Research Topics at CIMS as of Jan. 22, 2015

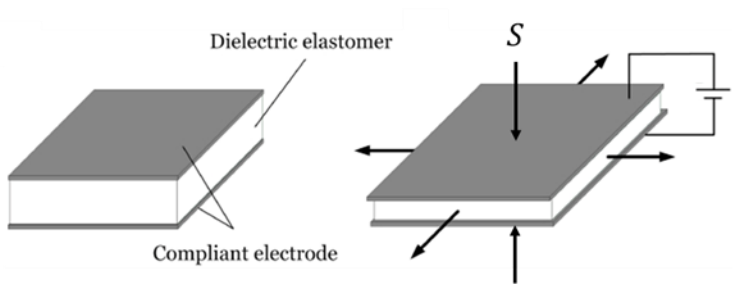
1. Soft Matter based Robotic hand design which is composed of active polymer and sensing polymer

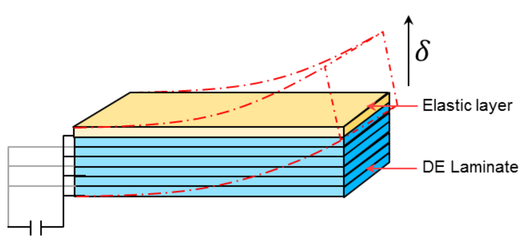
Develop electroactive polymer (EAP) actuators for use in a robotic hand

Requires both actuation and sensing

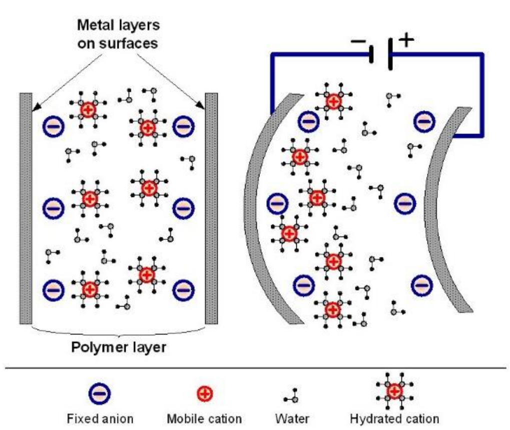
EAP actuators being researched:

Dielectric elastomer actuators (DEA)

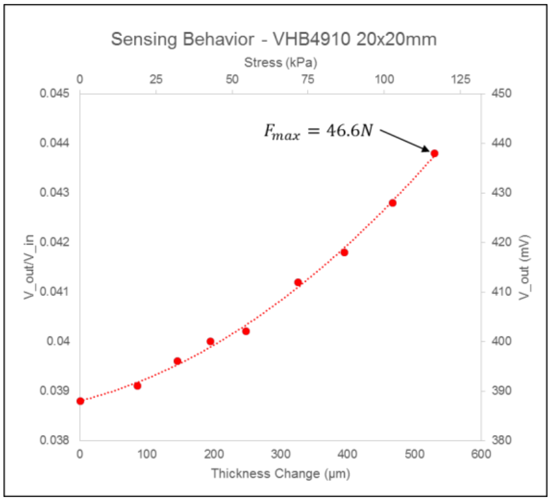




Flemion actuators (IPMC)



DE sensor, Applied pressure(P) induces voltage(V) , with non-linear relation between P and V as shown below.



2. **Nano-actuators based on ferromagnetic shape memory alloy for diagnosis and treatment of cancers.**

Hybrid Mechanism of FSMA and FSMA composites

Chain-reaction:

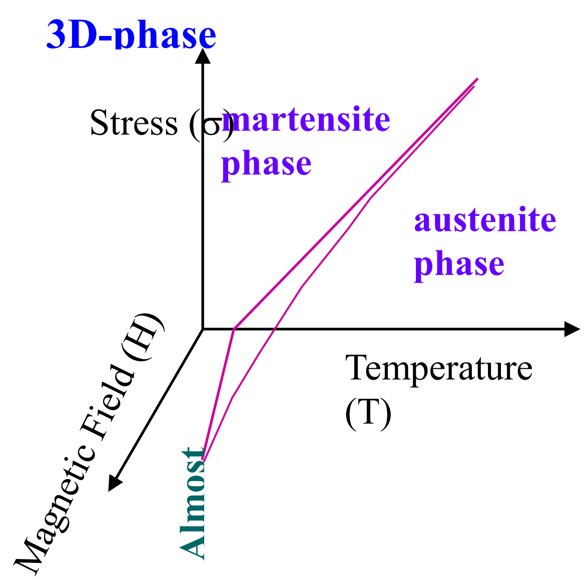
Applied magnetic field gradient

→ magnetic force

→ Stress-induced martensite transformation

→ low stiffness of FePd

→ large deformation



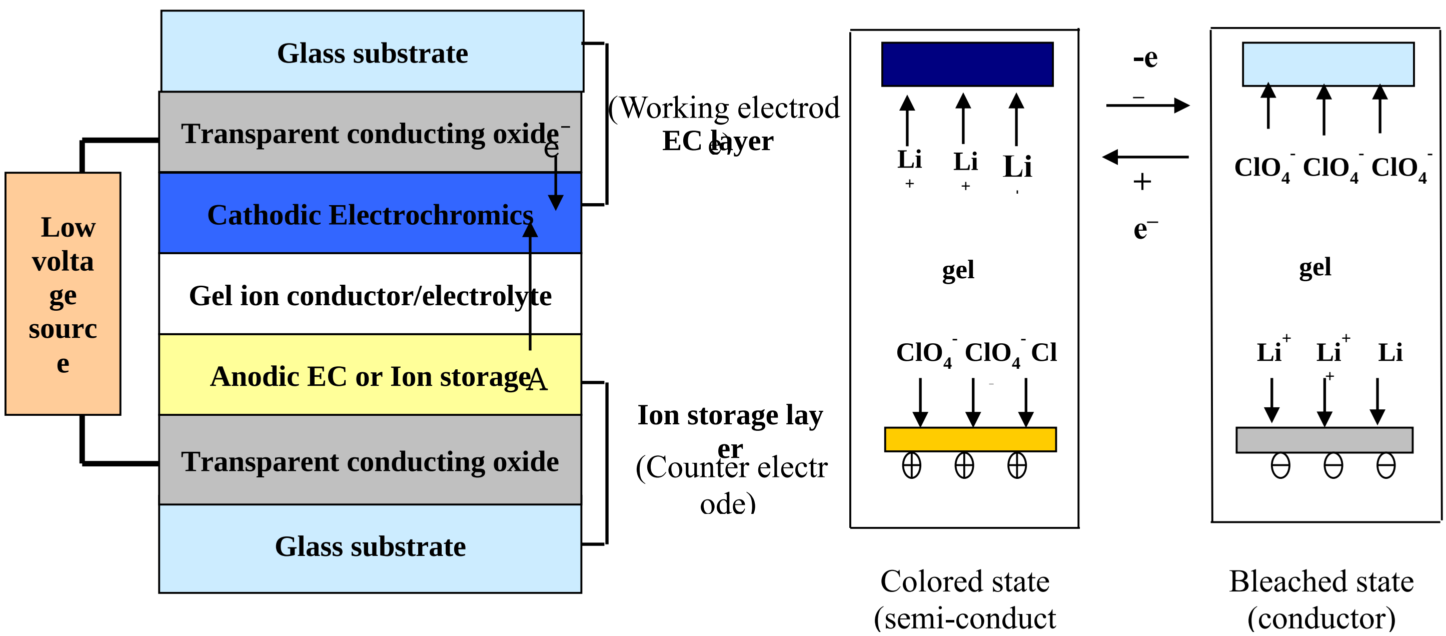
3. **Micron-actuators for orthodontic surgery based on ferromagnetic shame memory alloy**

Goal: reduce the surgery time of an orthodontist from currently 30 – 60 minutes to within 5-10 minutes by the new design of actuator system

4. Electrochromic window (ECW) technology:

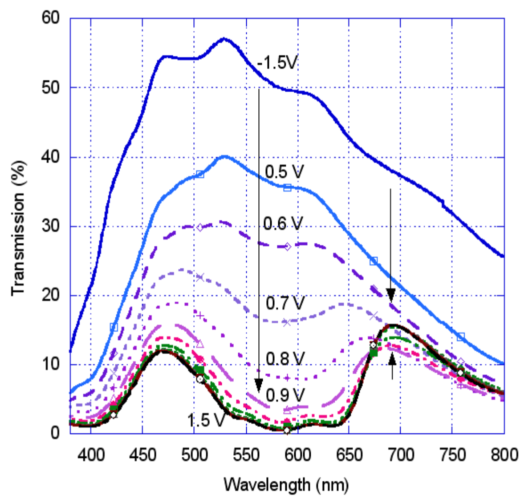
A.Low-cost and large surface area of ECW based on conjugated polymers.

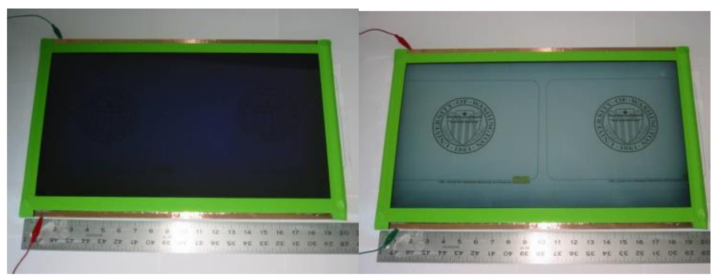
Principle of Organic Electrochromic Window(ECW) based on Redox reaction for control of visual transmission and solar heat gain coefficient:
Low cost due to room temperature processing
Scalable to larger size
Longer durability



It is noted in the above figure that the key active material is conjugated polymer, cathodic electromic film, ProDOT-Me2, which undergoes redox reactions paired with mobile Li ion; in oxidized stage, the color is transparent, in reduction stage it is dark blue.

Transmittance changes under various applied low potentials



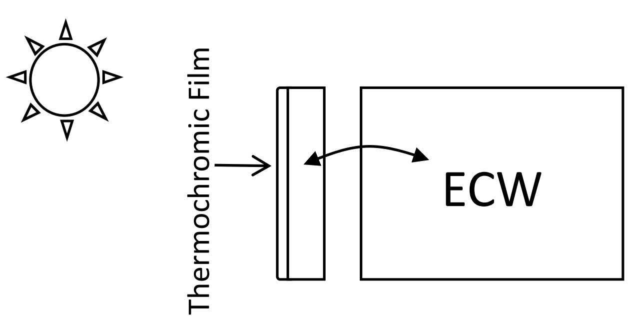


The right side photos show dark and transparent stage of 20 inch x 12 inch ECW

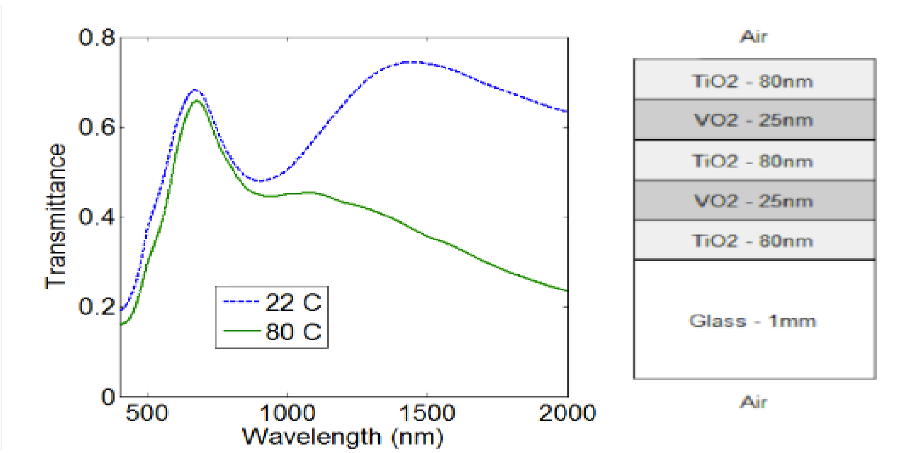
It is noted that ECW can control solar heat gain coefficient, thus, saving the cooling energy of the room with such ECW in summer time.

B. Integration of organic ECW and inorganic thermochromics film

The proposed integrated ECW-thermochromic(TC) film shown below is to protect the organic ECW from IR waves, while passive TC film can control the IR waves depending on the tempature outside a house, in summer (hot) environment, the TC film reflect while in cold winter environment, the IR waves can pass through TC film into the rooms inside a house.



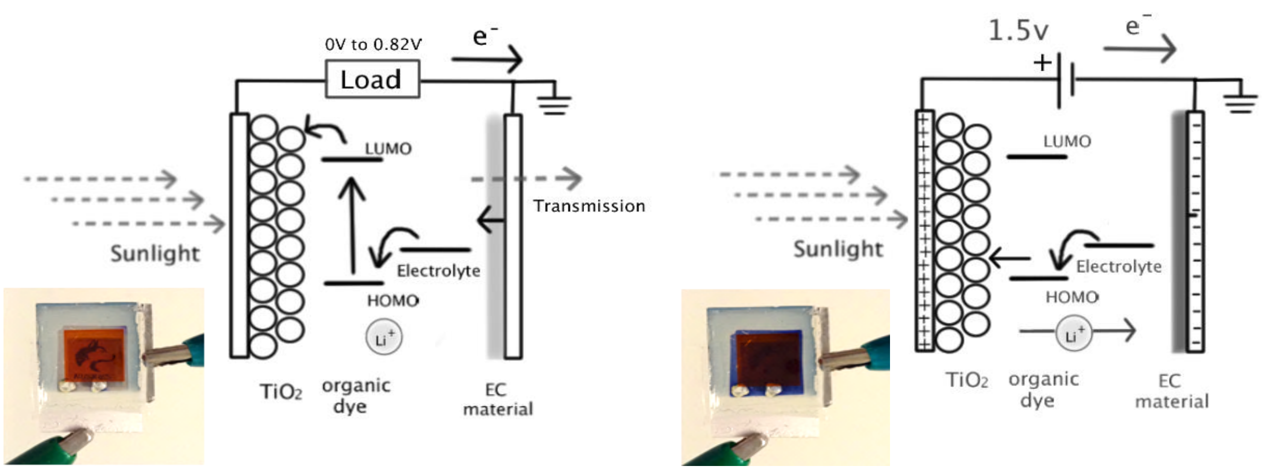
The proposed TC film is made of nano-laminate as shown in the following figures.



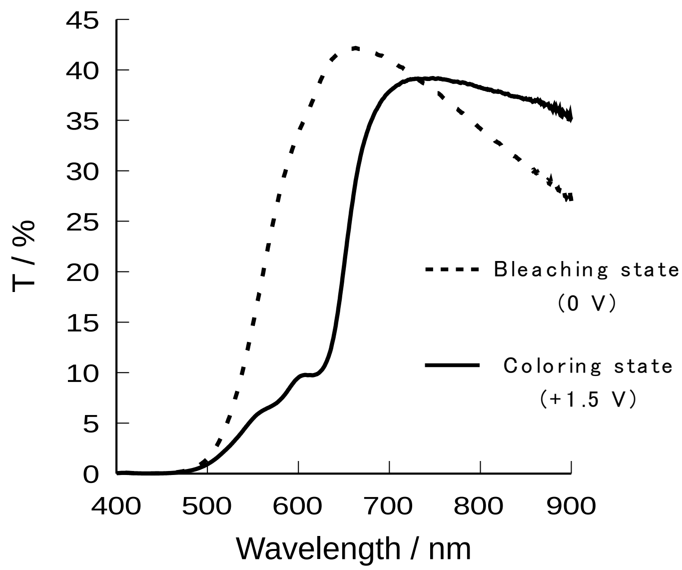
It is noted that ECW with TC film can control wider solar waves , thus, more energy-efficient than just ECW alone.

C.Energy-harvesting ECW.

This energy-harvesting ECW (EH-ECW) is ideal ECW which can harvest solar energy and its concept is given below.



Left figure shows the energy-harvesting mode while the color of EH-ECW is tinted, while the right figure shows the dark color while the energy harvesting function stops. The key EH-ECW is dye molecular (SA13),see the full paper (*)



The above figure shows the measured transmittance change, ΔT = 36 % at 628 nm (T_{max} = 41 %, T_{min} = 5 %) achieved. The solar energy harvesting efficiency is 4.5%.

***See Advanced Energy Materials, 2015, 1400379 by Amasawa et al**

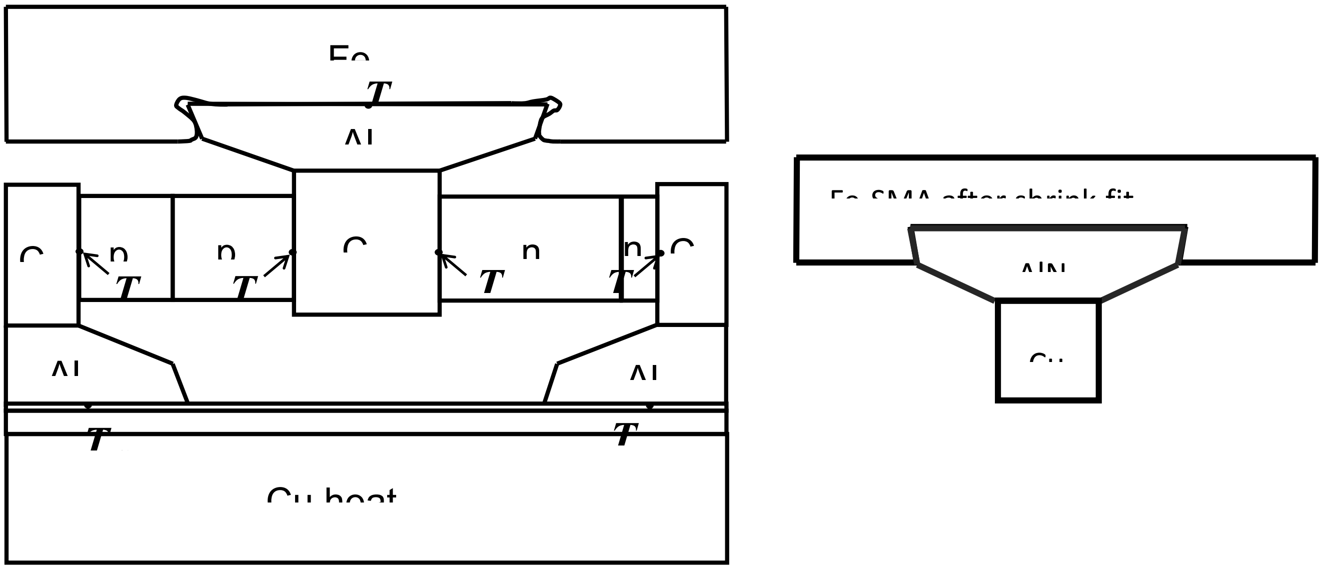
5. Thermoelectric materials and modules

We have been working on development of a set of lower-cost and light weight p- and n-type thermoelectric(TE) materials (MgSi and MnSi based), and design of a set of light-weight TE modules; pai design and linear design. The details of these works are in the recent papers:

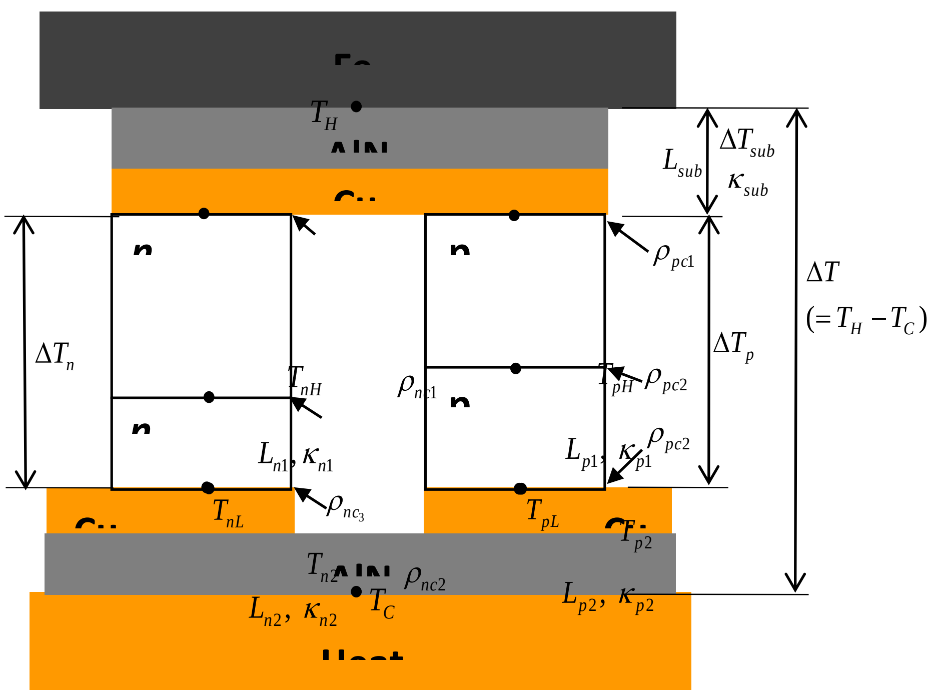
MSE B185, 2014, 45-52,"Design of segmented thermoelectric generator based on cost-effective and light-weight thermoelectric alloys" by HS Kim et al. --------Pai TE module design

MSE B183, 2014, 61-68, "Design of linear shaped thermoelectric generator and self-integration using shape memory alloy" by HS Kim et al. -------------------------Linear TE module design

illustrations of the the above TE modules are shown on next page, and they can be applied to air, ground vehicles and also underwater facilities where there exists reasonably large temperature difference.



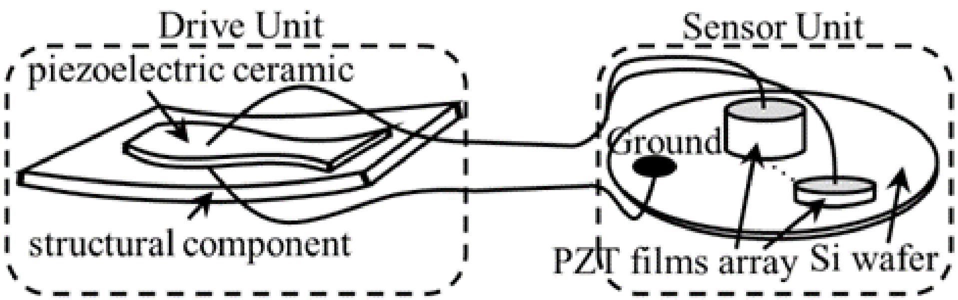
Linear TE module design



Pai TE module design

6. Structural health monitoring system

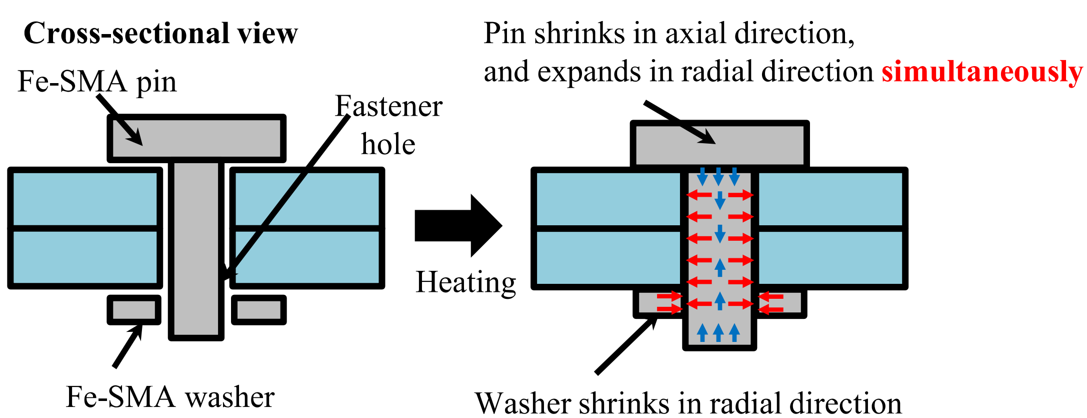
We have been working on the new structural health monitoring system which records only large unexpected stress loading to a given structure. The key concept is given in the following figure.



The drive unit is attached to the structural component to sense its mechanical loading, the signals of which are converted to voltage as a function of time, which are filtered through the SHM circuitry, then , finally , the numbers of critical large stress loading are recorded. So the proposed SHM system is lower-cost, robust, and least electric power consumption. The SHM system can be installed to civil infrastructures, ground and air vehicles, and even for helmets used by foot ball players.

7. Reliable and robust fastener system for laminated structural members made of metals, polymers etc.

The key material for the proposed new fastener system is Fe-based shape memory alloy (Fe-SMA). The key fastener mechanism is shrink,or swell-fit bonding, as shown in the following figure.

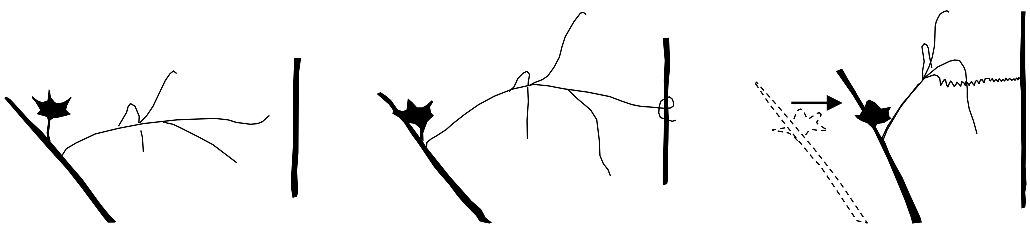


The amount of shape memory strain is as large as over 3 %, thus, able to bond strongly closing the gap that existed between holed laminate and Fe-SMA pin , and the gap between the Fe-SMA pin and washer.

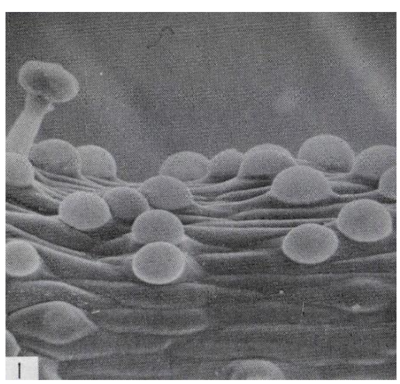
8. Bioinspired design of actuators and sensors

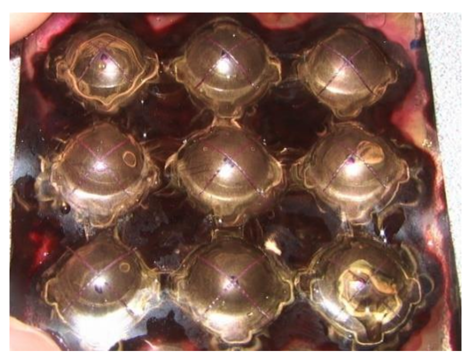
We have been working on bioinspired design of a set of new active materials and sensing materials and their devices, for examples:

a. Bioinspired tactile sensor based on cucumber tendrils



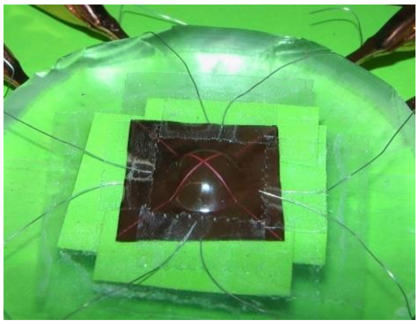
Sequence of searching a stable stay by cucumber tendril, at the ventral side of which has a number of single tactile sensor cells (papillae), see the following photo (Junker, 1977).

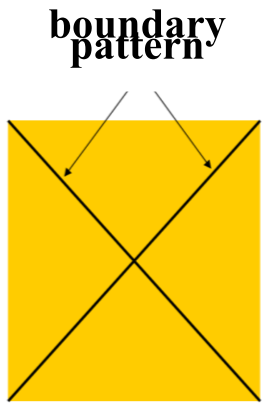




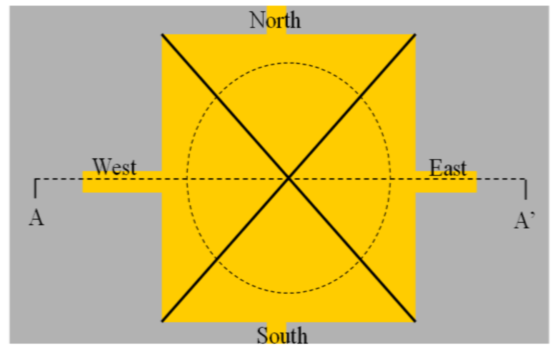
Left: Tactile sensor cells (on tendril of cucumber) , right bioinspired tactile sensor arrays based on Flemion.

These papillae can sense vectorial forces (Fx, Fy and Fz) , thus ideal tactile sensor design, which was recently transferred to synthetic tactile sensor design which is based on Flemion member (ionic membrane). The following figures illustrate the concept of our tactile sensor , only one cell is shown for simplicity where four electrode segments are generated by laser cutting.

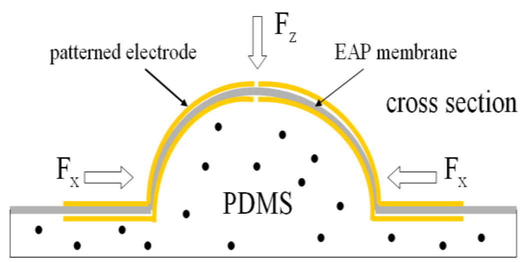




(a)



(b)

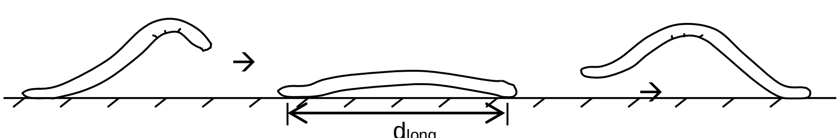


The details of the above tactile sensor system is in our paper,

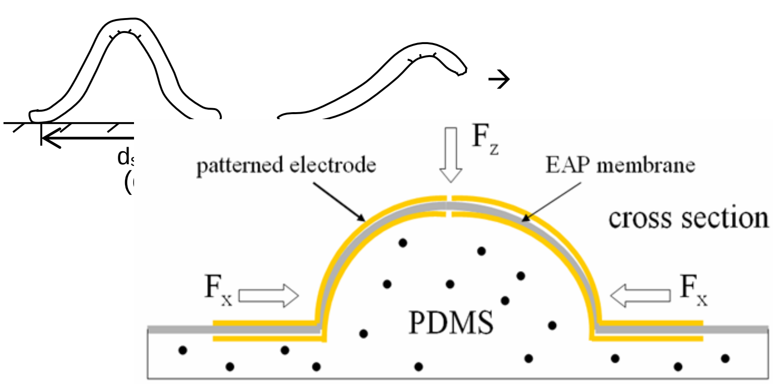
Wang, J, Sato, H, Xu, Chunye and Taya, M., 2009, "Bioinspired design of tactile sensors based on Flemion", J. Applied Physics, 105, 083515.

b. Inchworm actuators

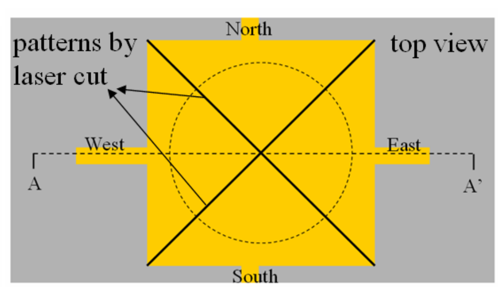
The motion of an inchworm is illustrated in the following figure.



(a) (b) (c)

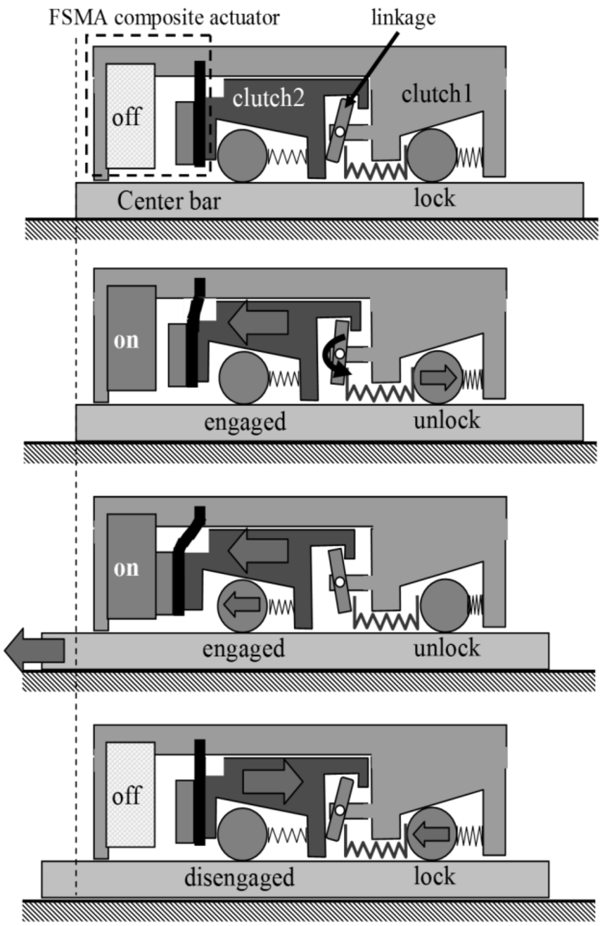


(a)

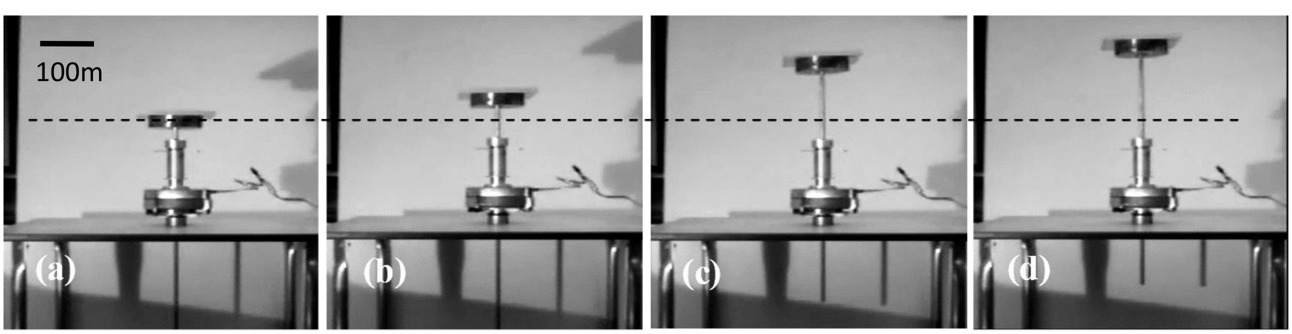


(b)

Based on the above locomotion mechanism, we designed inchworm actuators based on ferromagnetic shape memory alloy. The key part of FSMA inchworm actuator is shown in the following figure.



The demonstration of our FSMA inchworm actuation in lifting some weight upward is shown below:



The details of the FSMA inchworm is given in our paper,

Liang, Y., Taya, M., Xiao, JQ and Xiao , G., 2012, "Design of the inchworm actuator based on the ferromagnetic shape memory alloy composite", Smart Mater. Struct. 21,115005

A new book , "Bioinspired actuators and sensors", co-authored by M. Taya, E. Van Volkenbutgh, M. Mizunami and S. Nomura will be published sometime in 2015 by Cambridge University Press. This book covers a variety of topics:

1. Introduction
2. Principles of structural organization and functions in biological species
2.1 Plant structures and motor cells
2.2 Structural and functional elements of insects

3. Sensory and motor systems of the living world

3.1 Sensory systems in living systems
3.1.1 Visual system of insects
3.1.2 Olfactory system of insects
3.1.3 Tactile sensing
3.1.4 Sensory neuron network
3.1.5 Structural color in nature
3.1.6 Light harvesting of plants and bacteria
3.2.1 Morphing structures in plants
3.2.2 Morphing structures of wings of birds, bats and insects
3.2.3 Morphing of plasmodal slimes and caterpillars
3.2.4 Neuronally controlled movements of insects
3.2.5 Swimming/flying ,propulsion systems in bacteria, insects, fish, birds and flying seeds
3.2.6 Attachment/de-atachment in animals and plants (gecko/English ivy, lotus leaf, mussel)

4. Synthetic sensing materials and sensors
4. 1 Sensing materials and sensors for mechanical environment (stress and strain)
4. 2 Sensing materials and sensors for hygeothermal environment (temperature and humidity)
4. 3 Sensing materials and sensors for chemical and biological environment
4.4 Sensing materials and sensors for IR
4.5 Sensing materials and sensors for magnetic field

5. Synthetic active materials and actuators
5.1 Polymer based active materials and actuators
5.1.1 Electro-active polymers
5.1.2 Thermally active polymers
5.1.3 Light-active polymers
5.1.4 Electrochromic polymers
5.1.5 Carbon nanotube based active materials and actuators

5.2 Metal based active materials and actuators
5.2.1 Shape memory alloys
5.2.2 Ferromagnetic Shape memory alloys
5.3 Ceramic based active materials and actuators

6. Bio-inspired designs of sensors, actuators
6.1 Morphing structures
6.2 Tactile sensors
6.3 Photon energy harvesting and storages
6.4 Structured colors: camouflage skin and color change strain sensor
6.5 Inch-worm actuators
6.6 Velcro adhesives, hydrophobic surfaces and anti-fouling films
7. Design of autonomous systems
7.1 Flying insects and birds
7.2 Artificial Cilia and Robo-fish
7.3 Autonomous building
8. Concluding remarks