Electrically Driven Mechanochemical Artificial Muscle:

for smooth 3-Dimensional Movement in Robotics and Prosthetics

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FLC Northeast Meeting

September, 26, 2007

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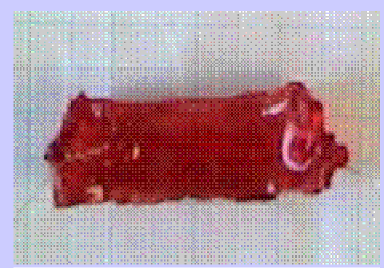
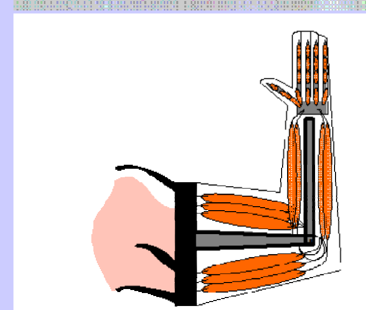
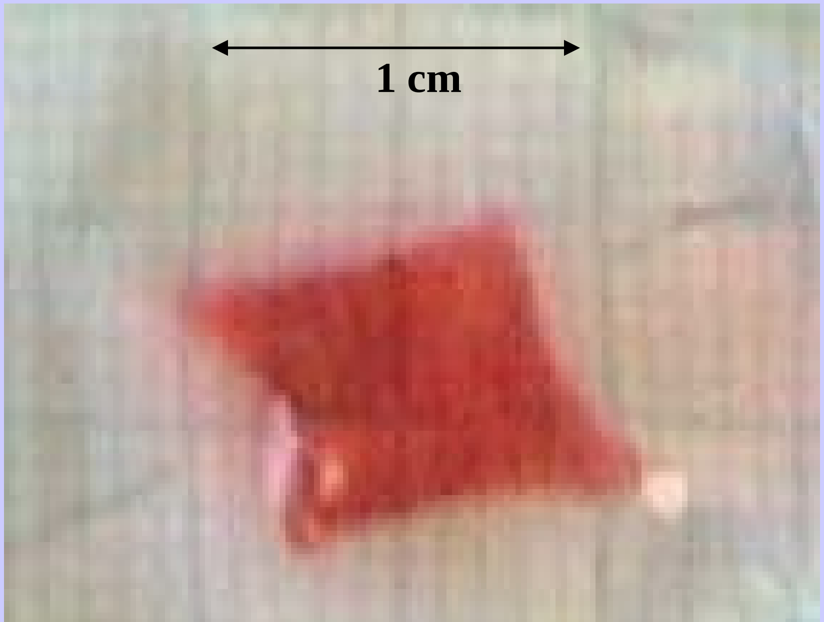
Ras Labs ~ Chemistry, Biology, Biochemistry, & Engineering

RASLABS





Electroresponsive materials designed by Ras Labs



A. Before electric impulse

B. During electric impulse

Note: Red dye added to improve visualization.

Embedded streams from video here (shows motion).

Factors in Producing Electroresponsive Material Actuator

- **Actuators should have good**
  - **Electroresponsiveness**
  - **Strength**
  - **Toughness**
  - **Durability**

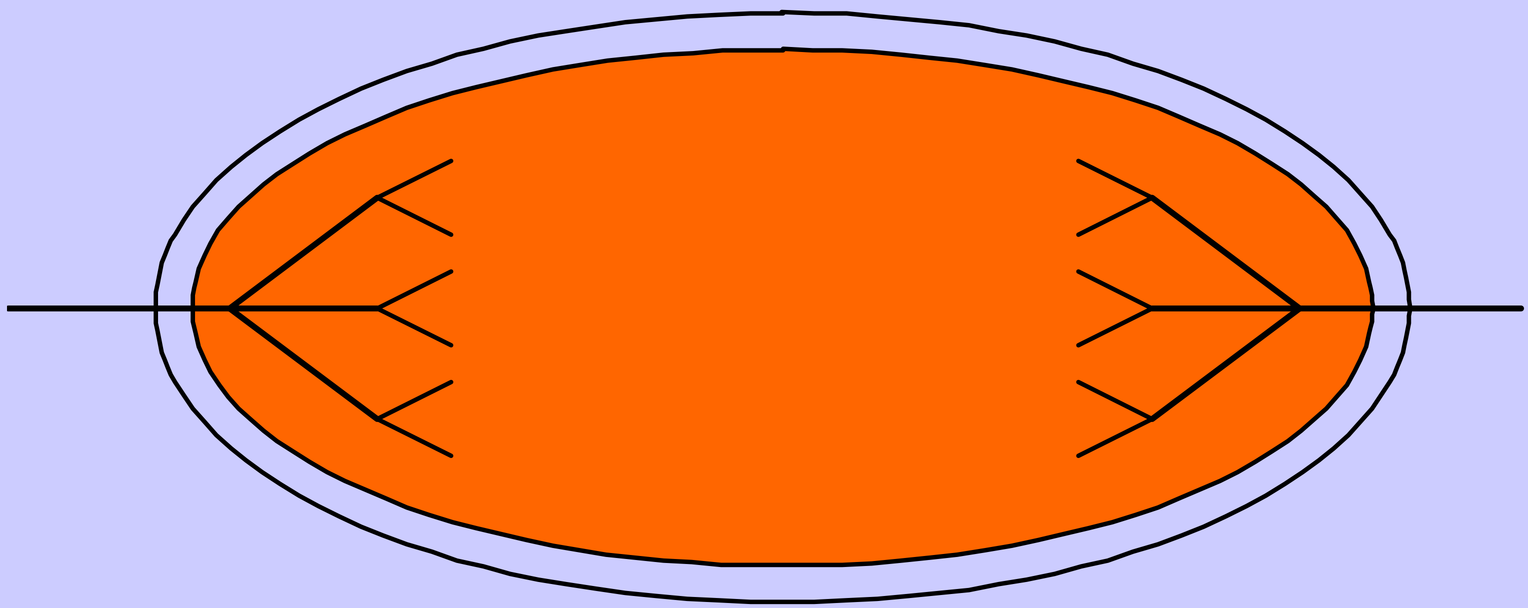
- **Materials**
  - Choice of ionomers, amount of cross-linking, & other technologies
  - Counter ions / electrolytes / type of solvation
- **Coatings**
  - Elastomeric coating(s) allows actuator to be independent
- **Delivery of electric stimulus**
  - Noncorrosive
  - External electrodes or
  - Internal / embedded electrodes

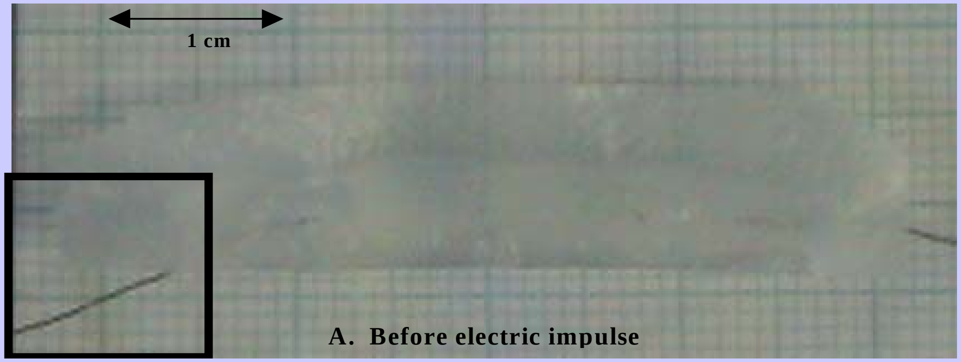
Table Comparing Tensile Strengths

Materials	Tensile Strength (MPa)
Poly(acrylamide) gels (Investigated by T. Tanaka/ MIT)	**0.03**
Poly(vinyl alcohol)-poly(acrylic acid) gels (Investigated by T. Shiga/ Toyota Central R & D Laboratories, Inc.)	**0.23**
Poly(hydroxyethylmethacrylic acid)-poly(methacrylic acid) cross-linked network gels (Investigated by L. Rasmussen/Ras Labs, L.L.C.)†	**0.33**

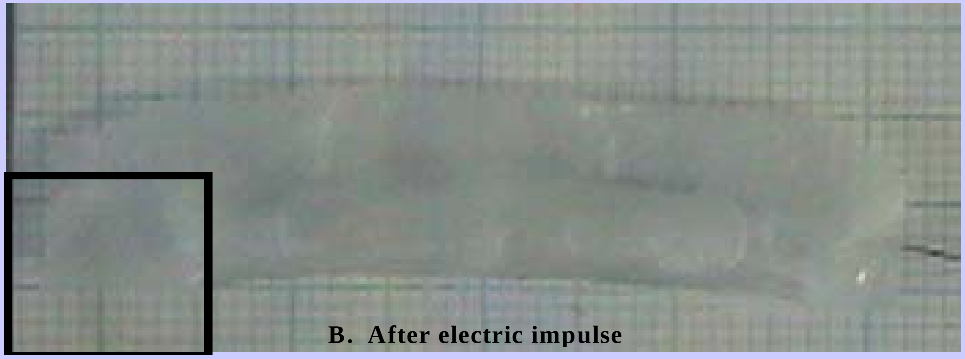
† 0.28 to 0.76 MPa range for these types of materials

Depiction of encapsulated electroresponsive smart materials with embedded electrodes



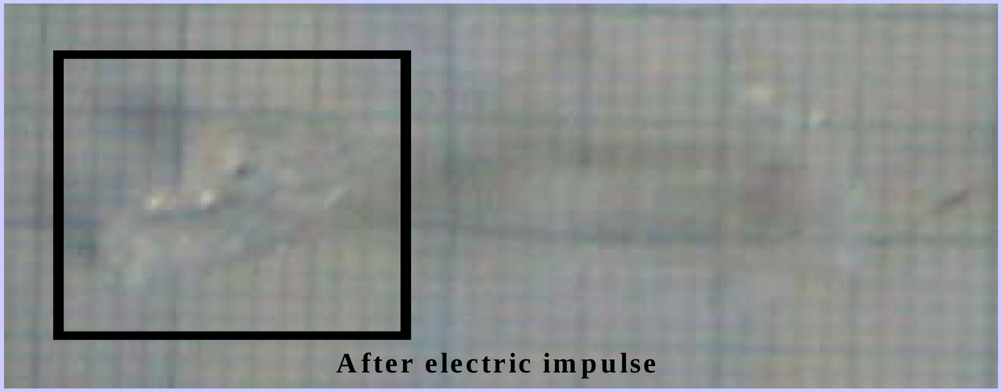


A. Before electric impulse



B. After electric impulse

Damage to electroresponsive material in boxed area.



After electric impulse

Ras Labs, LLC and Princeton University Plasma Physics Laboratory formed CRADA (2007)

Combines

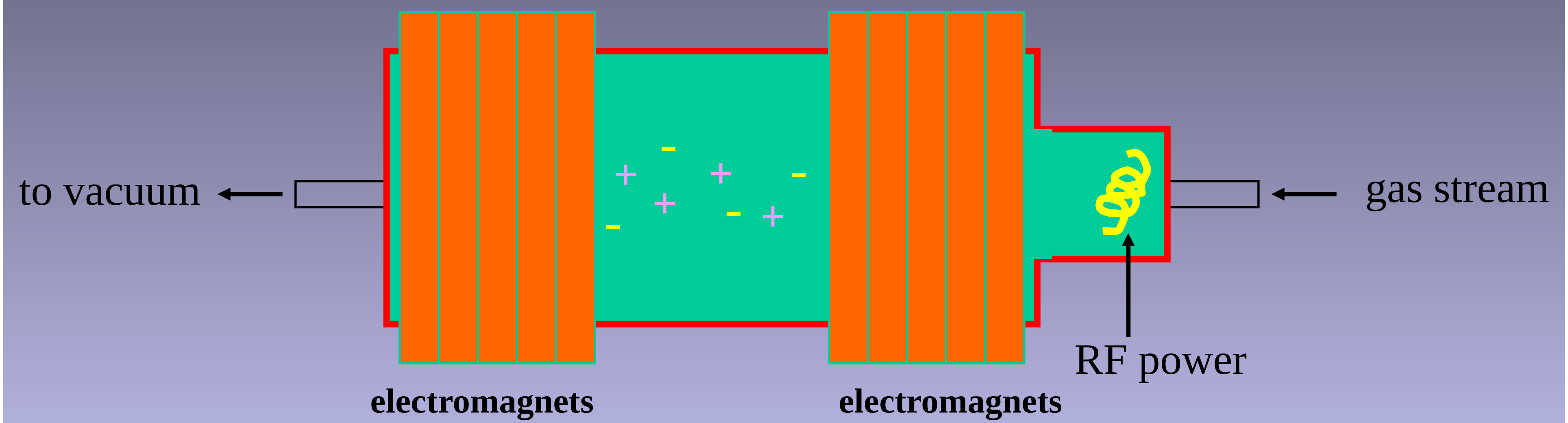
synthetic expertise of Ras Labs

plasma expertise of PPPL

Superior Electroresponsive Actuators

Plasma is partially or wholly ionized gas with about an equal number of positively and negatively charged particles, and sometimes is referred to as the "fourth state of matter." While plasma is neither gas nor liquid, the properties of plasma are similar to those of both gases and liquids.

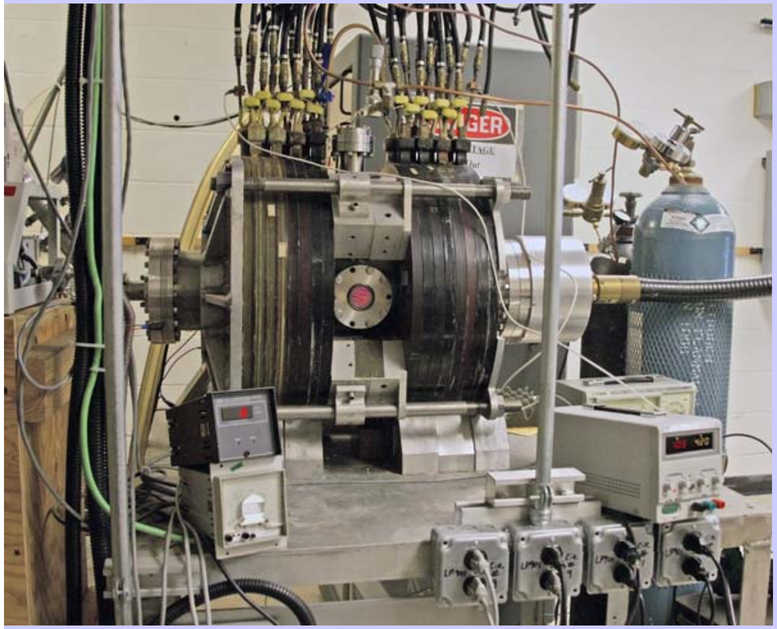
Plasma chamber

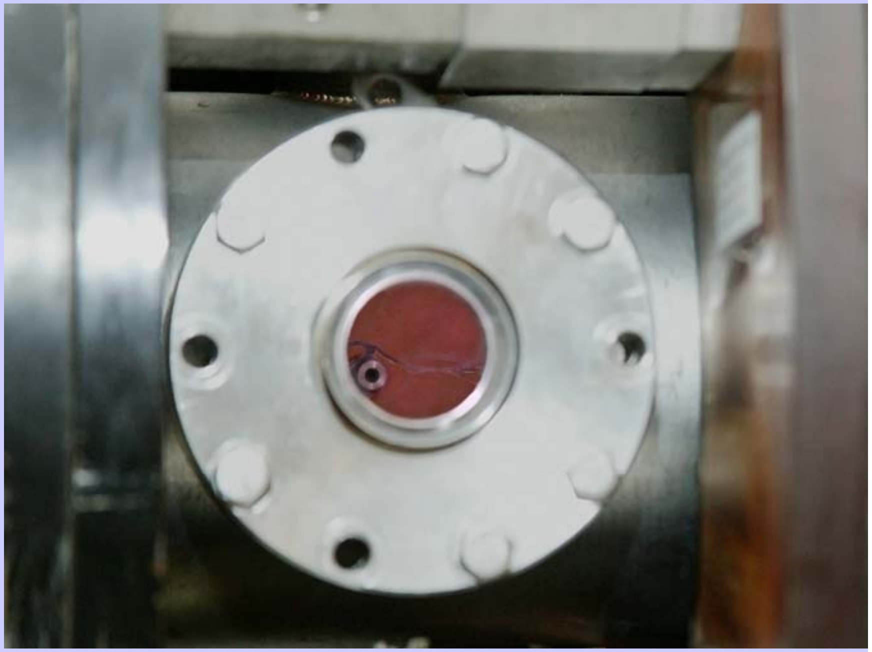


Sterilization and improving the adhesion between two surfaces are a common applications. Good adhesion requires strong interfacial forces by chemical compatibility and/or chemical bonding. Plasma surface treatment can create chemically active functional groups such as amine, carbonyl, hydroxyl and carboxyl groups, which can greatly improve interfacial adhesion. Plasma is used to improve bonding on substrates such as glass, polymers, ceramics, and metals.

Plasma treatment can also enhance performance. Surface crosslinking is often used to enhance the performance of polymers, particularly in terms of strength and toughness. Plasma treatment can create a higher crosslinking density within the material to depths of a few thousand angstroms. The resulting increase in hardness and chemical resistance can substantially enhance performance.

PPPL Plasma Surface Modification Laboratory





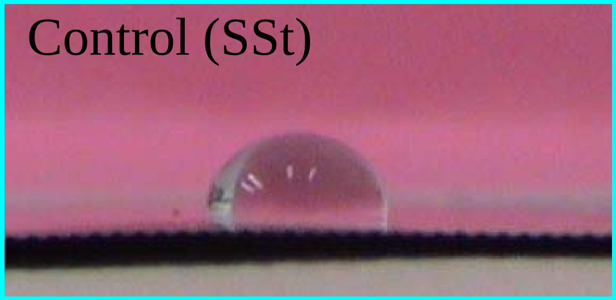
Results: Contact Angle Water Drop Test

Stainless Steel

Sample	**Contact Angle (º)**
Control	111
He	63
H	84
N	136
SA	140

Titanium

Sample	**Contact Angle (º)**
Control	45
He	125
N	140
SA	157



Results: Modified T-peel Test

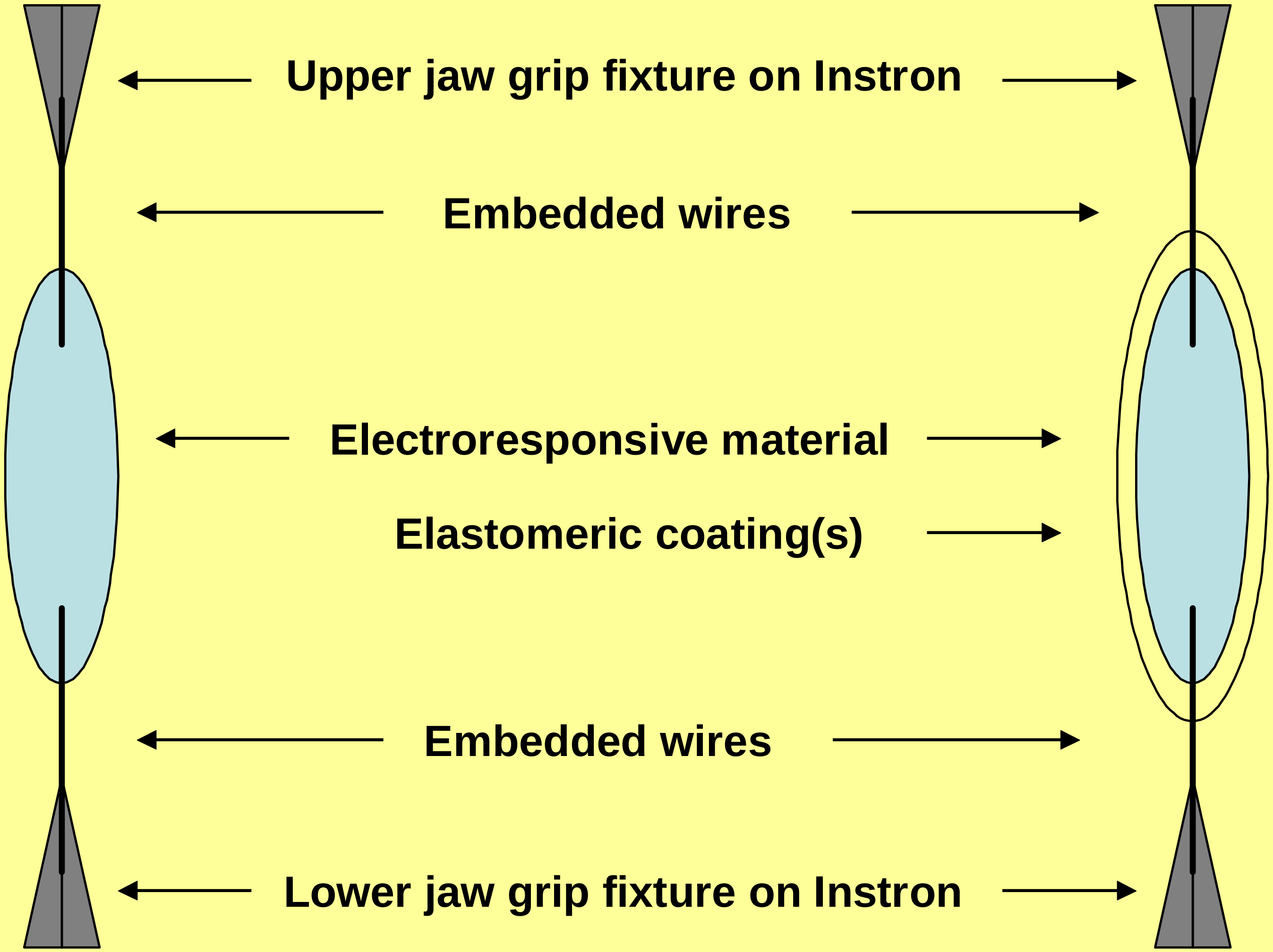
Stainless Steel

Sample	**Average Peak Force (N)**
Control	2.736
H	5.326
He	5.098
N	3.350
SA	4.430

Titanium

Sample	**Average Peak Force (N)**
Control	1.810
He	3.374
N	**9.486**
SA	4.050

Proposed Testing of Actuator Configuration



Conclusions and Goals

- Research and development to significantly improve the polymer-electrode interface is currently being performed, with good results. **Goal:** For both the electroresponsive smart material and the embedded electrodes to move as a unit, analogous to our muscles and nerves moving together. The embedded electrode serves a dual purpose: conducting the electric stimulus, analogous to a nerve; and connecting the electroresponsive material to jointed levers, analogous to a tendon connecting muscle to bone.
- Cross-linked ion-containing polymer networks have produced electroresponsive smart materials with good strength, durability, and electroresponsiveness.
- Thin elastomeric coatings or coverings, which also serve as a moisture barrier, act as "skin," preventing evaporation and leakage of the electrolyte solution(s) and allowing these actuators to be fully operational anywhere.

Acknowledgements

Lew Meixler
Princeton University Plasma Physics Laboratory

Don Harper and Kimun Park
TRI Princeton

Department of Energy