WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

December 2002 **WW-EAP Newsletter** **Vol. 4, No. 2**

http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm

FROM THE EDITOR

Yoseph Bar-Cohen, yosi@jpl.nasa.gov

The infrastructure of the EAP field, as defined by the Editor, is continuing to solidify. Significant development is reported in each of the key areas ranging from theoretical modeling and improved understanding of the mechanisms that drive the various EAP materials to the explorations of novel applications. The characteristics of resilience, fracture tolerance and induced large displacement, which emulate biological muscles, have made EAP materials highly attractive. As a result, users are increasingly seeking to develop mechanisms and devices that can only be possible using this type of actuators The growing availability of forums of communication such as the SPIE's annual EAPAD Conference and information archives like this Newsletter, the WW-EAP webhub with links to leading research and development labs worldwide and the book entitled "Electroactive Polymers (EAP) actuators as artificial muscles" [see references at the end of this Newsletter issue] are providing a wealth of information and cooperation opportunities for this multidisciplinary field.

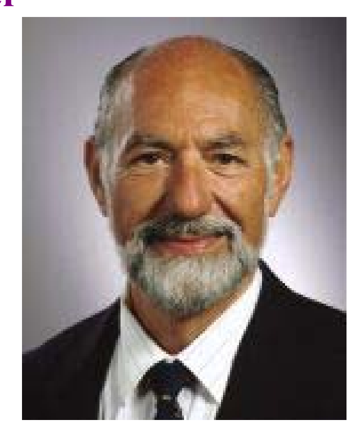
We are continuing to be away from meeting the challenge of an EAP actuated robotic arm winning against human in a wrestling match. While it is a futuristic objective, significant progress has been made in advancing the critical elements of the field infrastructure.

Being part of the biologically-inspired technology, which is also known as biomimetics, EAP is enabling enormous possibilities to such fields as robotics, entertainment, toys, space, medical, military and others. In recent years, the growth of the field of biomimetics gained great momentum and new conferences were initiated, various forums of information exchange were formed and books were published [see example at the end of this issue]. Further, as described on page 4 of this Newsletter issue, a new society has just been formed.

The Editor believes that one of the areas that requires strengthening is the commercialization of low cost EAP materials. It is becoming increasingly critical to have EAP materials as consumer products. The unavailability of such materials is hampering potential users worldwide from being able to explore possible research, development or application tasks. In this issue, a new section was added offering emerging suppliers the opportunity to present their company information.

ABOUT THE EXPERTS

Sia Nemat-Nasser



Congratulations to Sia Nemat-Nasser, Director of the Center of Excellence for Advanced Materials (CEAM) and Professor of Mechanical and Aerospace Engineering, for receiving the ASME's 2002 Nadai Medal. Sia's research areas include Micromechanical and constitutive modeling of nonlinear response and failure modes of materials; analytic, computational, and experimental mechanics and mechanics of materials, especially those of ceramics, ceramic composites, advanced metallic and polymeric composites, particularly polyelectrolytes and ionic polymer-metal composites, high strength alloys and superalloys, as well as rocks and geomaterials. Beside his contributions to this extensive list of areas he made significant contributions to the understanding of the electro-chemo-mechanical actuation mechanism of IPMC materials

Zhongyang Cheng

In August 2002, ZhongYang (Z.-Y.) Cheng joined Auburn University's Materials Engineering program (http://materials.auburn.edu) as an assistant professor and core member of the AU Detection and Food Safety Center (www.auburn.edu/audfs). Prior to this appointment, Cheng was a research associate with the Materials Research Institute at Pennsylvania State University, University Park. His research emphasis is in preparation and characterization of various functional materials (electroactive polymers, ferroelectrics, piezoelectrics, dielectrics, electrets, nonlinear optical material and composites) and design, fabrication and characterization of electromechanical sensors, actuators and transducers. At Auburn University, Cheng expanded his research to biology, especially in the application of these functional materials to biosensor development. He can be reached at chengzh@eng.auburn.edu, or 334-844-4913

John D. Madden

John Madden has been appointed Assistant Professor of Electrical and Computer Engineering at the University of British Columbia in Vancouver, Canada. Up until recently, John has led the effort in developing conducting polymer actuators and devices in the Bioinstrumentation Laboratory at MIT, where he was a Research Scientist working with Ian Hunter and Timothy Swager.

At his new affiliation John is continuing his investigation and development of conducting polymer as well as carbon nanotube actuators, supercapacitors and sensors, including research on new molecular mechanisms of actuation, and maintains close ties with the MIT group. Peter Madden (peterm@mit.edu) will now lead the polymer program in the BioInstrumentation Laboratory at MIT.

Contact Information: John D. Madden - Department of Electrical and Computer Engineering, University of British Columbia, 2356 Main Mall, Vancouver BC V6T 1Z1, Canada jmadden@ece.ubc.ca

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GENERAL NEWS

The WW-EAP Webhub is continuing to be updated with information regarding the EAP activity Worldwide. This webhub is hosted at the JPL's NDEAA Technologies Website: http://ndeaa.jpl.nasa.gov

Opportunities Website

Funding opportunities for research in the field of EAP is critical to advancing this technology. To help with the need for information about such opportunities the following website was formed http://www.acq.osd.mil/sadbu/sbir/solicitations/sttr02/navy02.htm

Biomimetics Website

In August 2002, the NDEAA homepage entitled "Biomimetics: Biologically-Inspired Technologies" was selected by www.Biomat.com as one of the top 5. This NDEAA website http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm contains interesting resources, such as "Creatures and plants that offer a useful model on biomimetics", "Biomimetics technologies" and "Biomimetic links". Besides providing a wide range of useful information related to the field, it includes links to videos and articles.

Actuator 2002

Roy Kornbluh, kornbluh@erg.sri.com

This was the 8th International Conference on New Actuators and 2nd Exhibition on Smart Actuators and Drive Systems. It was held on June 10-12, 2002 and as always in Bremen, Germany.

For the first time in it's 16-year history, the Actuator series of conferences featured an entire session devoted to polymer actuators. At the previous conference, Actuator 2000, Yoseph Bar-Cohen of JPL presented a review paper on polymer actuators. He impressed the conference organizers enough to have them include an entire session. Peter Sommer-Larsen of Risoe National Laboratory (Denmark) and Roy Kornbluh of SRI International (USA) were the co-chairs for Actuator 2002.

The conference had about 400 attendees, with roughly 50% from Germany. At any one time during the conference, there are only two talks going on allowing for attendees to attend most of what is of interest to them.

Although the Polymer Session was the last session of the conference it was well attended and well received. Peter Sommer-Larsen and Roy Kornbluh presented an overview of the state-of-the-art in polymer actuators.

The other presenters were Mohammed Bensilmane from Danfoss (Denmark) who presented their dielectric elastomer actuators, Edwin Jaeger from Micromuscle (Sweden) presented their biomedically-oriented conducting polymer work, and Markus Jungmann from Darmstadt University of Technology (Germany) presented their work on making a refreshable Braille display with dielectric elastomers.

The polymer posters included J. Kim of Inha University (Korea) presenting paper based EAP, T. Ikehara of the National Institute of Advanced Industrial Science and Technology (Japan) presenting an optical actuator, George Jeronimidis from Reading University (UK) presented on tailored fibrous structures for gel-based muscles and Frederico Carpi on his study of acrylic dielectric elastomer. A Shridhar MH of Risoe also presented on some corrugated electrode silicone actuators.

The conference was quite informative and extremely well organized, thanks largely to the experience and diligence of Hubert Borgmann, the conference organizer since Actuator 1990. The exceptional food and atmosphere of Bremen made the overall event very enjoyable. Borgmann, was impressed with the polymer actuator presentations and promised that EAP would be featured again at Actuator 2004. For information about Actuator 2004, Bremen, Germany, see www.actuator.de

2002 Transducing Materials & Devices Conference

The first Transducing Materials and Devices (TransMaD) conference was held at Brugge, Belgium from Oct. 30 to Nov. 1, 2002. The objective of this conference is to provide a forum for information exchange among the experts from the various related disciplines. The resulting interaction is hoped to lead to new initiatives, help improve existing technologies and introduce new ones. The conference papers covered analytical and experimental studies that are associated with these materials and their applications. In organizing this conference effort were made to cover, but not limit to, the following topics:

- Transducing material science and engineering

- Theoretical models, analysis and simulation of the material behavior
- Support technologies, including electroding, synthesis, processing, shaping and fabrication
- Methods of testing and characterization
- Actuators, sensors, transducers, displays and other applications of transducing materials
- Design, control, and activation issues related to the applications of transducing material
- Integration of smart systems
- Small scale devices and systems (MEMS, micro and nano)
- Biologically inspired mechanisms and devices, biomimetics, and reconfigurable robots
- Large scale mechanism and actuated structures (Sonar, Gossamers, etc.)
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FIGURE 1: The Keynote speaker, Carl Skjoelstrup, Senior Director of Technology for LEGO, Denmark.

The Keynote speaker was Carl Skjoelstrup, Senior Director of Technology for LEGO, Denmark. Skjoelstrup presented LEGO's view of the requirements for transducing materials in an effort to make better smart toys that would be highly attractive to children. Beside the state of the art overview of the technologies, including novel actuation materials, MEMS, information technology, and others, he presented his view of the challenges.

Overall 34 papers were included in the program of this conference and leading experts from the Europe, Japan and USA attended the conference. Several papers covered studies related to the topic of EAP. Eric Cross from Penn State University, who is a prominent expert in the field of ferroelectric materials, made an invited paper presentation covering the state-of-the-art of the ceramic and polymer ferroelectric materials and his efforts in the field over the last thirty years. The other invited paper presenters included Francisco J. Arregui, Public University of Navarra, Spain; and Takashi Iijima, AIST, Osaka, Japan.

FIGURE 2: Attendees of the conference

Vaclav Bouda, Czech Technical Univ. (Czech Republic), covered his group efforts to develop an equivalent to biological muscles using nano-technology. M. Lindner, from Johannes Kepler University (Austria), covered the development and application of ferroelectric-like cellular polymer electrets. Generally, one of the widely used commercial products that are based on the use of electrets includes microphones. This group from Austria found that PTFE (a form of Teflon) is an excellent electret material. Another expensive alternative material is the PFCB. To make a material electret it needs to be charged in a dipole form using the 2nd order non-linearity. In the process of driving such materials these researchers observed emission of plasma as a blue light resulting from electric breakdown. This breakdown occurs over a period of microseconds. Another interesting property that was reported is the presence of optical hysteresis due to change in "polarization states". This phenomenon is found in charged piezoelectric polymer foams offering a great potential for a light emitting mechanism. A major disadvantage that this material exhibits is the loss of response when the temperature exceeds 50^{o}C.

BAM 2002 - First world congress on Biomimetics and Artificial Muscles

The first world congress on Biomimetics and Artificial Muscles (BAM 2002) was held in Albuquerque, NM, from December 8 to 11, 2002. The congress included several sessions on EAP and several symposia on other types of actuation materials, bioelectric and biomagnetic phenomena and biomimetics. Nearly 200 scientists and researchers participated in this congress. The program and the list of attendees can be viewed on www.world-congress.net. The second world congress on BAM will be held in Williamsburg, Virginia, April 2004 and the third will be held in France in August of 2005. As a conclusion of the congress a new society of "Biomimetics" is being formed and further information can be obtained from Mohsen Shahinpoor (shah@unm.edu).

2003 SPIE EAPAD Conference

The EAPAD Conferences started in 1999 and it is continuing to be the leading international forum for the field of EAP. The conference is held in San Diego, California, over four days from March 3 to 6, 2003. The presentations will cover a broad range of topics from analytical modeling to application. The program of the EAPAD 2003 Conference is now available on: http://spie.org/Conferences/Programs/03/ss/conferences/index.cfm?fuseaction=5051 The papers are going to focus on issues that can help transitioning EAP to practical use thru better understanding of the principles responsible for the electro-mechanical behavior, improved materials, analytical modeling, methods of processing and properties/performance characterization as well as various applications.

FIGURE 3: The Keynote Speaker, Anna Maria R. McGowan from NASA

The upcoming conference will be opened with another interesting and exciting Keynote presentation. The speaker will be Anna Maria R. McGowan from NASA Langley Research Center and her presentation is entitled "**Biologically-Inspired Technologies in NASA's Morphing Project**." In this presentation she will cover one of the topics of biomimetics related to flying objects to which EAP can contribute enormously.

As in the previous EAPAD conferences, another EAP-in-Action Session is planned where some of the latest practical implementations of EAP will be demonstrated. This Session is a forum of interaction between the technology developers and potential users and it offers a "hands-on" experience with this emerging technology. During this session, the attendees are given opportunity to see demonstrations of EAP actuators and devices.

On Wed. March 5, 2003, an Open Panel Discussion Session will be held to debut the status of the field of EAP. The conference Chair, Cochair, and the invited speakers will serve as the discussion panelists. Each of the panelists will be given an opportunity to make a short statement and the attendees will be invited to express their thoughts and to debut the topics that will be presented. This session is intended to stimulate ideas and thought and help define the future direction of the development of EAP. The three key topics for the open discussion include:

- Areas of EAP weakness and shortcoming of the EAP technology infrastructure.
- What is the gap between the needed and available EAP and how to bridge it.
- Future science and engineering directions.

EAP ADVANCEMENTS

ITALY - Centro "E. Piaggio", University of Pisa,

D. De Rossi, derossi@piaggio.ccii.unipi.it
F. Carpi, carpi@piaggio.ccii.unipi.it
A.Mazzoldi, alberto@piaggio.ccii.unipi.it
G. Pioggia, pioggia@piaggio.ccii.unipi.it
W. Rocchia, rocchia@piaggio.ccii.unipi.it
G. Serra, gio@piaggio.ccii.unipi.it

The research at the Center "E. Piaggio" on electroactive polymers is moving in several directions. We are considering materials requiring two complementary stimulation conditions (low voltage and high voltage): conducting polymers and electrostrictive polymers, respectively. This approach requires overcoming several challenges:

conducting polymers show low active strains and short lifetime, whereas electrostrictive polymers require high stimulation voltage. Given this premise, we have developing different strategies to avoid these problems.

For conductive polymer base EAP, the use of a recently disclosed liquid electrolytes should permit an increase in the stimulating voltage window and to the lifetime of the actuator. In fact, these liquids don't produce parasite reactions, as oppose to what happens with traditional electrolyte solutions. Moreover, the application of I-R compensation can permit to optimize the effect of the electrochemical stimulation, yielding better performances. In fact, through a correct evaluation of the electrochemical impedance of the solution, it is possible to design new stimulation signals that force the system to respond at higher stimulation rates.

Using a McKibben-like configuration, we are seeking to amplify the axial active strains of conducting polymer fibers, (see Figure. 4). This configuration should enable to convert and amplify the radial strains. It has been observed that conducting polymers show a radial strain, which is higher than the one along the axial direction. This behavior and the possibility to convert radial deformations along the axial direction, should allow achieving considerable strains at lower stimulation levels and to decrease the fatigue of the polymer.

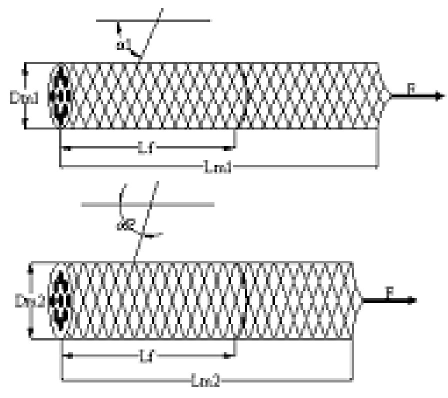


FIGURE 4: McKibben-like actuator

Using electrostrictive polymers efforts are made to design a configuration that induces a high radial strain. This design is considered for integration with the McKibben-like actuator configuration. Thus, it should be possible to obtaining the same strain while using a lower driving voltage. This configuration is currently under development and it is shown in Figure 5, where an electrostrictive polymer structure is twisted along its central axis and two electrodes are connected to complete the device.

The above-mentioned materials are currently investigated for use in two applications:

- Kinesthetic smart active glove (Figure 6)
- Silicone emotional display called FACE (Facial Automaton for Conveying Emotions), as shown in Figure 7.

FIGURE 5: Electrostrictive actuator under development

FIGURE 6: Kinesthetic Smart Active Glove

FIGURE 7: Photo of the *FACE*

JAPAN - Tokyo Inst. of Tech., AIST, and RIKEN

Development of Linear Artificial Muscle Actuator Using Ionic Polymer for Biped Walking Robots

M. Yamakita, N.Kamamichi, Y.Kaneda (Tokyo Inst. of Tech.), K.Asaka (AIST), and Z.W.Luo (RIKEN)
Email: yamakita@ctrl.titech.ac.jp URL: http://www.ctrl.titech.ac.jp/~yamakita/coe/

We are developing a linear artificial muscle actuator using ionic polymer-metal composites (IPMC), an EAP that bends in response to electric stimuli. The goal of our study is to use this actuator in robotic applications especially for biped robots since the back drive ability should be effective for biped walking. The structure of the actuator's elementary unit is shown in Figure 8. The elementary component consists of four IPMC films, with two of them are connected by a flexible conductive material. The elementary unit can be easily connected in serial and in parallel without electric and spatial interferences.

The characteristics of the unit are modeled as a linear time invariant (LTI) system with two inputs, the input voltage, load and one output, which is the displacement. The transfer function from the load input to the displacement has a relative degree 2 so that an impulsive effect of impact between the robot's foot and its floor can be taken into account in a later simulation. The parameters of the model were identified from input-output data using a subspace identification method.

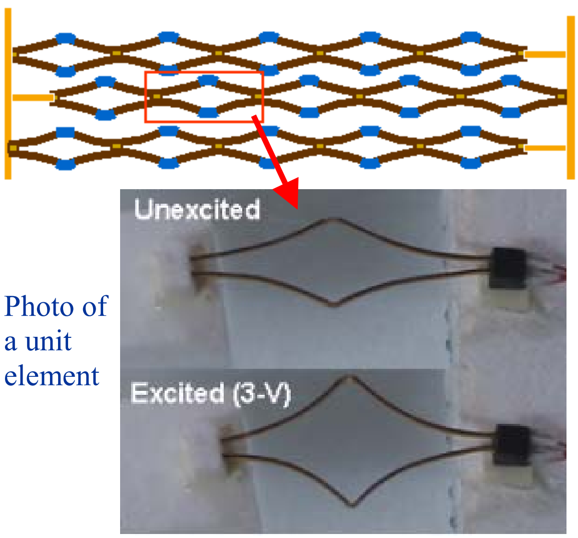
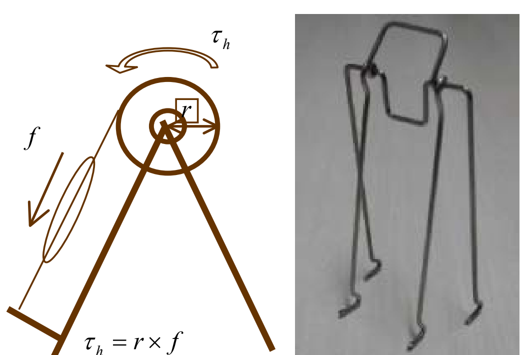


Photo of a unit element

IPMC: Nafion 117 (Dupont); Au: 10[mg/cm^2]; **L** - 20mm; **W** - 2 mm

FIGURE 8: Structure of the linear actuator



TITech/RIKEN Wire Walker I

FIGURE 9: Model of a biped walker and its physical parameters

In our numerical simulation, we assumed that the developed actuators are connected both in serial and in parallel to a joint of a small compass like biped walking robot (Figure 9) so that the actuators supplies enough torque to the robot and that they are sufficiently stretched and compressed. It is shown that the biped robot with the actuators can walk on level grand with a period 0.24 [sec]. Stick diagram and phase plane trajectories were used and we are now constructing a non-linear model of the actuator. We are also preparing an experimental system of TITech/RIKEN wirewalker I.

University of Tokyo & Hokkaido University

Starfish-shaped Gel Robots made of EAP

Mihoko Otake mike@jsk.t.u-tokyo.ac.jp
Yoshiharu Kagami, Yasuo Kuniyoshi, Masayuki Inaba, Hirochika Inoue

Novel robots called 'Gel Robots' are being developed by the University of Tokyo and Hokkaido University. Deformable robots, such as slug, eel, and snake-like robots can adapt to situations in which conventional artifacts consisting of rigid links and joints often fail. Actuators for robots of the future are expected to be made of electroactive polymers (EAP) because their shapes and sizes are controllable by electric field.

The objective of our research is to develop systems for deformable robots using EAP. Towards this end, we have been building prototype 'Gel Robots', which are made entirely of an EAP gel. We are exploring the mechanical design and control methodology required for such deformable robots. As a typical example, a turnover motion of starfish-shaped gel robots was generated [1]. The materials, which consist gel robots, are poly (2-acrylamido-2-methylpropane sulfonic acid) gel (PAMPS gel) [2] and its co-polymer gel.

Originally, this material was only bending between parallel electrodes. However, its driving mechanism suggests that parallel electrodes are not necessary for controlling the shape of the gel. We discovered that large transformations are possible using a linear array of electrodes, which generate spatially varying electric fields. Based on these results, starfish-shaped gel robots and their driving system were designed. The electrodes were arranged into a matrix of four rows and four columns in the same plane. The robot turned over by cooperatively working their distributed muscles, supporting their weights while they were in motion (Figure 10). The results provided fundamental background for the implementation of biological understanding of muscular hydrostats system in which the muscle provides both the mechanical support and forces [3].

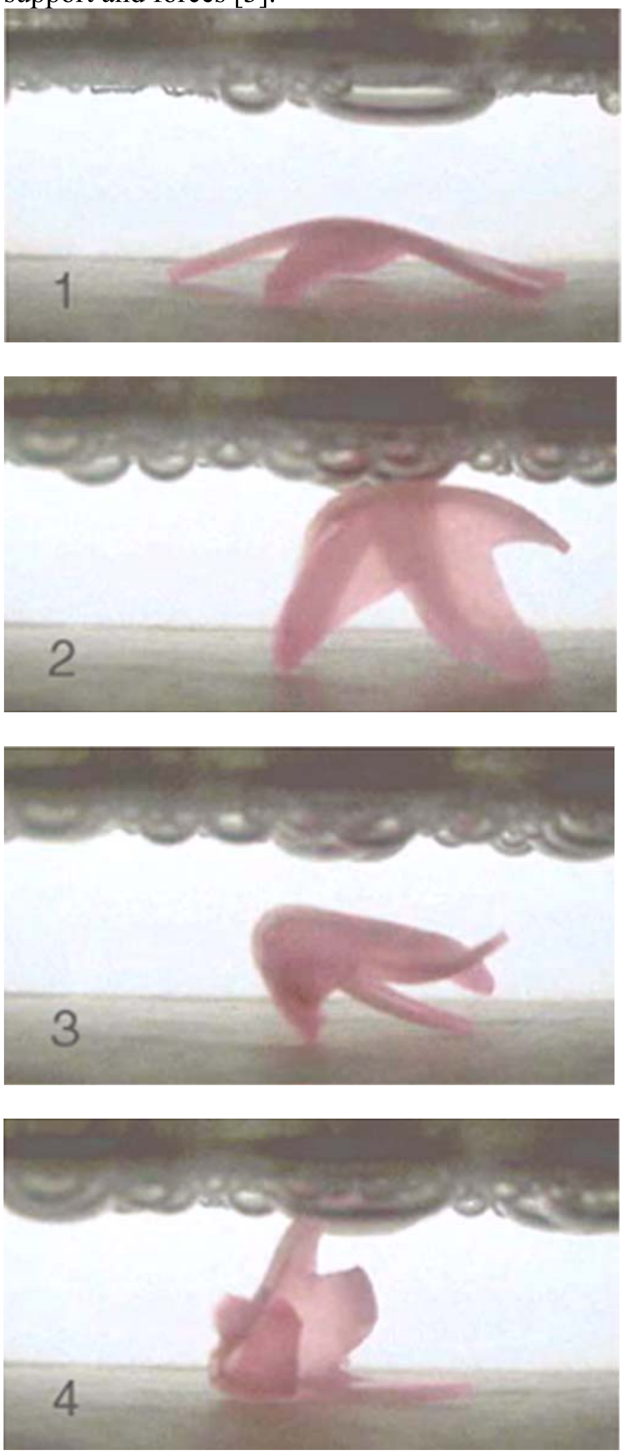


FIGURE 10: A turnover motion of a Starfish-shaped Gel Robots made of EAP

References:

[1] M. Otake et al. *Robotics and Autonomous Systems* **2002** Vol.40 pp.185.

[2] Y. Osada et al. *Nature* **1992** Vol.355 pp.242.

[3] Frank W. Grasso. *WW-EAP Newsletter* **2001** Vol.3 no.1 pp.7.

TAIWAN, Industrial Technology Research Institute and National Chung Hsing University

Biocompatibility of Partial Fluoro-Ionomers

Wen-Liang Liu[*] WLLiu@itri.org.tw , Jen-Luan Chen[*] LCCheng@itri.org.tw and Shan-hui Hsu[**]

[*]Materials Research Laboratories, Industrial Technology Research Institute, Hsinchu, 310

[**]Chemical Engineering Dept., National Chung Hsing University, Taichung, Taiwan 402

We are reporting herein a new ionic EAP composite made of PVDF-g-SPS and elastomers. The large electrically induced strain, force output, actuation time, mechanical flexibility and ease of processing are offering significant advantages over traditional ionic EAP. However, before the benefits of this material can be exploited, their biocompatibility properties need to be studied

- **Materials:**

  Polyvinylidene fluoride(PVDF) based on partial fluoro-ionomer with fluoro- or carbon/ hydrogen-polymer matrix. This ionomer has 50~160 wt % of grafting side chain, with sulfonic acid on such side chain. (Samples 307 and 384)

- **Fabrication Methods:**

  1. Endothelial cell culture: The materials were placed into the bottom of 24-well culture plate. 5×10^4 human umbilical vein endothelial cells were seeded in each well. The culture plate was placed in an incubator (37.5% CO_2). Cells on the materials were trypsinized and counted after 24 h and 72 h.
  2. Platelet activation: The materials were placed into the bottom of 24-well culture plate. 1 ml of platelet-rich plasma was added into each well. After being incubated for 1 h, the platelets adhered on the surface were trypsinized and counter.

- **Results:**
  Overall, #307 had better biocompatibility results. This better biocompatibility may be associated with the larger nano-microphase separation of the sample (see microstructure in Figure 11). Based on Table 2 data the sample #307 showed better endothelial cell affinity. Also, #307 had less platelets adhered onto the surface.

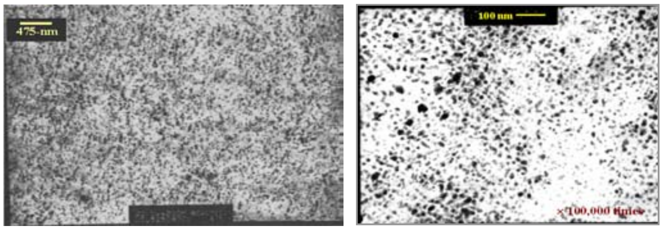


FIGURE 11: The microsctructure of sample #307

TABLE 1: Endothelial cell attachment and proliferation on the surface

	Number×10^6
Control (glass)	1.09±0.59
307	4.42±0.67*
384	12.25±2.59

* $p<0.05$

TABLE 2: The number of platelet adhesion on the surface.

	24 hrs (×10^4)	72 hrs (×10^4)
Control (Tissue culture Culture Polystyrene)	5.83±0.24	21.92±0.07
307	2.72±0.17*	12.76±0.3*
384	2.12±0.17	5.58±0.24

- $p<0.05$

USA - MRL, Pennsylvania State University

All-organic composites with high dielectric constant for artificial muscles

Qiming Zhang qxz1@psu.edu

In an effort to significantly reduce the applied electric field in the field type EAPs (the response is controlled by external fields) while maintaining high strain and high elastic energy density, several novel all-organic composites with high dielectric constants have been developed at Penn State, Qiming Zhang's group.

In last few years, several field type EAPs have been reported which can generate strain and elastic energy density far above those from the traditional piezoelectric materials. However, in order to achieve the high elastic energy density in these field type EAPs, a high electric field (> 100 V/μm) is required. The high operation field required to generate high strain and high elastic energy density in these field type EAPs in fact has its origin from the principle of energy conservation. For a field type EAP, the total elastic energy density from all the strains generated cannot exceed the input electric energy density because of the energy conservation. As a linear dielectric material, this input electric energy density from the external electric source is $U_E = ½ K\varepsilon_0 E^2$, where E is the applied field, ε_0 is the vacuum dielectric permittivity (=$8.85x10^{-12}$ F/m), and K is the dielectric constant of the polymer. In most of the field type EAPs, the dielectric constant K is less than 10. As a result, in order to generate a high input electric energy density, which can be converted to strain energy, a high electric field is required.

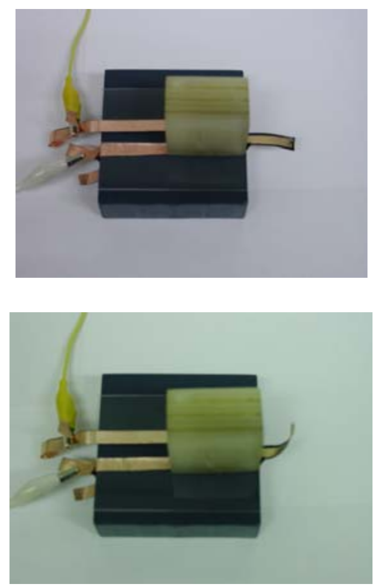


FIGURE 12: Unimorph EAP actuator activated by a low field (~ 5 V/μm).

By using an all-organic composite approach in which the high dielectric constant organic particulates (K>10,000) were blended into a polymer matrix. The resulting composites are very flexible and the modulus in the range of 0.1 GPa to 1 GPa, by varying the particulates and matrix. These composites can exhibit dielectric constant in range from 300 to 1,000 (at 1 Hz). Due to the high dielectric constant, the electric field required to generate high strain in these composites is much lower than the early field type EAPs. For example, a strain of near 2% can be induced under a field of 13 V/μm for a CuPc-PVDF based terpolymer composite which has an elastic modulus of 0.75 GPa (the strain is proportional to the square of the applied field). In another composite with different class of organic particulates, a strain of 1.5% can be induced under a field of 9.5 V/μm (elastic modulus~0.4 GPa). Some of the results have been reported in 19 September 2002 issue of *Nature* (Vol. 419, pp284-287).

Acknowledgement
The graduate students and post-docs who contributed to this work are Huang Cheng, Feng Xia, Hengfeng Li, Martin Poh, Z.-Y. Cheng (now at Auburn University), and H. Xu (now at TFE, Sweden).

JPL and Penn State University

Characterization of EAP Bending Ferroelectric EAP Samples from PSU

JPL: Xiaoqi Bao xbao@jpl.nasa.gov,
Y. Bar-Cohen yosi@jpl.nasa.gov
Penn State U.: Qiming Zhang qxz1@psu.edu

A series of Ferroelectric EAP based bending beam actuators were recently made by Penn State University. Each sample consists of two or three polymer layers, where one of the layers is inactive (i.e. without electrodes). The polymer is a stretched and electron irradiated P(VDF-TrFE) copolymer. The sample dimensions are about 60-μm thick, 4-5 mm wide, the modulus is about 1 GPa (at 1 Hz) and the density is about 1.8-g/cc. These samples were evaluated at NDEAA Lab, JPL and the test results showed average values as follows.

$K_{@1KV}$ - 100-200 m^{-1} (Free bending curvature at 1-KV)

$F_{@1KV}$ - 100-200$10^{-3}$gf (Stall tip force of 10 mm long actuator at 1-KV)

R – 5-10 Nm^2 x10^{-8} (Calculated bending rigidity of the beam according to the free bending curvature and stall tip force measured at 1-KV)

E_{eq} - 0.8 10^9 Pa (Equivalent Young's modulus estimated by the rigidity, the thickness and width of the actuator using simple beam theory)

$\varepsilon_{@1MV/m}$ – 3.2% (The maximum estimated strain of the active polymer under the electric field of 100V/μm)

The following has been the test methods that were used:

Free bending curvature measurement – This measurement was made using an image acquisition and processing system. The samples were clamped at the root of the beam and made to bend horizontally to avoid loading effect of the weight of the beam itself. The active length of the beam is around 30mm and images were recorded under various applied voltages and an example is shown in Figure 13. The edges of the beam were extracted and were fitting by circular curves as shown in Figure 14. The bending curvature of the beam was calculated as the inverse of the circle radius. The bending curvatures were predicted to be proportional to the V^2 and the agreement between the predictions and experimental data are shown in Figure 15.

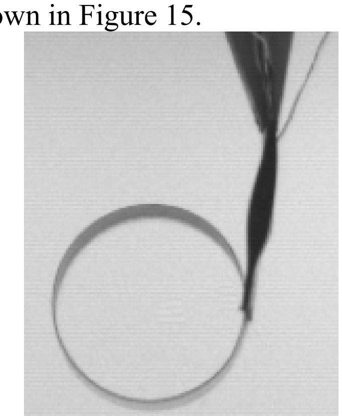


FIGURE 13: Response of one of the sample under 1000 V

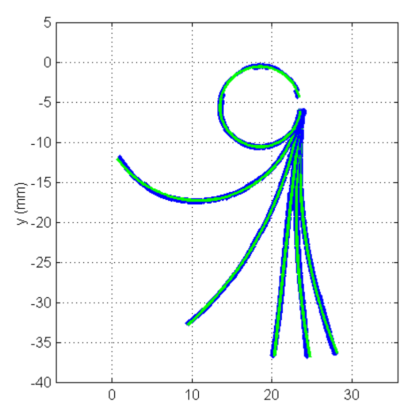


FIGURE 14: Circle fitting for a sample subjected to 0, 240, 340, 500, 700 and 1000 V

Stall tip force measurement - The stall tip force was measured using a load cell with a sensitivity of 0.5 V/g-f. The beam was clamped at a position 10 mm above the tip of the load cell as shown in Figure 16. Under the applied voltage, the beam bends and the force was also found to be proportional to V^2 (see Figure 17).

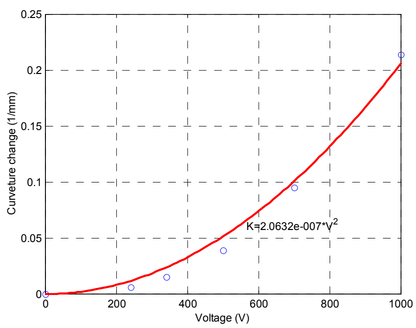


FIGURE 15: Curvature change of the sample S1 by applied voltage

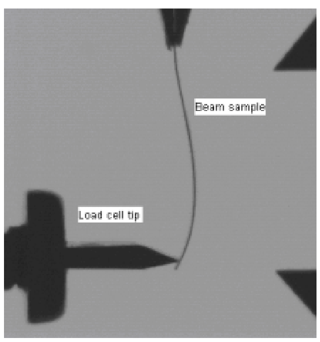


FIGURE 16: Stall tip force measurement, S1 under 1000 V

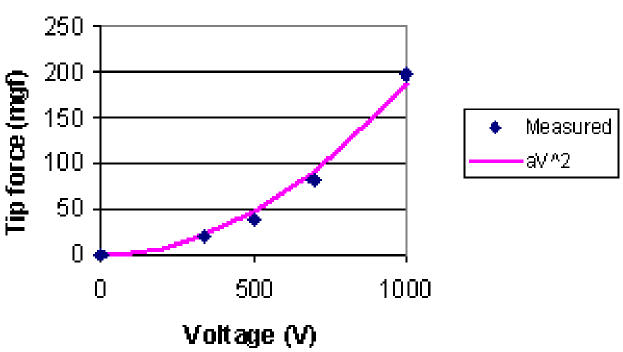


FIGURE 17: Stall tip force of a 10 mm long sample

Material property estimation - The equivalent Young's modulus E_{eq} was estimated by simple beam theory from the data of the rigidity, total thickness and width, assuming the beam is made of a uniform material. The estimated strain of the active polymer under the electric field of 1MV/m, $\varepsilon_{@1MV/m}$, was calculated by simple beam theory. It is the strain without any load. The breakdown electric field of this type material is around 1.5 MV/m according to the test performed at Pennsylvania State University.

Bending rigidity – This parameter is defined as $R = \frac{q}{K}$ where q is the momentum applied to the beam and K is the corresponding bending curvature. A computer program was developed to calculate the shape of a pre-bent cantilever beam with a tip force, where the pre-bent curvature was determined using the free bending measurement. The rigidity R was determined by adjusting the beam until the position of the contact point of the load cell and the beam agree with the experiment. An example of the calculated result is shown in Figure 17.

EMERGING EAP SUPPLIERS

As mentioned before, it is the opinion of the Editor that one of the key obstacles to advancing the field of EAP is the unavailability of material suppliers. This section was formed to promote the emergence of suppliers in order to address this critical need.

Ionic Polymer Metal Composites (IPMC)

Environmental Robots Incorporated is pleased to inform the EAP community that complimentary samples of IPMC can be provided upon request free of charge to any interested researcher or institution. (www.environmental-robots.com)

Contact information: Mohsen Shahinpoor
Environmental Robots Incorporated
909 Virginia Avenue, NE, Suite 205
Albuquerque, New Mexico 87108
Tel: (505) 265 4479 Or send an email to
(shah@unm.edu)

BOOK REVIEWS

Biologically-Inspired Intelligent Robots

Y. Bar-Cohen and C. Breazeal (Editors)

With today's technology one can quite well graphically animate the appearance and behavior of biological creatures (e.g., Shrek and other cartoon movies). Advances in biomimetics are increasingly making it feasible to emulate creatures to the point that viewers will eventually react with "gosh, this robot looks so real!" just like the reaction to an artificial flower. There is already extensive heritage of making robots and toys that look and operate similar to human, animals and insects. The emergence of artificial muscles is expected to make such a possibility a closer engineering reality. A book, entitled “Biologically-Inspired Intelligent Robots,” covering this topic of biomimetic robots is currently in preparation and it is expected to be published in February 2003. The cover page of the book (Figure 18) presents the challenges to making such robots in terms of appearance, operation, facial expression, stability, robustness, etc. Where the hands and legs were made of parts of the Editor’s arm wrestling challenge for EAP.

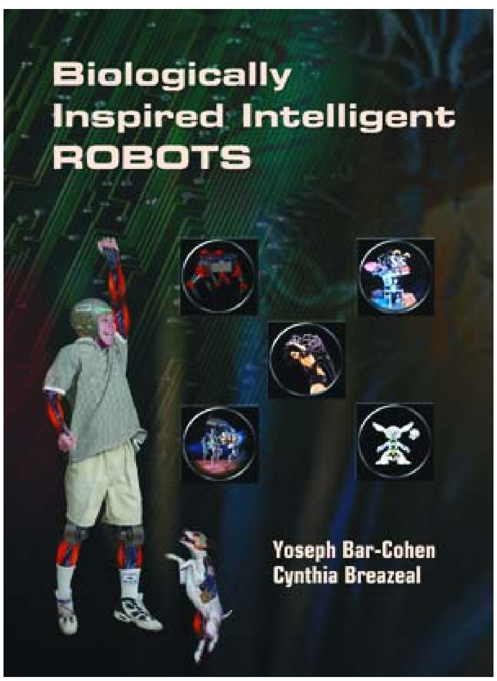


FIGURE 18: The draft of the cover page of the upcoming book on biomimetic robots. This book will describe the state of the art and challenges to making such robots

The issues that are involved are multidisciplinary and they include: materials, actuators, sensors, structures, functionality, control, intelligence and autonomy. It is interesting to address these technical issues but there are also fundamental ones that also need to be addressed. Some of these issues include self-defense, controlled-termination and many others. Inspiration from science fiction sets expectations that will continually be bound by reality and the state of the art. Effectively, this book is about the electro-mechanical equivalence of cloning and ….who knows, as these robots become more engineering reality they may rise to become a topic of public debut similar to the topic of cloning biology.

Further information about this book is available outline from SPIE Press on:
http://www.spie.org/web/abstracts/oepress/PM122.html

Acknowledgement
The graphics of the book cover-page was produced at JPL. A special thanks to Zensheu Chang, JPL, for making the pose of hopping and smiling for the photo that was used to create the human-like robot. Also, thanks to Jill Bonneville, JPL, whose eyes and nose photo were superimposed onto the face of the human-like robot. Moreover, thanks to David Hanson, Entrepreneur, for his contribution of the dog graphics that was used to produce the dog-like robot on the cover-page.

UPCOMING EVENTS

March 3-6, 2003	EAPAD, SPIE’s joint Smart Materials and Structures and NDE Symposia, San Diego, CA., Jill McClellan jillm@spie.org Website: http://spie.org/Conferences/Programs/03/ss/conferences/index.cfm?fuseaction=5051
June 2003	11th International Seminar on the Technology of Inherently Conductive Polymers, Matt Aldissi at: maldissi@fractalsystemsinc.com
April 2004	2nd “Biomimetics and Artificial Muscles,” Williamsburg, Virginia,M. Shahinpoor shah@unm.edu
June 14-16, 2004	ACTUATOR 2004, Messe Bremen GMBH, Germany. H. Borgmann, actuator@messe-bremen.de Website: http://www.actuator.de
August 2005	3rd “Biomimetics and Artificial Muscles,” France, M. Shahinpoor shah@unm.edu

EAP Archives

Information archives and links to various websites worldwide are available on the following (please use the web address below with no spaces):

Books and Proceedings:
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

Webhub: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm

Recipe: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-recipe.htm

Newsletter: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/WW-EAP-Newsletter.html

Opportunities:
http://www.acq.osd.mil/sadbu/sbir/solicitations/sttr02/navy02.htm

Biomimemtics: http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm

WorldWide Electroactive Polymers (EAP) Newsletter

EDITOR: Yoseph Bar-Cohen, JPL, http://ndeaa.jpl.nasa.gov

All communications should be addressed to:

Dr. Y. Bar-Cohen, JPL, M.S. 82-105, 4800 Oak Grove Dr., Pasadena, CA 91109-8099
Phone: (818)-354-2610, Fax: (818)-393-3254 or E-mail: yosi@jpl.nasa.gov