# WorldWide ElectroActive Polymers


# EAP

# (Artificial Muscles) Newsletter

**December 2000** **WW-EAP Newsletter** **Vol. 2, No. 2**

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

## FROM THE EDITOR

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

The field of EAP is continuing to expand and the number of investigators and potential users that are joining this effort is steadily growing. A reflection of this growth has been seen in the number of abstracts that were submitted to the upcoming SPIE EAPAD 2001 Conference. While in the first two years about 50 abstracts were submitted, for the upcoming conference over 70 abstracts were submitted. The topics of research that would be presented are covering a broad range of topics spanning from analytical modeling to application considerations.

In an effort to simplify the terminologies that are related to EAP materials, the Editor sought terms for grouping these materials. Initial attempt was made using the terms dry and wet however such materials as conductive polymers can be made both ways. Recently, the Editor initiated the terms electronic, and ionic. This distinction is related to the mechanism of actuation that is involved, where electronic refers to movement of electrons as in the case of ferroelectric and dielectric EAP. On the other hand, ionic EAPs are involved with mobility of cations or ions and the presence of electrolyte.

Applications are now being considered in numerous areas and it is hoped to see transition to practical use and the emergence of commercial products. It is increasingly recognized that the key to the growth of the field of EAP is the development of niche applications that take advantage of the unique capabilities of EAPs. The following are the application categories are currently being considered: (a) Human-Machine Interfaces: Haptic and tactile interfaces, Simulated textures and body orientation Indicators, Interfacing neuron to electronic devices, Active tactile display for the blind and artificial nose; (b) Planetary Applications; (c) Controlled Weaving: Garments, clothing and anti G-Suit; (d) Biologically-Inspired Robotics, Toys and Animatronics; (e) Medical Applications: EAP for biological muscle augmentation or replacement, Miniature in-vivo EAP robots for diagnostics and microsurgery, Catheter steering mechanism, Tissues growth engineering, and active Bandage (f) Liquid and gas flow control and pumping; (g) Noise reduction; (h) Electromechanical polymer sensors and transducers; and (i) Micro-electro-mechanical systems (MEMS)

## ABOUT THE EXPERTS

**Elisabeth Smela**
**is now at the University of Maryland, USA**

Elizabeth Smela moved in September from Santa Fe Science and Technology, Inc. (SFST) to the Department of Mechanical Engineering at the University of Maryland. This move brings here back to the area of micro-electro-mechanical systems (MEMS) and she will focus on actuators using electroactive polymers for microfluidics and micromanipulation. Also of interest to her are other microfabricated conjugated polymer devices, such as LEDs on silicon. Smela is considering the application of EAP also in small smart systems. Elisabeth Smela's new e-mail address is smela@eng.umd.edu her phone number is 301-405-5265 and her website address is: www.wam.umd.edu/~smela

**Toribio Otero**
**is now at the Polytechnical University of Cartagena, Spain**

At the beginning of October 2000, Toribio Otero left the University of the Basque Country, San Sebastian, Spain, to join the School of Industrial Engineering at the Polytechnical University of Cartagena, Spain. His new university was established at the end of 1998 and it is seeking to establish a department for smart materials. At his prior affiliation he has established a leading group in the area of EAP based on conducted polymers. He was the advisor for 20 doctoral graduates in theses related to EAP materials. He specialized in the control of the properties of conductive polymers through electro-synthesis, particularly polypyrrole, for which he patented the first related artificial muscle in 1992. Toribio Otero can be reached at the Universidad Politécnica de Cartagena, Cartagena, Spain, Phone: +34 68 325519, Fax: +34 68 325433, e-mail: toribio.fotero@upct.es

## LIST OF CONTENTS



# 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

## 2000 Nobel Prize in Chemistry

**2000 Nobel Prize in Chemistry for the developme nt of Conductive Polymers**

The Royal Swedish Academy of Sciences awarded the Nobel Prize in Chemistry for 2000 jointly to: Alan J. Heeger, University of California at Santa Barbara, USA; Alan G. MacDiarmid University of Pennsylvania, Philadelphia, USA; and Hideki Shirakawa, University of Tsukuba, Japan. The award was given for the discovery and development of conductive polymers. The winners made their seminal findings about the conductivity of polymers at the end of the 1970s and have subsequently developed conductive polymers into a research field of great importance for chemists as well as

physicists. The area of conductive polymers has also yielded important practical applications that are in use or being developed industrially, including anti-static substances for photographic film, shields for computer screen against electromagnetic radiation and for "smart" windows (that can exclude sunlight). In addition, semi-conductive polymers have recently been developed for light-emitting diodes, solar cells and as displays in mobile telephones and mini-format television screens. Currently, conductive polymers are used to produce EAP materials by combining layers of electrodes and electrolytes and dry forms were demonstrated as also reported in this issue of the Newsletter. Further information about this award and the winners is available on:
http://www.wam.umd.edu/~smela/nobel.htm

## 2001 SPIE EAPAD Conference

The 3nd Conference on EAP Actuators and Devices (EAPAD) will be held as part of the 8th SPIE Conference on Smart Structures and Materials in Newport Beach, California. The program of this EAPAD Conference (#4329) is now available for access via the internet on: http://spie.org/web/meetings/programs/ss01/confs/4329.html . This upcoming conference will be focused on electro-mechanically-active polymers and will include open discussion with a panel that consists of the invited speakers and the Conference Chair and Cochair. SPIE is currently considering the broadcast of the discussion on the internet and to allow participates to send online questions to the Panelist. An EAP-in-Action Session is now being planned for the conference and it is intended to allow the participants to see the latest EAP materials responding to electrical stimulation.

**KEYNOTE PRESENTATION: Brain-Machine Interfaces for Translating Thoughts into Action** - The Keynote Speaker at the EAPAD 2001 is Miguel Nicolelis from Duke University and he will be covering the topic of interfacing brain with robotics. Nicolelis and his coinvestigators have recently demonstrated the interfacing of the brain of a monkey to a robotic arm and the control of the arm using electrodes connected to the brain [http://www.dukenews.duke.edu/Research/niconat.htm]. Such a development is opening important opportunities for the EAP technology in the medical field. It may become feasible in future years to control EAP actuated artificial limbs directly from the brain of a human. This capability may allow physically impaired individuals to operated their prosthetics and independently perform tasks that may not possible otherwise.

**Miguel Nicolelis, Duke University, is the keynote speaker at the EAPAD 2001**

## 2001 MRS Fall Meeting

MRS is including a Symposium on EAP during the upcoming Fall 2001 meeting. This Symposium will be held in Boston, Nov. 26-30, 2001. The objective of this symposium is to provide a forum for the EAP researchers to exchange information and stimulate discussions and to present the recent advances to the audiences who are interested in the applications of this class of materials. The organizers are Siegfried Bauer (Johannes-Kepler Universitaet Linz, Austria), Yoseph Bar-Cohen (JPL), Eiichi Fukada (Koboyasi Institute of Physical Research, Japan), and Qiming M. Zhang (Penn State University). The Invited speakers are: F. Bauer (ISL, France), R. Fleming (Monash U., Australia), T. Furukawa (SU Tokyo, Japan), H. Kodama (Rion Co., Japan), K. Ikezaki (Keio U., Japan), F. Kremer (U Leipzig, Germany), J. Lekkala (VTT, Finland), M. Marsella (UC Riverside), Geoff Spinks (Australia), Danilo de Rossi (Italy), J. Su (NASA), Y. Tajitsu (Yamagata, Japan), K. E. Wise (USA). For more information you can contact Qiming M. Zhang qxz1@psu.edu or visit http://www.mrs.org/meetings/fall2001/

## Actuator 2002

A Session on EAP will be included in the ACTUATOR 2002, 8th International Conference on New Actuators, and 2nd International Exhibition on Smart Actuators and Drive Systems Bremen, Germany, 10-12 June 2002. ACTUATOR is a leading international Conference on piezoactuators,

magneto-strictive actuators, microactuators, microfluidics, shape memory actuators, electro-/magnetorheological actuators, low-power electro-magnetic actuators, vibration control, nanopositioning, actuators for artificial limbs, and other actuators as single components and, more importantly, as integrated parts of systems or even microsystems. For the first time polymer actuators are to be presented in a separate session. Abstracts are due by 30 November 2001 to actuator@messe-bremen.de. For additional information you can contact Hubert Borgmann, Messe Bremen GMBH Germany or visit http://www.actuator.de

## Biotechnology Materials

Recent advances in biotechnology are providing a basis for the design and synthesis of a wide range of novel materials, which may include EAP. There are a number of successful commercial and medical applications of biomaterials and biocatalysts. Also, there are additional areas in materials science where biocatalysts, biomolecules, or biomaterials can provide enabling technologies. Several groups in USA and Europe are exploring biotechnology in materials research. In contrast, the use of biotechnology for aerospace applications is in its infancy. To address this topic several workshop are being held in search for strategies to exploit the potential of biotechnology. Particular interest is in the identification of promising research topics in biocatalysis, biosensors, biobased materials, and biomimetics. A Europian on-line newsletter is being issued on this subject and it is accessible via http://www.biomat.net/ and the most recent issue is No. 11. For further information you can contact Jim Spain, jcspain@earthlink.net

# WORLDWIDE EAP INPUTS

## INDIA

### CHARACTERIZATION OF EAP USING ANTI-COMPTON EFFECT

- *T. Patel and B. Mallick* *tpatel@rec.ori.nic.in*

Electronic system (i. e. crystal, atom or molecule) of most of the atoms in polymeric material gets excited and some electrons recoil when the material is irradiated with X-rays in Compton process. When this recoil electron transfers it's kinetic energy partly or fully to another incident X-ray photon, it produces scattered radiation of higher frequency called anti-Compton effect [1]. Peaks resembling anti-Compton like scattering have already been found in Compton scattering experiment by Y. H. Woo [2]. Most probably due to lake of proper theory he could not identify these peaks as anti-Compton peak. Using this discovery, the authors suggested methods to develop X-Ray Frequency Multiplier [3], to calculate excited volume plasmon energy of polymeric materials [4] and to estimate lifetime of excited states in solid polymers [5] in papers presented in various seminar and symposia. Moreover, the properties of the electrons in solid can be better understood by X-ray using anti-Compton and Compton spectra which are very sensitive to band structure near fermi level and may also help in understanding fermiology of high Tc superconductor.

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## JAPAN

### CSE Kyushu Institute of Technology

### CONDUCTIVE POLYMERS OPERATING IN AIR

- *Keiichi Kaneto, Masamitsu Kaneko and Alan G. MacDairmid (Pennsylvania, Philadelphia )* *Kaneto@cse.kyutech.ac.jp*

Artificial muscles (soft actuators) are generating great interest in view of their potential for robots, medical equipment and the possibility of replacing human organs. Polymer gels [1], ion exchange membranes [2] and conducting polymers [3] so far have been studied as electroactive materials. In 1993, the authors started their study of soft actuators using the conducting polymer polyanilines. The most

interesting effort was the demonstration of "Shell" type actuators [4], which can be operated in air atmosphere as shown in Figure 1. This operation has been distinguished from the usual soft actuators operated in electrolyte solutions.

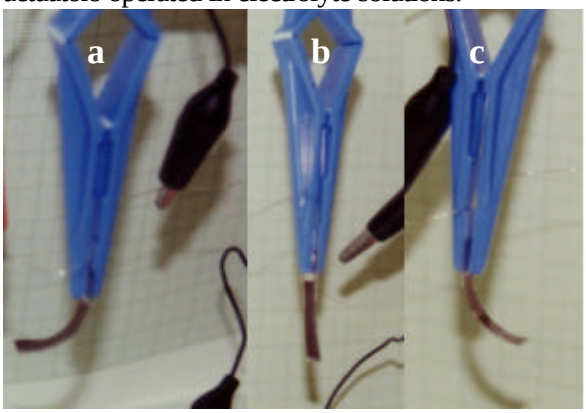


**FIGURE 1:** Movement of 'Shell type'' actuator in air based on polyaniline films References

The polyaniline actuators are operated in strong acid of pH < 3, which is not convenient for practical use. It has been found [5, 6] that the polypyrrole actuators, can be operated in quite wide pH ranges of 4 < pH < 10, indicating that the actuators can be used in such environmental electrolyte solutions as sea water, blood and urine. Recently, we found that polypyrrole film prepared by electrochemical deposition expands and contracts by about 1-3% with a contraction force of .5 MPa. The advantages of conducting polymer actuators include large contraction with a strong contraction force and ease to fabricate.

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## Tokushima University

**Control over gel's spatial conformation by light** - *Hiroaki MISAWA*
*misawa@eco.tokushima-u.ac.jp*

Polymer gels can be made to shrink or swell when exposed to changes in pH, temperature, chemical environment, and other factors. We have demonstrated that the radiation force of a focused laser beam also can cause polymer gels to shrink or expand (Figure 2), i.e. to undergo volume-phase transition, reversibly [*Nature* **408**, 178 (2000)]. Rod-shaped gels of poly(*N*-isopropyl-acrylamide) were prepared inside glass microcapillary tubes. The gels were soaked in $D_2O$ rather than $H_2O$ because it isn't significantly heated by the 1064-nm laser light (absorption coefficient of $D_2O$ at 1064 nm is only 0.1 $cm^{-1}$). Indeed, experiments showed that local heating was not responsible for the gel's collapse, because just a 1-2°C local temperature rise was measured from photoluminescence data at illumination laser power of 1.2 W (0.75 W laser power was enough to trigger volume-phase transition). Experiments were carried out at 27°C and the temperature of gel's volume-phase transition, 34°C, was never reached by direct local laser heating. Rather, the radiation pressure (a tightly focused laser illumination was used) upsets the balance of opposing attractive and repulsive forces between neighboring coils of polymer network and between polymer–solvent ($D_2O$) that usually hold the polymer in shape. This expands an applicability of the, so-called, laser tweezers for the tasks of control over volume phase transitions in polymer gels. The volume change occurs on a scale of seconds (depends on the initial diameter of the gel rod) by a $D_2O$ diffusion out of polymer network and is comparatively fast due to small dimensions. For example, the waist of a collapsed state (like in Figure 1b) on a gel rod of 30-μm diameter is totally formed within 2.5 s. The fast conformational changes of gel allows translating the shrunken location along a gel rod (Figure 2), even a formation and translation of the pre-programmed patterns could be feasible. The volume-phase transitions caused by other stimuli usually lacks control over the location, where it is induced and it is slow when dimensions of gels are on macro-scale (larger than 100 μm). The doping of PNIPAM gel by an ionic material, such as sodium acrylate (SA), allows controlling the temperature of the volume-phase transition. The doping by SA increases the temperature of the transition in PNIPAM gels. We think, our work may allow gels to be used as light-sensitive actuators and sensors, and perhaps for controlled release of a drug from a gel by local control over their volume-phase transition.

Co-authors: Saulius Juodkazis, Naoki, Mukai, Ryosuke Wakaki, Akira Yamaguchi, and Shigeki Matsuo.

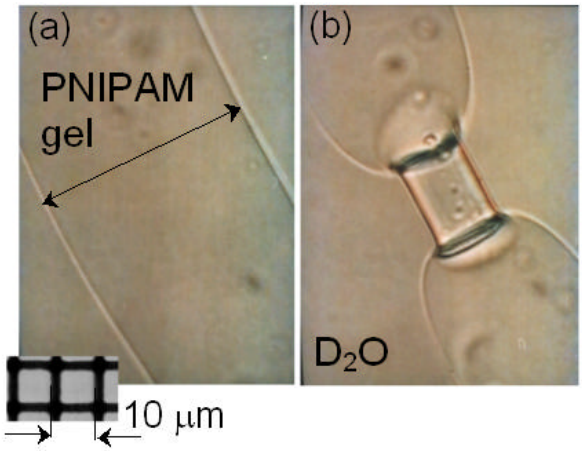


**FIGURE 2:** Micro-video image of Poly(*N*-isopropylacrylamide) (PNIPAM) gel rod in $D_2O$ before (a) and after (b) illumination by 0.75 W power laser illumination at $\lambda$ = 1064 nm wavelength.

## RUSSIA

### Moscow State University

**LIGHT-RESPONSIVE CHIRAL-PHOTOCHROMIC LIQUID CRYSTALLINE COPOLYMERS** - *V. Shibaev (lcp@genebee.msu.su), A. Bobrovsky, N. Boiko*

In parallel to the creation and study of EAP actuators, the photoresponsive liquid-crystalline cholesteric polymers with light-controllable optical properties are of considerable interest due to their helical supramolecular structure (Figure 3a) [1-3].

These polymers are the binary acrylic copolymers consisting of side nematogenic phenyl benzoate fragment and chiral-photochromic fragment containing menthyl and azobenzene groups in the same monomer unit. The latter plays the role of switchable trigger undergoing the *trans-cis* isomerization under the UV-irradiation. The action of the light leads to the change of the configuration and shape of photoisomerizing azobenzene fragments that is accompanied by the dramatic decrease of helical twisting power; helix is untwisted and helix pitch P increases (Figure 3b). If the initial film (before irradiation) selectively reflects the green light (~560 nm) so the region of selective reflection of light shifts to the red region (~620 nm) after irradiation.

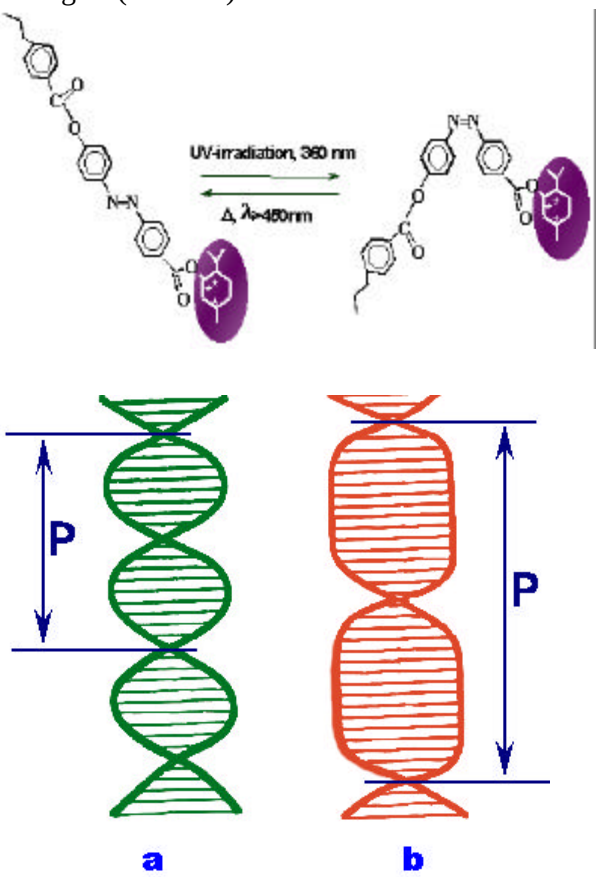


**FIGURE 3:** Scheme of cholesteric helix (**a**) before the irradiation and (**b**) untwisting of the cholesteric helix after UV-irradiation of polymer film.

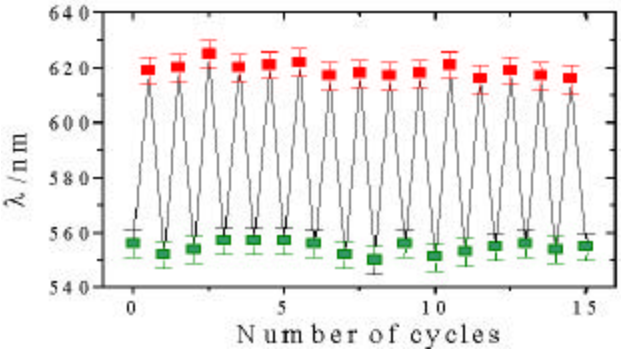


**FIGURE 4:** Reversibility of the helix "untwisting – twisting" process under the UV-irradiation and heating of the polymer film.

However, this process is completely reversible and reflection of light is again shifted to the green region after heating or irradiation of the film by the light with $\lambda$>450 nm (Figure 4). The polymers changed reversibley their color characteristics and other optical properties enabling new type of light-

controlled polymeric smart materials. Such materials can be used to create light sensitive devices, sensors, different kinds of light-sense receptors and other promising applications.

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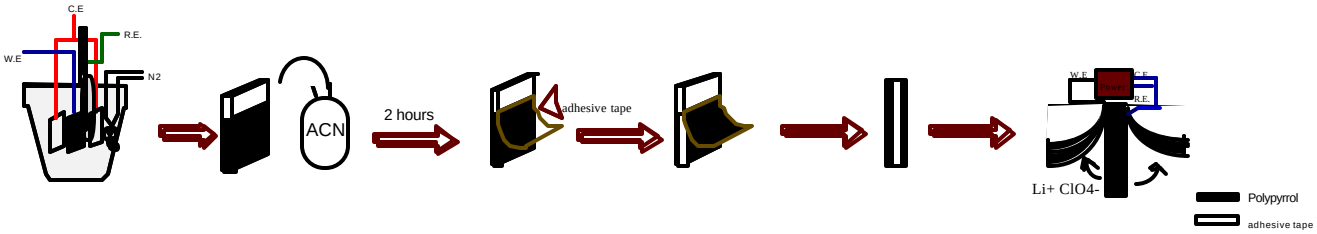


**FIGURE 5:** Fabrication of a triple layer device and electrical connections.


***ACKNOWLEDGMENT***

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## SPAIN

### TRIPLE LAYER ARTIFICIAL MUSCLES: ACTUATOR AND SENSOR


- *T. F. Otero*

*qppfeott@sq.ehu.es*, *MªT. Cortés*


Following the methodology [1] developed by our laboratory to produce double layers, a triple layer device: conducting polymer/double-sided tape/ conducting polymer, was obtained. A steel sheet (3 cm x 1.5 cm) was (2 cm x 1.5 cm) coated by electropolymerization using square waves of potential from acetonitrile containing pyrrole, $LiClO_4$ and a 2% of water. Once rinsed and dried a double-sided tape, one side protected, is adhered to the partially oxidized polypyrrole film coating one of the steel surfaces. The polypyrrole / double sided plastic tape was stuck to the second polypyrrole coated face of the steel. The final triple layer polypyrrole/double-sided plastic tape/ polypyrrole is removed and is ready to be used inside a solution. Experimental procedure and electrical connections are shown schematically in Figure 5.

The displacement of the material was characterized under different electrical or chemical conditions. Table 1 shows the results that were obtained under a constant current of 10 mA and changing the concentration of the electrolyte. The intensity and direction of the current (the charge) flowing through the system controlled both the rate and direction of the angular movement. Being constant the current, consumed charges, movement rates and times required to cross over 90 degrees are constant: the movement is under electrical control and it is working as an electro-chemo-positioning device.

Changes of the chemical variable originate shifts of the electric potential between the working electrode and the reaction electrode: increasing concentrations originate decreasing consumed electrical energies. The straightforward relationship between consumed energy and concentration indicates that our actuator behaves, at the same time like a sensor without any additional wire. In Figure 6, this actuator is shown carrying about 60 times its own weight.

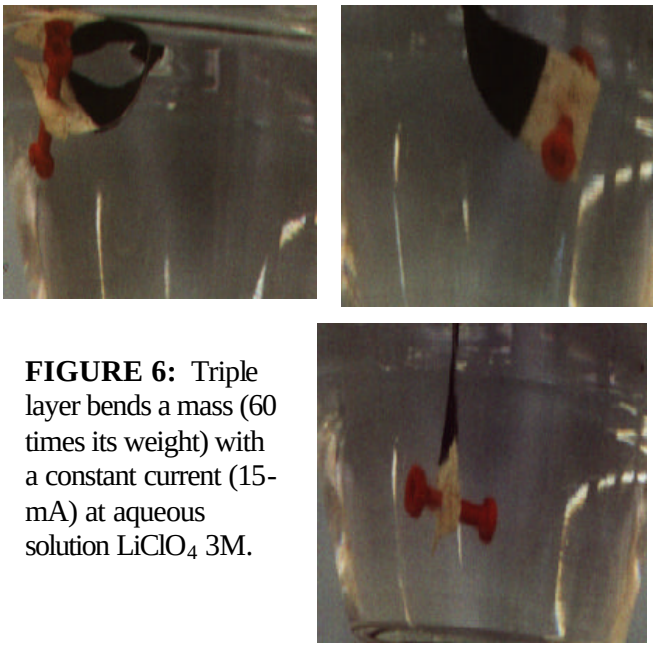

**FIGURE 6:** Triple layer bends a mass (60 times its weight) with a constant current (15-mA) at aqueous solution $LiClO_4$ 3M.

**TABLE 1**: Influence of electrolyte concentration on the movement of a trilayer in galvanostatic conditions (10 mA), to cross over 90° from equilibrium position.

| [LiClO4] (M) | 0.05 | 0.1 | 0.25 | 0.5 | 1 | 3 |
|---|---|---|---|---|---|---|
| **Time (s)** | 27 | 26 | 26 | 26 | 25 | 25 |
| **Consumed Charge (mC/mg)** | 24 | 23 | 23 | 23 | 23 | 23 |
| **Consumed Electrical Energy (kJ/Kg)** | 44 | 31 | 22 | 19 | 17 | 15 |
| **Movement Rate (rad/s)** | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |


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# USA

## Jet Propulsion Laboratory (JPL)

### EAP CHARACTERIZATION – IPMC OPERATION UNDER LOAD - *Y. Bar-Cohen, yosi@jpl.nasa.gov, S.-S. Lih, V. Olazábal, J. Sansiñena, JPL, K.* Bhattacharya *and Yu Xiao, Caltech*

Implementing EAP materials as actuators requires the availability of properties database and scaling laws to allow the actuator or transducer designers to determine their response at the operational conditions. A metric for the comparison of these materials' properties with other electroactive materials and devices is needed to support users in making these materials as actuators of choice. In an effort to address this need a series of test capabilities are being established/developed at JPL. IPMC was identified as posing the greatest challenges and one of the areas that require adequate attention is the determination of properties under electrical excitation. An experimental setup and inversion algorithm were developed and currently being studied to extract the elastic modulus, the saturation curvature at unit applied voltage and the time-constant. The tip of IPMC strips is loaded with various weights and the data is recorded. The detailed conditions of clamping the sample and the mass are elements that affect the accuracy and repeatability of the measurement and efforts are made to address these issues. The video acquisition system is based on the system that was reported in previous issues and the process of data acquisition is being automated for consistency.


**ACKNOWLEDGMENTS**

This research is carried out under a DARPA contract.



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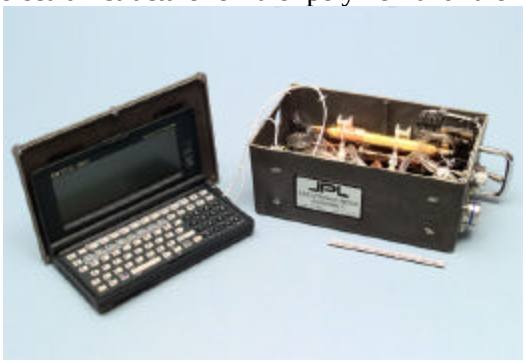
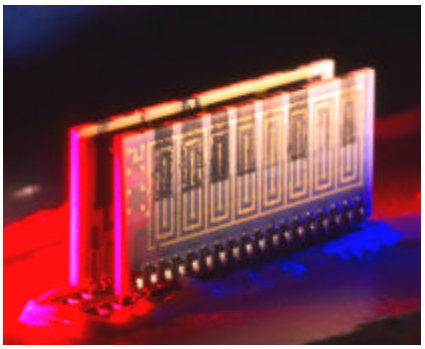
### ARTIFICIAL NOSE - *Margaret Amy Ryan* *Margaret.A.Ryan@jpl.nasa.gov*

An electronic nose is an array of weakly specific chemical sensors, controlled and analyzed electronically, mimicking the action of the mammalian nose by recognizing patterns of response to vapors. Unlike most existing chemical sensors, which are designed to detect specific chemical compounds, the sensors in an electronic nose are not specific to any one compound, but have overlapping responses. Gases and gas mixtures can be identified by the pattern of the responses of the sensors in the array. The Electronic Nose or Artificial Nose is a concept that has been discussed since the mid-1980s. There are several such devices, which have been built and tested, and with some that are using chemical sensors in an array [Bartlett and Gardner, 1999]. The technology is now at the level that there are commercially available electronic noses, and they have been applied to environmental monitoring and quality control in such varied fields as food processing and industrial environmental monitoring.

Chemical sensors are made from several different materials and act by several different mechanisms, including conducting polymers and insulating polymers. Conducting polymers such as polyanilines or polypyrroles can be used as the basis for a conductometric sensor, where change at the sensor is read as change in resistance. The ability of conducting polymers to detect a wide variety of compounds can be extended by mixing other polymers with the conductor [Freund and Lewis, 1995]. An electronic nose that uses polymers as the basis of the chemical sensors is under development at JPL (see Figure 7) for such applications as event

monitoring on the International Space Station. The polymer-based sensors used in the JPL ENose were developed at Caltech [Lonergan, et al, 1996]. They are insulating polymers, which have been loaded with a conductive material such as carbon black. A thin film of the polymer/conductor composite will absorb vapor molecules into the matrix and the matrix will change shape, changing the relative orientation of the conductive particles. That change results in a change in resistance, which is used to form the pattern of response. The magnitude of the response can be related to the concentration of vapor, and mixtures of a few compounds can be deconvoluted. The library of compound patterns that the ENose contains depends on the particular space in which it is used and the hazards of that space. New compounds can be added to the library as the device is exposed to them. ENoses in different spaces can be equipped with different polymers in the array and, therefore, a different library. The polymers for an array are selected by molecular structure of the polymer and the target





compounds for that array.

**FIGURE 7:** A photographic view of the JPL's Enose system (left) and the chemical sensor array (right)

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## Massachusetts Institute of Technology (MIT)

### LARGE STRAIN MOLECULAR ACTUATORS


*- John D. Madden jmadden@mit.edu, Hsiao-hua Yu, Patrick A. Anquetil, Timothy M. Swager and Ian W. Hunter*


Actuation in low voltage EAP devices is generally attributed to ion and solvent flux. An alternative approach to generating work makes use of molecular scale conformational changes along the polymer backbone. In this collaboration, we are synthesizing and characterizing a number of candidate electroactive polymers that promise to generate strains of 20 % or more at stresses in excess of 0.5 MPa. One of the polymers under study is shown in Figure 8. It features molecular hinges separated by stiff thiophene oligomer rods. Electrochemical and EPR data from this and related polymers suggest that oxidation leads to π-stacking of thiophene oligomers [2], producing a reversible displacement as depicted in Figure 9. We are proceeding to mechanical testing. This work is supported by the Office of Naval Research.

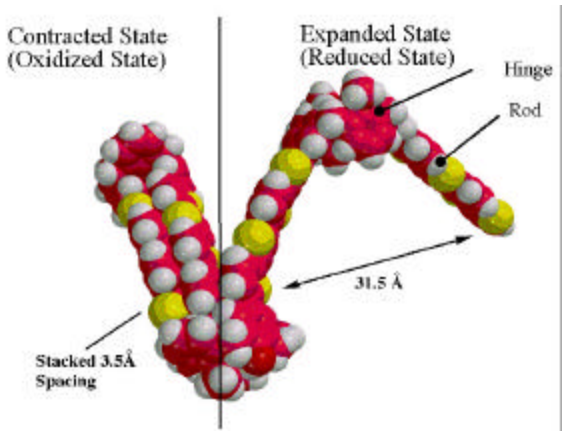



**FIGURE 8**: Chemical structure of a candidate molecular actuator.

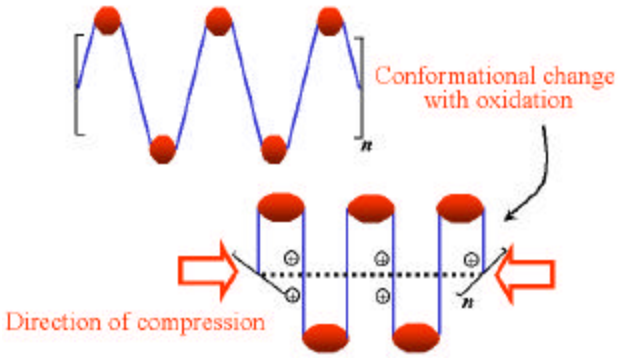



**FIGURE 9:** Actuator contraction mechanism.

**REFERENCES**

1. Kingsborough, Richard P. and Swager, Timothy M. Polythiophene Hybrids of Transition-Metal Bis(Salicylidenimine)s: Correlation Between Structure and Properties. Journal of the American Chemical Society, 1999, 121(38), 8825-8834.

2. See http://bioinstrumentation.mit.edu .

## NASA LaRC

**POLYMERIC SENSOR-ACTUATOR DUAL FUNCTIONAL MATERIALS** - *Ji Su, j.su@larc.nasa.gov and Joycelyn S. Harrison, j.s.harrison@larc.nasa.gov*

Recent development shows that electrostrictive graft elastomers can offer promising electromechanical actuation due to their large electric field-induced strain and good mechanical modulus. The excellent processability of the materials allows the development of a sensor-actuator dual functional polymeric molecular hybrid system with piezoelectric poly(vinylidene fluoride)(PVDF)-based copolymers. The hybrid system contains electrostrictive and pie zoelectric components (Figure 10 and 11). The system exhibits in addition to the electrostriction also improved piezoelectric response and temperature dependence of the piezoelectric response. The co-existance of the piezoelectric and electrostrictive mechanisms makes the materials good for both piezoelectric sensor function and electrostrictive actuator function. The promising electro-mechanical properties combined with their excellent processability make the dual functional materials a good candidate for many applications, especially micro-electro-mechanical systems (MEMS) and electro-optical devices. The development of the electrostrictive-piezoelectric sensor-actuator dual functional materials offers a new route to develop desired polymeric smart materials through molecular engineering.

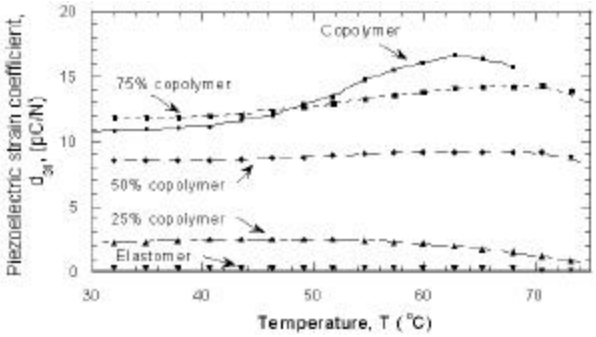



**FIGURE 10**: .The temperature dependence of the piezoelectric strain coefficient, $d_{31}$,of the blend films (1 Hz) as a function of the various compositions.

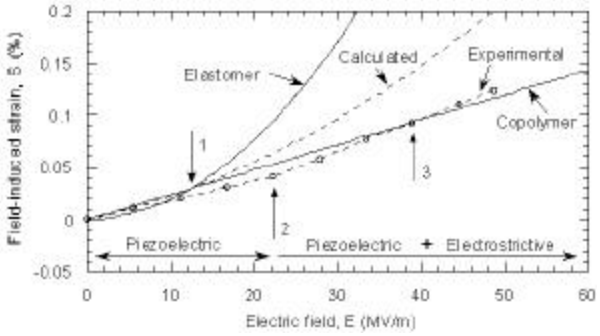



**FIGURE 11**: Comparison between the experimental strain response of the 75 wt.% copolymer blend with the prediction

## SRI International

**DIELECTRIC ELASTOMER PRODUCES A STRAIN OF 380%** -*Roy Kornbluh kornbluh@lax.erg.sri.com, Ron Pelrine, Roy Kornbluh and Qibing Pei*

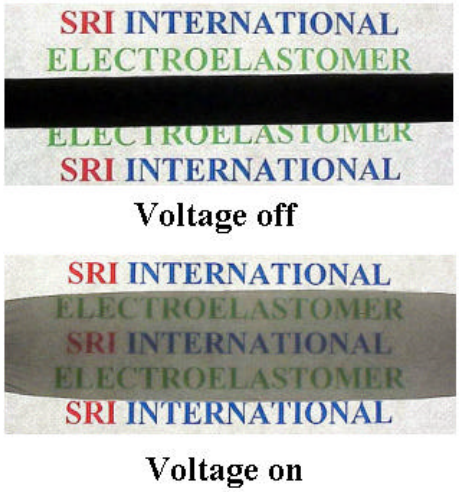



**Figure 12:** Opacity variation of an acrylic-based dielectric elastomer film due to an applied voltage.

Researcher Qibing Pei of SRI international has broken SRI's own record for strain response in an electric-field-activated polymer. An in-plane strain of 380% was induced in an acrylic-based dielectric elastomer film. Such large strains can enable new classes of devices. For example, SRI has shown that large planar strains can be used to modulate the amount of light through a film. Figure 12 shows how the application of a voltage to an electroactive polymer film makes the film more transparent.

## University of Arizona (UA)

### ELECTRICALLY DRIVEN MINIATURE HYDROGEL AS MUSCLE-LIKE ACTUATORS - *Yuka Yoshioka*

*yukay@u.arizona.edu and Paul Calvert*
*calvert@engr.arizona.edu*

New synthesis methods for ionic hydrogel EAP materials are needed to provide a rapid response and higher strength. Miniaturization is one approach to improve the response speed, since the time for the volume change is proportional to the square of the gel size. Gels based on vinyl polymers such as poly(acrylamide-acrylic acid) copolymer and poly(vinyl alcohol-sodium acrylate) copolymer have been widely studied. In past work, we made electrically-driven actuators based on an asymmetric stack of acrylic acid and acrylamide hydrogel. The different response of the two surfaces resulted in a linear contraction and expansion, rather than bending, when current was passed [1]. We want to make sub-millimeter scale versions of these actuators but it is difficult to carry out controlled free radical polymerizations on this small scale. We are making amine-epoxy based gel actuators since this chemistry scales down easily and is expected to give enough strength for practical use with highly crosslinked networks. In this study, a small drop of cationic polyelectrolyte gel was prepared by crosslinking of trifunctional polyethereamines with ethylene glycol diglycidyl ether. The response of these materials to electrical stimuli, pH and metal ions is controlled by the crosslink density and ionic strength of the medium. When gels contact a platinum anode, positive charges on amine groups are generated and this repulsion causes the swelling. Reversing current neutralizes amines and the hydrogen bonding interaction causes a volume collapse. These gels show large and rapid swelling in response to an electrical and chemical input in sub-millimeter scale. Now, we are forming these gels by printing on a metal PC board {Figure 13}, which could be used to move a device on, such as a tiny valve or a mirror to reflect a laser beam.

**REFERENCES:**

1. Liu, Z., Calvert, P., *Adv. Mater.* **2000**, *12*, 288
2. http://www.aml.arizona.edu/faculty/calvert/

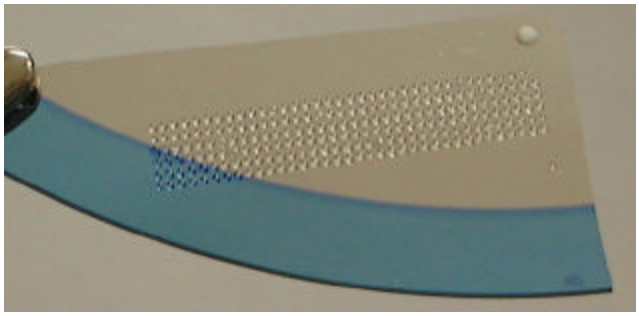


**FIGURE 13**: Printed gels on the platinum board, (dots are 100 microns apart).

# DESIRED EAP APPLICATIONS

The field of EAP has enormous potential to many areas and, judging from the range of inquiries that the Editor received so far, it seems that almost any aspect of human life can be impacted. While some ideas may still be science fiction it is important to scope the requirements to the level that current materials can address. As an emerging field, at this time, the Editor is still not aware of any commercial product that is driven by EAP as an actuator. Using EAP to replace existing actuators may be a difficult challenge and therefore it is highly desirable to see a niche application enabling new capabilities. This objective of this section is to help accelerating the progress towards practical applications by providing those who are seeking to use such material a forum to express their need directly to the EAP materials developers. Interchange among those who are expressing the need and the developer is highly welcome and feedback as well as success story submitted to this Newsletter would be greatly appreciated.

## NETHERLANDS

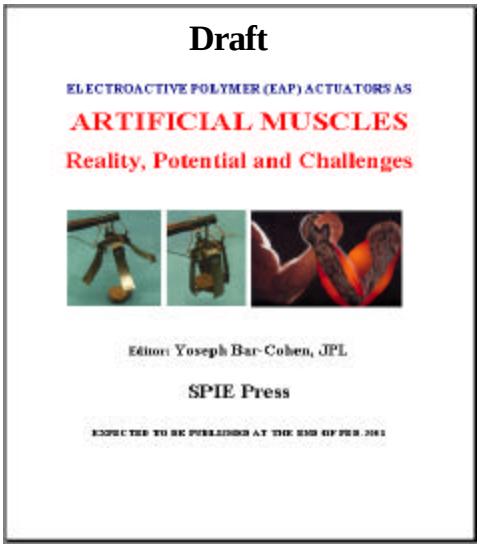
### Ruijsink Dynamic Engineering

http://www.ruijsink.nl/mm_hoofd.htm

**ACTUATORS FOR MICRO MODEL AIRCRAFT** - *Rick Ruijsink, info@ruijsink.nl*

Not only the military world is looking into the prospects of microflight, but also in the hobby/ scientific world there is a growing interest in the extremes of flight. Currently the smallest commercial radio-control gear is based on magnetic actuators. The smallest actuators now have a mass of 0.7 grams, delivering about 0.02 N with a stroke of ± 5 mm when powered with 3 Volts 30 mA. We see a use for EAP actuators that can deliver more power at lower weight and from a power source of 5.0 down to 1.8 volts. A position control is preferred over a force control. The control shall be bi-directional. The desired controlspeed is full deflection in 0.3 seconds or less while the actuator shall sustain its deflection or at least 80% of it under steady state conditions (several minutes). Operational temperatures range from 0°C to 50°C.

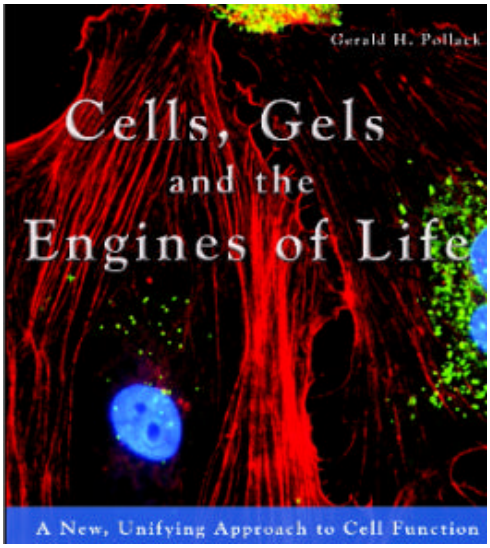
# BOOKS AND PUBLICATIONS




**Y. Bar-Cohen (Ed.), "ELECTROACTIVE POLYMER (EAP) ACTUATORS AS ARTIFICIAL MUSCLES Reality, Potential and Challenges," SPIE Press.**

This book on EAP is being published by SPIE Press and it is expected to be available at the end of Feb. 2001. This book is reviewing the state-of-the-art of the field of Electroactive Polymers (EAP), so-called Artificial Muscles. In writing this book, efforts were made to cover the field of EAP from all its key aspects, i.e., its full infrastructure, including the available materials, analytical models, processing techniques, characterization methods and applications that are being investigated. It is intended to serve as a reference book, technology users guide, and tutorial resource, as well as create a vision for the future direction of this field. The draft of the book outline is available on

http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-book_outline.htm The book is expected to be published by SPIE Press at the end of February and to be available during the EAPAD 2001 conference. For information about purchasing the book you can contact SPIE by calling (360)-676-3290, or e-mail to bookorders@spie.org or visit the SPIE site http://www.spie.org/bookstore




"**Cells, Gels and the Engines of Life: A New, Unifying Approach to Cell Function**" by Gerald H. Pollack, Dept. of Bioengineering, Univ. of Washington, Seattle. Published by Ebner and Sons, early 2001.

This provocative book challenges the current wisdom of how cells work. It emphasizes the gel-like nature of the cell, and builds on this feature to explore underlying mechanisms of communication, transport, contraction, division, and other essential cell functions. These mechanisms turn out to be

considerably simpler than those currently envisioned in textbooks. Emphasis is placed on mechanisms of biological movement, which may be of interest to those in the EAP field. The book is written by an engineer, in a style that is accessible to non-experts. For more information please visit: www.cellsandgels.com

## UPCOMING EVENTS

| | |
|---|---|
| March 5-9, 2001 | SPIE joint Smart Materials and Structures and NDE, Newport Beach, CA., Pat Wight patw@spie.org Website: http://spie.org/web/meetings/programs/ss01/confs/4329.html |
| Nov. 26-30, 2001 | MRS, Boston, MA, Website: http://www.mrs.org/meetings/fall2001/ |
| March 17-21, 2002 | Space 2002 and Robotics 2002 Albuquerque, New Mexico. Stewart Johnson StWJohnson@aol.com |
| June 10-12, 2002 | ACTUATOR 2002, Hubert Borgmann, Messe Bremen GMBH, Germany. Website: http://www.actuator.de |
| June 18 – 21, 2002 | Optatech, Active Materials & Applications, Photonic Devices Europe, Frankfurt, Germany, SPIE, Terry Montonye, terry@SPIE.org |

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***WorldWide Electroactive Polymers (EAP) Newsletter***

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