Bioinspired soft actuators using metal – polymer nanocomposites

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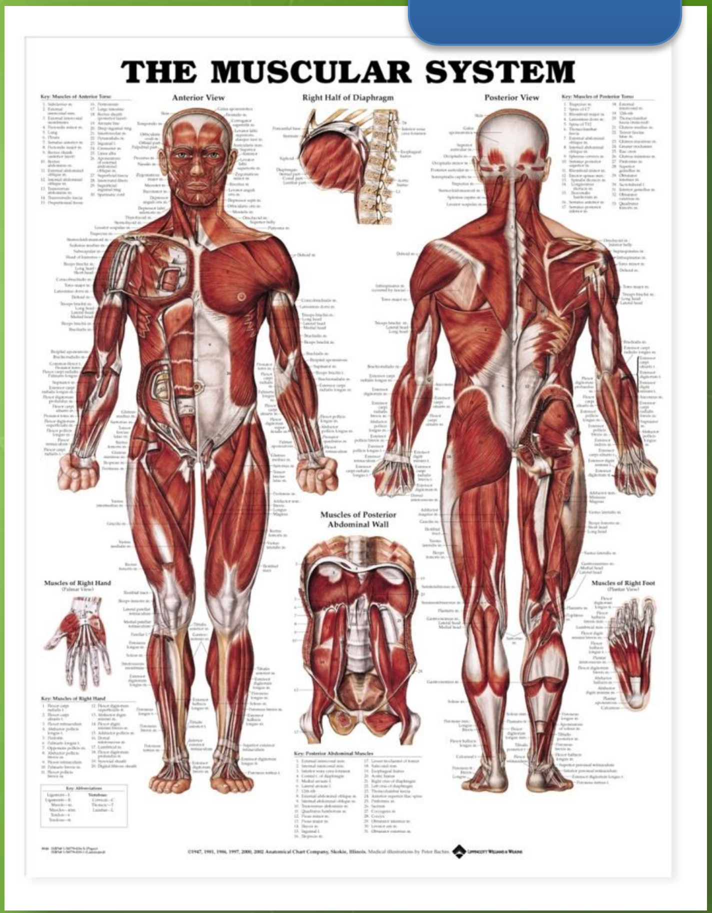
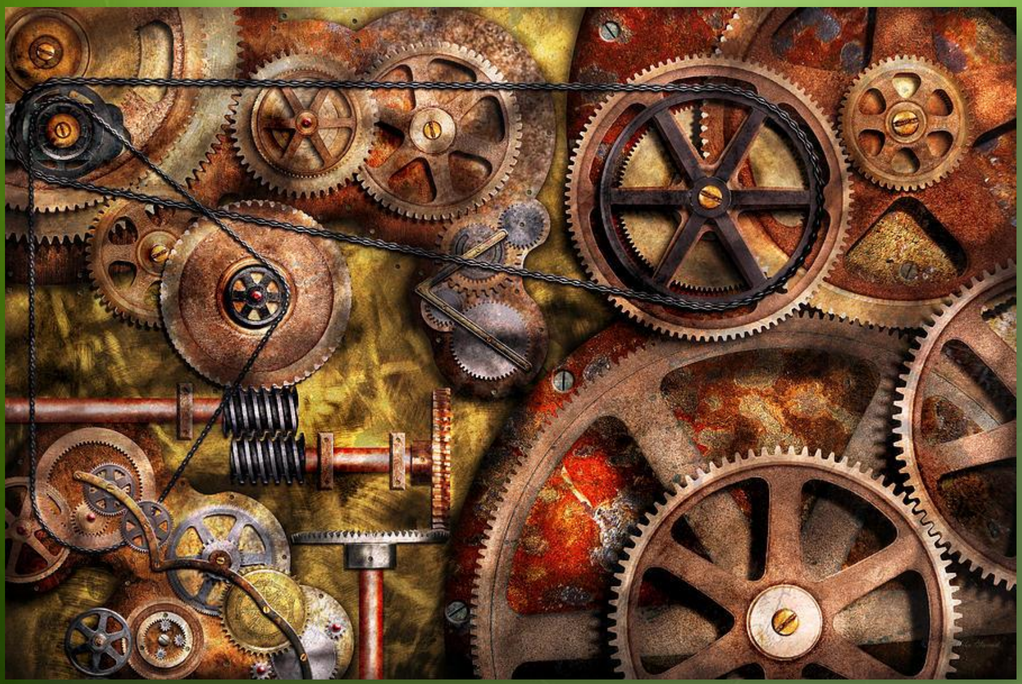
An actuator is a device for moving or manipulating objects

Classical Actuators

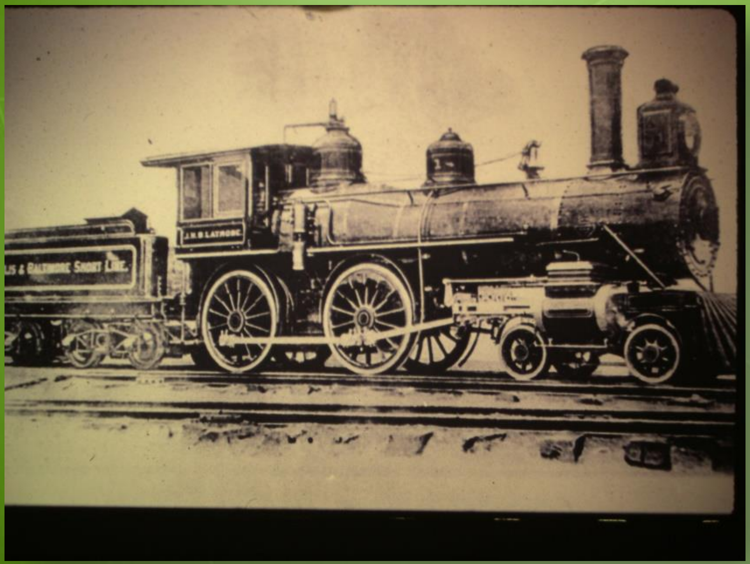
Biological Actuators

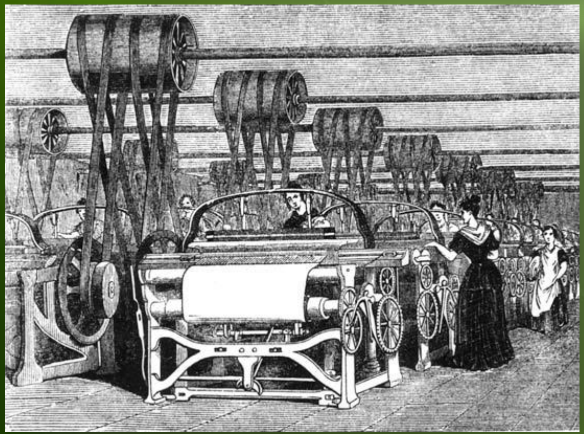


Classical actuators are based on as simple as old paradigm: the wheel

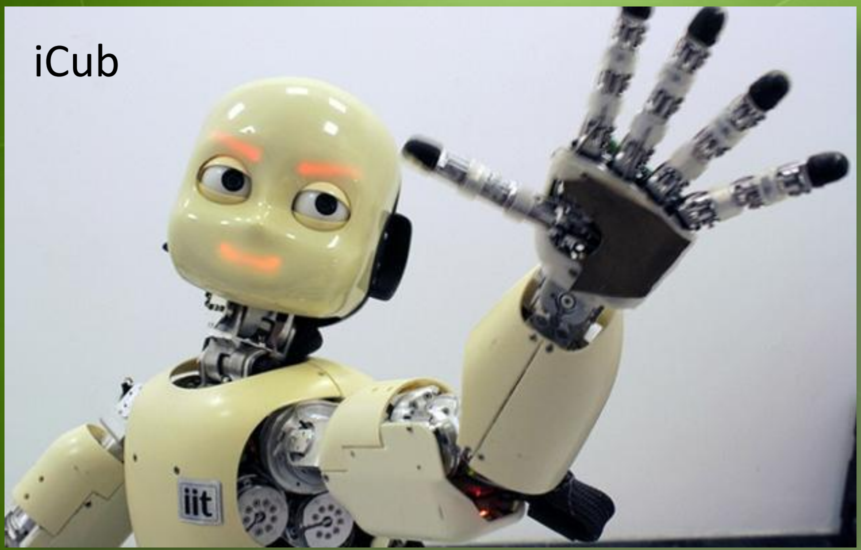


Early actuators

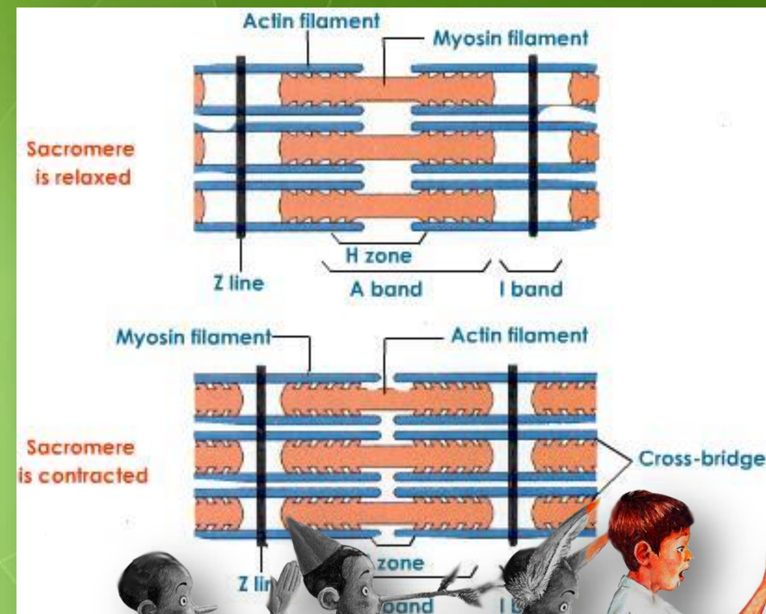




Nowadays actuators permit fine displacement and mimic few features of biological limbs. Devices made with these actuators are still too rigids, heavies, expensive and power-consuming. They work well only in the environments they were designed for.



Muscles are flexible actuators that contract and relax under electrical stimuli



Muscles flexibility allow living beings to interact with complex environment and to manipulate objects






An octopus can easily squeeze its body to pass through a one inch hole

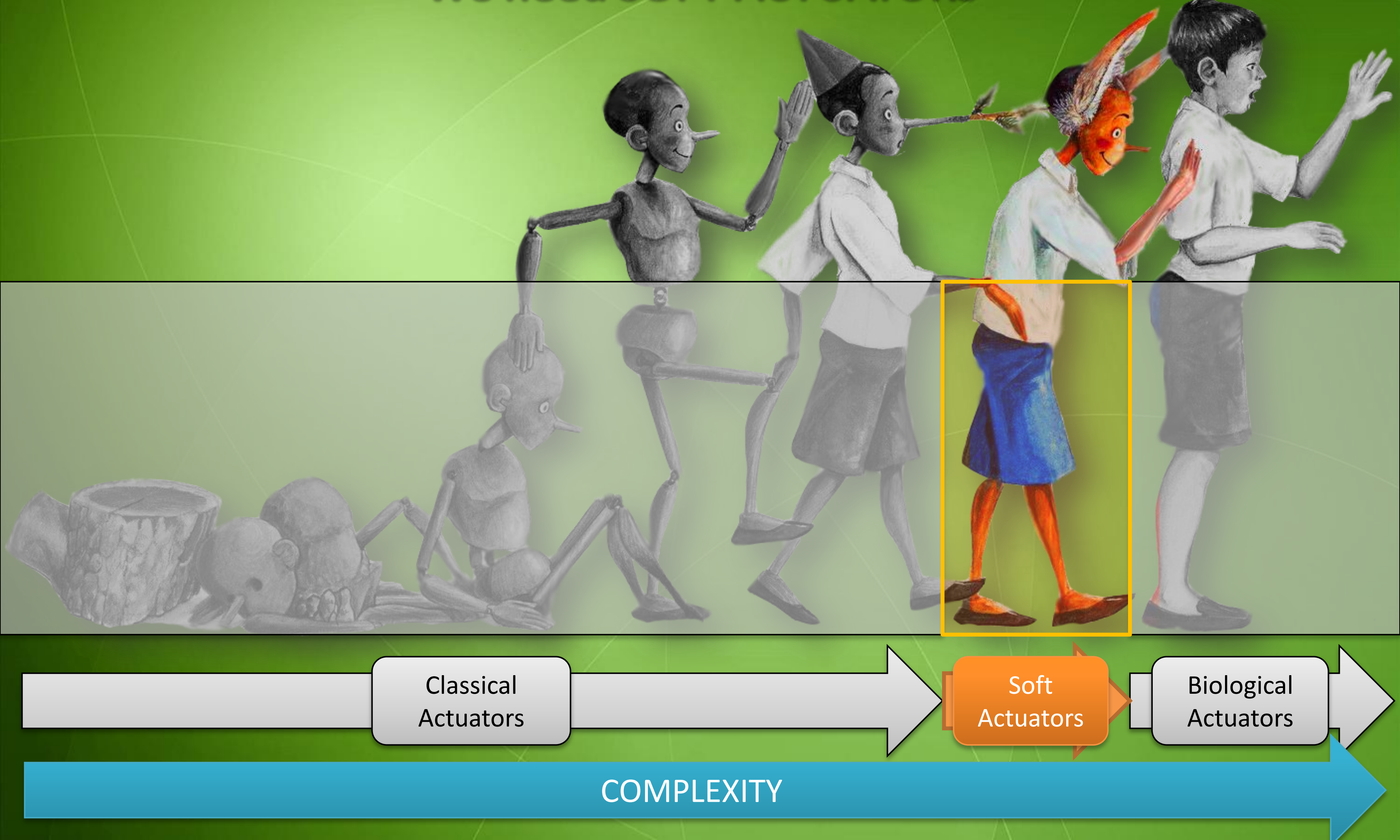
Classical actuators permit fine movements and they supply high power but are expensive. Robots based on them work only in simple and well known environments.
Biological actuators are flexible allowing the living being to adapt in complex environments. They are more like general-purpose actuators

		
Composition	Metallic and Plastic	Biological
Power Source	Electricity	Chemical (“water and sugar”)
Power Generated	Up to 10^5 W	Up to 10^2 W for few minutes
Efficiency	≈ 90%	14% to 77%[1]
Costs	10^3 -> 10^5 €	≈ 100 € (5 € as feed supply)
Degree of freedom	It depends by the number of actuators	Virtually Infinite [2]
Flexible	It depends by the number of actuators	YES
Stretchable	No	YES
Self-Healing	No	YES

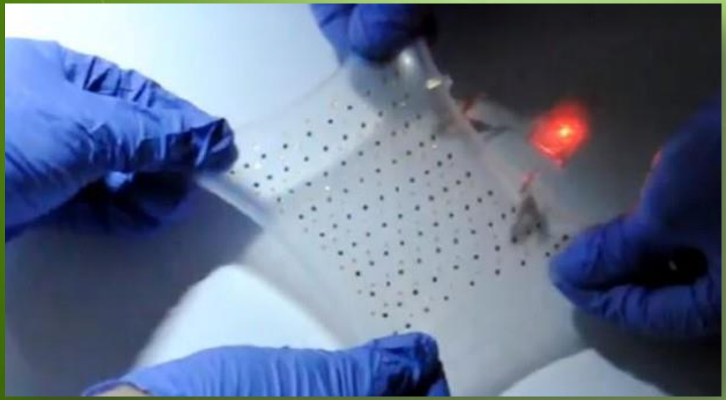
[1] N. P. Smith et al: **The efficiency of muscle contraction.** Progress in Biophysics & Molecular Biology 88 (2005) 1–58
[2] Gutfreund et al: **Organization of Octopus Arm Movements: A Model System for Studying the Control of Flexible Arms.** Journal of Neuroscience 1996, 16(22):7297–7307

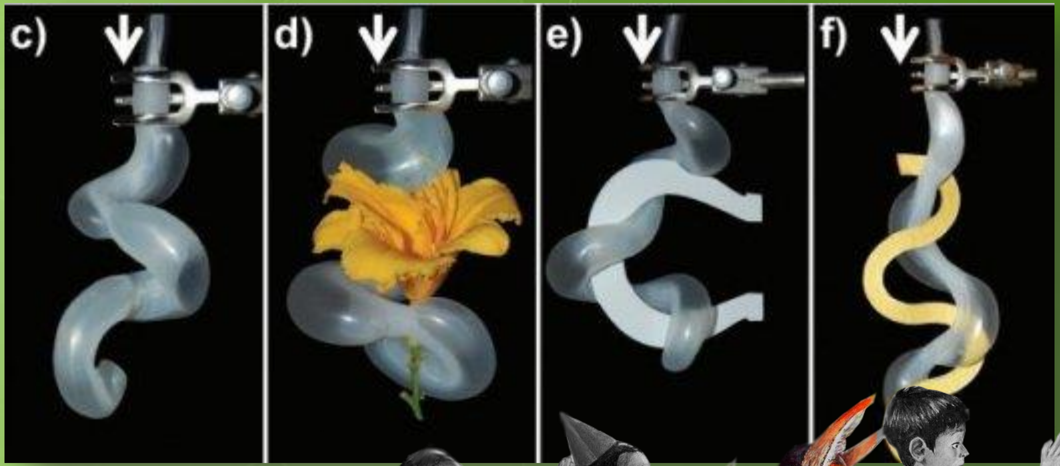
What is the next step to develop more flexible actuators?

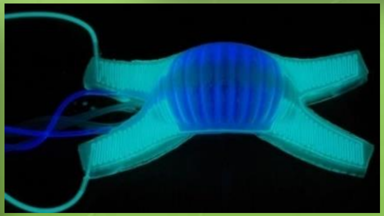
We must change paradigm to develop muscles-like actuators
Wheels are OLD!!!
We need SOFT ACTUATORS



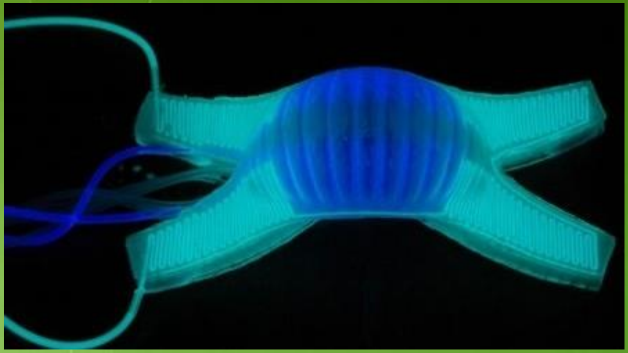
Soft Actuators are made by ELASTOMERIC POLYMERS (soft materials) and they have multiple degrees of freedom which simply enable them to do something that conventional actuators cannot do, like mimic biomotion





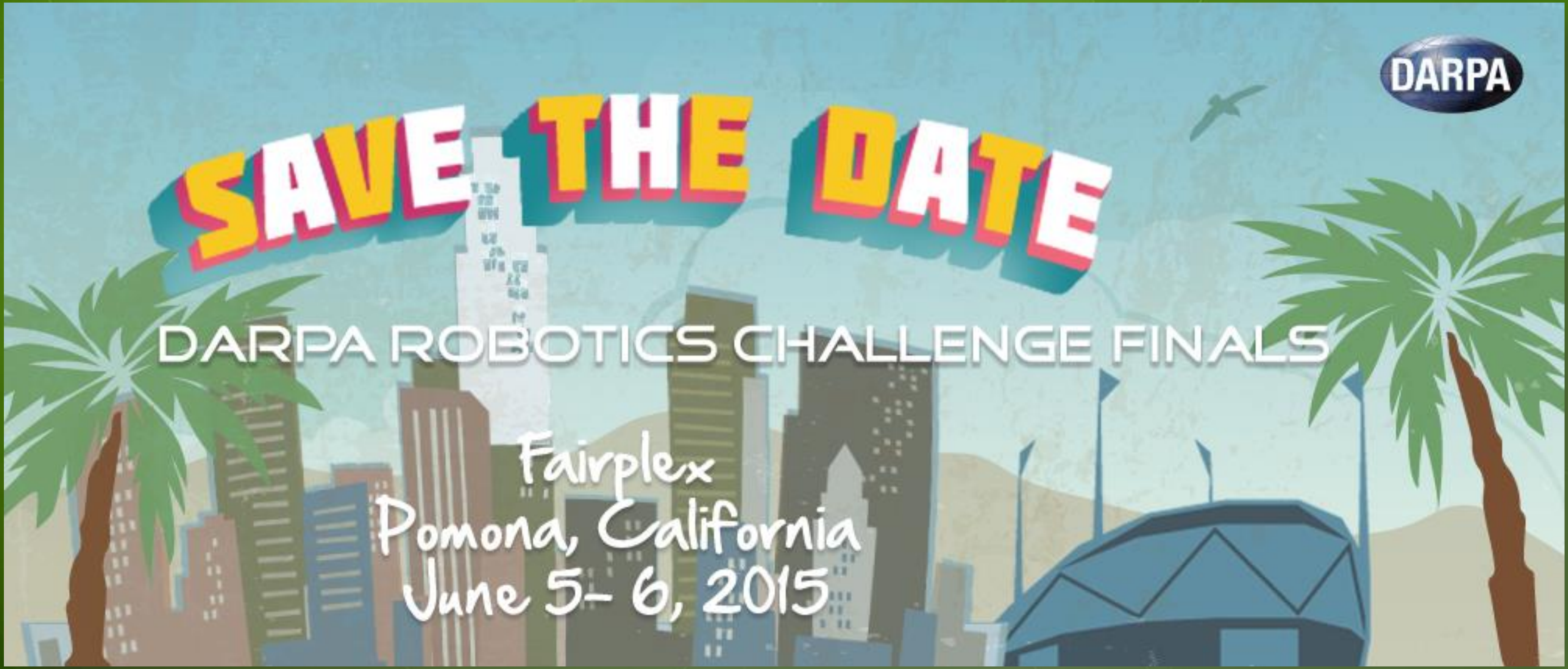


A soft robot can adapt its shape and perform tasks almost impossible for robot based on rigid actuators



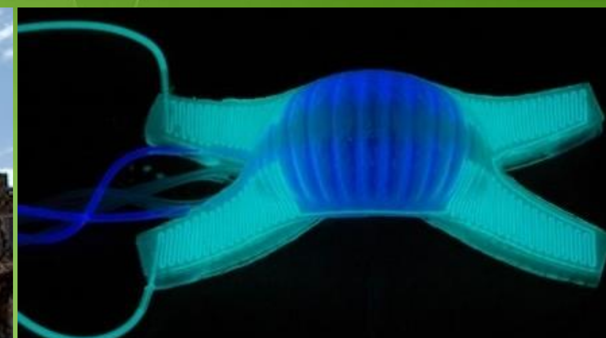
Why am I not made by polymers?

The Defense Advanced Research Project Agency (DARPA) announced in 2013 a competition to develop robots capable of assisting human in responding to disasters, with a 2 M$ price



Google acquired the highest-scoring team

A robot made by classical actuators is rigid and unsuitable for walking through the landscape of this (tragic) scenario.
A soft robot is way more suitable



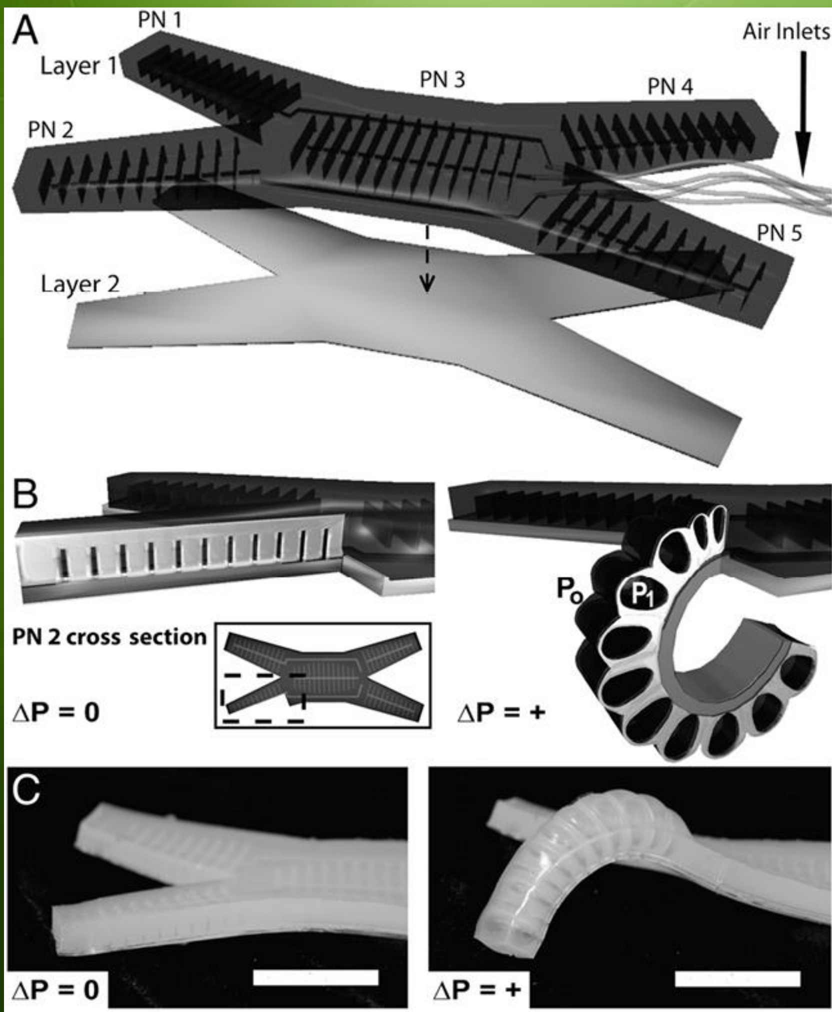
- GPS
- Camera
- Radio transceiver

HOW CAN WE MAKE SOFT MATERIALS ACT AS MUSCLES-LIKE ACTUATORS?

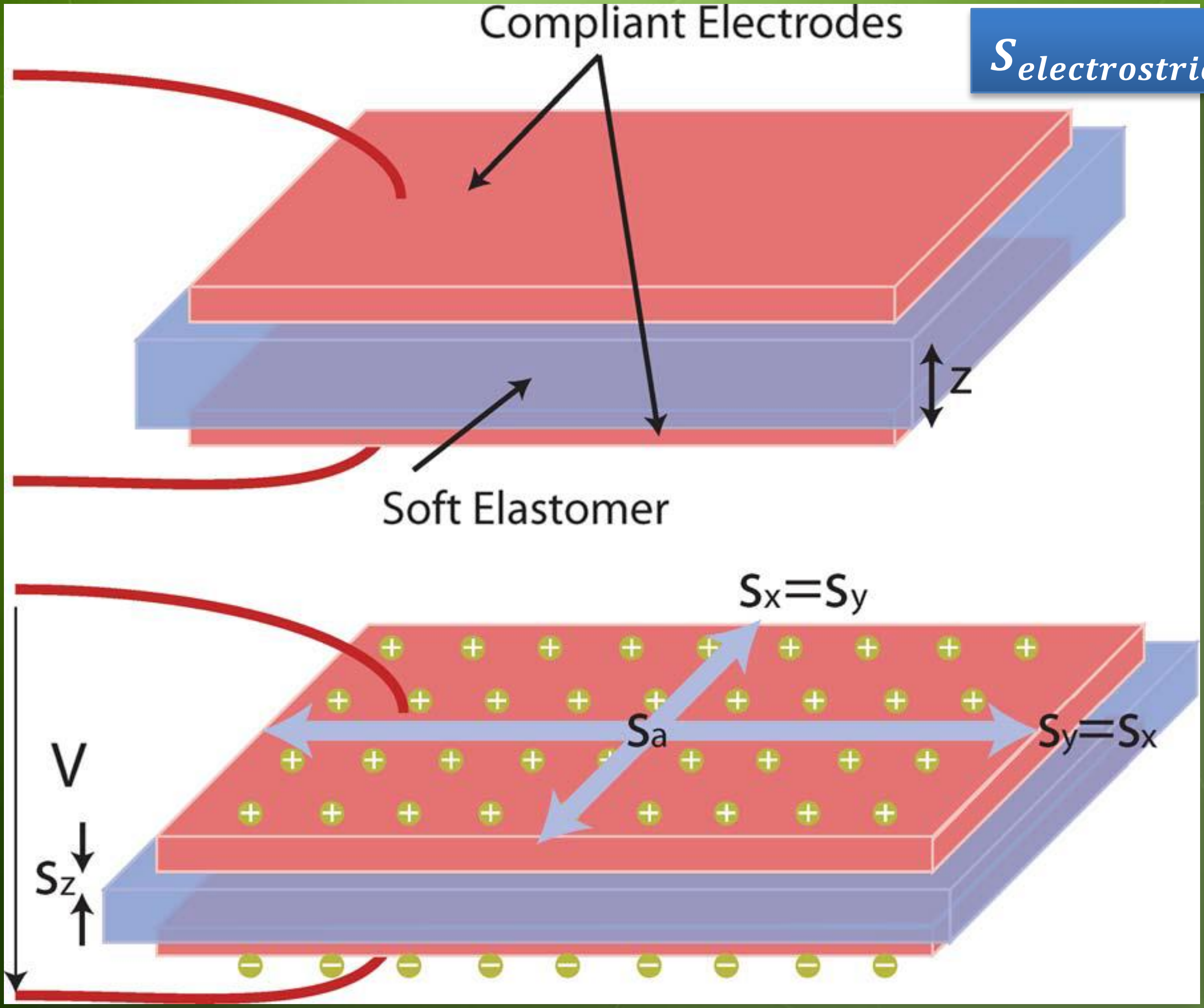
No magic involved. I guarantee!!

The first generation soft actuators are made to move with the aim of liquids or gasses. Thus this actuators class needs a compressor.

They CANNOT be used stand alone



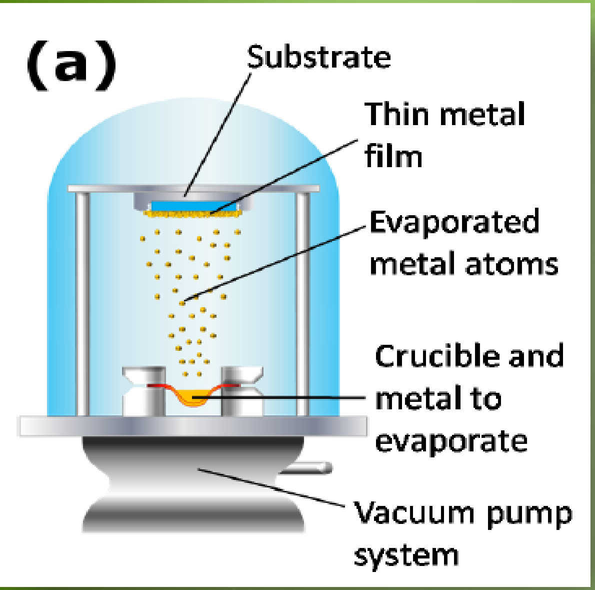
Second generation soft actuators are electrically driven. It is possible to stretch a polymer exploiting Electrostriction.

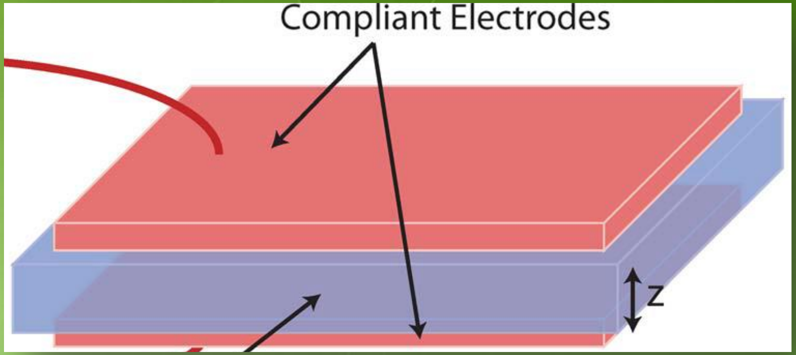


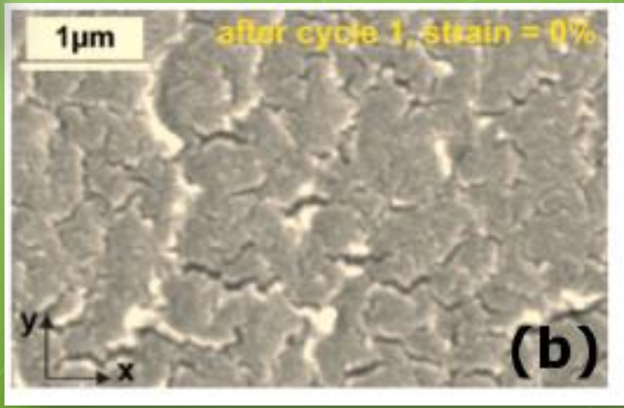
$$S_{electrostriction} = -Q\varepsilon_0^2(\varepsilon_r - 1)^2E^2 \quad (2)$$

- $S_{electrostriction}$ is the strain along the thickness direction of the film due to electrostriction
- Q is electrostrictive coefficient ,
- ε_0 is the permittivity of free space,
- ε_r is the relative permittivity
- **E** is the applied electric field.

Common electrodes fabrication techniques produce electrodes unable to stand the polymer deformation



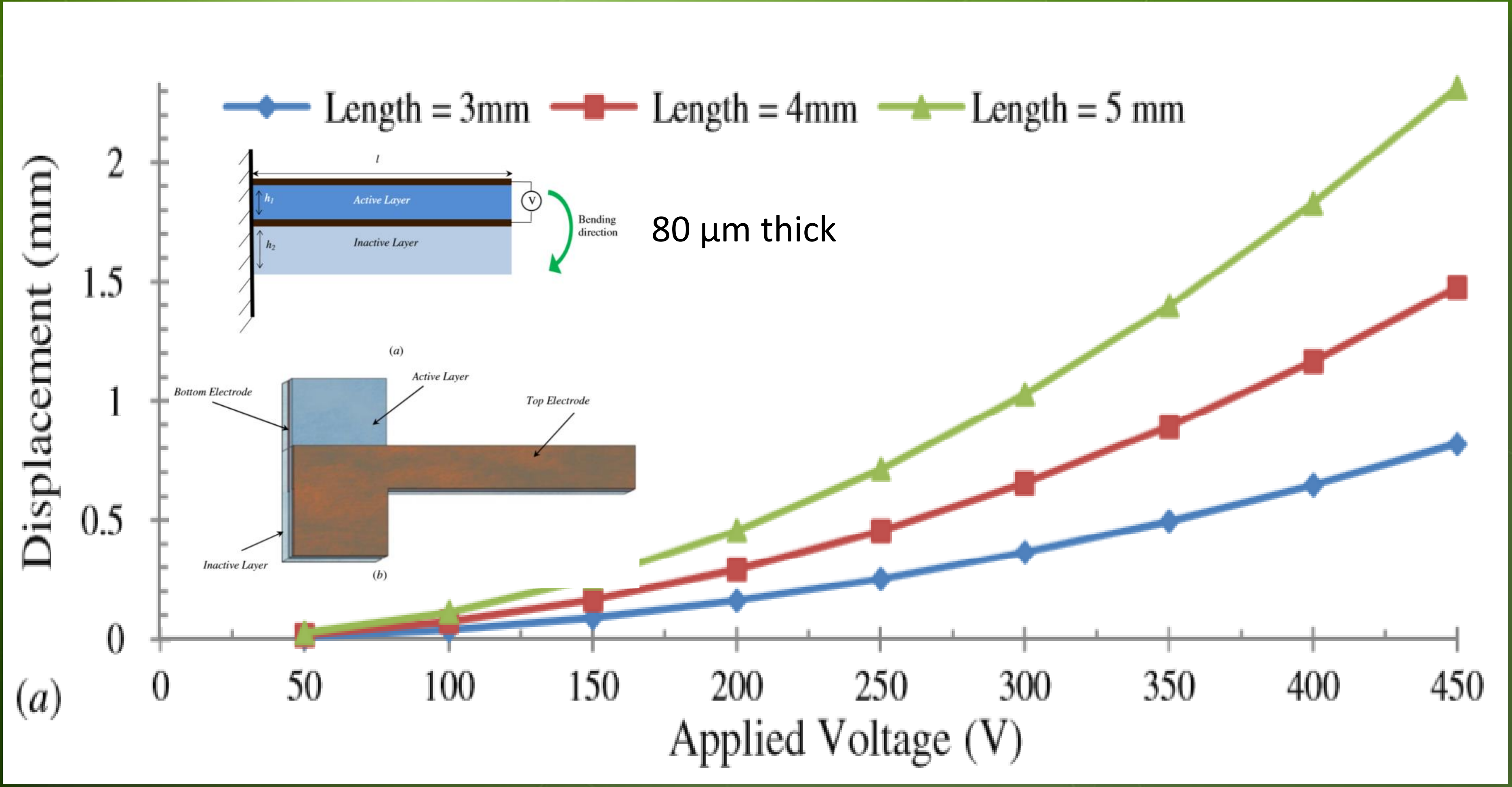




It is also reported an increase in polymer stiffness [1]

[1] M. Niklaus, S. Rosset, P. Dubois, M. Dadras and H. R. Shea, **Modification of conductivity and of mechanical properties of electroactive polymer (EAP) thin films by titanium ion implantation,** *MRS Fall Meeting*, **2007**

Typical performances of soft actuators

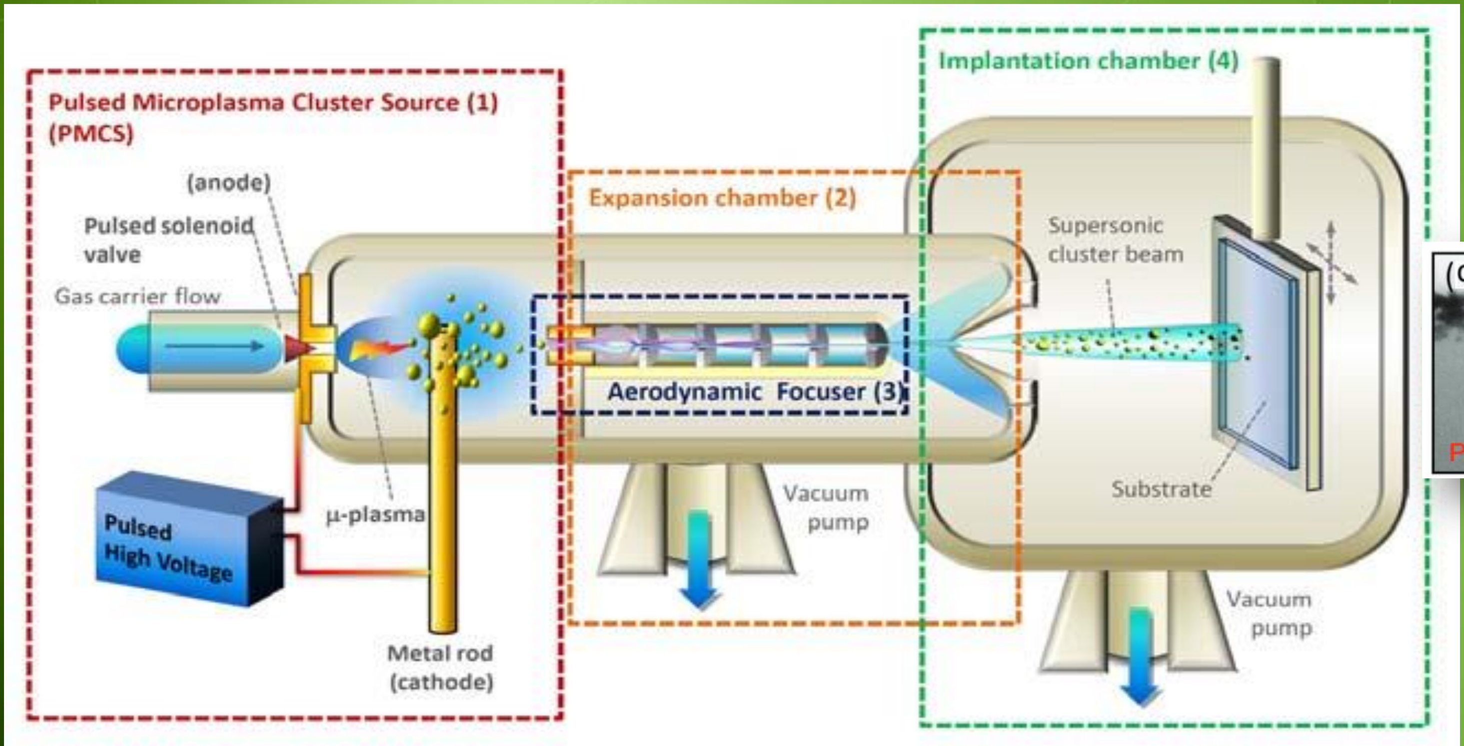


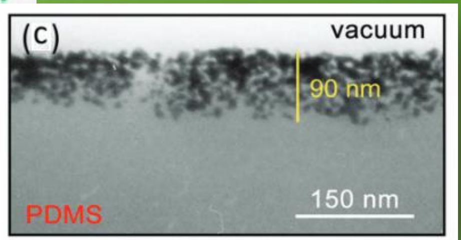
80 µm thick

T. Maleki et al. **A batch-fabricated laser-micromachined PDMS actuator with stamped carbon grease,** *J. Micromech. Microeng. 21 (2011)*

My PhD Project

Supersonic Cluster Beam Implantation (SCBI)[1,2] allows the production of metal-polymer nanocomposites[3] having the mechanical and electrical properties required for soft actuation.



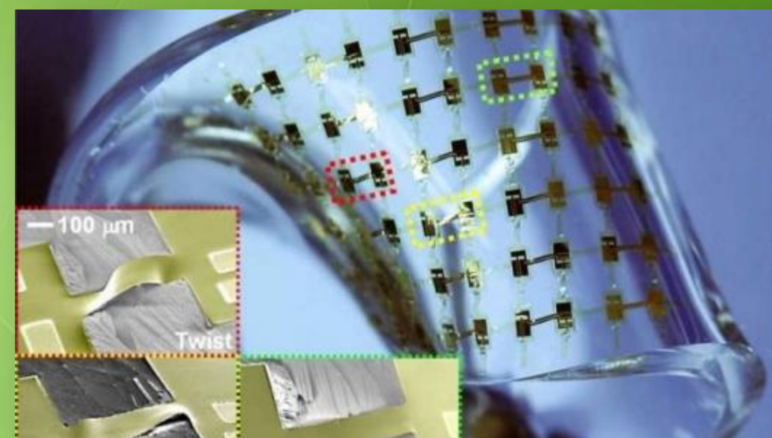


[1] *G. Corbelli.* **PhD Thesis, Università degli Studi di Milano**
[2] P. Milani et al. **J. Phys. D: Appl. Phys. 39, 2006**
[3] *G. Corbelli et al.* **Advanced Material, 23, 2011**

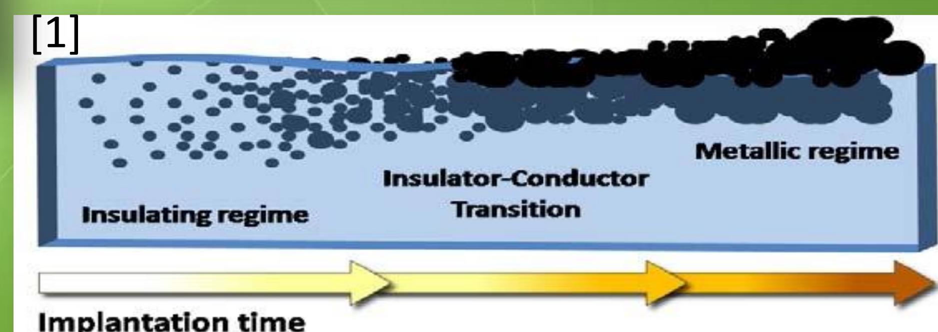
<u>Polydimetilsiloxane</u> (PDMS) is a low cost elastomeric polymer with excellent mechanical properties.

<u>Gold</u> is a good electric conductor

With SCBI it is possible to have a fine control also on the electrical properties

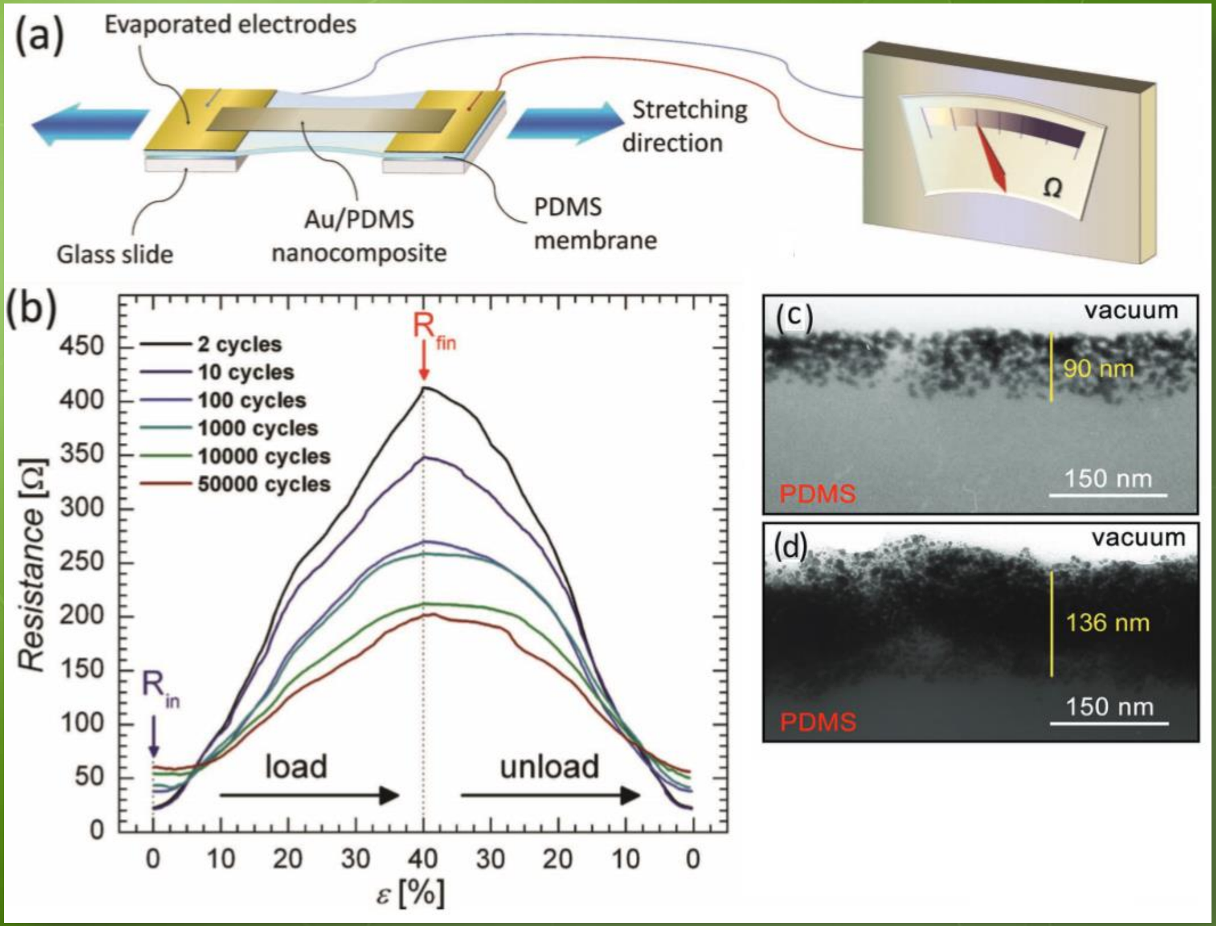


[1]



[1] *G. Corbelli.* **PhD Thesis, Università degli Studi di Milano**

It has already proven that SCBI successfully allow the fabrication of metal electrodes that can stand the huge stretching of PDMS [1,2,3]



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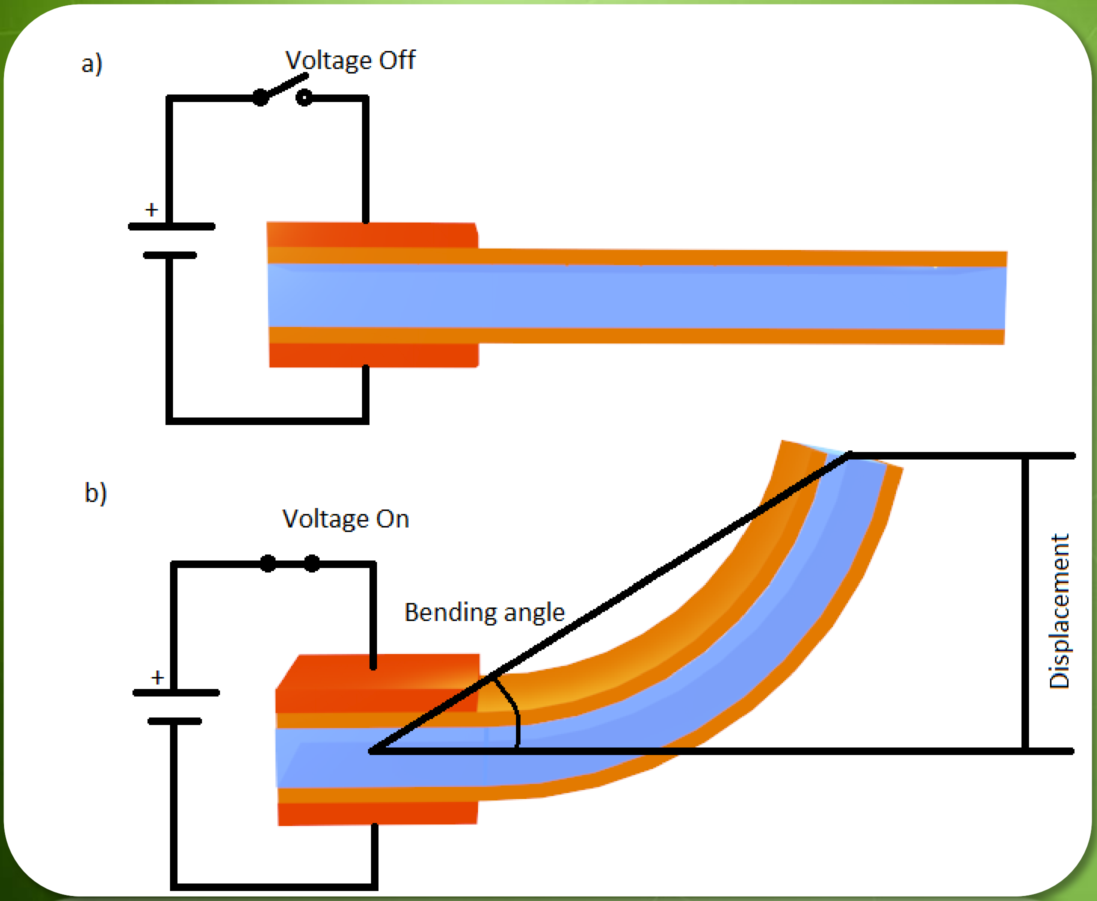
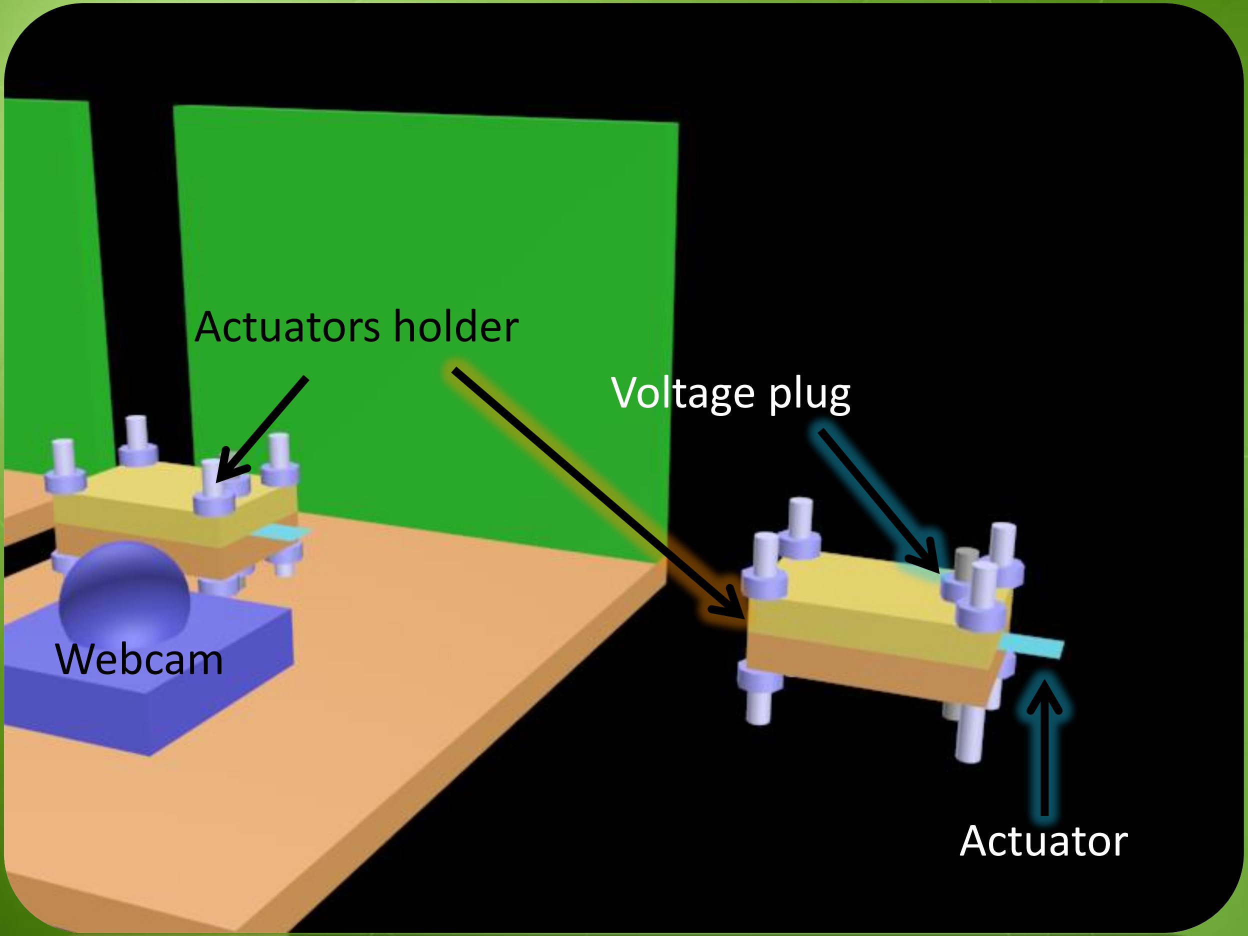
Characterizing an actuators means to perform electrical and mechanical tests

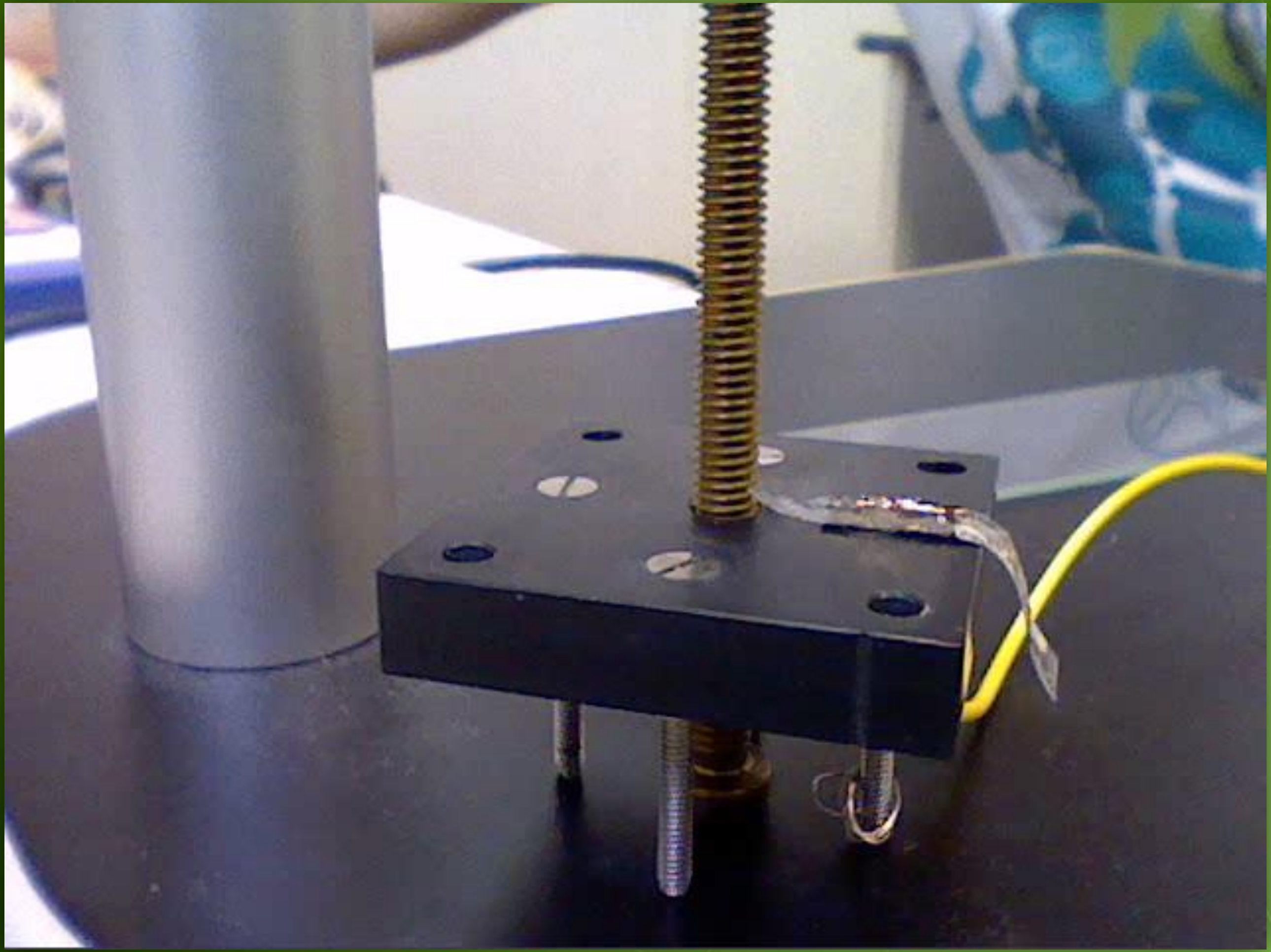


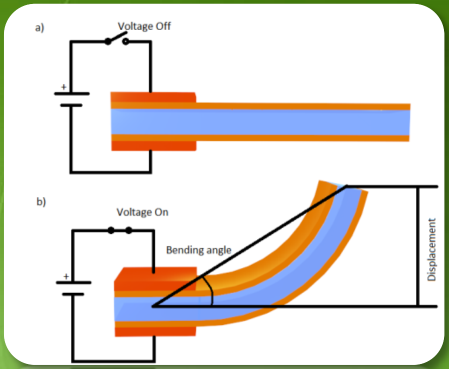
- Characterization of the electrical properties:
  - Resistivity as a function of the amount of nanoparticles implanted
  - During the stretching phase
- Characterization of the mechanical properties:
  - Young Modulus as a function of the amount of nanoparticles implanted
  - Force measures

Concept for a setup for electrical and mechanical tests



A soft actuator based on metal-polymer nanocomposite





- Length: 30 mm
- Width: 10 mm
- Thick: 0.1 mm
- Voltage: 1 kV
- Freq: 5 Hz
- Signal Shape: Squared Wave

Conclusions

- Classical actuators have excellent performance and permit fine movements, but are expensive, rigid and permits the design of mono-or-few-purpose devices
- Biological actuators have mediocre performance but allow the design of general-purpose devices. Living being can easily adapt their mechanical behaviors to interact with a complex environments and move in irregular landscapes
- Soft actuators can mimic biological actuators
- The most promising materials for soft actuators are Elastomeric Polymers but it is hard to produce electrodes that can sustain the polymer deformation
- Supersonic Cluster Beam Implantation is an effective technique I can exploit to fabricate stretchable electrodes for soft actuators

Thanks for the attention
Any question?