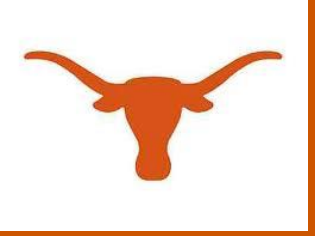

Mechanics and Materials of Bio-Integrated Electronics

Nanshu Lu, PhD

Department of Aerospace Engineering and Engineering Mechanics
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Texas Materials Institute
The University of Texas at Austin

September 21, 2013

Center for Mechanics of Solids, Structures and Materials

THE UNIVERSITY OF TEXAS AT AUSTIN

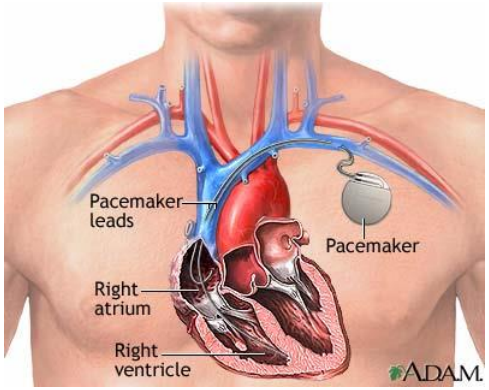
Roadmap

- **Motivation**
- **Deformability of polymer-supported metal and silicon thin films**
- **Case Study**
  - **Non-Invasive**
    - **Epidermal electronics**
    - **Electrotactile finger tube**
  - ***In Vivo***
    - **Instrumented balloon catheter**
    - **Cardiac web**
- **Outlook**

Bio-Integrated Electronics

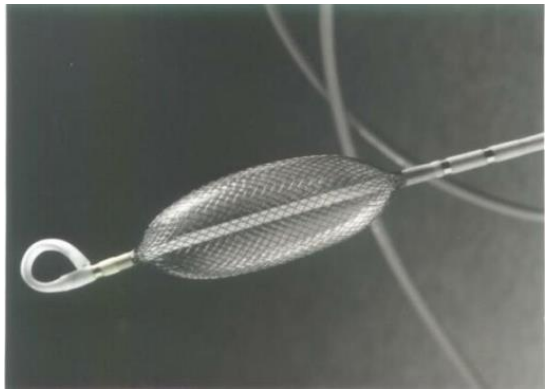
Health Monitoring

Implantable Electronics

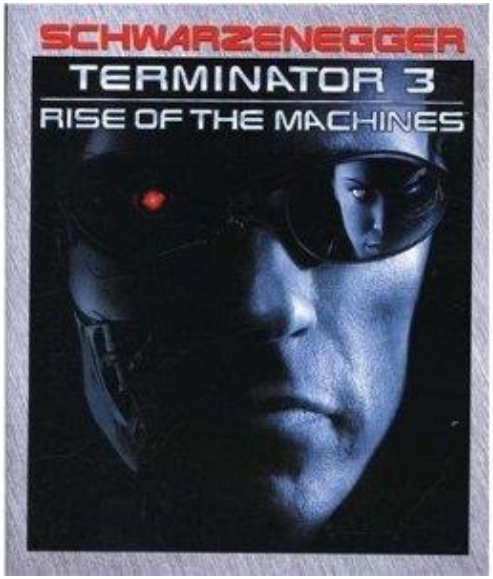


Assistive Devices

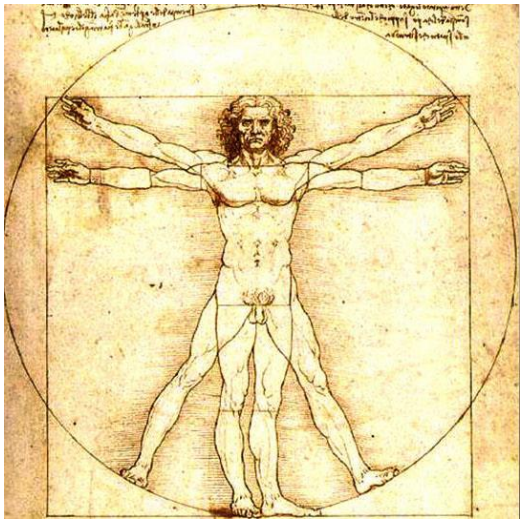
Surgical Tool



Human-Machine Interface

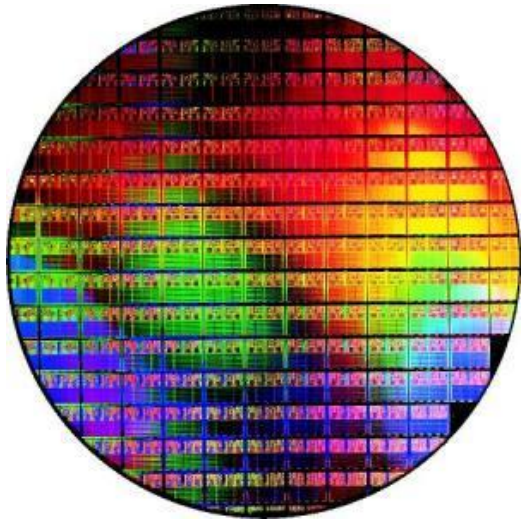


Fundamental Challenge



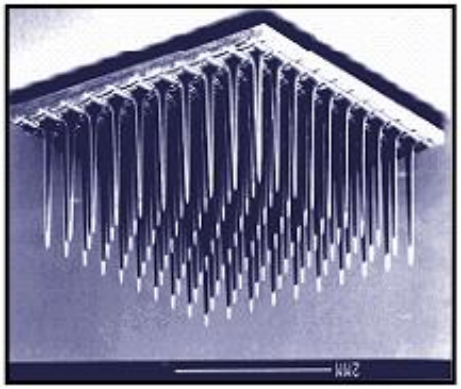
Soft
Resilient
Curvilinear
Dynamic

VS



Hard
Brittle
Planar
Rigid

Desired Properties



Mechanics

- Conformable
- Stretchable
- Robust binding without detachment

Materials

- High-performance
- Biocompatible
- Bioresorbable

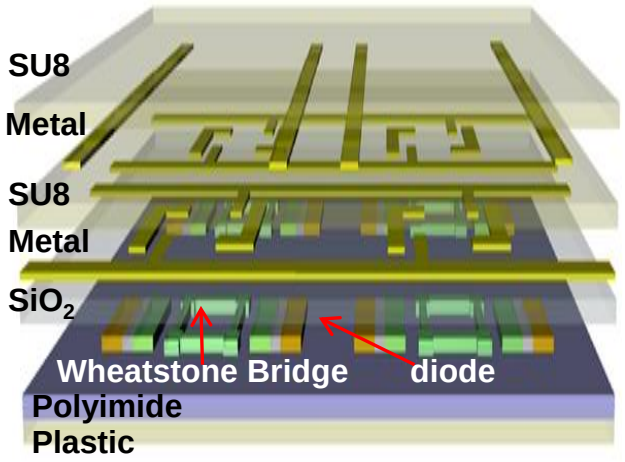
Functionality

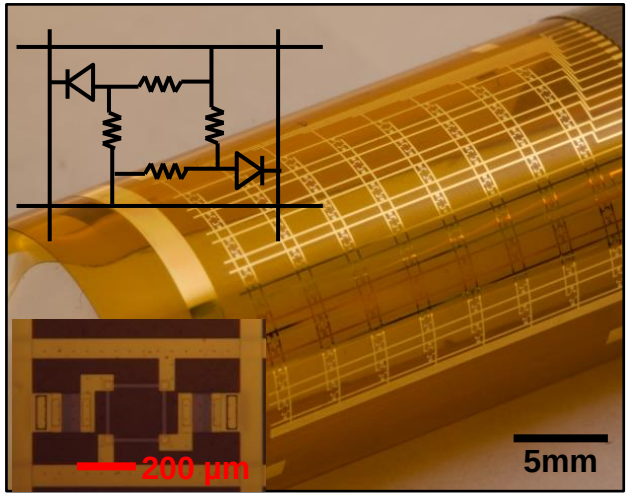
- Electrical, mechanical, thermal, optical, biomedical

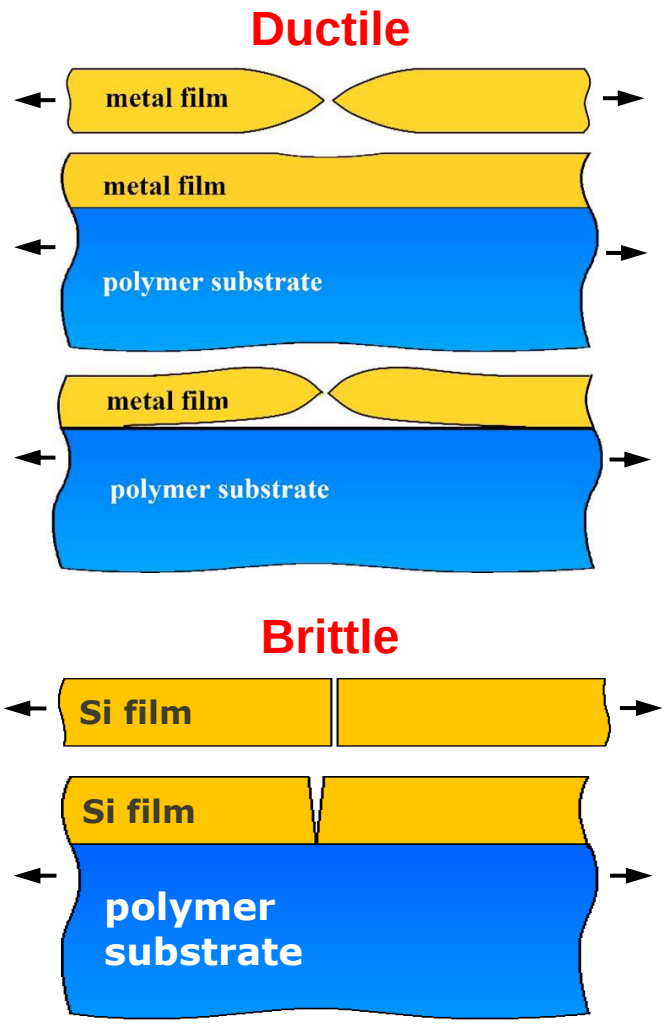
Cost, Power, Weight, Size

- Minimal

Polymer-Supported Metal and Silicon Films

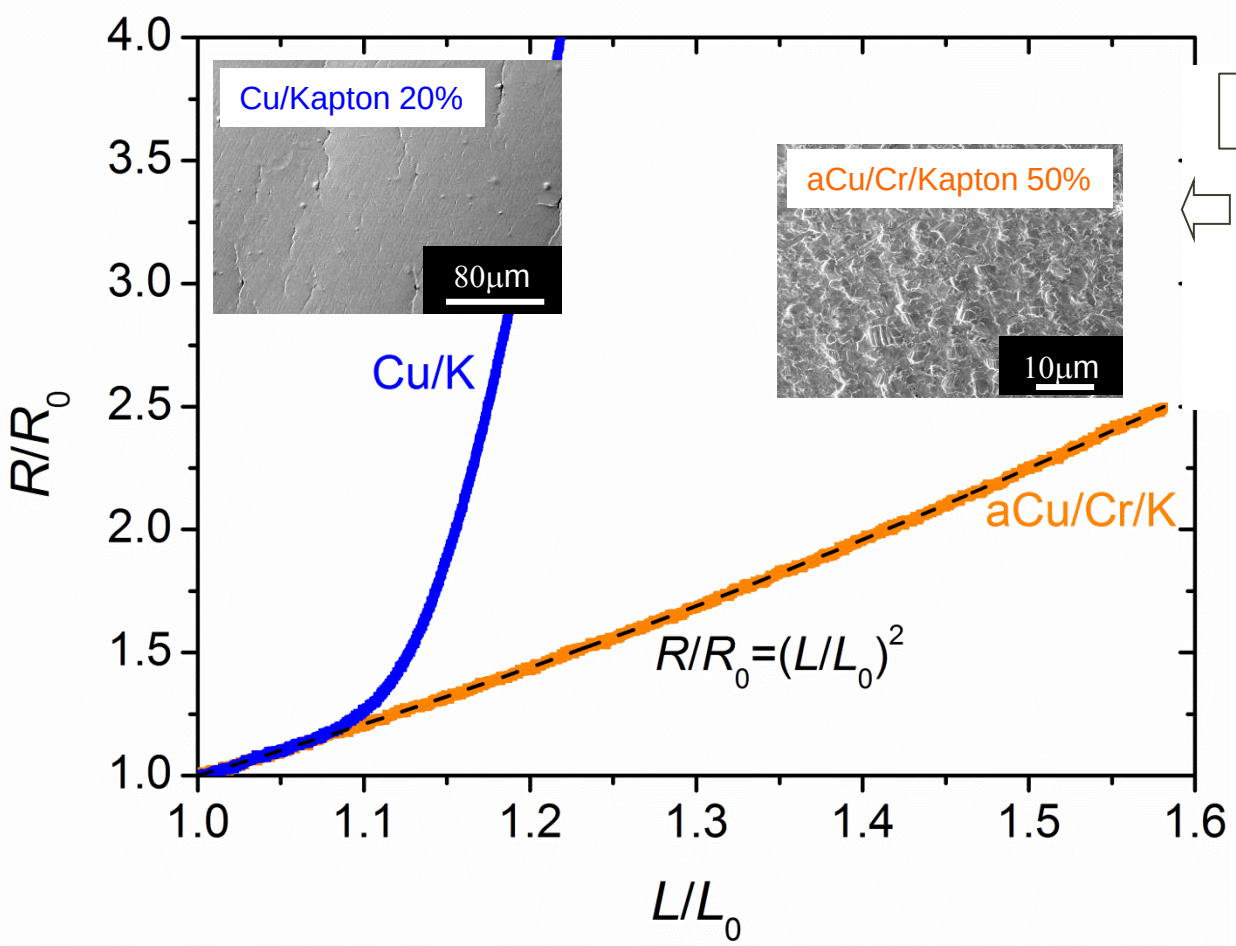


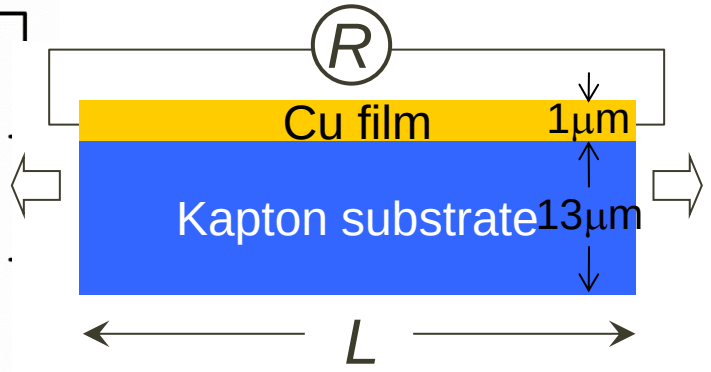


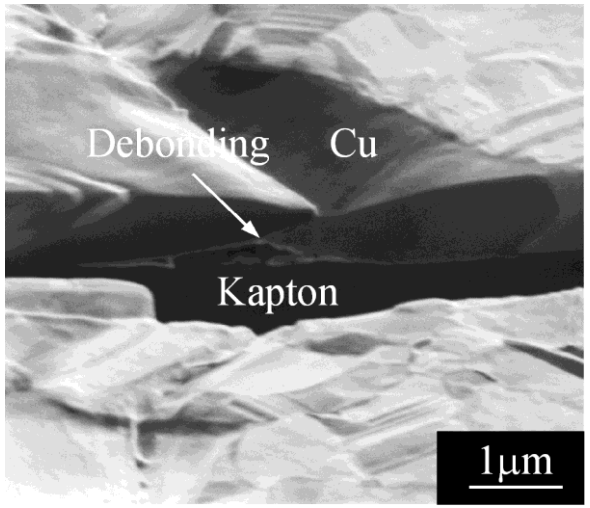


Won, Kim, **Lu**, Rogers, *IEEE Transactions on Electron Devices* **58**, 4074 (2011).

Stretchability of Blanket Metal on Polymer

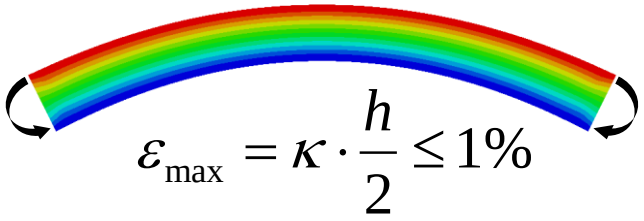




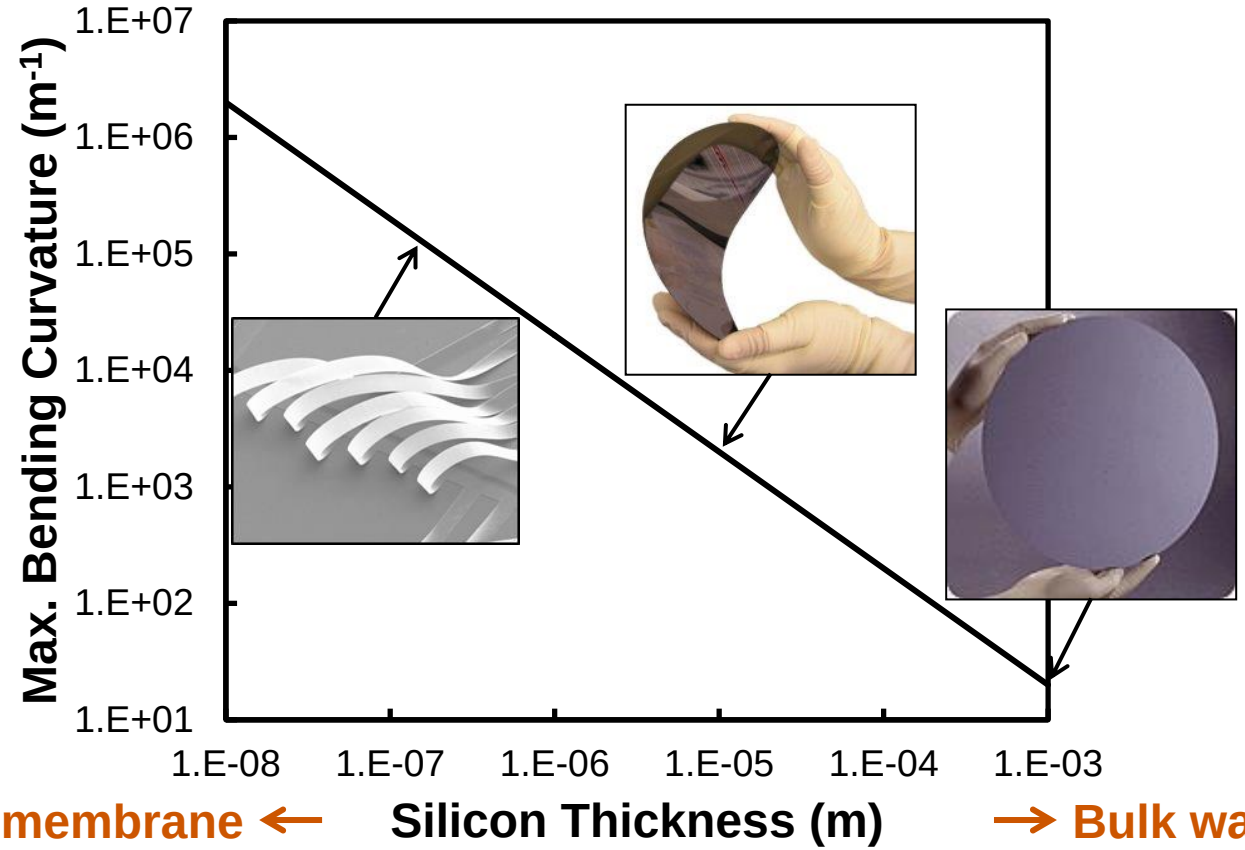


Lu, Wang, Suo, Vlassak, *Applied Physics Letters* 91, 221909 (2007).
Lu, Wang, Suo, Vlassak, *Journal of Materials Research* 24(2), 379-385 (2009).
Lu, Suo, Vlassak, *Acta Materialia* **58**, 1679-1687 (2010).

Bendability of Silicon

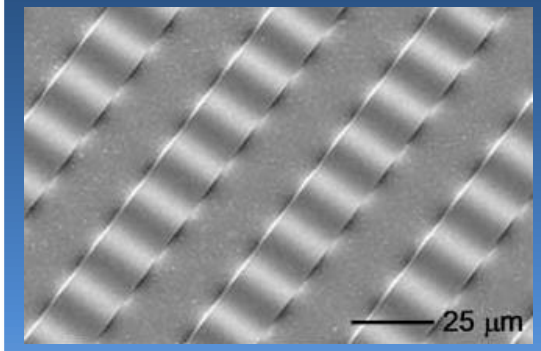


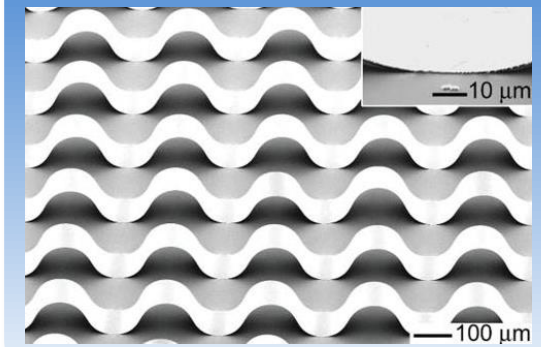
$$\varepsilon_{\max} = \kappa \cdot \frac{h}{2} \leq 1\%$$



Stretchability of Si-Based Electronics

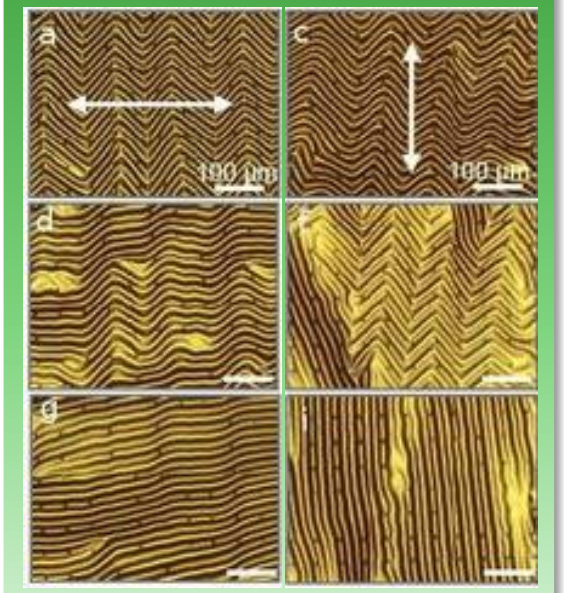
Buckled Ribbons





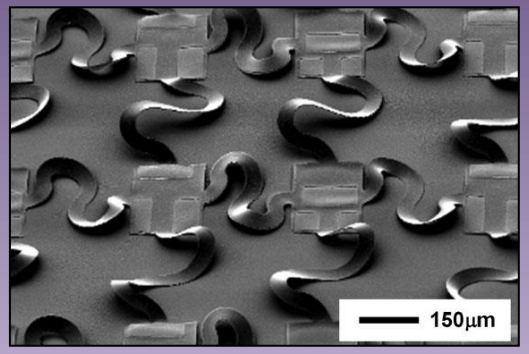
Sun *et al.*, *Nature Nanotech.* **1**, 201 (2006).

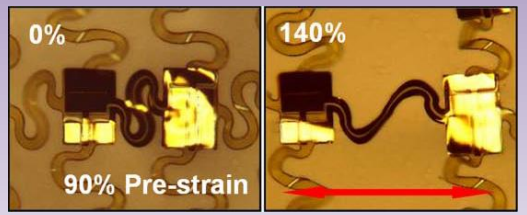
2D Wavy Membrane



Choi *et al.*, *Nature Lett.* **7**, 1655 (2007).

Si Islands + Interconnects



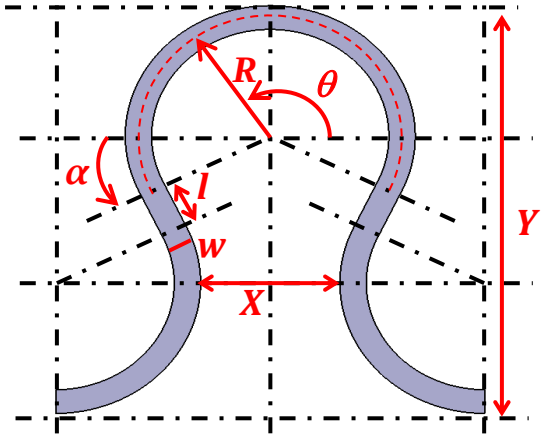


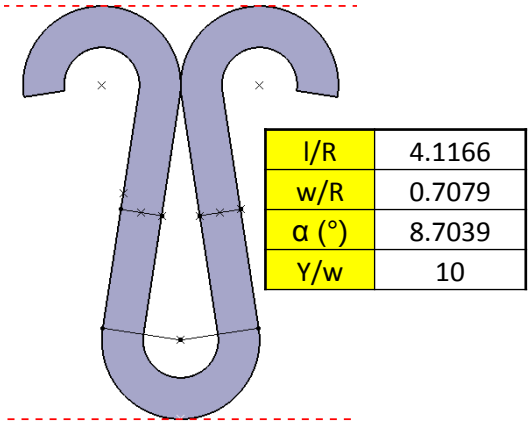
Kim *et al.*, *PNAS* **105**, 18675 (2008).

Stretchability of Serpentines

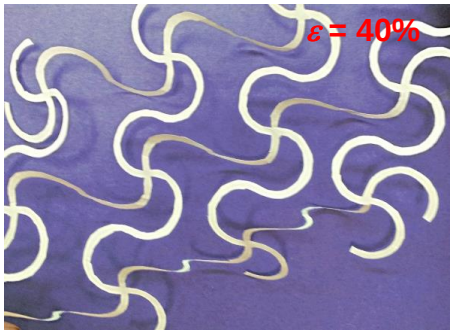
Unknowns: *w*/*R*, *l*/*R*, *α*

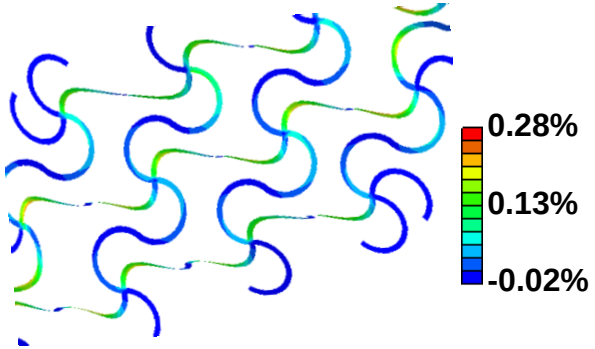
Constraints: 1). No overlap ($X = 0$); 2). *Y*/*w*=fixed; 3). Min. $\varepsilon_{\max} / \varepsilon_{\text{app}}$





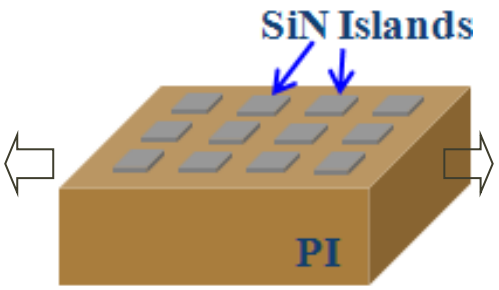
l/R	4.1166
w/R	0.7079
α (°)	8.7039
Y/w	10

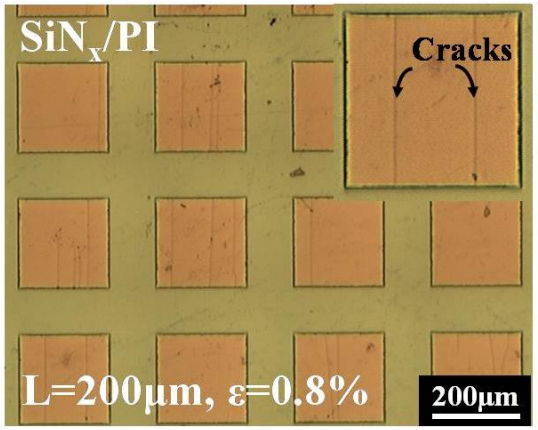


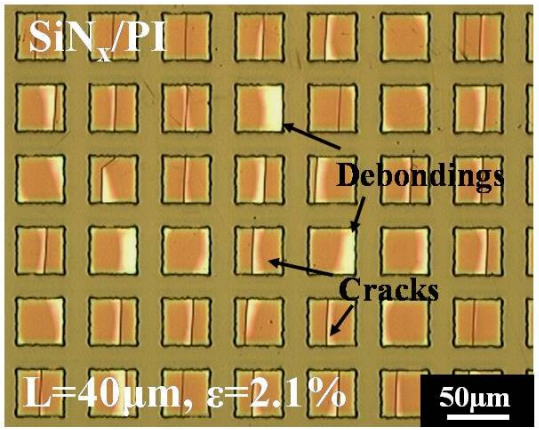


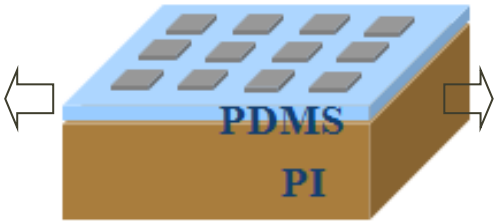
Widlund, Yang, **Lu**, to be submitted (2013).

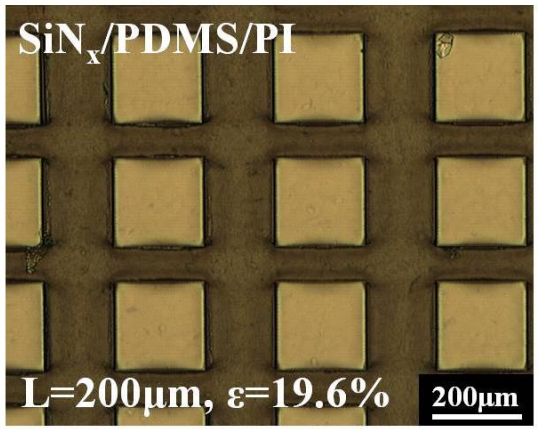
Stretchability of Brittle Islands

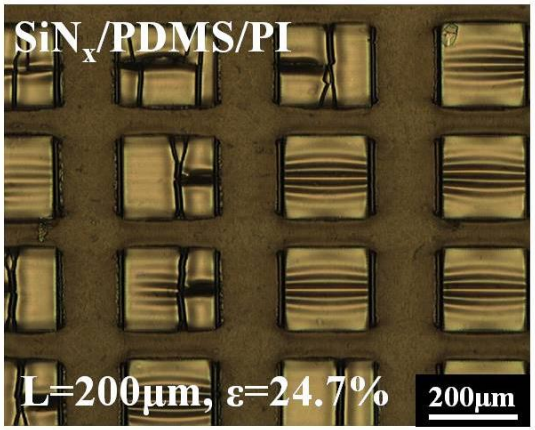






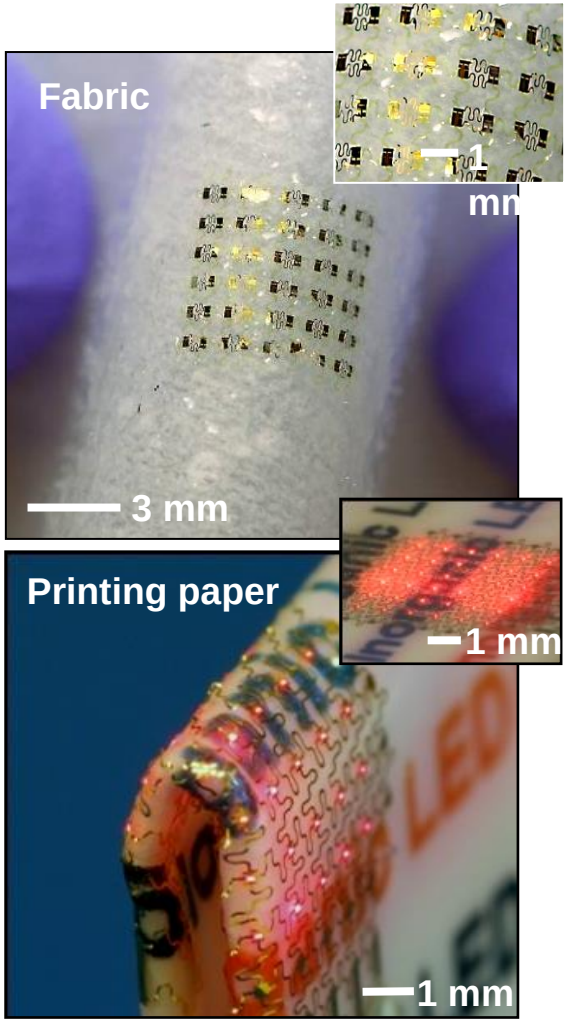


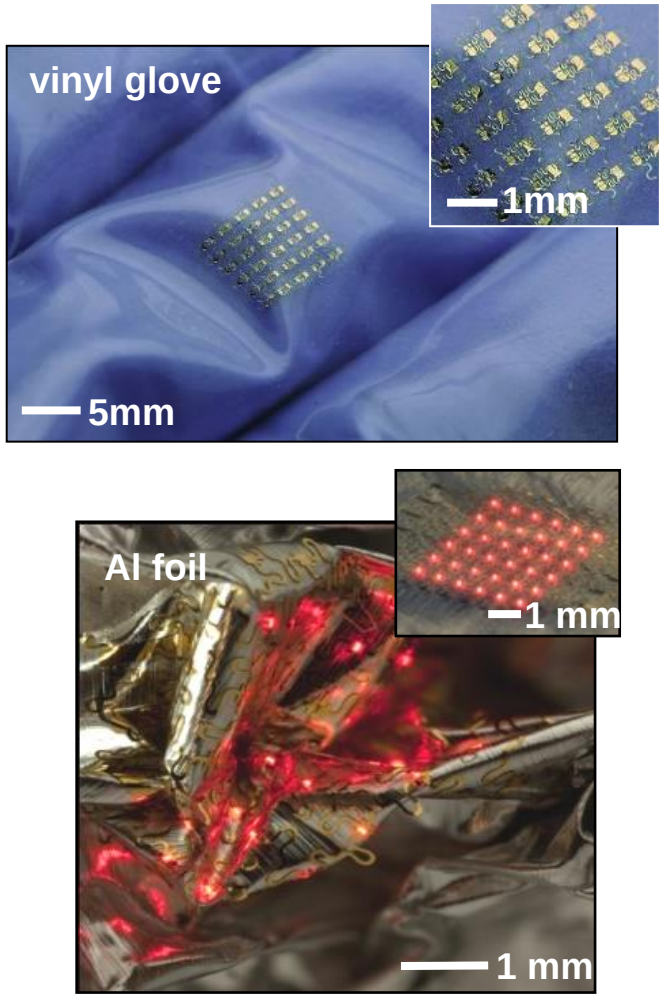




Sun, **Lu**, Suo, Vlassak *et al.*, *J. Mater. Res.* **24**, 3338 (2009).

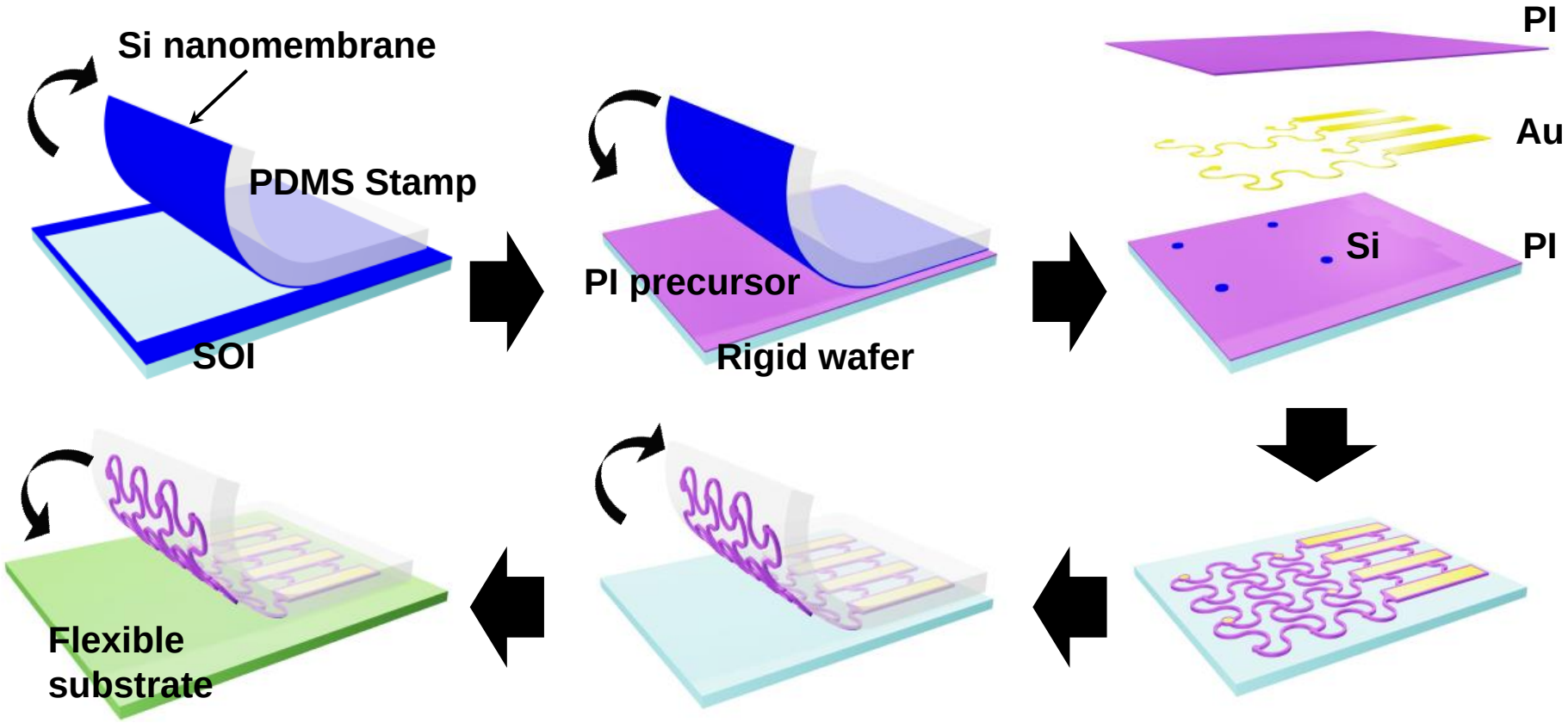
Electronics On Various Substrates





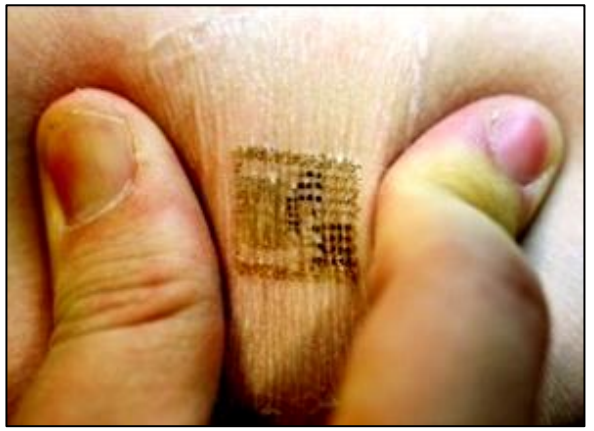
Kim, Rogers *et al.*, *Adv. Mater*. **21**, 3703 (2009).
Kim, Rogers *et al.*, *Nature Mater*. **9**, 929 (2010).

Micro-Transfer Printing Technique

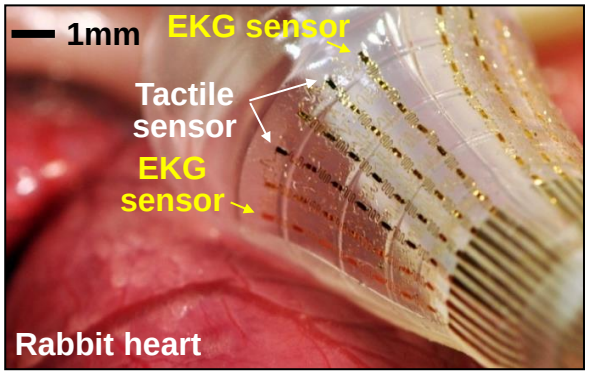


Case Study

- Non-invasive
  - Epidermal Electronics: extreme compliance, non-invasive
  - Wearable Finger Tube



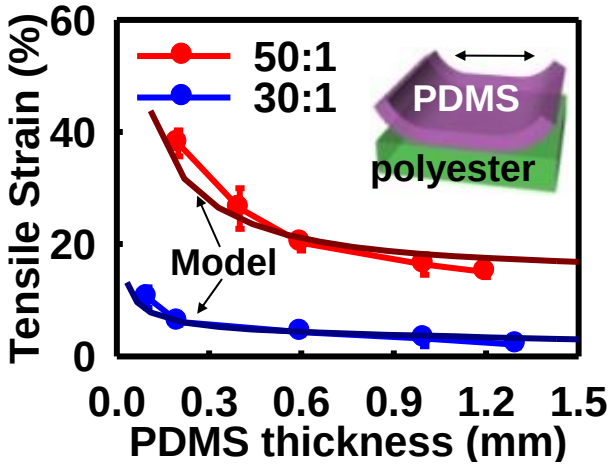
- *In Vivo*
  - Balloon Catheter: extreme expandability,
  - Cardiac web



Polymer on Skin

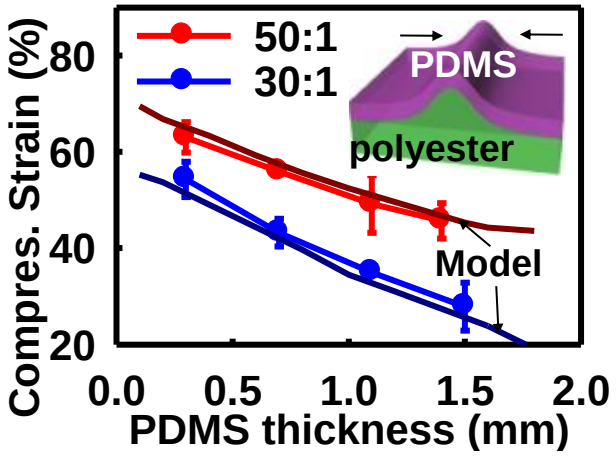
Stiff and thick

PDMS E = 145 kPa, h = 0.6 mm

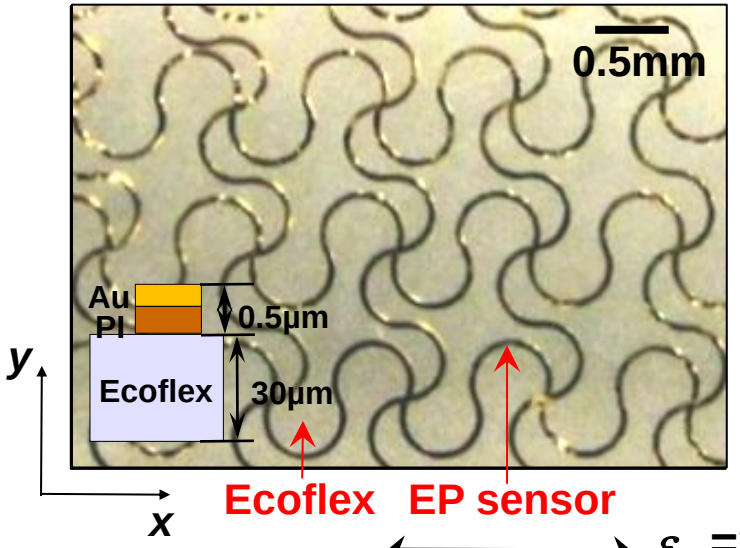


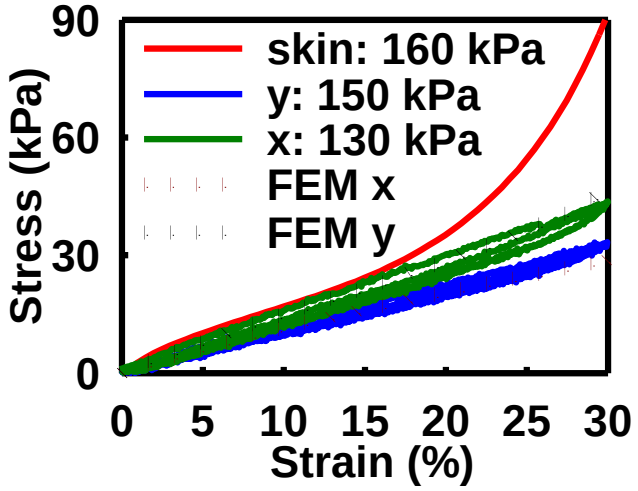
Soft and thin

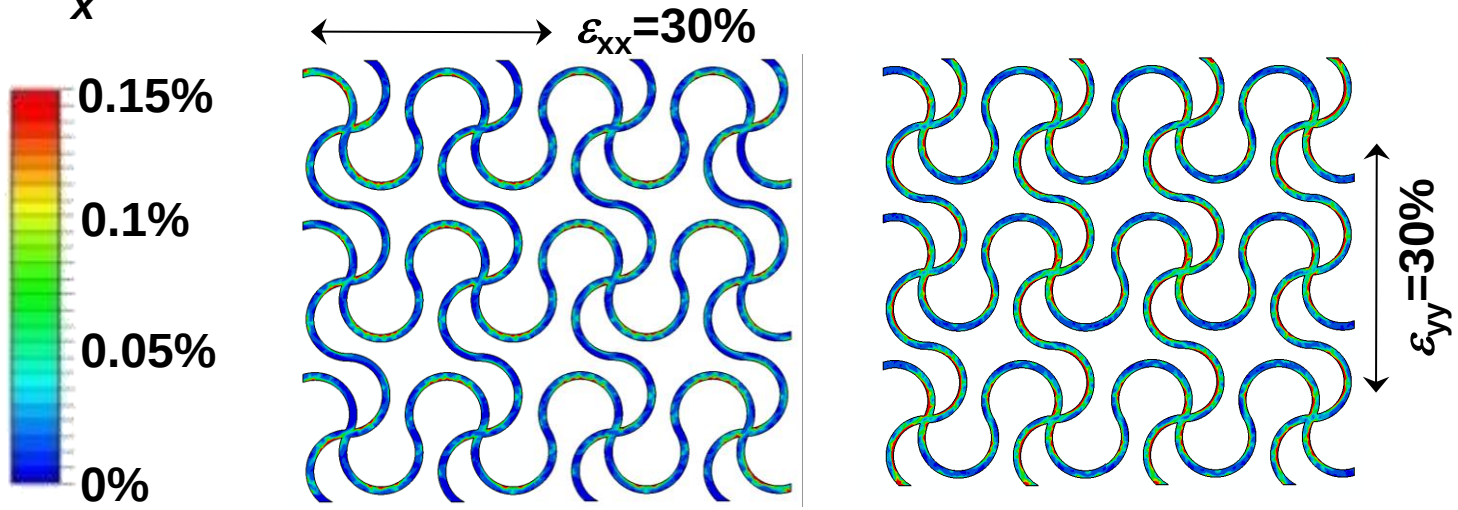
PDMS E = 19 kPa, h = 0.3 mm



Compliance and Stretchability

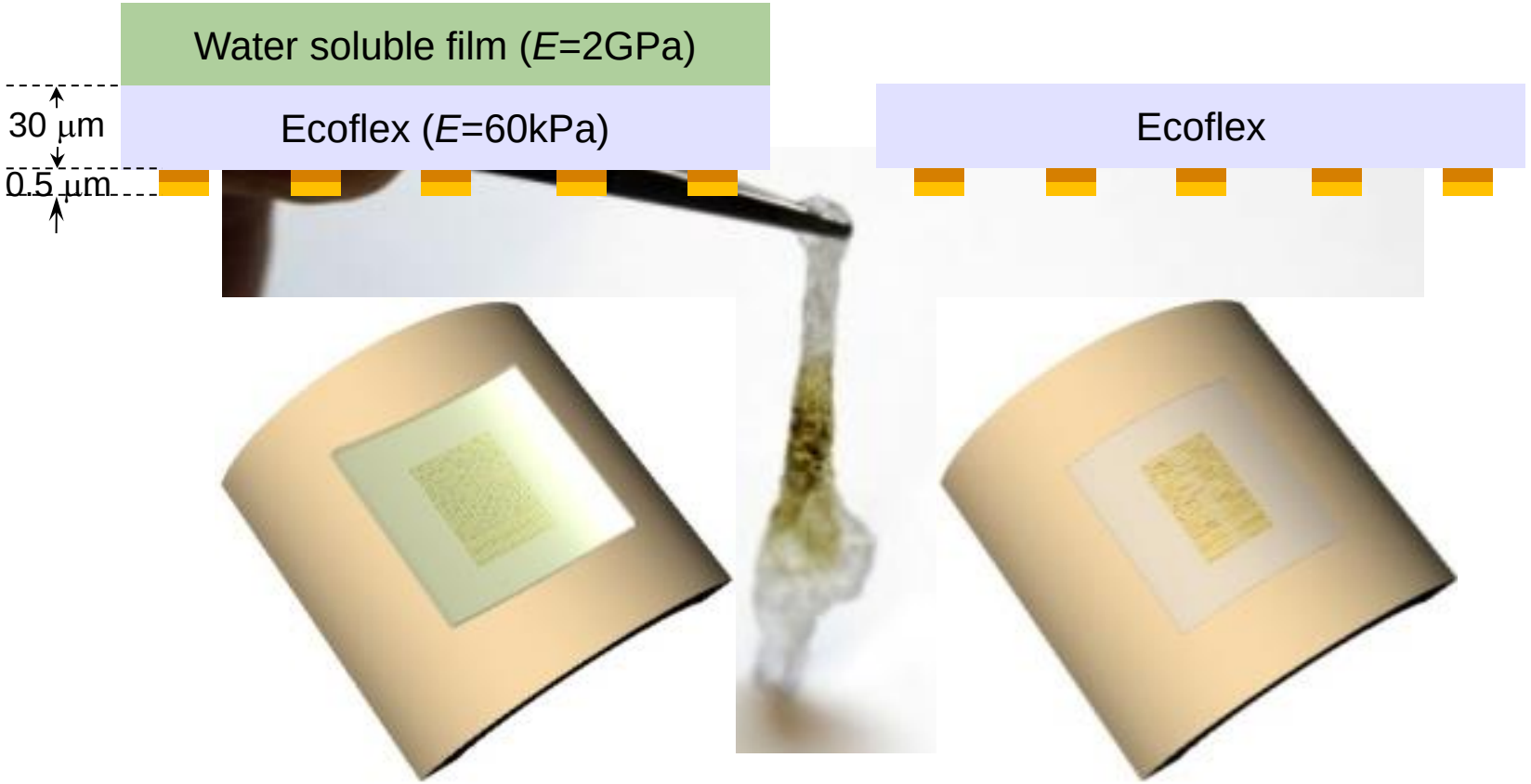






Kim*, **Lu***, Ma* (*equal contribution), Rogers, *et al.*, *Science* **333**, 838, (2011).

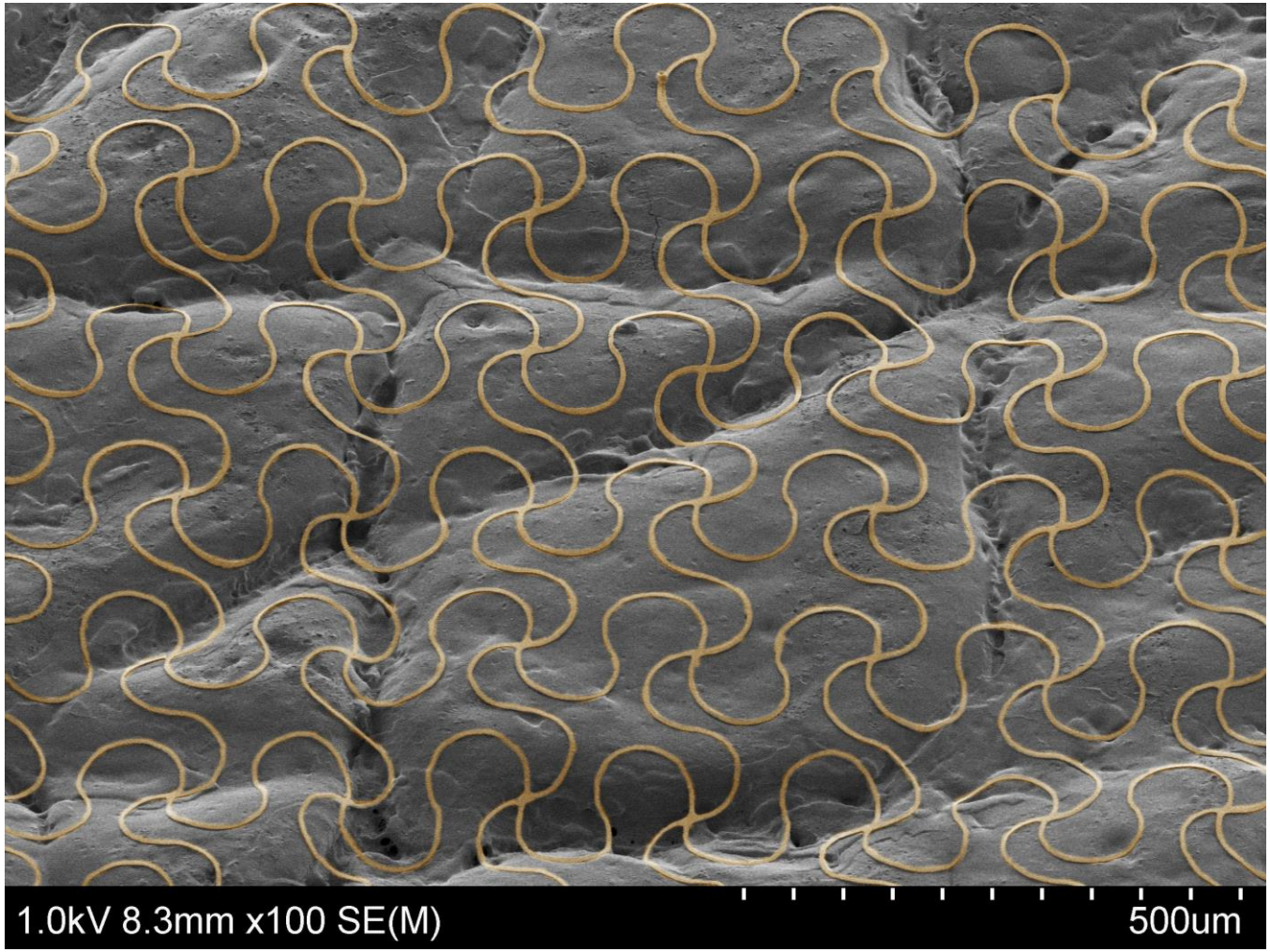
Thinning Down



Mounting and Removal

Sample credit: Dae-Hyeong Kim, Nanshu Lu
Arm credit: Dae-Hyeong Kim
Video credit: Yun-Soung Kim

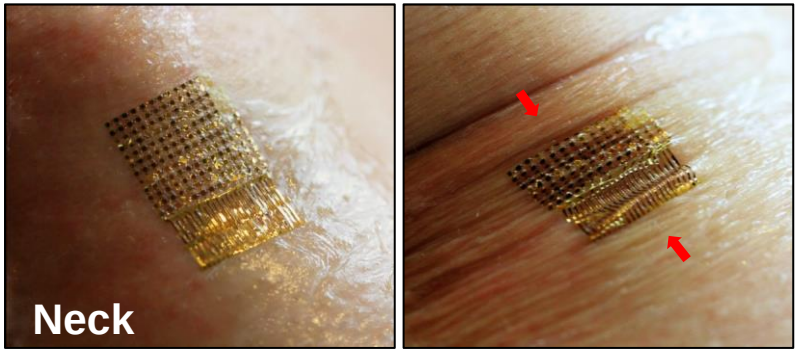
Extreme Compliance & Conformability

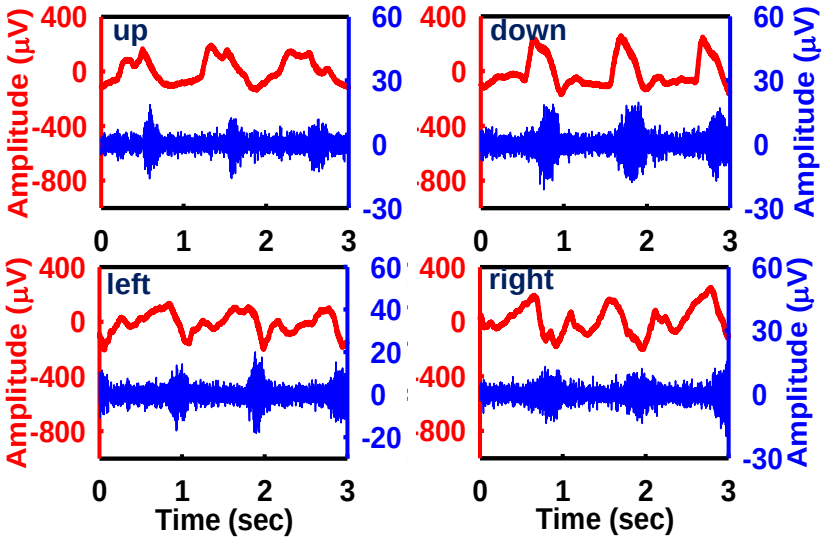


Yeo, Rogers, *et al*, *Advanced Materials* 25, 2773–2778 (2013).

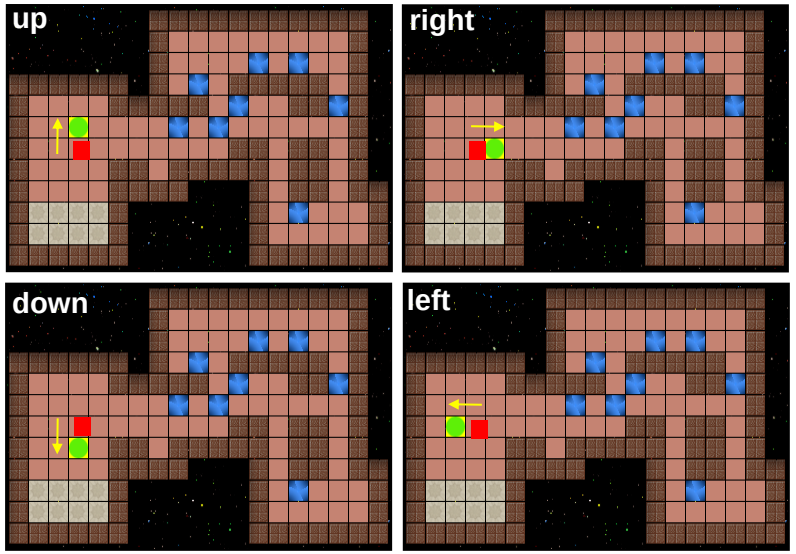
EMG Sensing

In collaboration with Todd Coleman, UCSD BME





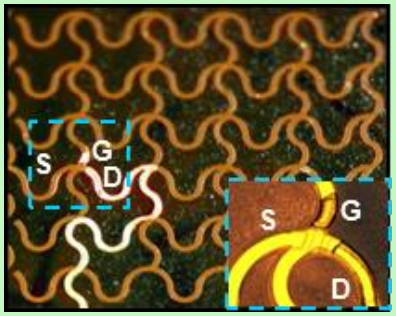
Sokoban



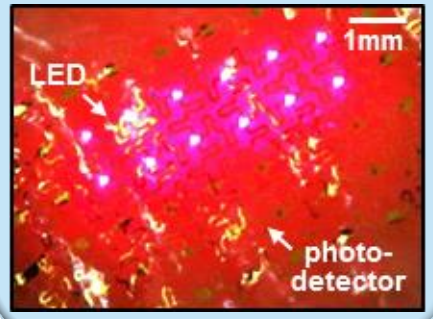
Kim*, **Lu***, Ma* (*equal contribution), Rogers, *et al.*, *Science* **333**, 838, (2011).

Apps

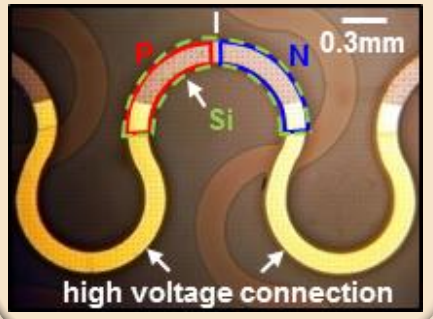
Amplifier



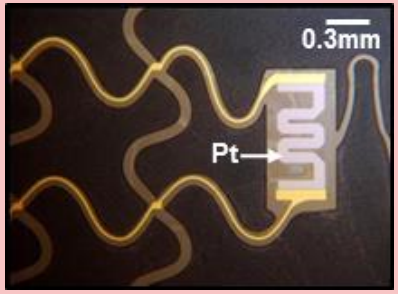
LED



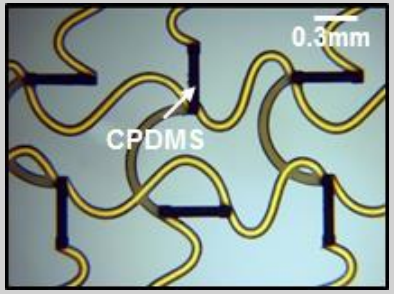
Solar Cell



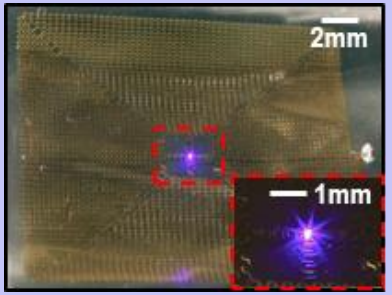
T Sensor



ε Gauge

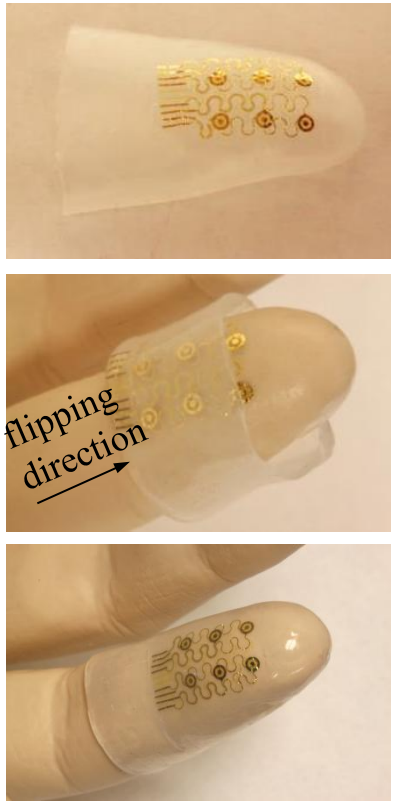


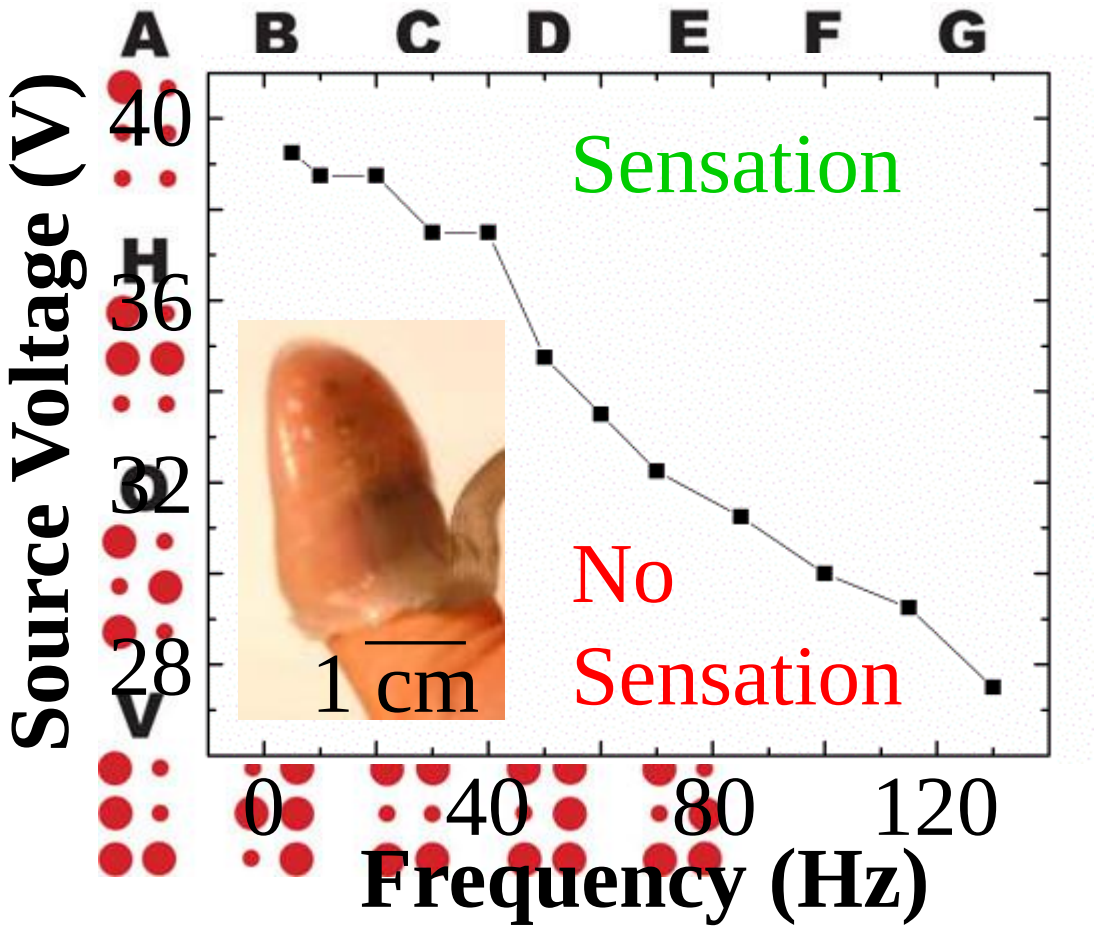
L Coil



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

Electrotactile Stimulators on Wearable Finger Tube

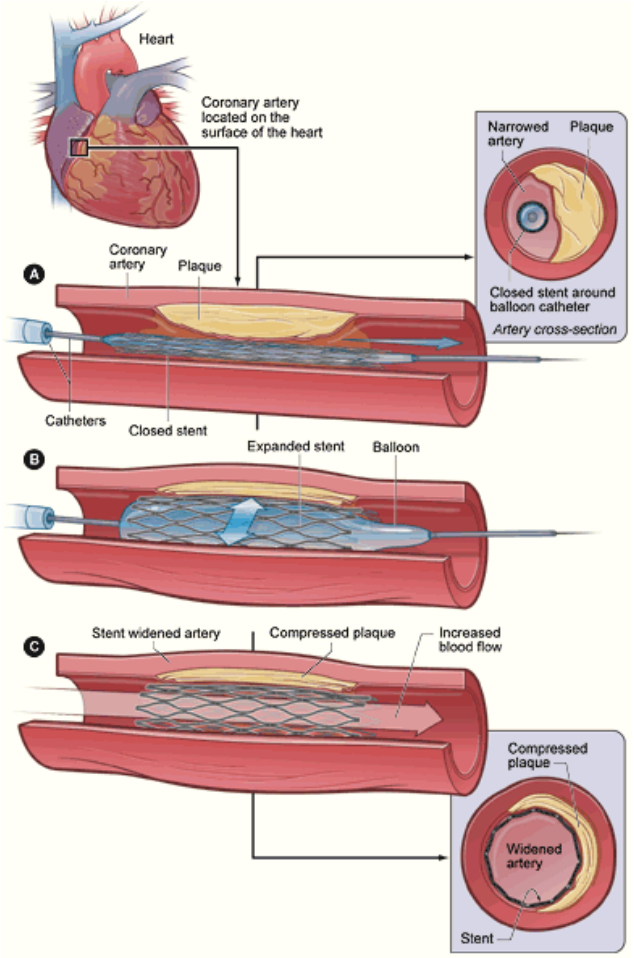




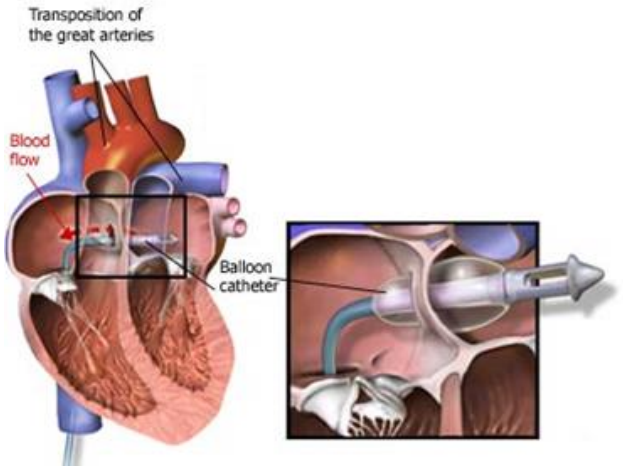
Ying, Bonifas, **Lu** *et al.*, *Nanotech* 23, 344004 (2012).

Balloon Catheters

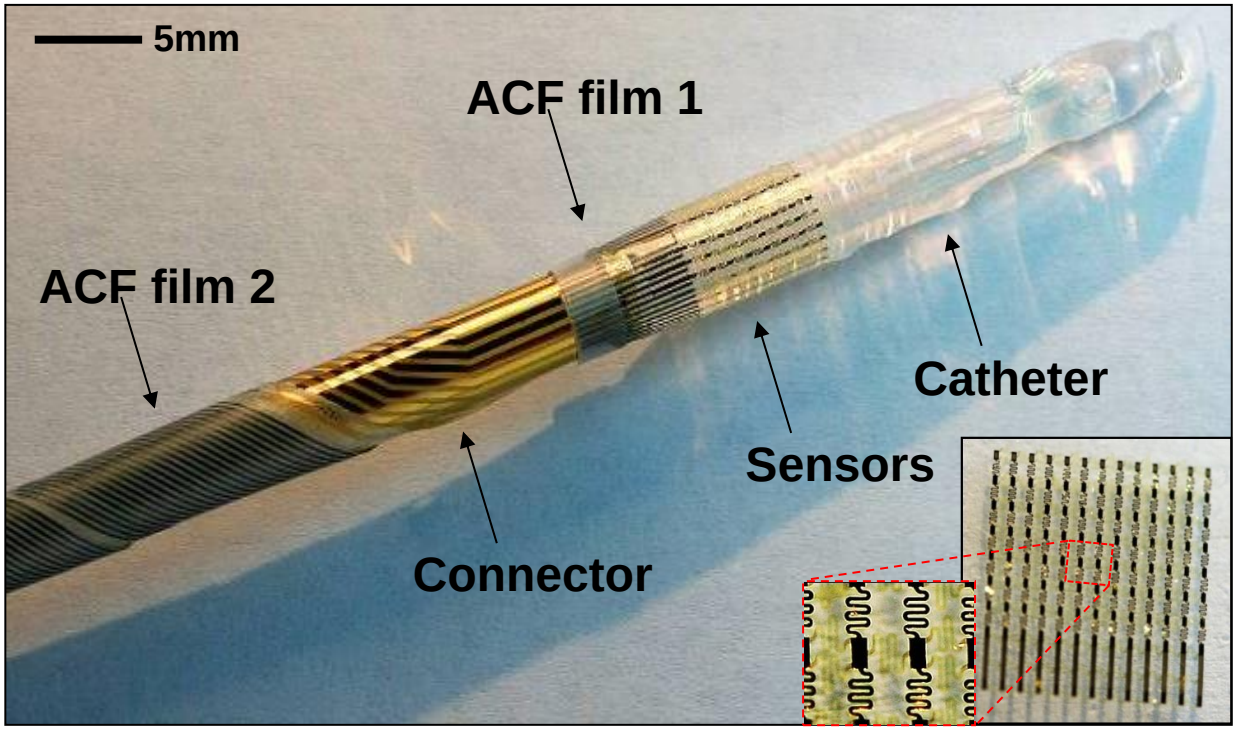
Angioplasty balloon catheter

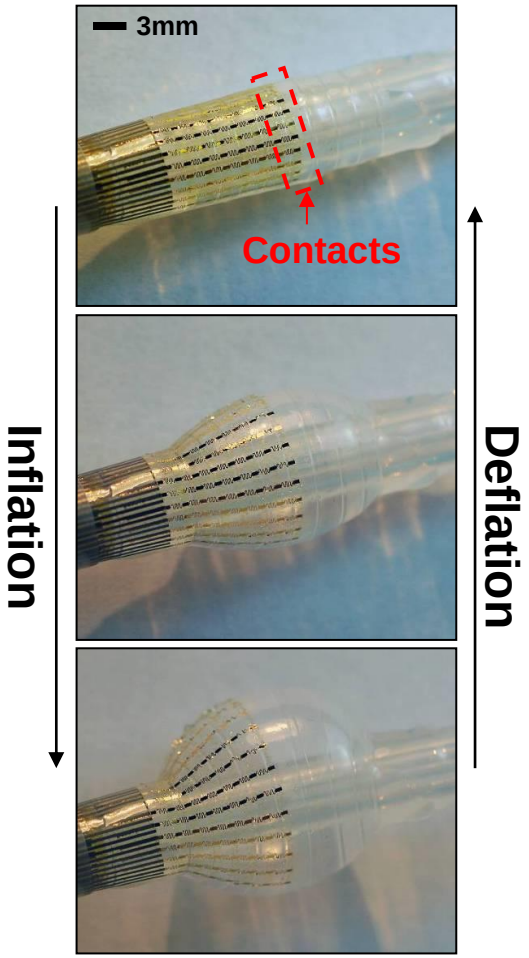


Balloon atrial septostomy



Instrumented Balloon Catheter

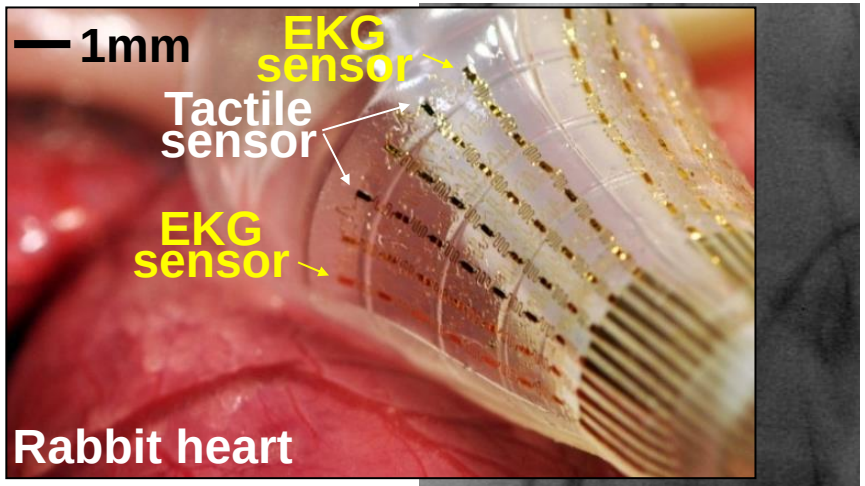


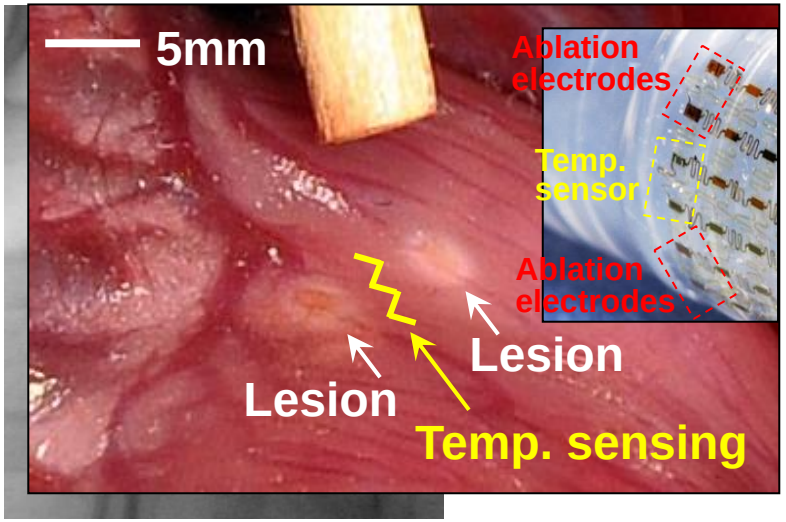


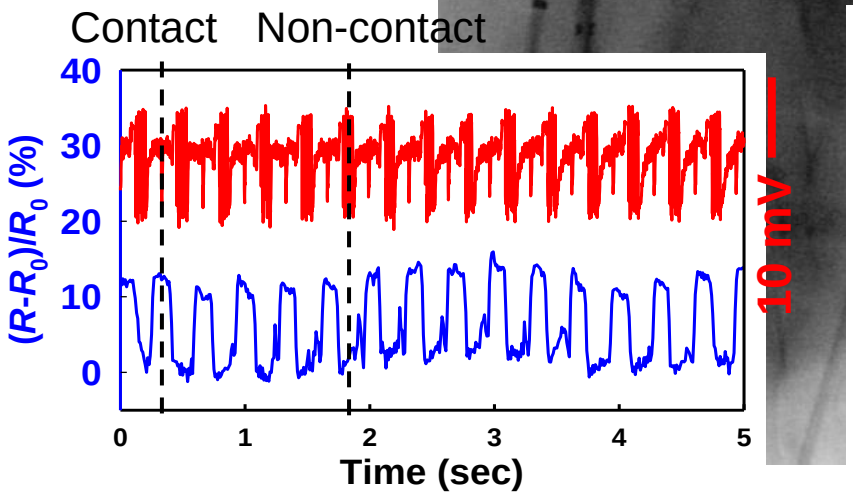
Kim*, Lu*, Ghaffari* (*equal contribution), Rogers, *et al.*, *Nature Mater*. **10**, 316 (2011).

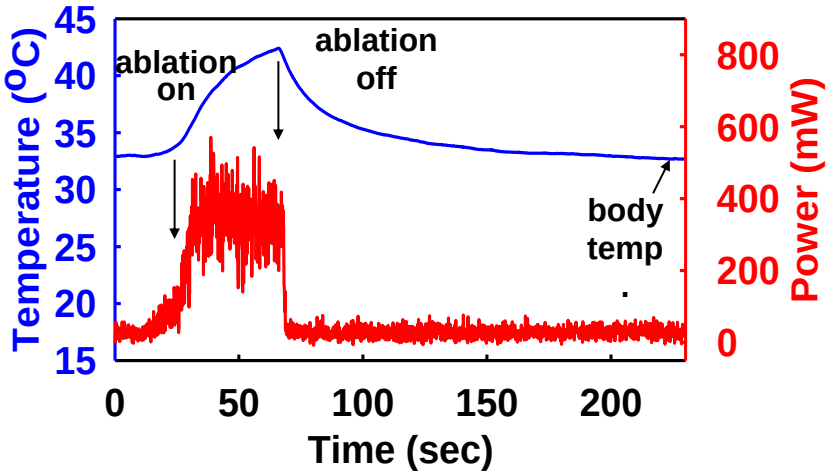
Sensing and Therapeutics

In collaboration with Marv Slepian, U of Arizona



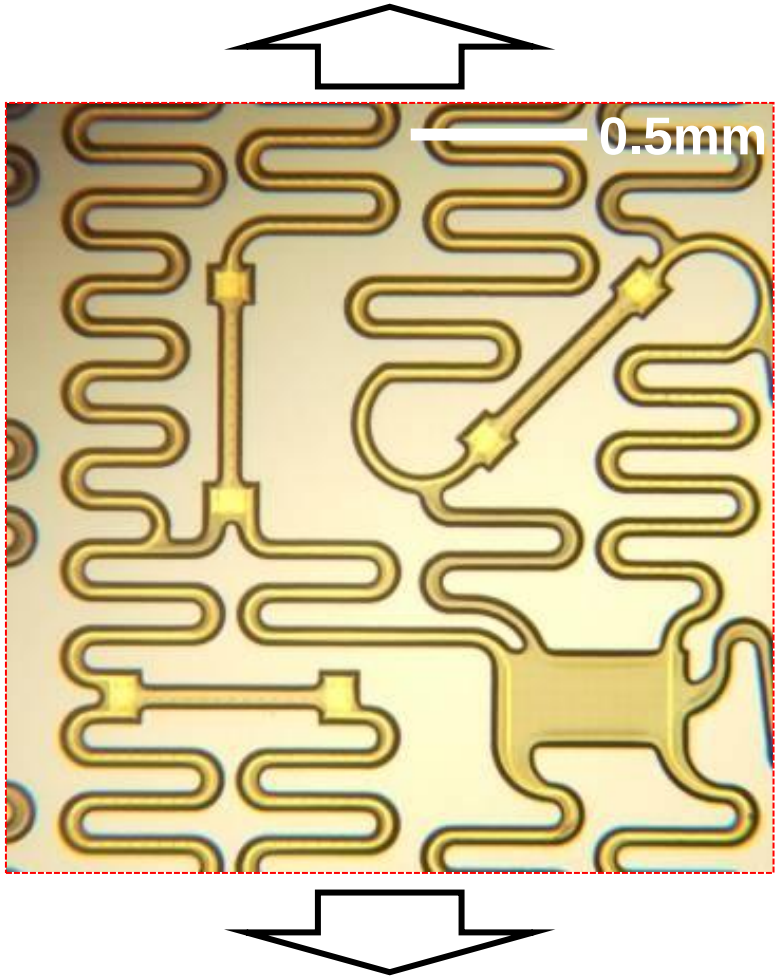


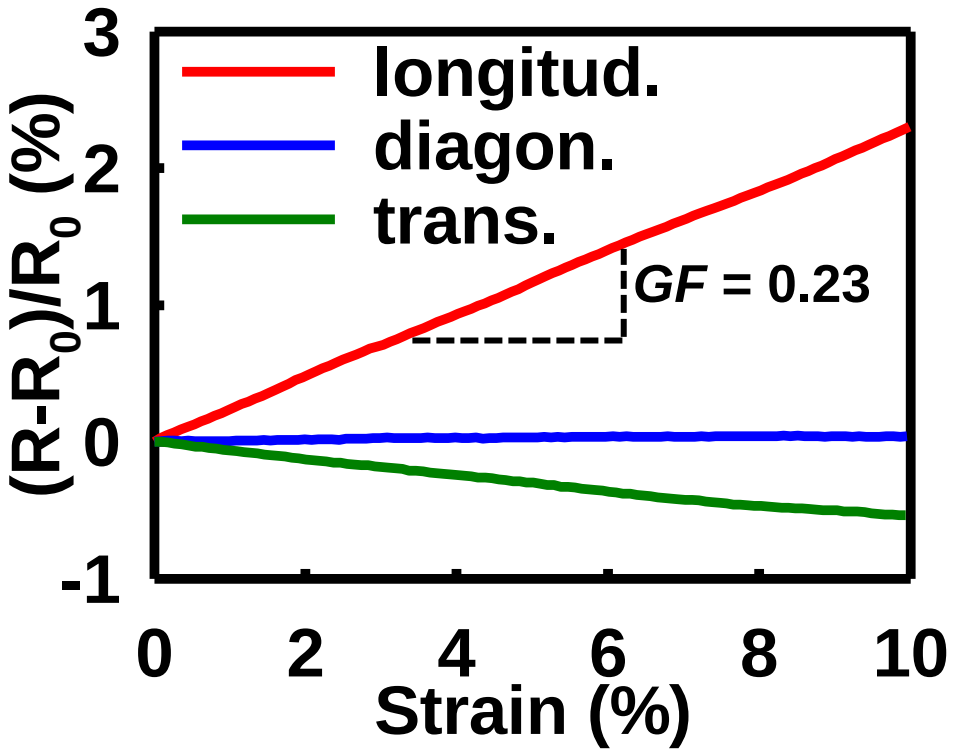




Kim*, **Lu***, Ghaffari* (*equal contribution), Rogers, *et al.*, *Nature Mater*. **10**, 316 (2011).

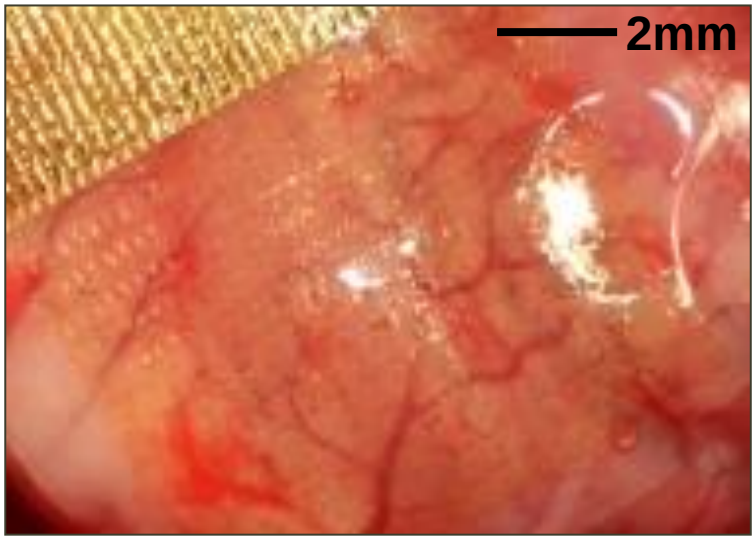
Stretchable Strain Gauges

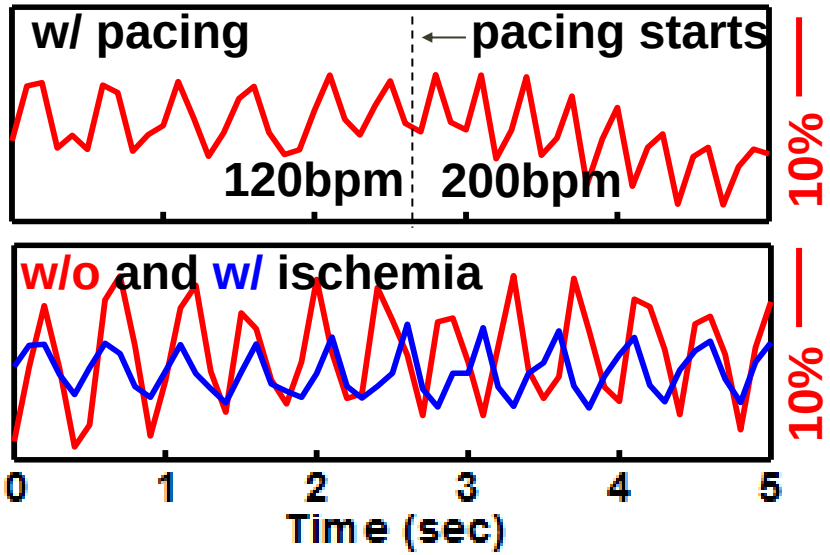




Kim*, Ghaffari*, **Lu*** (*equal contribution), Rogers, *et al.*, *PNAS* **109**, 19910 (2012).
Yang, **Lu**, *Sensors* **13**, 8577-8594 (2013).

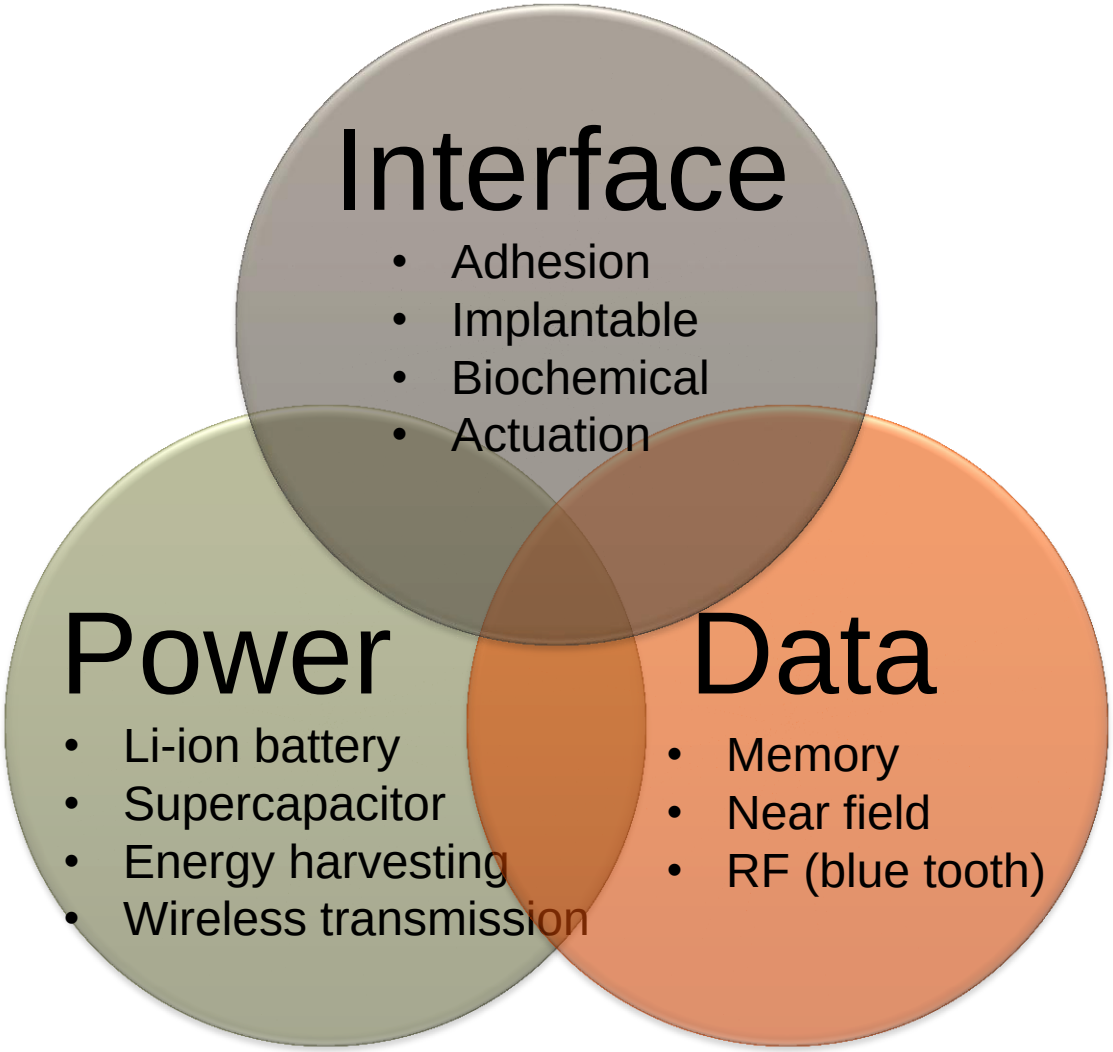
In Vivo Epicardial Sensing



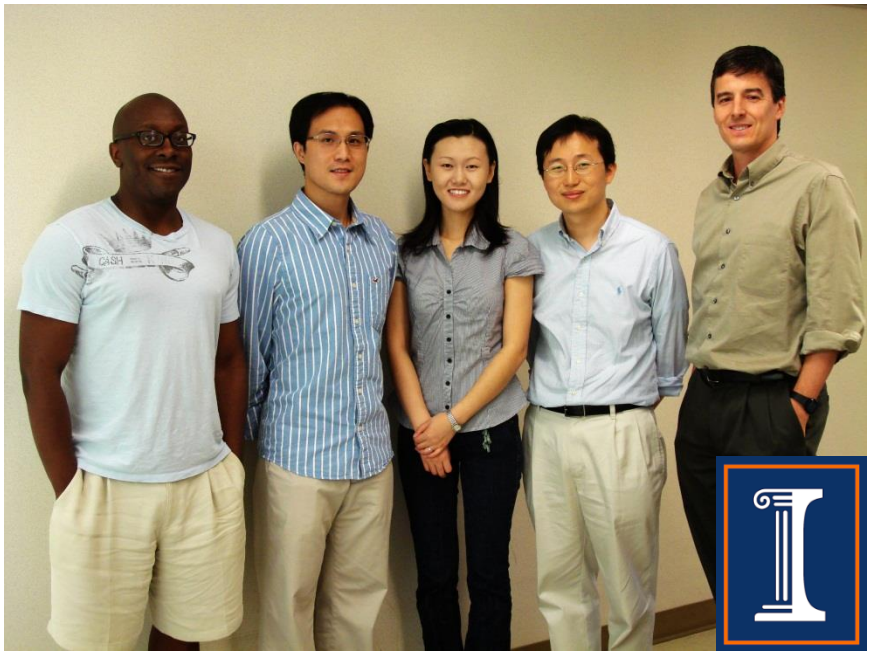


Kim*, Ghaffari*, **Lu*** (*equal contribution), Rogers, *et al.*, *PNAS* **109**, 19910 (2012).

What's Next?


Interface
• Adhesion
• Implantable
• Biochemical
• Actuation
Power
• Li-ion battery
• Supercapacitor
• Energy harvesting
• Wireless transmission
Data
• Memory
• Near field
• RF (blue tooth)

Acknowledgement



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AIR FORCE RESEARCH LABORATORY

NASCENT

Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies

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