WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

Vol. 9, No.1 **WW-EAP Newsletter** **June 2007**

http://eap.jpl.nasa.gov

FROM THE EDITOR

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

Progress is continuing to be made in this emerging field of Electroactive Polymers (EAP). Advances are reported in numerous communication forms and forums including journals, conferences, symposia, meeting, workshops and others. Further, the potentially significant role that EAP as artificial muscles can play in various engineering applications is now well recognized and sought after. The scale of the application of these materials has reached the level of 3-m device and it was presented by EMPA, Switzerland, at the recent EAPAD Conference that was held in San Diego, CA on March 19 this year. They demonstrated a blimp that was equipped with dielectric elastomer EAP actuators to allow controlling the angle of each of its four fins and thus steering it in air. Currently, EMPA is working on the possibility of developing a blimp with EAP that will control its surface such that it will be able to propel itself by wagging its tail like a fish. This would enable enormously powerful capability of making completely quiet blimps as flying machines. Not too far back, making such a blimp with active surfaces that emulates a fish movement while operating in air would have been considered a science fiction, but now it seems to be approaching an engineering reality.

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ABOUT THE EXPERT

Michael Wissler

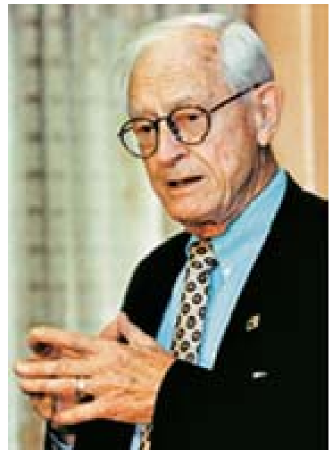
In April 2007, Michael Wissler successfully passed his PhD exam at ETH Zurich (Switzerland). Since 2003, he worked as PhD student at Empa (Duebendorf) and ETH. The topic of his PhD dissertation is "Modeling dielectric elastomer actuators". He investigated circular actuators made of VHB 4910 and he studied new constitutive models, electromechanical coupling, finite element simulations, material parameter optimization, numerical implementation and experimental characterization. Now that he completed his PhD studies he plans to work in industry. For contact or ordering the thesis, the email address of Michael Wissler is mtwissler@hotmail.com.

Ravi Shankar

In June 2007, Ravi Shankar successfully completed his PhD in Fiber and Polymer Science and Materials Science and Engineering from North Carolina State University. The topic of his PhD dissertation was "Electroactive Behavior of Nanostructured Polymers". He is an active member of our SPIE's EAPAD community since 2006. He presented parts of his work on electroactive nanostructured polymers (ENPs) at Materials Research Society (MRS), and SPIE EAPAD, conferences in 2006 and 2007, respectively. Ravi has published an invited review of the EAP literature with an emphasis on dielectric elastomers in 'Soft Matter' along with his advisors Dr. Tushar K. Ghosh and Dr. Richard J. Spontak. For contact, the e-mail address of Ravi Shankar is ravishankar.aggarwal@gmail.com.

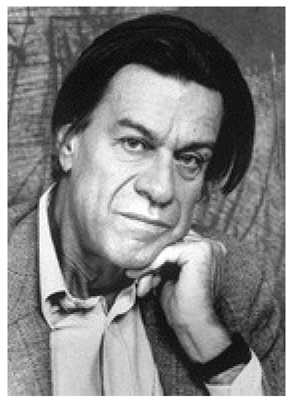
OBITUARIES FOR 2 NOBEL LAUREATES

Alan MacDiarmid



Alan MacDiarmid, one of the three 2000 Nobel Prize winners for the contributions to the development of Conductive Polymers, died on February 7. He was born in 1927 in Masterton, New Zealand. He received his M.S. degree in 1952 and his PhD in 1953 from the University of Wisconsin-Madison. He completed a second PhD, in 1955, from Cambridge University under a Shell Scholarship. He then took a position at the University of Pennsylvania and in 1964 he became a full Professor.

Pierre-Gilles de Gennes



Pierre-Gilles de Gennes, a Nobel Laureate French physicist, who was a member of our SPIE's EAPAD Conference Organization Committee since 2002, has passed away near Paris on May 18 at the age of 74. He was well known for his research that led to the modern liquid-crystal displays. He received the 1991 Nobel Prize for his contribution to the understanding of what happens at the crucial times and places of transition, in which the geometric orderliness of molecules in crystals turns into out of order molecules in a liquid. Pierre-Gilles de Gennes was born in 1932 in Paris, France. In 1959, he did postdoctoral research in solid-state physics at the University of California at Berkeley. He then served in the France's Navy where he worked initially on superconductors and then on liquid crystals.

GENERAL NEWS

The WW-EAP Webhub is continually being updated with information regarding the EAP activity Worldwide. This webhub can be reached on http://eap.jpl.nasa.gov and it is a link of the JPL's NDEAA Technologies Webhub of the Advanced Technologies Group having the address: http://ndeaa.jpl.nasa.gov

First DARPA Prosthetic Limb Prototype

Under the DARPA's Revolutionizing Prosthetics Program, an international team led by the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Md., has developed a prototype of the first fully integrated prosthetic arm that can be controlled naturally, provide sensory feedback and allows for eight degrees of freedom. The developed prosthetics is a complete limb system that also includes a virtual environment used for patient training, clinical configuration, and to record limb movements and control signals during clinical investigations. The first prototype was fitted onto the patient Jesse Sullivan for clinical evaluations by the Rehabilitation Institute of Chicago (RIC). He was able to reposition his thumb for different grips, remove a credit card from a pocket, stack cups while controlling his grip force using sensory feedback verses vision, and to walk using the free swing mode of the limb for a more natural gait. This new limb system includes a natural-looking artificial covering that was created using photographs of the patient's native limb taken before he had the accident that made him a disabled. Further information is available at http://www.jhuapl.edu/newscenter/pressreleases/2007/070426.asp

RECENT SPECIAL ISSUES OF JOURNALS DEDICATED TO EAP

J. Bioinspiration and Biomimetics

The June 2007 (Vol. 2, No. 2, 2007) issue of the Journal of Bioinspiration and Biomimetics - Learning from Nature was dedicated to the topic of biomimetics using electroactive polymers as artificial muscles. The Guest Editor of this issue is the Editor of this Newsletter, Y. Bar-Cohen. He also wrote the introduction and background article entitled "Focus on Biomimetics Using Electroactive Polymers as Artificial Muscles." The following is the list of the papers that are part of this issue. This issue is published in a hardcopy and internet version and the address for the latter is http://www.iop.org/EJ/toc/1748-3190/2/2 (papers can be downloaded free of charge till Aug. 5, 2007).

Fujisue H., T. Sendai, K. Yamato, W. Takashima and K. Kaneto, "Work behaviors of artificial muscle based on cation driven polypyrrole," p. s1

Tangorra J., P. Anquetil, T. Fofonoff, A. Chen, M. Del Zio and I. Hunter, "The application of conducting polymers to a biorobotic fin propulsor," p. s6.

Alici G., G. Spinks, N. N. Huynh, L. Sarmadi and R. Minato, "Establishment of a biomimetic device based on tri-layer polymer actuators—propulsion fins," p. s18

Yim W., J. Lee and K. J. Kim, "An artificial muscle actuator for biomimetic underwater propulsors," s31

Jung K., J. C. Koo, J.-D. Nam, Y. K. Lee and H. R. Choi, "Artificial annelid robot driven by soft actuators," p. s42

Carpi F., and D. de Rossi, "Bioinspired actuation of the eyeballs of an android robotic face: concept and preliminary investigations," p. s50

J. of Smart Materials and Structures

The April issue (Volume 16, Number 2, 2007) of the J. of Smart Materials and Structures was dedicated to the topic of Electroactive Polymer Materials. The Guest Editors are Yoseph Bar-Cohen, Kwang J Kim, Hyouk Ryeol Choi and John D W Madden. This issue and its papers can be viewed at http://www.iop.org/EJ/toc/0964-1726/16/2 The issue starts with an editorial article authored by its Guest Editors and it is entitled "Electroactive polymer materials." It provides introduction and background to this issue. The other papers include:

Zhang L., and Y. Yang, " Modeling of an ionic polymer–metal composite beam on human tissue," p. S197
V. B. Sundaresan and D. J. Leo, "Controlled fluid transport using ATP-powered protein pumps," p. S207
Wang J., C. Xu, M. Taya and Y. Kuga, "A Flemion-based actuator with ionic liquid as solvent," p. S214
Dogruer D., J. Lee, W. Yim, K. J. Kim and D. Kim, "Fluid interaction of segmented ionic polymer–metal composites under water," p. S220
Plante J-S, and S. Dubowsky, "On the properties of dielectric elastomer actuators and their design implications," p. S227
Cho M S, H J Seo, J D Nam, H R Choi, J C Koo and Y Lee, "An electroactive conducting polymer actuator based on NBR/RTIL solid polymer electrolyte," p. S237
Mirfakhrai T., J. Oh, M. Kozlov, E. C.W. Fok, M. Zhang, S. Fang, R. H. Baughman and J. D. W. Madden, "Electrochemical actuation of carbon nanotube yarns," p. S243

Kaneto, K. H. Fujisue, M. Kunifusa and W. Takashima, "Conducting polymer soft actuators based on polypyrrole films—energy conversion efficiency," p. S250
Akle B., S. Nawshin and D. Leo, "Reliability of high strain ionomeric polymer transducers fabricated using the direct assembly process," p. S256
Chen Z., Y. Shen, N. Xi and X. Tan, "Integrated sensing for ionic polymer–metal composite actuators using PVDF thin films," p. S262
Delille R., M. Urdaneta, K. Hsieh and E. Smela, "Compliant electrodes based on platinum salt reduction in a urethane matrix," p. S272
Mok Ha S., W. Yuan, Q. Pei, R. Pelrine and S. Stanford, "Interpenetrating networks of elastomers exhibiting 300% electrically-induced area strain," p. S280
Jung K., J. Lee, M. Cho, J. C. Koo, J.-d. Nam, Y. Lee and H. R. Choi, "Development of enhanced synthetic elastomer for energy-efficient polymer actuators," p. S288
Tsai H.-K. A., K.-S. Ma, C. Wang, H. Xu, C. Wang, J. Zoval, L.e Kulinsky and M. Madou, "Development of integrated protection for a miniaturized drug delivery system," S295
Carpi F., C. Salaris and D. De Rossi, "Folded dielectric elastomer actuators," S300
Kovacs G., P. Lochmatter and M. Wissler, "An arm wrestling robot driven by dielectric elastomer actuators," p. S306

RECENT CONFERENCES

2007 SPIE EAPAD Conference

The EAPAD Conferences, which started in 1999, is continuing to be the leading international forum for the field of EAP. The conference this year was held again in San Diego, California, from March 18-22, 2007 and it was chaired by Y. Bar-Cohen, JPL, and Co-chaired by Gabor Kovacs, EMPA Dübendorf. As in past years, this conference included presentations from leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas. The papers were 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 characterization of the properties and performance as well as various applications. Also, as in past years, an EAPAD Course (see Figure 1) was given on Sunday, March 18, and an EAP-in-Action Session was held on Monday, March 19, 2007. The students who attended were from various counties and affiliations (including academia and industry).

FIGURE 1: Some of the students that attended the 2007 EAPAD course

The Keynote Speaker was George V. Lauder, who is an Alexander Agassiz Professor of Zoology and Professor of Organismic and Evolutionary Biology at Harvard University (Figure 2). He presented a paper entitled "How fishes swim: flexible fin thrusters as an EAP platform." In his paper, he discussed the results of recent experimental kinematic, biomechanical, and hydrodynamic studies of fish fin function, with a special focus on possible applications of EAP materials in aquatic robots. Recent high-resolution video analyses of fish fin movements during locomotion show that fins undergo much greater deformations than previously suspected. Experimental work on fin mechanics shows that fishes also possess a novel mechanism for actively adjusting fin surface curvature to modulate locomotor force. Experimental study of fish propulsion in combination with computational fluid dynamic analysis provided a basis for the design of robotic fin-thrusters for use in low-speed maneuvering underwater vehicles. EAP technology could play an important role in the development of such biomimetic thrusters.

FIGURE 2: George V. Lauder, Harvard University, was the Keynote Speaker in the EAPAD 2007

In this conference, there were eight invited papers including:

- Jean-Sebastien Plante, MIT (with Steve Dubowsky), "A Road to Practical Dielectric Elastomer Actuators Based Robotics and Mechatronics: Discrete Actuation"
- Federico Carpi, U. of Pisa, Italy, " Contractile folded dielectric elastomer actuators"
- Tony Jun Huang, Penn State U., "Towards Artificial Molecular Motor-Based Electroactive/ Photoactive Biomimetic Muscles"
- John D. Madden, Canada, "Electro-active polymer actuator database and online reference"
- Barbar J. Akle, Virginia Polytechnic Institute and State Univ., "Development and Modeling of Novel Extensional Ionic Polymer Transducers"
- Rick Minato (& Gürsel Alici) Univ. of Wollongong, Australia (Only 20 minutes), "Tri-layer Conducting Polymer Actuators with Variable Dimensions"
- Seon-Jeong Kim,, Hanyang Univ. (Only 20 minutes), "New Modified EAP Nanofibers for Biomedical Applications"
- James L Tangorra, MIT, "The Application of Conducting Polymers to Biorobotic Fins and Other Devices"

Also, on Monday, March 19, an EAP-in-Action session was held as part of this Conference. As in past years, this Session is intended to turn the spotlight on EAP materials and their applications as well as increase the recognition of their potential. It offers a forum of interaction between the technology developers and potential users as well as "hands-on" experience with this emerging technology. The attendees are given a great opportunity to see the capability of state-of-the-art of EAP as potential actuators-of-choice. The Session consisted of five research and industry presenters who demonstrated their latest EAP actuators and devices. The affiliation of the presenters includes Artificial Muscle, Inc.; EMPA - Materials Science & Technology, Switzerland; Ras Labs, L.L.C., Intelligent Materials for Prosthetics & Automation; SRI International; and University of Pisa, Research Centre "E. Piaggio", Italy. Photographs taken during this EAP-in-Action Session showing the various presenters is given in Figure 3. The group from EMPA demonstrated a 3-meters EAP-actuated blimp that was flown inside the conference room and its fins were actuated by a dielectric Elastomer EAP.

FIGURE 3: Photos from the EAP-in-Action

UPCOMING CONFERENCES

2008 SPIE EAPAD Conference

The next SPIE's EAPAD conference is going to be the 10th one and it will be held again in San Diego, California, from March 9 - 13, 2008. This Conference will be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Emillio P. Calius, Industrial Research Limited, New Zealand As in past years, this conference will include presentations from leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas. The papers will 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 characterization of the properties and performance as well as various applications. As in past years, a Course will be given on Sunday, March 9, and the EAP-in-Action Session will be held on Monday, March 10, 2007. Abstracts are due on August 27, 2007. Information about this SPIE conference, which is part of the Smart Structures and NDE Symp., is available at: http://spie.org/app/program/index.cfm?fuseaction=conferencedetail&export_id=x12536&ID=x12233&redir=x12233.xml&conference_id=795963&event_id=795943

3rd UT Arlington Workshop on Energy Harvesting

On January 29 – 30, 2008, the Materials Science & Engineering Dept. and the Automation & Robotics Research Institute of The University of Texas at Arlington' College of Engineering will host their 3rd national workshop on energy harvesting. Their workshop has grown to become the nation's largest meeting that is focused on energy harvesting technologies. This workshop is endorsed by the Electronics Division of the American Ceramic Society; and by the North Texas (Dallas) Chapter of ASM International. Nationally-recognized experts from federal agencies, national labs, and industry will review past developments, current challenges and future development in the fields. The topics in this workshop will include:

- Piezoelectric, Inductive, and Thermoelectric Energy Harvesting
- Micro Batteries
- Photovoltaics
- Structural Health Monitoring

This workshop also features products by companies in the area of piezoelectric energy harvesting and demonstrations of their latest technologies. A competition of teams of undergraduate students will be held to promote education in this inter-disciplinary field. In this event, demonstrations will be given of energy harvesting devices that utilize piezoelectric, thermoelectric, photovoltaic, inductive and electrostatic energy generation.

Abstracts are due by August 31, 2007. Further details are available at: http://www.uta.edu/piezo or by contacting Shashank Priya spriya@arri.uta.edu

Biological Approaches for Engineering Conference

March 17 thru 19, 2008, the Biological Approaches for Engineering Conference will be held at the University of Southampton, Chilworth Manor, Southampton, UK. The objective of this Conference is to review the exciting developments that are arising from links across biology, the physical sciences and engineering and technology. It will be held as a single track meeting covering the following topics: Novel Materials, Sensors and Senses, Aria1 Locomotion, Communication, Bio-acoustics, Marine dynamics, Cooperative Behavior, Systems Design and Structure, and Cellular Behavior.

Abstracts of no more than 250 words are due on Sept. 1, 2007 and they should be sent electronically to BAEC@isvr.soton.ac.uk Full papers of up to 6 A4 pages will be required by 1 December 2007. Selected papers from this Conference will published in a special issue(s) of the Journal of Bioinspiration and Biomimetics. For further information about this conference please visit:
http://www.isvr.soton.ac.uk/bioinspire/Abstracts.htm

Comparing Design in Nature with Sci. & Eng. Conf.

The 4th International Conference on Comparing Design in Nature with Science and Engineering is going to be held in Algarve, Portugal from June 24 to 26, 2008. This Conference will cover various aspects of biomimetics and will also solicit related EAP papers. For further information contact Carlos Brebbia, Wessex Institute of Technology, UK: carlos@wessex.ac.uk

ADVANCES IN EAP

BMC Riken (Japan) and Bristol University (UK)

Complex shapes from simple IPMCs

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Boyko Stoimenov stoimenov@bmc.riken.jp

Collaborations between Bristol University and the Bio-mimetic Control Research Center of RIKEN have led to new breakthroughs in the design and manufacture of arbitrary curved IPMCs. Such actuators can bend from a relaxed shape into a complex predetermined curved shape with a single power supply. This ability is founded on two core technologies: conductive through-polymer connections and variable electrode overlapping. Through-polymer connections are electrical connections from one electrode to the other through the main polymer film and typically use the same high-conduction material as the electrodes. Although these connections can be fashioned after the main actuator it is more efficient to integrate them into the main manufacturing process. This process is applicable for both the common chemically-deposited electrodes (Fig. 4) and newer cast polymer electrodes. By varying the overlap between opposing electrodes the degree of bending can be varied along a single strip of IPMC. This degree of overlap is achieved by partitioning electrodes such that some areas of the actuator are subject to a potential difference, while other areas act as passive electrical connections to subsequent sections.

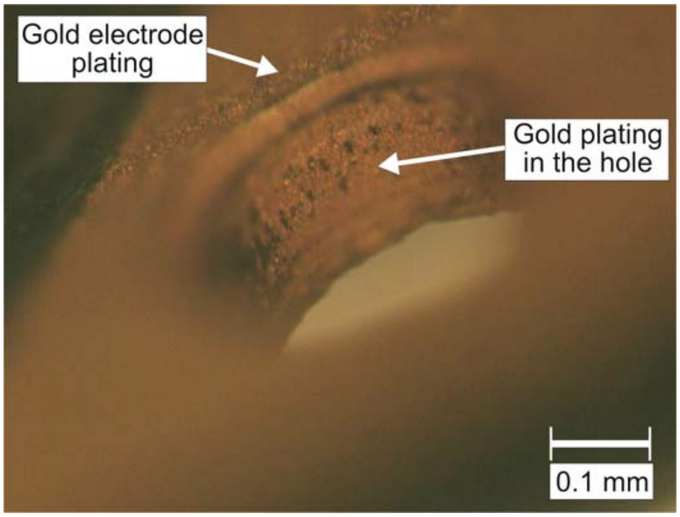

FIGURE. 4: Through-polymer connection

Applications are many and widespread. A sophisticated eel-like robot with reduced number of control signals was realized. It utilizes 3-phase driving signals and the through-polymer connection to make the adjacent segments bend in opposite directions. Another realization is an active bi-stable beam structure (Fig. 5) which can switch itself from one stable state to the other when voltage is applied to one of the ends. By pairing two strips with segmentations similar to the bi-stable beam structure, the authors were able to realize linear motion from the IPMC, which normally only bends under actuation (Fig. 6). Further, it is envisioned to apply this technology to build more complex and powerful linear actuators (Fig. 7) and medical devices such as heart compression devices that only apply pressure at predetermined safe points.

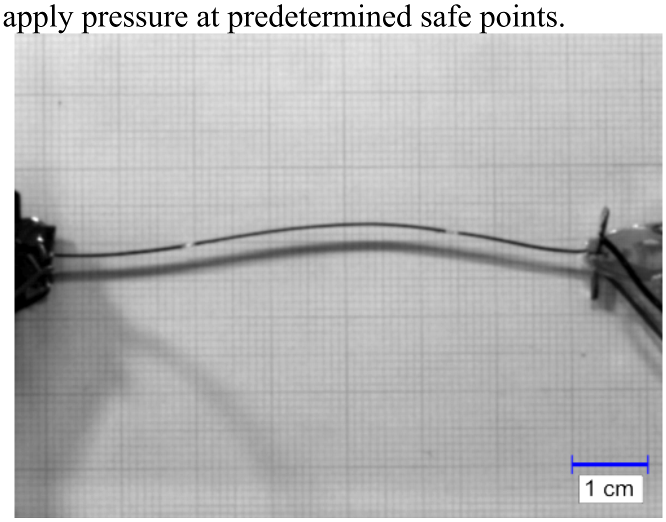

FIGURE.5:. Bi-stable buckled beam

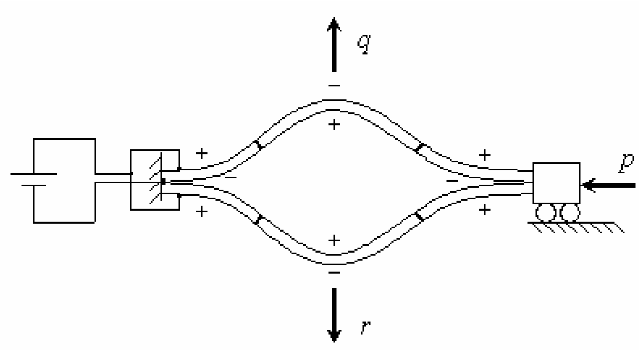

FIGURE. 6: Linear actuation

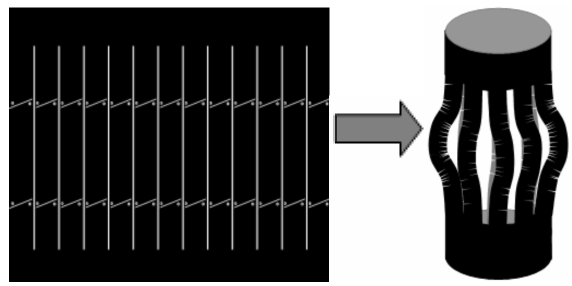

FIGURE 7: Concept of a linear actuator rolled-up from a single sheet.

EMPA - Switzerland

Modeling Dielectric Elastomer Actuators

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Dielectric elastomer actuators made of an acrylic elastomer (using VHB 4910, 3M) were the subject of a PhD Dissertation. The passive mechanical response of this elastomer is decoupled from the electromechanical problem. Electrostatic forces are assumed to arise only at the interface between the electrodes and the elastomer. The elastomer behaves as a passive layer and there is no direct interaction between electric field and its mechanical properties. The electromechanical coupling, an equation proposed by Pelrine et al. (Sensors and Actuators A, 64, 1998), was evaluated by analytical and numerical methods. The dielectric constant of VHB 4910 was determined by LCR measurements for various prestrain levels as well as by spring roll experiments. The passive mechanical response of the elastomer is described using a 'quasilinear visco-hyperelastic model' suitable for large strains and viscoelasticity. The constitutive model and the electromechanical coupling are implemented in finite element models for simulating the behavior of circular actuators. A systematic experimental characterization of circular actuators under various prestrain and voltage conditions has been carried out. Over 40 actuators were tested at 11 different prestrain/voltage levels. These experimental data were essential for model definition and validation purposes. The constitutive model was further evaluated using different deformation configurations. Uniaxial tensile and relaxation tests, aspiration tests and compression tests were carried out and compared to corresponding simulations.

The mechanical model (with an optimized parameter set) was found valid over a wide deformation and time range, for circular actuator tests at different prestrain and voltage levels as well as for uniaxial, aspiration and compression tests. The concept of quasilinear viscoelasticity was validated by uniaxial relaxation tests which showed that the normalized stress-relaxation function is independent of the magnitude of the deformation. For the simulation of the circular actuators, a novel finite element technique was developed which allows direct simulation of the actuator activation by the applied voltage. An analytical model was derived for circular actuators. An equation was obtained that links the voltage, the prestrain and the active strain. The analytical model is valid for hyperelastic materials (time-dependent effects are neglected) and can be used for the design of silicone actuators, with less pronounced viscoelastic behavior. It has been demonstrated that fitting the strain energy forms of Yeoh, Ogden and Mooney-Rivlin to uniaxial data leads to different simulation results in the VHB 4910 actuator behavior. This illustrates the importance of characterizing the biaxial response of the elastomer. This step was omitted in previous work on dielectric elastomers, where material models were based only on uniaxial test data. The numerical analysis for the evaluation of the electromechanical coupling provides the charge, electric field and electrostatic force distribution for a circular actuator. It is found that the electromechanical pressure acts in thickness direction and with the same magnitude in lateral direction. By considering a superimposed hydrostatic stress state, the resulting out-of-plane pressure corresponds to the equation proposed by Pelrine et al. This analysis provides a new physical interpretation for the electromechanical coupling. Measurements of the dielectric constant demonstrated that its value decreases by increasing prestrain. The dielectric constant of VHB 4910 is about 3.2 in the relevant prestrain range and not 4.7 as was proposed by Kofod et al. (Journal of Intelligent Material Systems and Structures, 14, 2003) and used by many researchers. This result was also confirmed by spring roll experiments.

Environmental Robots Inc. (ERI)

Two new EAP products

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ERI has recently introduced an undulated flapping wing (see Figure 8) and PAN (polyacrylonitrile) nanomuscles made with PAN nanofibers that can contract significantly. Videos of these products in action are available at www.environmental-robots.com These two products are now part of the other collection of products offered by ERI. This company has already delivered to customers in many countries such products as ionic polymeric conductor nanocomposite, distributed nanosensors, and nanoactuators.

FIGURE 8: Undulated EAP-IPMC flapping wing actuated in air.

Harvard University

A method to analyze electromechanical stability of dielectric elastomer actuators

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http://www.deas.harvard.edu/suo

Dielectric elastomer actuators are susceptible to electromechanical instability. As the electric field increases, the elastomer thins down, so that the same voltage induces an even higher electric field. A positive feedback may cause the elastomer to thin down drastically, resulting in electrical breakdown. A method was recently developed to analyze this instability [Zhao et al, 2007]. The free energy of an actuator was analyzed using stretches and nominal electric displacement as generalized coordinates, and pre-stresses and voltage as control parameters. When the Hessian of the free-energy function ceases to be positive-definite, the electromechanical instability occurs.

Figure 9 sketches a planar actuator, consisting of a thin layer of dielectric elastomer sandwiched between two compliant electrodes. A battery applies a voltage between the electrodes, and two weights apply forces in the plane of the actuator.

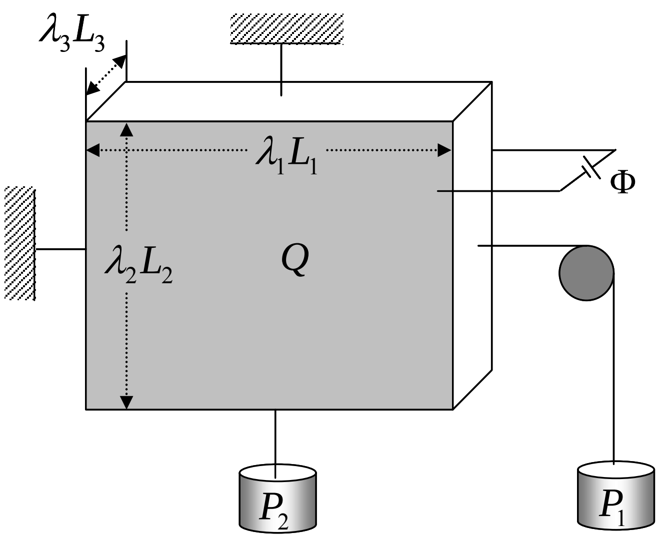


FIGURE 9: A layer of a dielectric elastomer coated with two compliant electrodes, and loaded by a battery and two weights.

Figure 10 shows the effects of uniaxial and biaxial pre-stresses on the critical electric field and the critical actuation stretch for electromechanical instability. Note that when the actuator is uniaxially pre-stressed, the critical true electric field is low, and the actuation stretch is large. This trend agrees with experimental observations [Pelrine, et al 2000; Plante et al 2006].

1. Zhao, X. and Z. Suo, A method to analyze electromechanical stability of dielectric elastomer actuators, 2007 http://imechanica.org/node/1456
2. Pelrine, R., et al., High-Speed Electrically Actuated Elastomers with Strain Greater Than 100%, Science, 2000. 287: p. 836.
3. Plante, J.-S. and S. Dubowsky, Large-scale failure modes of dielectric elastomer actuators. International Journal of Solids and Structures, 2006. 43: p. 7727.

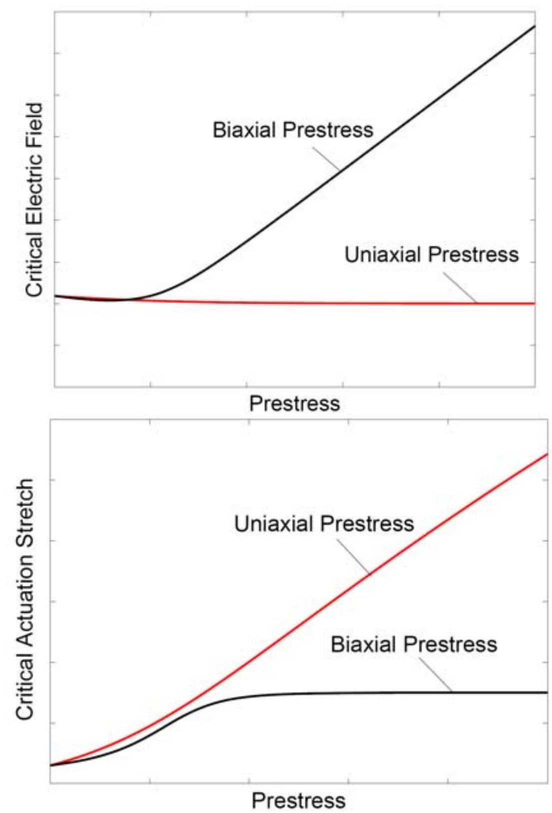


FIGURE 10: Electromechanical responses of dielectric Elastomer actuators subject to pre-stresses.

North Carolina State University

Electroactive Behavior of Nanostructured Polymers

Ravi Shankar ravishankar.aggarwal@gmail.com

During his doctoral studies (under the supervision of Professors Tushar K. Ghosh and Richard J. Spontak), Ravi developed novel nanostructured elastomers exhibiting impressive electroactive behavior. His findings demonstrated that thermoplastic elastomer gels (TPEGs) produced via incorporation of a low-volatility, aliphatic-rich solvent (e.g., mineral oil) into a nanostructured poly[styrene-b-(ethylene-co-butylene)-b-styrene] (SEBS) triblock copolymer yields physically cross-linked micellar networks capable of significant actuation upon electrical stimulation. These materials, collectively referred to as electroactive nanostructured polymers (ENPs) to reflect their supramolecular design, produced as much as 250% areal actuation at a relatively reduced electric field of only 22 V/μm. In general, the dielectric strength of these ENPs increases with increasing copolymer concentration, and their electromechanical coupling efficiencies are comparable, if not superior, to other EAPs reported in the literature. The mechanical hysteresis behavior of these ENPs under cyclic loading/unloading at constant strain (100 cycles at 400% strain) confirmed that these materials undergo far less nonrecoverable strain than other EAPs (e.g., VHB acrylic elastomers), which often suffer from high viscoelastic losses. In fact, his ENPs containing a mere 5 wt% copolymer do not show any evidence of nonrecoverable strain. Comparison of ENPs with homopolymer-based EAPs demonstrates that the ENPs exhibit broadly tunable electromechanical behavior. An increase in copolymer molecular weight or, conversely, a reduction in copolymer concentration significantly improves actuation performance at low electric field. Some of the ENP compositions also revealed possess significant electrical response in the absence of prestrain. For example, ENPs of a relatively low-molecular-weight SEBS triblock copolymer, have shown ~19% areal strain without an applied prestrain, as shown in Fig. 11. These ENPs convert a large fraction of input energy into useful mechanical work more effectively than either (i) ENPs containing high-molecular-weight copolymers of comparable composition or (ii) EAPs based on acrylic dielectric elastomers in the absence of mechanical prestrain. Under both conditions (with and without prestrain), the ENPs afford higher electromechanical coupling efficiencies than the benchmark acrylic elastomer. We anticipate that this type of EAP would prove useful in emerging technologies wherein precise impedance matching is crucial.

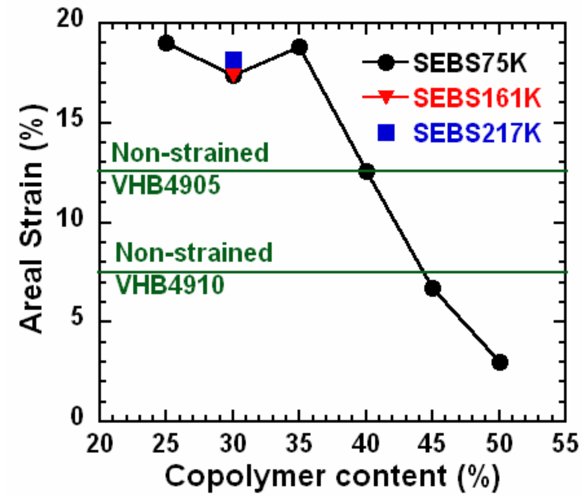


FIGURE 11: Maximum areal strain as a function of copolymer content of SEBS triblock of three different molecular weights under no-prestrain conditions.

AVAILABLE POSITIONS

Generally, available positions are listed and updated at http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/Positions.htm

Materials Scientist at Artificial Muscle, Inc. (AMI)

Artificial Muscle, Inc. (AMI) is an OEM manufacturer of products based on Electroactive Polymer Artificial Muscle (EPAM™) technology. With its Universal Muscle Actuator platform, AMI enables a new generation of valves, pumps, sensors, motors, generators, speakers, linear actuators and more. AMI's clients include many Fortune 100 companies and other high profile technology companies.

Position Description: A material scientist is sought for formulating materials and testing their physical and electrical properties for artificial muscle devices. Such tasks will require interaction with material vendors, laboratory mixing and processing of components and standardized testing of the prepared materials. At times unique tests must be developed in order to evaluate material performance. This position requires a blend of "hands-on" laboratory work with interpretation of data and the presentation of results to a multi-disciplinary research team. The selected candidate will be responsible for:

- Conduct research into the structure and properties of elastomeric materials.
- Plan and conduct laboratory experiments to formulate materials for artificial muscles and test the electrical and mechanical properties of these materials.
- Utilize physical models and statistical methods for data interpretation.
- Prepare test results for easy interpretation and for inclusion in reports and presentations.
- Initiate and maintain contacts with key material suppliers
- Troubleshoot problems arising during the execution of experiments
- Value and work with a diverse group of individuals.
- Work independently and as part of a multi-disciplinary team

<u>The required qualification:</u>

- B.S. in chemistry, material science, chemical engineering or related field
- 2 or more years of industrial experience preferred.
- An understanding of polymer materials.
- Knowledge of materials testing techniques - especially mechanic and dielectric properties is a plus.
- Knowledge of the principles and strategies used in the Design of Experiments is also a plus.
- Mechanical aptitude and an eagerness to "get your hands dirty" to solve problems
- Possess both good written and oral communication skills
- Desire to flourish in "start-up" environment.

Application for this position should be sent with resume to careers@artificialmuscle.com

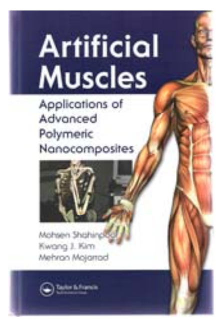
Polymer chemist at Pavad Medical

A position of polymer chemist is available at Pavad Medical. The polymer chemist will be responsible for material development, characterization, testing, reports and task co-ordination. The required chemist will be a key member of the material development group and will be working very closely with other team members, vendors and OEM manufacturers. Some of the duties include fabrication and characterization of electro active polymers, as well as conducting failure mode analysis and process improvement. Job duties also include writing of standard operating procedures, test methods and manufacturing process instructions, test sample preparation, testing and report generation as well as lab setup and up keeping. He/she will be responsible for managing polymer development project, concept prototyping and maintaining project timeline. He/she may have the responsibility of supervising technicians and other operators in the team.

Candidates that sought should have a MS or PhD in chemistry, chemical engineering, material science/engineering, or in similar discipline with a strong background in organic chemistry. Working experience with IPMC, conducting polymers and other similar EAP materials is a must. Qualified candidates should send in their resumes to Human Resources at jobs@pavad.com or Pavad Medical Incorporated, 40539 Encyclopedia Circle, Fremont, CA 94538.

NEW BOOKS

Artificial Muscles



M. Shahinpoor, K. J. Kim and M. Mojarrad

A new book entitled "Artificial Muscles" was recently published by Taylor and Francis group (CRC/Chapman and Hall). The book is focused on IPMNC materials and it was coauthored by Mohsen Shahinpoor, Kwang J. Kim and Mehran Mojarrad. This book covers theories, modeling, and numerical simulations of IPMNC materials, their electrodynamics and chemodynamics, and industrial and medical applications of these materials. It highlights experimental results related to properties and characteristics of IPMNC.

UPCOMING EVENTS

Date	Conference/Symposium
Jan. 29 – 30, 2008	3rd UT Arlington Workshop on Energy Harvesting. Abstracts due by August 31, 2007. For information contact Shashank Priya spriya@arri.uta.edu or see Website http://www.uta.edu/piezo
March 9 - 13, 2008	2008 EAPAD Conf., SPIE's Smart Structures & Materials and NDE Symposia, San Diego, CA., For information contact: Mike Stiles , SPIE, mikes@SPIE.org Website: http://spie.org/smart-structures-nde.xml
March 17 thru 19, 2008	"Biological Approaches for Engineering Conference" University of Southampton, Chilworth Manor, Southampton, UK. For information contact: Margaret Howls, baec@isvr.soton.ac.uk Website: http://www.isvr.soton.ac.uk/bioinspire/Abstracts.htm
June 24 to 26, 2008	4th International Conference on Comparing Design in Nature with Science and Engineering. For information contact Carlos Brebbia: carlos@wessex.ac.uk

EAP ARCHIVES

Information archives and links to various websites worldwide are available on the following (the web addresses below need to be used with no blanks):

Webhub: http://eap.jpl.nasa.gov

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

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

EAP Companies: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-material-n-products.htm

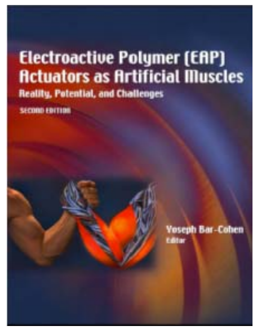
Biomimetics: http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm

Armwrestling Challenge: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

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

2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)

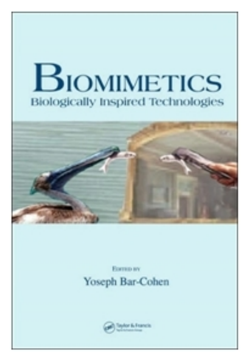


In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published. This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent to provide a reference about the subject, tutorial resource, list the challenges and define a vision for the future direction of this field. Observing the progress that was reported in this field is quite heart warming, where major milestones are continually being reported.

Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

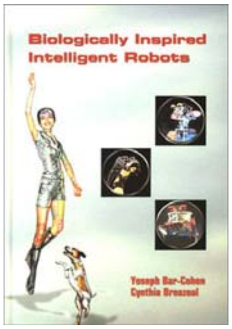
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm



This book about Biomimetics review technologies that were inspired by nature and outlook for potential development in biomimetics in the future. This book is intended as a reference comprehensive document, tutorial resource, and set challenges and vision for the future direction of this field. Leading experts (co)authored the 20 chapters of this book and the outline can be seen on http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biologically-Inspired-Technology.pdf

Biologically Inspired Intelligent Robots

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



The book that is entitled "Biologically-Inspired Intelligent Robots," covering the topic of biomimetic robots, was published by SPIE Press in May 2003. 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. The topics that are involved with the development of such biomimetic robots are multidisciplinary and they are covered in this book. These topics include: materials, actuators, sensors, structures, control, functionality, intelligence and autonomy.

WorldWide Electroactive Polymers (EAP) Newsletter

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