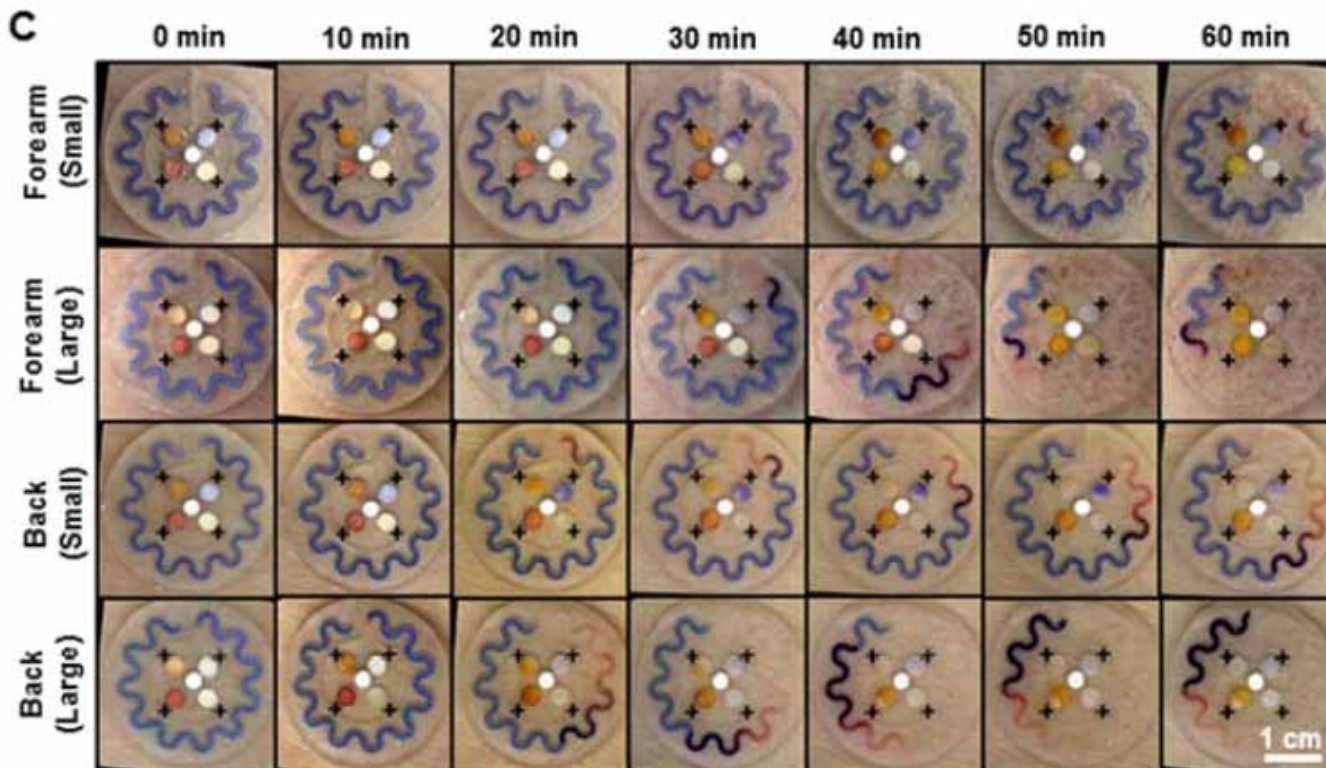
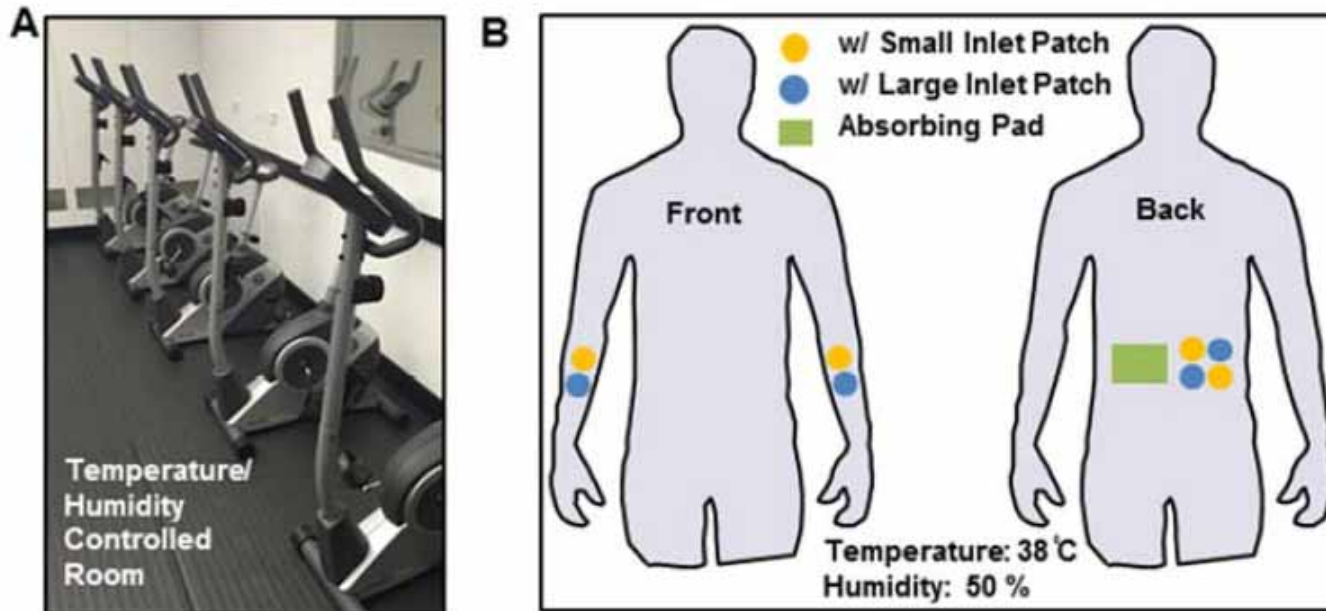
# Epidermal Microfluidics, and Sweat Analytics





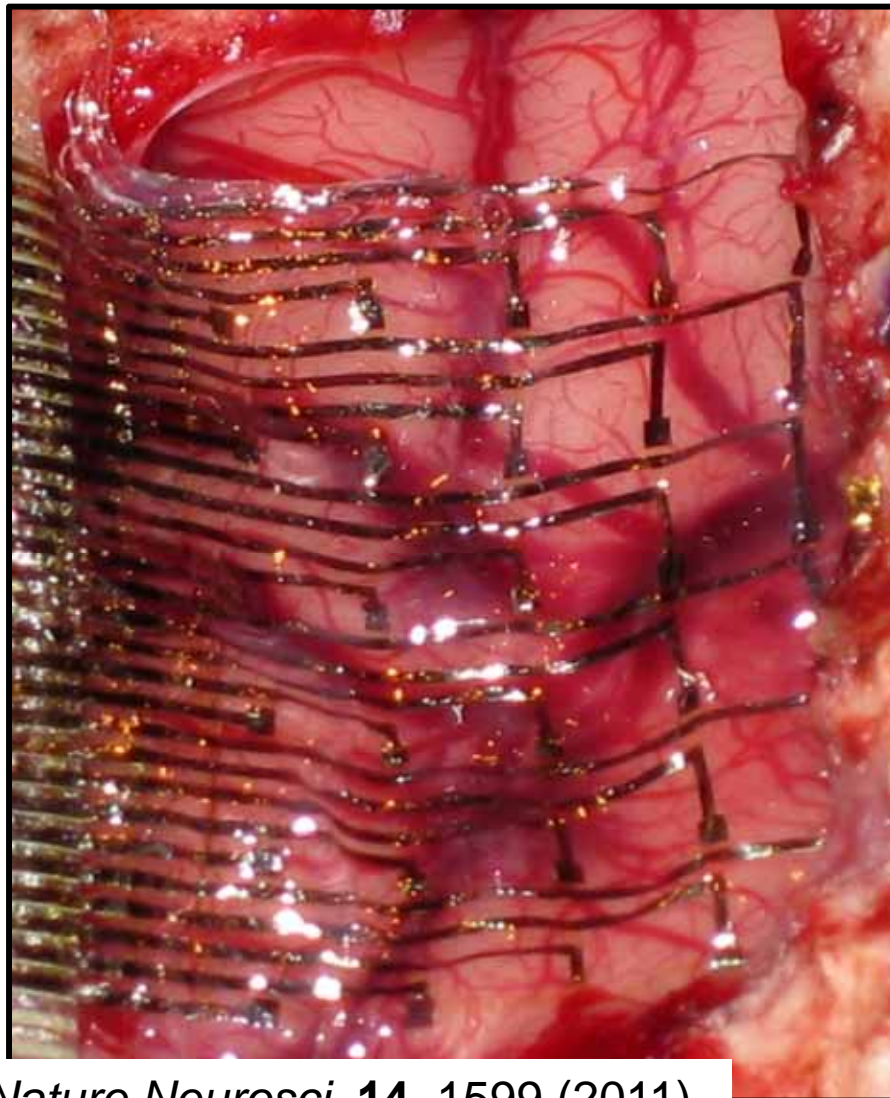


# Epidermal Sweat Analytics



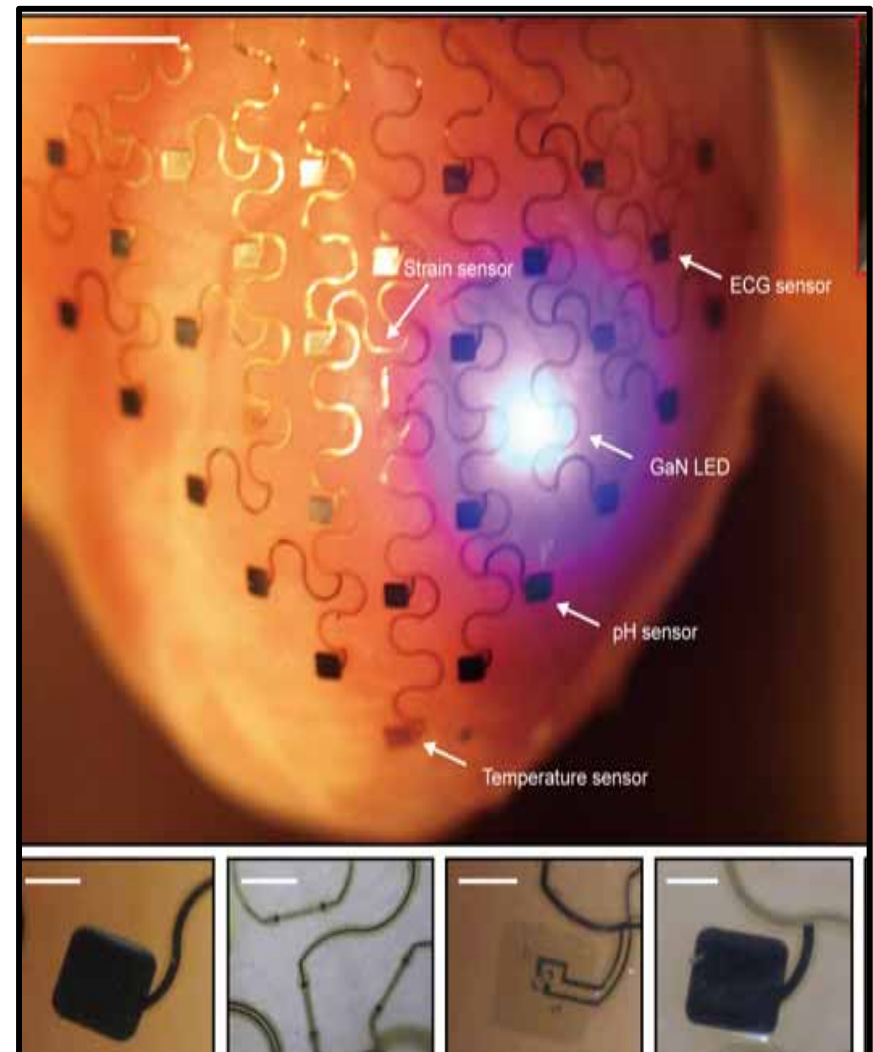
# Bio-Integrated Electronics

## Brain



*Nature Neurosci.* **14**, 1599 (2011).

## Heart



*Nature Comm.* 10.1038/ncomms4329 (2014)



# An Alternative Future for Electronics: Bio / Eco Resorbable, *Transient*

Past



Current



Future



***Industrial***



***Personal***



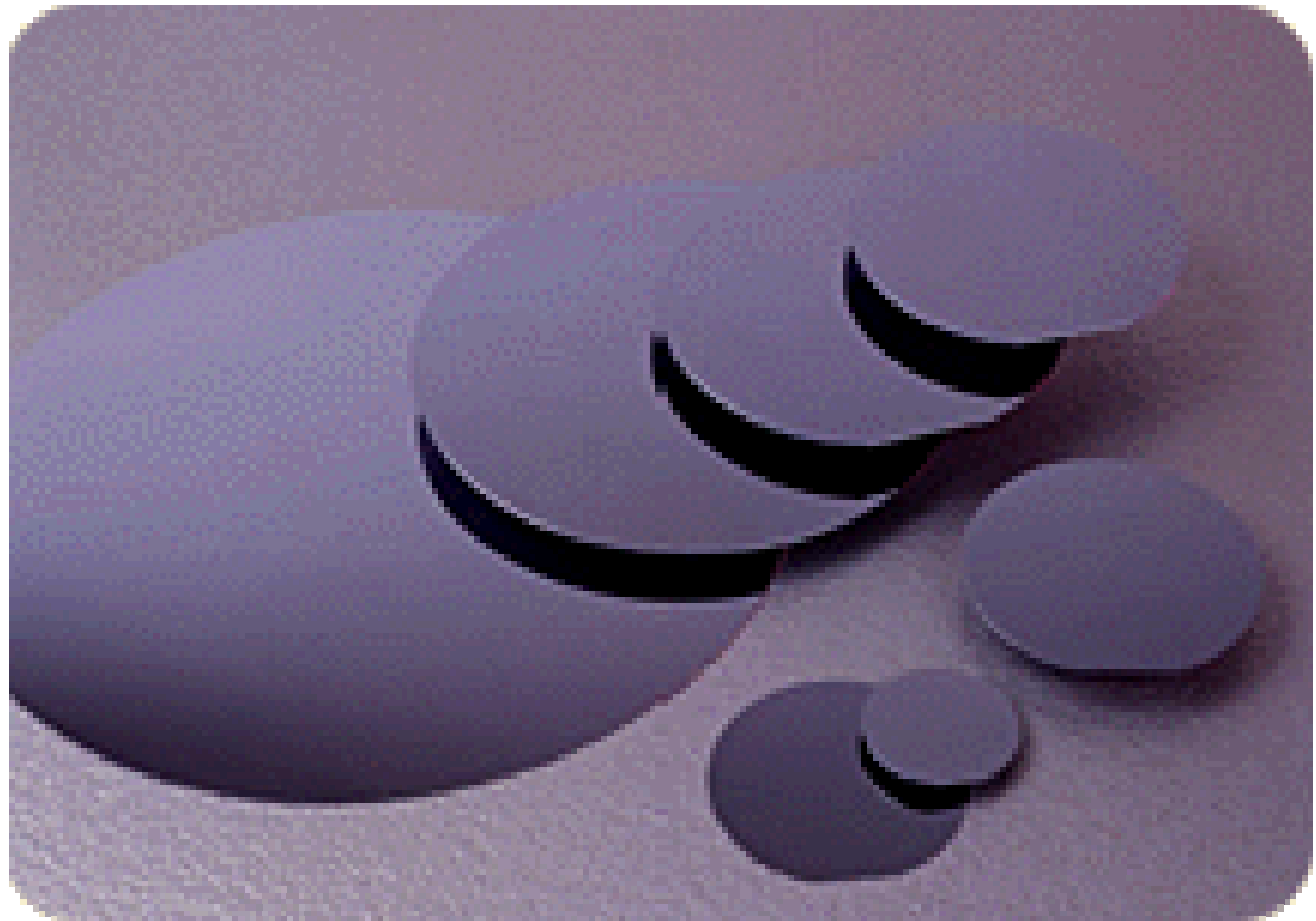
***Bio / Eco Resorbable***

## Potential Applications

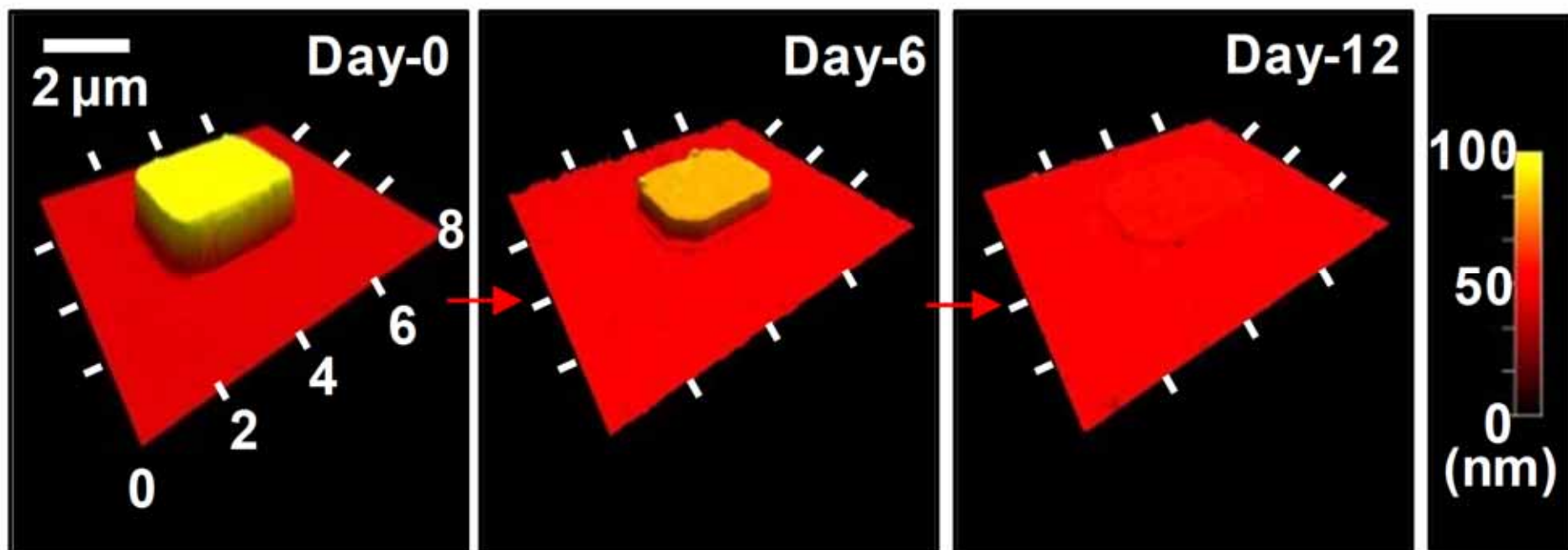
---

- 1) Zero/Reduced E-Waste Consumer Electronics**
- 2) Implantable Therapeutics / Diagnostics**
- 3) Environmental Monitors / Sensors**
- 4) ...**



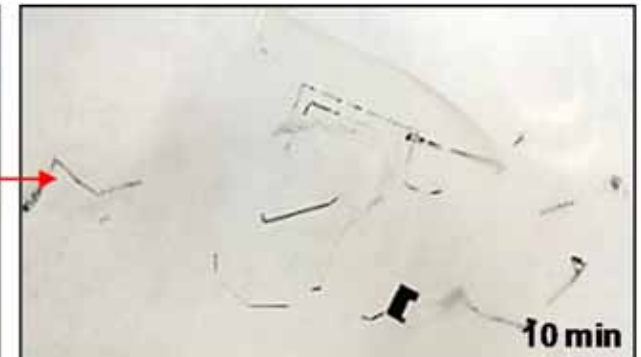
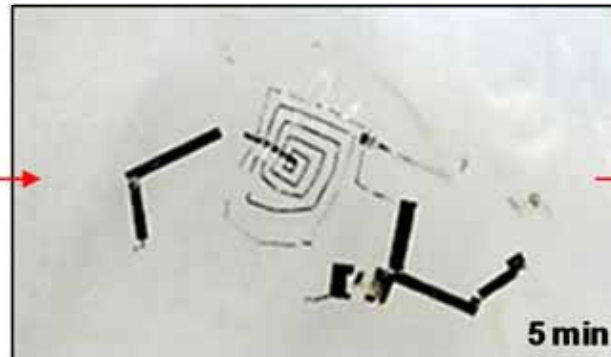
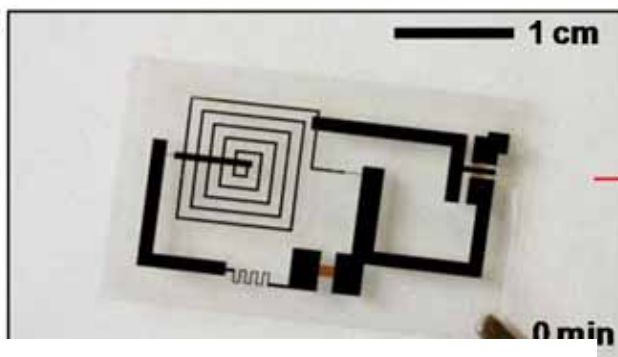
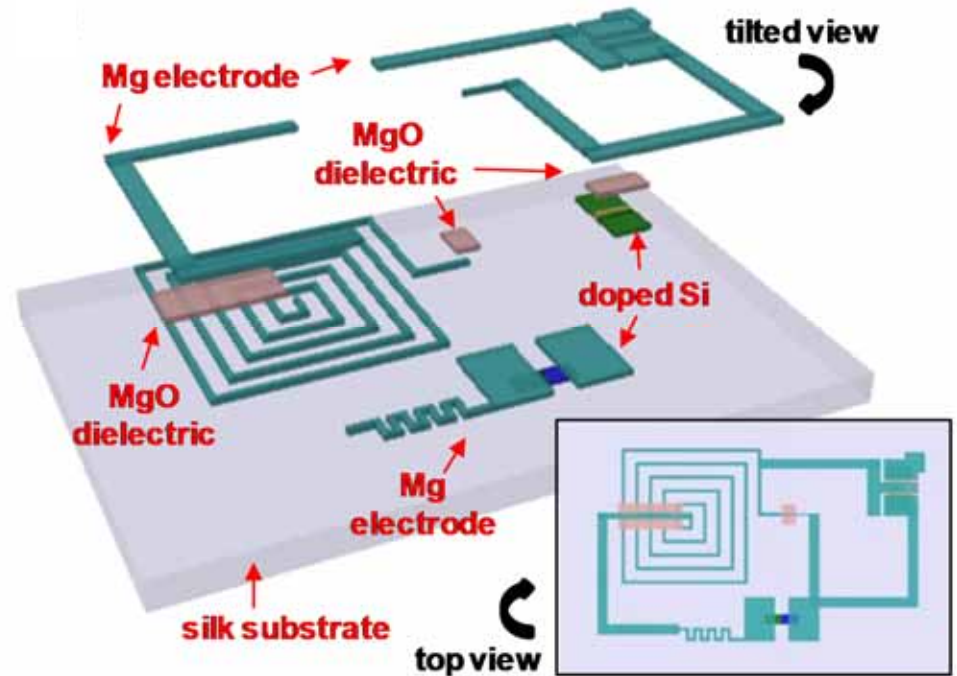
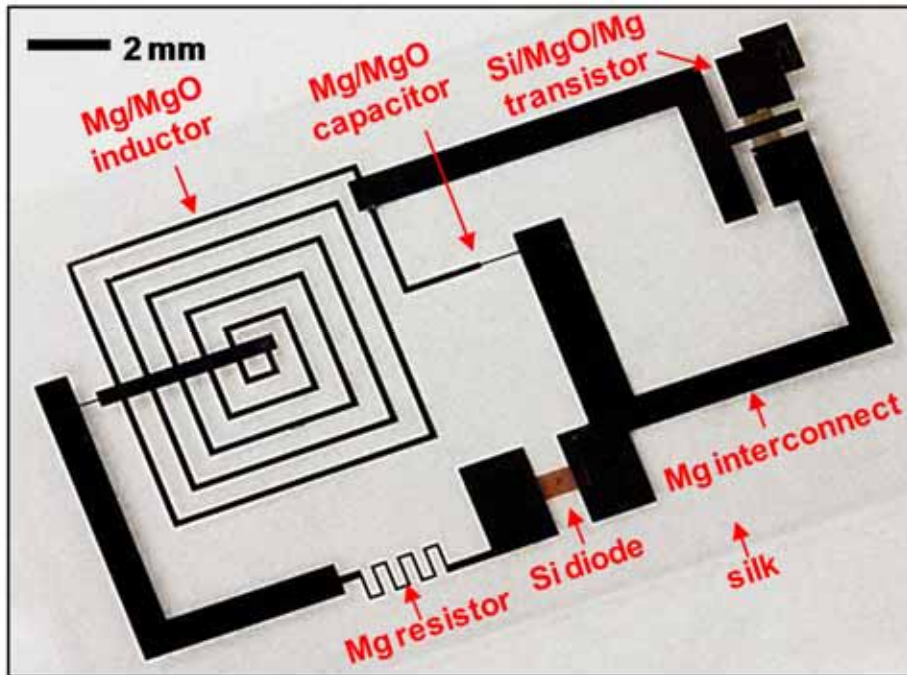


## Silicon is Water Soluble !

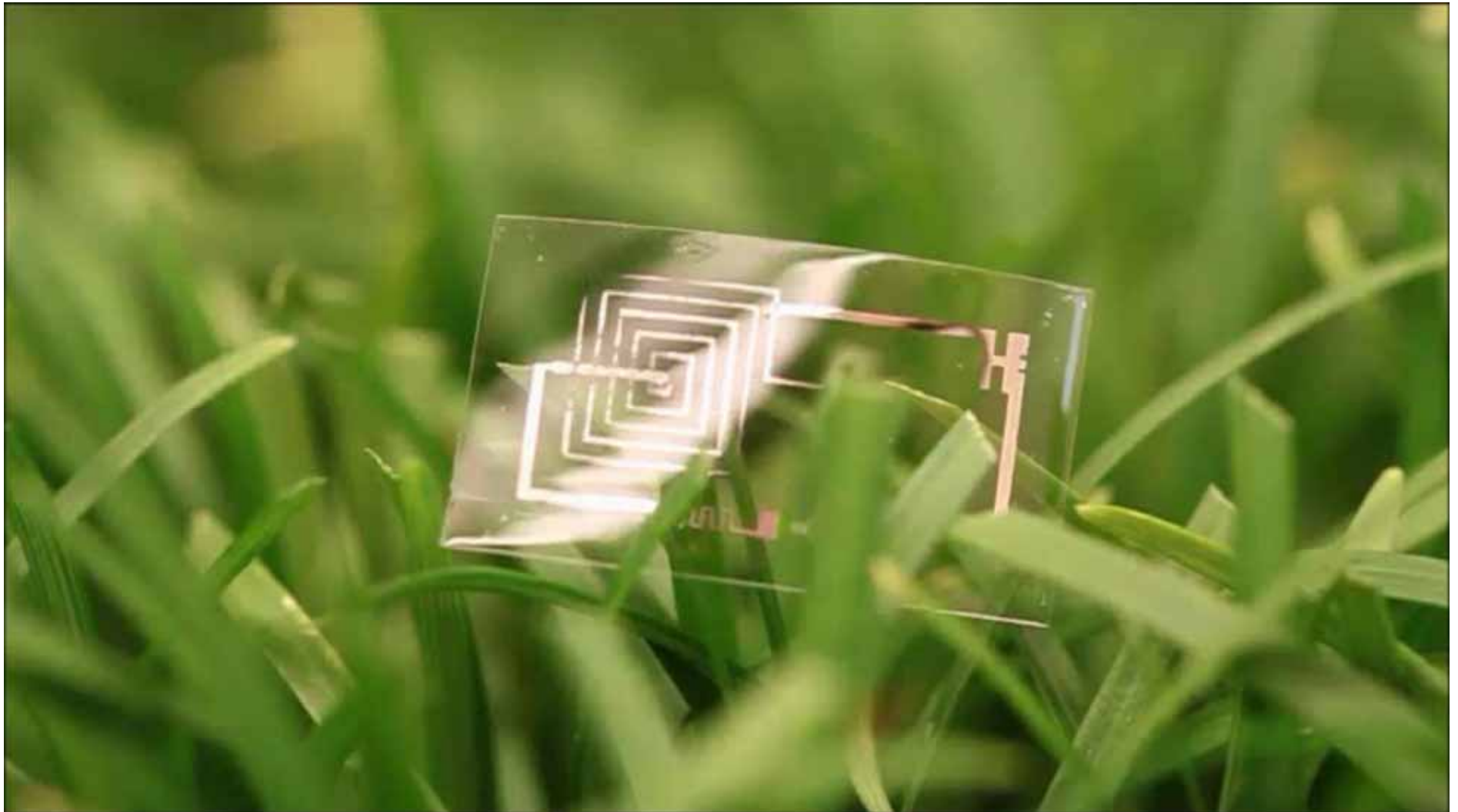


# Transient Electronics – Test Platform

## Si, SiO<sub>2</sub>, Mg, MgO and silk



Science **337**, 1640 (2012).





# Intracranial Monitors for TBI

## Current

Non-degradable → Secondary surgery  
Wired operation → Restricted movement  
External interface → Infection / hemorrhage

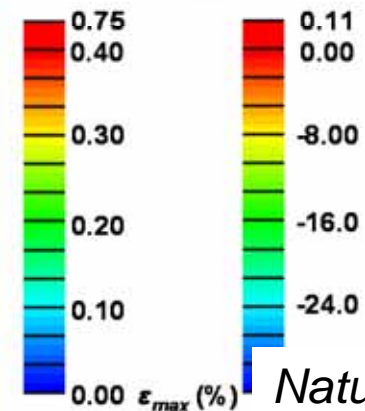
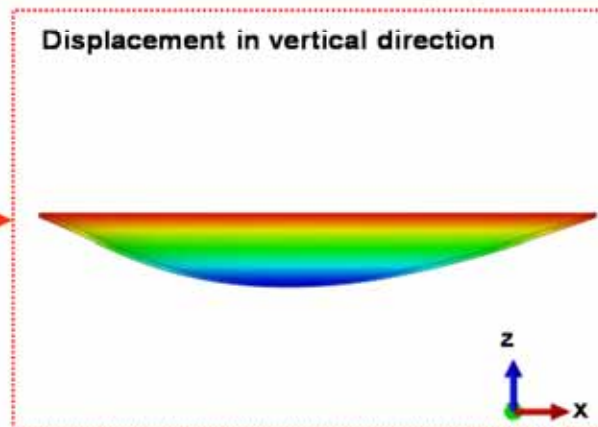
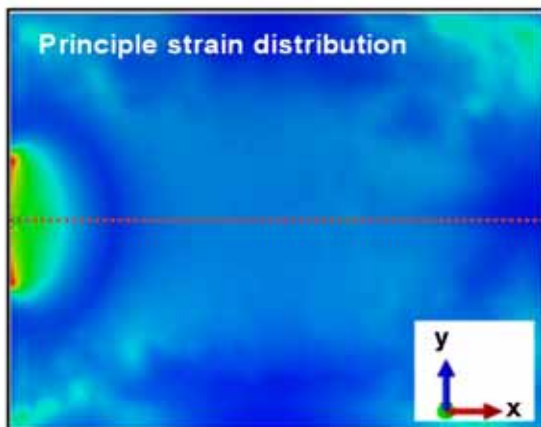
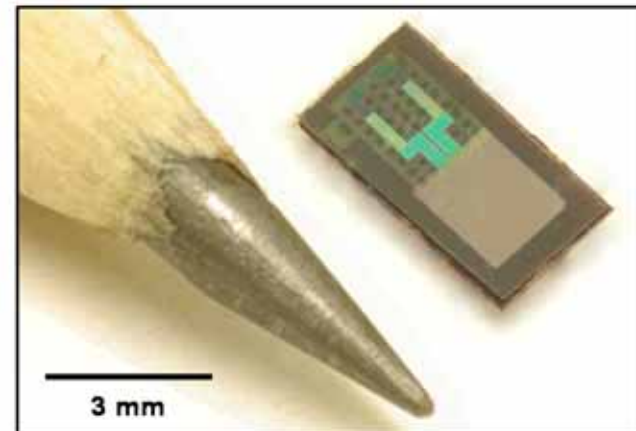
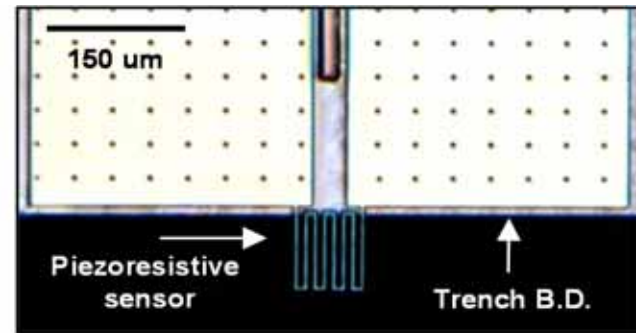
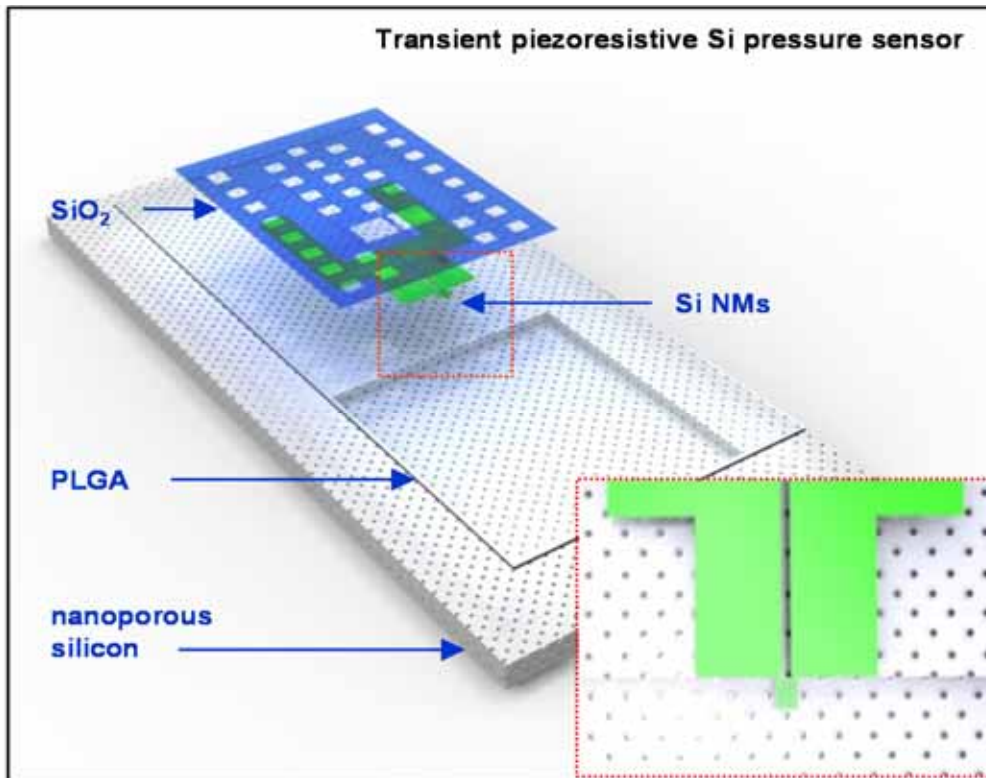


## Future

Bioresorbable → Eliminate extraction  
Wireless operation → Free movement  
Fully sutured → Safe, minimal risk



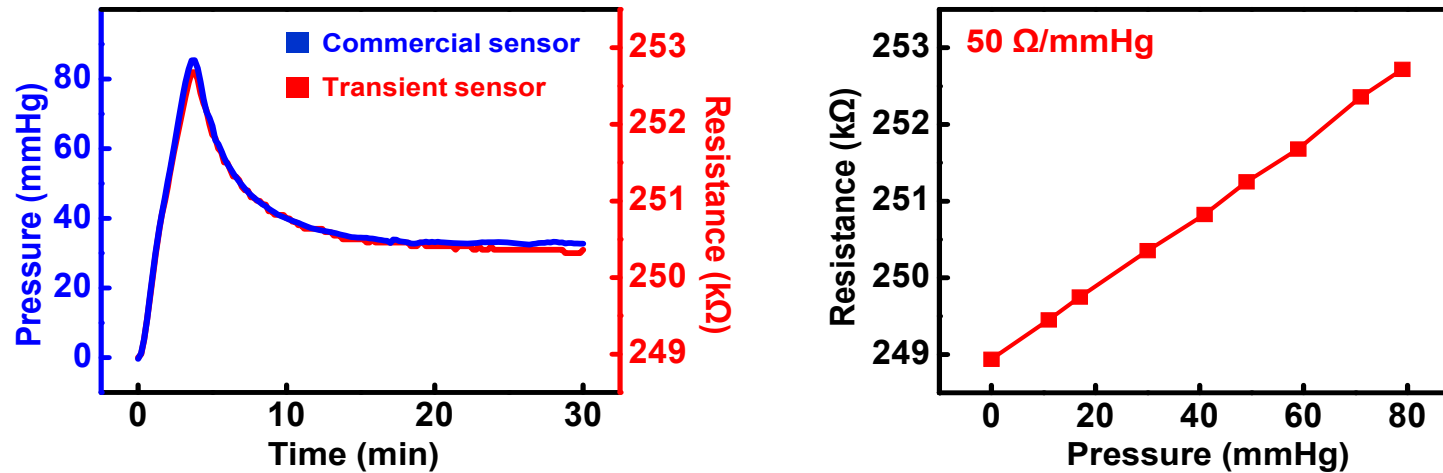
# Bioresorbable Intracranial Pressure Sensors for TBI



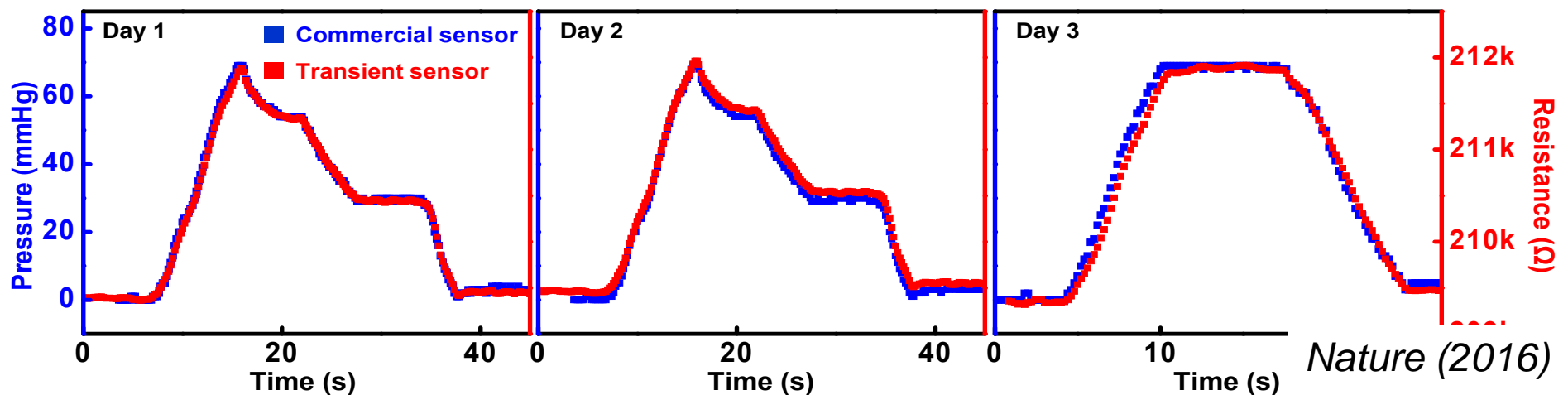
*Nature (2016)*

# Performance in Water and aCSF

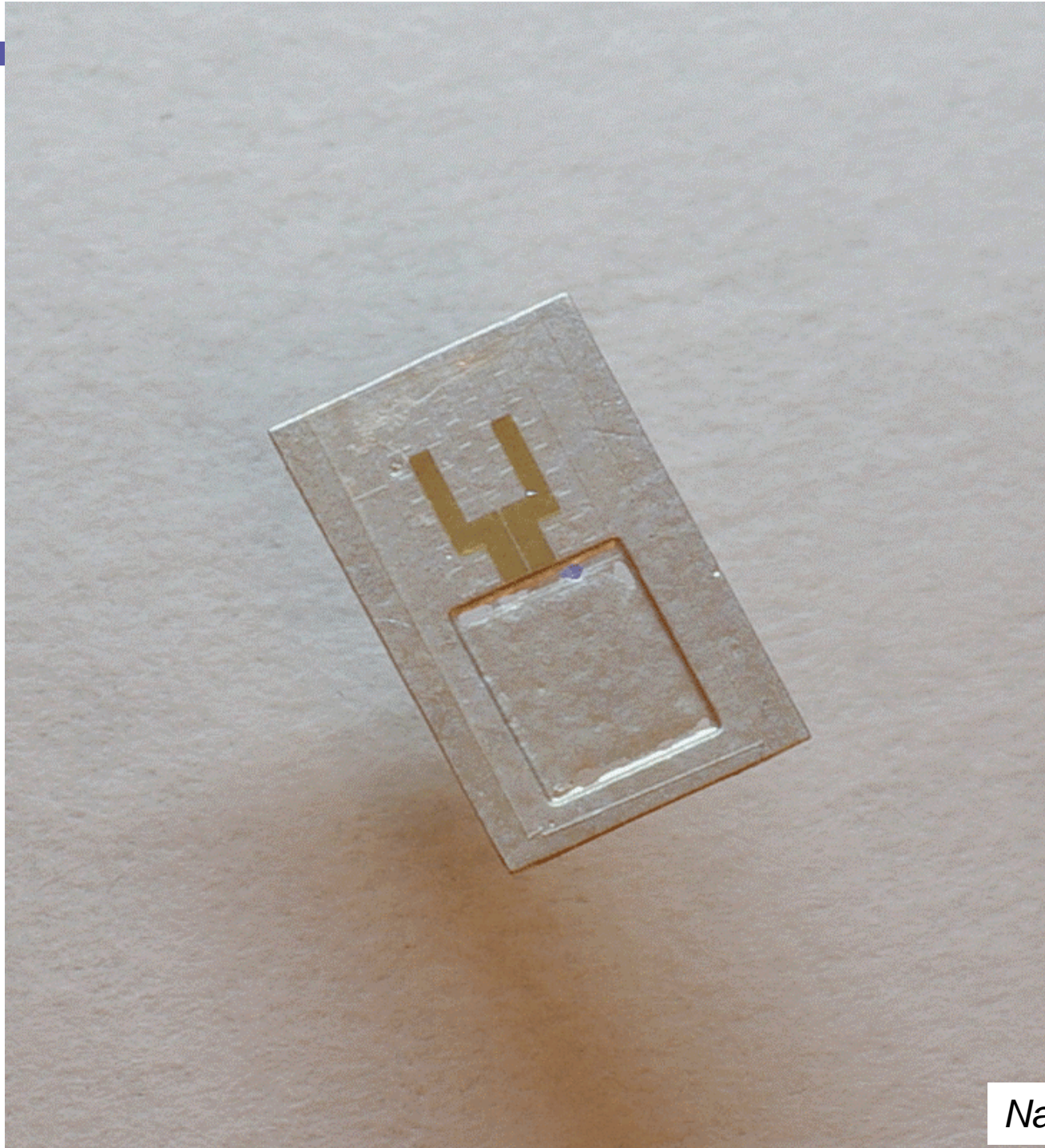
## In-vitro Operation in DI



## In-vitro Operation, With PLGA Encapsulation in aCSF @ 37 C





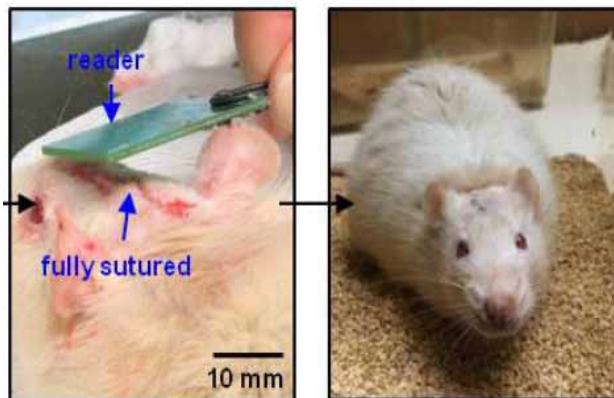
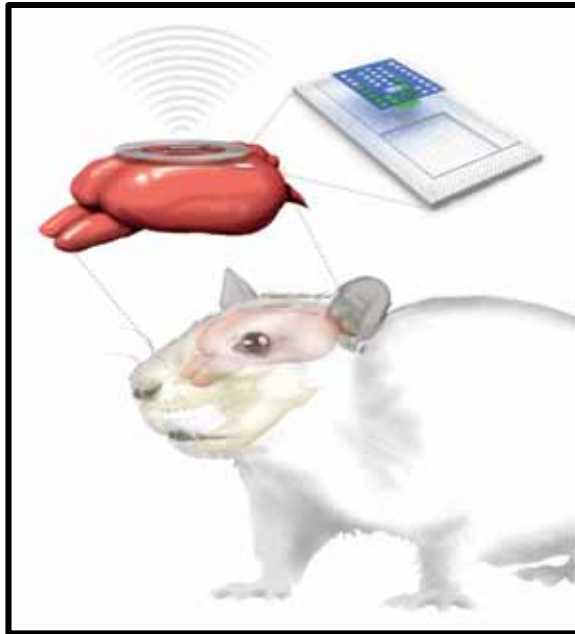


*Nature (2016)*

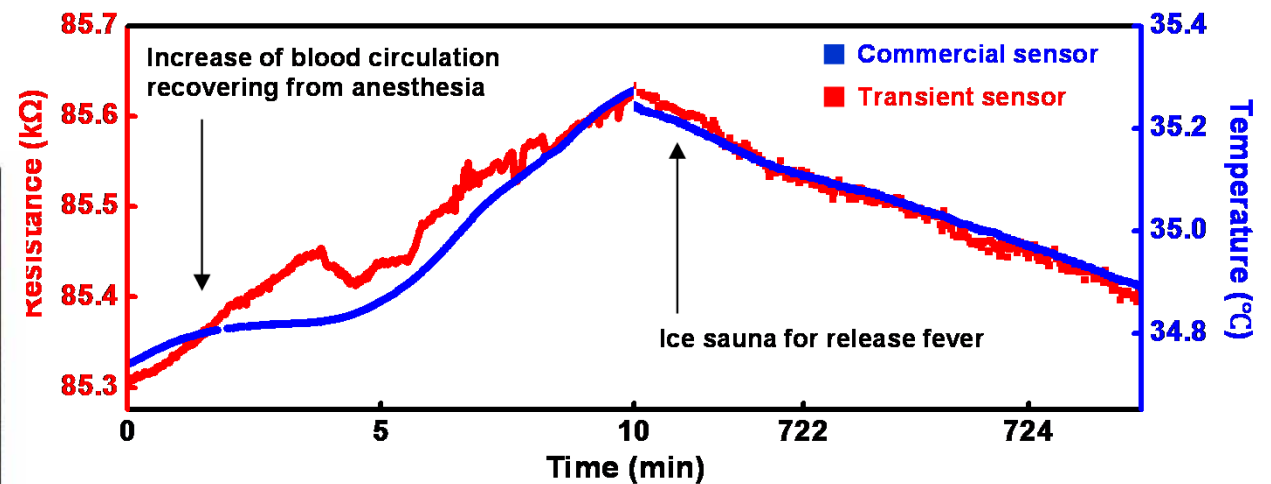
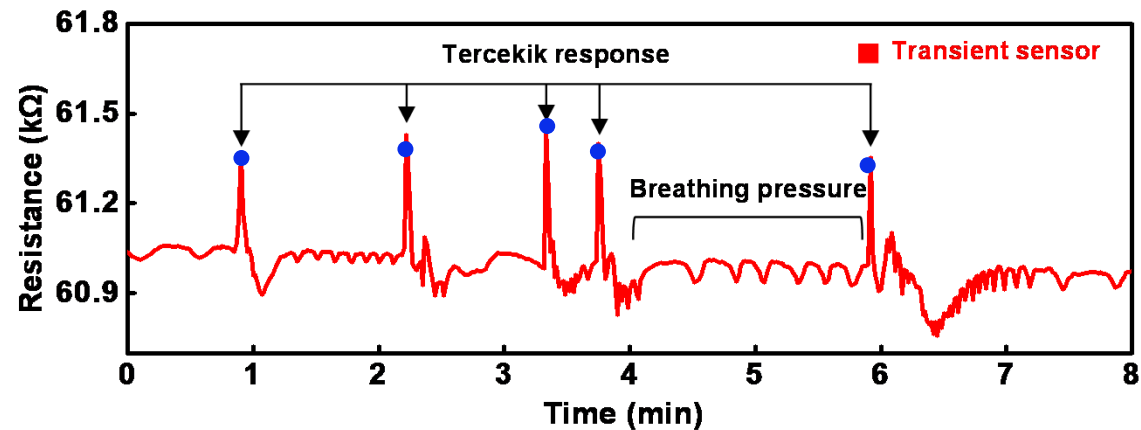


# In-vivo Wireless Monitoring – Pressure and Temperature

## Schematic



## In-vivo Results Using A Rat Model

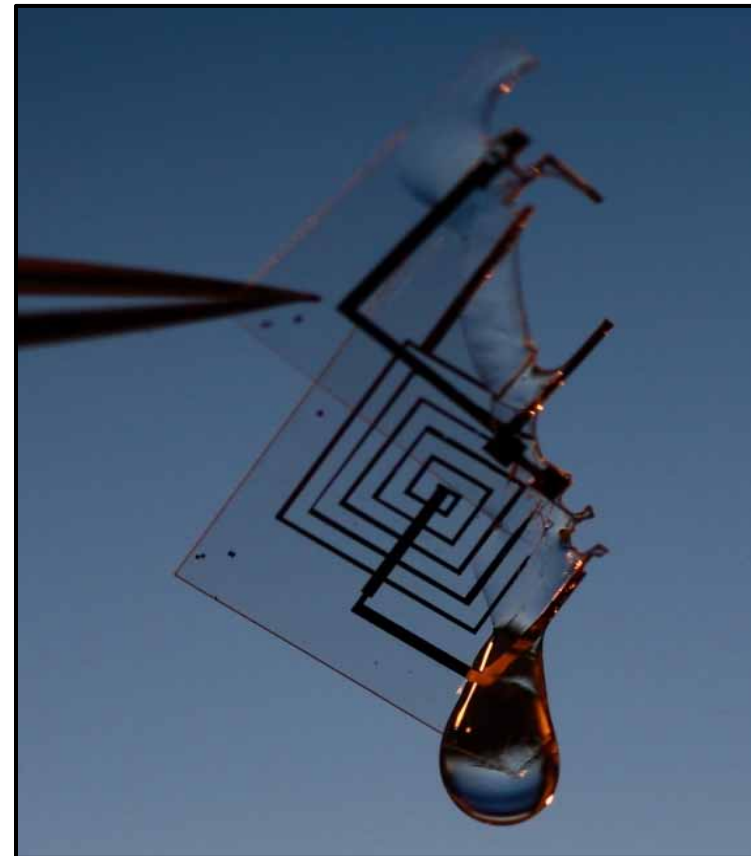


# The Future of Electronics is *Stretchy* and *Bioresorbable*

## *Epidermal* Electronics



## *Transient* Electronics



## Senior Collaborators

### Engineering Science

*Prof. Y. Huang (NU) – mechanics modeling*

*Prof. P. Ferreira (UIUC) – manufact.*

*Prof. R. Nuzzo (UIUC) – surf. chem.*

*Prof. X. Li (UIUC) – MOCVD*

*T. Lyszczarz (LL) – CMOS proc.*

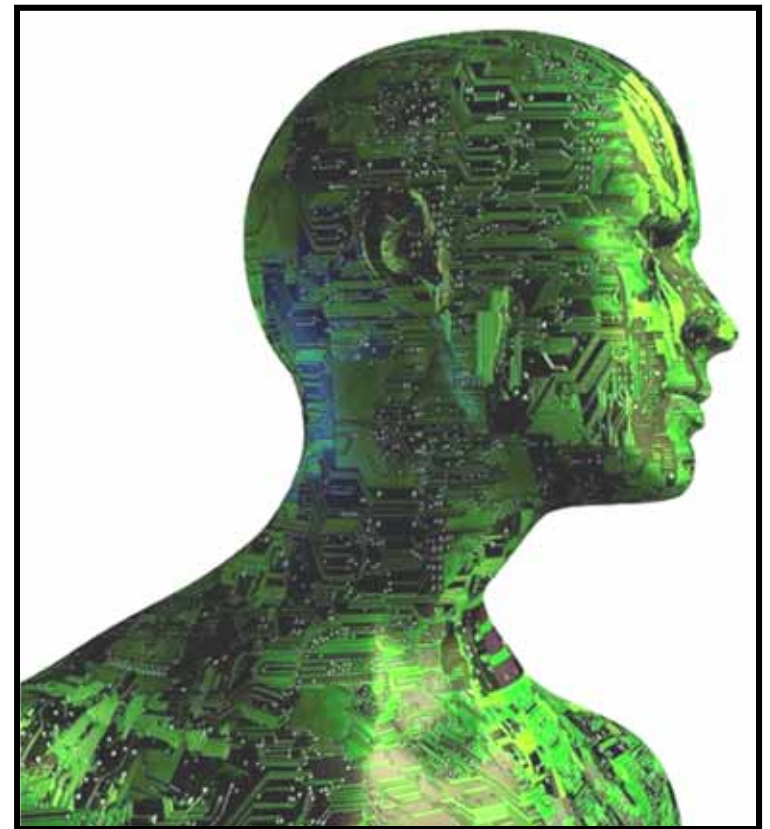
### Clinical Medicine

*Dr. B. Litt (Penn) – epilepsy*

*Dr. M. Kliot (NU) – neurosurgery*

*Dr. M. Slepian (Sarver) – cardiology*

*Dr. A. Paller (NU) – NICU*





# Rogers Research Group

