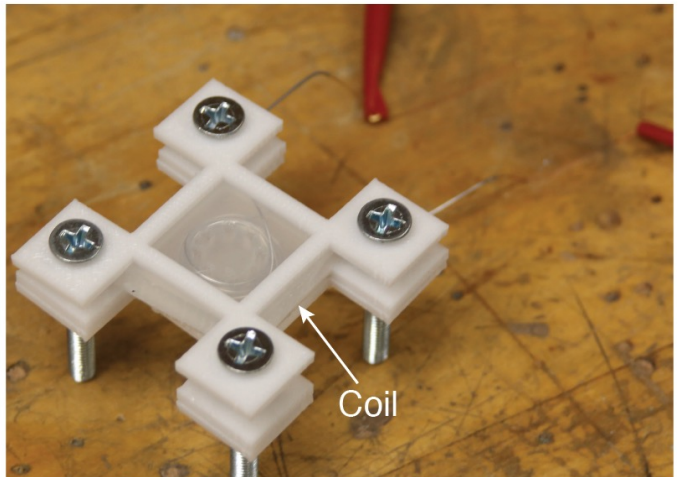
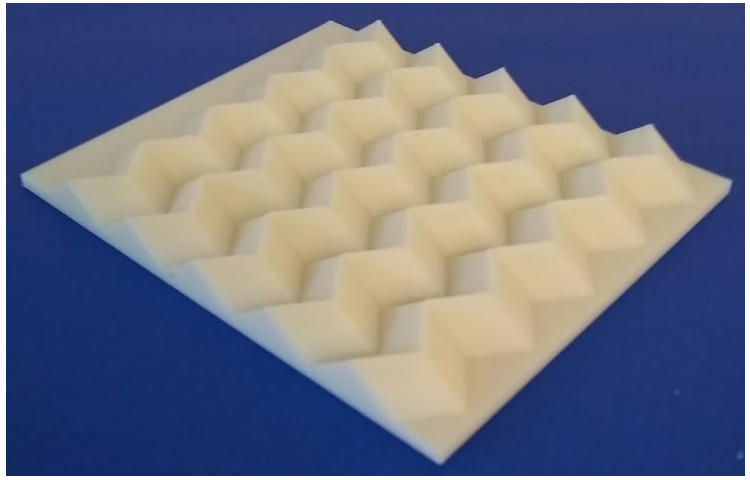
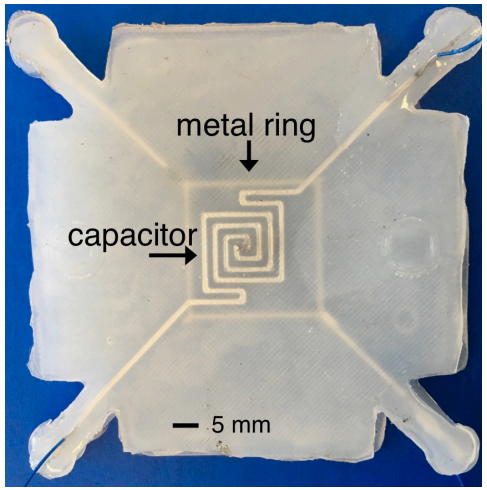
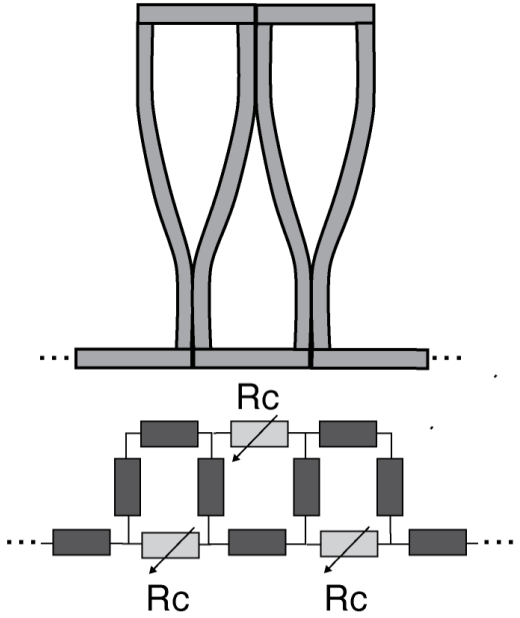




Kris L. Dorsey
MLK Visiting Assoc. Prof.
MIT Media Lab

Assoc. Prof.
Elec. and Comp. Eng.
Northeastern University





Who I am…

College:
Olin College of Engineering

Grad School:
Carnegie Mellon University

Postdoc Research:
UC Berkeley & UC San Diego

2

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Wearable mechanical sensors for healthcare, rehabilitation, and assistance

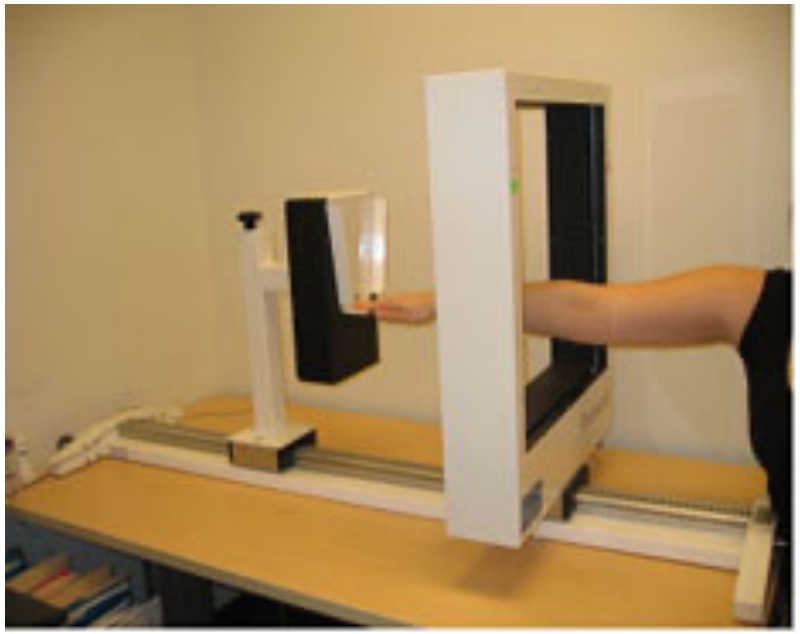
Purpose:

Monitor limb swelling (edema)

- Can affect limb function and threaten life
- Warning sign for cardiac conditions, DVT, etc.

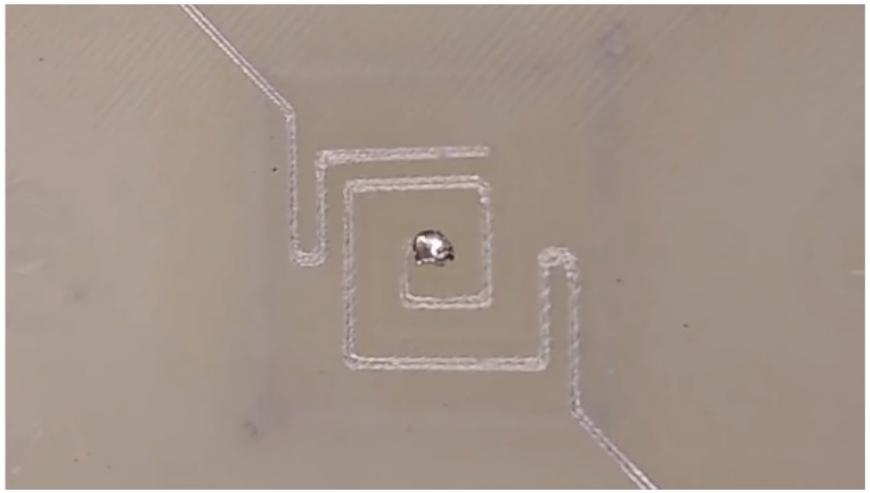
MD Anderson Cancer Center

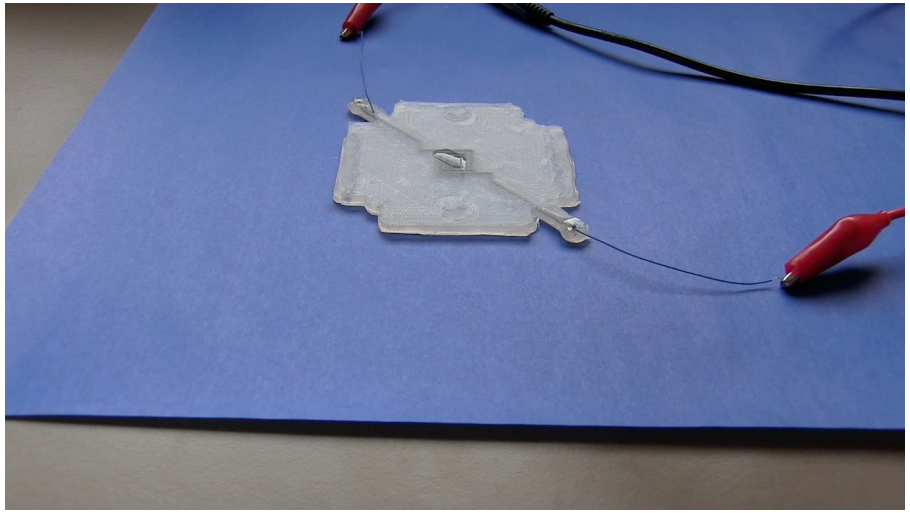
Mark Bugnaski

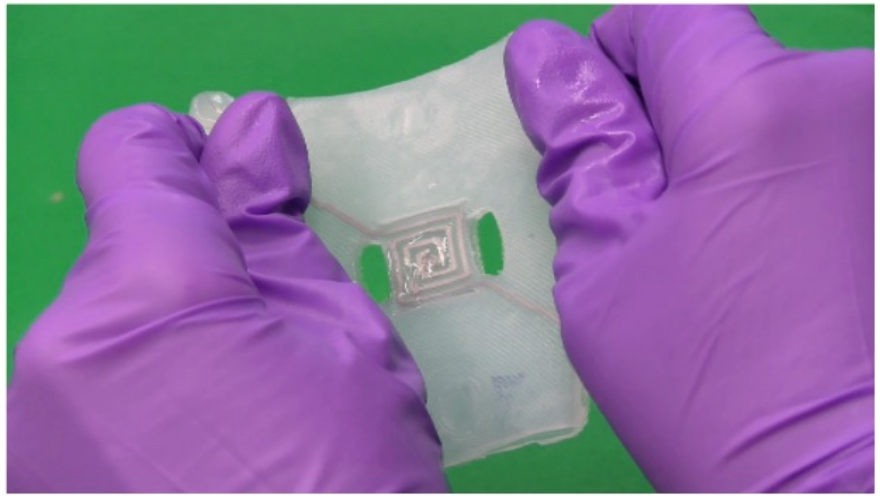


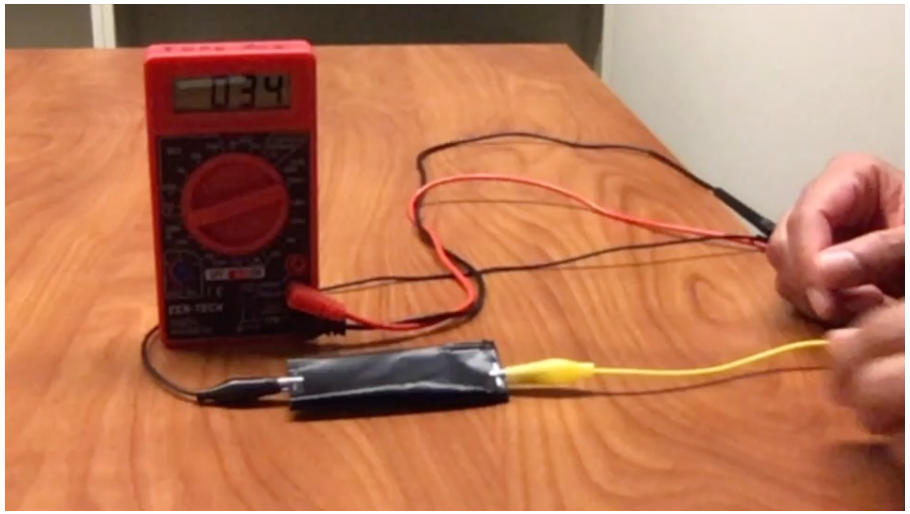
Mass General Hospital

Soft, elastic sensors can sense deformations but are not inherently selective or tunable

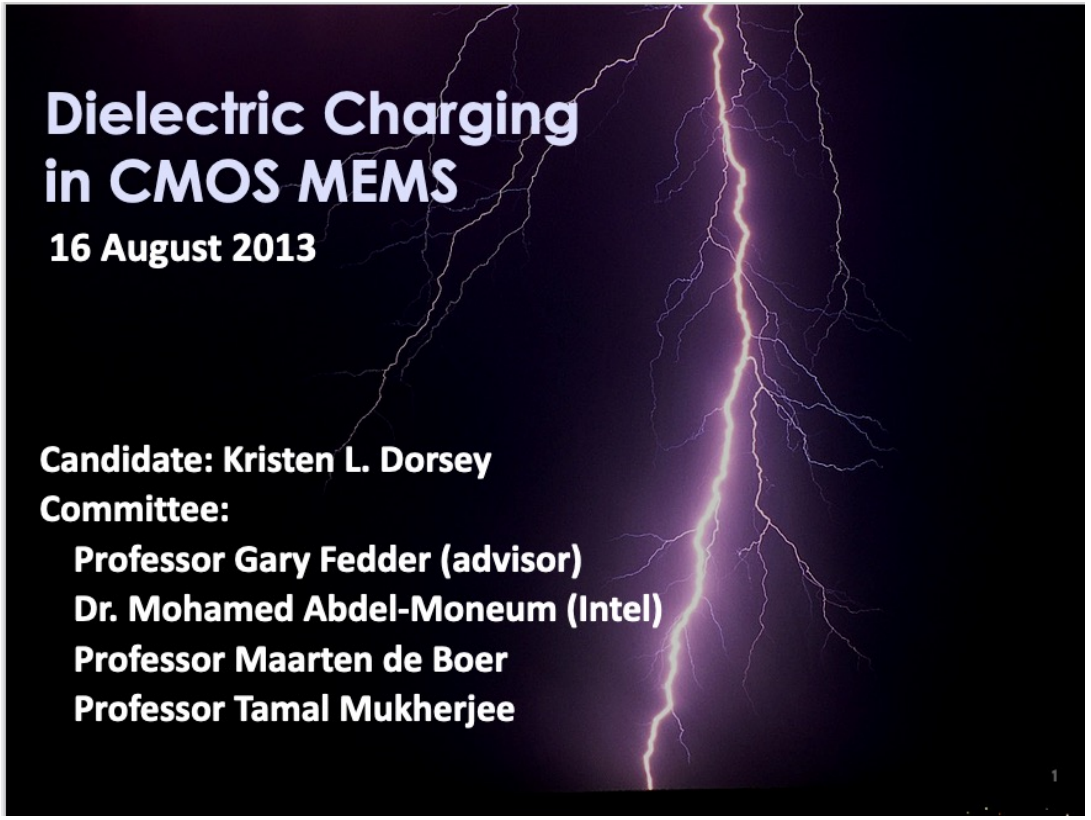


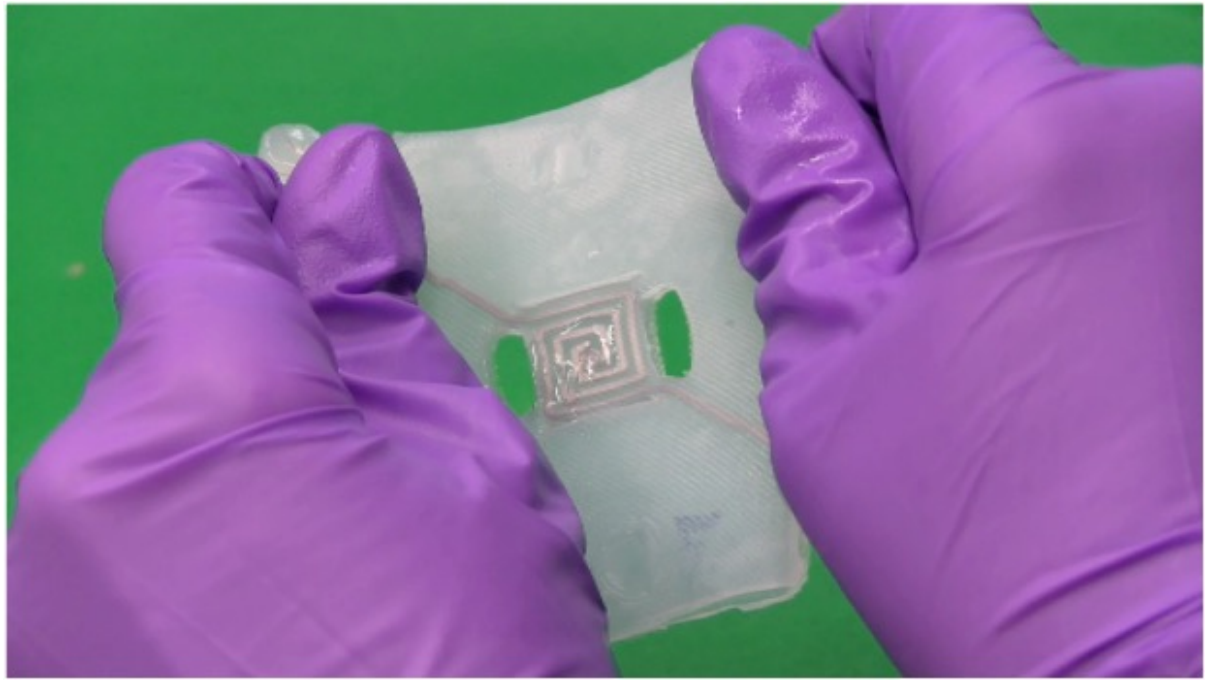




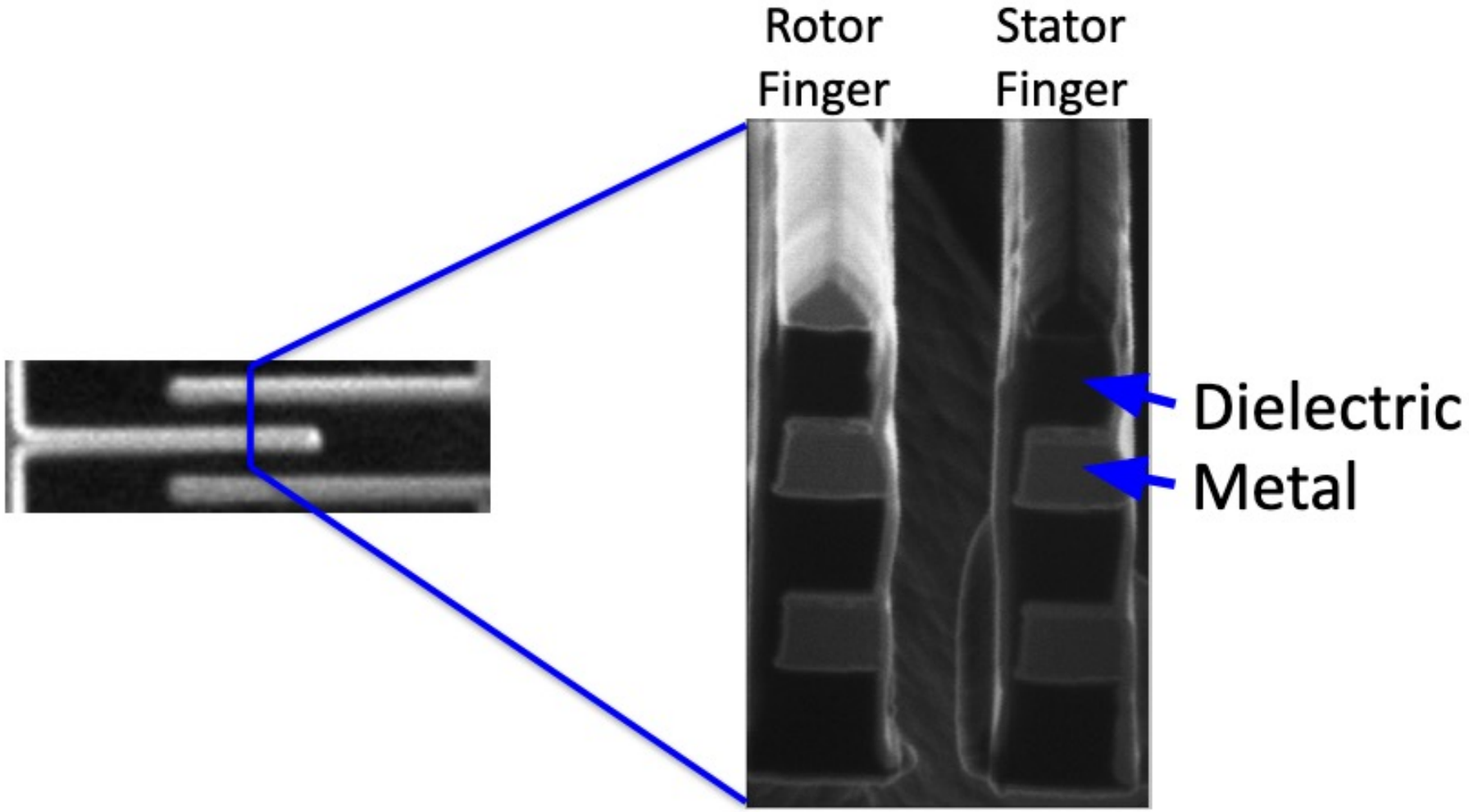


What I'll talk about: How I got from MEMS to robotics



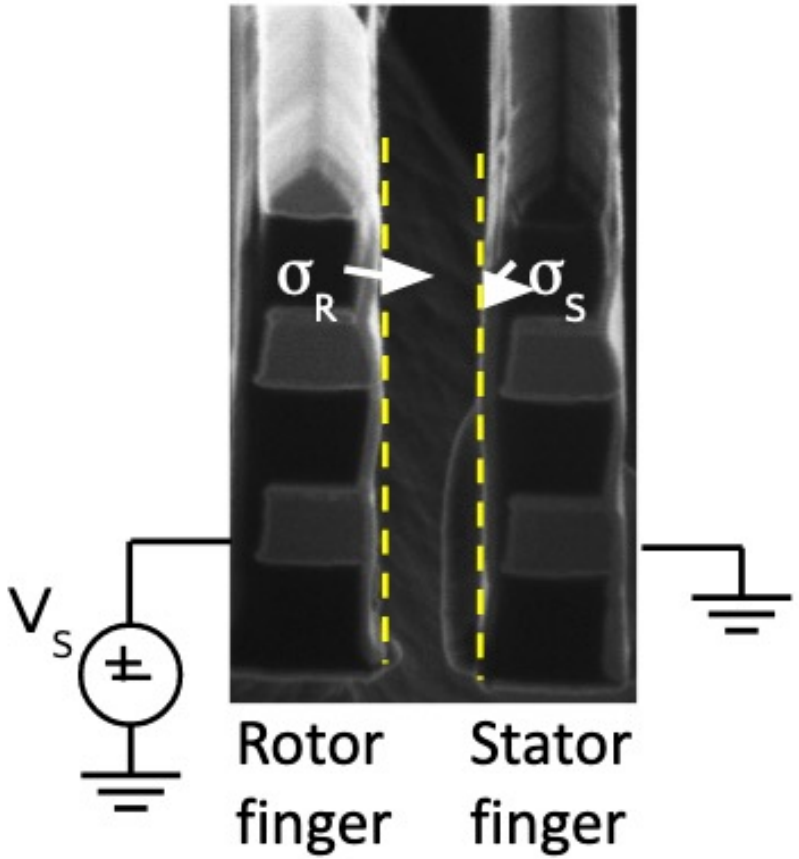


Comb Drive Cross Section



CMOS MEMS Cross section

Charge and Built-in Voltage



- Trapped charge in dielectrics
- Map charge to the surface
- Summarize charge as built-in voltage, ΔV

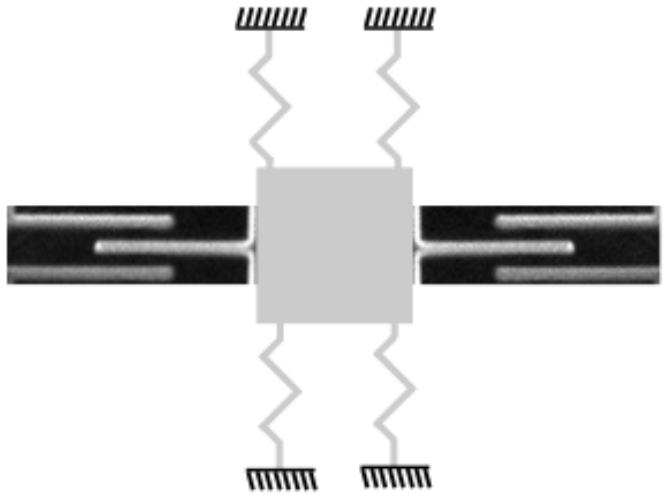
$$\Delta V \propto \sigma_R - \sigma_S$$

$$V_{GAP} = V_S + \Delta V$$

J. Wiebbler, et. al., "Parasitic charging of dielectric surfaces in capacitive MEMS," J. Sensors and Actuators A, 1998.

Built-in Voltage Effects

$$f \approx \sqrt{\frac{k - \gamma_s \left(V_s + \Delta V\right)^2}{m}}$$



Voltage Sensitivity (i.e., spring softening) + **Transient Built-in Voltage (e.g., trapped charge)**

= **Unstable Resonant Frequency**

Yes, My Dream Job Summer Internship!

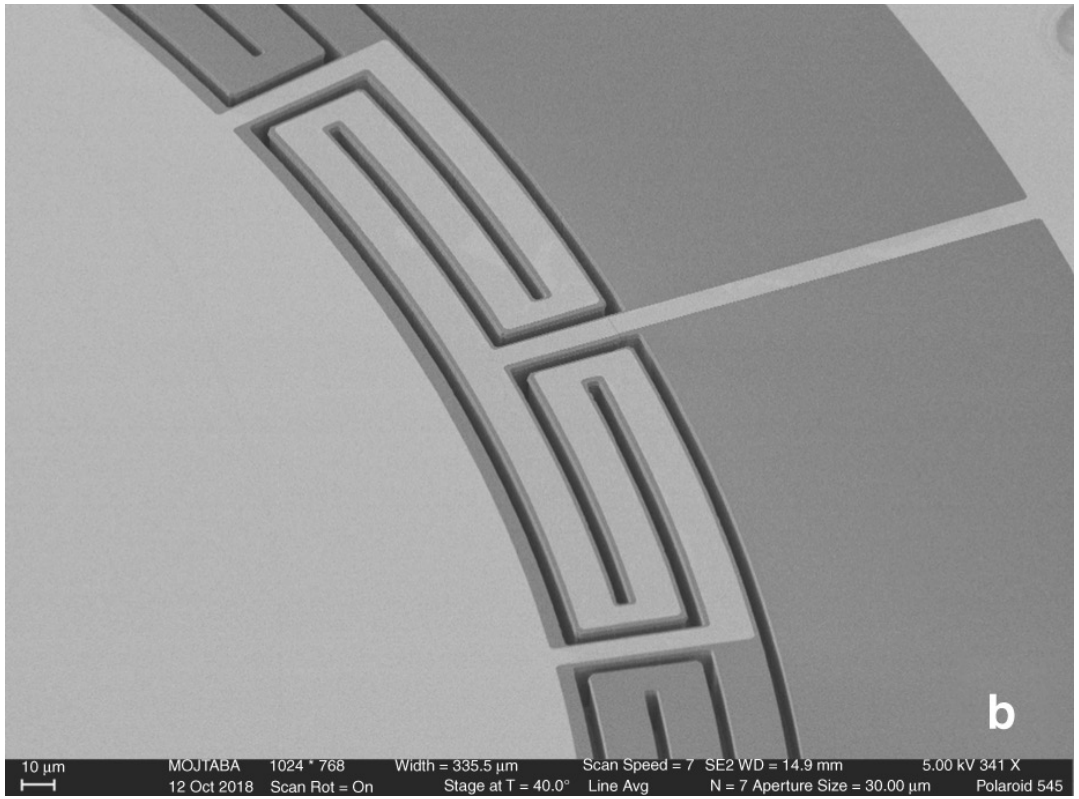
REDACTED

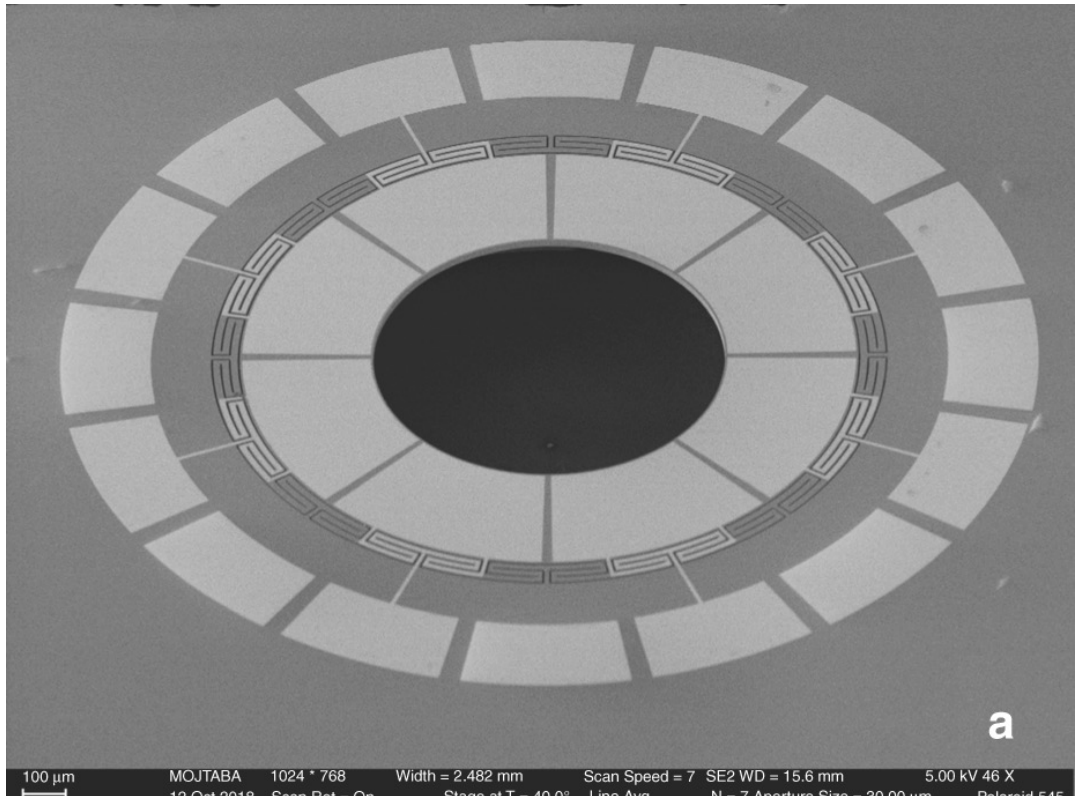
Oh [bleep], I think I want to be a professor?

REDACTED

- Industry wasn't what I wanted
- Didn't have the publication record I wanted for academia
- …let's do a postdoc!

The Plan: study frequency stability in /different/ MEMS



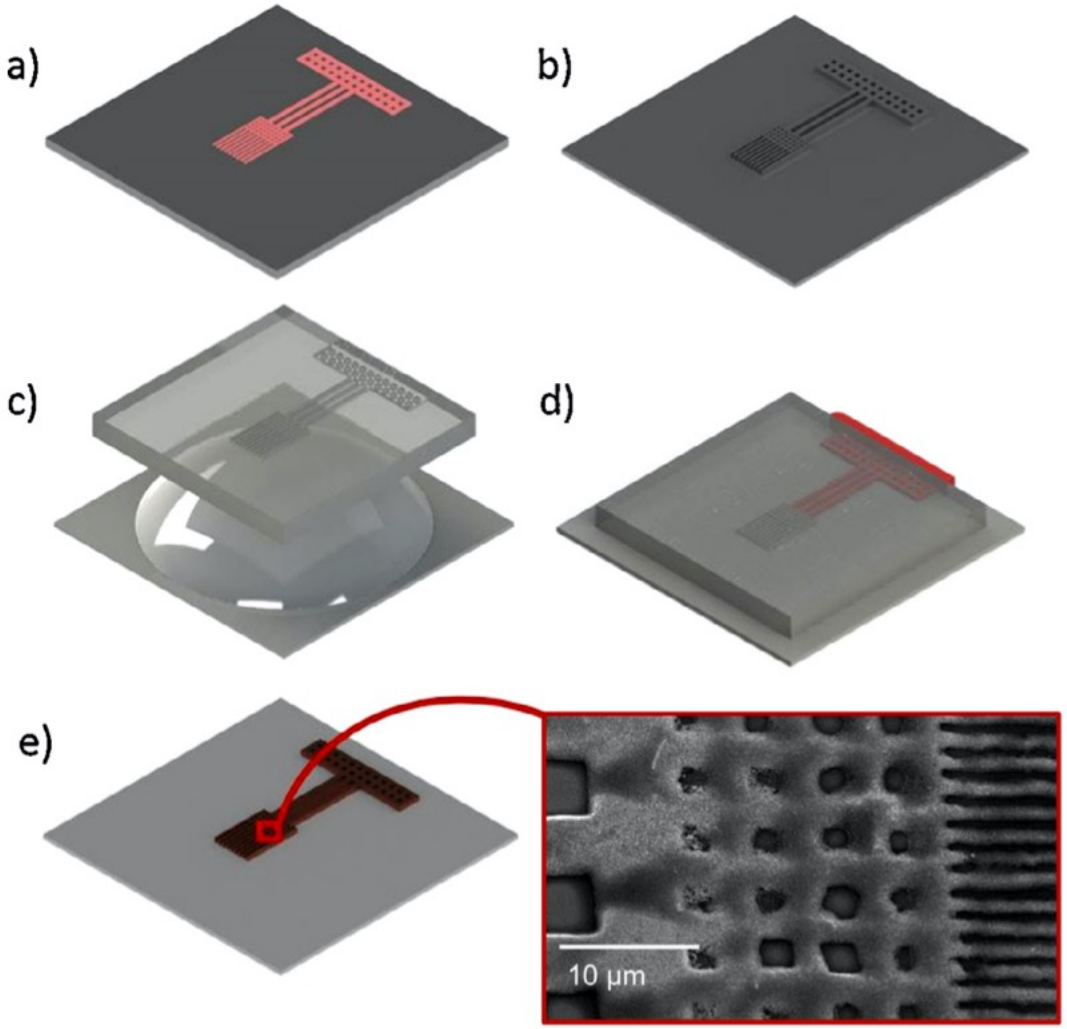


M. Hodjat-Shamami and F. Ayazi, Microsystems and Nanoengineering, 2020

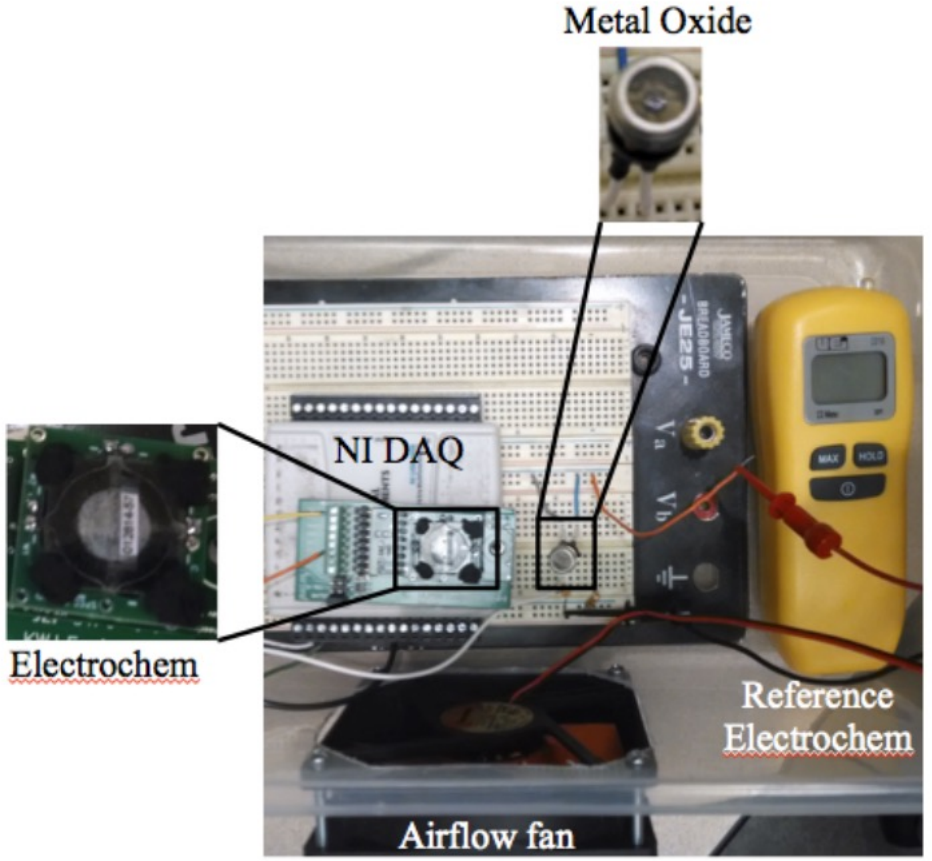
The Wrench: the lab was moving to San Diego

Nano @ Stanford

When life gives you lemons…

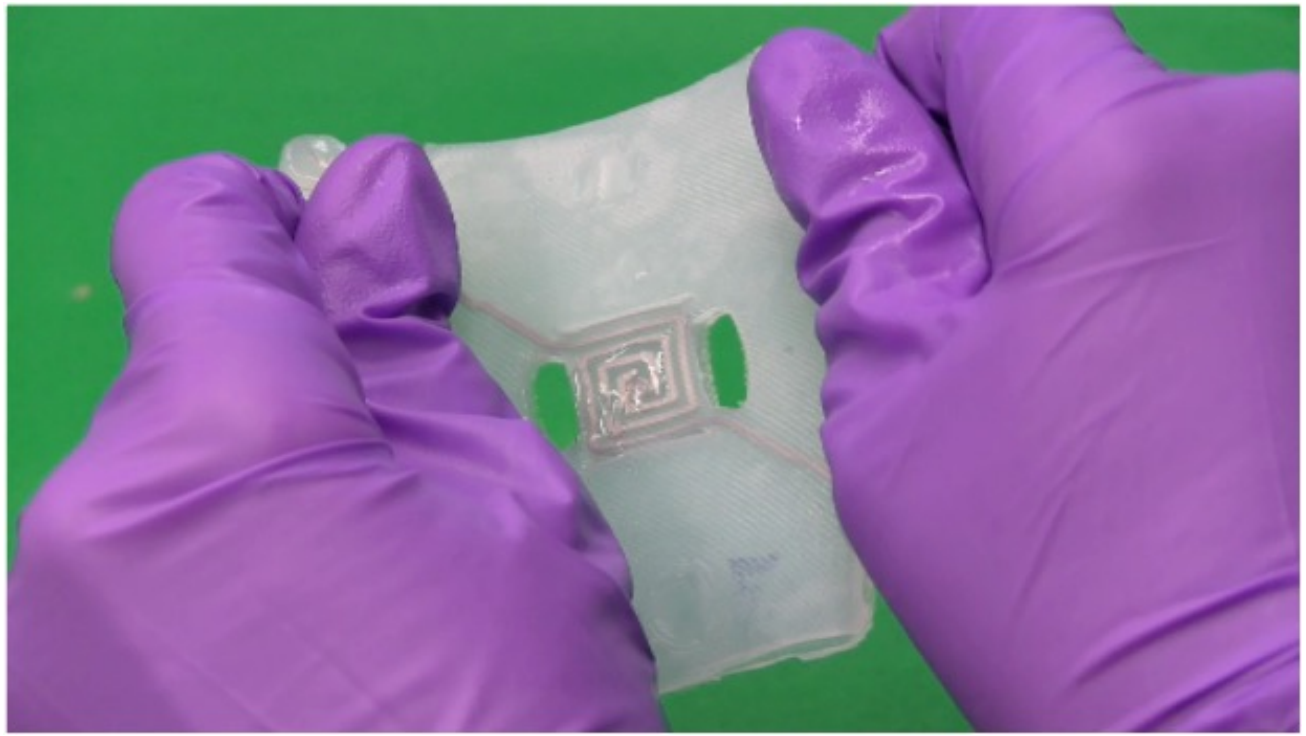


Template Printing



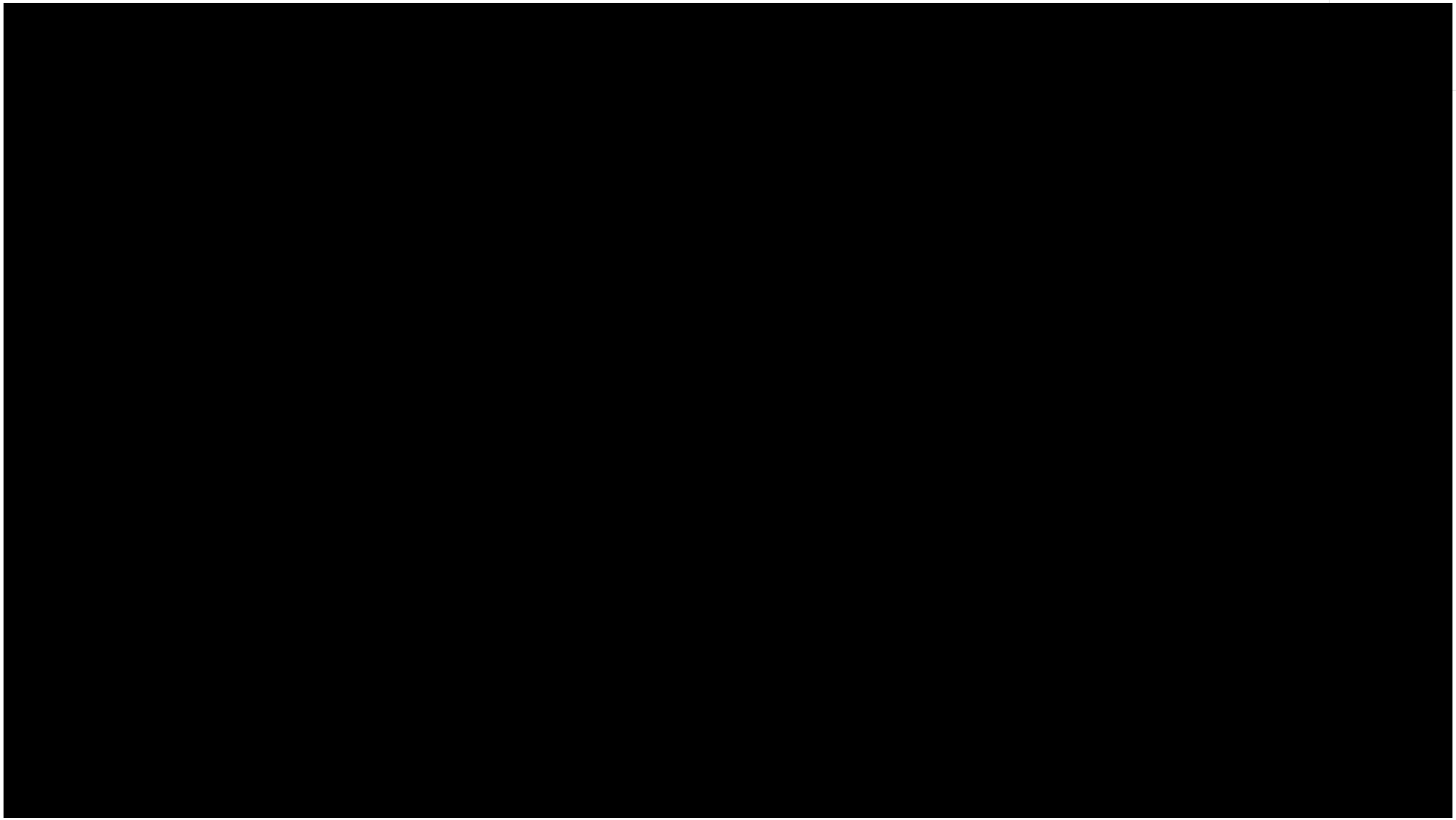
Chemical sensing

Movin' on up, to the east side (of the US)



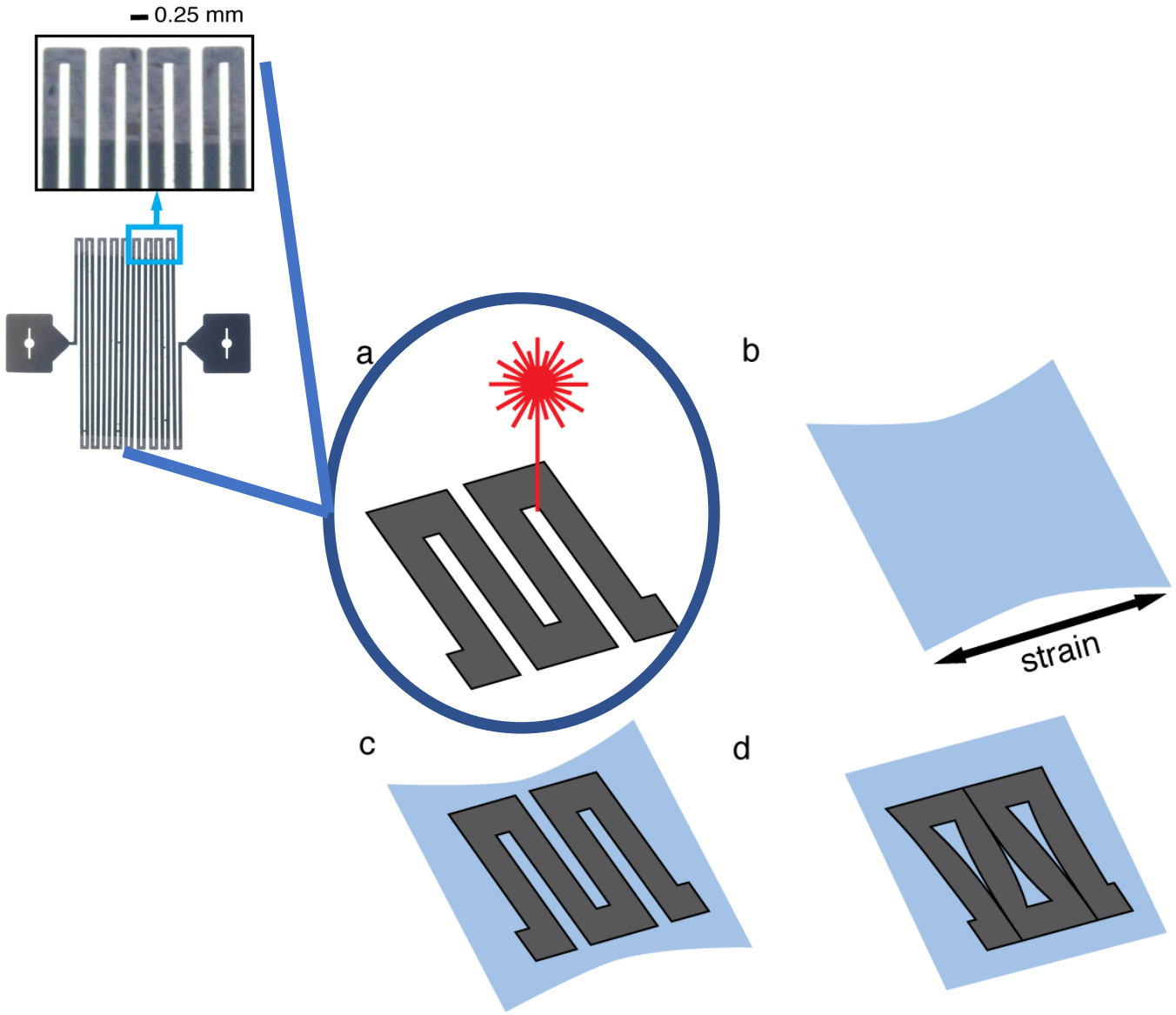
- Knew how to work with silicones
- No cleanroom? No problem!
- Excited to work with ugrad students
- Get to work on a "hot" topic

SCARS: A flexible, sensitive, robust strain sensor

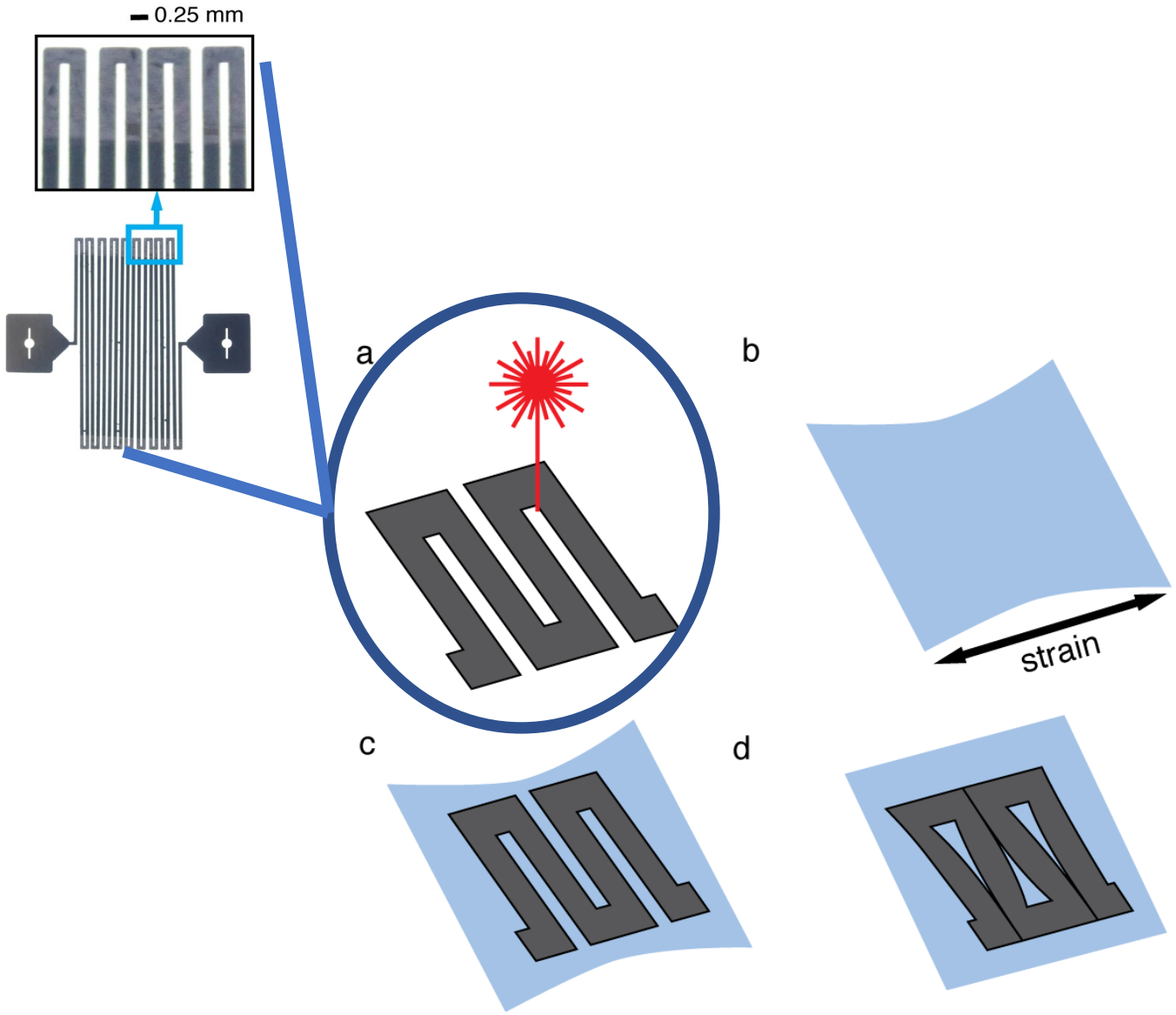


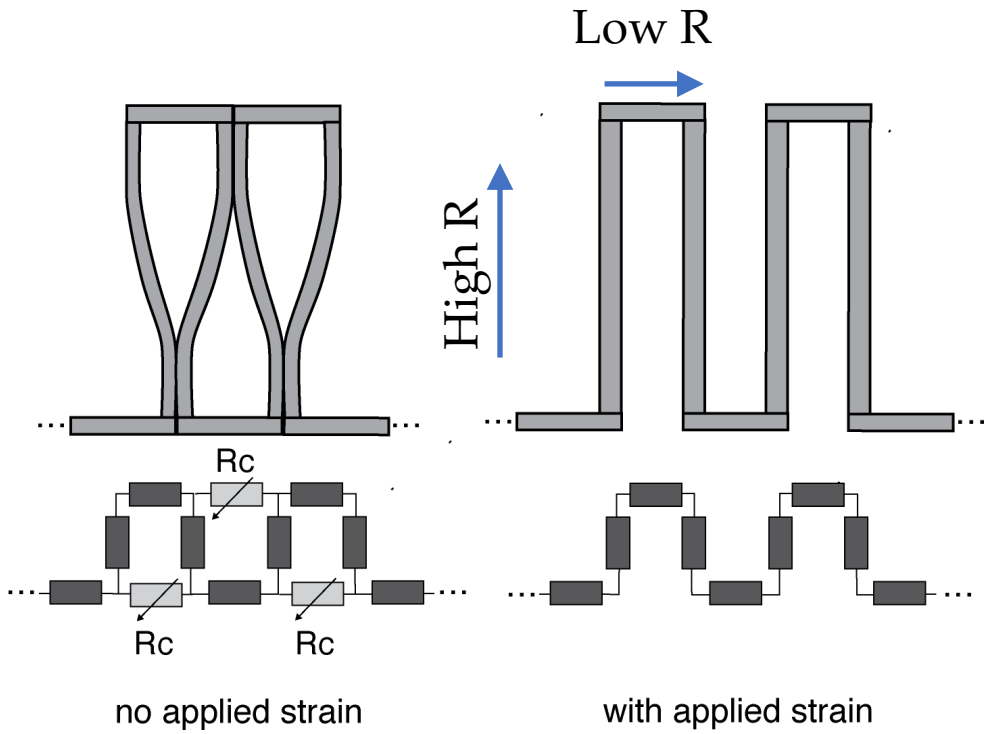
O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

Selective electrical contact between beams of a flexible carbon fiber serpentine transduces strain

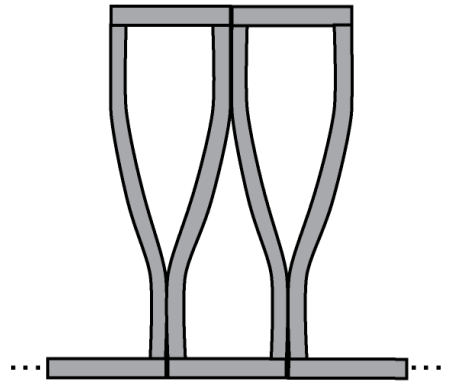


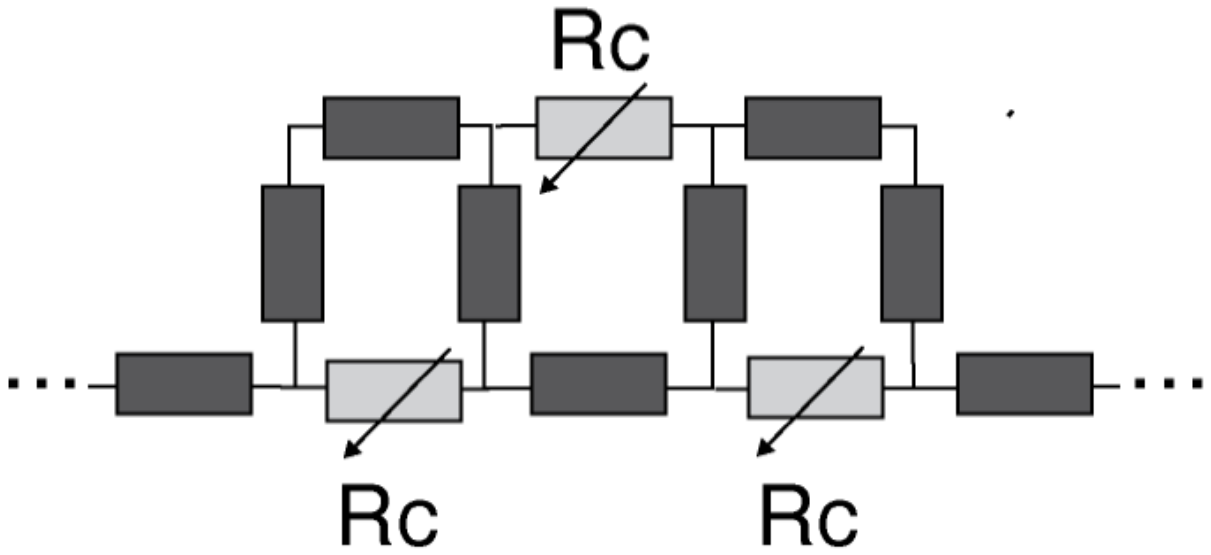
Selective electrical contact between beams of a flexible carbon fiber serpentine transduces strain





The sensor is modeled as a network of large fixed and small variable resistors that represent contact

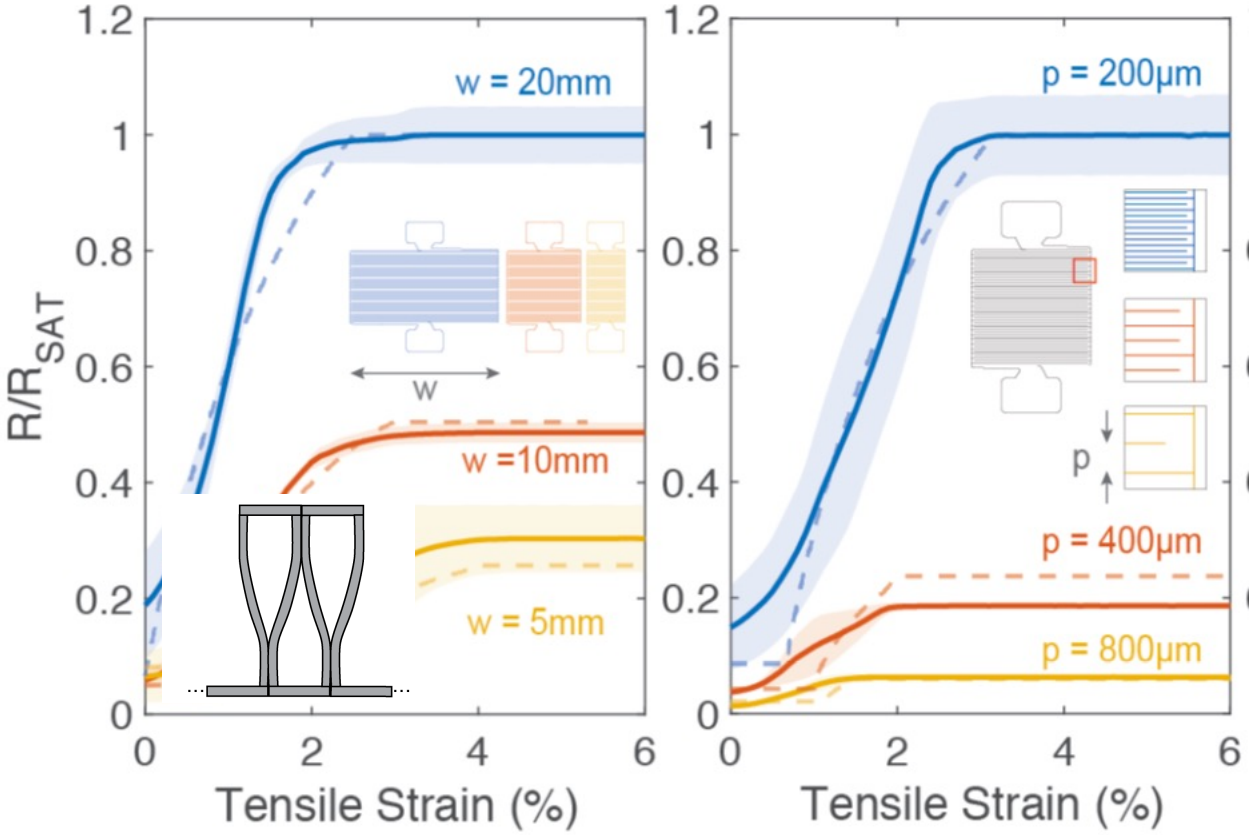




$$\begin{bmatrix} \frac{-1}{R_{c1}} - \frac{1}{R_L+R_S} & \frac{1}{R_L+R_S} & \frac{1}{R_{c1}} & 0 & 0 \\ \frac{1}{R_L+R_S} & \frac{-1}{R_L+R_S} + \frac{-1}{R_L} + \frac{1}{R_{c2}} & \frac{1}{R_L} & \frac{-1}{R_L} + \frac{-1}{R_{c1}} + \frac{-1}{R_S} & \frac{1}{R_{c2}} \\ \frac{1}{R_{c1}} & \frac{1}{R_L} & \frac{-1}{R_S} + \frac{-1}{R_{c3}} + \frac{-1}{R_L} & \frac{1}{R_S} & 0 \\ 0 & 0 & \frac{1}{R_S} & \frac{-1}{R_S} + \frac{-1}{R_{c3}} + \frac{-1}{R_L} & \frac{1}{R_L} \\ 0 & \frac{1}{R_{c2}} & 0 & \frac{1}{R_L} & \frac{-1}{R_L} + \frac{-1}{R_{c2}} + \frac{-1}{R_S+R_L} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

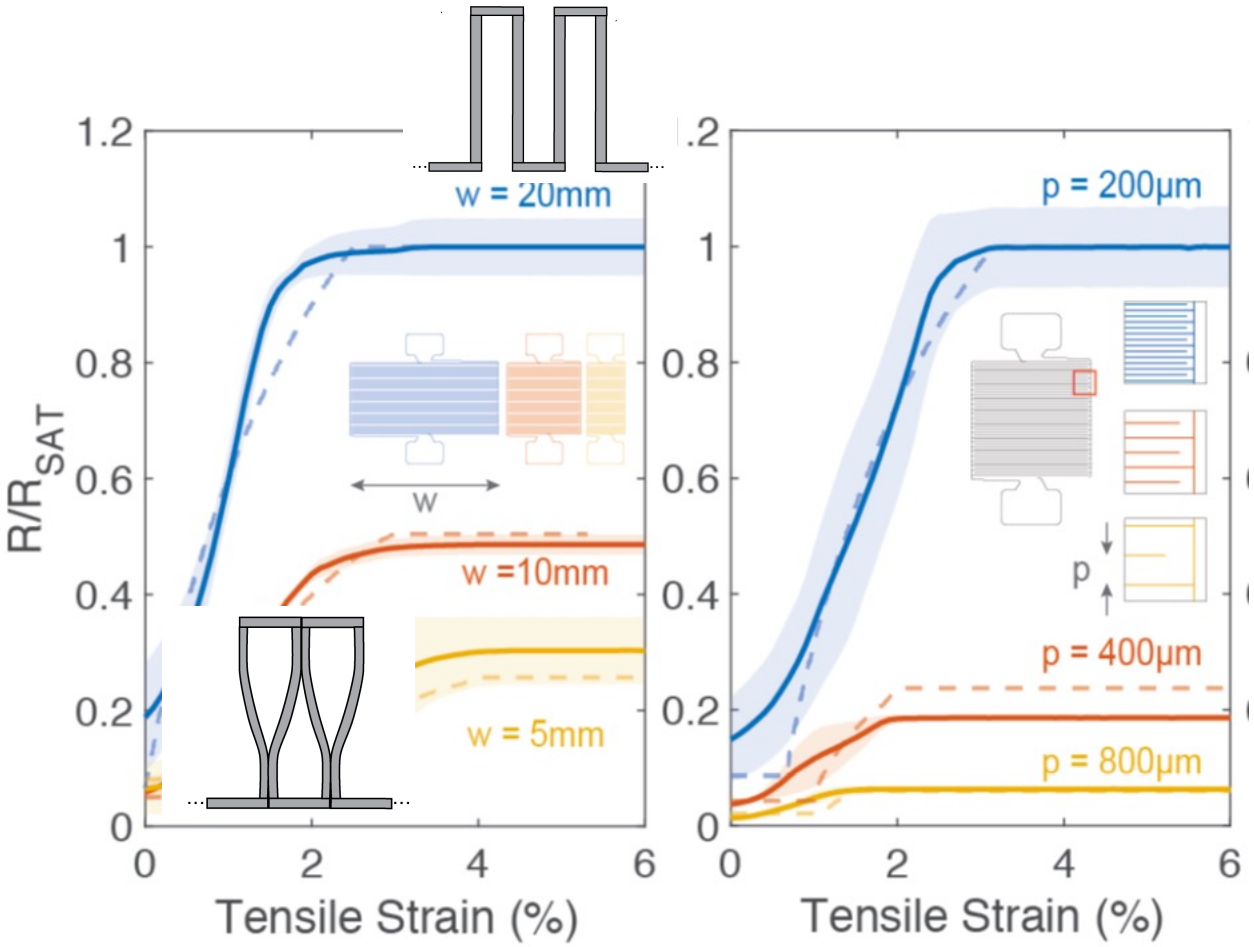
O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

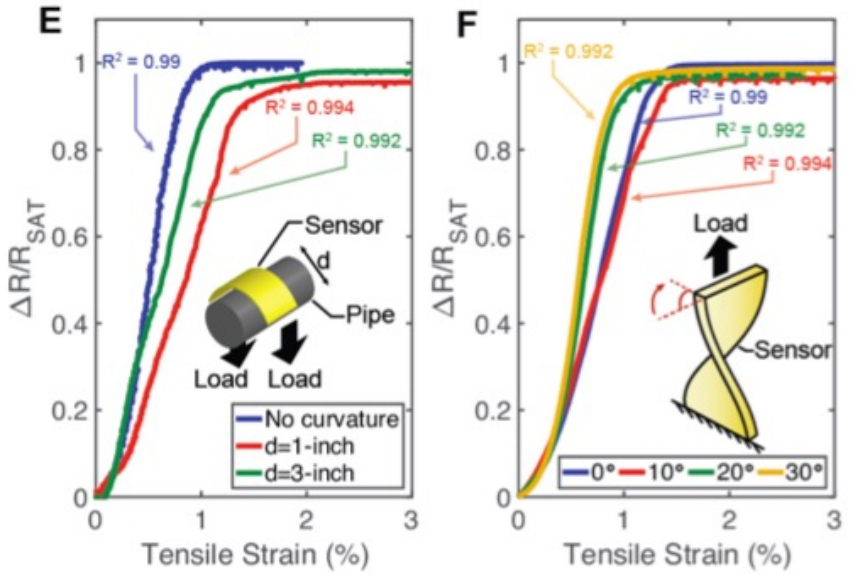
The resistance is tunable through the CF geometry. Strain sensitivity can be predicted from beam bending + electrical model.

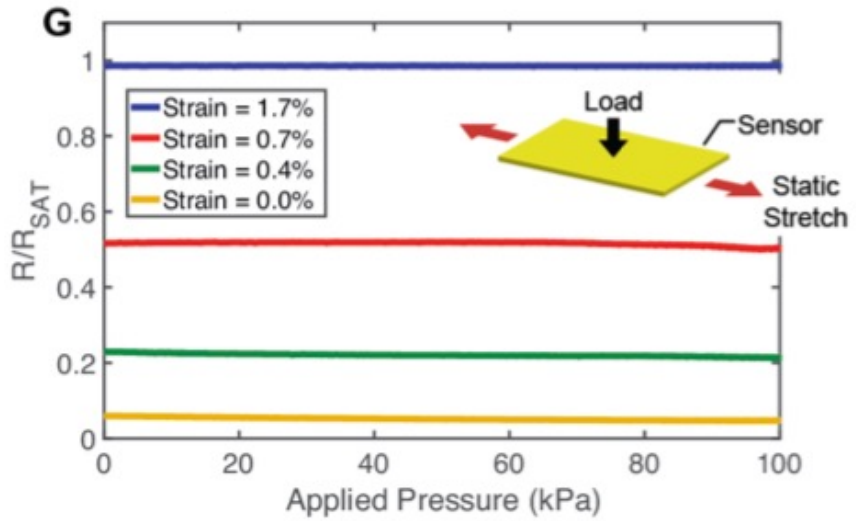


O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

The sensor is selective to strain over bending, torsion, and pressure because contact is maintained

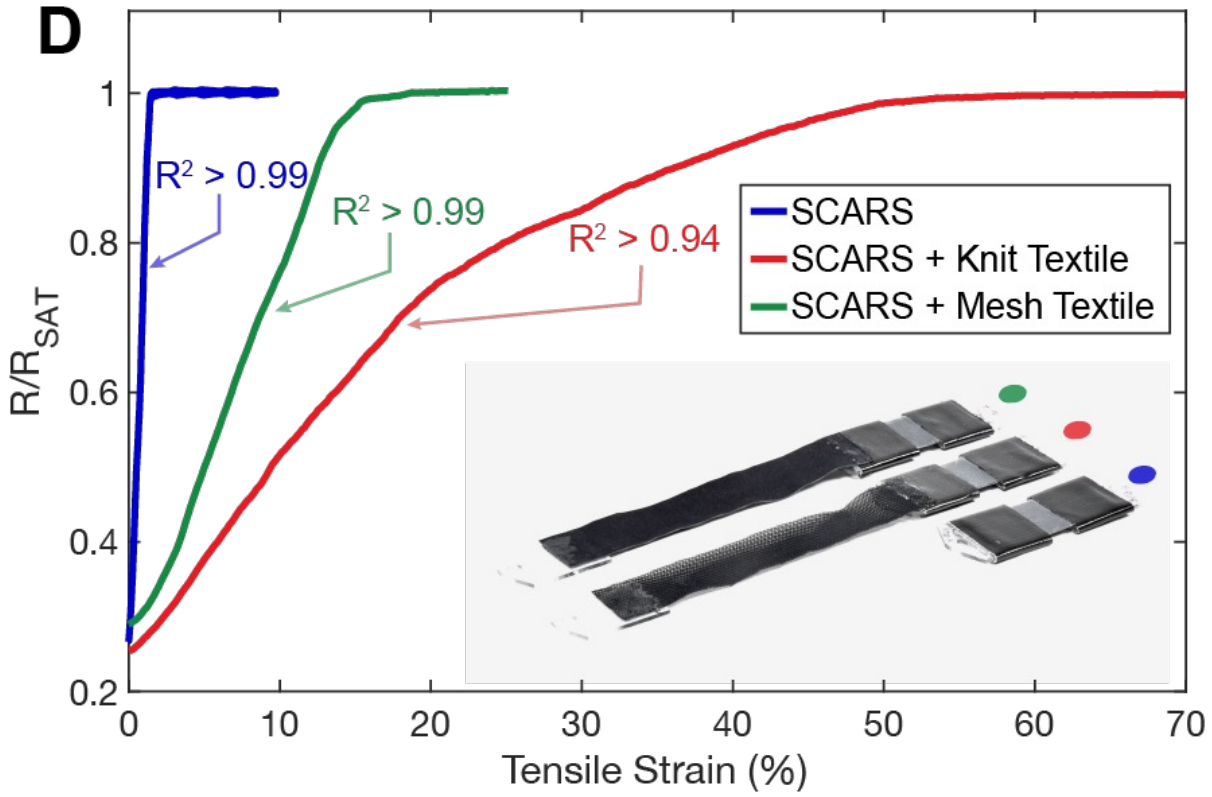






O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

The substrate stiffness and pre-stretch ratio permits control over sensor mechanical response



Use prestretch to tune for:

- body size
- limb placement
- sensitivity

$$U_{tot} = q\int_0^L (x - x_{pre})^2 d\xi + \int_0^L \frac{M^2}{2EI} d\xi$$

- Pre-stretch gradient
- Substrate compliance

The versatility of the transduction methodolgy allows for a variety of stretchable encapsulation materials to be used, such as knit textiles.

We incorporate these textile-integrated sensors into a custom smart sleeve.

O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

Applications to edema robotics and healthcare

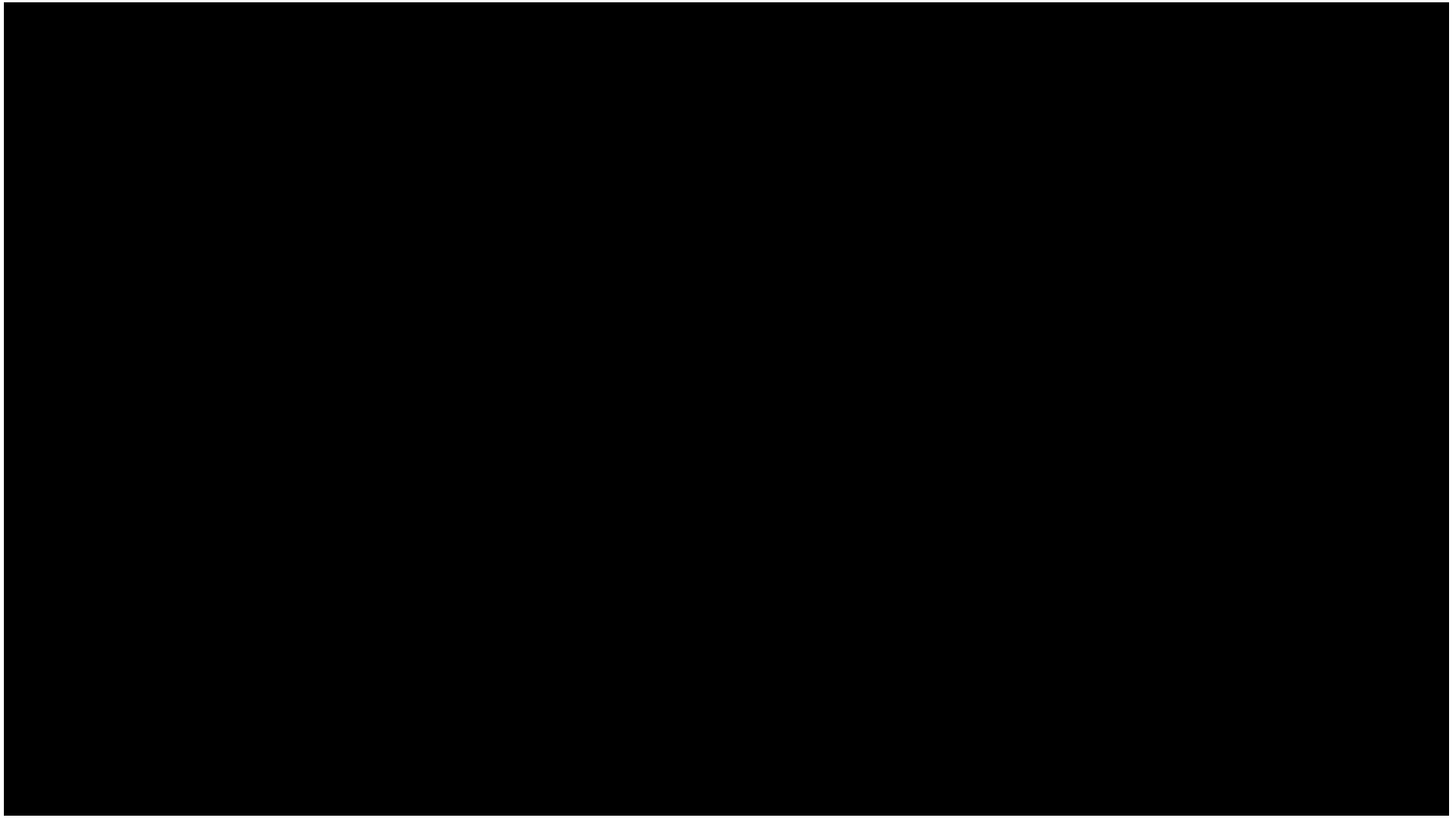
-Detecting changes in limb size with fine temporal resolution

-Informing "high-risk" activities that trigger edema episodes

-Determining when to seek more aggressive treatment, or when to apply active compression or lymph drainage techniques

O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

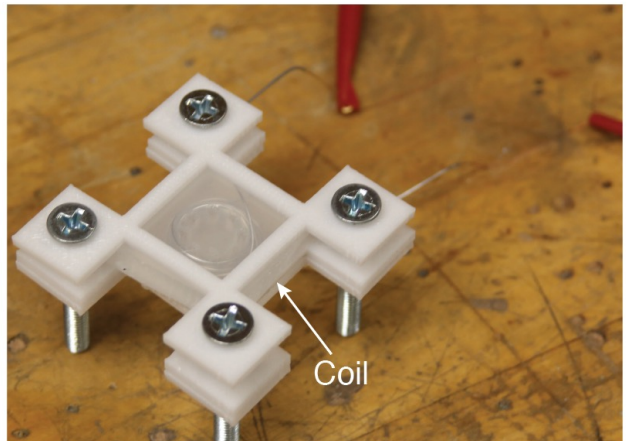
SCARS: Selective contact sensors

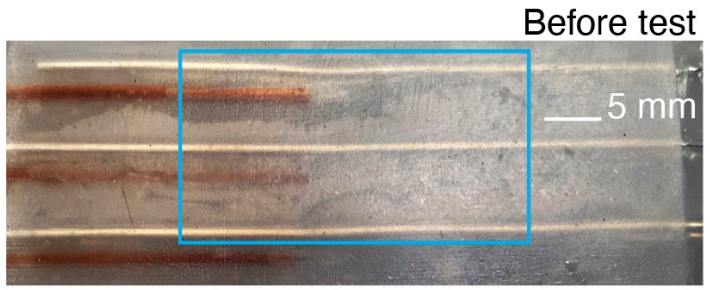


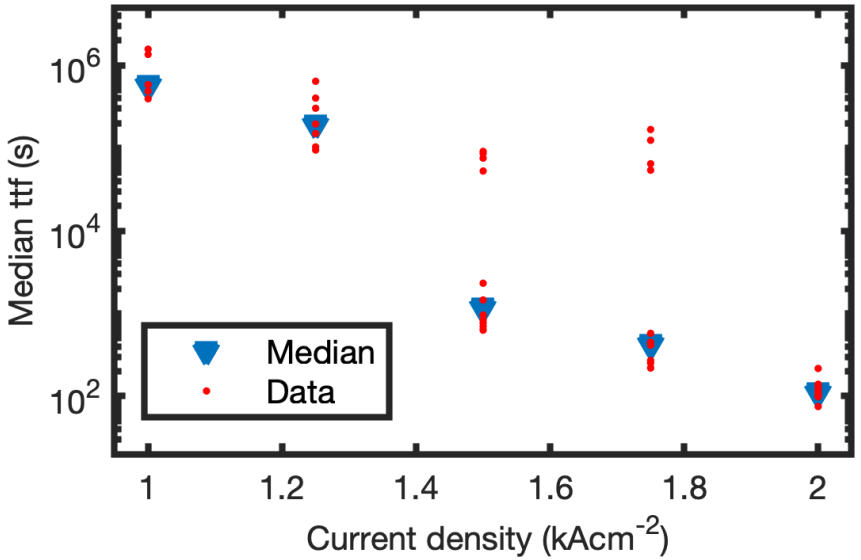
O.A. Araromi, M.A. Graule, K.L. Dorsey, et al., *Nature*, 2020

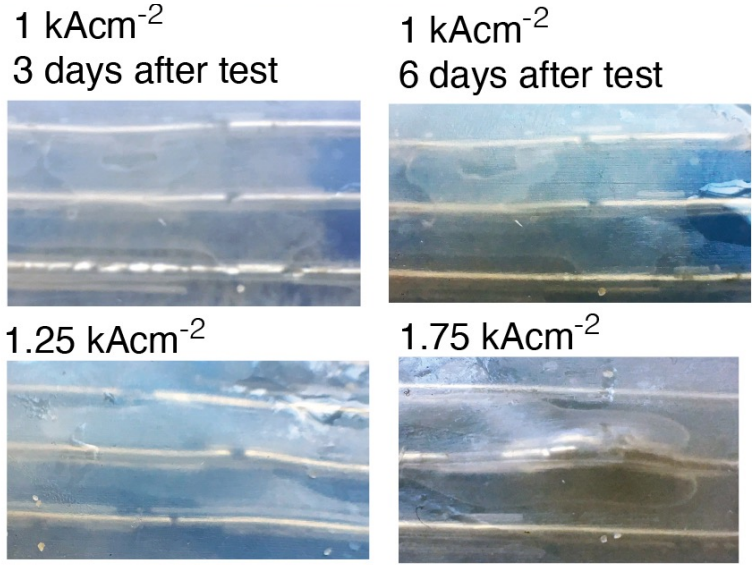
Sensor and actuator properties can also be *reconfigured* by reversible stiffness change

Problem: Liquid metals used in many soft sensors and actuators have poor lifetime (~5 h) at high current





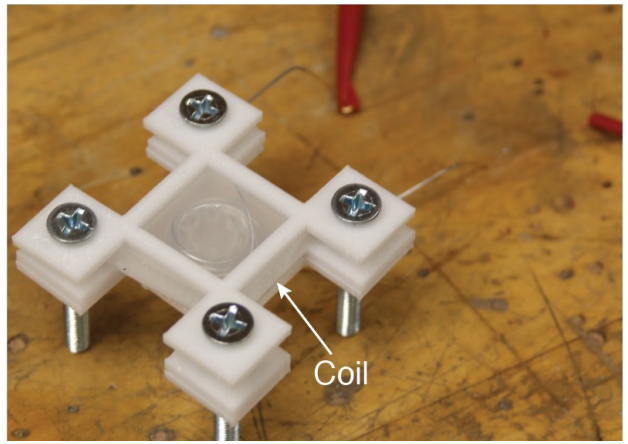


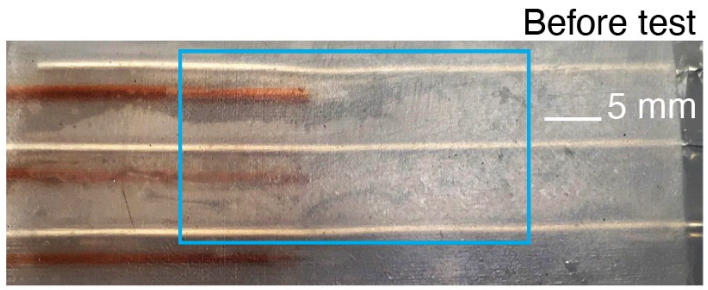


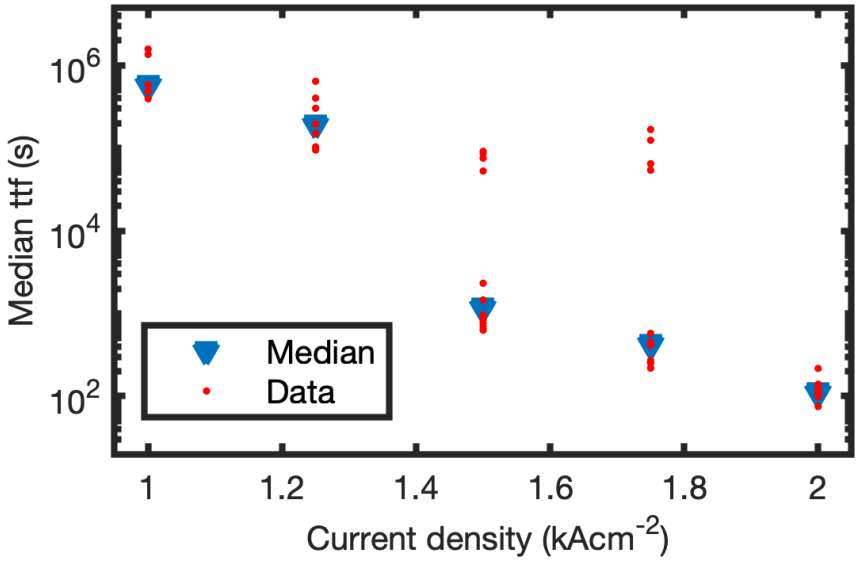
Use gallium alloys for:
Stretchable heaters
Flexible antennas
Electromagnetic valves

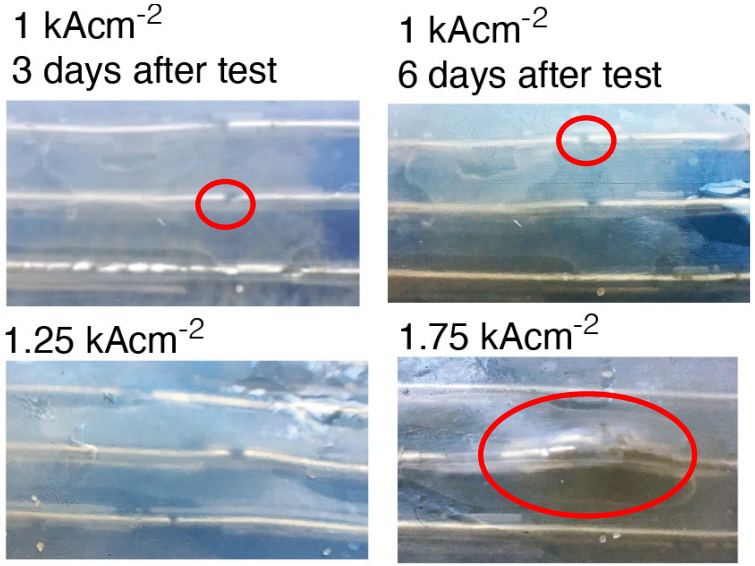
K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

Studying samples at high currents shows voids and buckling





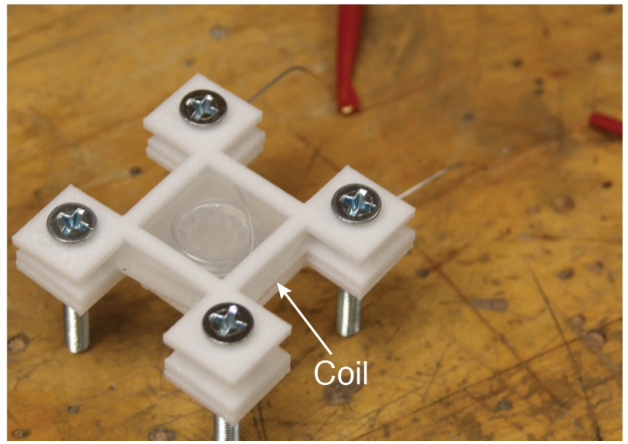




Use gallium alloys for:
Stretchable heaters
Flexible antennas
Electromagnetic valves

K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

Studying samples at high currents shows voids and buckling with development of hot spots in wires



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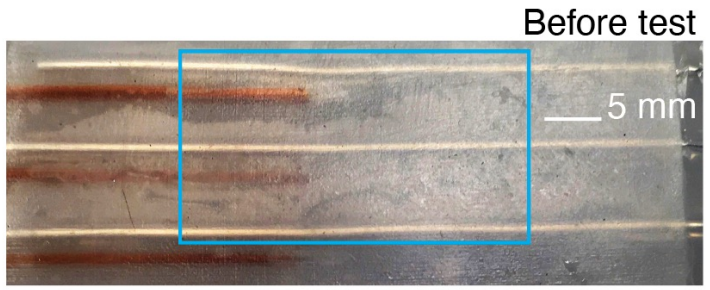
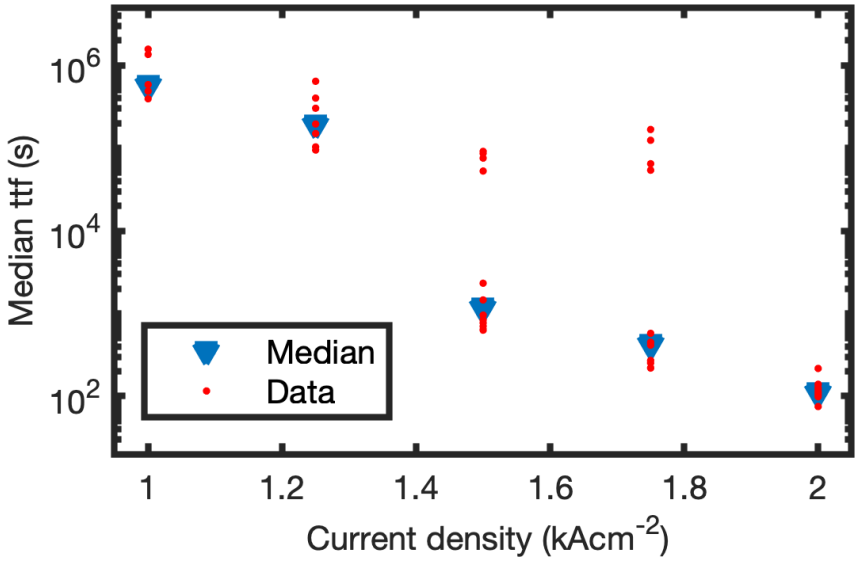
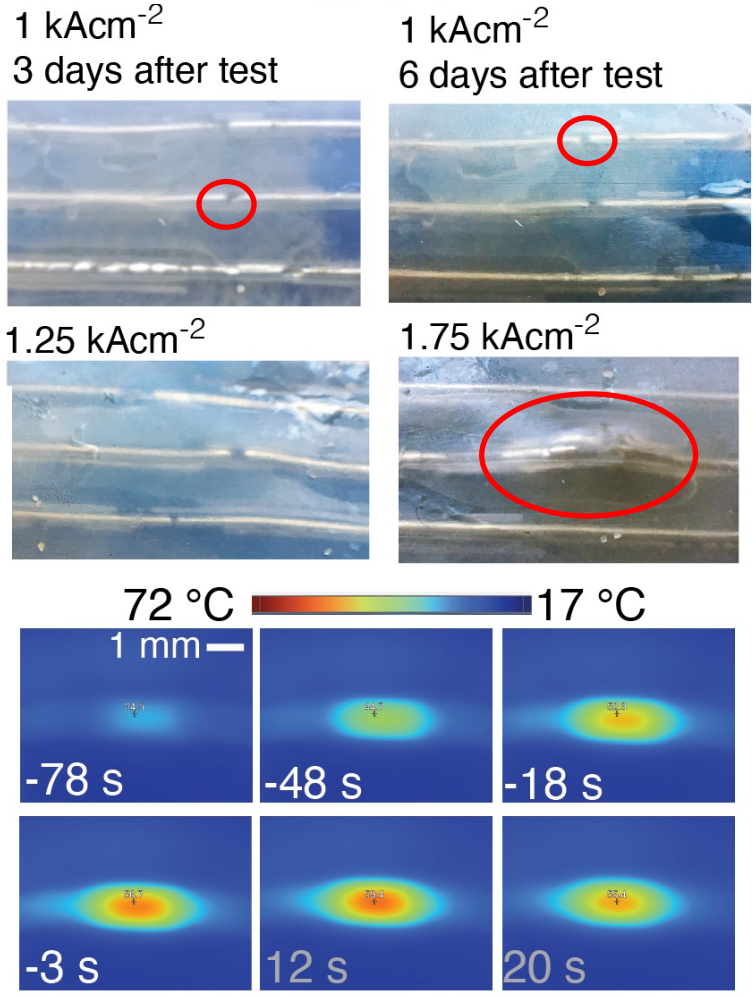






K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

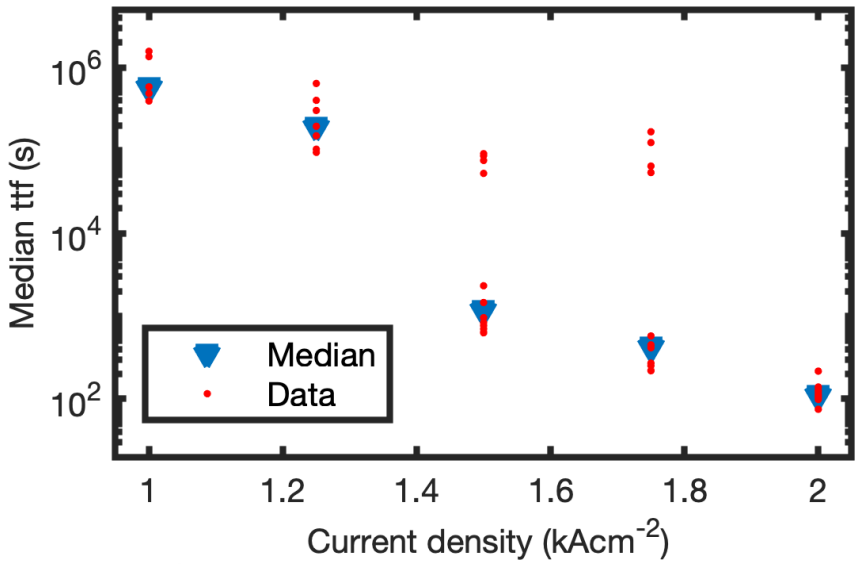
Failure could be caused by **electromigration** or thermal exp

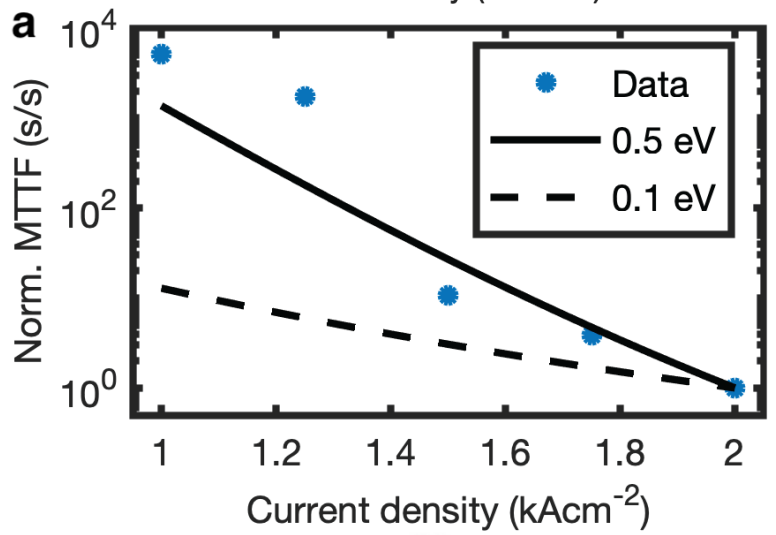
1 kAcm^{-2}
3 days after test

1 kAcm^{-2}
6 days after test

1.25 kAcm^{-2}

1.75 kAcm^{-2}





$$\mathrm{MTTF} = ACJ^{-2}\exp(E_a / kT)$$

K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

Failure could be caused by electromigration or **thermal expansion**

1 kAcm^{-2}
3 days after test

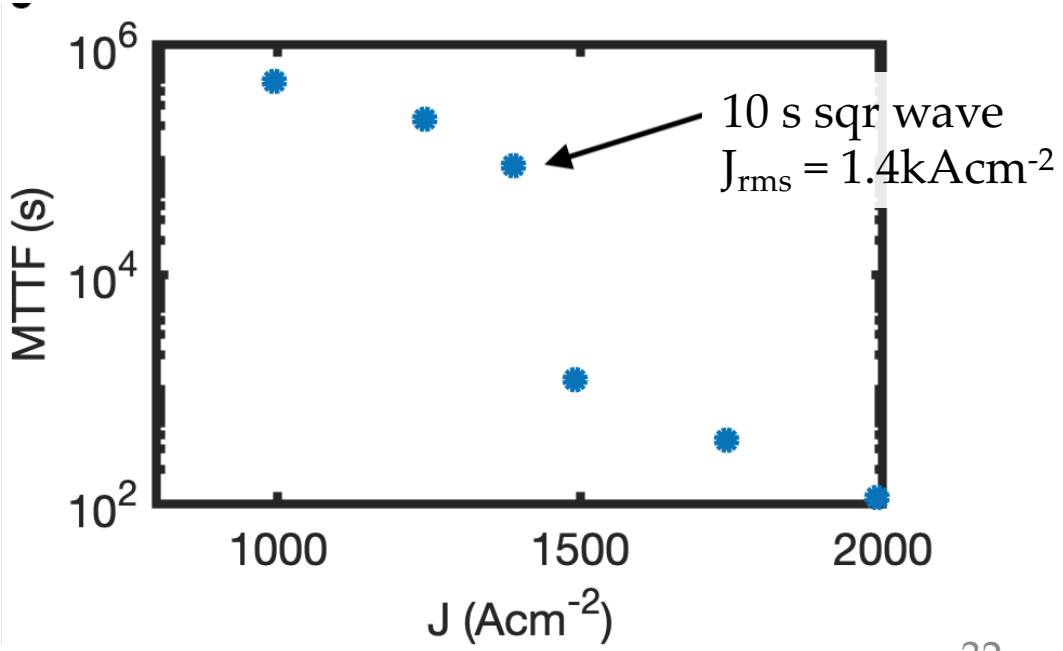
1 kAcm^{-2}
6 days after test

1.25 kAcm^{-2}

1.75 kAcm^{-2}

Failure time with:

- 2 kAcm^{-2} DC (112 s)
- Heat sink (138 s)
- Pelletier cooling (39900 s)
- 0.1 Hz sqr wave(50600 s)



K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

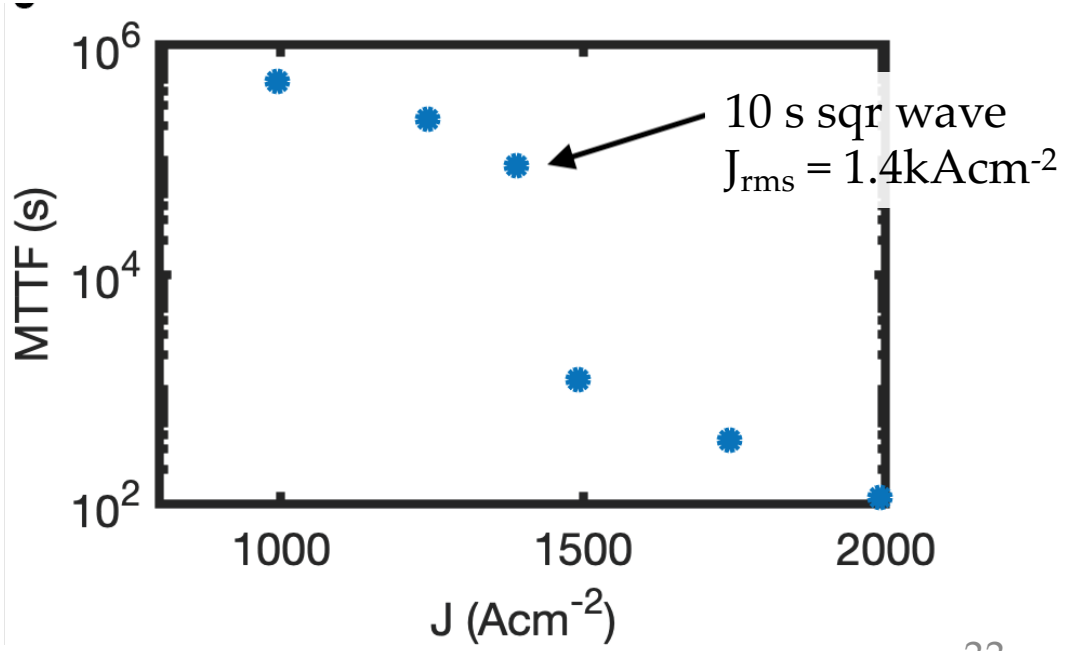
Failure is likely caused by expansion of elastomer

Migitate failure by:

- Increasing passive cooling
- Pulsing power
- Avoid CTE mismatch between elastomer and liquid metal

Failure time with:

- 2 kAcm^{-2} DC (112 s)
- Heat sink (138 s)
- Pelletier cooling (39900 s)
- 0.1 Hz sqr wave(50600 s)



K.L. Dorsey and N. Lazarus, Advanced Materials Technologies, 2021

Smith College for 6 years

It's time for a change!

PARSES

Northeastern University

Principal Investigator

Kris L. Dorsey, PhD

Associate Professor

Personal website

Research Staff

Sonia F. Roberts, PhD

Postdoctoral Research Fellow

Personal website

Grad Researchers

Ibrahim Abubakar

PhD Student (2022-

Damla Leblebicioglu

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Lilly A. Rizvi

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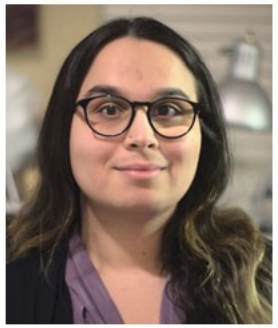

Ugrad Researchers

Musheera Khandaker

Joined 2022

What's new?
What's next?

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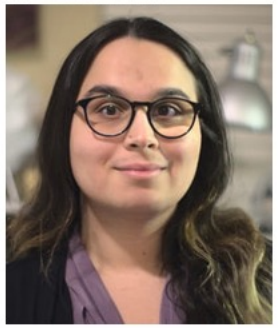


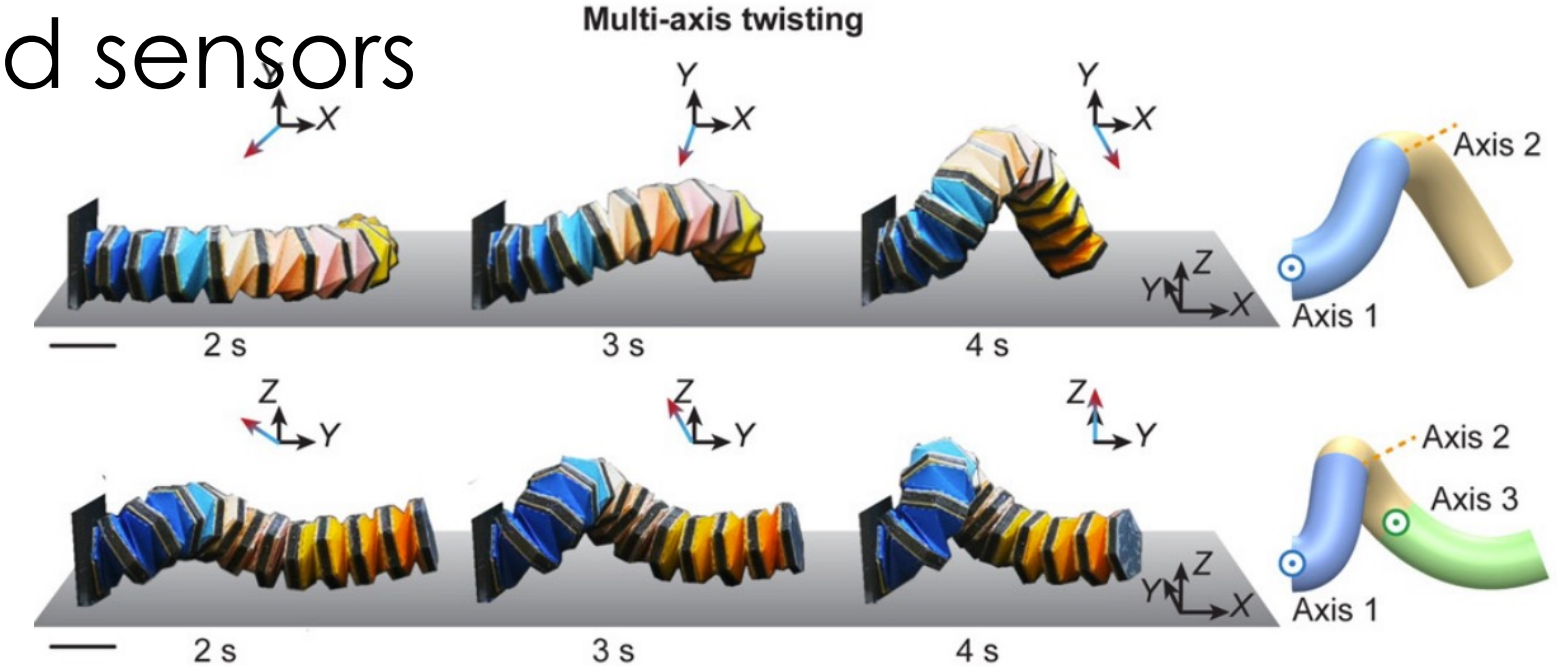
Ugrad Researchers

Musheera Khandaker

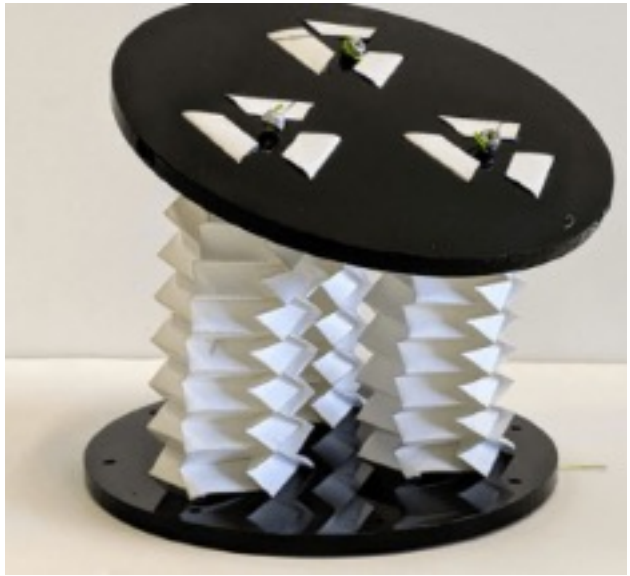
Joined 2022

Origami inspiration has been demonstrated in ***many*** actuators and sensors

M. Mete and J. Paik, IEEE RAL, 2021

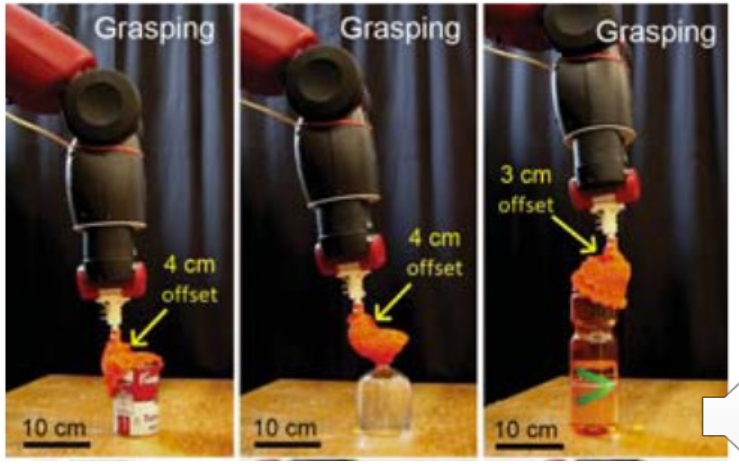


S. Wu, et al., PNAS, 2021



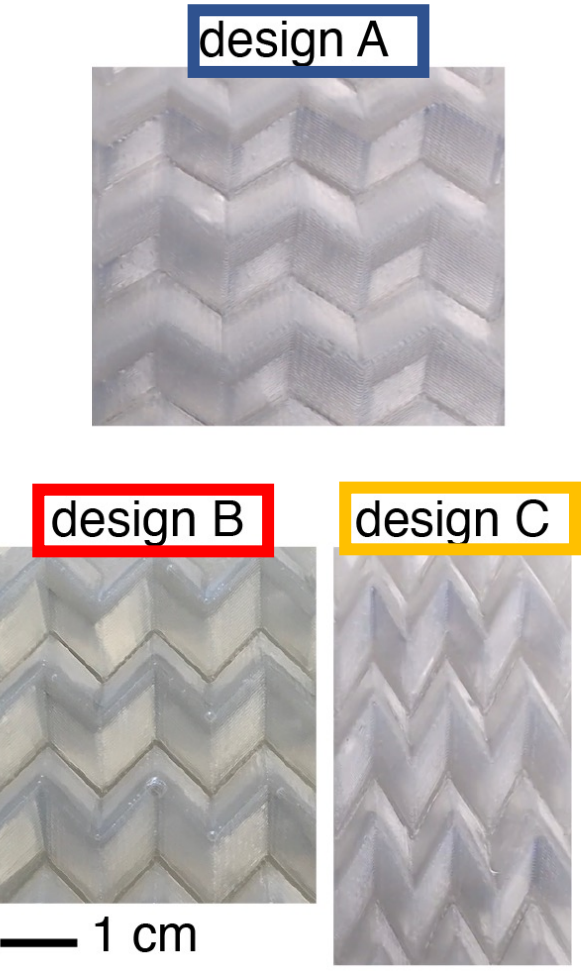
Chen, et. al., IEEE RAL, 2020

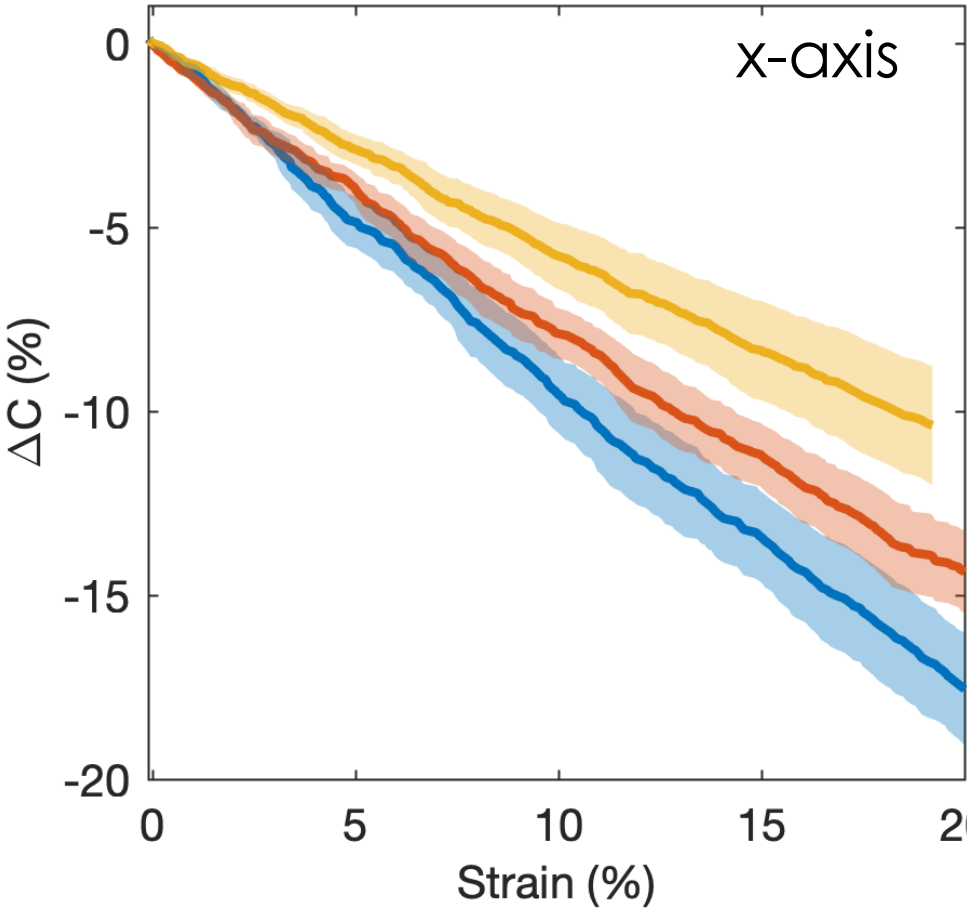
X. Liu, et. al., IEEE J Sensors, 2021

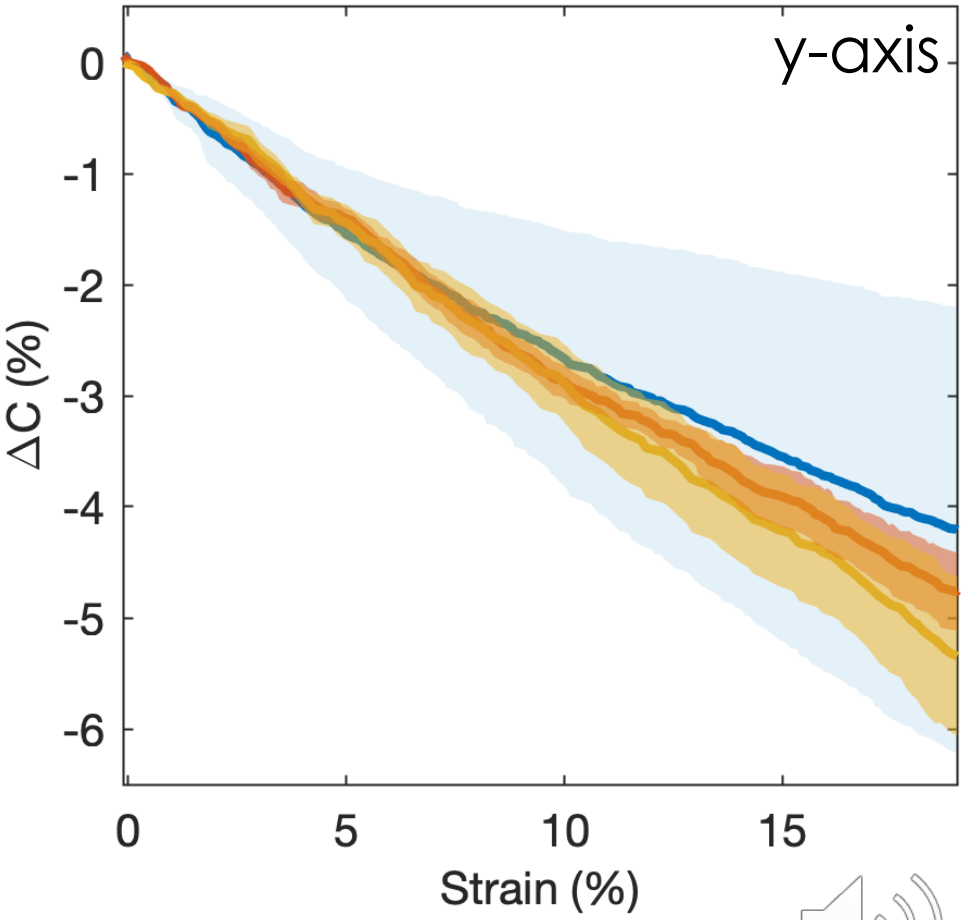


S. Li, et. al., ICRA, 2019

Even with stretching, a tuning ratio of 1.8 exists in the x-axis, but sensitivity relationship is inverted







Dorsey et al., *Multifunctional Materials*, 2022

What do YOU want to know?

tinyurl.com/doorcMay16