Epidermal Sensor Systems for Sensing and Therapy

New Modality for Wearable Electronics

IEEE Central Texas Consultants Network Meeting
May 25, 2016

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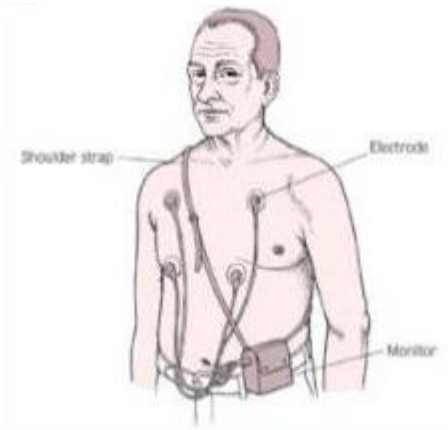
Cofounder and CEO
Stretch Med, Inc.



Wearable Health Monitoring Devices

Mood Control Headband (Thync)

Smart Glasses (Google etc.)

Smart Contact Lens for Blood Glucose Monitor (Google)

Wearable Interactive Projector (OmniTouch)

Fitness Tracking Vest (GPSport) Heart Rate Strap (Polar)

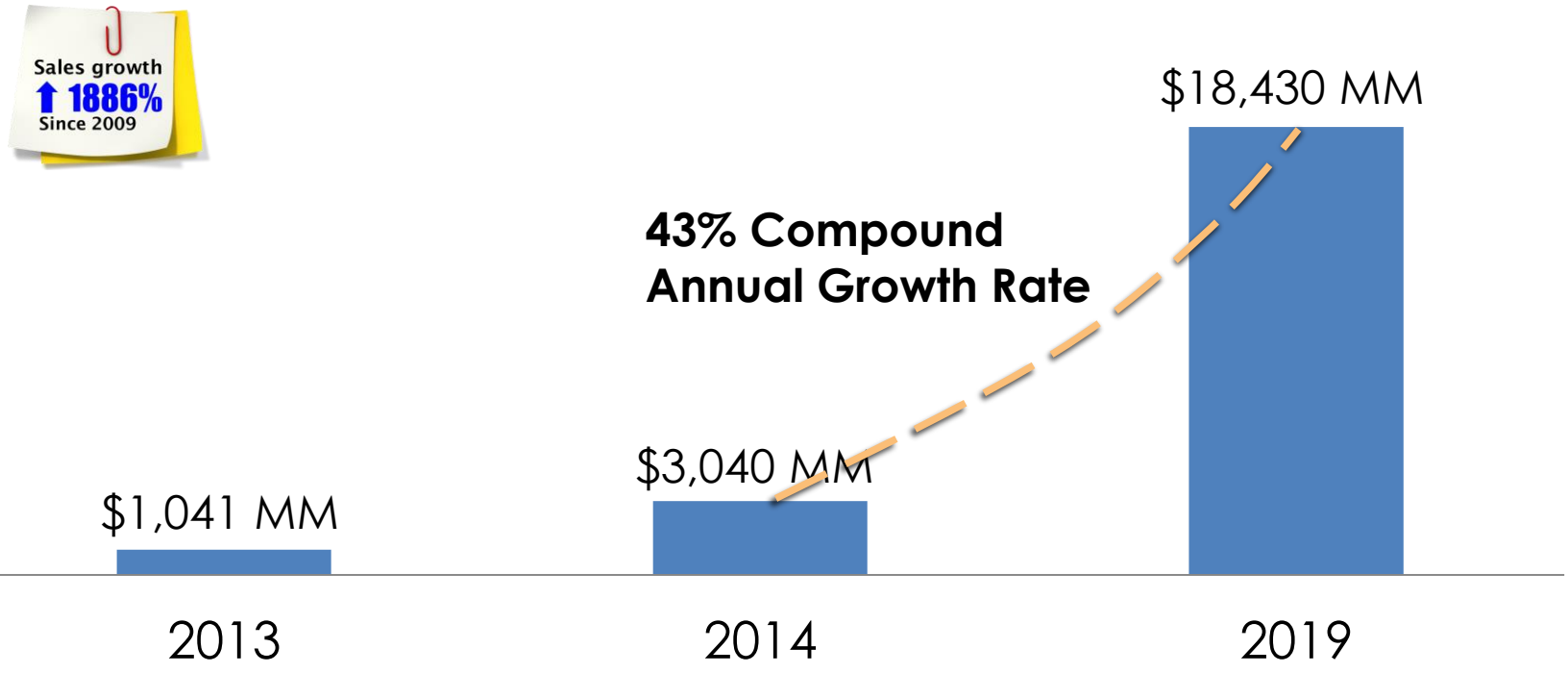
Navigation Footwear (Lechal etc.)

Smart Watch

Wearable Device Market

Global Market for Wearable Health and Fitness Monitoring Devices

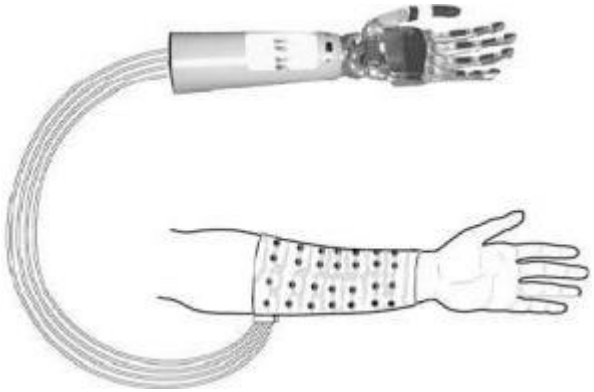
(Source: BCC research report, 2015)



Applications of Skin-Mounted Sensors

1. Mobile Health

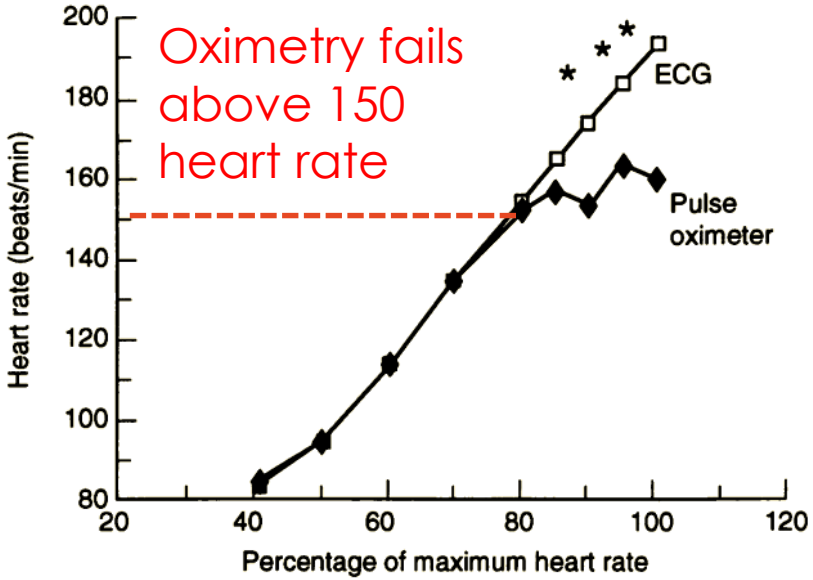
2. Human-Machine Interface



Challenges for Heart Rate Monitors

Inaccurate

Pulse oximetry: used in all smartwatches



Uncomfortable

ECG: gold standard for heart rate measurement

- ***Need to wet the strap***

"Works great - if you "Lick it like a Dog..."""

- ***Restrict chest movement***

"Slips when it gets to wet."

- ***Cause skin irritation***

"Chafes, doesn't work reliably."

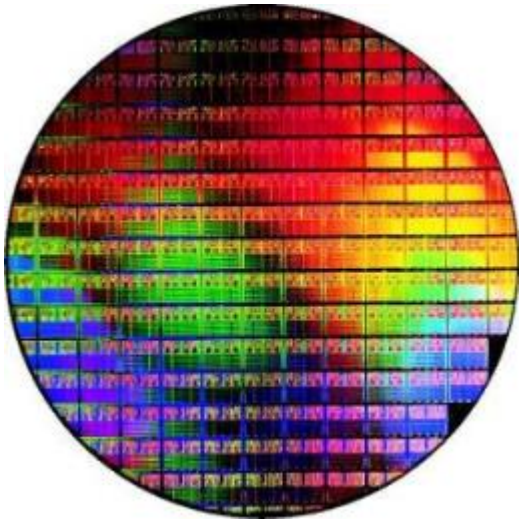
Quotes from customer feedbacks on Amazon.com

Iyriboz, Y., *et. al.*, *British Journal of Sports Medicine*, ***25***, *162 (1991)*

When Bio Meets Electronics

Soft
Curvilinear
Dynamic

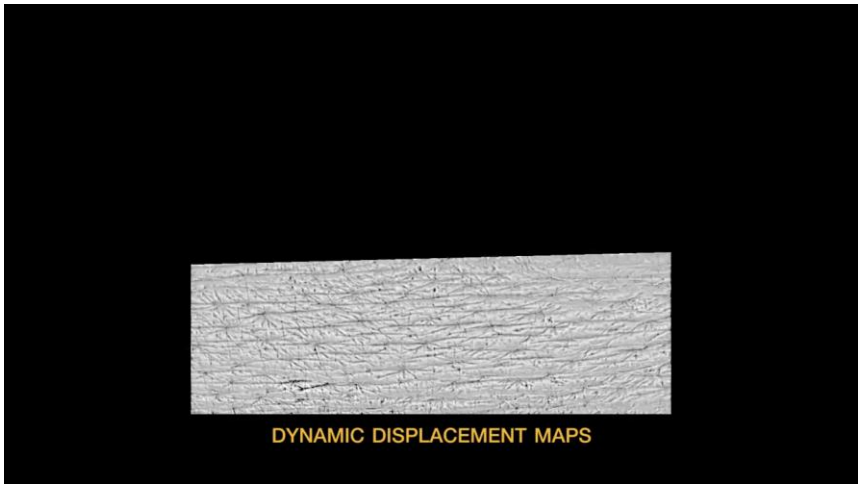
VS.



Hard
Planar
Rigid

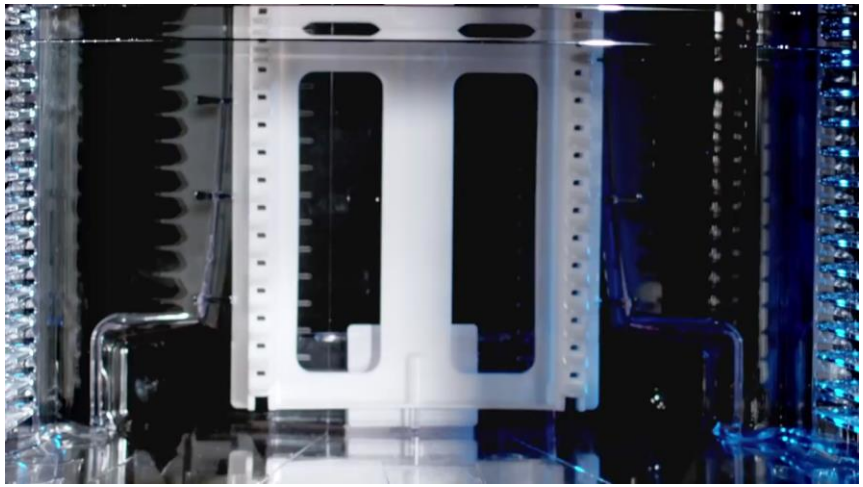
Skin vs. Silicon

$E_{Skin} = 130 \times 10^3$ Pa



Credit: ICTGraphicsLab @ USC

$E_{Si} = 130 \times 10^9$ Pa

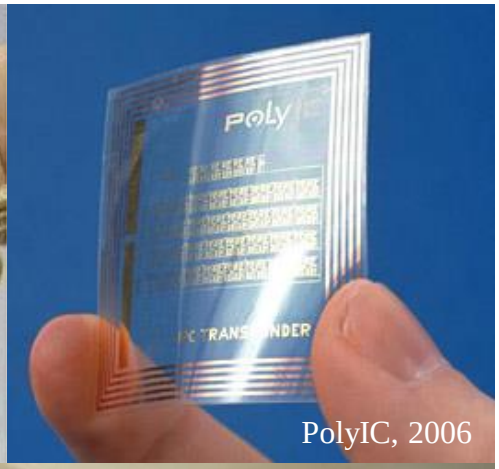


Credit: Intel

Flexible Electronics

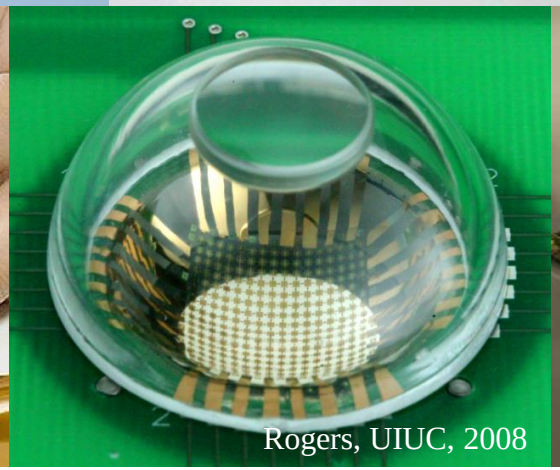

PowerFilm, 2004

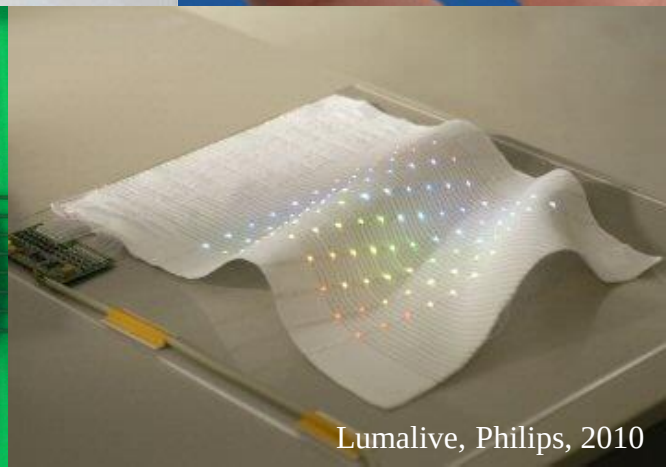

Someya, U of Tokyo, 2005



PolyIC, 2006


Sony, 2007


Rogers, UIUC, 2008

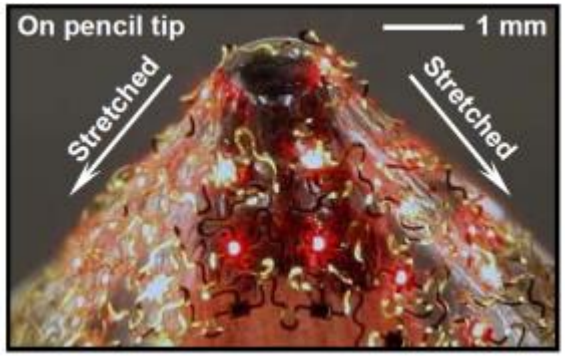

Lumalive, Philips, 2010

Stretchable Electronics

Stretchable Transistors

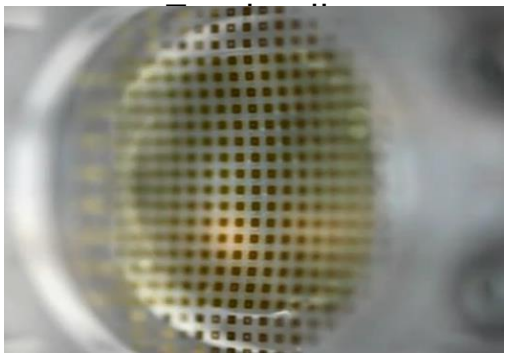
Science **321**, 1468 (2008).

Conformal LED



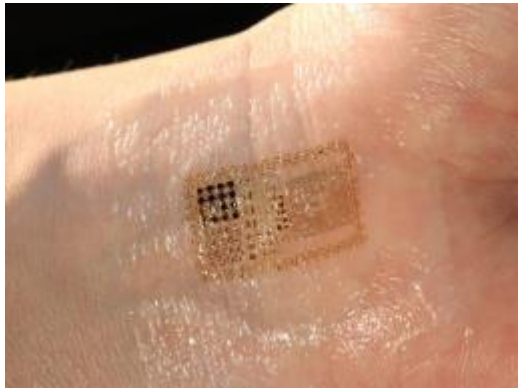
Nature Materials **9**, 929 (2010).

Tunable Electronic



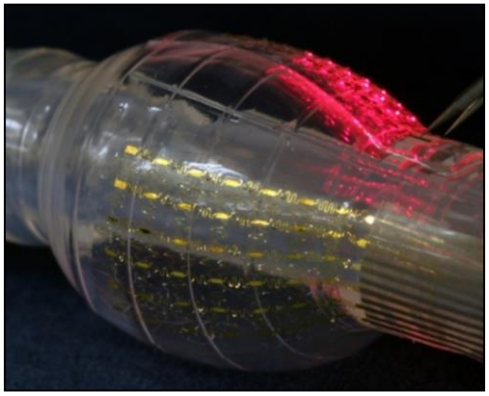
PNAS **108**, 1788 (2010).

Epidermal Electronics



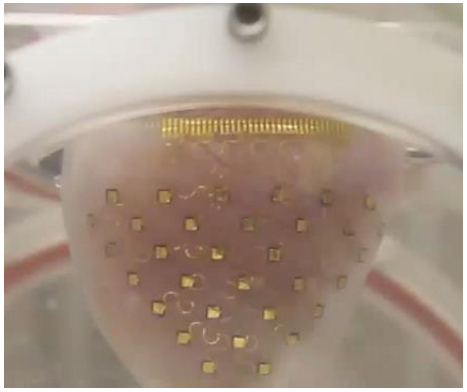
Science **333**, 838 (2011).

Balloon Catheter



Nature Materials **10**, 316 (2011).

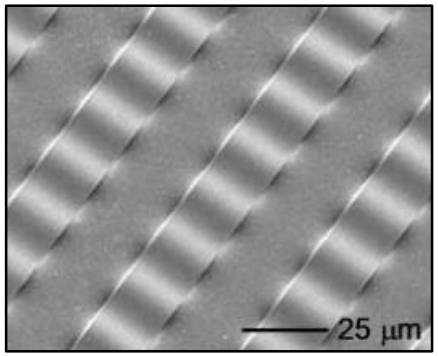
Heart "Sock"

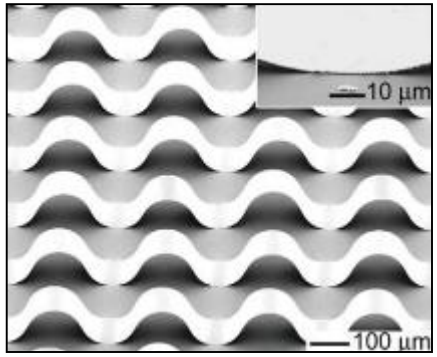


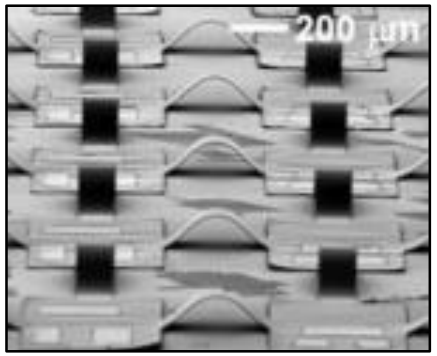
Nature Comm. **5**, 3329 (2014).

Strategies for Stretchable Electronics

Out-of-Plane Buckling





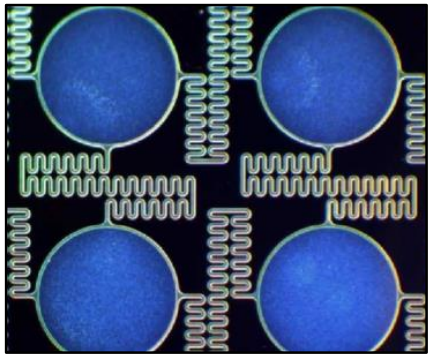


Nat. Nanotech. **1**, 201 (2006)

PNAS **105**, 18675 (2008)

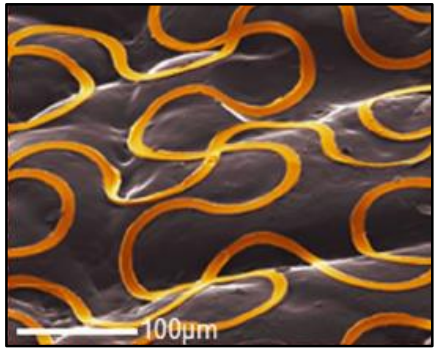
In-Plane Serpentines

Island + serpentine



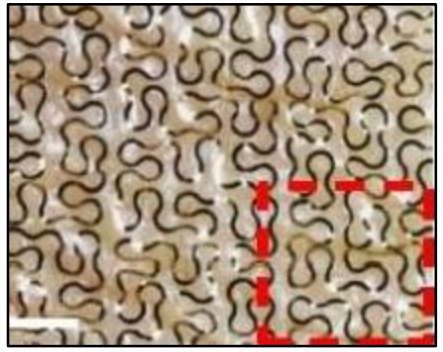
Nat. Comm. 4, 1543 (2008)

Filamentary serpentine

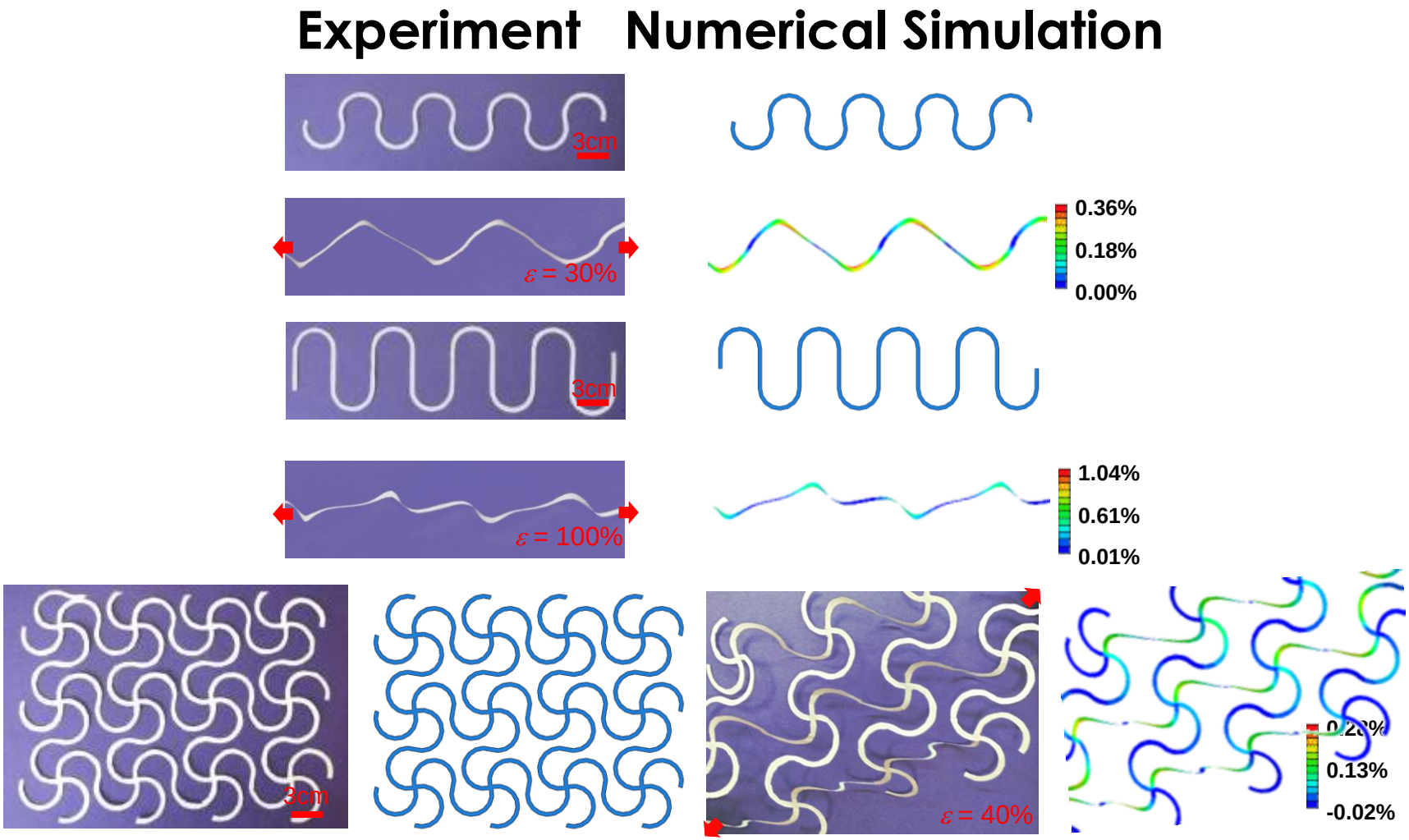


Adv. Mat. **25**, 2773 (2012)

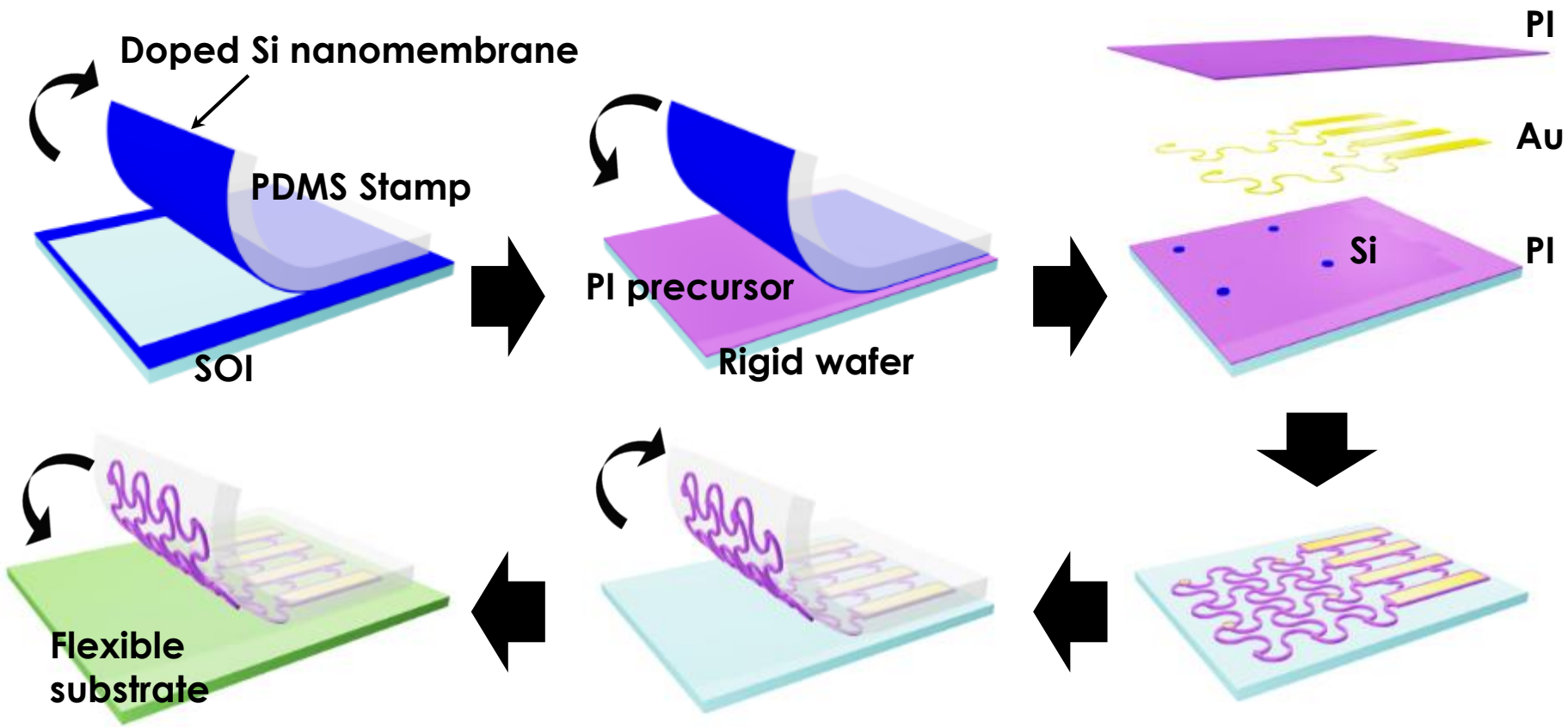
Fractal serpentine



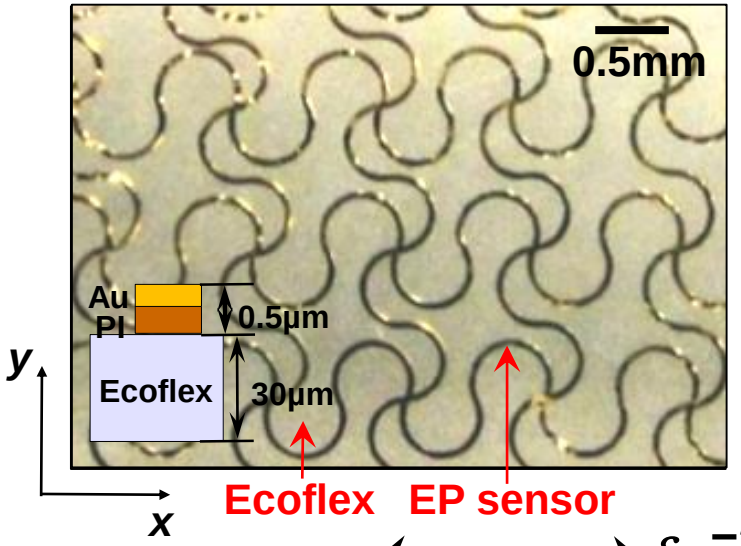
Stretchable Structure - Serpentine

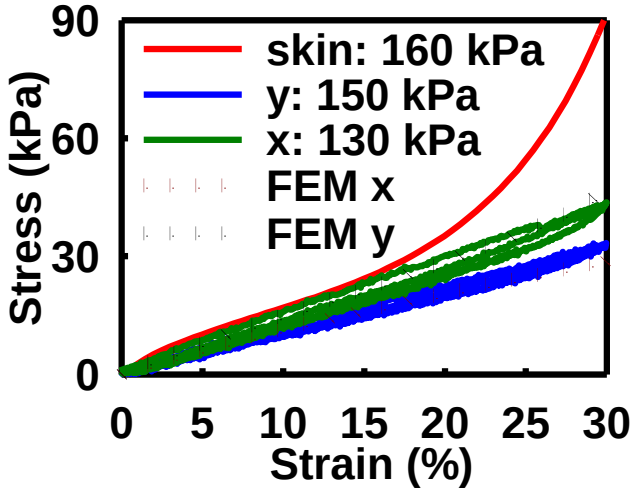


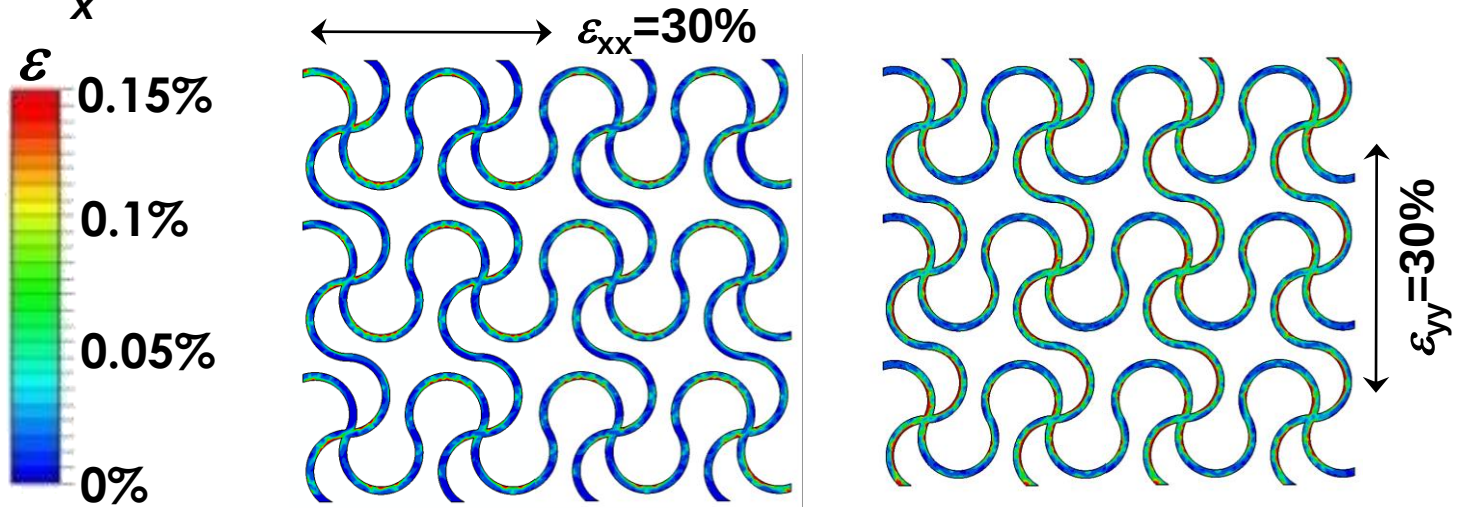
Microfabrication of Stretchable Electronics



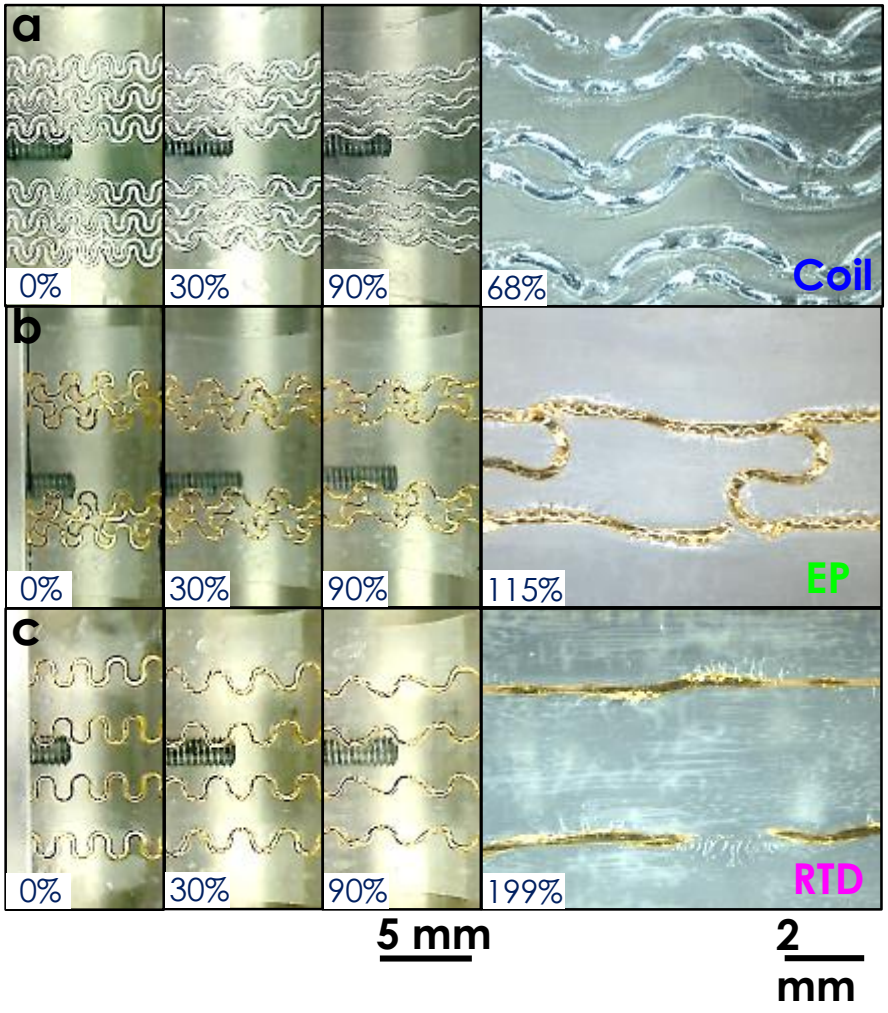
Compliance of Filamentary Serpentines

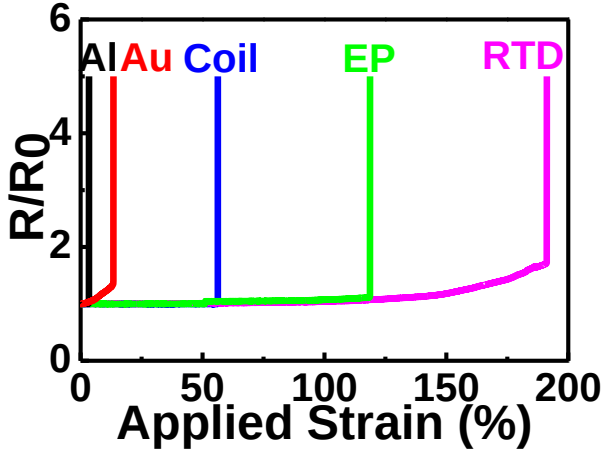


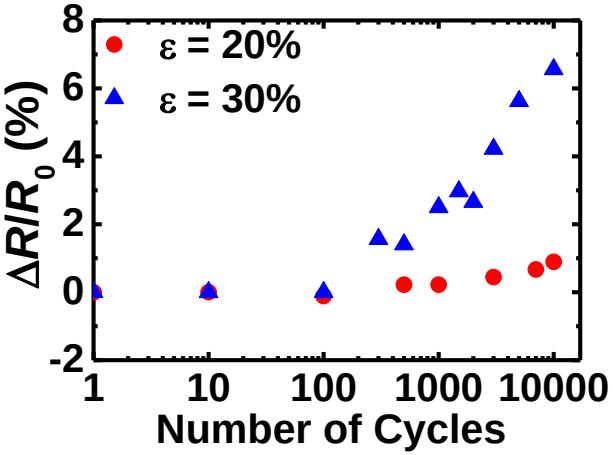




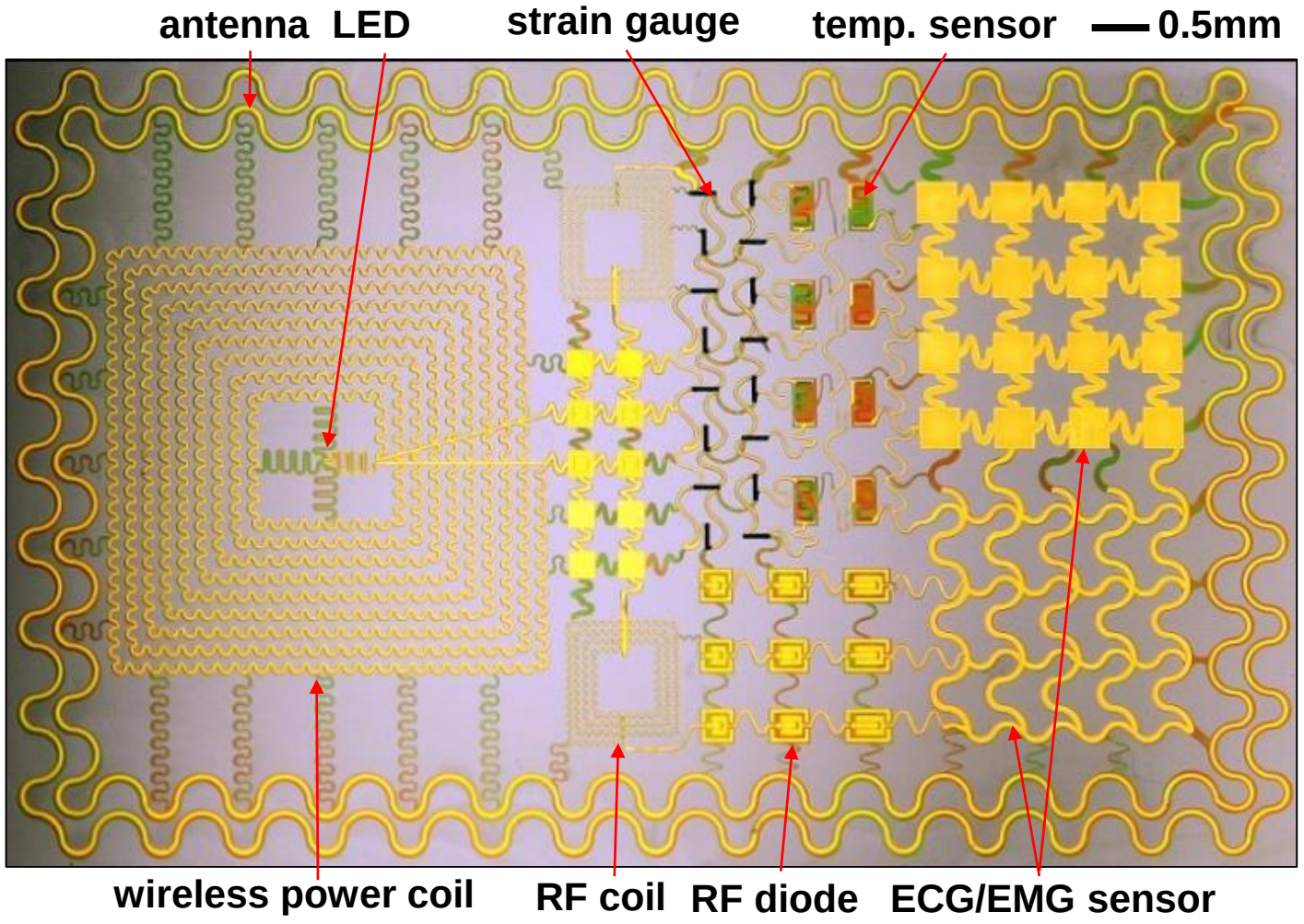
Stretchability & Cycleability







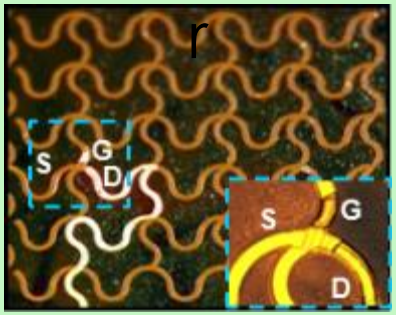
Multi-Functionality



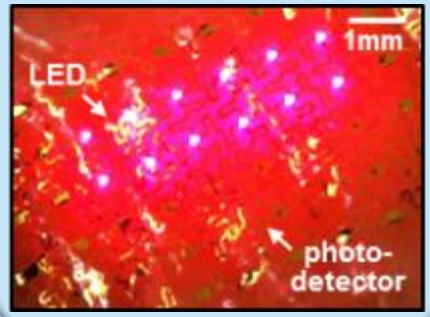
Kim*, Lu*, Ma* (*equal contribution), Rogers, *et al.*, *Science* **333**, 838, (2011).

Apps

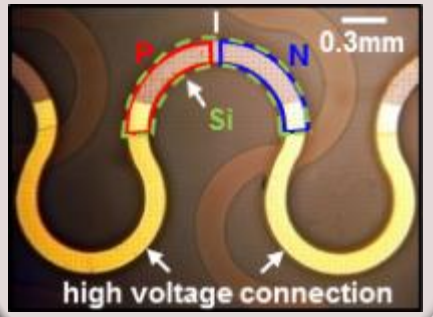
Amplifier



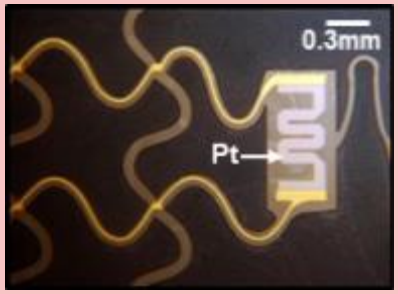
LED



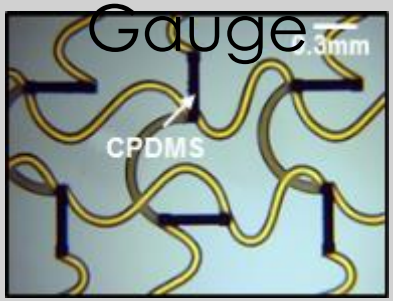
Solar Cell



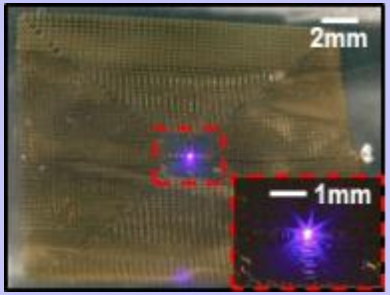
T Sensor



ε Gauge

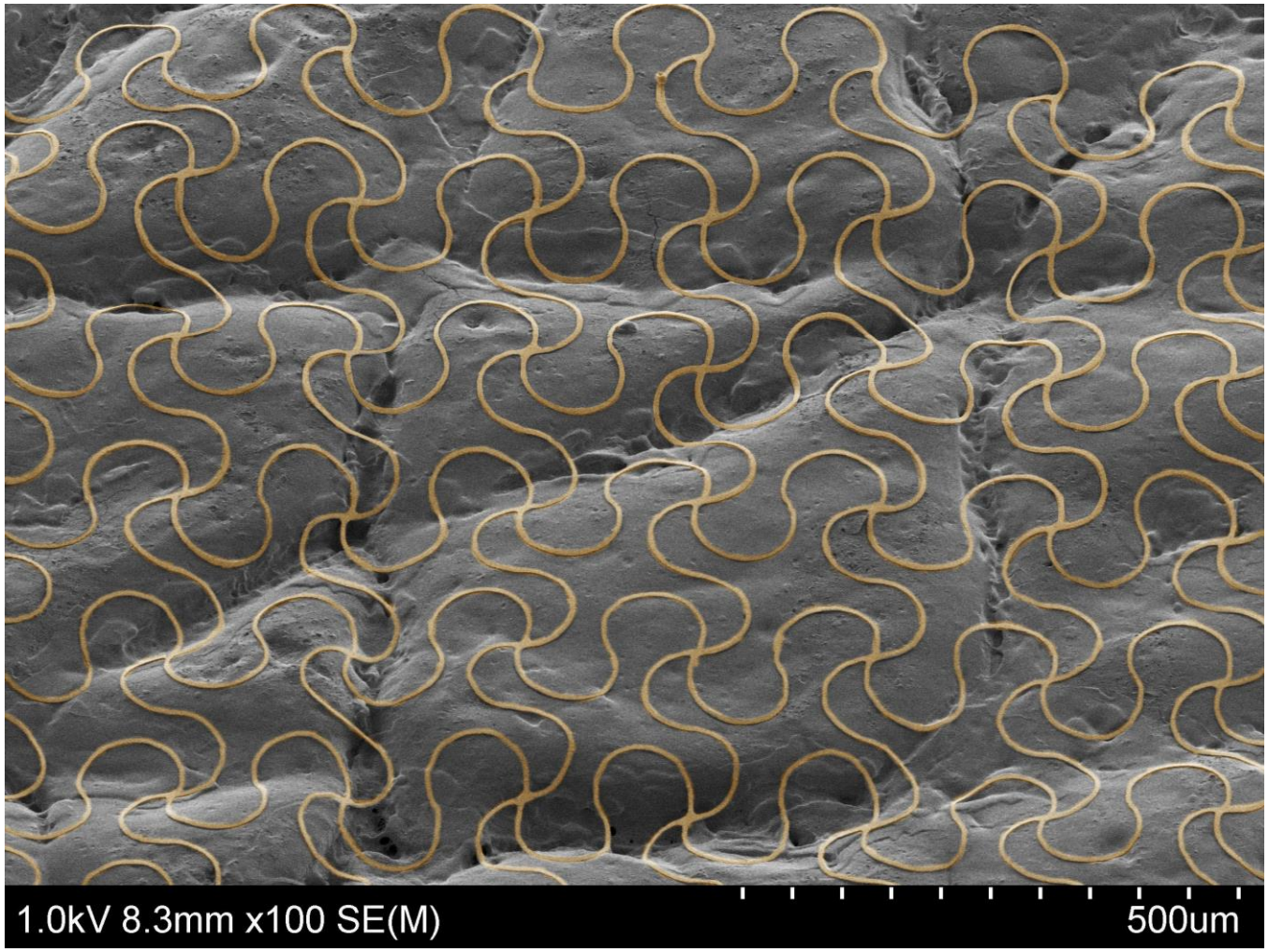


L Coil



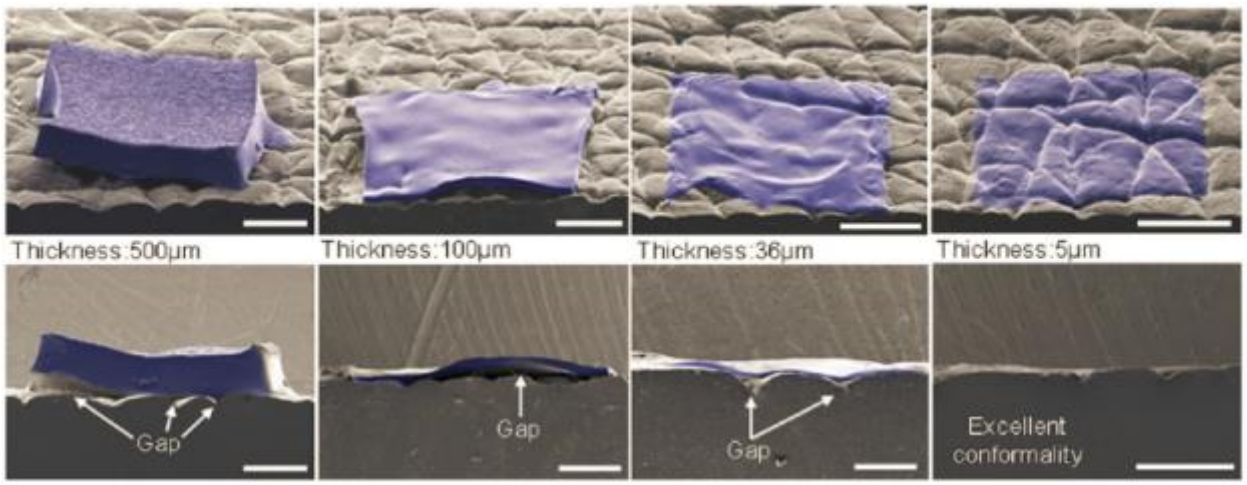
Mounting and Removal of Epidermal Electronics

Epidermal Electronics on A Skin Replica

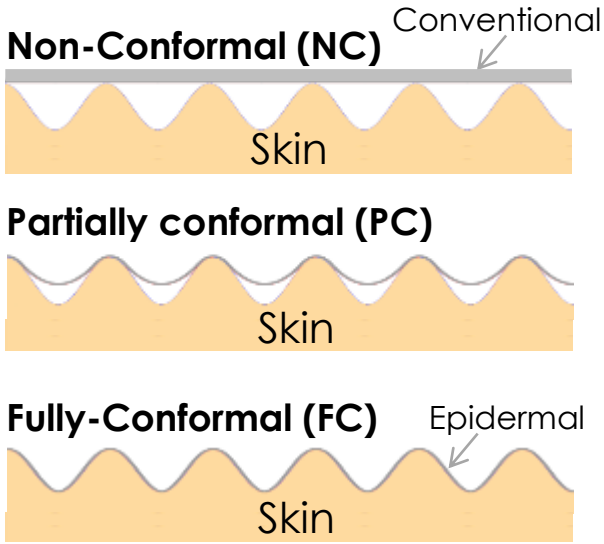


Yeo, Rogers, *et al*, *Advanced Materials* 25, 2773–2778 (2013).

Why Is Conformability Important?

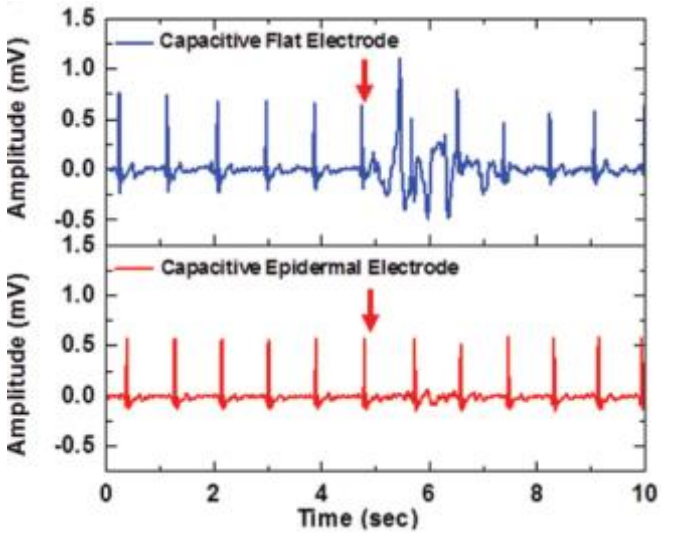


Jeong, *et. al.*, *Adv. Mater.* **2013**, 25, 6839



Conformable contact ensures

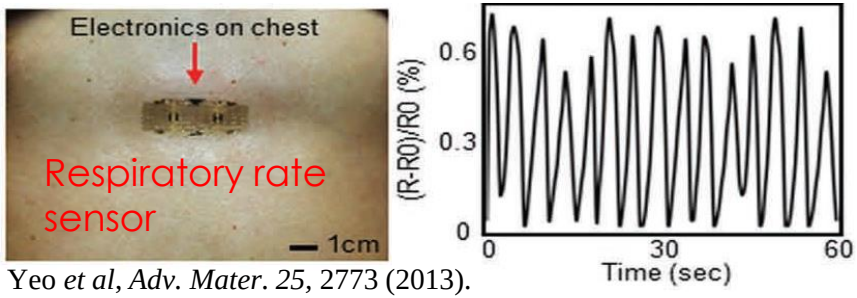
- Low interface impedance → higher signal to noise ratio
- Less relative motion → less motion artifacts
- Better heat or mass transfer



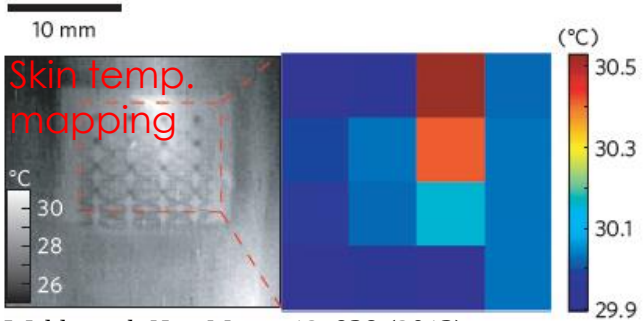
Jeong, *et. al.*, *Adv. Healthcare Mater.* **2014**, 3, 642–648

Recent Development in Epidermal Electronics

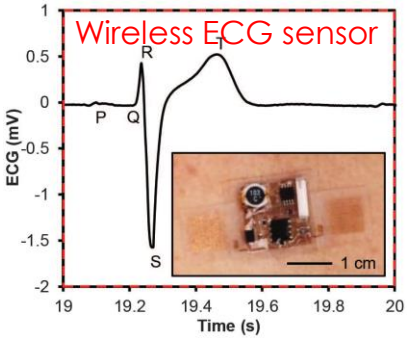
Kim*, **Lu***, Ma* (*equal contribution), Rogers, *et al.*, *Science* **333**, 838, (2011).



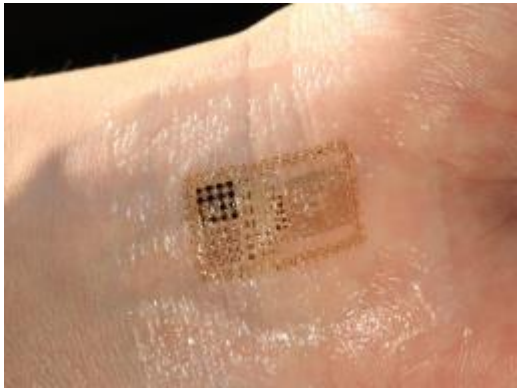
Yeo *et al*, *Adv. Mater.* *25*, 2773 (2013).



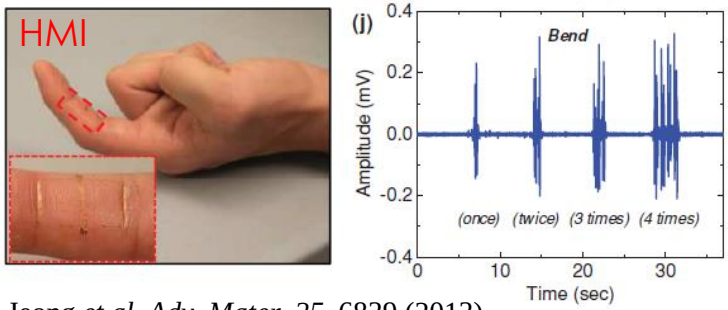
Webb *et al*, *Nat. Mater.* 12, 938 (2013).



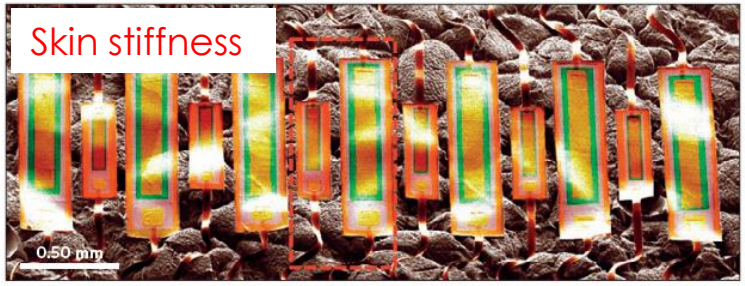
Xu *et al*, *Science* 344, 70 (2014).



Son *et al*, *Nat. Nanotech.* 9, 397 (2014).

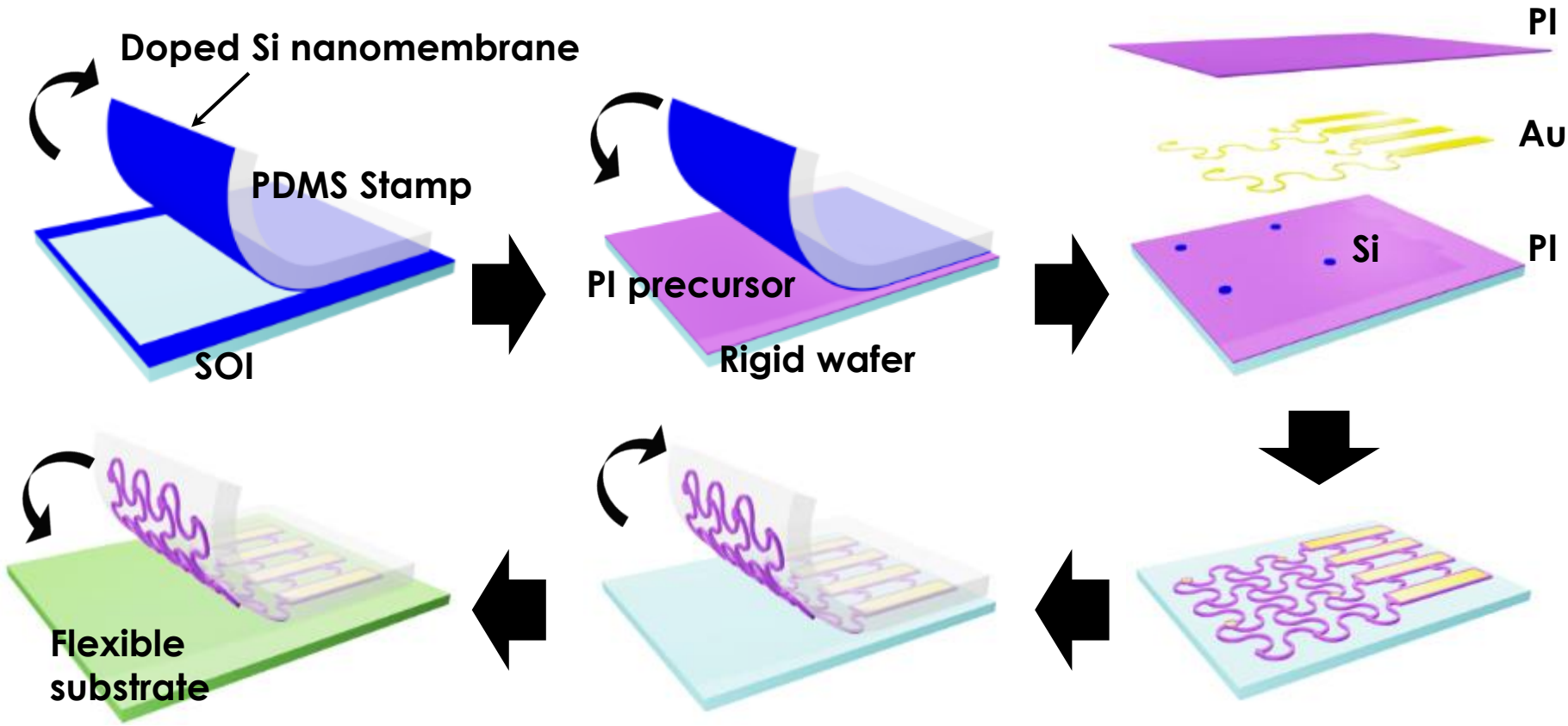


Jeong *et al*, *Adv. Mater.* *25*, 6839 (2013).



Dagdeviren *et al*, *Nat. Mater.* *14*, 728 (2015).

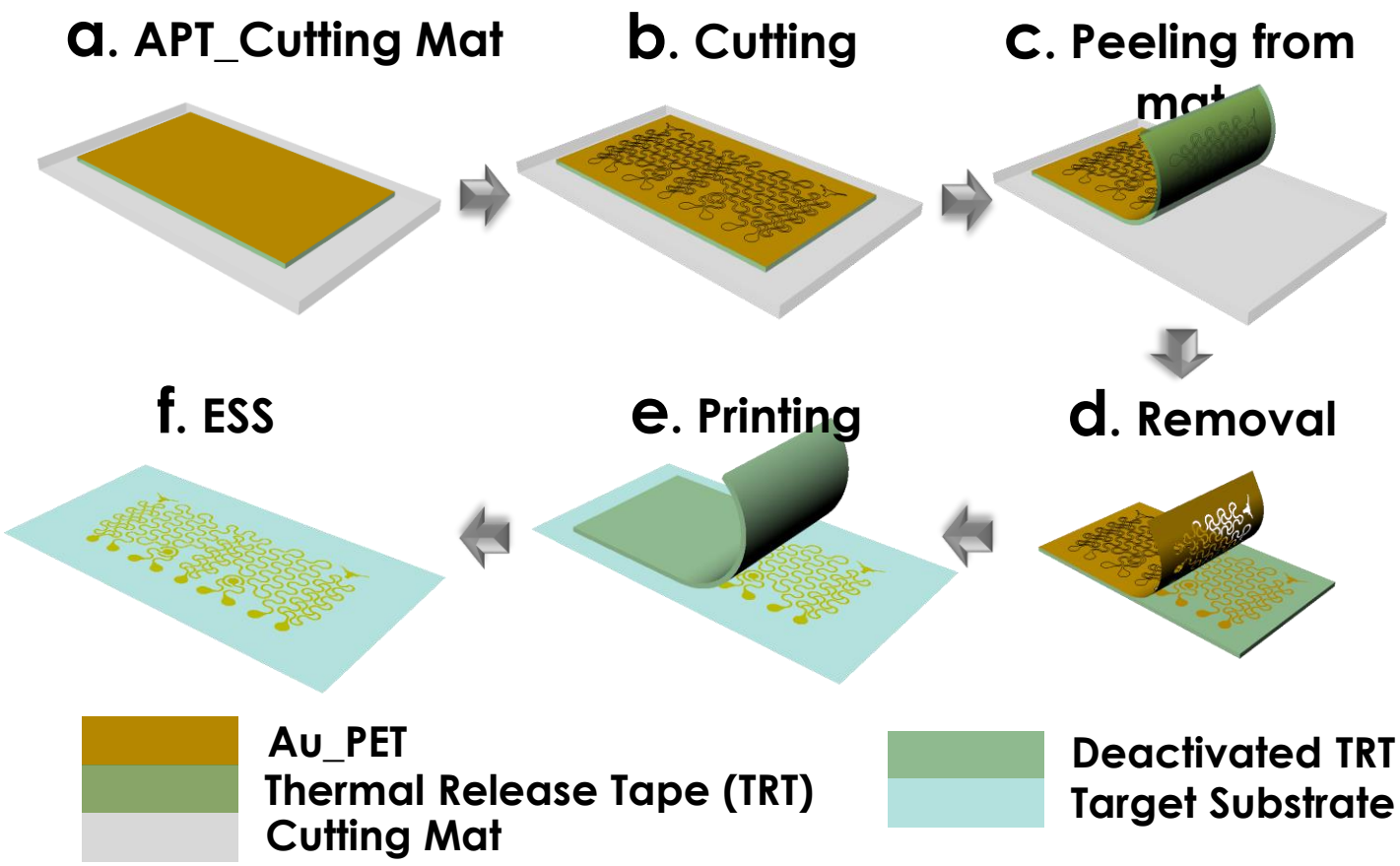
Microfabrication of Stretchable Electronics



Cleanroom, time consuming, low yield, high cost, wafer-based

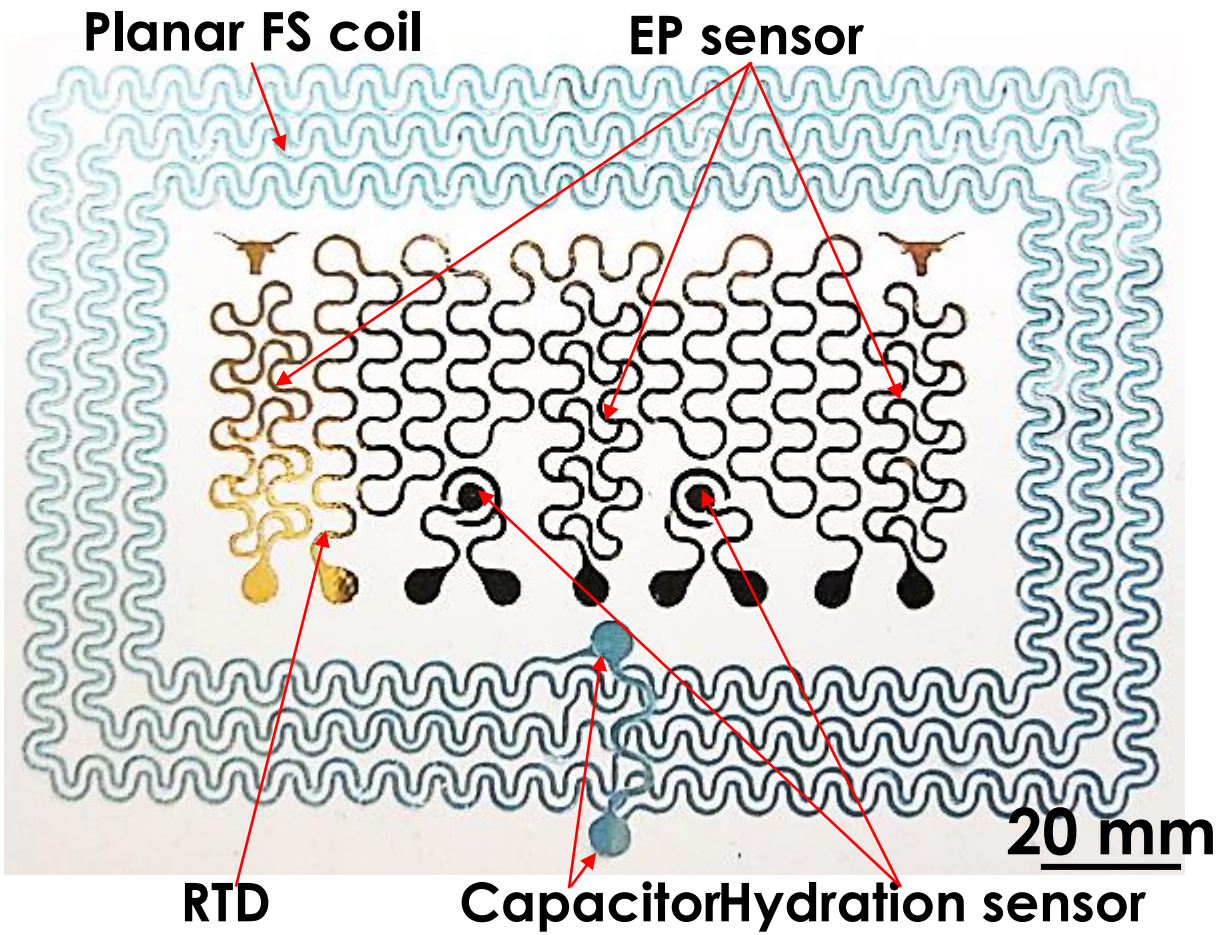
Cost and Time Effective "Cut-and-Paste" Method

Yang, *et al*, *Adv. Mater.* DOI: 10.1002/adma.201502386 (2015).

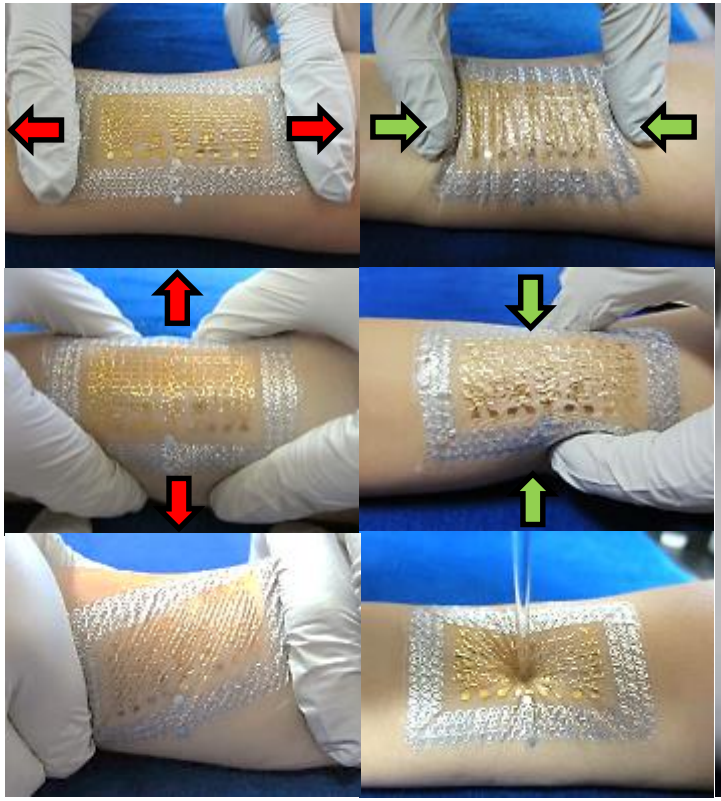


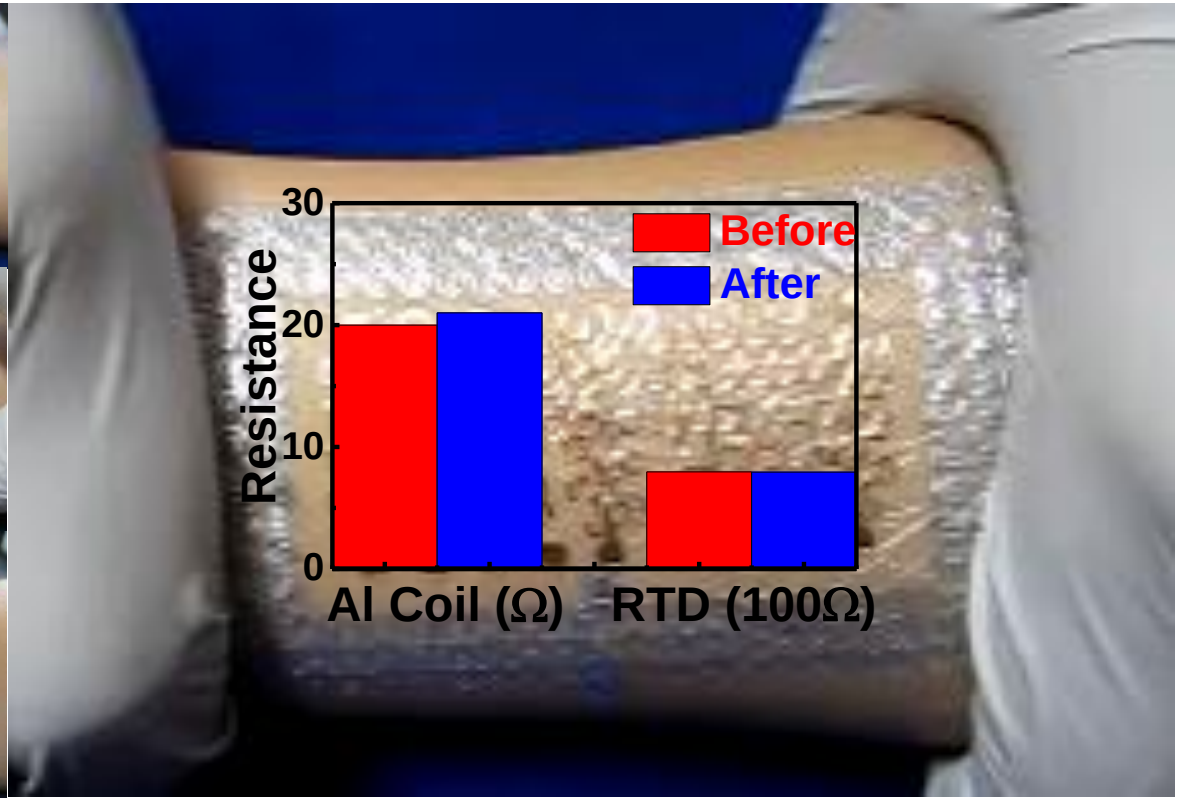
Subtractive, dry, desktop, portable, green & roll-to-roll compatible

Multiparametric Epidermal Sensor System



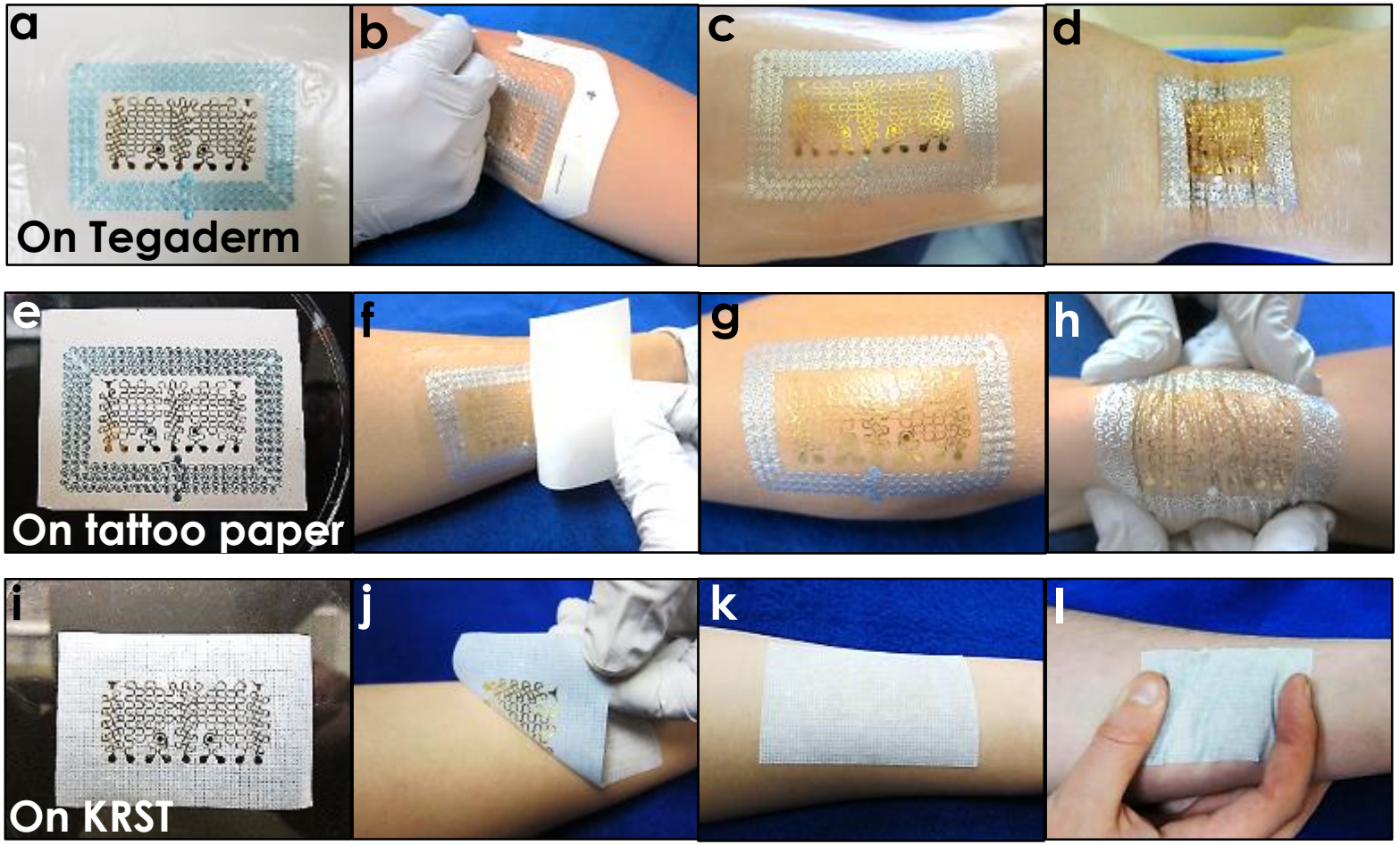
Disposable Epidermal Sensor System (ESS)





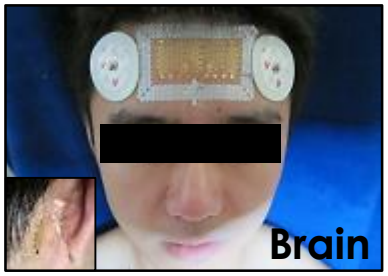
Yang, *et al*, *Adv. Mater.* DOI: 10.1002/adma.201502386 (2015).

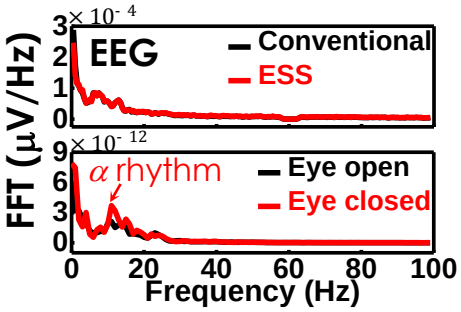
Different Types of Substrates

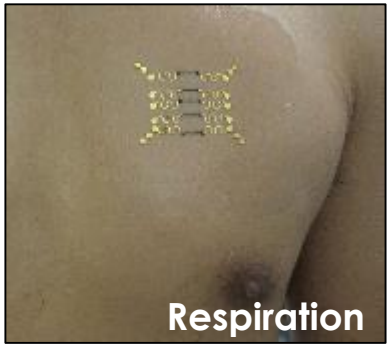


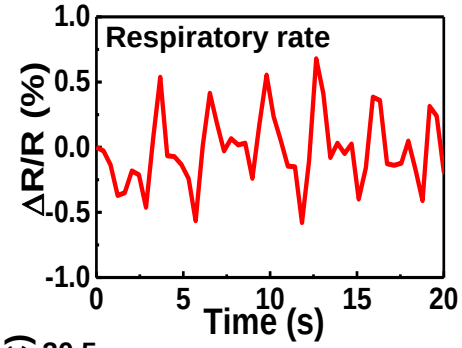
Yang, *et al*, *Adv. Mater.* DOI: 10.1002/adma.201502386 (2015).

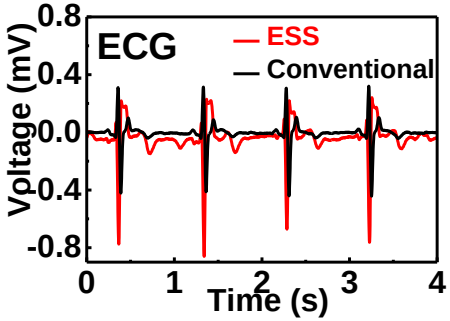
Multifunctional Epidermal Sensor System (ESS)

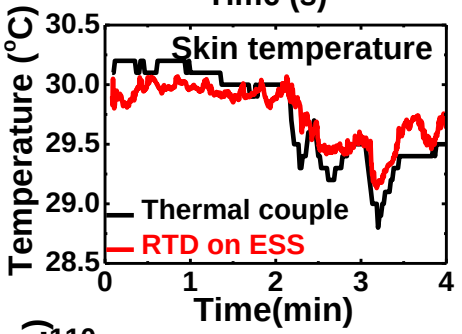


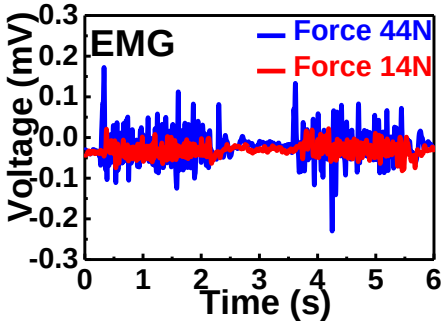


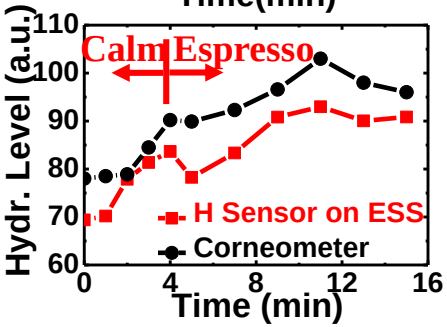






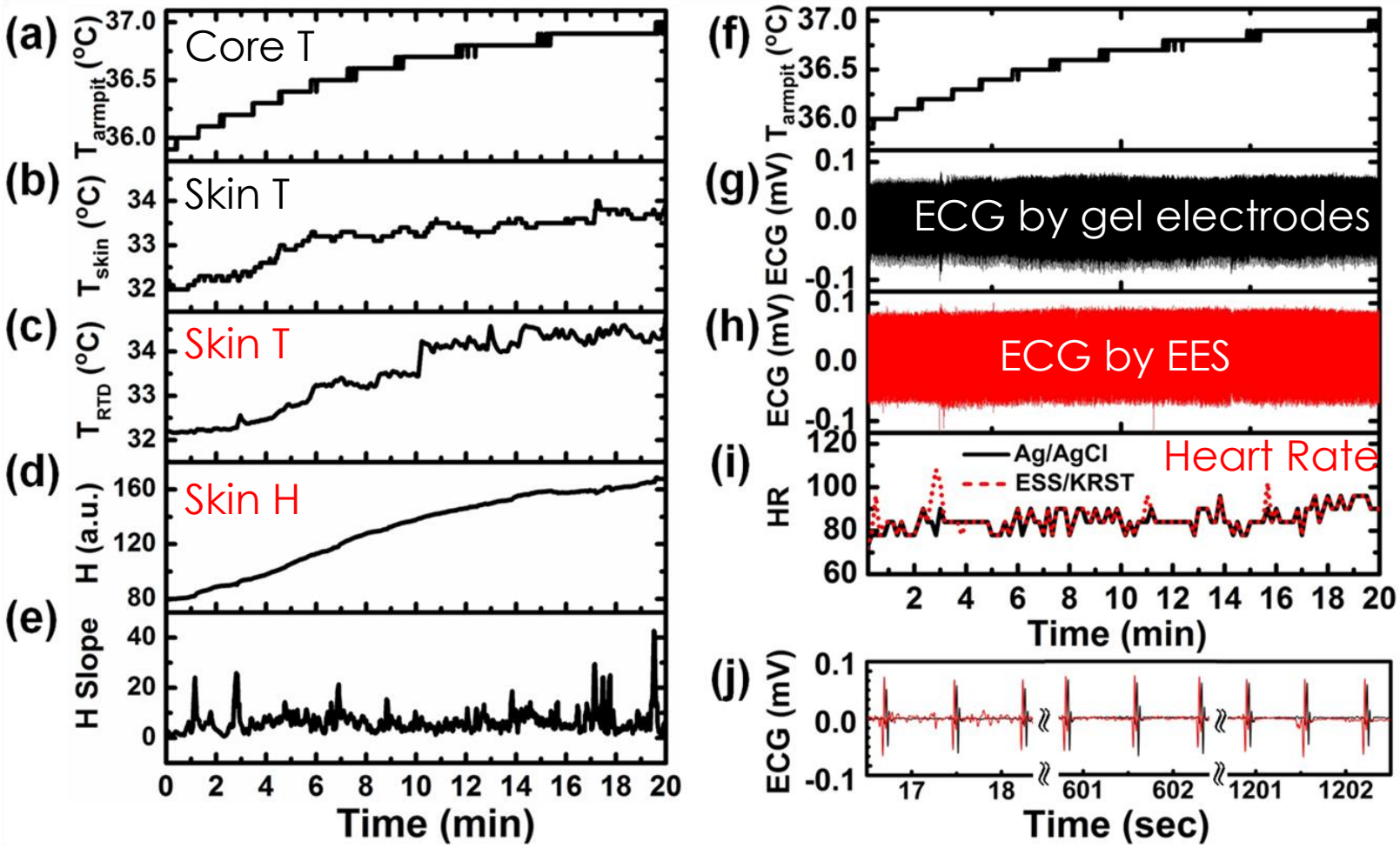






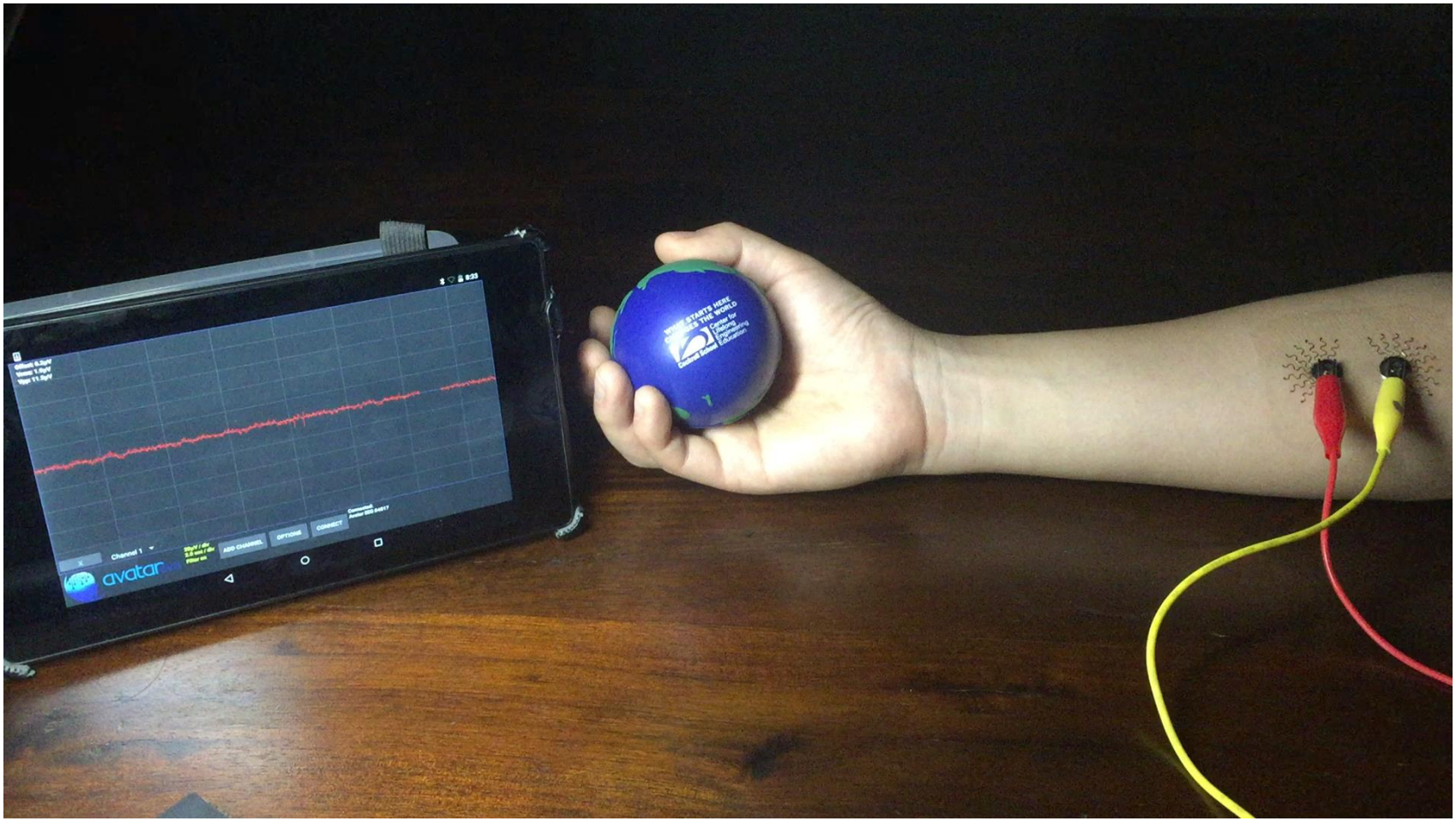
Yang, *et al*, *Adv. Mater.* DOI: 10.1002/adma.201502386 (2015).

Synchronous Multimodal Measurements



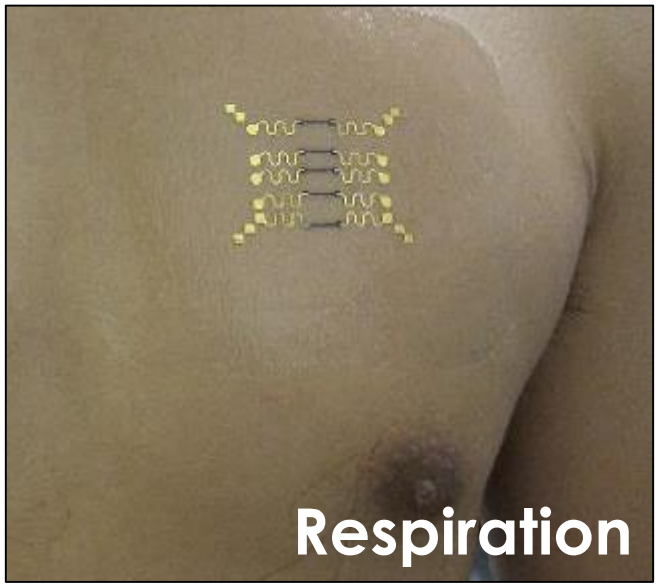
Chen *et al*, to be submitted (2016).

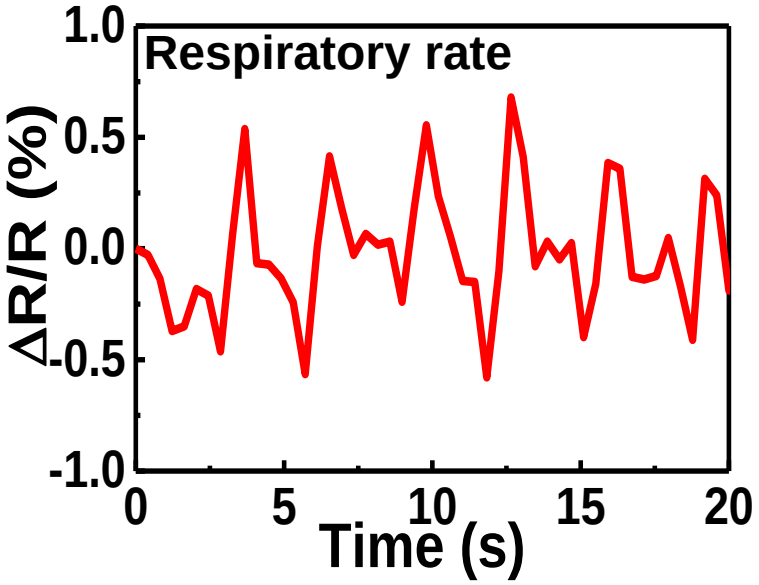
Exp. 1 - EMG Sensor on Muscles



Quantification of Muscle Fatigue

Exp. 2 - Soft Strain Gauges Measuring Skin Deformation



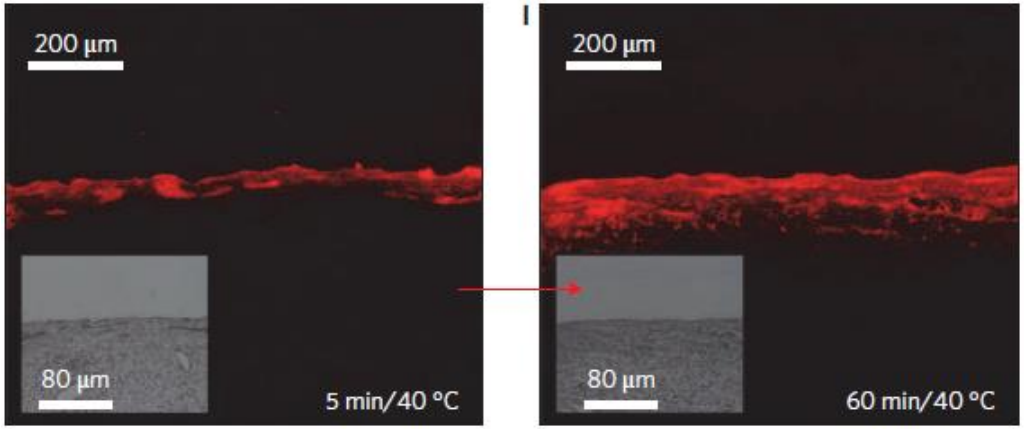


Exp. 3 - Skin Mounted Heater

Thermal joint therapy

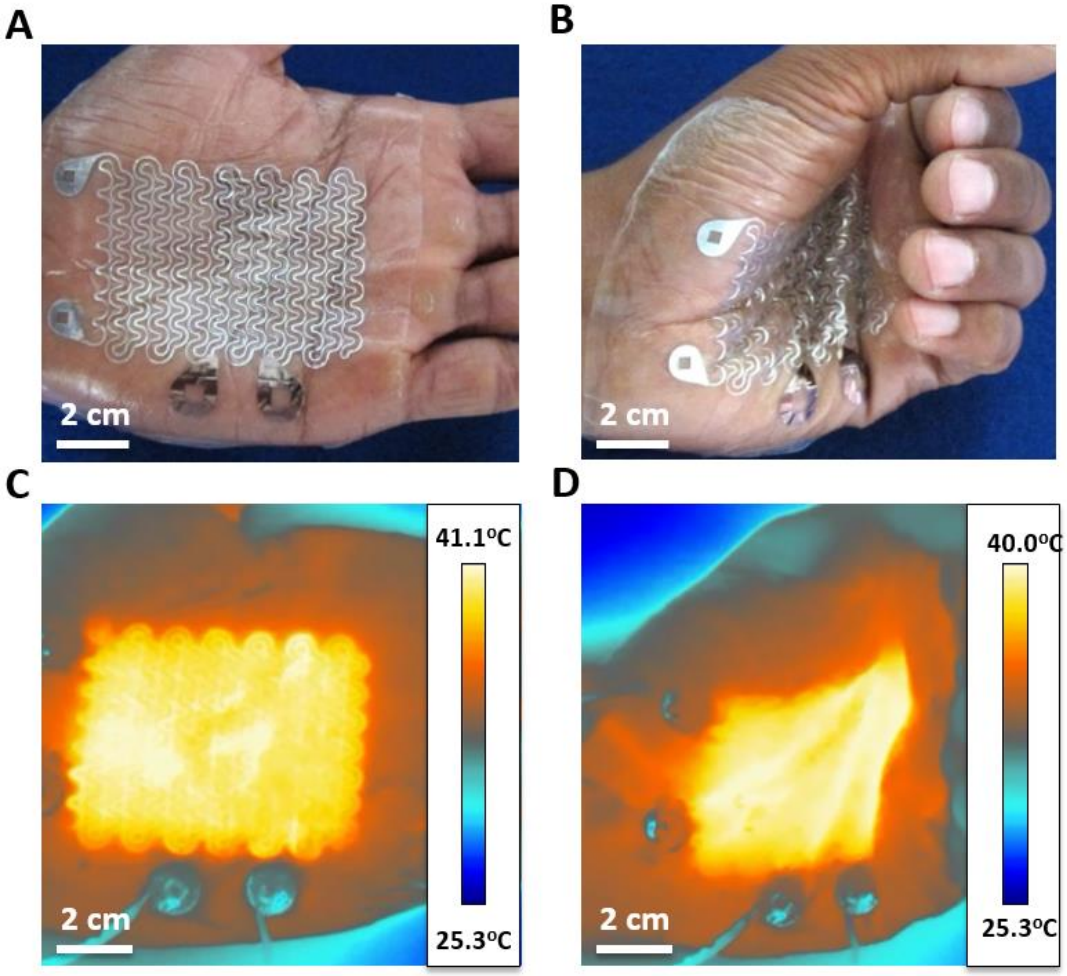
Perioperative Warming

Expedited Transdermal Drug Delivery

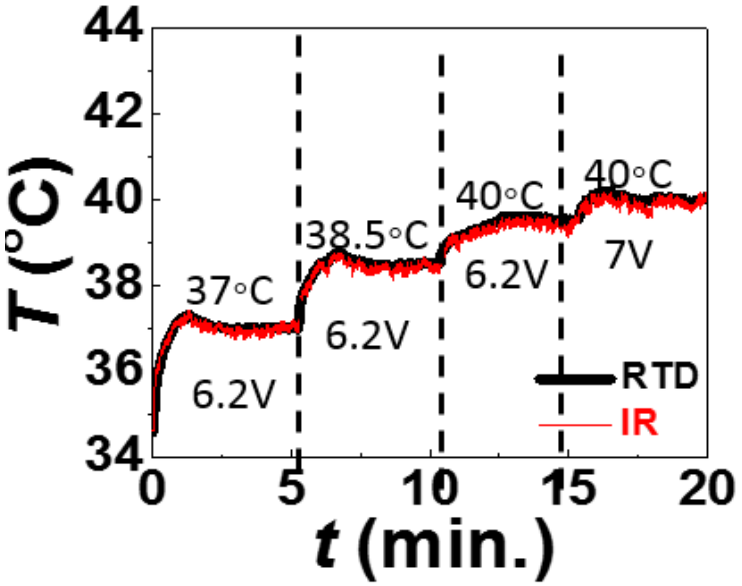


Son *et al*, *Nature Nanotechnology* **9**, 397–404 (2014).

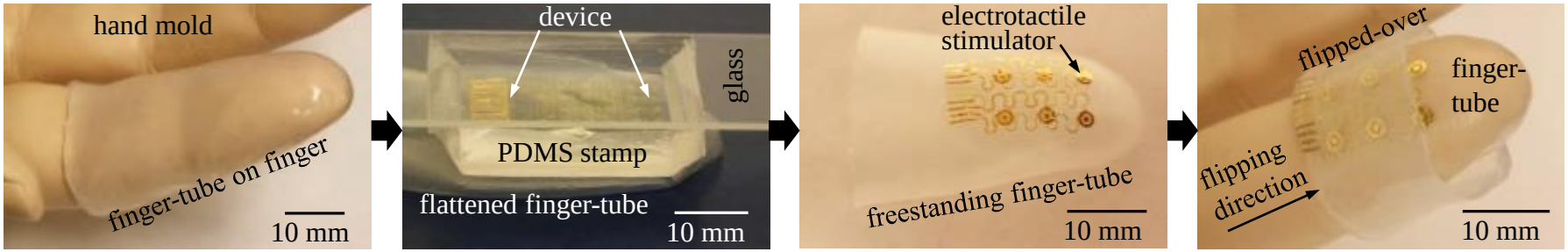
Epidermal Programmable Heater

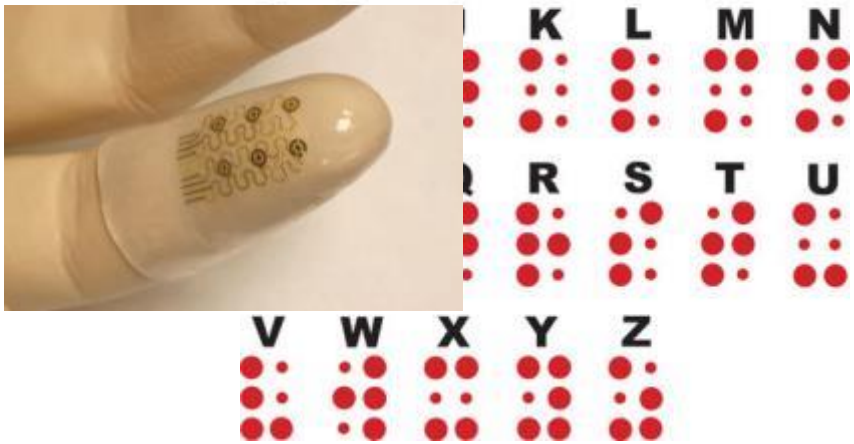


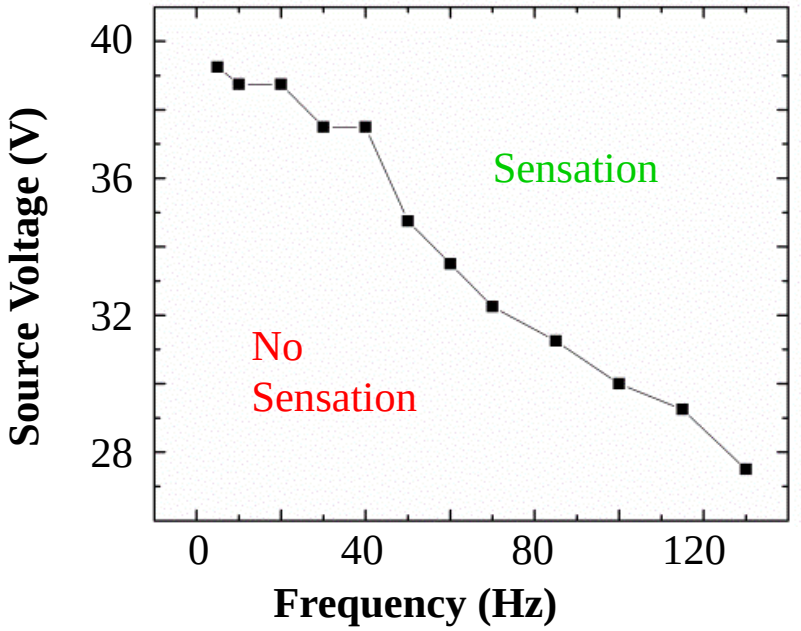
Epidermal heater integrated with T sensor allowed feedback control



Exp. 4 - Electrotactile Stimulator







Ying, Bonifas, **Lu** *et al.*, *Nanotech* 23, 344004 (2012).

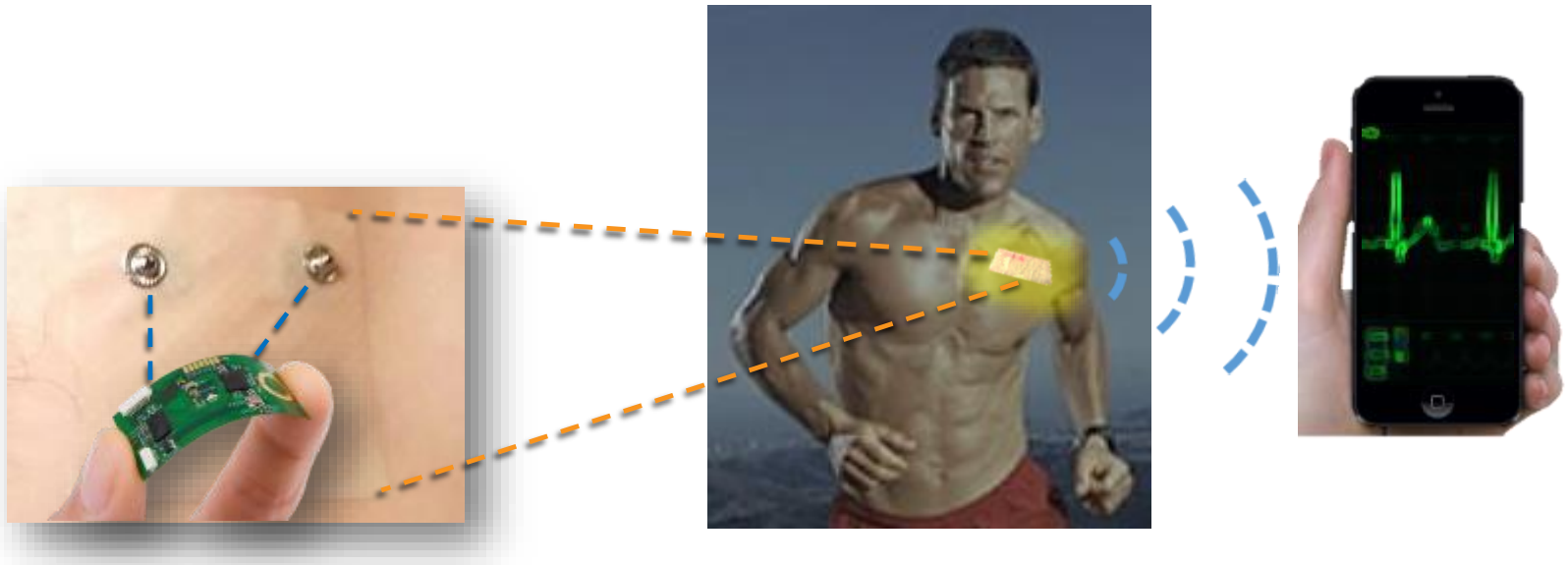
Long-term ECG

Conventional Holter Monitor

ZioPatch

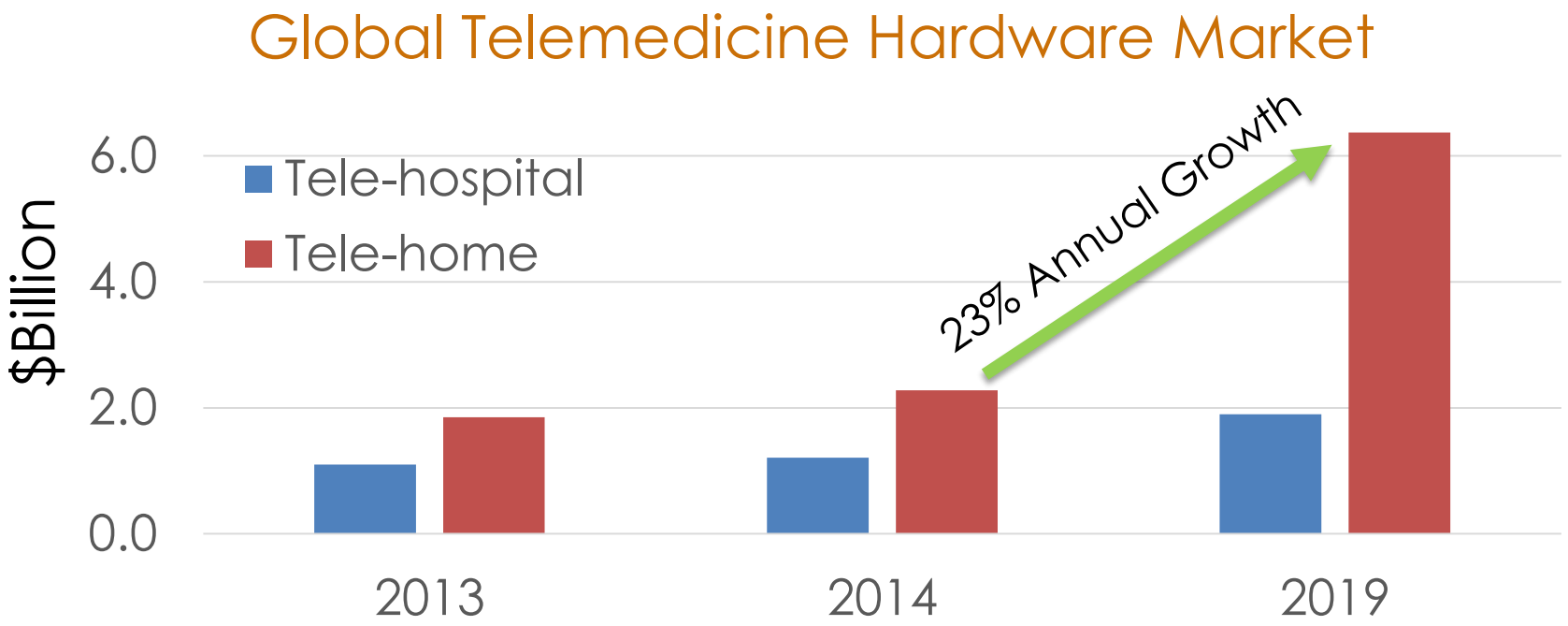
V-Patch

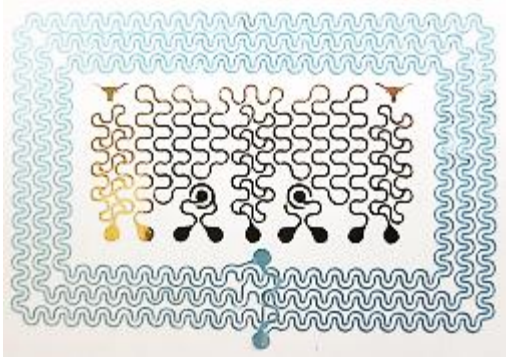
VitalPatch



Stretch Med Guardian Patch

The Ultimate Goal – One Patch Solution for Telemedicine



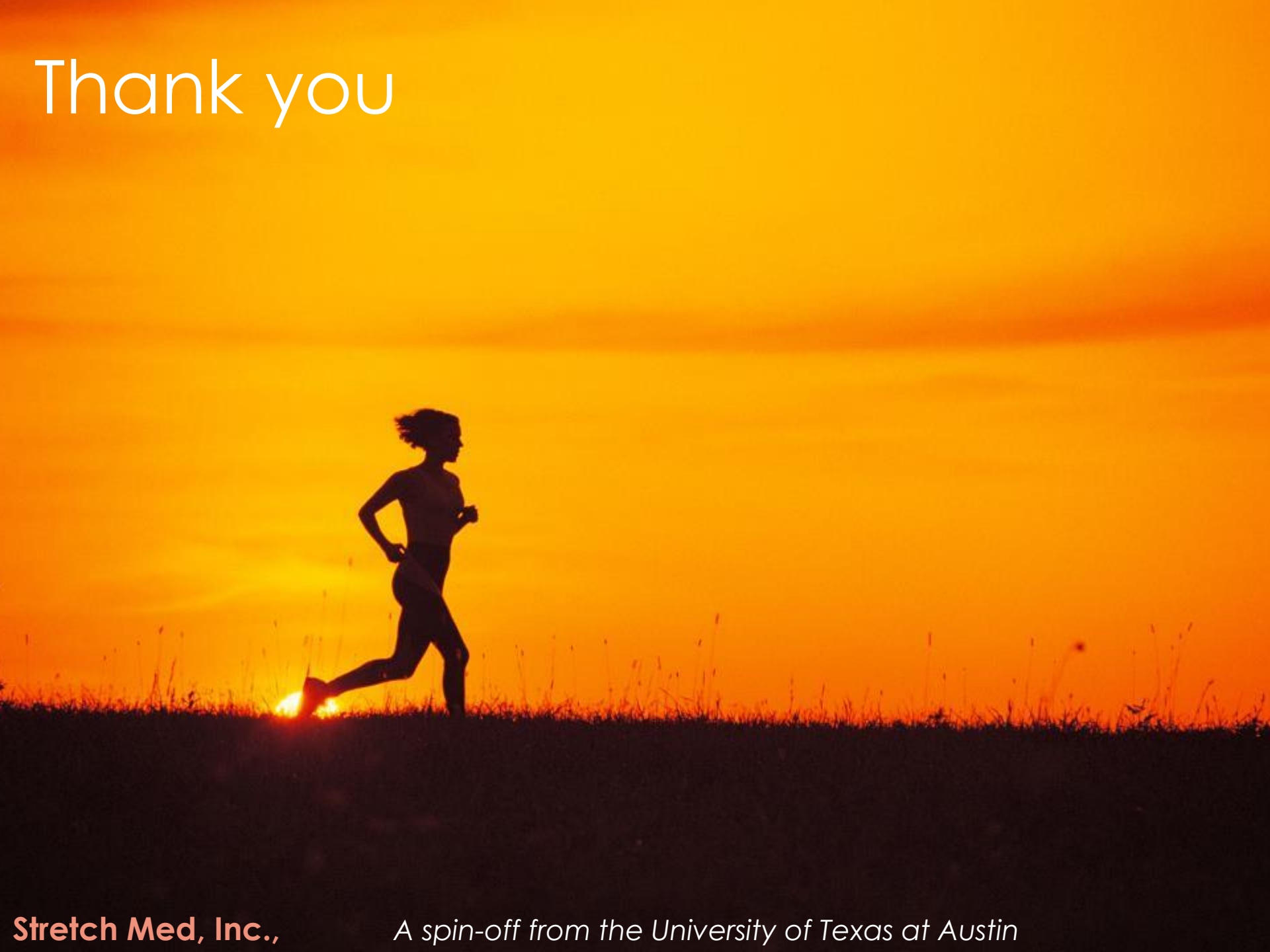


"Global markets for telemedicine technologies", BCC Research 2014

Acknowledgement

NSF
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
UNITED STATES AIR FORCE
DEPARTMENT OF THE NAVY
ONR
Science & Technology
NATIONAL INSTITUTES OF HEALTH
NASCENT
3M

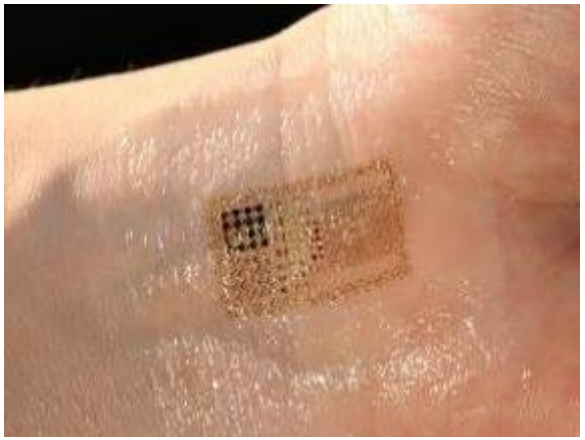
Thank you

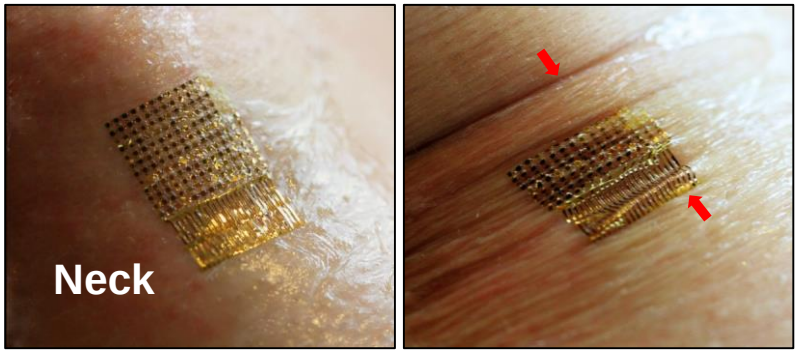


Stretch Med, Inc., *A spin-off from the University of Texas at Austin*

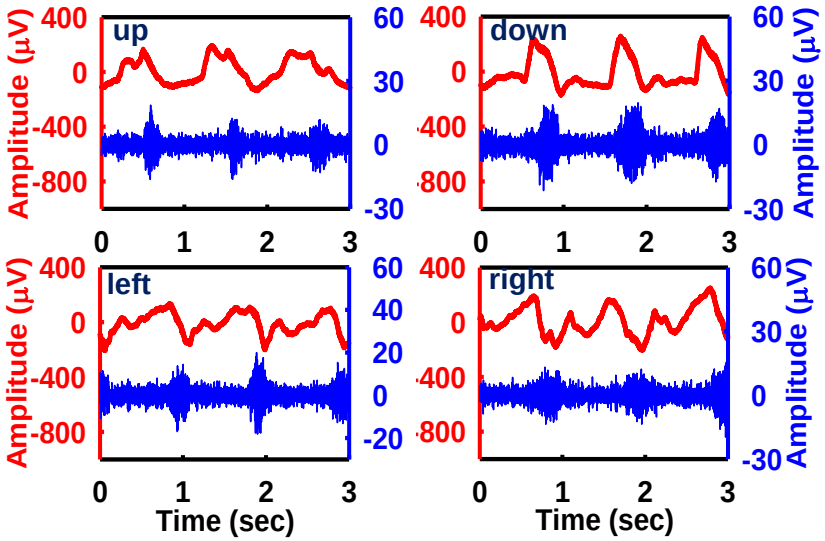
Application of Stretchable Electronics

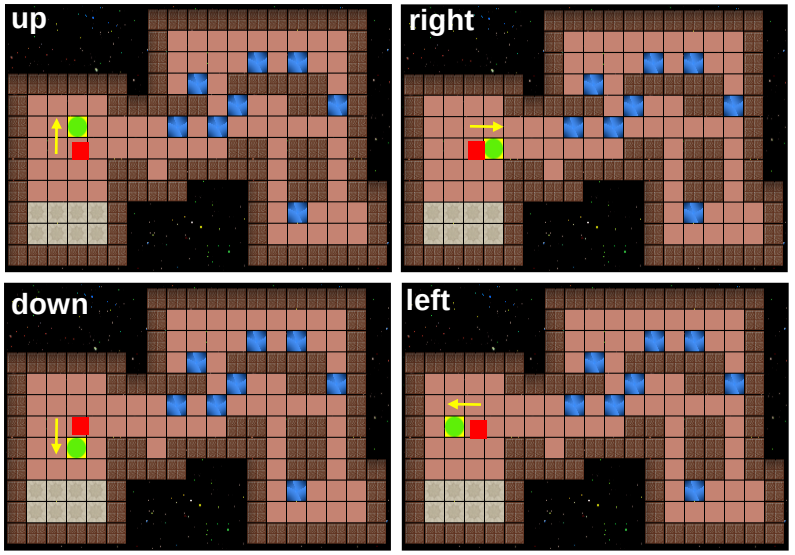
Epidermal Electronics





Sokoban

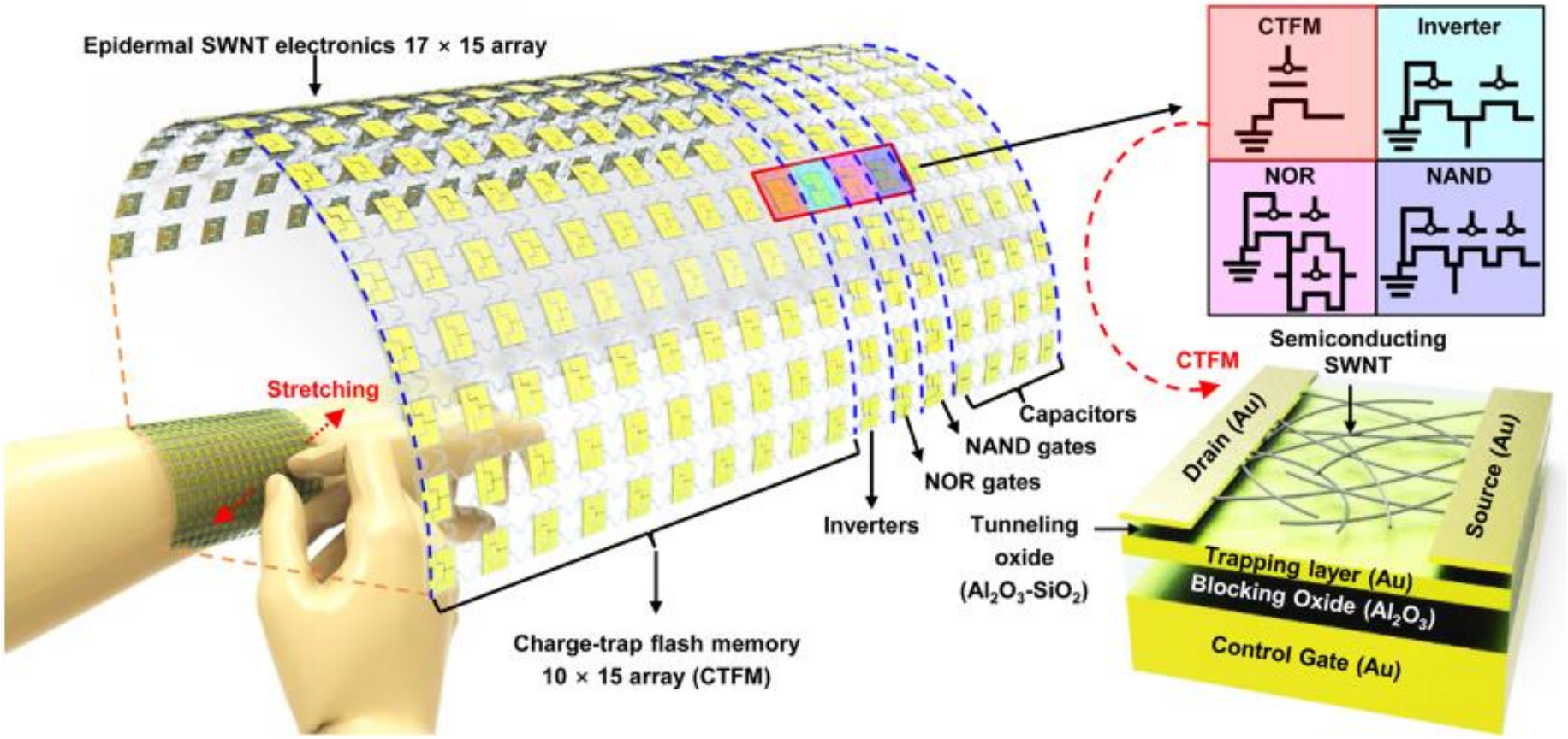




Kim, D., et al., Science, **333**, 838 (2014)

Prof. Roger at UIUC

Charge-Trap Floating-Gate Memory and Logic Devices

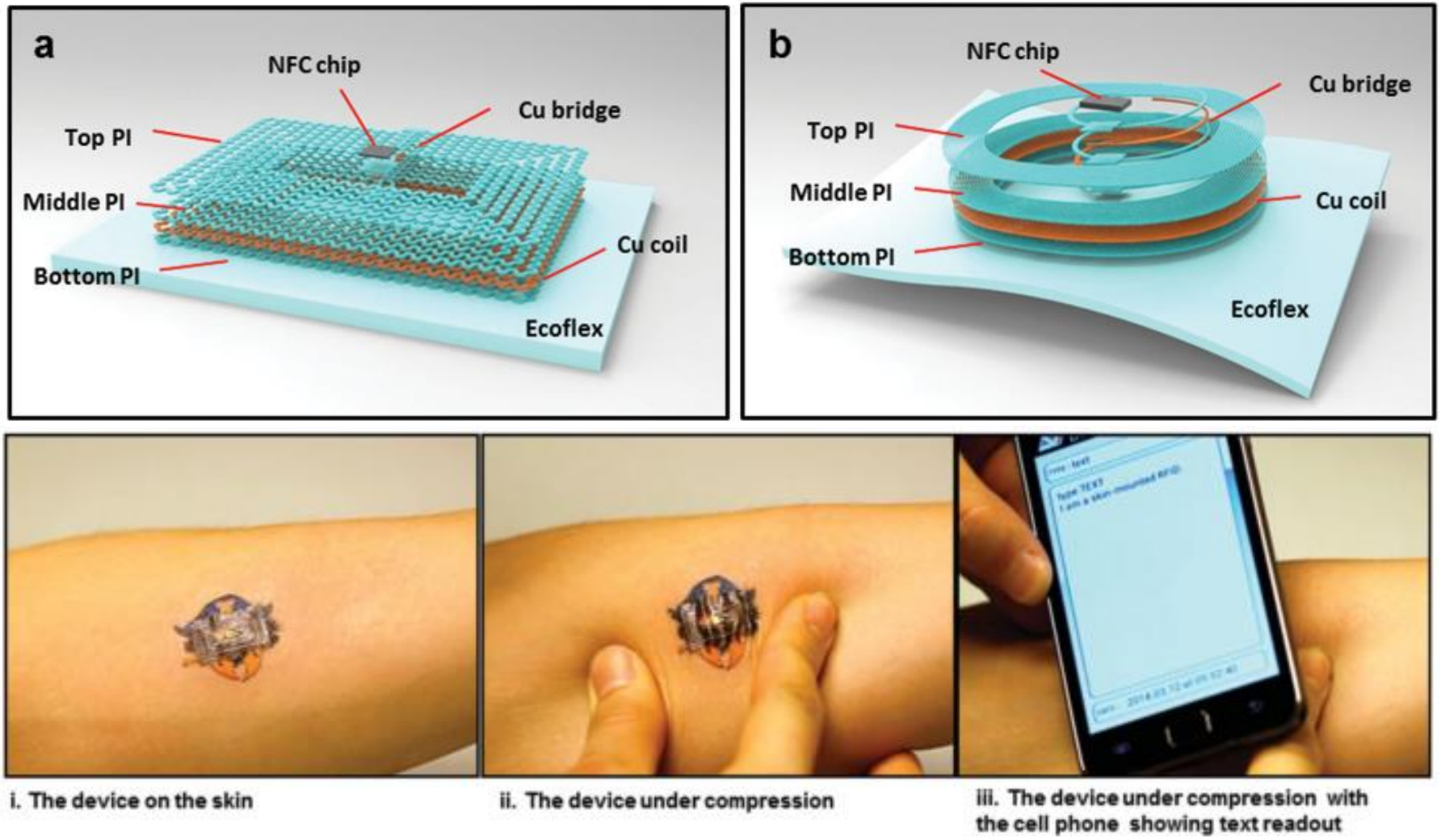


- Single-walled carbon nanotube (s-SWNT)-based devices
- Consists of units, capacitors, and logic circuits

Son, D., et al., ACS Nano, **9**, 5585 (2015)

Prof. Dae-Hyeong Kim at Seoul National U, Korea

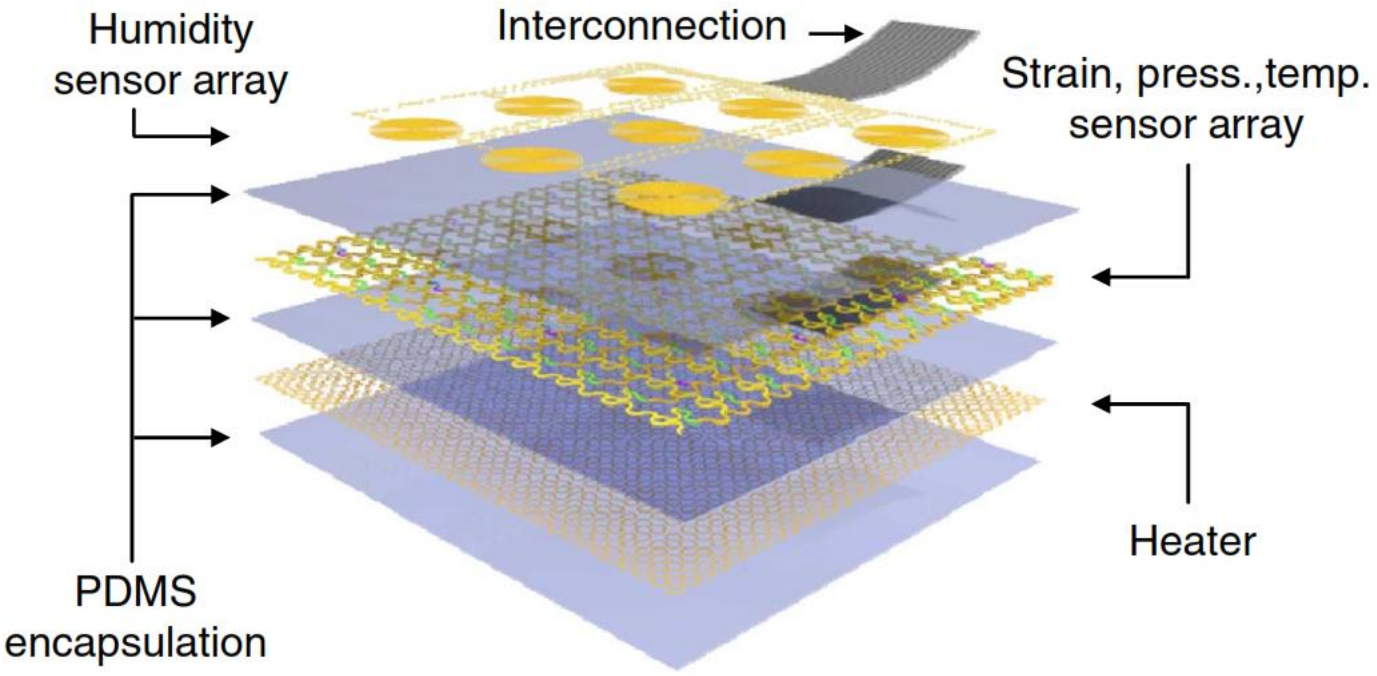
Near-Field Communication (NFC)



Kim, J., et al., Small, **11**, 906 (2015)

Prof. Roger at UIUC

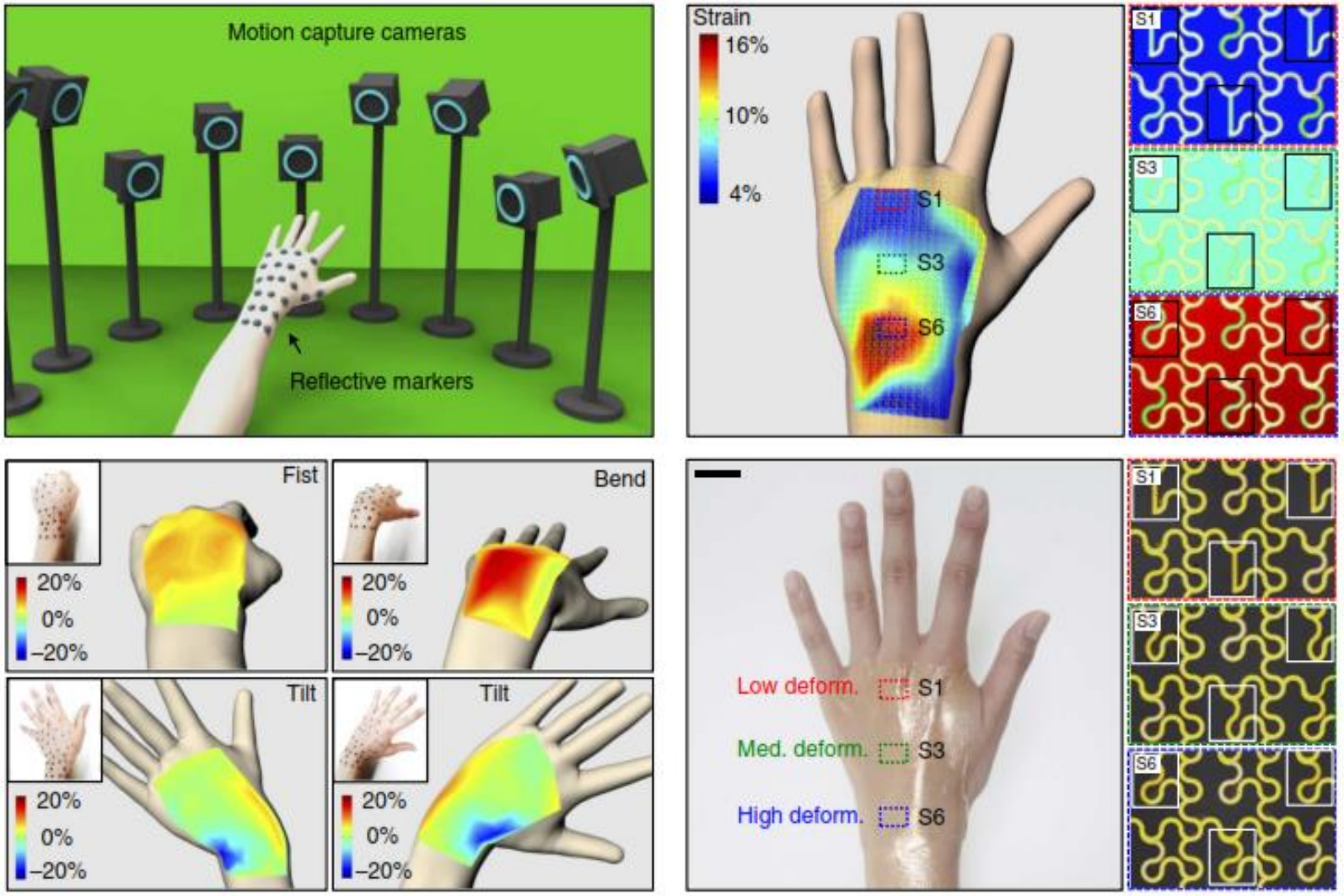
Skin Prosthesis



Kim, J., et al., Nature Communication, **5**, 5747, doi:10.1038/ncomms6747, (2014)

Prof. Dae-Hyeong Kim at Seoul National U, Korea

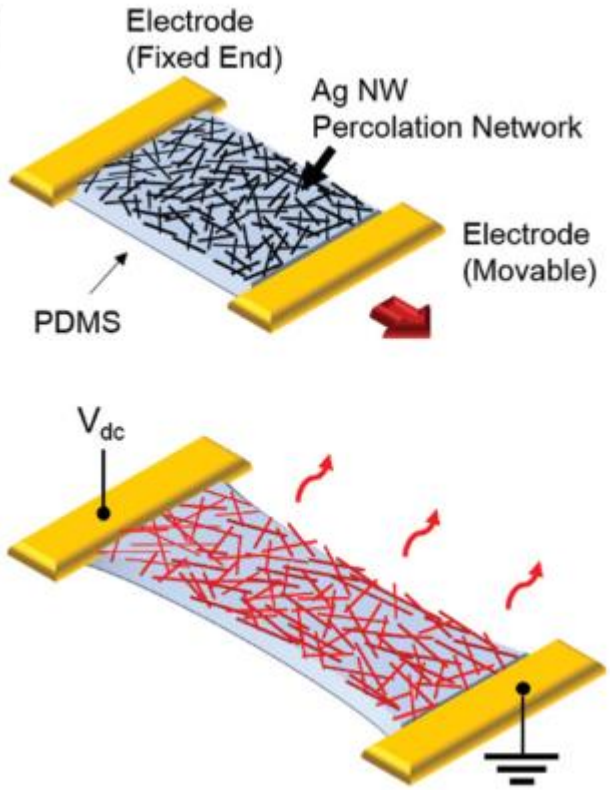
Skin Prosthesis

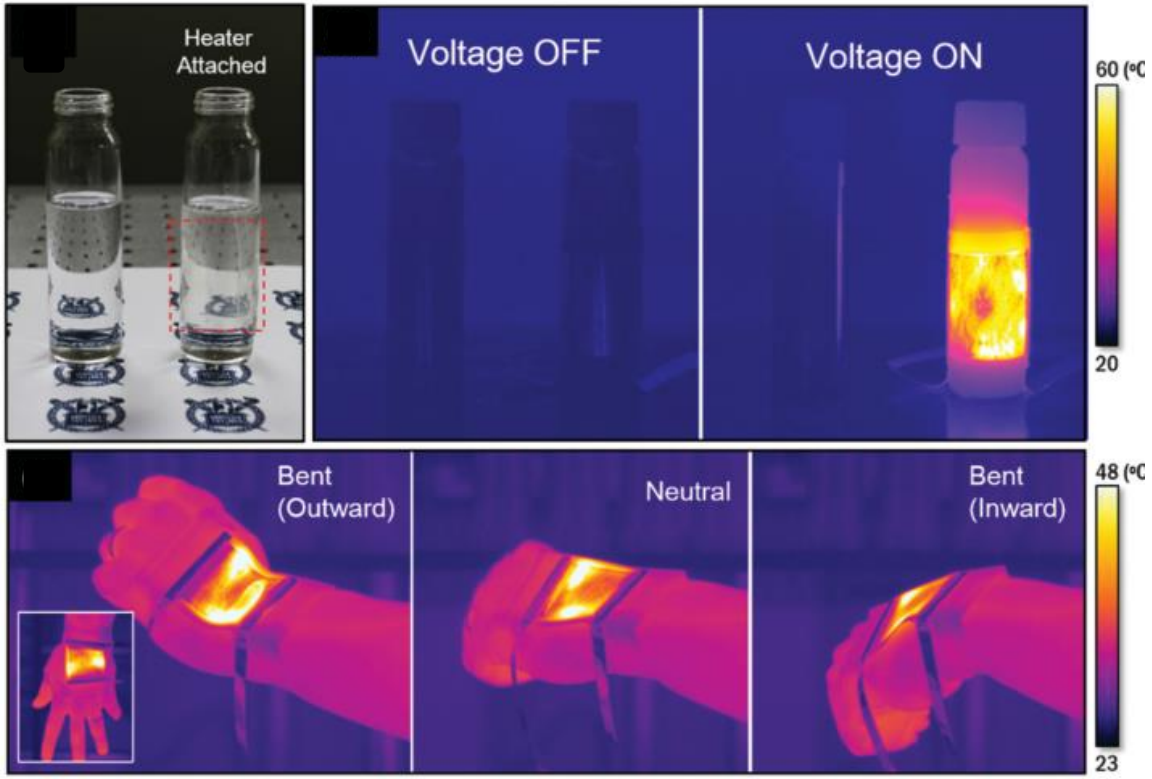


Kim, J., et al., Nature Communication, **5**, 5747, doi:10.1038/ncomms6747, (2014)

Prof. Dae-Hyeong Kim at Seoul National U, Korea

Stretchable and Transparent Heater



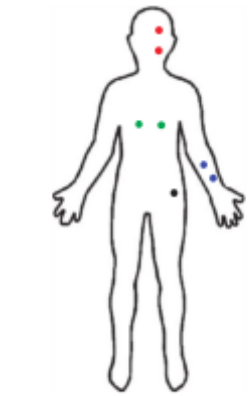


- Stretching up to 60%
- Device thickness less than 500 μm

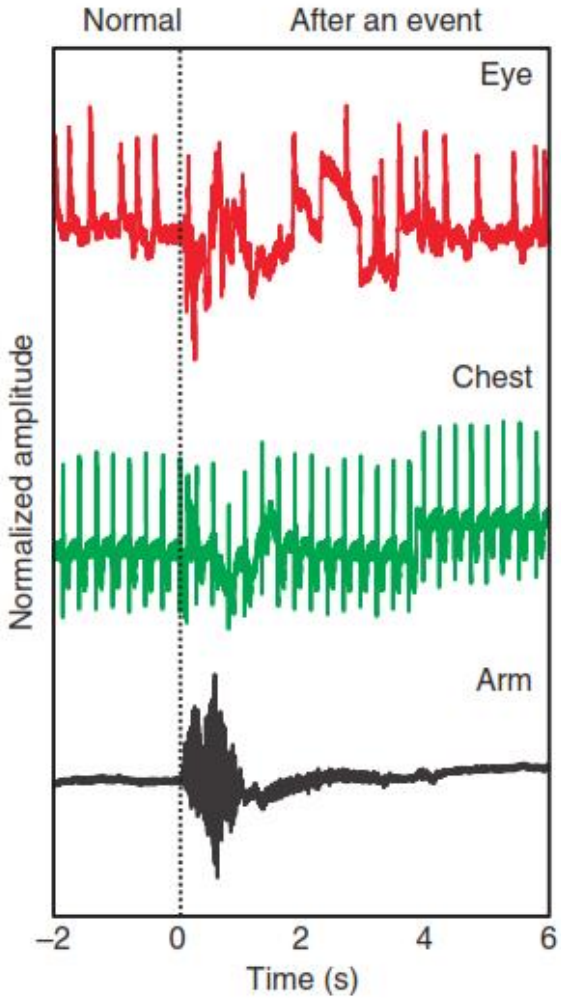
Hong, S., et al., Advanced Materials, **27**, 4744 (2015)

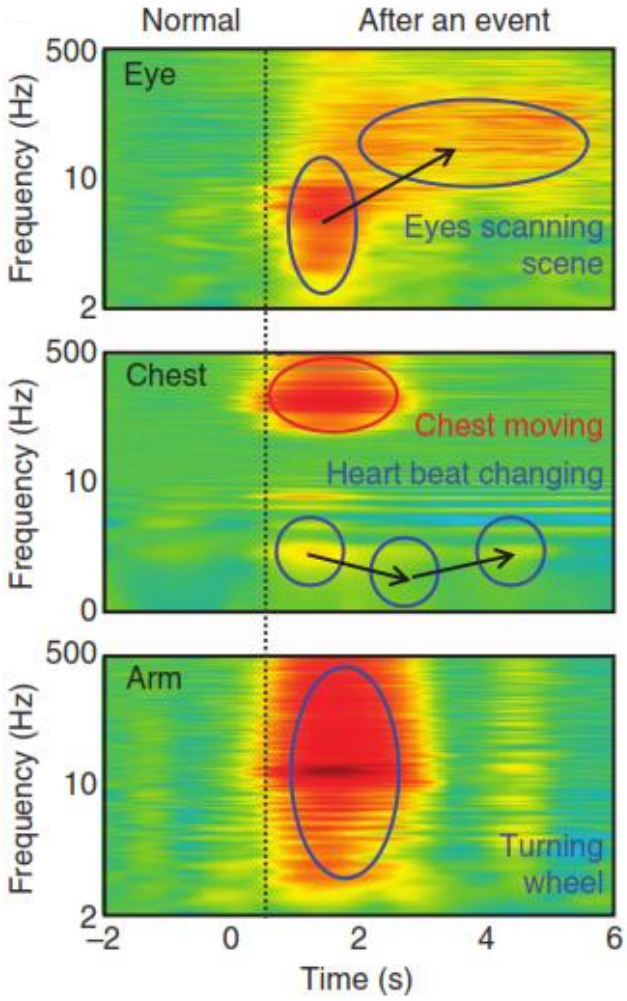
Prof. Seung Hwan Ko at Seoul National U, Korea

Transcutaneous Monitoring



EP sensors on body

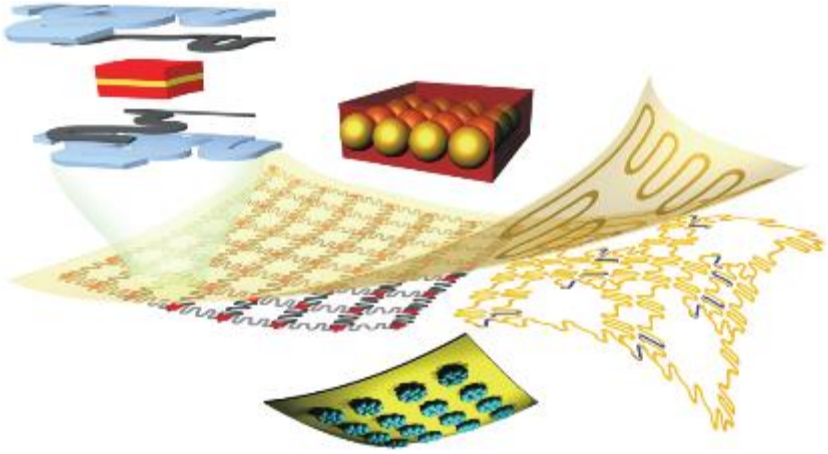


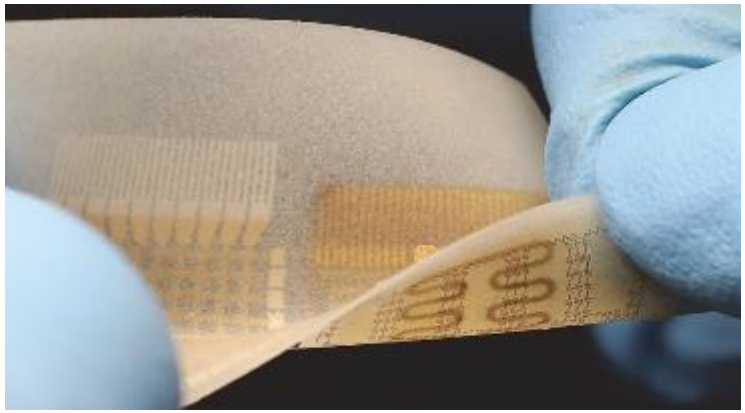


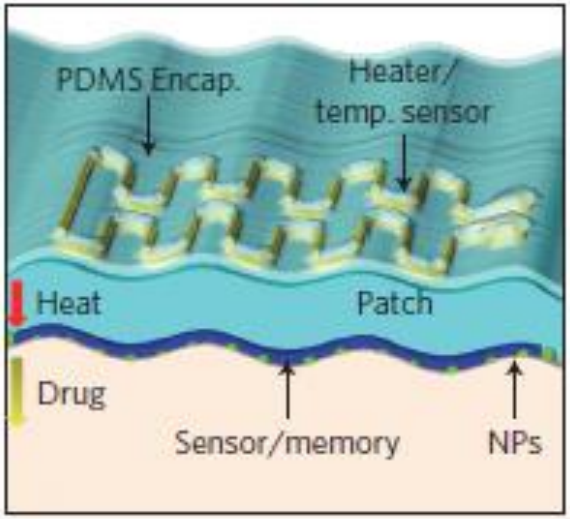
Jang, K., et al., Nature Communication, **5**, 4779, doi:10.1038/ncomms5779, (2014)

Prof. Roger at UIUC

ESS for Drug Delivery



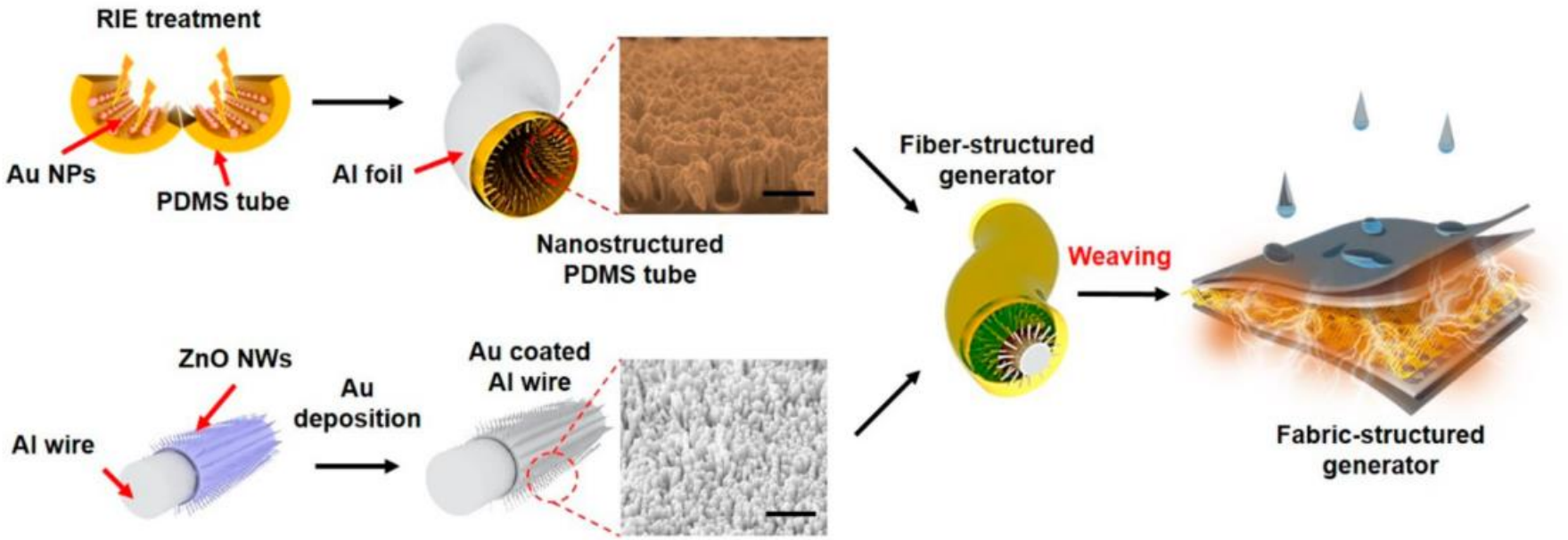


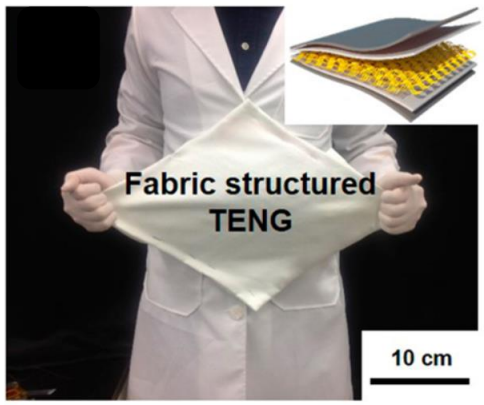


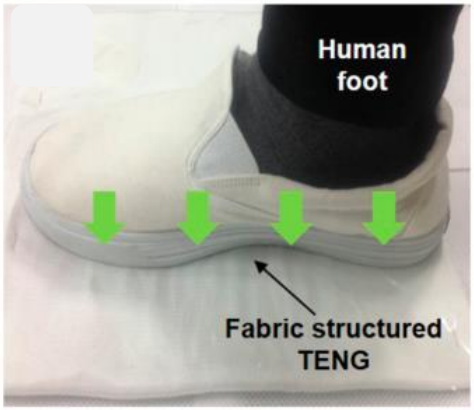
Son, J., et al., Nature Nanotechnology, **9**, 397 (2014)

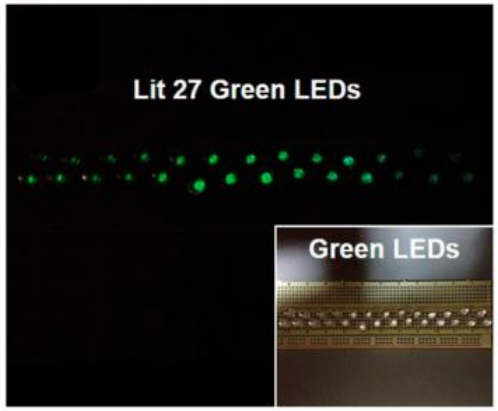
Prof. Dae-Hyeong Kim at Seoul National U, Korea

Triboelectric Nanogenerator



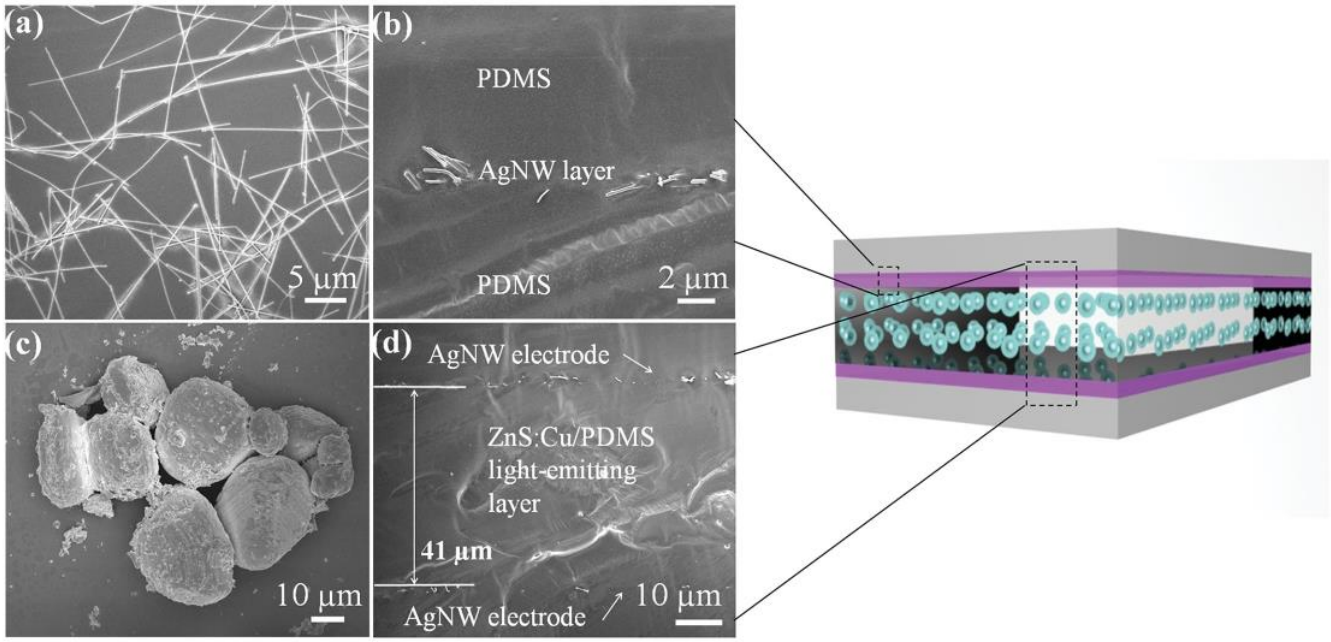


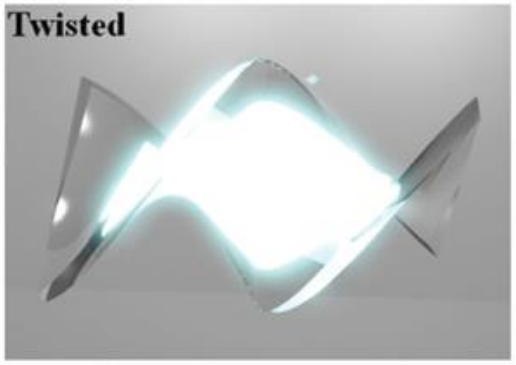


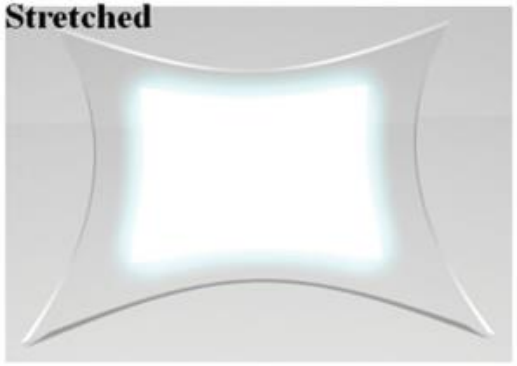


Kim, K. N., et al., ACS Nano, **9**, 6394, doi: 10.1038/ncomms8647, (2015)

Stretchable Electroluminescent Device





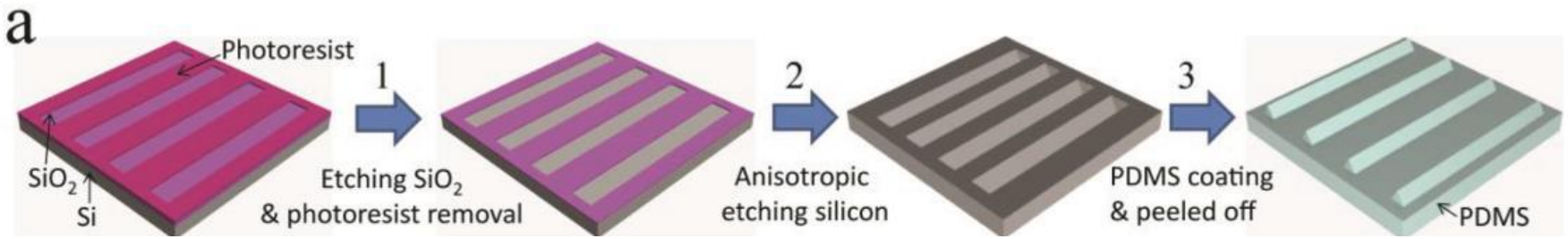


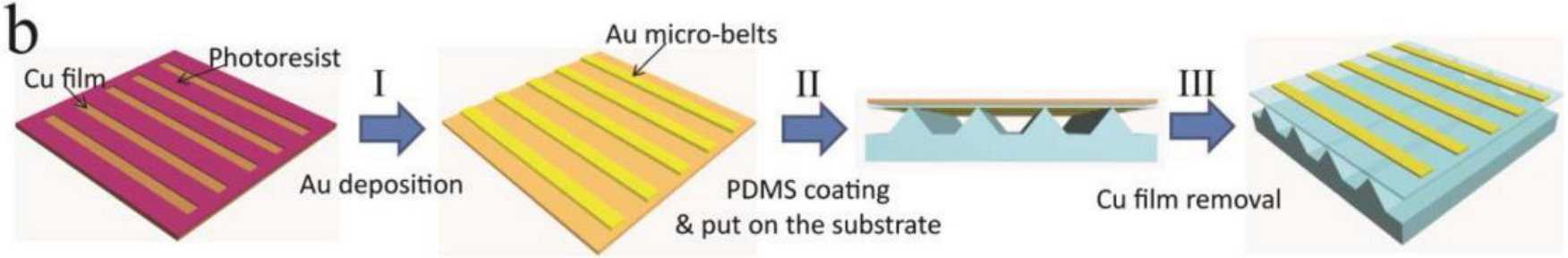
Wang, J., et al., Advanced Materials, **27**, 2876 (2015)

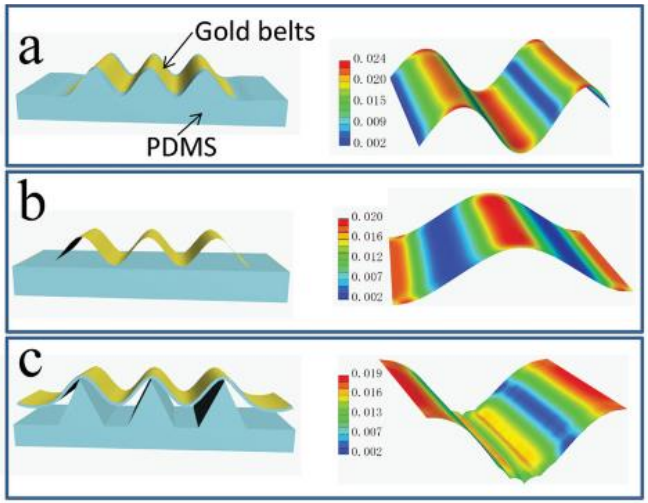
Prof. Pooi See Lee at Nanyang Technological U, Singapore

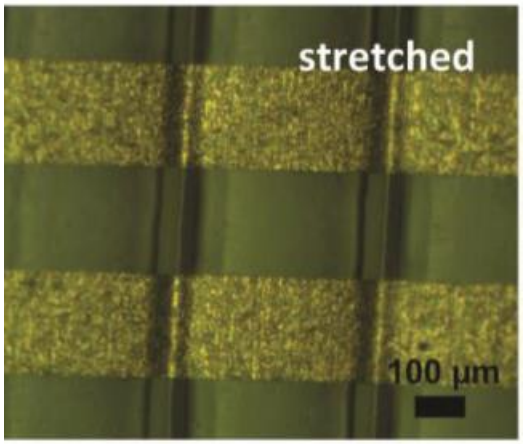
Fabrication of Stretchable Electronics

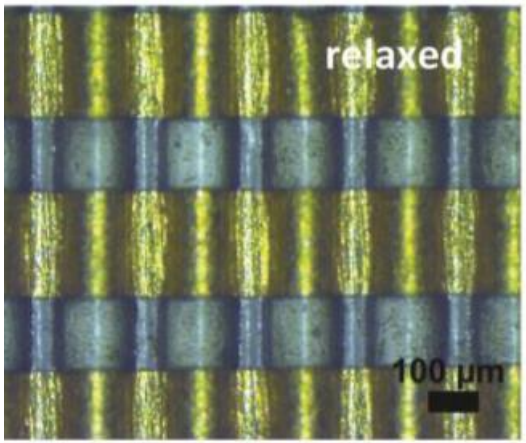
Gold Nanobelts with Sinusoidal Structures (Change to Rogers)







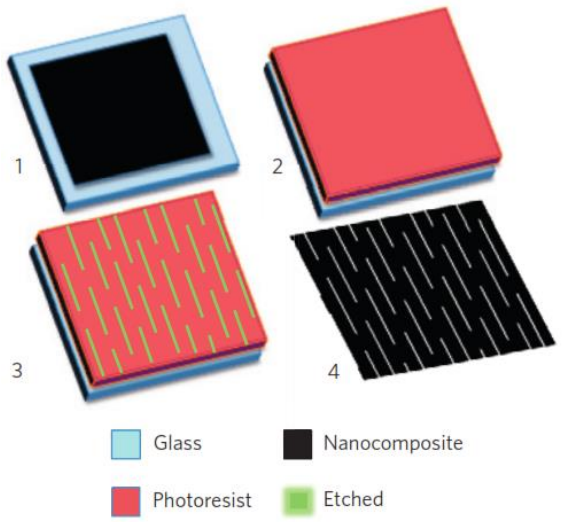


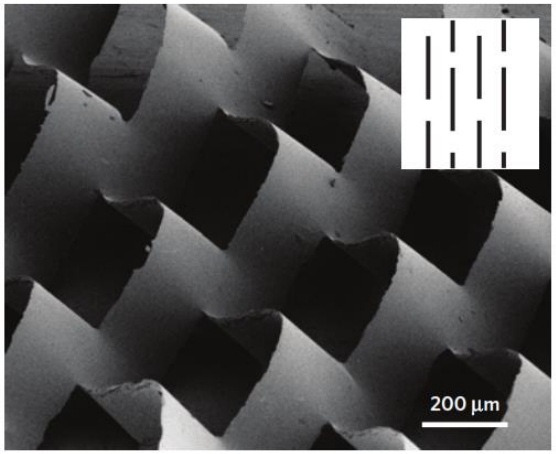


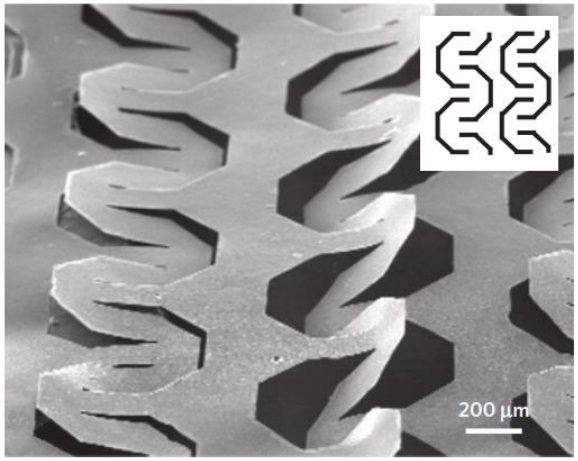
Qi, D., et al., Advanced Materials, **27**, 3145 (2015)

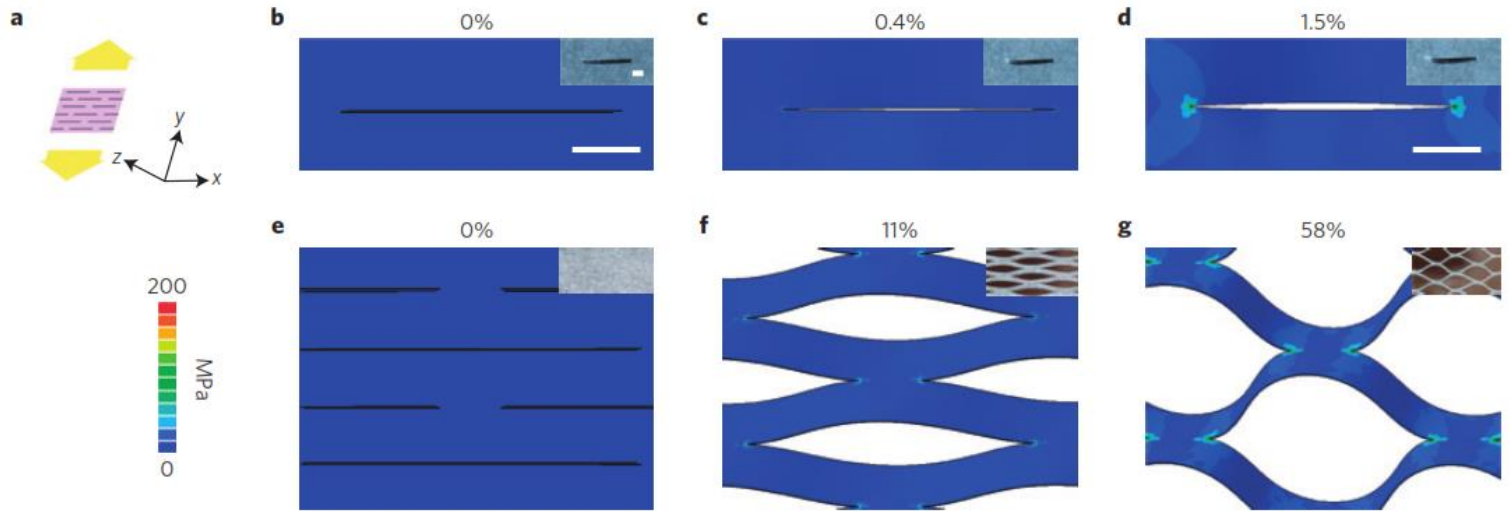
Prof. Zhe Yu at Nanyang Technological U, Singapore

Kirigami-Inspired Engineering





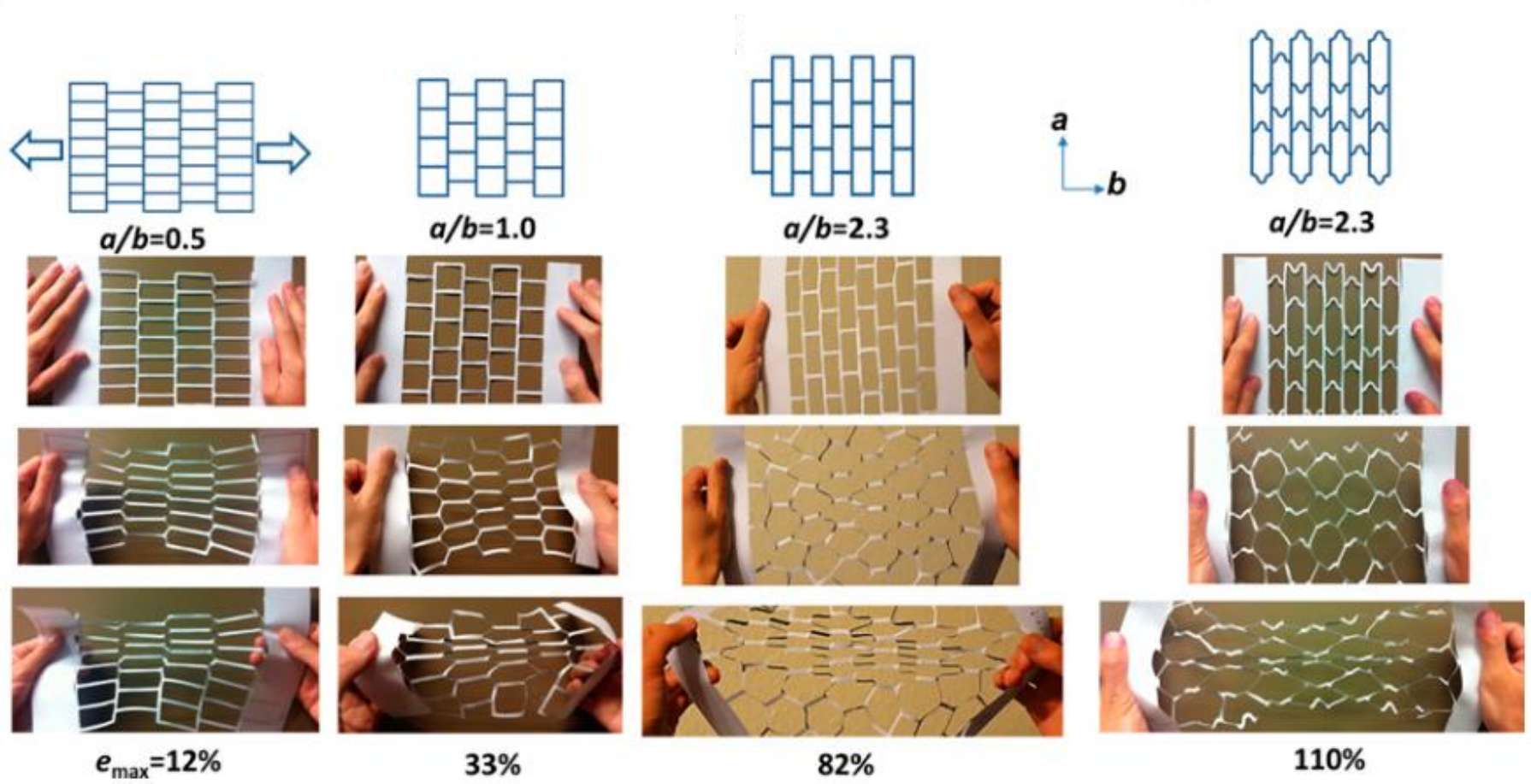




Shyum T. C., et al., Nature Materials, **14**, 785 (2015)

Prof. Shtein at U Michigan

Mesh-Like Engineering

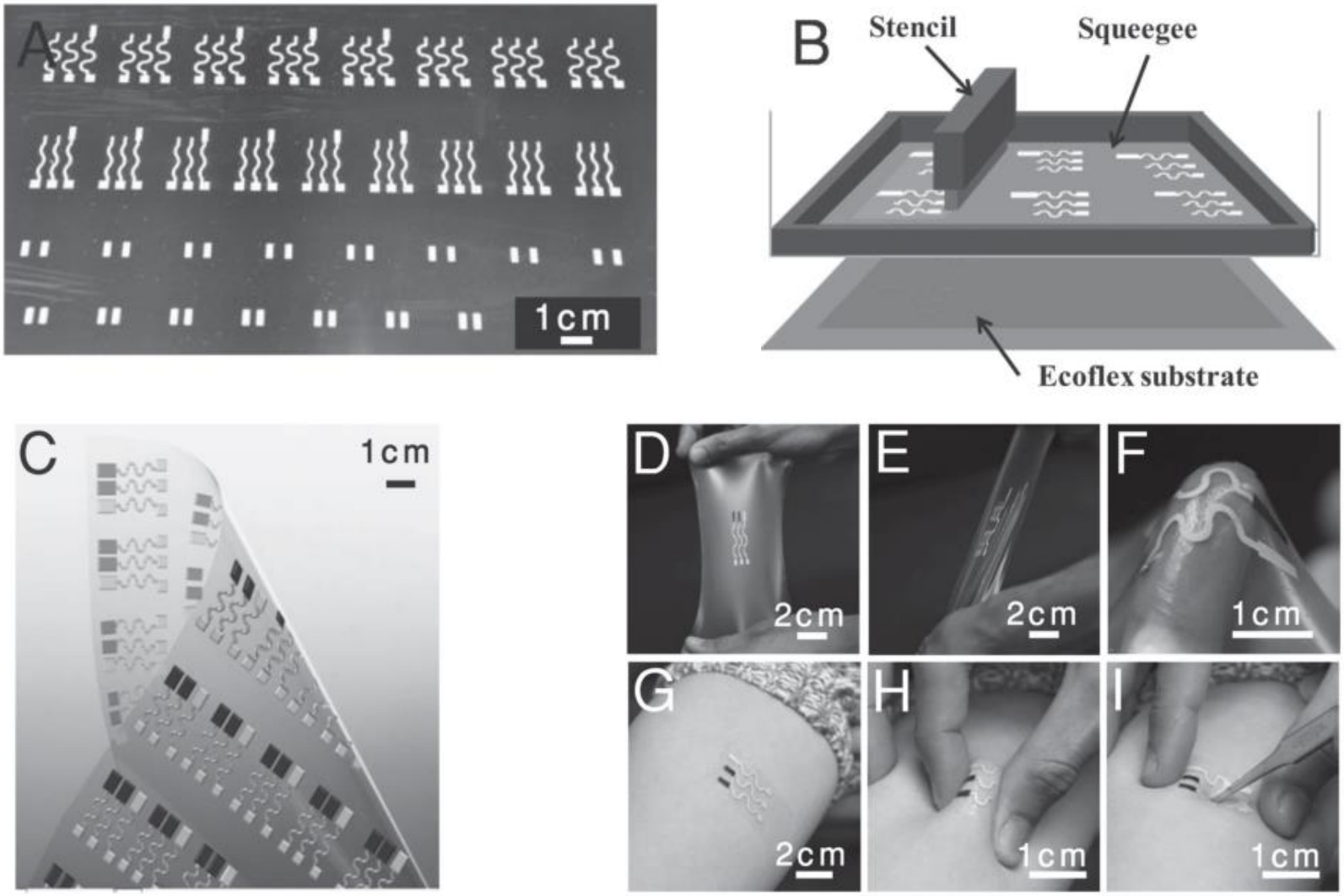


- Fatigue-free, superstretchable, transparent, and biocompatible metal electrodes

Guo C. F., et al., Proceeding of National Academy of Science, **112**, 12332 (2015)

Prof. Ching-Wu Chua at U Houston

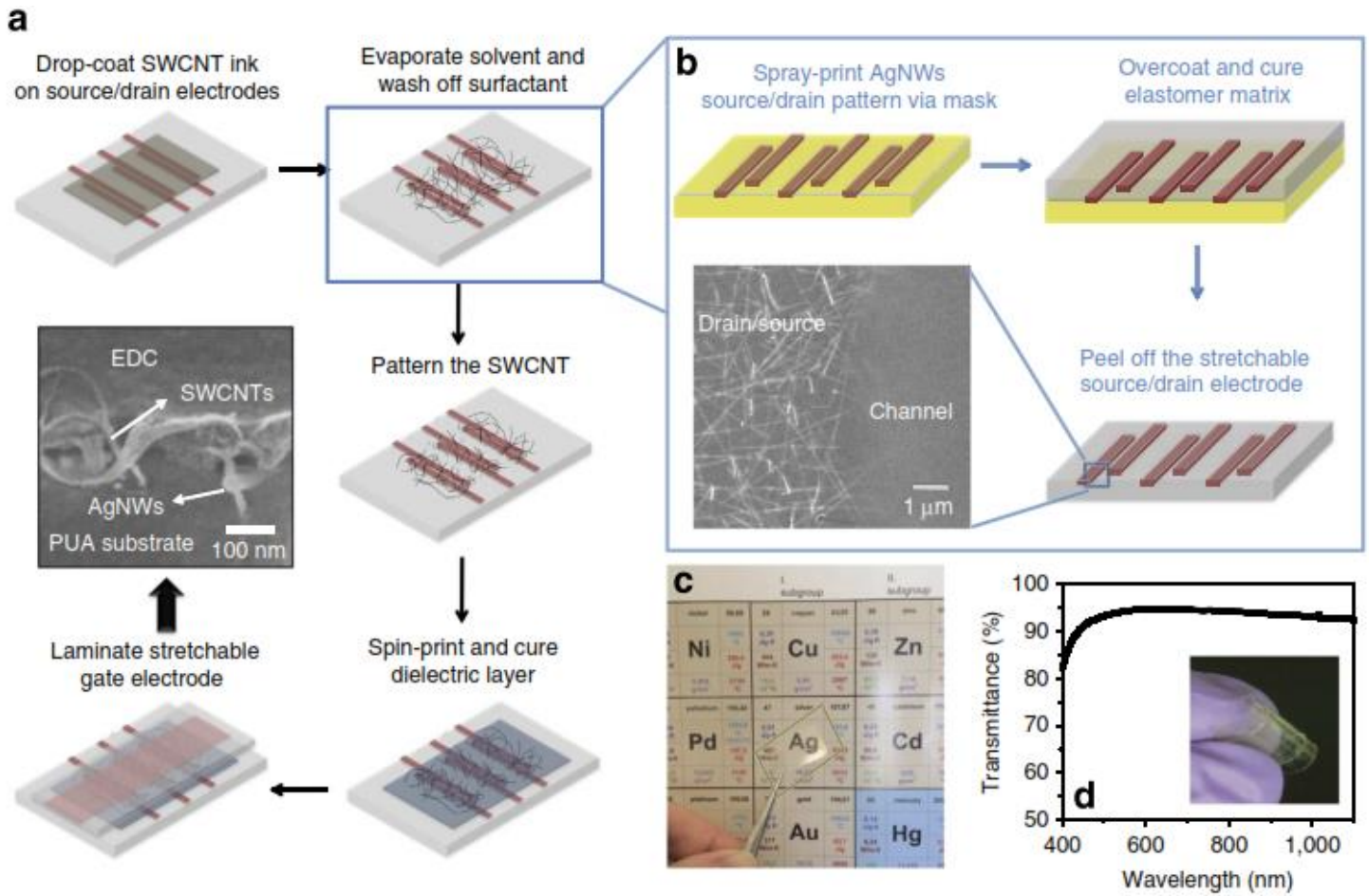
Printable Electronics



Bandodkar, A., et al., Advanced Materials, **27**, 3060 (2015)

Prof. Wang at UCSD

Printable Silver Nanowires

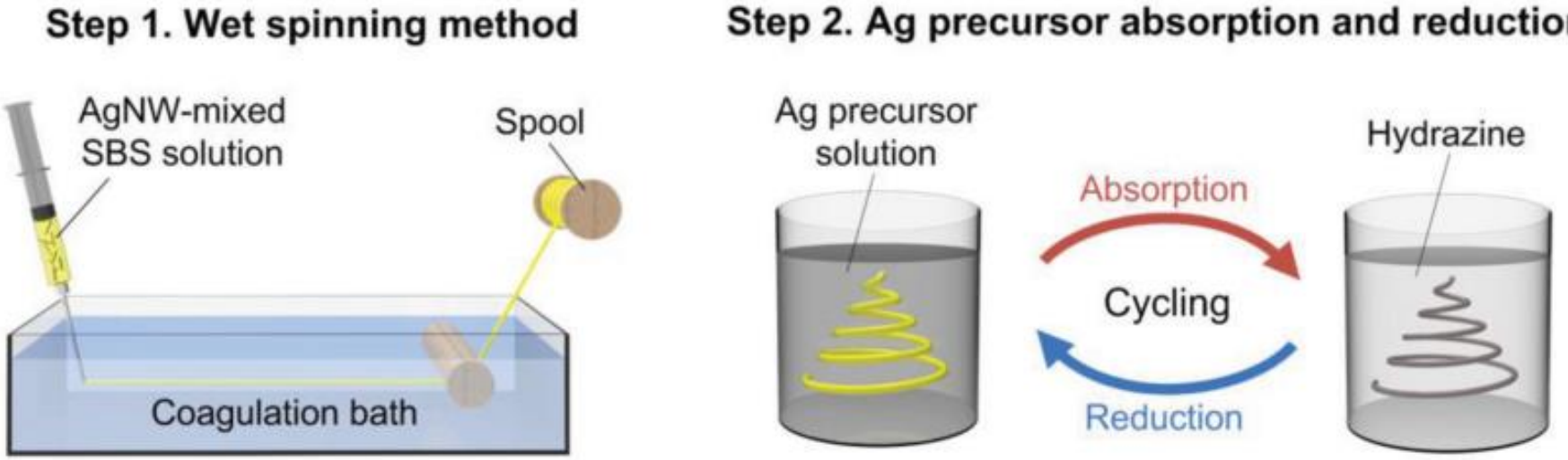


- Stretching up to 50%, 500 cycle at 20% without significant loss in electrical property

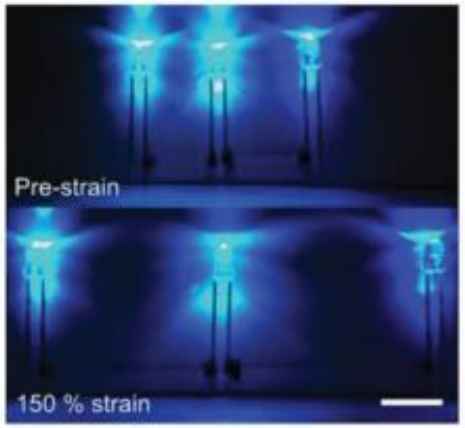
Liang, J., et al., Nature Communication, **6**, 7647, doi: 10.1038/ncomms8647, (2015)

Prof. Pei at UCLA

Wet Spinning Method



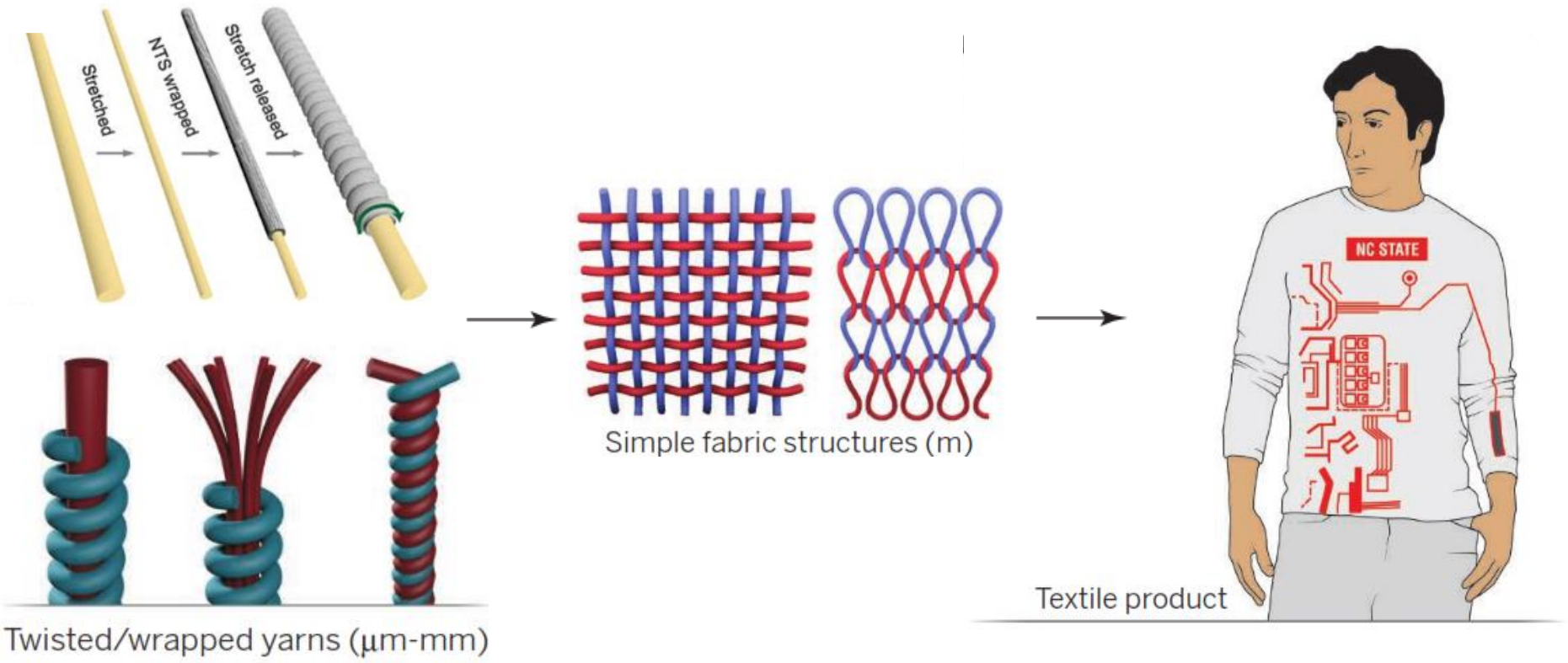
- Stretching up to 220%
- Only biaxial stretch



Lee, L., et al., Advanced Functional Materials, **25**, 3114 (2015)

Prof. Taeyoon Lee at Yonsei U, Korea

NTS () based Conductive Yarn



- Stretchable Carbon Nanotube Texile
- Highly stretchable (up to 1320%)

Liu, Z. F., et al., Science **349**, 400 (2015)
Ghosh, T., Science **349**, 382 (2015)