I am a big fan of the feature of the 'flexibility' :

Flexible ideas & devices & dreams & innovations & future & bodies & relationships,

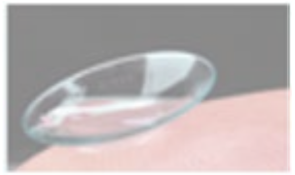

EMERGENCY
EYE WASH

Can you define yourself with an object?

Motivation

Devices

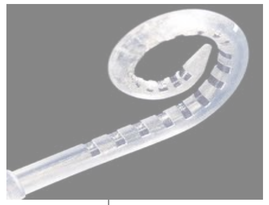
Contact Lens



Hydrogel Adhesive

Balloons (polyurethane)

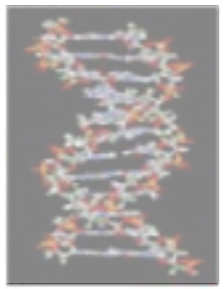
Cochlear implants



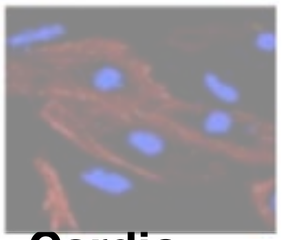
Cardiac pacemaker

100 Pa 1 kPa 10 kPa 100 kPa 1 MPa 10 MPa 100 MPa 1 GPa 10 GPa 100 GPa

Biology



DNA



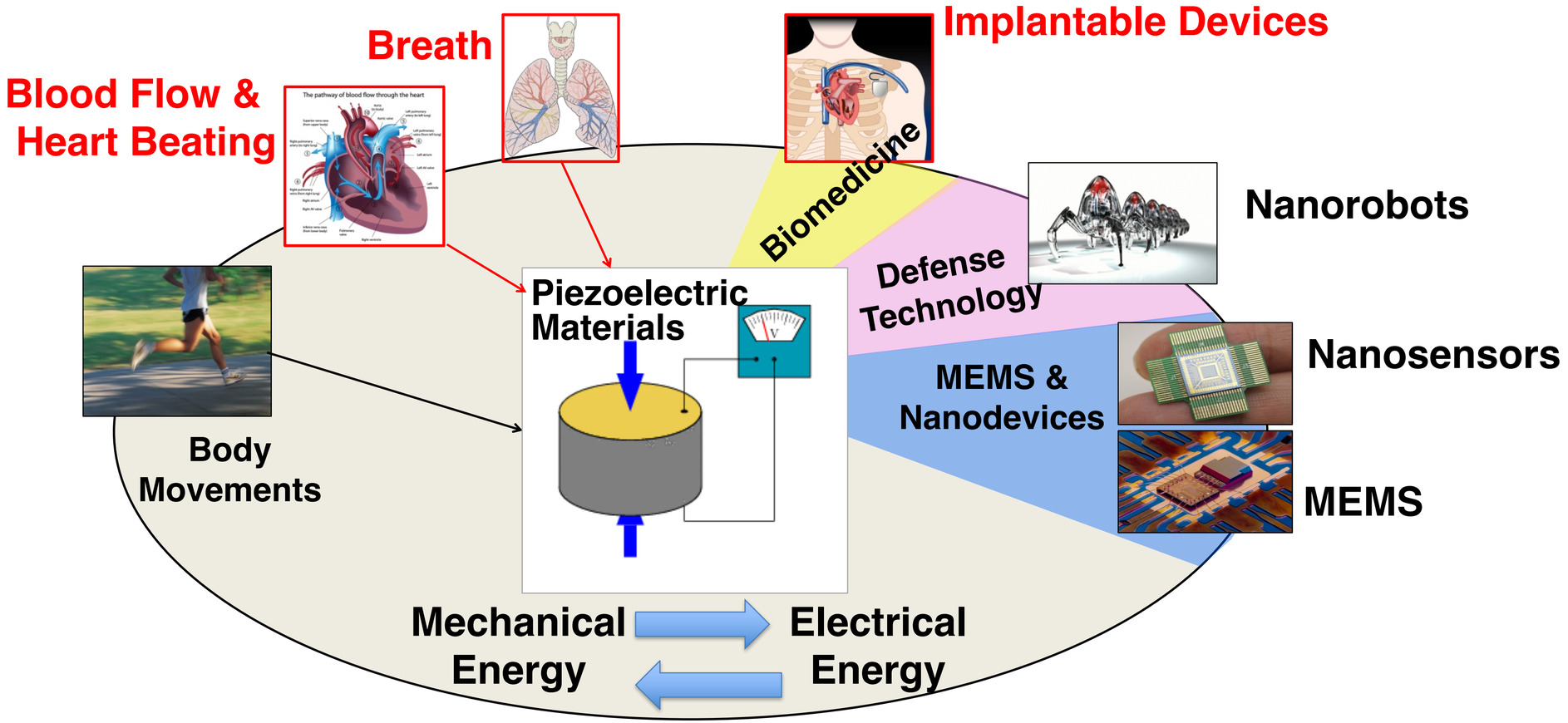
Cardio-myocyte

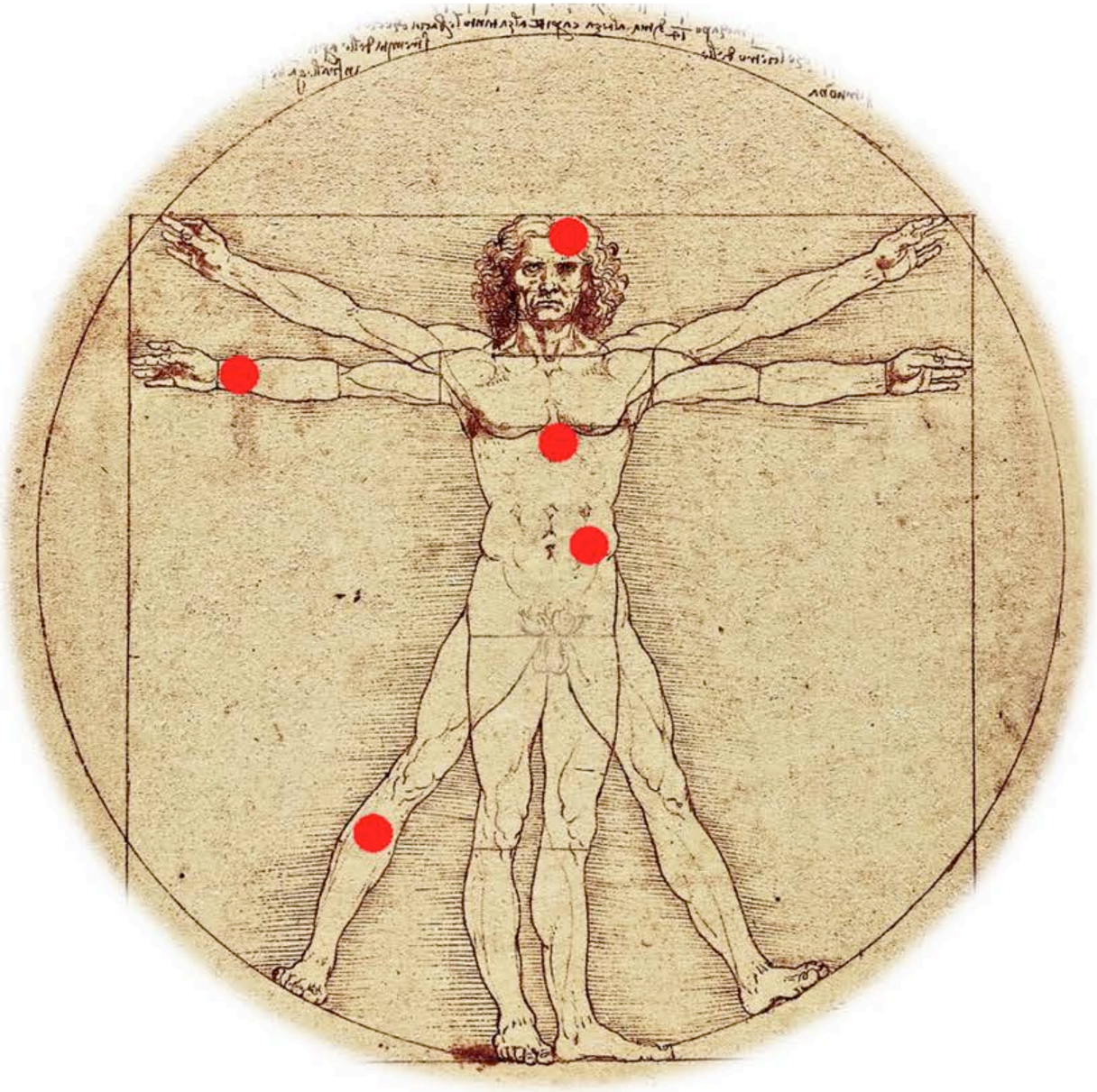
Heart tissue

Articular cartilage

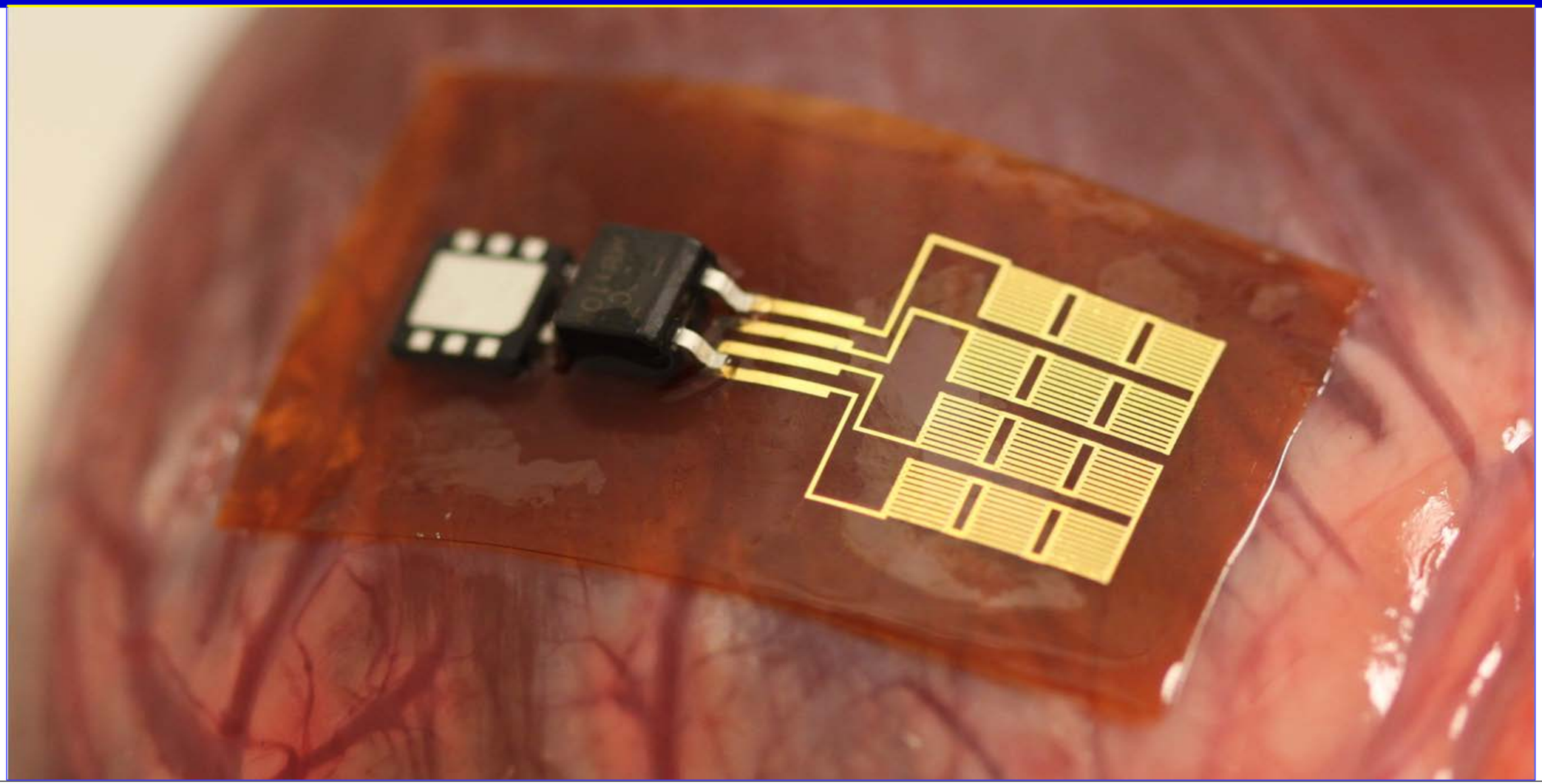
Human hair

Background

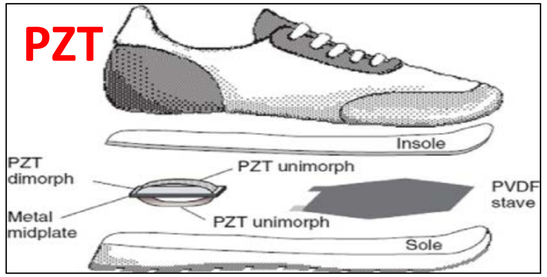

Breath
Blood Flow &
Heart Beating
Implantable Devices
Biomedicine
Nanorobots
Defense
Technology
Piezoelectric
Materials
Nanosensors
MEMS &
Nanodevices
MEMS
Body
Movements
Mechanical
Energy
Electrical
Energy



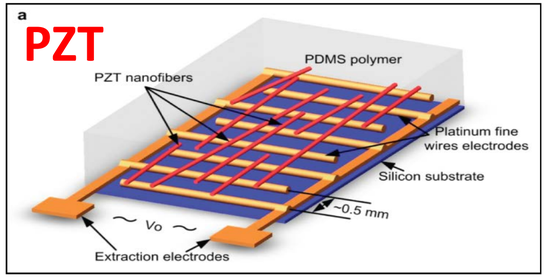
Conformal, Multilayer Piezoelectric Energy Harvesting and Storage From the Motion of the Heart, Lung and Diaphragm



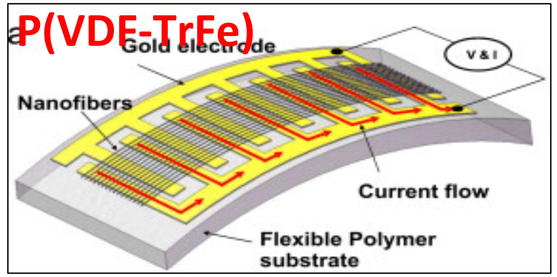
Background



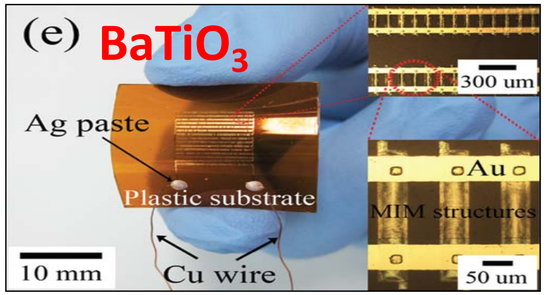
N.A. Shenck, IEEE Micro, 2001



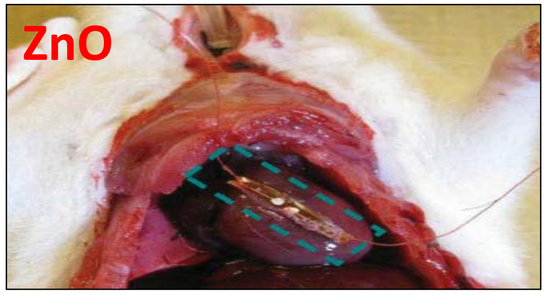
X. Chen, Nano Lett., 2010



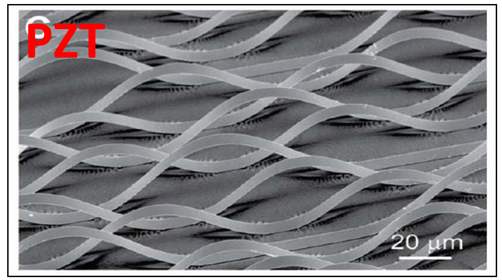
L.Lin, IEEE, 2011



K. Park, Nano Lett., 2010



Z. Li, Adv. Mater., 2010



M. McAlpine, Nano Lett., 2011

Our device has

- High power density

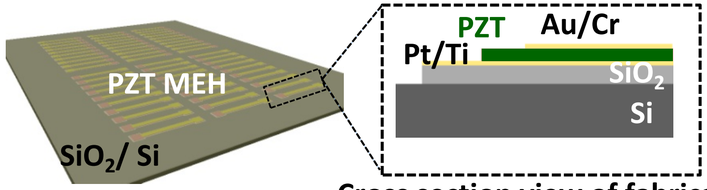
- Controllable design

- High flexibility, Conformal

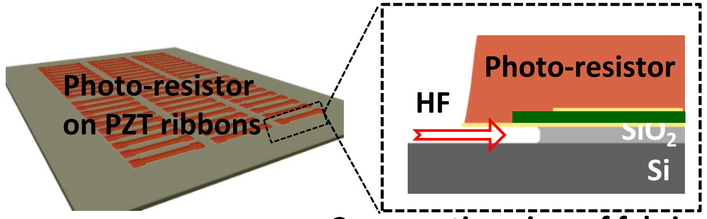
- Ultrathin and Lightweight forms

Results & Discussion

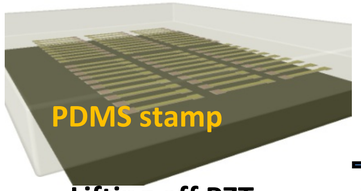
Schematic illustration of procedures for fabricating a PZT MEH



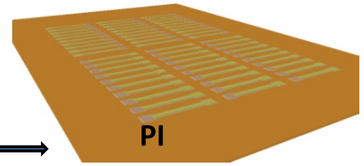
Cross section view of fabricated PZT nanoribbon on Si wafer



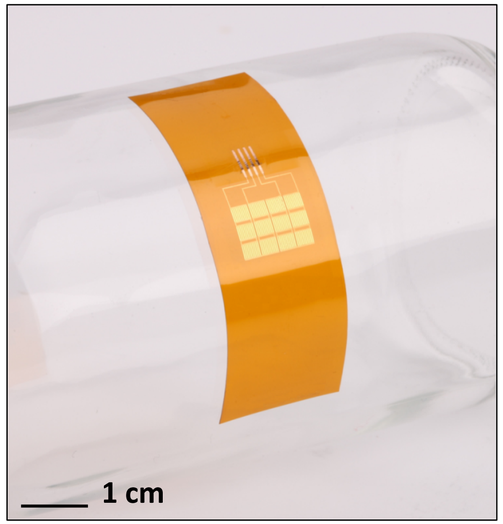
Cross section view of fabricated PZT nanoribbon during undercutting

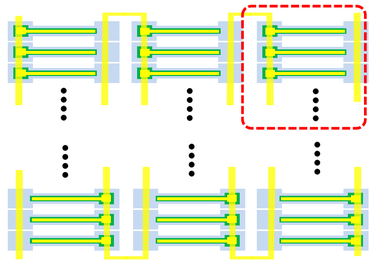


Lifting off PZT nanoribbons with PDMS stamp



Transferprinting PZT nanoribbons on flexible substrate





10 ribbons in parallel

12 groups are connected in series

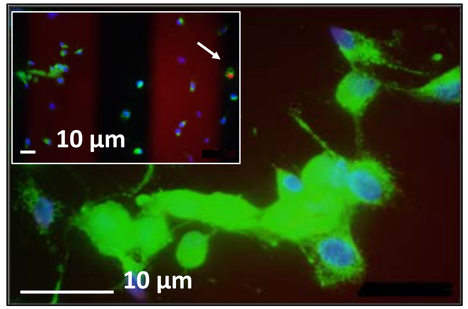
Interconnection Layout

C. Dagdeviren, *et al., PNAS,* 111 (5), 1927-1932 (2014)

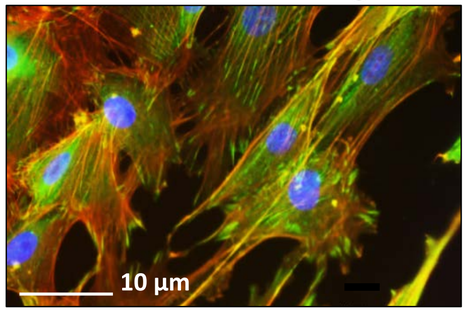
Results & Discussion

Tests of biocompatibility using rat smooth muscle cells

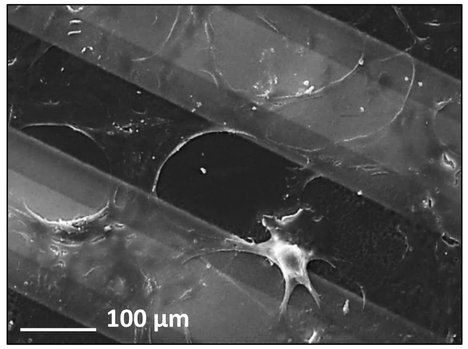
Live/dead viability assay



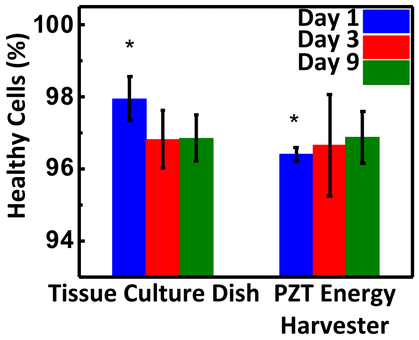
Fluorescent image



SEM image



Lactate dehydrogenase assay



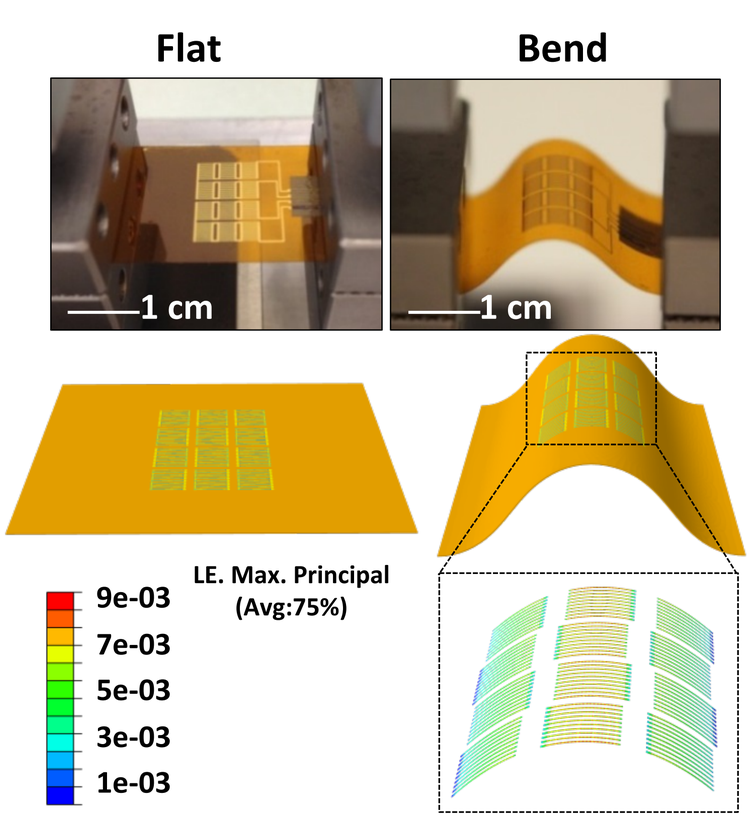
- The adherence, growth and viability of rat smooth muscle cells (SMC) were examined

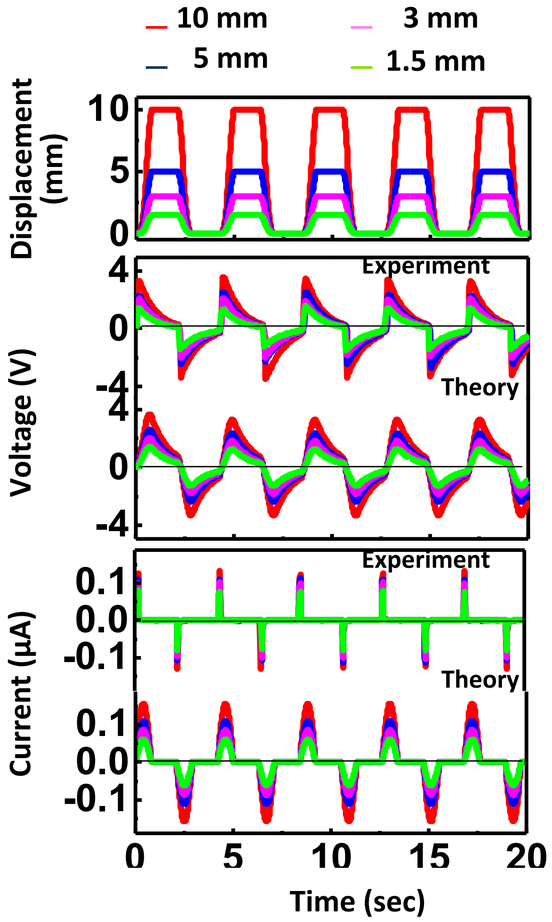
- **No detectable cytotoxicity** was observed in a live/dead™ assay

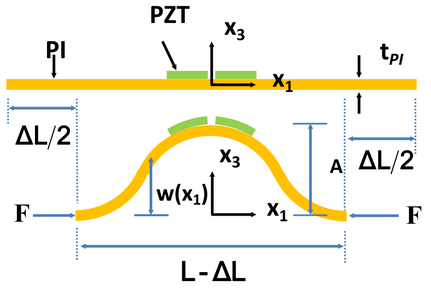
C. Dagdeviren, *et al., PNAS,* 111 (5), 1927-1932 (2014)

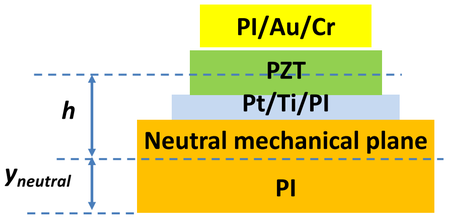
Results & Discussion

Experimental and theoretical studies of the electrical behavior of PZT MEHs









Displacement $w = A\left[1+\cos\left(2\pi x_1/L\right)\right]/2$

Membrane strain $\varepsilon_m = 4\pi \dfrac{\overline{EI}_{PI}}{\overline{EI}_{comp}} \dfrac{h}{L}\sqrt{\dfrac{\Delta L}{L}}$

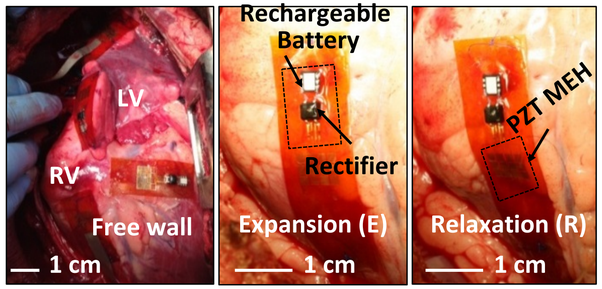
Current $I = \left(-\bar{e}\right) A_{PZT} \dfrac{d\varepsilon_m}{dt}$

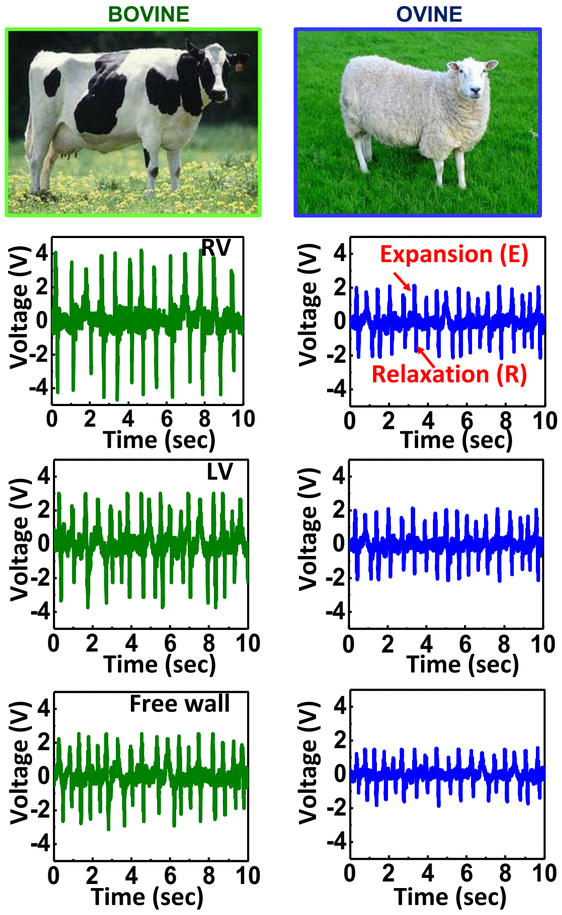
Voltage $V = \dfrac{\left(-\bar{e}\right) N t_{PZT}}{\bar{k}} e^{-\frac{N t_{PZT}}{A_{PZT} R \bar{k}} t} \int_0^t \dfrac{d\varepsilon_m}{dt} e^{\frac{N t_{PZT}}{A_{PZT} R \bar{k}} t} dt$

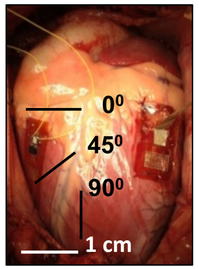
C. Dagdeviren, *et al., PNAS,* 111 (5), 1927-1932 (2014)

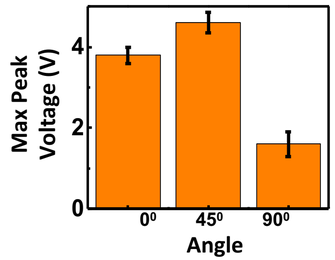
Results & Discussion

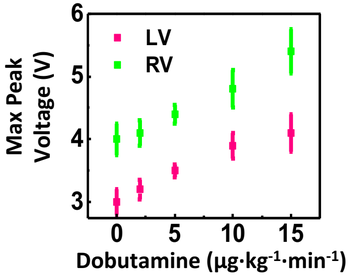
In vivo evaluation for the optimal placement and orientation of PZT MEHs on the heart

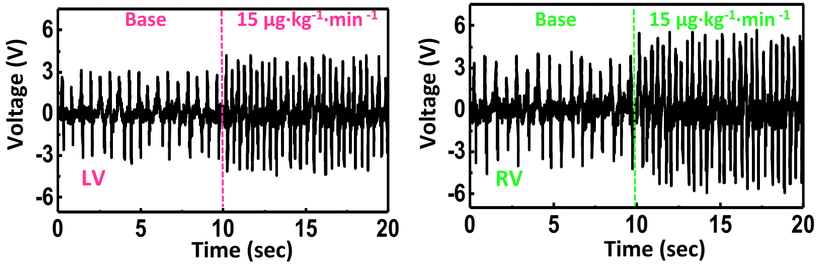










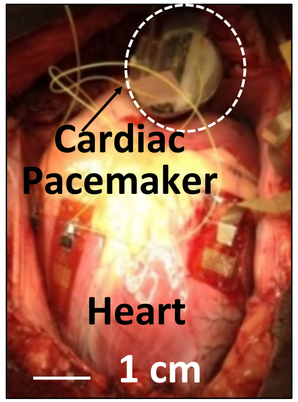


- The **longitudinal direction of PZT** ribbons along with various angles with respect to the Apex
- **Inotropic dobutamine infusion to increase** the force of contractility of myocardium

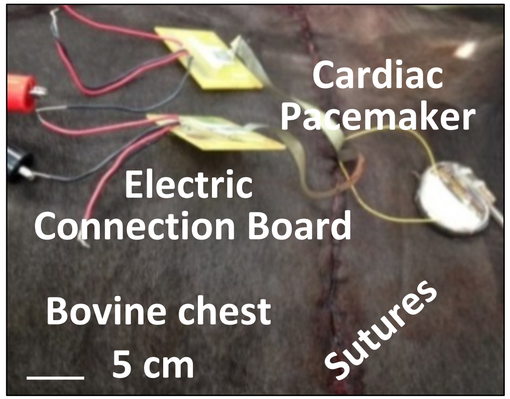
C. Dagdeviren, *et al., PNAS,* 111 (5), 1927-1932 (2014)

Results & Discussion

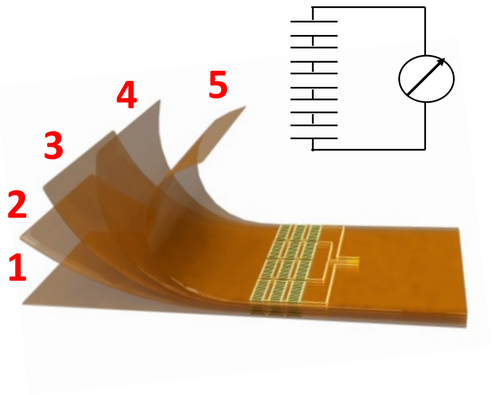
Performance of a PZT MEH evaluated with the chest open and closed and scaling of power output in multilayer stacked designs

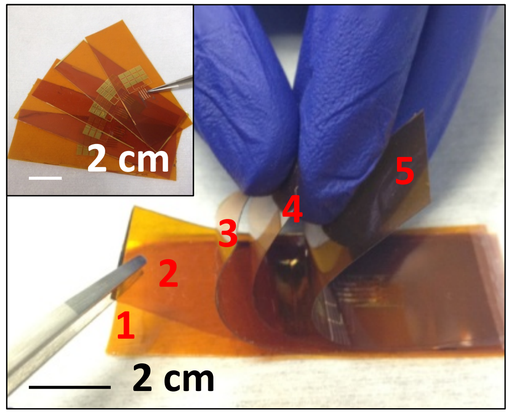


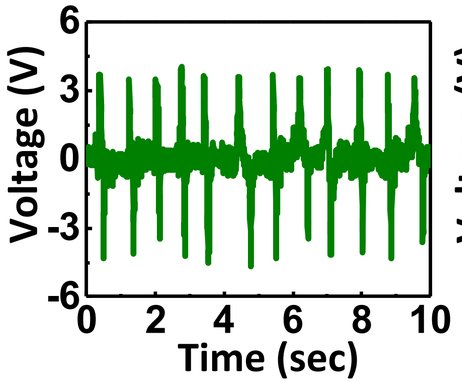
Open chest

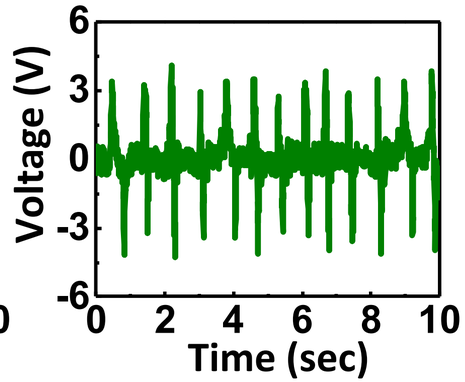


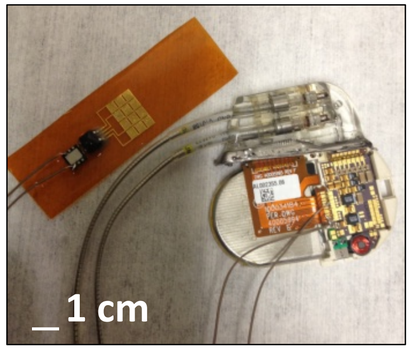
Closed chest

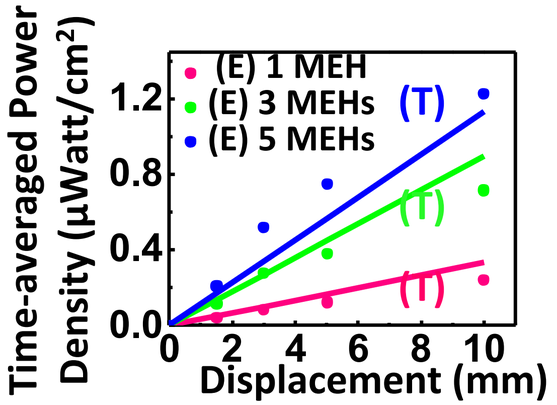












C. Dagdeviren, *et al., PNAS,* 111 (5), 1927-1932 (2014)

At Media Lab

Finger Motion

Arm Motion

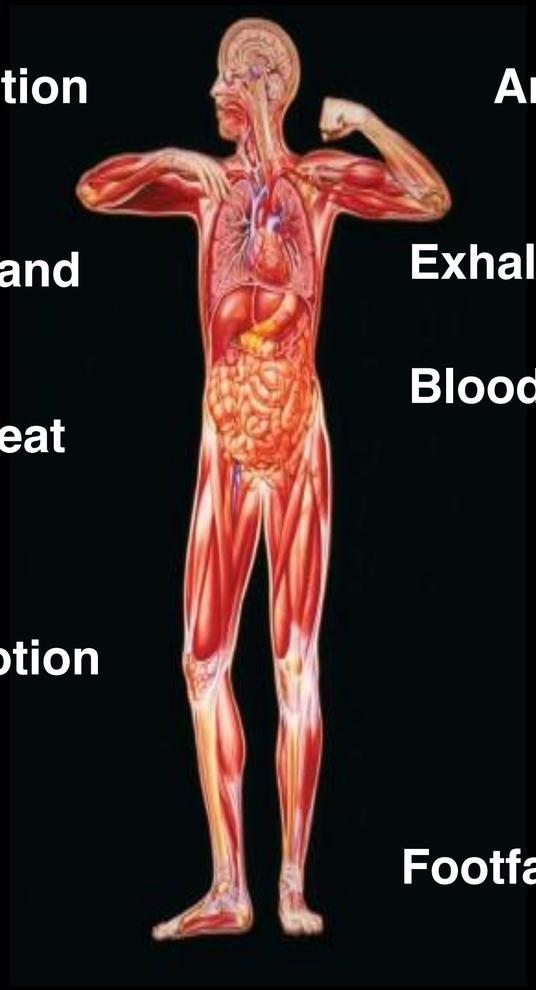
Breathing Band

Exhalation

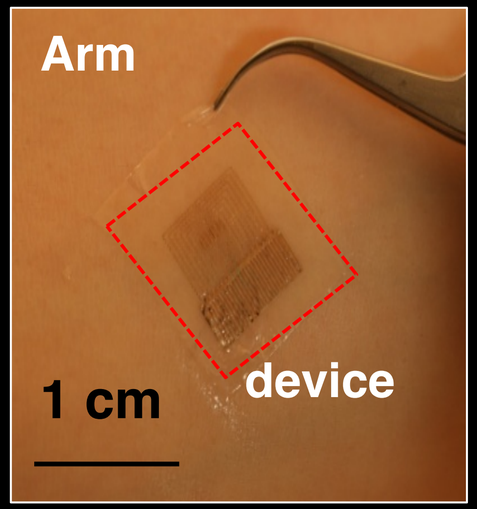
Blood Pressure

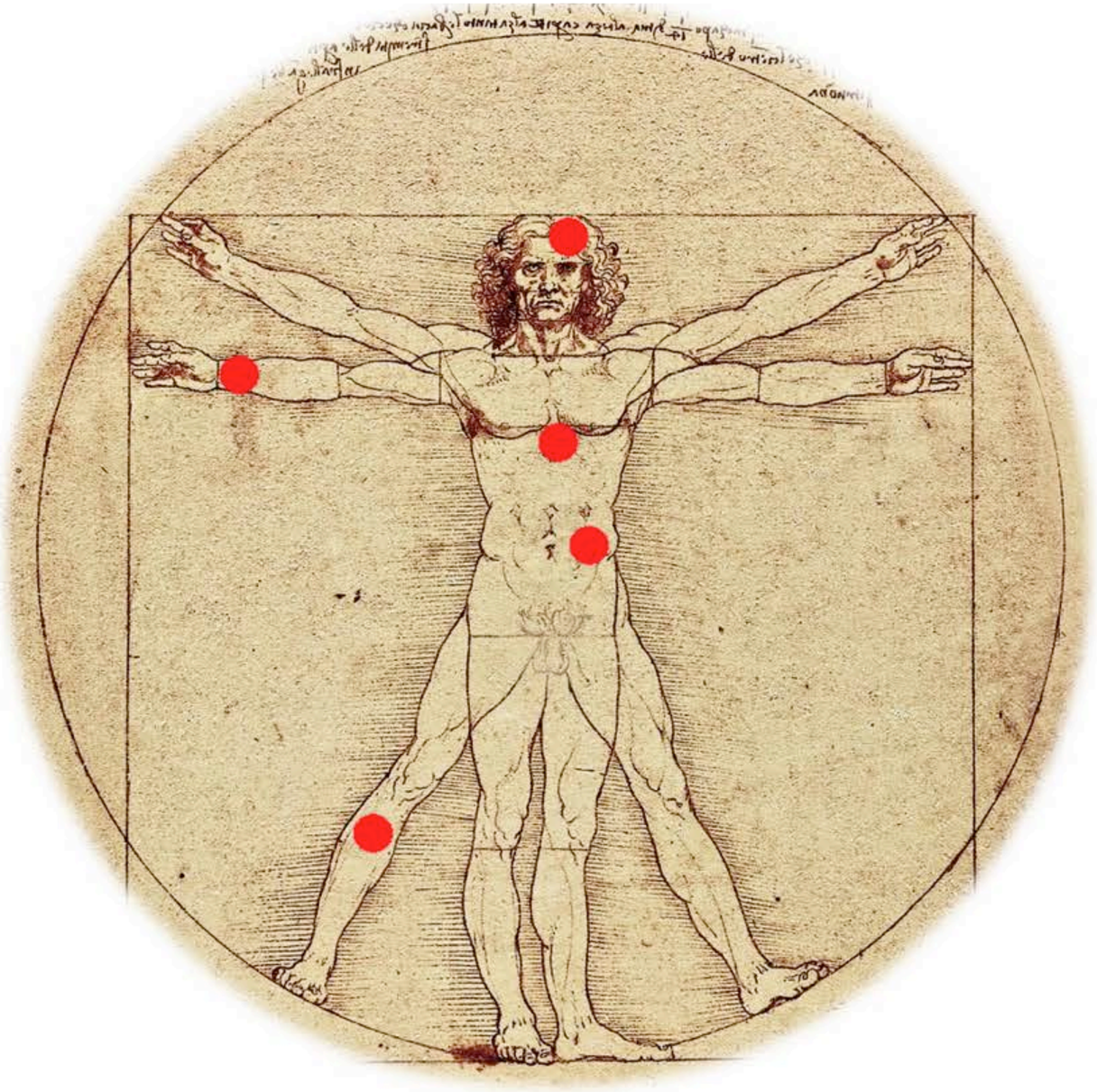
Body Heat

Joint motion

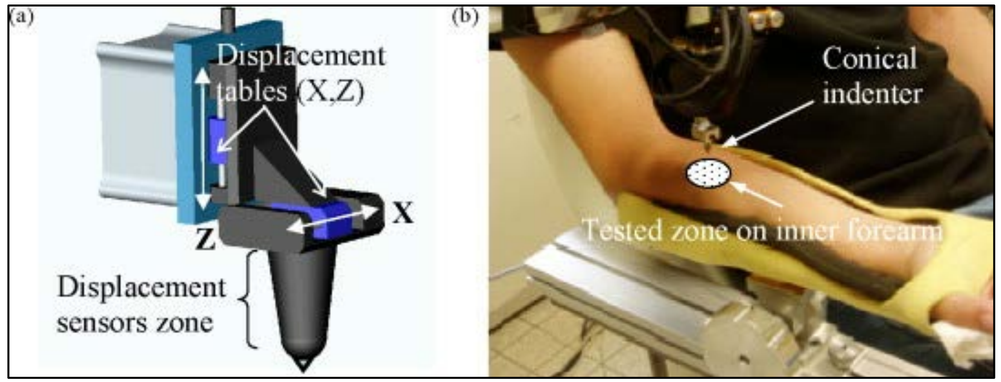


Footfalls

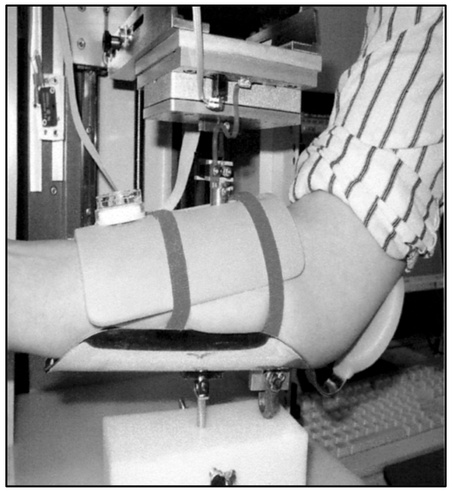




Background



Mats Malm, et. al., 1995

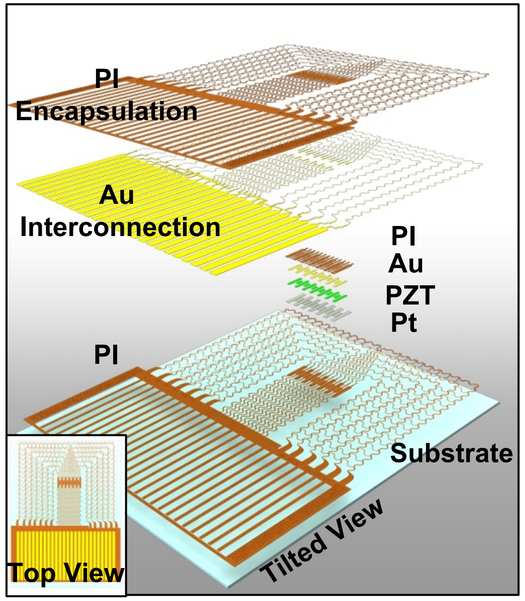


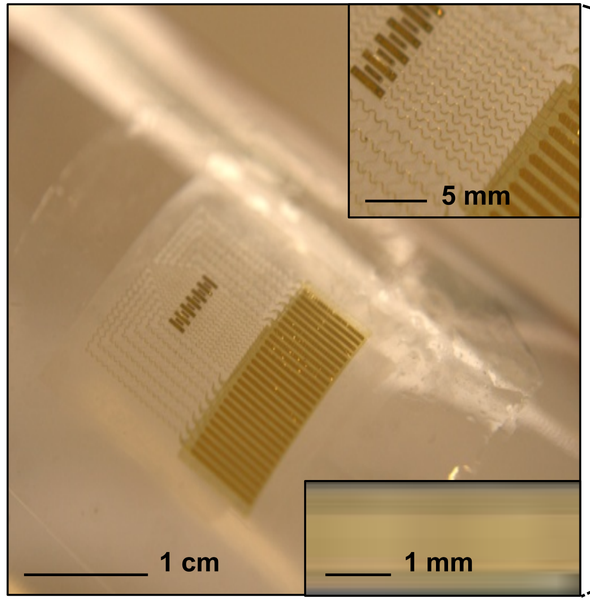
Methods:
- Suction
- Torsion
- Indentation
- Elastography

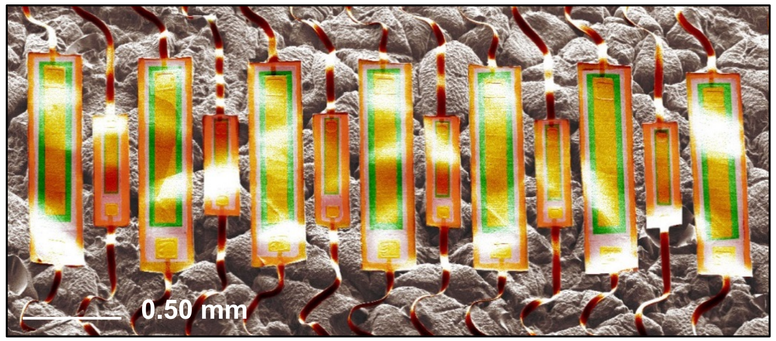
Drawbacks:
- Various locations can not be examined,
- Painful, not comfortable, bulky,
- Not conformal,
- Measurement parameters may vary; 3 orders of magnitude from 0.02 MPa to 57MPa,
- Stress gives varying results.

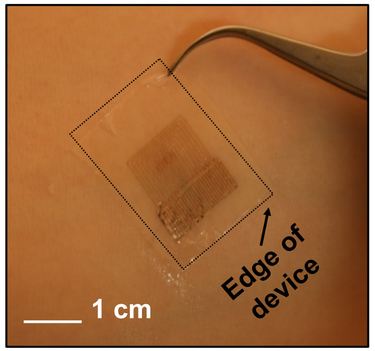
Results & Discussion

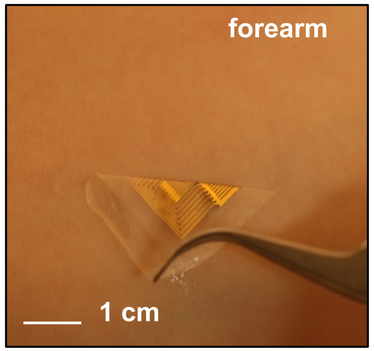
Schematic illustration of PZT Skin Modulus Sensor (PZT SMS)







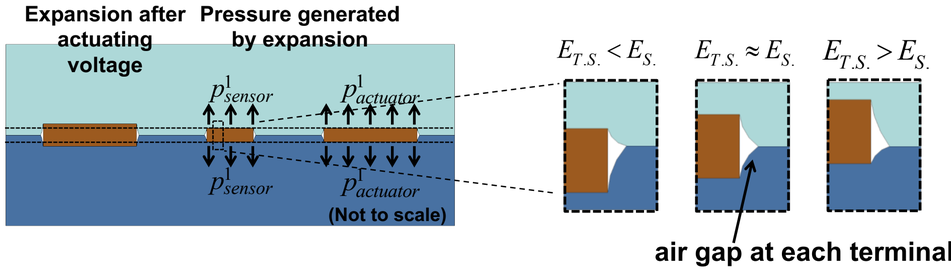




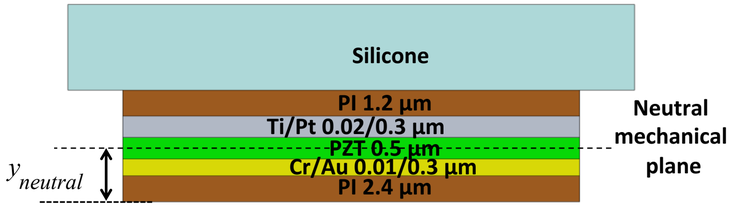
C. Dagdeviren, *et al., Nature Materials,* 14, 728-736, (2015)

Results & Discussion

Experimental and theoretical studies of the electrical behavior of PZT SMS



$$V_{sensor} = \alpha E_{T.S.} V_{actuator}$$



$$y_{neutral} = \left[\sum_{i=1}^{n} E_i t_i \left(2\sum_{j=1}^{i} t_j - t_i\right)\right] \Big/ \left(2\sum_{i=1}^{n} \bar{E}_i t_i\right)$$

$$h = \sum_{i=1}^{n} t_i + \frac{t_{n+1}}{2} - y_{neutral}$$

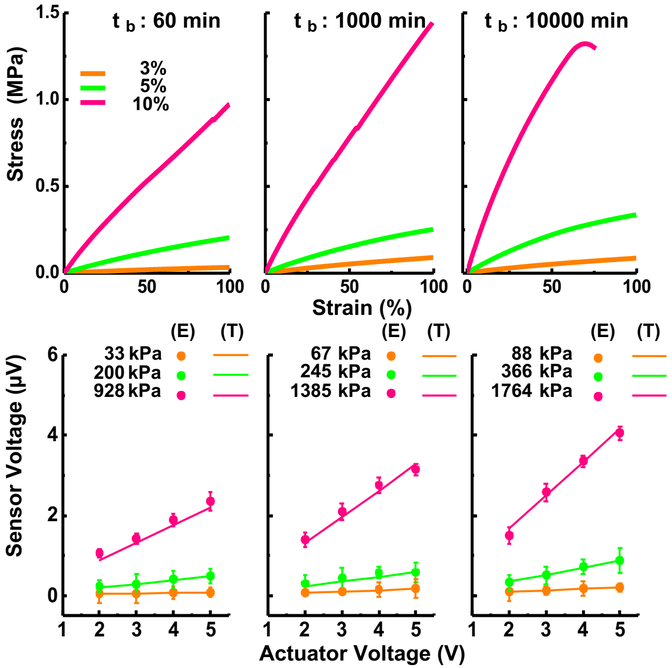
Boundary conditions for the crack line

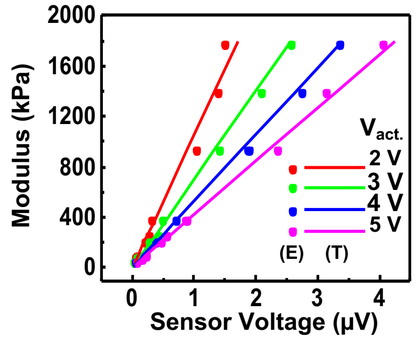
Crack opening of the active actuator — Acquired from multilayer analysis

Crack opening of the other actuator/sensor

$$\begin{cases} \delta_{active-actuator} = u_z \\ \delta_{actuator/sensor} = 0 \\ \delta_{between-airgap} = 0 \end{cases}$$

Crack opening of the adhesion part between the air-gaps



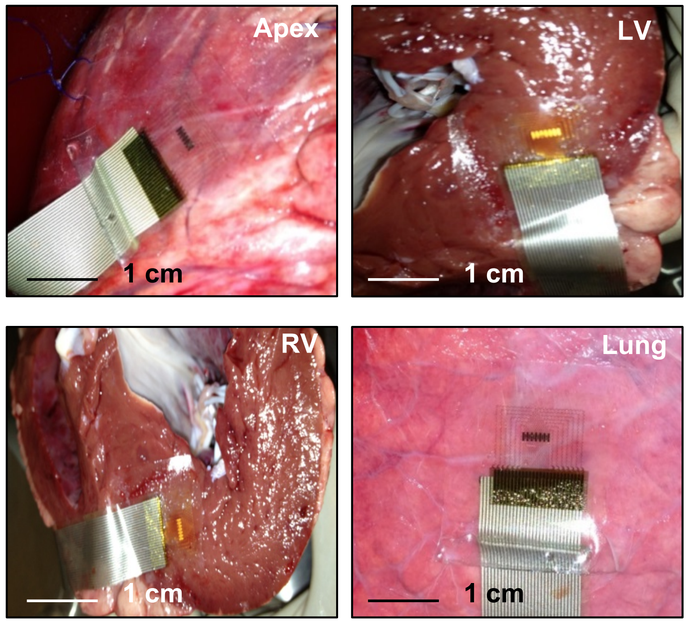


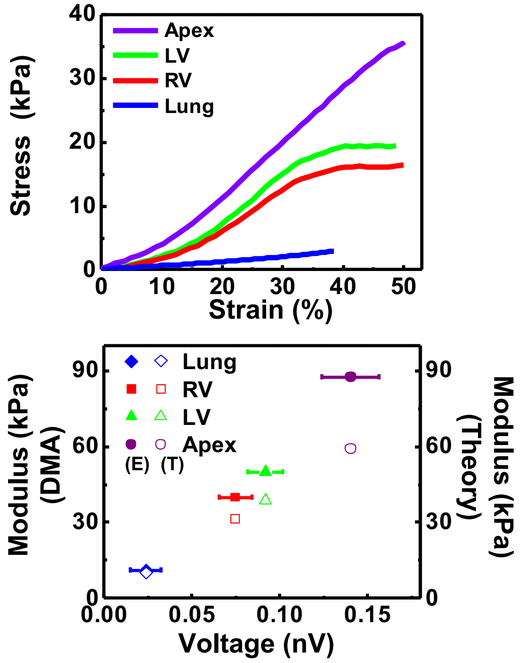
$$V_{sensor} = \alpha E_{T.S.} V_{actuator}$$

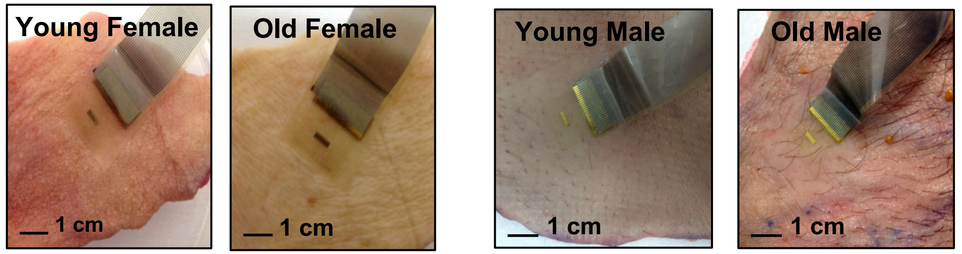
C. Dagdeviren, *et al., Nature Materials,* 14, 728-736, (2015)

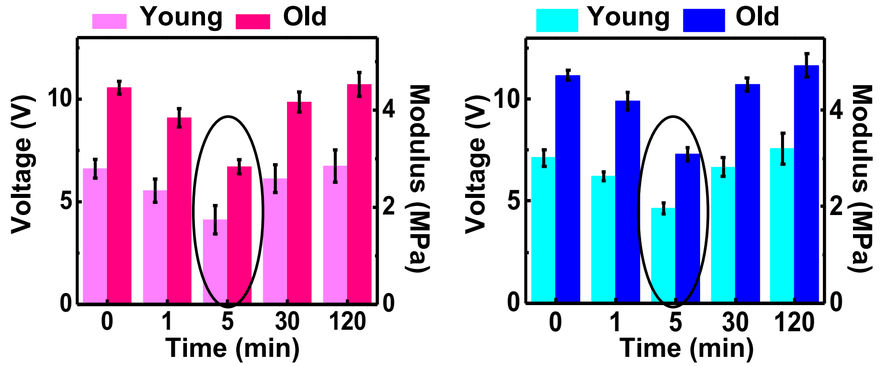
Results & Discussion

Ex-vivo tests on explanted animal organs & on human skin (abdomen)







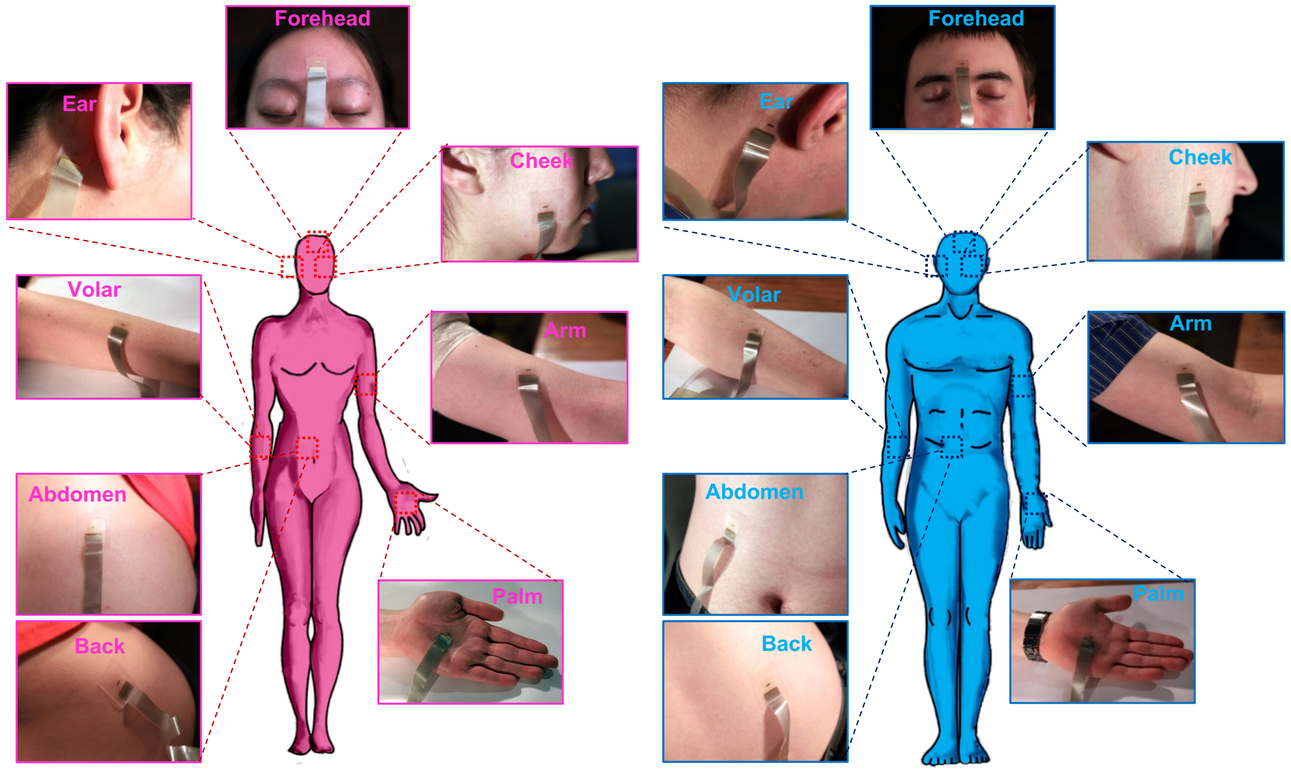


Hydrating effect of glycerol, plasticizing effect of urea → a strong interaction of protein components

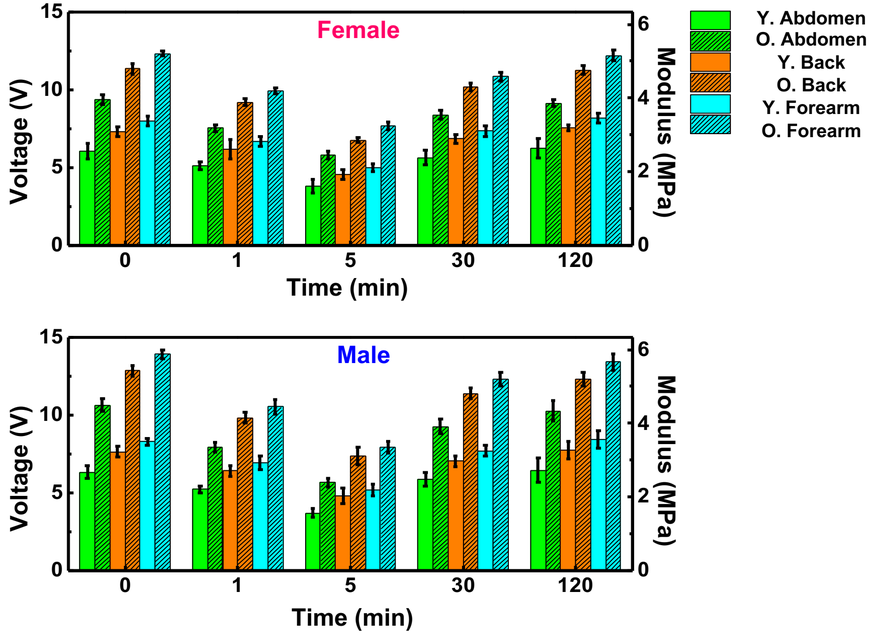
3% Glycerin solution effect on various parts of body

Results & Discussion

In-vivo tests on various locations of human body



3% Glycerin solution effect on various parts of body



$E_{Abdomen} < E_{Back} < E_{Forearm}$

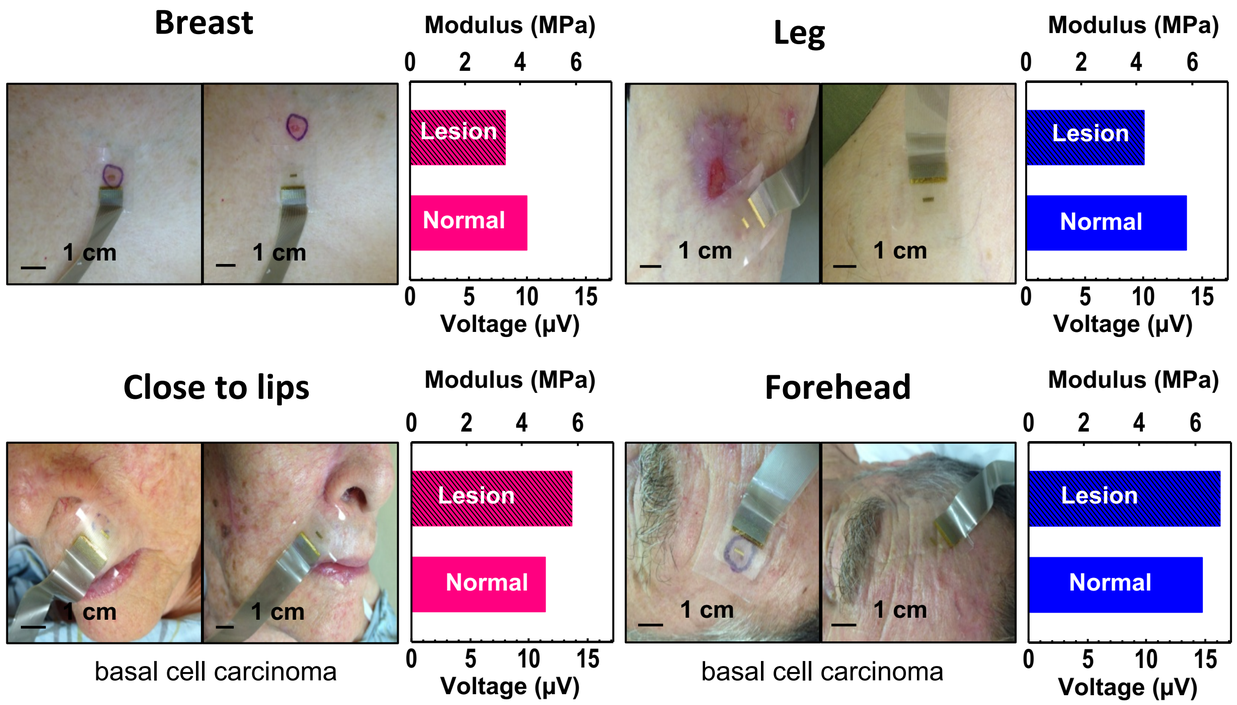
$E_{Male} > E_{Female}$

- Dense content of collagen
- Thicker SC

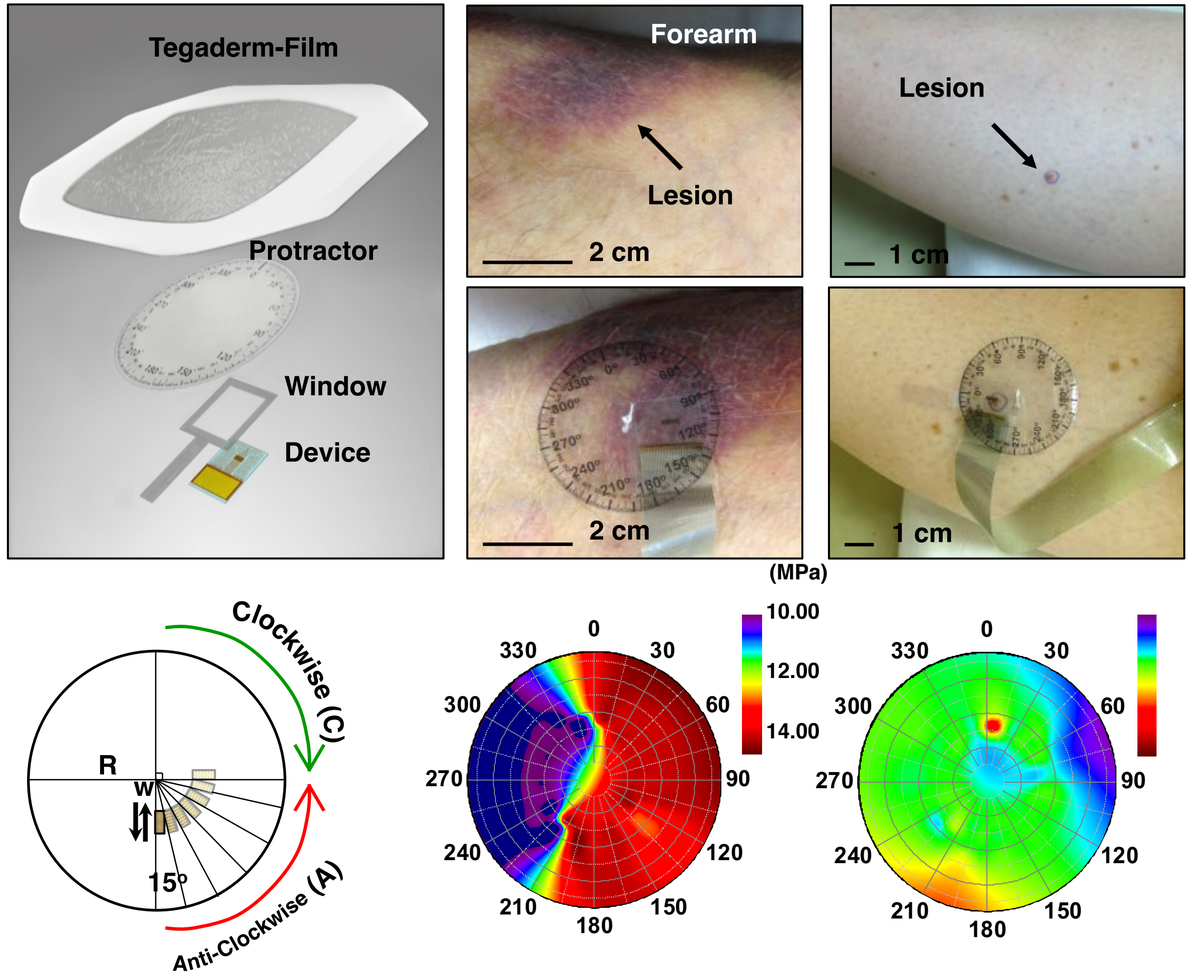
- 3 times lower standard deviation (~4-8%) compared to other methods
  - Suction: 10-24%
  - Dynamic indentation: 24-32%

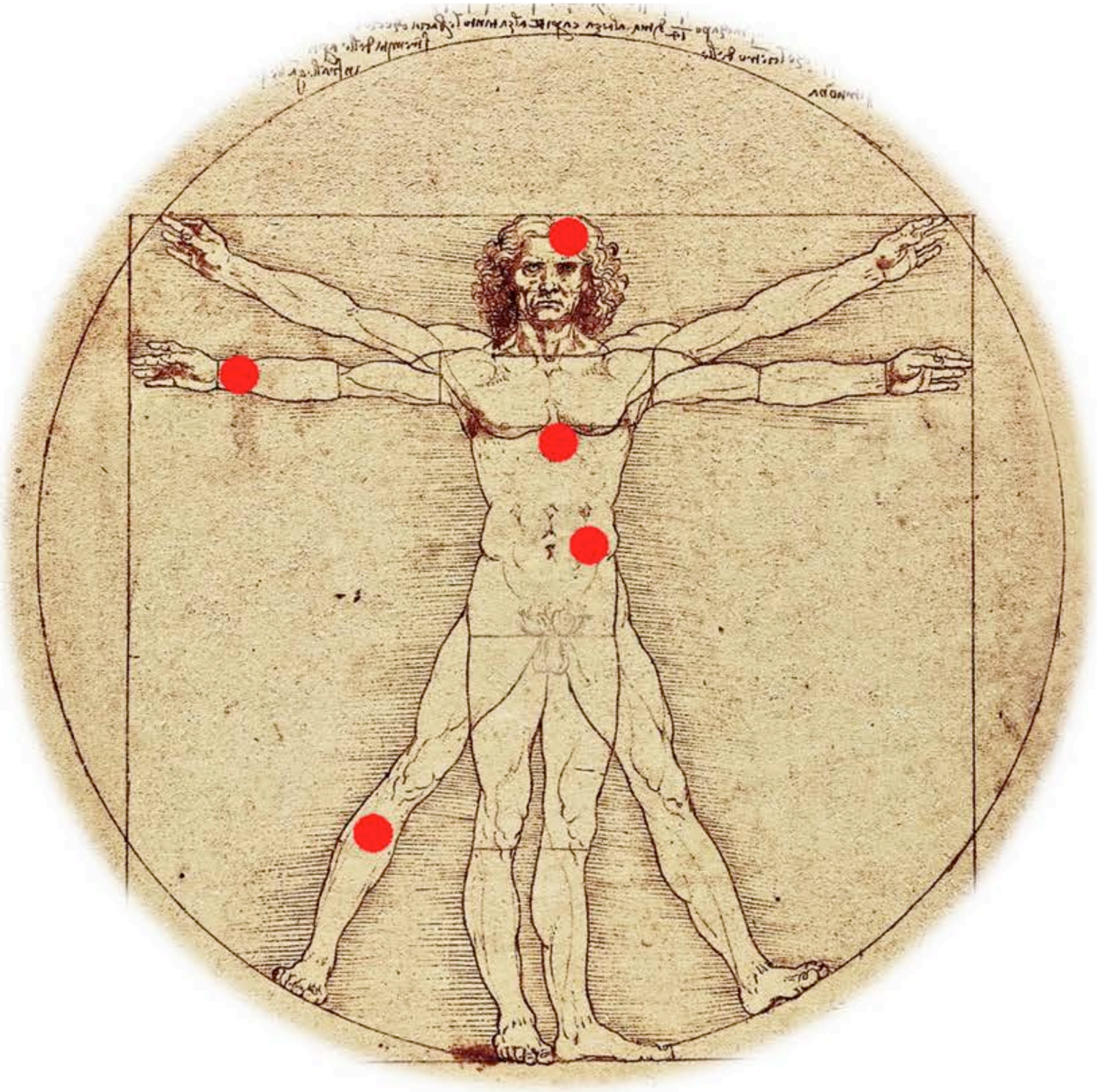
Results & Discussion

In-vivo tests on various dermal disorders

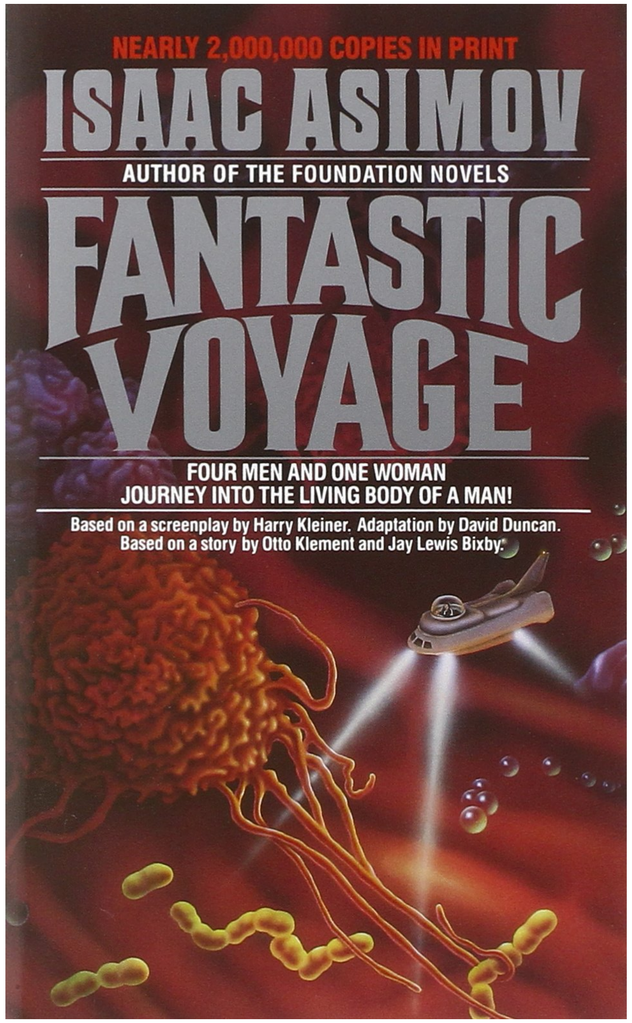


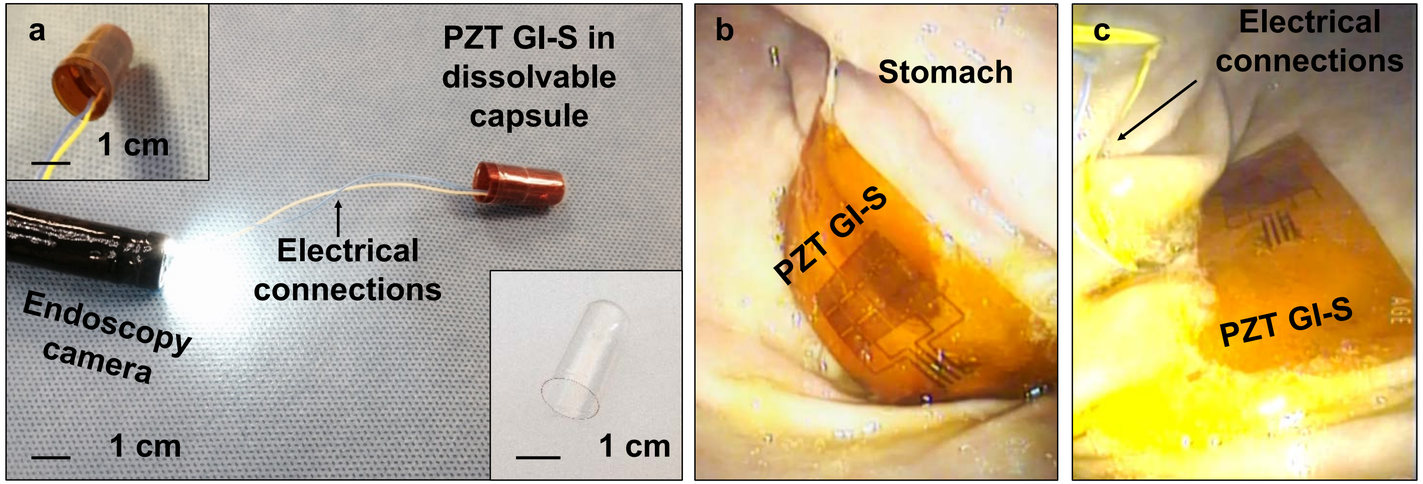
Directional Modulus Mapping with PZT SMS Protractor

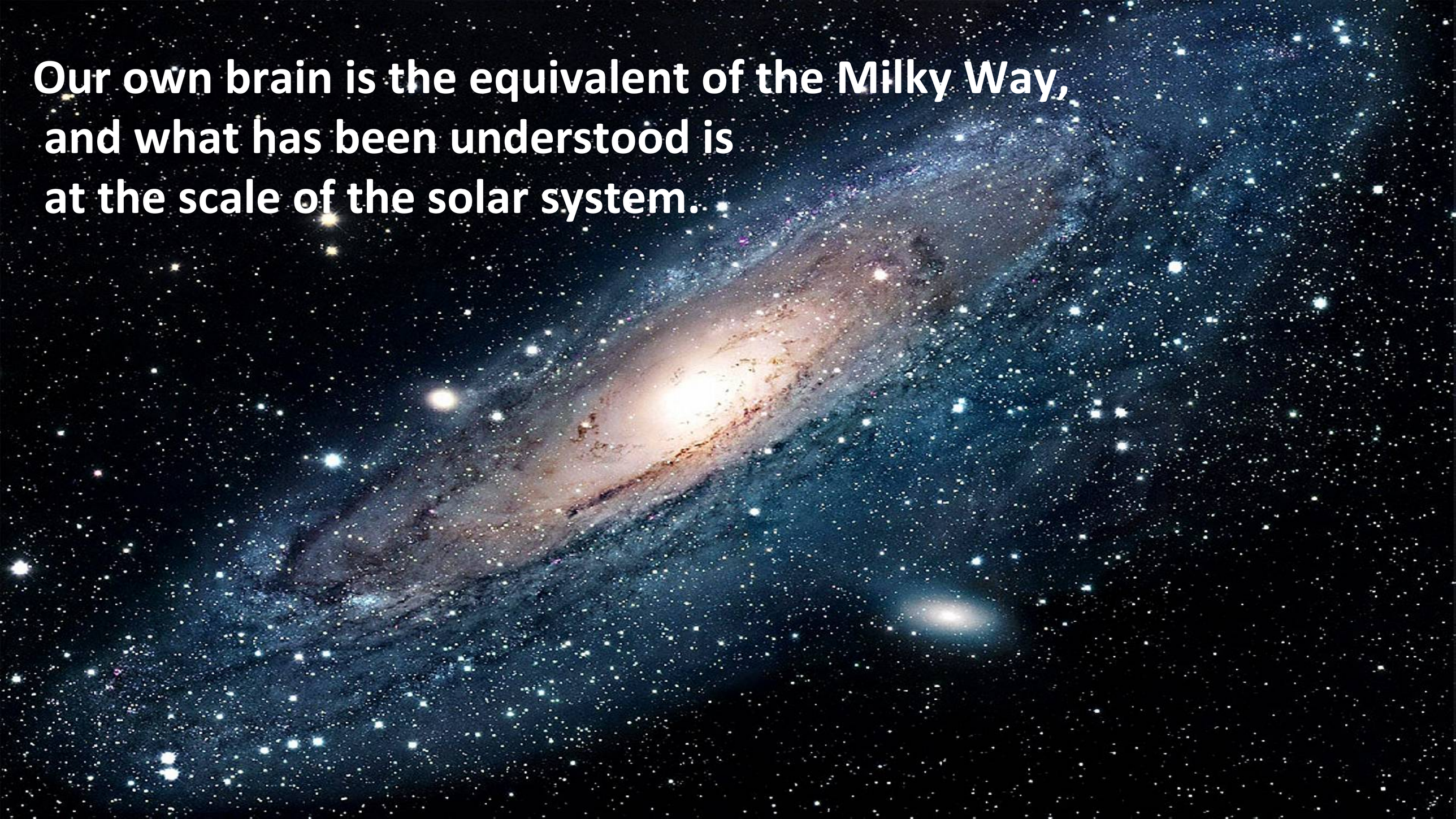




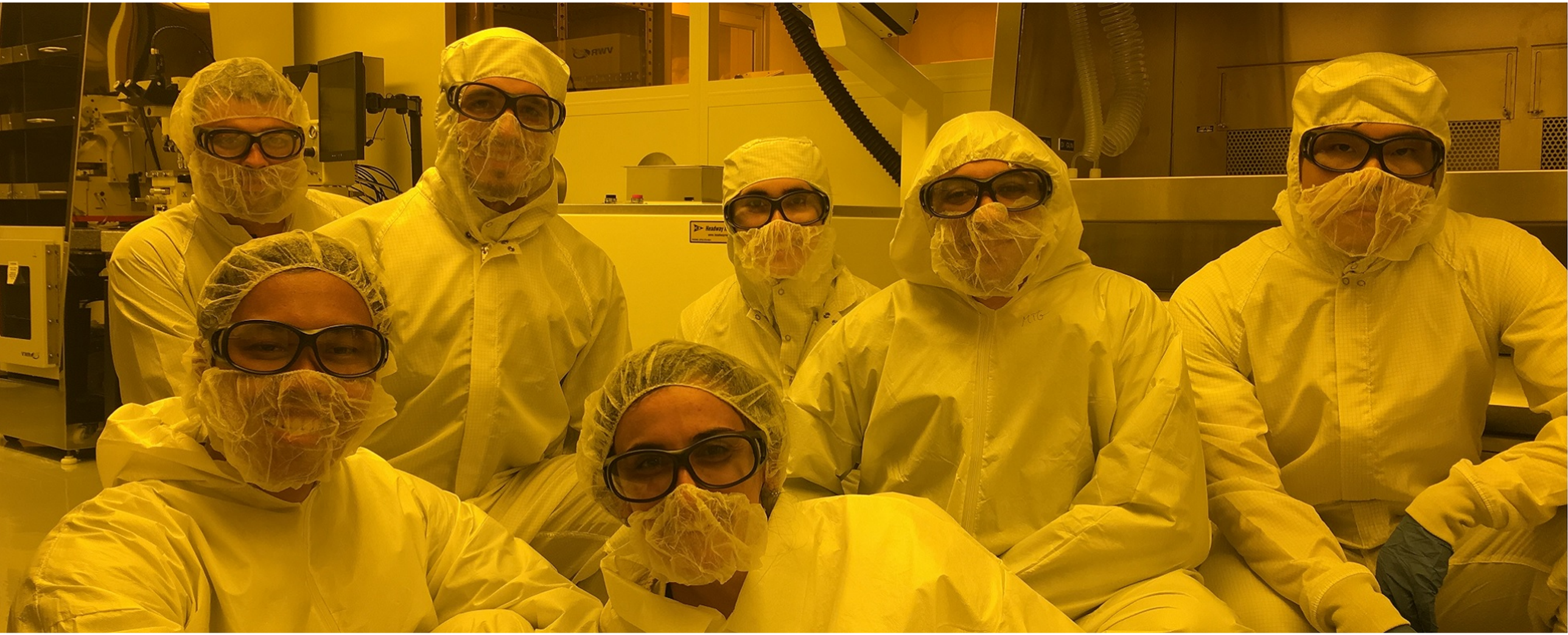
“Fantastic Voyage” à la Isaac Asimov






Our own brain is the equivalent of the Milky Way,
and what has been understood is
at the scale of the solar system.

Team Members



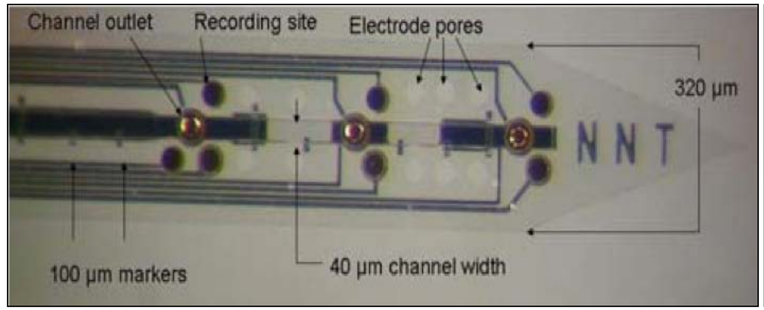
Background

Need: Accurately timed infusion of neurochecmicals on a chronic basis

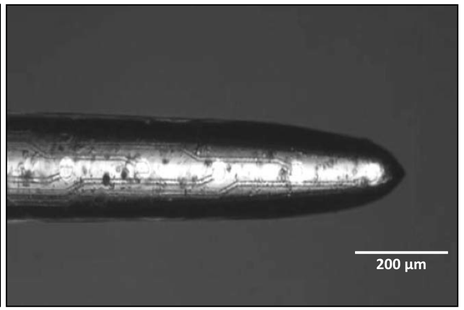
Biology: Brain is heterogeneous

Problem: Off-target exposure, undesired effects of therapeutic agents

Microelectrodes

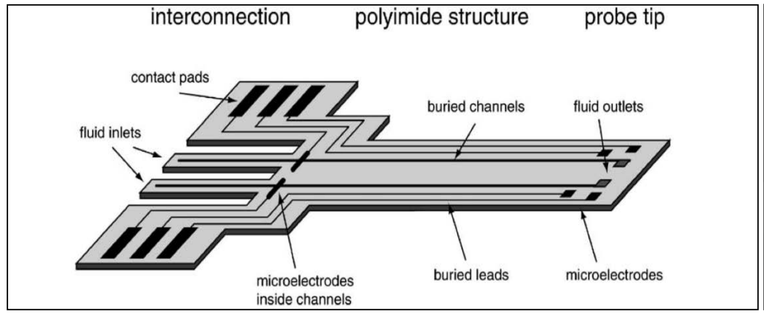


Pellinen *et al, IEEE, 2005*

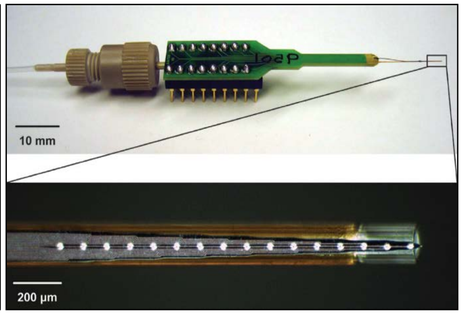


Kim *et al, Biomaterials, 2005*

Microelectrodes + Microfluidic Channels



Metz *et al, Biosensors and Bioelectronics, 2004*



Rohatgi *et al, Neurosurgical Focus, 2009*

Biology: Many key neural circuit nodes have volume of sub-mm^3

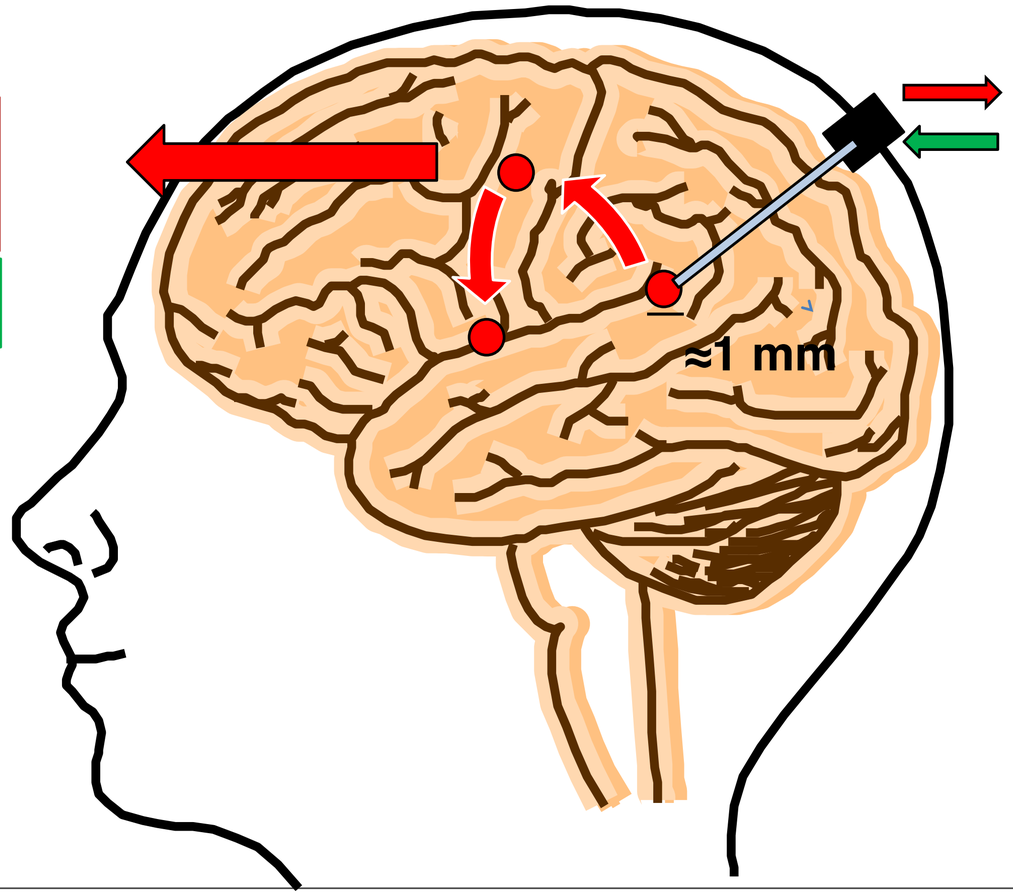
Need: Small-volume modulation, smaller probes

Problem: Penetration only in superficial parts, small aspect ratio

The MiNDS:
a Device for Chronic Treatment of Circuit Disorders

Behavioral[1,2]/
Mood [3] Dysfunction

Normalized behavior

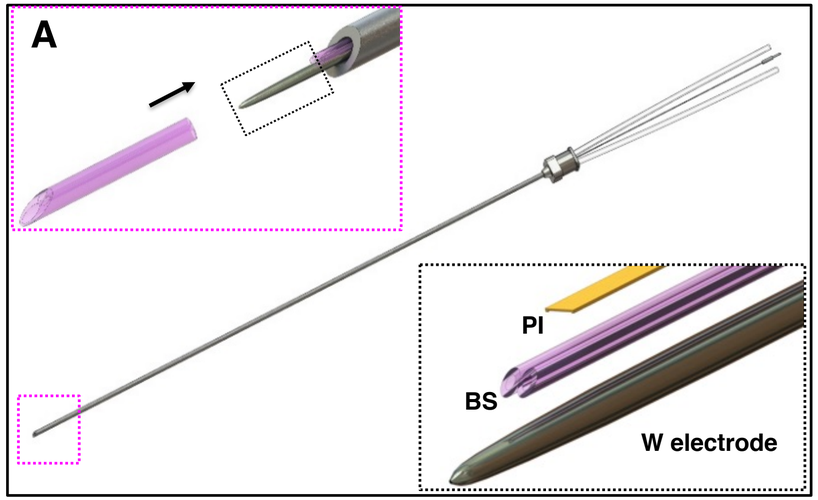


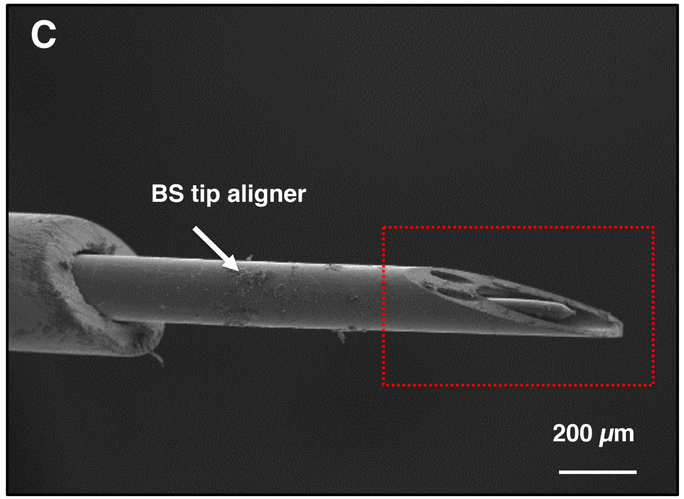
Neural activity recording
Normalizing chemical stimulus

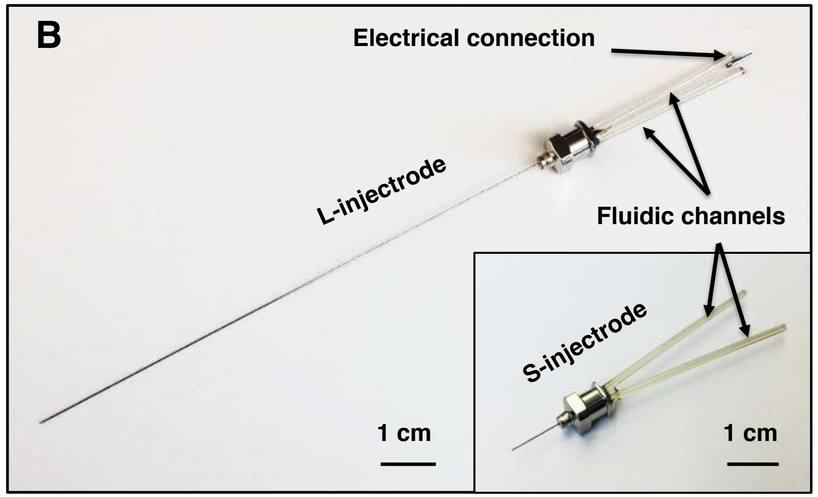
1. Amemori, K.-i. et al. (2012). Nat Neurosci
2. 2. Mayberg, H. S., A. M. Lozano, et al. (2005). Neuron.
3. 3. DeLong, M. R (2007).Arch Neurol 64(1): 20-24.

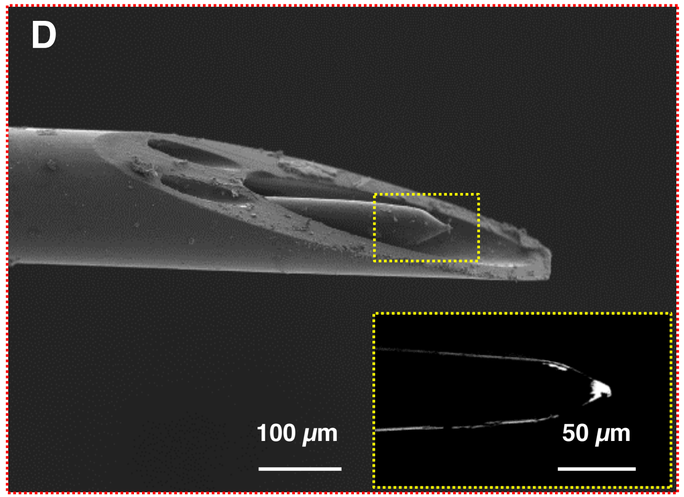
Results & Discussion

Microfabrication and Device Assembly









A minimally invasive neural drug delivery system with a diameter of 200 μm and an aspect ratio of 500,

Tested in small (i.e., rodent) and large (i.e., NHP) animal models: chronic behavioral and acute electrophysiological effects.

W electrode with a dielectric stack of silicon dioxide (SiO_2) (50 nm)/ aluminum oxide (Al_2O_3) (10 nm)/ SiO_2 (50 nm)

Engineer vs Architect

What is YellowBox?

Facility

- State-of-the-art cleanroom Microfabrication & Characterization facility.
- The first-of-its-kind cleanroom built inside the MIT Media Lab.

Purpose

- Devoted to the exploration of novel materials, device design, and fabrication strategies to create micro- and nanoscale electromechanical systems with mechanically adaptive features, which allow intimate integration with the objects of interest.

Staffing

- YellowBox is supported by full-time staff, including:
  - A dedicated Administrative Assistant
  - A Lab Manager with experience in microfabrication operations and development environments

3 Major Areas

- Gowning Area
- Specimen Prep Area (Class 10,000 - 300 ft^2)
- Cleanroom Area (Class 1,000 - 400 ft^2)

Conclusion

1D

2D

3D

4D

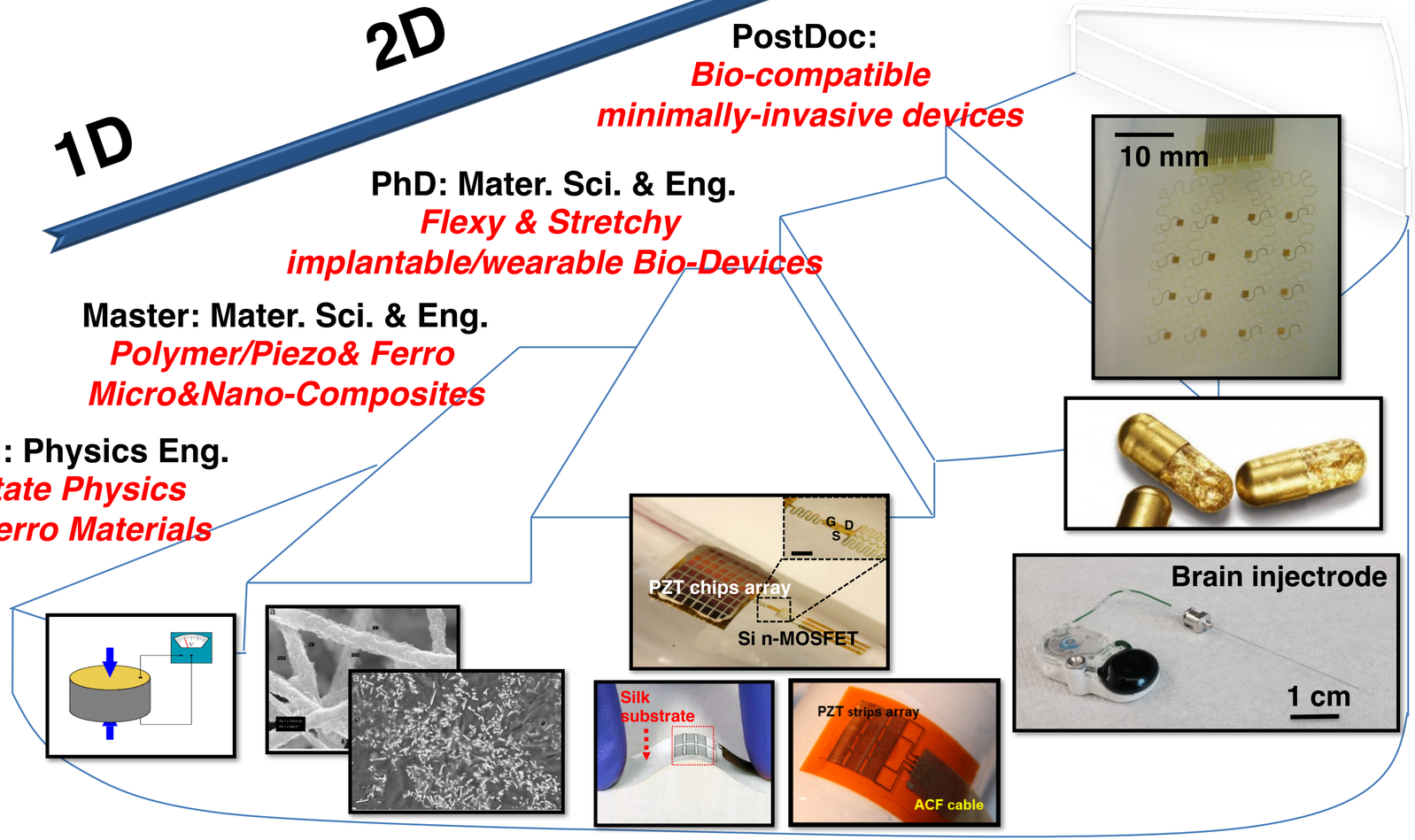
Future:
Conformable Decoders
Electro-active cloth=Talking body
Ingestible-electro pills
Non-spilled, on-demand drug delivery

PostDoc:
Bio-compatible
minimally-invasive devices

PhD: Mater. Sci. & Eng.
Flexy & Stretchy
implantable/wearable Bio-Devices

Master: Mater. Sci. & Eng.
Polymer/Piezo& Ferro
Micro&Nano-Composites

Undergrad: Physics Eng.
Solid State Physics
Piezo& Ferro Materials



Pajama vs. Suit

Personalized Medicine
via
advanced, ‘unusual’ engineering

Acknowledgments

Prof. John A. Rogers

Prof. Robert Langer

Prof. Ann M. Graybiel

Prof. Michael J. Cima

Conformable Decoders Group

L'ORÉAL

DARPA

KOCH INSTITUTE for Integrative Cancer Research at MIT

HARVARD UNIVERSITY
CENTER FOR NANOSCALE SYSTEMS

MTL microsystems technology laboratories massachusetts institute of technology

NIH


decode the magic of the world