WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

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http://eap.jpl.nasa.gov

FROM THE EDITOR

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

We are about to reach a milestone in the field of EAP – the upcoming SPIE Conference on Electroactive Polymer Actuators and Devices (EAPAD) is going to be the 10th and will be held from March 9 thru13, 2008, in San Diego, CA. This conference, which was the first large forum to be held on this subject, continues to be the largest focal meeting for reporting and seeing the progress in the field.

In the coming conference, which will be Co-chaired by Emilio P. Calius, Industrial Research Limited, New Zealand, one of the highlights is a special session that will be dedicated to the hot topic of Energy Harvesting using EAP. Also, we are going to have, the EAP-in-Action session on Monday, March 10, at 4:30 to 5:45 pm, and it will include 8 demonstrations. The presenters will be from labs in Australia, China, Italy, New Zealand, Switzerland, and the USA. Some of the demo highlights of this session tentatively include a huge blimp that is steered by EAP, which is made by EMPA, Switzerland. Also, we may have possibly an EAP actuated wrestling arm, called "Kiwi Arm", made by Auckland Biomimetics Laboratory Bioengineering Institute, and Industrial Research Ltd, New Zealand. This arm is currently under development and may be ready for operation at this session.

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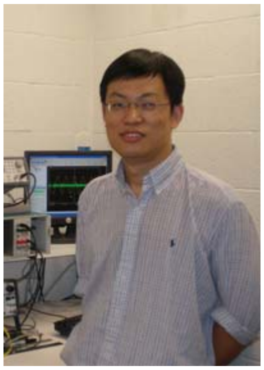
ABOUT THE EXPERT

Cheng Huang

In November 2007, Cheng Huang joined Engineering Mechanics Group, Energy Science & Technology Directorate as a staff member of

Battelle Pacific Northwest National Laboratory. He moved from Johns Hopkins University where he was a Postdoctoral Fellow. Cheng graduated from Materials Research Institute and Electrical Engineering Department, Pennsylvania State University. His research expertise is multifunctional polymer composites and structures by smart design, synthesis, and processing. At PNNL, he is developing advanced polymer composites and nano-bio-technology for energy efficiency and renewable energy, including bio-based composites, morphing and electroactive smart materials, and new materials for energy harvesting and storage. He can be reached at cheng.huang@pnl.gov, or 509-372-4386.



Patrick Lochmatter

In May 2007, Patrick Lochmatter successfully passed his PhD exam at ETH Zurich (Switzerland). Since 2002, he worked as a PhD student at Empa (Dubendorf) and ETH.

The topic of his PhD thesis is "Development of a shell-like electroactive polymer (EAP) actuator" (ISBN 978-3-89963-565-2). In his thesis, he explored the potential of soft dielectric EAPs mainly from VHB 4910 for the design of shell-like actuators with the ability to perform complex out-of-plane displacements. The resulting shell-like actuator was composed of seven interlinked active segments where the pre-stretched DE films were arranged in an agonist-antagonist configuration. At equal activation of all segments the actuator displayed free angles of displacement exceeding 90^o in both directions. At sinusoidal, phase-shifted activation of the segments the actuator showed a propagation of transversal displacement waves traveling along its principal axis, which resembled the swimming motion of e.g. fish. Now that he has completed his PhD studies he intends to work in industry. For contact the email address of Patrick Lochmatter is patrick.lochmatter@yahoo.de. His thesis (28.7 MB) can be downloaded from http://e-collection.ethbib.ethz.ch/cgi-bin/show.pl?type=diss&nr=17221

Ravi Shankar

For outstanding contributions to the field of materials science, Ravi Shankar of Intel Corporation received from the Materials Research Society (MRS) one of this year's Graduate Student Silver Awards. He received this award at the Fall 2007 National Meeting in Boston, MA, His dissertation research for which he won this award, as well as the 2007 Richard D. Gilbert Award in Polymer Science, focused on the subject of "Electroactive Behavior of Tunable Nano-structured Polymers."

Shankar has published with his advisors Tushar K. Ghosh and Richard J. Spontak, North Carolina State University several peer-reviewed papers on the topic of tunable nanostructured EAPs. For further information, He can be reached at ravi.shankar@intel.com
or ravishankar.aggarwal@gmail.com.

Xuezheng Wang

In August 2007 Xuezheng Wang obtained his Ph.D. degree from the University of Maryland, College Park. Wang is an expert in the field of ion transport in conjugated polymers. From 2001 to 2007, he worked with Elisabeth Smela on actuation mechanisms of conjugated polymer actuators. The original scientific contributions of his research include developing a novel experiment that displays ion movement in PPy(DBS) with electrochromism and studying ion transport in PPy(DBS) with Nernst-Planck-Poisson equations. Wang has publications in *Advanced Materials, Journal of Material Research, and Acta Mechanica Sinica*. Dr. Wang has given invited talks and presentations in *EAPAD, ICSM, ASME, APS, and World Congress of Biomimetics, Artificial Muscles, & Nano-Bio*. For discussion of his related research topics, please contact him at xwang@flhlaw.com.

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

EAP rules for the Armwrestling

The intent of the armwrestling contest that was initiated in 1999 is to challenge and encourage advances in the development of EAP materials. With progress in the field of EAP, the "bar" is going to be continually raised on the related requirements. Eventually, the EAP wrestling arms are expected to be at a level of performance that is superior to a human arm. As of the 10th EAPAD conference that will be held in March 2008, a consensus was reached with the conference organization committee regarding the definition of EAP that are allowed to be used in the contest.

The consensus now is that EAP is considered acceptable to drive a wrestling arm if it is made of a material or combination of materials that are primarily composed of polymers that convert(s) electric to mechanical energy for which the presence of the polymer(s) is a key to the generated force and displacement. The response should be reversible, namely, the actuated robotic arm should be able to use the same actuation mechanism to return to the starting position.

- No actuators that involve input of gases, liquids or chemicals will be accepted (e.g., actuated by pneumatic, hydraulic, or use of acid/base).
- An exception will be given to the use of polymers that are indirectly driven by electric current or field but they will need to be identified as being so. For example, thermally actuated polymer materials will be accepted if they use embedded electrical heating elements.

UPCOMING CONFERENCES

2008 SPIE EAPAD Conference

The next SPIE's EAPAD conference is going to be the 10th anniversary and it will be held again in San Diego, California, from March 9 - 13, 2008. This Conference will be chaired by the Editor of this Newsletter and Co-chaired by Emilio 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. This conference is going to include 91 scheduled papers, of which 65 are oral presentations and 26 are posters.

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, 2008.

This course will provide an overview of the field of EAP covering the state of the art, challenges and potential. Two general classes of polymer materials are described, namely those that involve ionic mechanisms (Ionic EAP), and field activated materials (Electronic EAP). The lead instructor is Yoseph Bar-Cohen, JPL, the topic of ionic EAP will be taught by Qibing Pei, professor of materials science and engineering, Univ. of California, Los Angeles (UCLA) and Kwang Kim, Professor and Chair, Mechanical Engineering Department, University of Nevada, Reno. The basic mechanisms responsible for the electroactive behavior of EAP materials will be covered and compared with natural muscles. Analytical models, fabrication processes and methods of characterizing these materials will be described. Moreover, the currently considered applications will be reviewed including actuators, robotics, animatronics, medical, and biologically inspired mechanisms, so called biomimetics. The course begins with an overview of the field, current capabilities, potential and challenges. The course follows with a description of the currently available EAP materials and principles of operating them as actuators and artificial muscles. The course ends with a review of the future prospect of EAP as actuators in systems, mechanisms and smart structures for space, industrial and medical applications.

FIGURE 1: The EAPAD's Keynote Speaker, Adam Summers from UC Irvine (UCI).

The Keynote Speaker in this conference is going to be Adam Summers, physiology professor, UC Irvine (UCI). His presentation title is “High-performance with a 'soft' skeleton: the shark cartilage composite.” Adam has been an advisor to the movie studio Pixar in the production of the movie “finding Nemo” providing information about fish behavior. Further details about this movie are at: http://www.ultimatedisney.com/findingnemo.html In Figure 1 Adam is shown with a wild blue and gold macaw parrot that is resident at a floating village in the Amazon. He encountered this parrot while he was on a field trip to look at the biting and burrowing performance of Amazonian fishes and reptiles. He did not do any research on the parrot though the bite forces are quite impressive and well damped. Generally, Adam Summers is interested in materials that have been structured at the micro and nano-scales by natural selection. The keratin over bone composite material of the parrot’s beak is a wonderful example of a self sharpening sacrificial surface layered onto a dynamically remodeled supporting structure. His research on biological composite materials includes investigations of fish scales, shark skeletons, the smashing appendages of mantis shrimp and silk produced by the feet of tarantula spiders.

We are going to have 7 invited papers as follows:

- Gordon G. Wallace, Javad Foroughi, Charles Mire, Marc in het Panhuis, Geoffrey M. Spinks, Univ. of Wollongong (Australia): “Fiber spinning and ink-jet printing: advances in conducting polymer device fabrication“

- Donald J. Leo, Virginia Polytechnic Institute and State Univ.“: Advances in the modeling and performance of ionomeric polymer transducers (IPMCs)”

- Aleksandra M. Vinogradov, Montana State Univ./Bozeman: “Accomplishments and future trends in the field of electroactive polymers”

- Minoru Taya, Univ. of Washington: “Organics-based energy harvesting and storage system for future aerospace vehicles: overview”

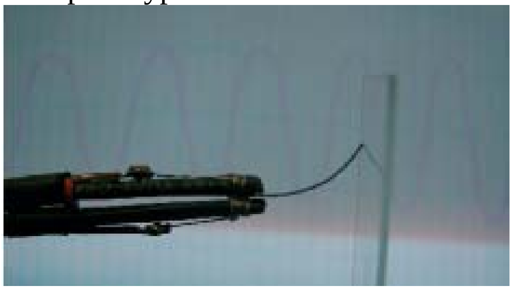
- Reinhard Schwödiauer, Ingrid Graz, Simona Bauer-Gogonea, Siegfried Bauer, Johannes Kepler Univ. Linz (Austria): “From dielectric elastomers to cellular ferroelectrets: soft matter as electroactive transducer materials”

- Silvain A. Michel, EMPA (Switzerland); Alexander Bormann, Aeroix (Germany); Christa

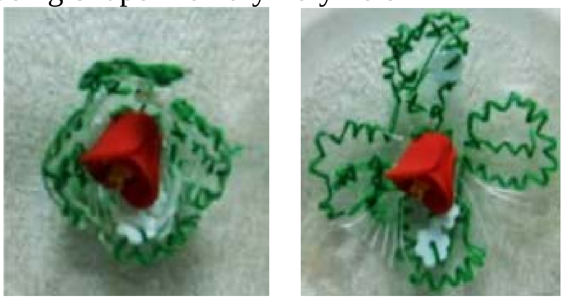
Jordi, EMPA (Switzerland); Erick Fink, Technische Univ. Berlin (Germany)" "Feasibility studies for a bionic propulsion system of a blimp based on dielectric elastomers"

Also, on Monday, March 10, 2008, we are planning to hold the EAP-in-Action session. This Session is continues to provide a spotlight on Electroactive Polymers (EAP) materials, their capability, and their potential for smart structures. New materials and applications are continuing to emerge and this is a great opportunity for the attendees to see state-of-the-art demonstrations of the unique capabilities of EAP as possible actuators-of-choice. This Session offers a forum for interaction between developers and potential users as well as a "hands-on" experience with this emerging technology. It was during this session that he first Human/EAP-Robot Armwrestling Contest was held in 2005. We are going to have 8 research and industry presenters demonstrating their latest EAP actuators and devices including

- Geoff Spinks, and Scott McGovern, University of Wollongong, Australia - A fast (100 Hz) polypyrrole trilayer actuators and sensors as well as prototype robotic fish



- Jinsong Leng, Harbin Institute of Technology, China – A flower that opens when it gets hot using Shape Memory Polymers



- Federico Carpi, University of Pisa, Research Centre "E. Piaggio", Italy - Contractile folded dielectric elastomer actuators and buckling dielectric elastomer actuators

- Iain Anderson, Todd Gisby, and Ben O'Brien, Auckland Biomimetics Laboratory Bioengineering Institute, and Emilio Calius, Industrial Research Ltd, New Zealand - Several demonstration will be made showcasing applications of Dielectric Elastomer Minimum Energy Structure (DEMES) bending actuators, and novel methods for fine control of DE transducers including electro-physiological signals.
  NOTE: A wrestling arm called "Kiwi Arm" is currently under development and may be ready for operation at this session.

- Silvain Michel, Head of EAP Research Group, and Christa Jordi, Swiss Federal Laboratories for Materials Testing and Research / Empa, Switzerland – A giant blimp with EAP-driven control surfaces. An improved 2nd version will be shown in an indoor flight demonstration and it would show the successful integration of membrane dielectric elastomer actuators in a Lighter-than-Air vehicle.

- Manuel Aschwanden, David Niederer and Mark Blum, Optotune (\ a Start-up company at EMPA), Dübendorf, Zürich, Switzerland - "Tunable Optical Elements based on Dielectric Elastomer Actuators," Two continuously tunable optical components will be adjusted by dielectric elastomer actuators including (1) Optical element is a phase shifter that achieves a phase shift of up to 10 l. (2) Focus tunable lens that can be tuned from a convex (+20 dpt.) to a concave (-20 dpt.) shape by simply applying a voltage to it. Both devices operate with high transmission, good optical quality, high damage threshold, and are polarization independent.

Highly tunable optical elements can be used in a wide range of applications including still image cameras, video cameras, projectors, endoscopes, microscopes and other optical systems where light modulation and beam shaping is required.

- Charlie Duncheon, Executive VP, Artificial Muscle, Inc., USA - Some of the latest prototypes and products at AM including Battery driven handheld devices displaying AMI's smartMovetm EAP technology; A smartMove energy harvesting demonstration; AMI's first standard product, the MLP-85 camera auto focus actuator; Omnidirectional planar actuator; other demos

- Seiki Chiba, Hyper Drive Corp. and Roy Kornbluh SRI International USA - New dielectric elastomer EAP actuated prototypes.

Information about the EAPAD Conf. is at:
http://spie.org/app/program/index.cfm?fuseaction=conferencedetail&export_id=x12536&ID=x12233&redir=x12233.xml&conference_id=795963&event_id=795943

EAP-in-Action session is available at:
http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAPIA/EAP-in-Action-Session-2008.htm

EAPAD course is available at:
http://spie.org/x12234.xml

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

Carbon Nanotube Actuator Workshop

On March 6th 2008, a Carbon Nanotube Actuator Workshop is going to be held at the German Aerospace Center (DLR) in Braunschweig, Germany. This workshop is intended to serve as a platform for exchange of ideas and progress on the topic of Carbon Nanotube, which is as very promising type of actuator. For more information please contact: Johannes.Riemenschneider@dlr.de

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

Actuator 2008

From June 9 to 11, 2008, the 11th International Conference and Exhibition on New Actuators will take place in Bremen, Germany. It includes a session on EAPs. The EAP sessions have generated quite a bit of excitement in previous years. The official abstract submission deadline has passed but submissions may still be accepted based on available space. Information about the conference can be found on www.actuator.de For further information please contact Roy Kornbluh, SRI International roy.kornbluh@sri.com or Peter Sommer-Larsen, Risoe National Laboratory, peter.sommer.larsen@risoe.dk

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

from June 24 to 26, 2008, the 4th International Conference on Comparing Design in Nature with Science and Engineering is going to be held in Algarve, Portugal. 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

Journal of Neuro Engineering and Rehabilitation (JNER) Special Issue on Artificial Muscles

The Journal of Neuro Engineering &Rehabilitation (JNER), publishing since late 2004 is an Open Access, peer-reviewed online journal that aims to foster the publication of research work that results from cross-fertilization of the fields of neuroscience, biomedical engineering, and physical medicine & rehabilitation. As such, the journal is well suited to the publication of articles on EAPs for artificial muscles, haptic and proprioceptive feedback and other bioengineered devices. Several EAP researchers have already published papers in this journal. A special issue on artificial muscles is scheduled for next year (2008). For information on the special issue on artificial muscle, please contact Roy Kornbluh at roy.kornbluh@sri.com and about the journal and how to submit articles, please visit http://www.jneuroengrehab.com/home/

ADVANCES IN EAP

University of Nevada, Reno

Dielectric elastomer (DE) actuator/sensor

K. Jung and K. Kim kwangkim@unr.edu

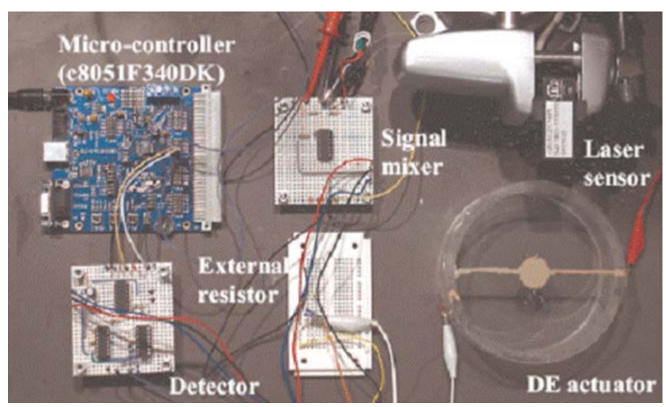


FIGURE 2: Dielectric elastomer (DE) actuator and sensor.

Recently, a novel self-sensing method was developed using dielectric elastomer (DE) actuator allowing the device to perform both sensing and actuation. The self-sensing is based on a capacitance characteristic of dielectric elastomer

EAP materials. The DE actuator with serial external resistors can serve as an electrical high-pass filter. The voltage gained using the high-pass filter, which is virtually built using a dielectric elastomer actuator, varies due to the change of overall capacitance when the actuator is expanded electro-mechanically. A photo of the circuit is shown in Figure 2.

PPPL Assists in the Development of Artificial Muscle

Lenore Rasmussen, raslabs@patmedia.net

NOTE: This article was published originally in the June 2007 issue of *PPPL Digest* and is repeated herein with permission. Further, a video clip from the NJ News called "Artificial Muscle," is available at: http://www.njn.net/newspublicaffairs/science/

Princeton University Plasma Physics Laboratory (PPPL) collaborator Lenore Rasmussen has the gift of serendipity. Two disparate life experiences sparked the polymer chemist’s interest in the development of electroresponsive “smart materials” — electrically-driven polymers — that are strong and durable enough to act as artificial muscles in prosthetic devices and robotics. Her early experience identifying DNA proteins and an injury suffered by her cousin in a farm accident triggered her interest in development of the materials. She brings to this work an extensive background in chemistry, biology, and biochemistry.

Rasmussen was using electrophoresis — the movement of suspended particles through a gel under the action of an electromotive force — to separate and identify protein molecules and DNA. “There are little wells in which you put your proteins or DNA samples. You turn on the electricity and watch how they migrate. Different proteins or DNA fragments will go through the gel at different speeds that depend on their molecular weights. The larger, heavier molecules will have a harder time getting through. One of the wells would contain known proteins for comparison. For DNA, the smaller fragments would move further and longer ones would end up closer to the starting point,” explained Rasmussen. But, as fate would have it, one day she made a mistake formulating the gel. “I goofed mixing the stuff together and (as a result) the gel responded to the electricity by contracting — a Eureka moment,” she said.

Later, while she was a graduate student at Purdue University pursuing a degree in biology with a biophysics specialty, one of her cousins was spreading hay on a land reclamation project. He slipped and his leg got caught in the hay spreader. His foot was not detached, but much of the muscle and circulation in the calf of his leg were damaged. Initially his doctors were not sure he would keep the leg. If gangrene set in, he would have to have it amputated. “I was the scientist in the family, so was asked if I could go and look at prosthetics to see what was out there in case he needed one. While I really liked what I saw for legs, I really hated what I saw for arms and hands. As it turns out, my cousin’s leg healed after a long recovery. But I kept thinking about my experience with the gels in DNA analysis and the need for better prosthetics. So I went on to Virginia Tech partly to get the background in polymer chemistry that I would need to develop artificial muscles,” said Rasmussen.

Currently, many prosthetics for the arm and hand are not functional unless they utilize metal devices that are controlled mechanically. Rasmussen wondered if a prosthetic limb could respond directly to a neural impulse, and whether they could be made more attractive and highly functional. In 2003 she established Ras Labs, LLC, a small, for-profit, innovative research and development laboratory in Hillsborough, NJ, devoted to projects that utilize polymer chemistry, biochemistry, biology and engineering.

Rasmussen envisions artificial muscles, or actuators, that are comprised of an electro-responsive polymer gel (the smart material) containing embedded electrodes, all encased in a molecular coating that acts as a kind of skin. The smart material is cross-linked, meaning that side bonds have been formed between polymer chains to increase strength and toughness. The embedded electrodes serve a dual role: providing the electric stimulus, much like a nerve, and attaching the smart material to a lever, like a tendon attaches muscle to bone. The thin elastomeric coating also serves as a moisture barrier, preventing evaporation and leakage of the electrolyte solution in the polymer, and allowing the actuators to be fully operational anywhere. When the electrodes are energized with direct current, the smart material either contracts or expands, depending on the formulation. It then relaxes when the current is turned off, acting much like real muscle tissue responding to a neural impulse from the brain. The goal is for both the electroresponsive smart material and the embedded electrodes to move as a unit, analogous to muscles and nerves moving together.

FIGURE 3: Lew Meixler and Lenore Rasmussen prepare a metal wire sample for plasma treatment at PPPL.

Rasmussen tested a variety of polymers and found a class of ion-containing cross-linked network gels, which respond quickly to electricity and have all of the other needed properties. But one challenge remained: the polymer often detached from the electrodes. However, from her former affiliation with Virginia Tech and Johnson & Johnson's Ethicon division, Rasmussen recalled that J&J performed plasma sterilization of its medical needles, and then coated them with polymers that allow them to slide more quickly into the patients, reducing discomfort. As it turns out, plasma treatment not only sterilizes the needles, but also improves the adherence of the polymer.

A potential solution was at hand. Frank Koos, a federal laboratory technology locator, put Rasmussen in touch with Lew Meixler, PPPL's Head of Applications Research and Technology Transfer. She met Meixler at a grant-writing seminar at which he presented information on cooperative research opportunities for small businesses at federal labs. Rasmussen's discussions with Meixler resulted in the establishment of a Cooperative Research and Development (CRADA) Agreement last December between PPPL and Ras Labs. The CRADA, with PPPL participants Lew Meixler and Yevgeny Raitses, revolves around PPPL's plasma sterilization equipment, an excellent apparatus in which to treat metal samples with plasma. Different ions are being studied to find a suitable metal and plasma combination that solves the detachment problem.

To date, tests conducted at PPPL are encouraging, resulting in improved bond strengths. Stainless steel and titanium are being treated with plasma comprised of ions of nitrogen, helium, or hydrogen. Oxygen ions derived from synthetic air (for safety) are also used. Ions are driven onto the surface of a 0.5-inch by 1.5-inch metal foil by a 40-volt electric potential for 12 hours. Following treatment, a polymer coating is sandwiched between two pieces of treated foil. The composite is sent the Textile Research Institute (TRI), which has the capability of performing adhesion tests on the small samples that fit into PPPL's apparatus. At TRI, a standardized testing apparatus controls the speed and strain with which the composite is peeled apart. Future tests will be conducted with actual wire electrodes treated in the PPPL apparatus.

FIGURE 4: Metal wire undergoing plasma treatment in PPPL apparatus.

In addition to identifying a suitable plasma treatment and metals, the tests at PPPL should provide insight into the mechanism responsible for improved adhesion of the polymer. Preliminary studies have shown that the plasma ions rough up the metal surface on a molecular scale and make the surface super clean by removing any oils that might be present. "Right after the peel test we check to see where the break has occurred. If necessary, we use scanning electron microscopy to view the surfaces. If the polymer comes off the metal cleanly, the interface is the problem. If there is polymer or patches of the polymer remaining on the metal, then the failure was in the polymer itself — or there could be other things going on," Rasmussen said.

FIGURE 5: Electroresponsive smart material with embedded electrodes. Red dye has been added to enhance visualization.

Whatever is learned from the PPPL plasma treatments, Rasmussen will continue her quest for electroresponsive smart materials that can have a profound impact on prosthetics and robotics, with excellent control, dexterity, and durability. If she is successful, a lot of folks may benefit.

FIGURE 6: Lew Meixler and Lenore Rasmussen at Ras Labs with UV photocuring equipment used in the production of electroresponsive gels.

Johannes Kepler University Linz and others

Electroactive Polymers Meet Plastic Electronics

Siegfried Bauer[a], Reinhard Schwödiauer[a], Barbara Stadlober[b], Sigurd Wagner[c], Ingrid Graz[d], and Stephanie Lacour[d]

[a]Johannes Kepler University Linz,
[b]Joanneum Research Weiz
[c]Princeton University and
[d]University of Cambridge

Reinhard.schwoediauer@jku.at, barbara.stadlober@joanneum.at, wagner@Princeton.EDU, and spl37@cam.ac.uk

Researchers from Johannes Kepler University in Linz, Austria, with Joanneum Research in Weiz, Austria, Princeton University, USA, and the University of Cambridge, UK, are exploring potential applications of electroactive polymers with piezoelectric properties in plastic electronics. At present plastic electronics is under intense research and development for applications in macroelectronics, mostly for flexible displays and solar cells, and printable radio-frequency identification tags. This development effort is putting in place a growing competence for the fabrication of flexible macroelectronic surfaces, which in turn is encouraging more experimentation with advanced human-machine interfaces. An important recent example is the integration of electro-active polymers in active-matrix cells (pixels) for distributed sensing and actuation:

Using cellular ferroelectrets and flexible amorphous silicon circuitry, the team at JKU, Princeton and Cambridge has demonstrated a "ferroelectret field-effect transistor," a paper-thin device that is sketched in Figure 7. The gate of this transistor is charged by the displacement current of a cellular ferroelectret laminate. The transistor was shown to function as a pressure activated switch, as a sensitive pressure sensor, and as a flexible microphone. The ferroelectric polymers also have been combined with organic field effect transistors with pentacene channels and ultrathin nanocomposite gate dielectrics, on flexible substrates. The teams of Joanneum Research and JKU have operated the element depicted in Figure 8 as a light driven switch and as a flexible, yet sensitive infrared sensor. Multifunctional electroactive polymer materials are shaping up as a conduit toward electronic skin, taking advantage of their capability for sensing heat and touch over flexible and conformably shaped surfaces.

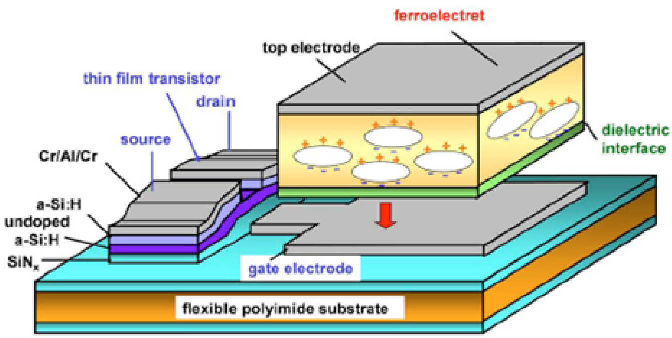


FIGURE 7: Concept of the “ferroelectret field-effect transistor”. The voltage generated by the ferroelectret upon touching the element, or by means of acoustical waves controls the current through the flexible field-effect transistor.

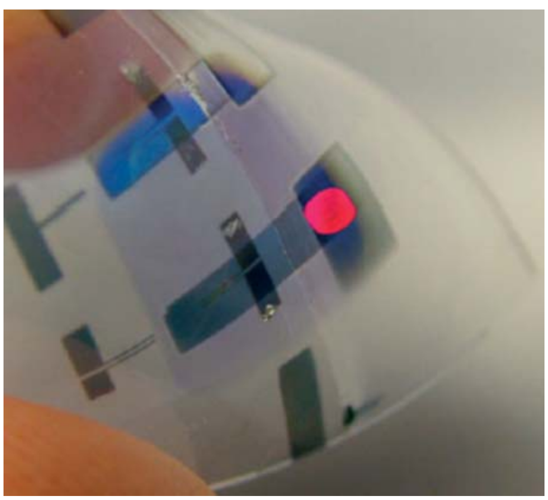


FIGURE 8: Operation of a flexible optothemal switch, based on pyroelectric copolymers of vinylidene fluoride and trifluoroethylene and -voltage organic field-effect transistors.

References:

Graz I., M. Kaltenbrunner, C. Keplinger, R. Schwödiauer, S. Bauer, S. P. Lacour and S. Wagner, Flexible ferroelectret field-effect transistor for large-area sensor skins and microphones, Appl. Phys. Lett. **89**, 073501 (2007).

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VTT Technical Research Centre of Finland

Compliant elastomer electrodes for polymer actuators (EAP)

Mikko Karttunen mikko.karttunen@vtt.fi and Mika Paajanen mika.paajanen@vtt.fi

VTT has developed novel stretchable electrodes for electroactive polymer (EAP) actuators as part of the Finnish nanotechnology program (FinNano). The main goal in the electrode development was to overcome the wearing and drying problems of commonly used carbon black powder and carbon or silver crease electrodes.

The new compliant electrode is based on water dispersions of polyaniline and selfcrosslinked ethylene vinyl acetate copolymer (EVA). It was observed that a solvent-based (e.g. toluene) polyaniline-elastomer solutions tended to have a harmful effect on the elastic properties of the dielectric elastomer EAP material. Thus the main advantage of water based dispersions is that it can be easily processed onto a stretched film eg. by spraying or by printing methods without significant changes in the tensioned state of the EAP.

In dispersions polyanile formed small particles some of which were in nano scale. Also the size of the EVA elastomer particles were at the nano and microscale. Highly dispersed PAni/EVA/water solutions were made with mechanical mixing and were subsequently treated by a sonotrode. The spraying of the dispersion onto a 3M VHB 4910 tape yielded a microscopically net-like structure, which made it possible to produce thin, easily stretchable electrodes with continuous electrically conductive network. Typically the thickness of the electrode was 3 to 5 µm. High adhesion to the acrylic elastomer tape was also achieved with this type of dispersion after drying at room temperature.

The level of surface resistance with PAni loadings of 30 w-% to 50 w-% is 10^5 ohm/sq. Relatively high PAni loadings are needed for electrodes yet. Under the biaxial stretching the sheet resistance of PAni/EVA/water dispersion electrodes, sprayed onto the acrylic tape increased only slowly when stretched up to 70 to 80 % (Figure 9). With higher stretching ratios the resistance tended to increase rapidly. Actuators prototypes built with the PAni electrodes (Figure 10) showed good performance and the initial tests show promising stability.

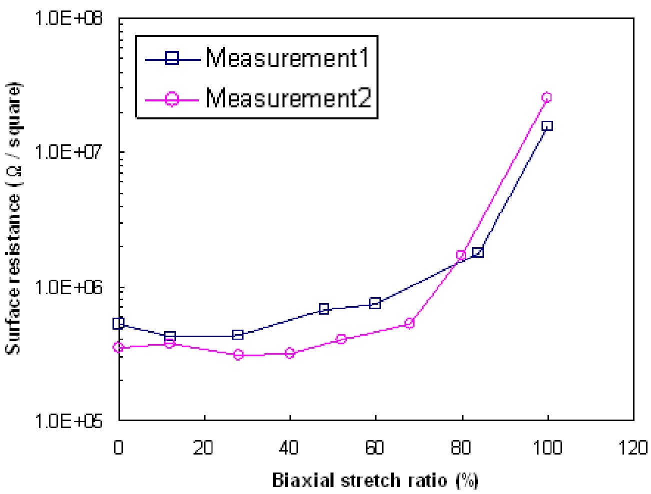


FIGURE 9: Surface resistance of PAni-EVA-electrodes as a function biaxial stretch ratio.

The PAni-based electrodes seemed to have a good durability against electrical breakdowns. Sometimes the sample could be used again after a short circuit. The electrode does not burst in flames like the carbon electrodes easily do. In general the long term performance of these electrodes is expected to be better than with crease and carbon black powder electrodes.

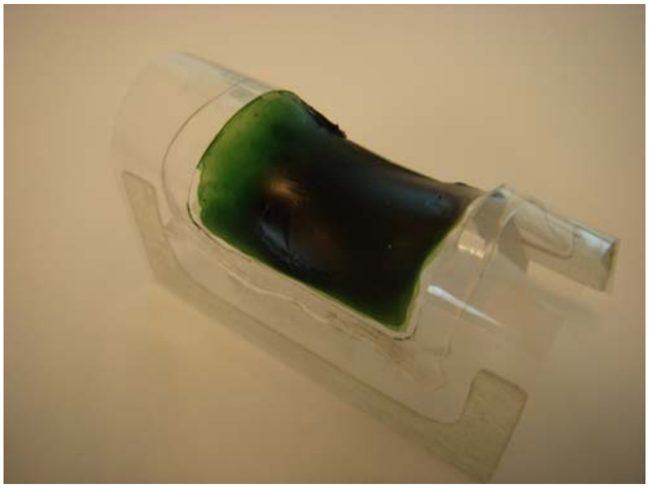


FIGURE 10: Soft frame actuator prototype with PAni-elastomer electrodes.

JPL/Caltech, Pasadena, CA

Cold Hibernated Elastic Memory (CHEM) self-deployable structures for commercial applications

Witold Sokolowski,
Witold.M.Sokolowski@jpl.nasa.gov

The concept called "cold hibernated elastic memory" (CHEM) utilizes polyurethane-based shape memory polymers (SMP) in open cellular (foam) structures or sandwich structures made of SMP foam cores and polymeric composite skins. The CHEM foam technology takes advantage of the polymer's heat activated shape memory in addition to the foam's elastic recovery to deploy a compacted structure. In practice, the CHEM foams are compacted to small volume above their softening (glass transition) temperature Tg. They may then be stored below their Tg without constraint. Heating to a temperature above their Tg restores their original shape. The CHEM processing cycle is illustrated in Figure 11 below.

The CHEM foam structures are under development by the Jet Propulsion Laboratory (JPL) and industry. Currently, the CHEM foam concept is well formulated, with clear space and biomedical applications.

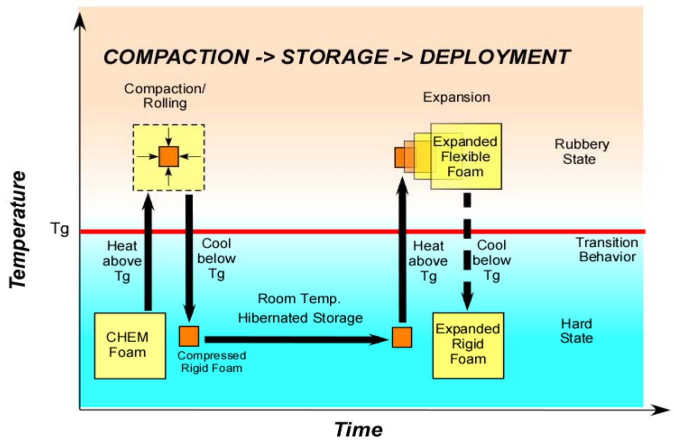


FIGURE 11: CHEM processing cycle

Although space and biomedical communities are the major beneficiaries, a lot of potential commercial applications are foreseen for the "earth environment".

Such applications could be made of CHEM foam with a Tg slightly above the highest ambient temperature. The CHEM products will be compacted, stowed unconstrained in small volumes at room temperature, transported if needed and deployed at required locations. The CHEM products can be deployed by using different heat sources such as portable heaters like a hair dryer or even by the solar radiation. They also can be dropped from aerial vehicles and deployed in hard-to-reach locations. Sensors, circuitry and automated components will be easily integrated to enable CHEM-based systems to act as smart structures which operate autonomously. In addition, CHEM structures are potentially self-repairable by temporary heating and re-cooling.

In conventional commercial applications, the CHEM structures can be utilized in deployable thermal insulation for building and transport systems, deployable impact absorption packaging, deployable recreation/sport products and automotive safety applications, deployable food equipment such as dishes/meal containers, plates, hot/cold storage for food, deployable toys and more.

However, this long list is by no means meant to be exhaustive. CHEM developers strongly believe that this technology has great promise for a host of commercial applications when fully developed. They have been already contacted regarding potential CHEM applications in recreation, automotive, packaging and construction sectors. Some development work is under way in automotive and packaging areas.

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 6, 2008	Carbon Nanotube Actuator Workshop, the German Aerospace Center (DLR) in Braunschweig, Germany. For information contact: Johannes.Riemenschneider@dlr.de
March 9 - 13, 2008	2008 EAPAD Conf., SPIE's Smart Structures & Materials and NDE Symposia, San Diego, CA., For information contact: Rob , SPIE, mikes@SPIE.org Website: http://spie.org/smart-structures-nde.xml
March 17 - 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 9 - 11, 2008, the 11th	Actuators 2008 - Bremen, Germany. For information Roy Kornbluh, SRI International roy.kornbluh@sri.com or Peter Sommer-Larsen, Risoe National Lab. peter.sommer.larsen@risoe.dk Website: www.actuator.de
June 24 - 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

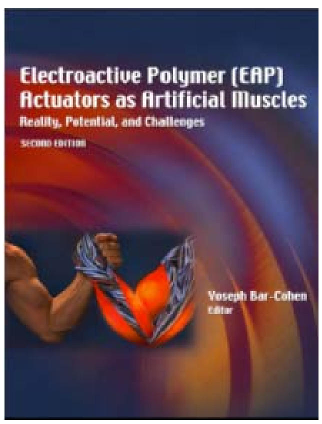
Biomimetics: http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm

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)



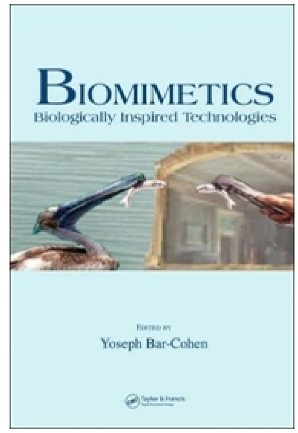
In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published. This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent 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

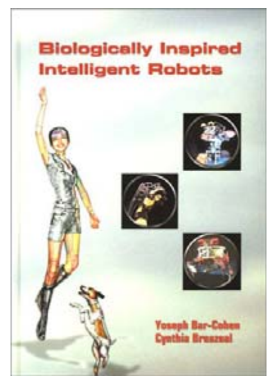
This book about Biomimetics review technologies that were inspired by nature and outlook for potential development in biomimetics in the future.



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.

Happy New Year

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. 67-119, 4800 Oak Grove Dr., Pasadena, CA 91109-8099
Phone: (818)-354-2610, Fax: (818)-393-2879 or E-mail: yosi@jpl.nasa.gov