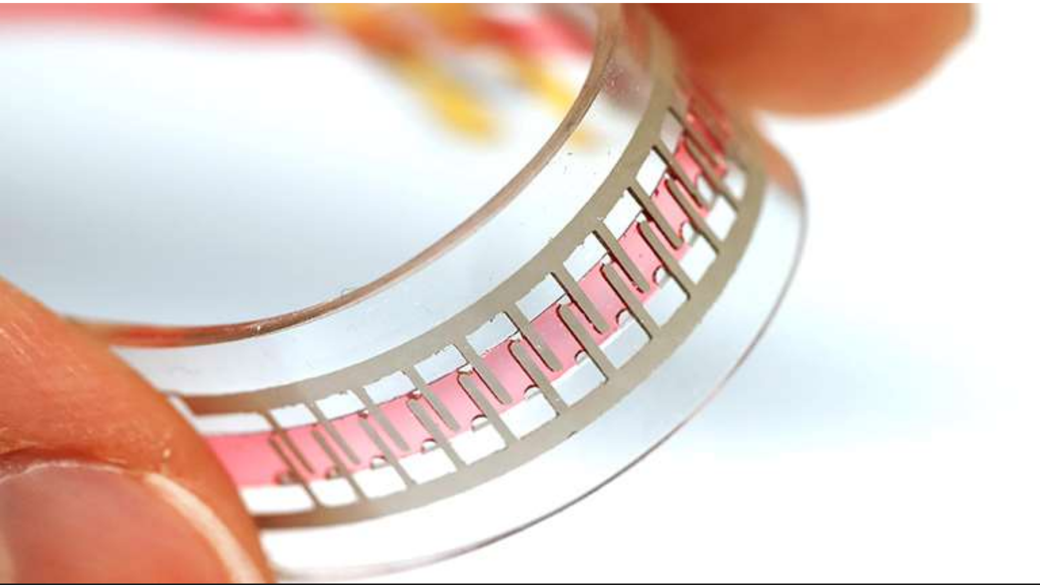
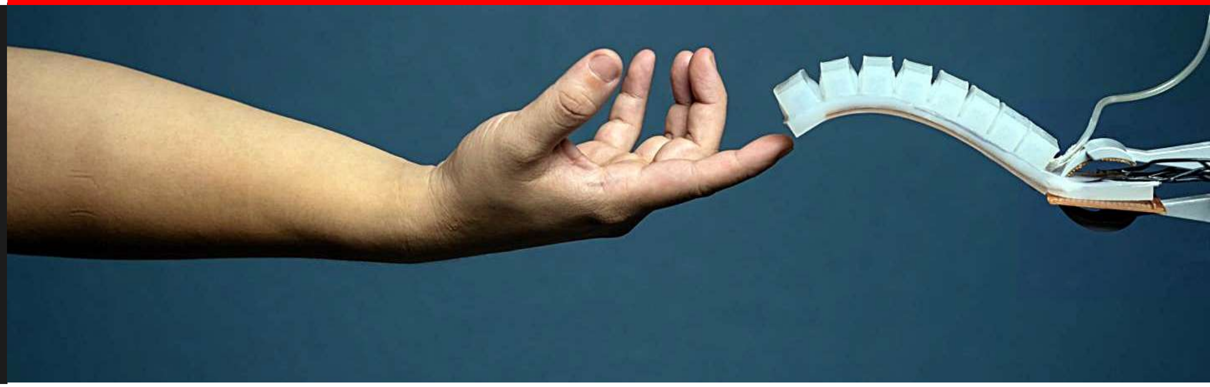


TP Robotique: Artificial Muscles (TP 10)



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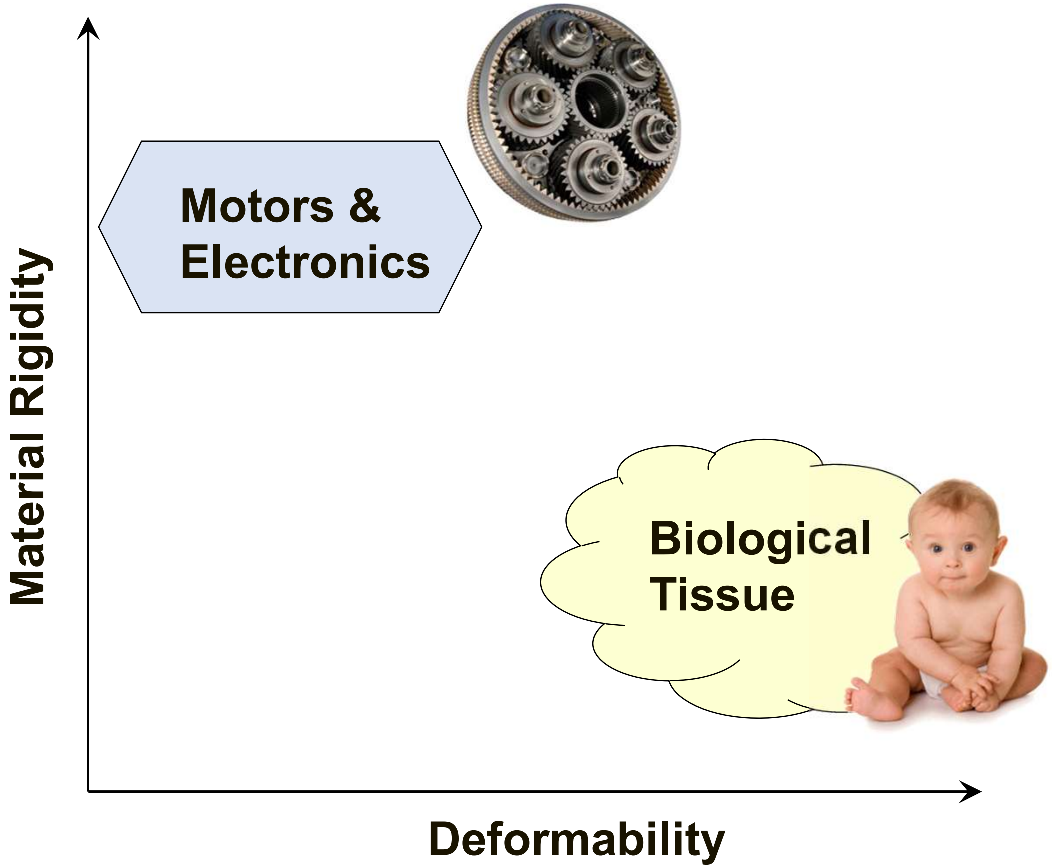
Outline of TP Sessions

- Lecture
  - Provide overview of artificial muscle technologies.
- DEA fabrication
  - Assemble elastomer films, rigid frames and conductive electrodes.
- DEA characterization
  - Perform tests to determine electrical and mechanical behavior
  - Compare results with theoretical predictions.
- EA assembly and characterization
  - Assembly of three EA pads
  - Perform tests to determine electrical and mechanical behavior.
- Robot building
  - Use knowledge gained about DEAs to build simple robots.

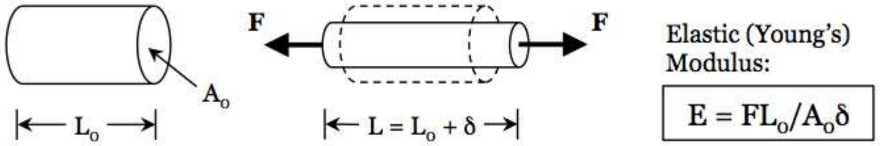
Why make robots soft?

Soft Robot Example

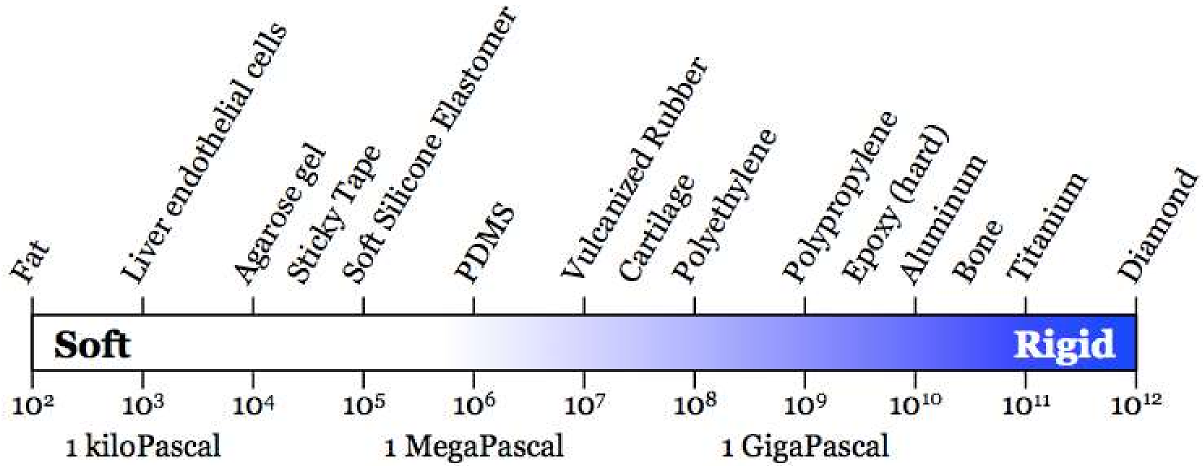
Big Hero 6: Baymax



Mechanical Impedance Mismatch



$E \sim 1$ Pascal [Pa] = 1 N/m^2

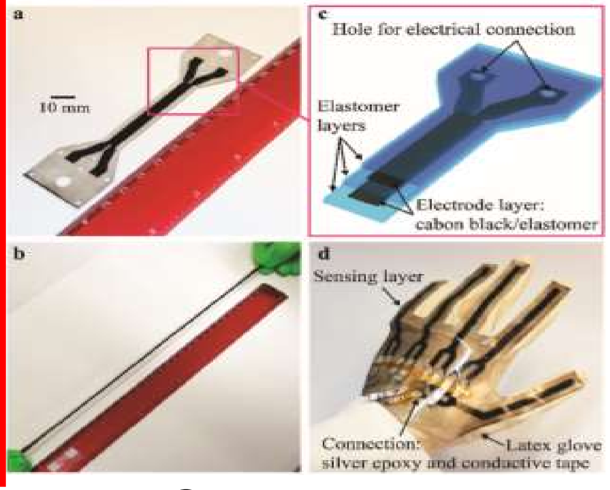


Majidi, "Soft Robotics – A Perspective" *Soft Robotics* **1** 5-11.

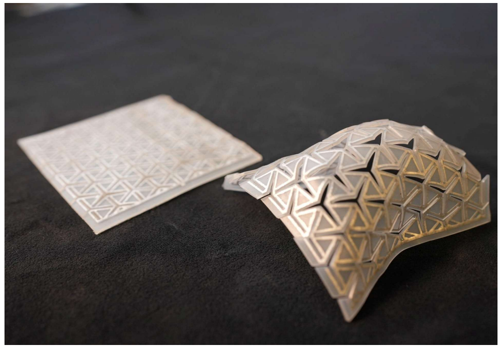
Mechanical Impedence Matching: To preserve the *natural mechanics* of the human body, wearable and implantable technologies must match the elastic compliance of natural skin, tissue, and organs.

Soft Robotics Components

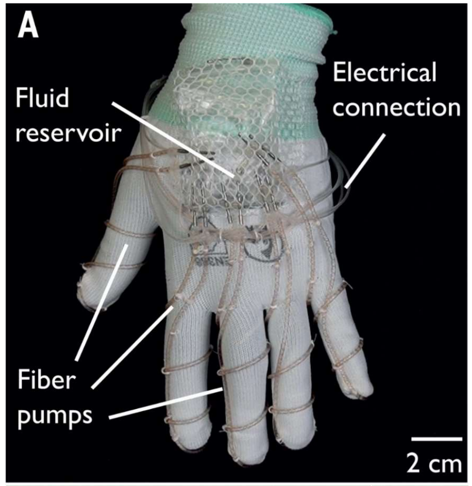
Actuators

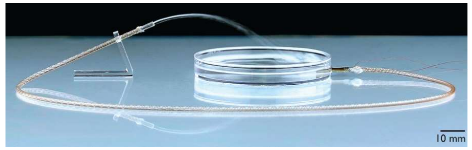


Sensors



Morphing matters



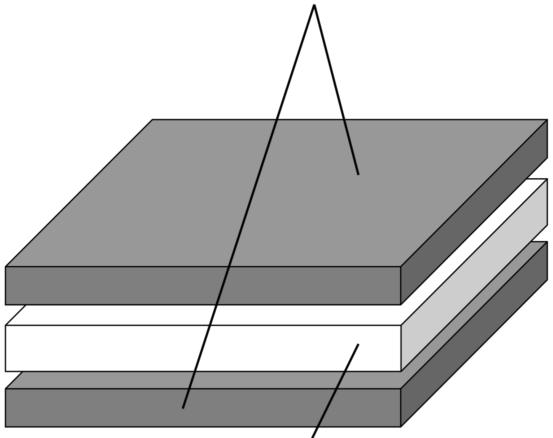


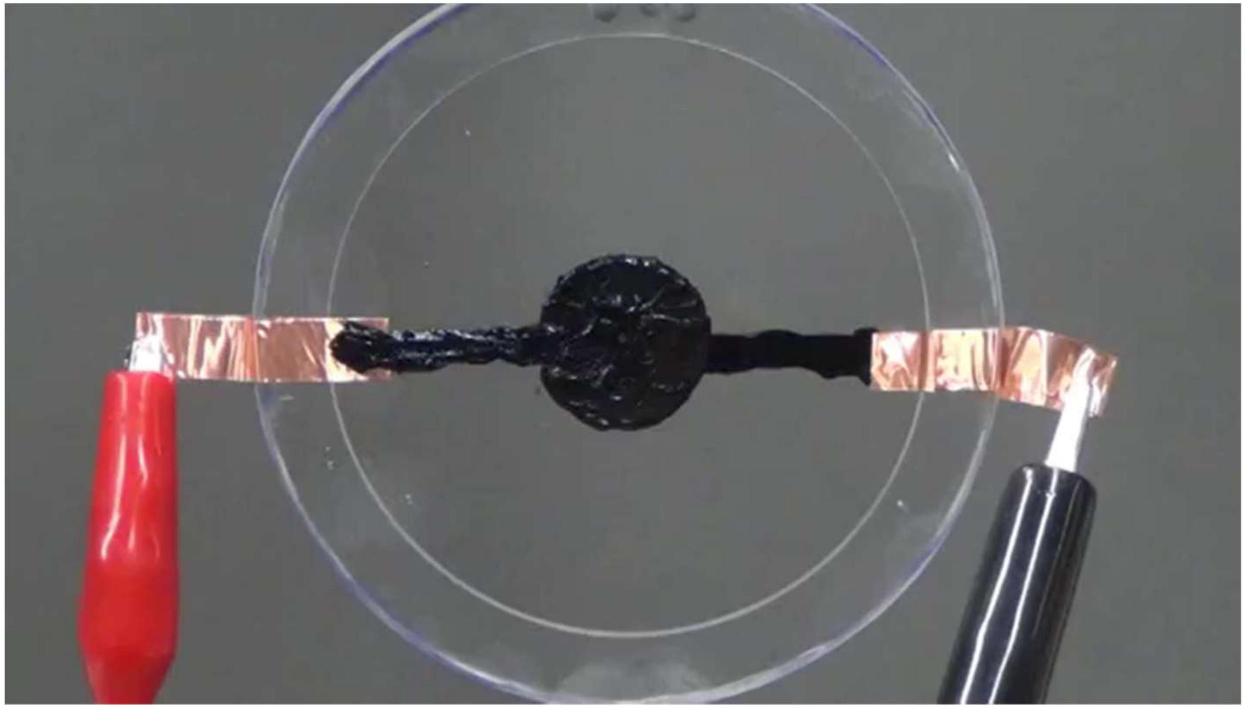
Pumps

Pneumatic Artificial Muscles

Session 1 is about it, guys!

Dielectric Elastomer Actuators





$$p = \varepsilon_0 \varepsilon \left(\frac{V}{z} \right)^2 = \varepsilon_0 \varepsilon E^2$$

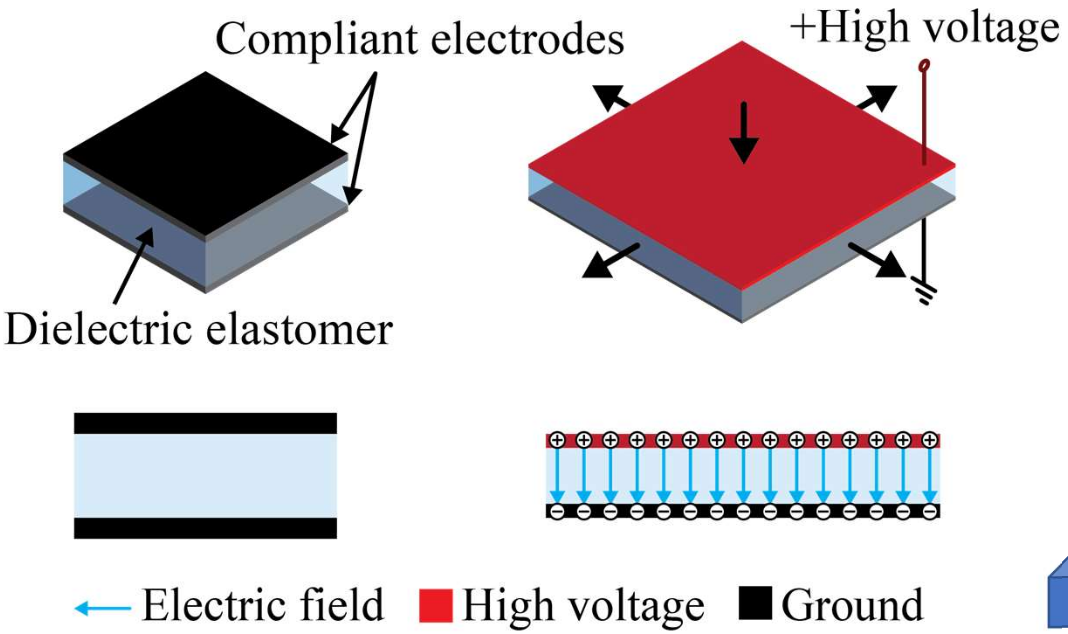
Electrostatic pressure (Maxwell stress)

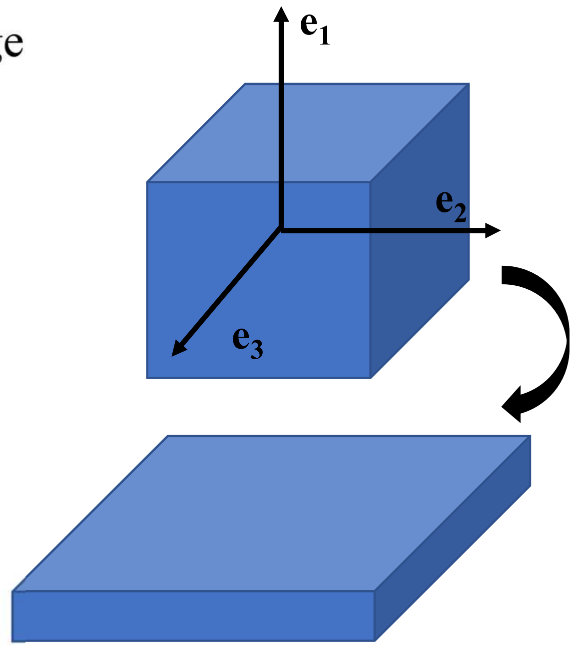
* $\boldsymbol{\varepsilon_0}$: vacuum dielectric constant, $\boldsymbol{\varepsilon}$: material dielectric constant

Dielectric Elastomer Actuators (DEA)

Operating principle

Electrostatic attraction causes soft dielectric to compress in the thickness direction. Due to the Poisson effect and charge repulsion, the dielectric also expands in the area direction.





$$\lambda_i = \frac{L_i}{L_{0i}}$$

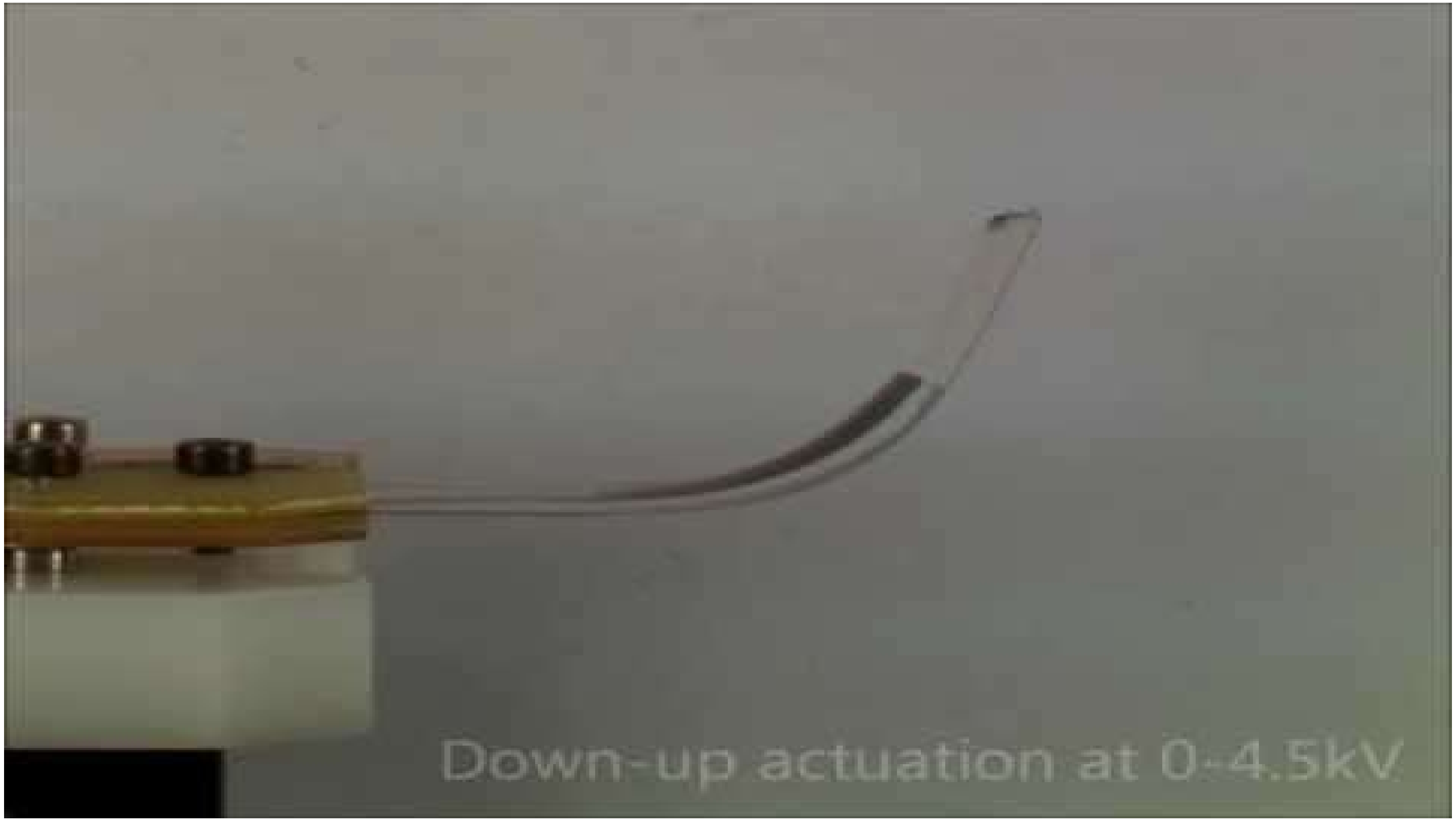
$$i = 1,2,3$$

For incompressible solids,

$$\boxed{\lambda_1 \lambda_2 \lambda_3 = 1}$$

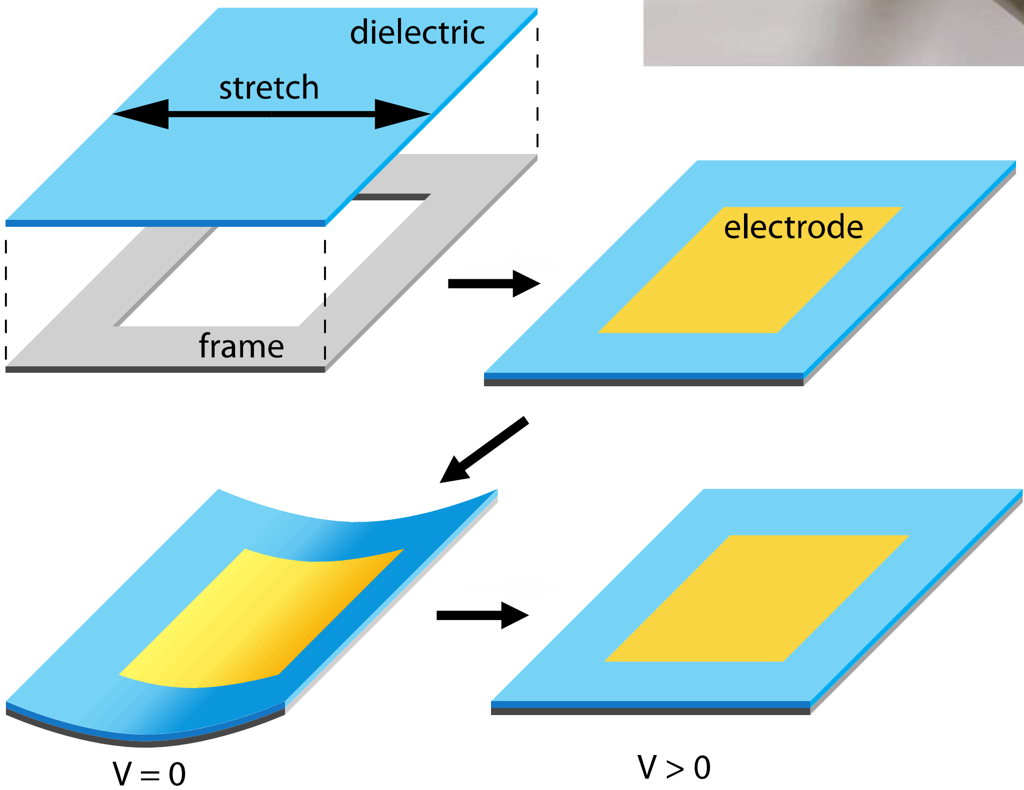
Volume remains the same

Dielectric Minimum Energy Structures (DEMES): from Squeezing to Bending



How to make it bend well?

1. Prestrained film is attached to a flexible frame.
2. The composite structure **bends into a minimum energy state**.
3. Stress from electric field causes dielectric to expand, relieving some of the strain.
4. The expansion makes the frame move towards its undeformed state.



Dielectric Elastomer Actuators (DEA)

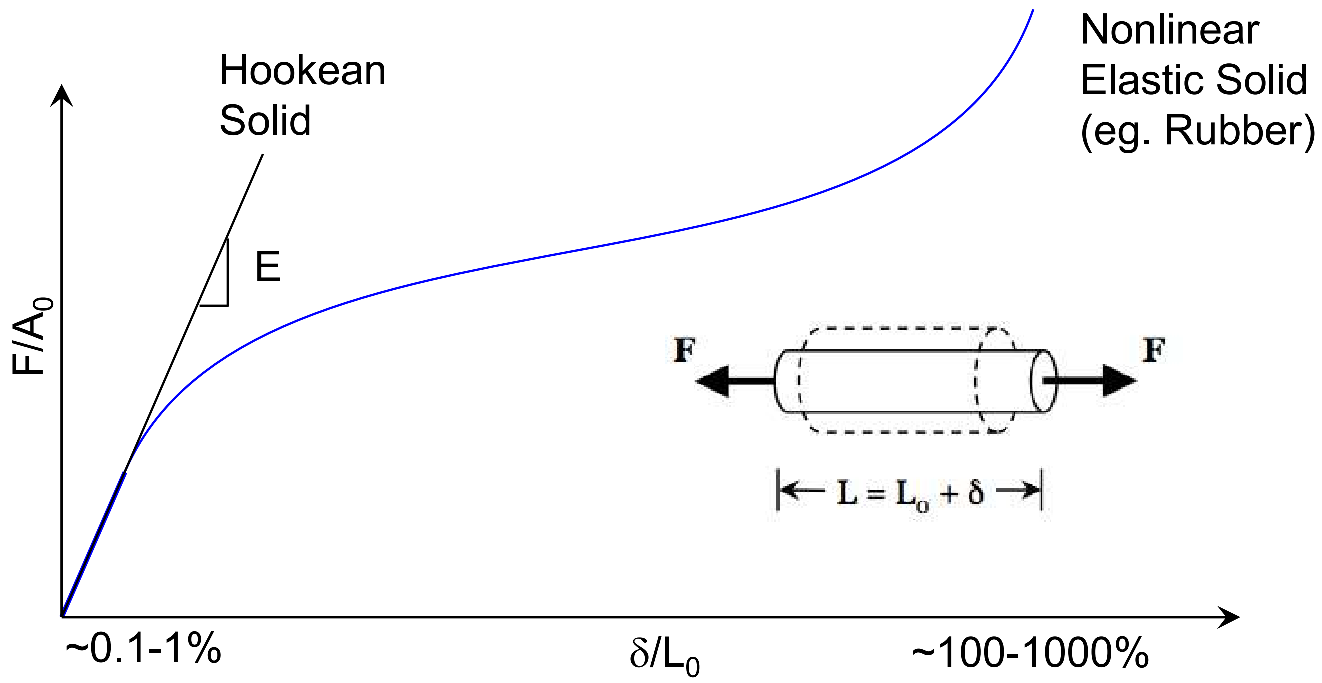
Dielectric Material

Many different materials can be used for the dielectric, but the best results have been obtained with **Acrylics** and **Silicones**.

Acrylics: larger actuation strain.
Silicones: faster.

Parameter	Acrylics	Silicones
Max strain (%)	380	120
Max stress (MPa)	8.2	3.0
Max energy density (MJ/m^3)	3.4	0.75
Dielectric loss factor @ 1kHz	0.005	<0.005
Max e-field (MV/m)	440	350
Relative permittivity	4.5-4.8	2.5-3.0
Elastic modulus (MPa)	0.1-3.0	0.1-2.0
Mechanical loss factor	0.18 @ 20 Hz	0.05 @ 80 Hz
Max efficiency	>80	>80

Nonlinear Elasticity



Hookean Solid:	$\sigma = E(L/L_0 - 1)$
Ogden Solid:	$\sigma = \mu_1\{(L/L_0)^2 - L_0/L\} + \mu_2\{(L/L_0)^4 - (L_0/L)^2\}$

Dielectric Elastomer Actuators (DEA)

Electrode Material

An ideal electrode would be able to maintain conductivity at very high strains (>300%), not impede the expansion and contraction of the dielectric, and be very fault tolerant.

Material	Fabrication	Pros	Cons
Conductive grease	Paint on conductive grease electrodes.	+Very easy to apply +Very high strains >300%	-Messy
Conductive elastomer	Mix conductive particles (carbon black, nanowires, etc.) with elastomer and cure.	+Good bonding +Highly tunable +High strains 200%	-Particles can aggregate over time and lose conductivity
Corrugated metal film	Metal film deposition on corrugated elastomer surface.	+High conductivity +Low stiffness increase of 1-2%	-Low strain 25-30%
Ion-implanted metals	Ion implantation of metal ions in the elastomer surface.	+High strain 175% +Easy microscale patterning	-High increase in local elastic modulus 50-350%

Session 3 is about it, guys!

DEA Robots

A Flying Robot Controlled by Artificial Muscle

Jun Shintake, Samuel Rosset, Bryan Schubert, Dario Floreano, and Herbert Shea

From "A Foldable Antagonistic Actuator", DOI: 10.1109/TMECH.2014.2359337

École polytechnique fédérale de Lausanne
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Swiss National Centre of Competence in Research

Versatile soft grippers with intrinsic electroadhesion based on multifunctional polymer actuators

Jun Shintake, Samuel Rosset, Bryan Schubert, Dario Floreano and Herbert Shea

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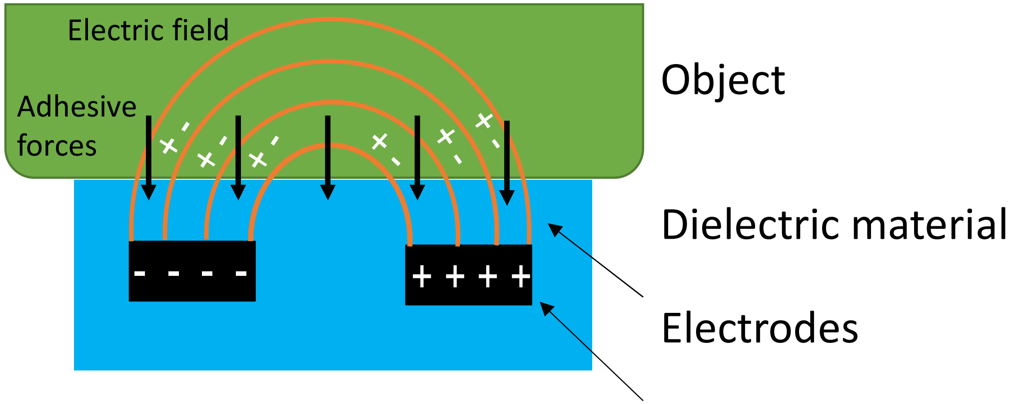
Example robots from EPFL LIS/LMTS

Electroadhesion

Adhesion due to electrostatic forces

Session 2 is about it, guys!

Attraction is between opposite charges on the surface



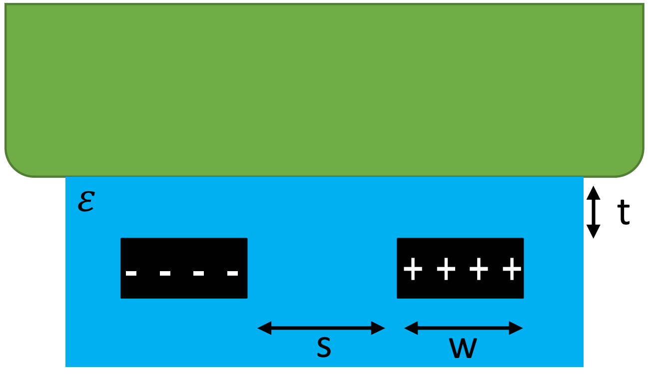
- Works on several materials, both conductors and insulators
- Works in different environments, including vacuum
- Works silently
- Required voltages in the range of kV

Force of electrostatic adhesion

$$U_e = f(E) \approx \frac{\varepsilon A V^2}{t}$$

U_e – electrostatic potential energy
E – electric field
ε – dielectric permittivity
V – voltage
t – thickness of dielectric
A – effective area of contact

w – width of the electrodes
s – space between electrodes



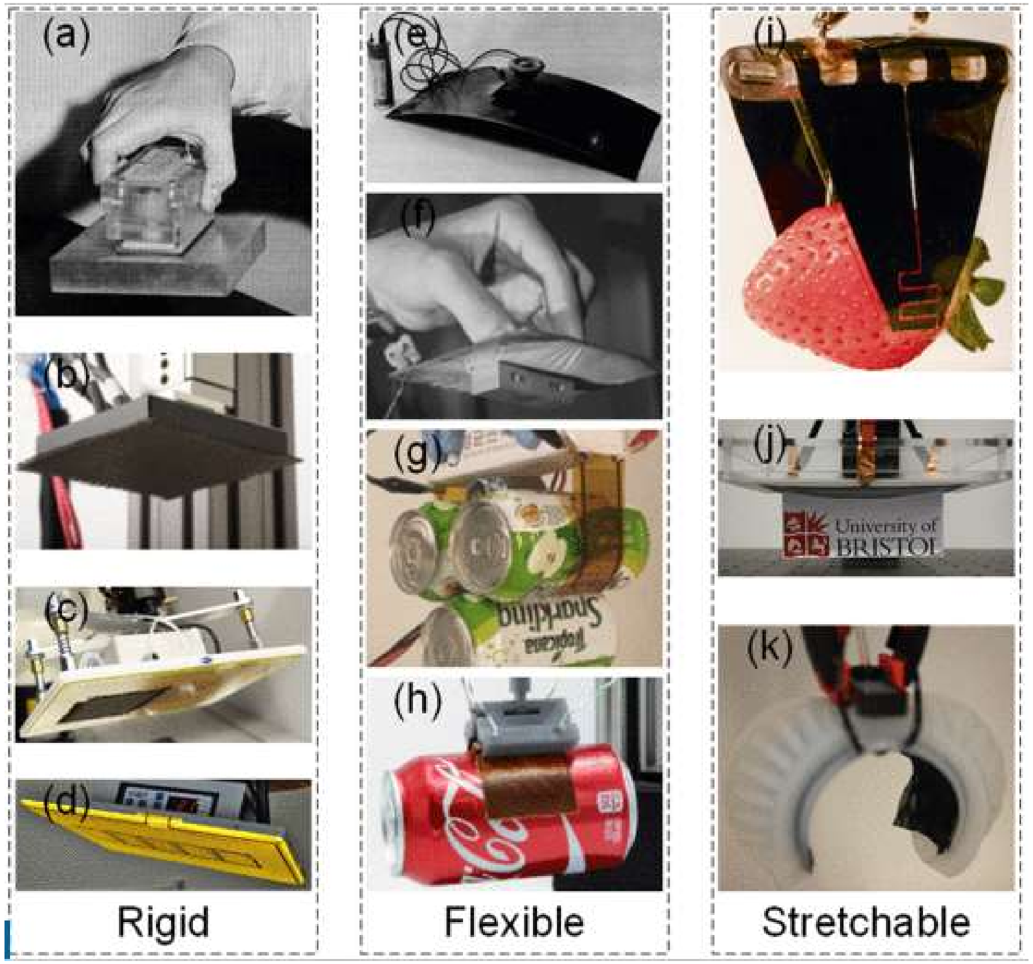
Voltage parameters	Applied voltage Voltage polarity Output current
Substrate parameters	Substrate thickness Substrate permittivity Substrate surface texture Electronegativity Crystallinity Molecular structure Substrate resistivity Molecular weight Molecular polarizability
Dielectric parameters	Dielectric resistivity Dielectric thickness Dielectric permittivity Dielectric strength Dielectric surface texture Molecular structure Molecular weight Molecular polarizability Crystallinity Electronegativity
Electrode parameters	Electrode pattern Space between electrodes Electrode width Electrode thickness Conductivity Electrode length
Environmental parameters	Environment temperature Environment humidity Environment pressure Air gap between pad and substrate Contaminates (such as dust)

Shear and normal forces are defined empirically

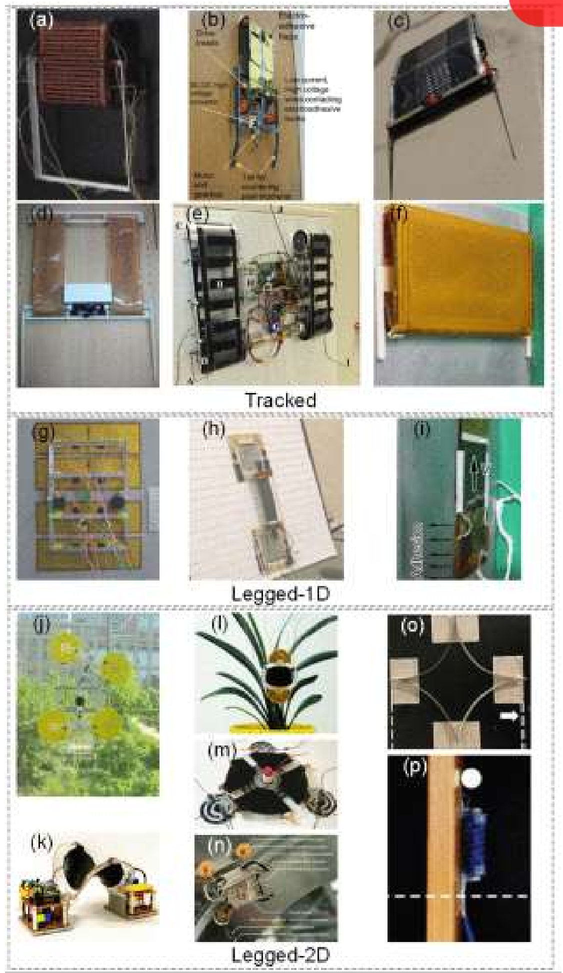
Shintake et al. Advanced Materials

Applications in robotics

Session 3 is about it, guys!



End effectors

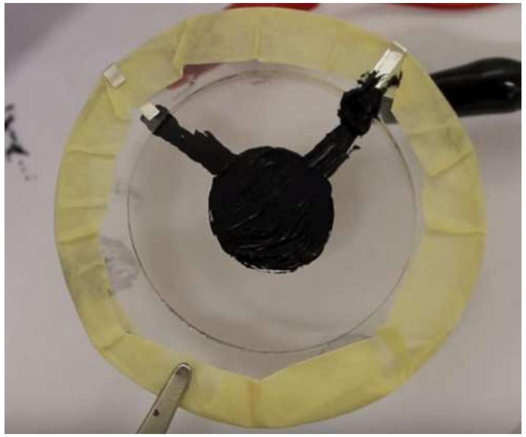


Crawling and climbing robots

Guo et al. Electroadhesion Technologies for Robotics: A Comprehensive Review

Components of TP Sessions

- Part 1: Circular DEA actuators, DEMES
- Part 2: EA patch
- Part 3: Make your own robot!




Robot example

Rules & Regulations

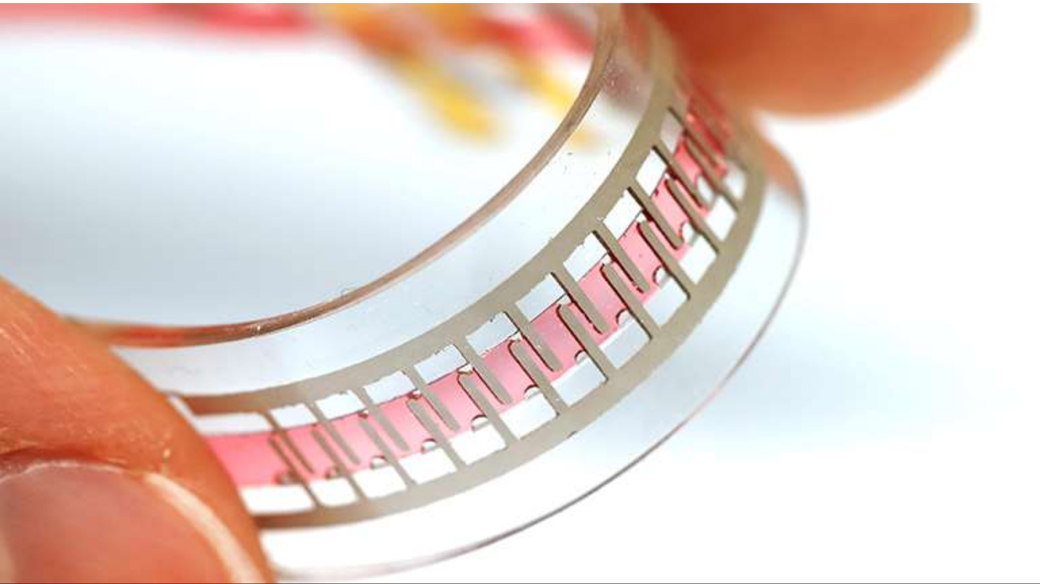
- **NO eating** or **drinking** in lab. Please leave room to do either.
- **Always** wear **gloves** when handling carbon grease and VHB films.
- Work on top of designated areas. Keep devices on paper towels to prevent spread of carbon grease.
- If you need to clean up a mess, **use paper towels and a solvent** if necessary. Remember gloves and goggles!
- Be **very careful** when working with **High Voltage**. Be sure to check that the power is off when connecting and disconnecting the wires. Also, before turning on the voltage, make sure that there are no possible shorts with wires, metal objects, other electronics, etc.
- Report size is **10 page max**.

Grading sheet

	Comments	Weight	Mark
DEA Results Discussion	+ Accomplished all the goals - There is a lack of data for thickness change, which leads to vague discussion on strain generation	20%	5
DEMES Results Discussion	+ Accomplished all the goals	20%	6
EA Results Discussion	+ Accomplished all the goals - The discussion part about the influence of applied voltage on the distance between electrode is unclear	20%	5.75
Robot Idea Modelling Design Implementation	+ Good modelling - The working robot was not achieved. Probably, the robot performance had to be checked more frequently during the practical session.	30%	4.75
Working Style Autonomy Communication with assistants Timeliness	+ Generally autonomous + Very prompt updates – no delays in meeting set commitments	10%	6

EPFL

Laboratory of Intelligent Systems



TP Robotique: Artificial Muscles (TP 10)

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