

WorldWide ElectroActive Polymers



EAP

(Artificial Muscles) Newsletter

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FROM THE EDITOR

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

We recently reached milestone of 10th anniversary of the SPIE Conference on Electroactive Polymer Actuators and Devices (EAPAD). This conference was held from March 9 thru 13, 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.

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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>

ABOUT THE EXPERT

Mohsen (Mo) Shahinpoor



Mohsen (Mo) Shahinpoor has accepted an academic leadership position at the University of Maine. He has been appointed as R.C. Hill Professor and

Chairman of the Department of Mechanical Engineering and the Director of Biomedical Engineering Laboratory at University of Maine. He will continue his research work on electroactive polymers and particularly ionic polymer conductor nano-composites (IPMCs, IPCCs, IPMNCs and IPCNCs). At his new affiliation he is involved with studies related to integrating EAP materials into robotic surgery, active artificial organs as well as biomimetics. In the above picture he is shown with his students and an artificial human torso equipped with active polymeric artificial organs. His new e-mail address is mohsen.shahinpoor@maine.edu

RECENT CONFERENCES

2008 SPIE EAPAD Conference

The 10th SPIE's EAPAD conference was held in San Diego, California, from March 9 - 13, 2008. This Conference was 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 consisted of presentations from leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas.

The papers focused 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 was given and the EAP-in-Action Session was held as part of this conference.

The course provided an overview of the field of EAP covering the state of the art, challenges and potential. The lead instructor was the Editor of this Newsletter, the topic of electronic EAP was taught by Qibing Pei, professor of materials science and engineering, Univ. of California, Los Angeles (UCLA) and the topic of ionic EAP was taught by Kwang Kim, Professor and Chair, Mechanical Engineering Department, University of Nevada, Reno. A photo of some of the students is shown in Figure 1.

The Keynote paper was given by Adam Summers (Figure 2), physiology professor, UC

Irvine (UCI). His presentation was entitled "High-performance with a 'soft' skeleton: the shark cartilage composite." Generally, Adam Summers is interested in materials that have been structured at the micro and nano-scales by natural selection. For his expertise in marine biology, he has been an advisor to the movie studio Pixar in the production of the movie "Finding Nemo" providing information about fish behavior. His Keynote presentation helped clarify the puzzling high performance of the shark in spite of its cartilage made skeleton.



FIGURE 1: Attendees of the 2008 EAPAD Course.



FIGURE 2: The EAPAD's Keynote Speaker, Adam Summers, from UC Irvine (UCI).

The Conference this year included 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”

On Monday, March 10, 2008, the EAP-in-Action session was held. This Session 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 the first Human/EAP-Robot Armwrestling Contest was held in 2005. This year there were 8 research and industry presenters who demonstrated their latest EAP actuators and devices including

- Geoff Spinks, and Scott McGovern, University of Wollongong, Australia, demonstrated a fast (100 Hz) polypyrrole trilayer actuators and sensors as well as prototype robotic fish (Figure 3).



FIGURE 3: A prototype robotic fish is being prepared for demonstration by Scott McGovern, University of Wollongong, Australia.

- Jinsong Leng, Harbin Institute of Technology, China, demonstrated a flower that opens when it gets hot using Shape Memory Polymers (Figure 4).



FIGURE 4: The flower that opens when activated is being demonstrated by Jinsong Leng and his team from the Harbin Institute of Technology, China

- Federico Carpi, University of Pisa, Research Centre “E. Piaggio”, Italy, demonstrated a contractile folded dielectric elastomer actuators and buckling dielectric elastomer actuators (Figure 5).



FIGURE 5: An articulated mirror being demonstrated by Federico Carpi, University of Pisa, Italy.

- Iain Anderson, Todd Gisby, and Ben O'Brien, Auckland Biomimetics Laboratory Bio-engineering Institute, and Emilio Calius, Industrial Research Ltd, New Zealand, demonstrated several applications of their Dielectric Elastomer Minimum Energy Structure (DEMES) bending actuators, and novel methods for fine control of DE transducers (Figure 6),



FIGURE 6: The New Zealand team preparing their demonstration (from right to left: Emilio Calius, Ben O'Brien, Iain Anderson, and Todd Gisby),

- Silvain Michel, Head of EAP Research Group, and Christa Jordi, Swiss Federal Laboratories for Materials Testing and Research/Empa, Switzerland demonstrated an improved 2nd version of their bleep. This bleep shows the successful integration of membrane dielectric elastomer actuators in their Lighter-than-Air vehicle (Figure 7).



FIGURE 7: Silvain Michel and Christa Jordi are demonstrating the blimp that is steered by dielectric elastomer actuators.

- Manuel Aschwanden, David Niederer and Mark Blum, Optotune (a Start-up company at EMPA), Dübendorf, Zürich, Switzerland, demonstrated a tunable optical elements based on Dielectric Elastomer Actuators (Figure 8).



FIGURE 8: Manuel Aschwanden is describing his Tunable Optics that are controlled by Dielectric Elastomer Actuators

- Charlie Duncheon, Executive VP, Artificial Muscle, Inc. (AMI), described some of the latest prototypes and products of AMI. His demos included battery driven handheld devices such as the smartMove[™] energy harvester; the MLP-85 camera auto focus actuator, which is AMI's first standard product; omnidirectional planar actuator; and others (Figure 9).



FIGURE 9: Charlie Duncheon describing the latest EAP products that his company, AMI, is making.

- Seiki Chiba, Hyper Drive Corp., and Roy Kornbluh, SRI International, demonstrated a dielectric elastomer EAP actuated energy harvesting prototype (Figure 10).



FIGURE 10: Philip von Guggenberg is presenting the latest in energy harvesting technology at SRI (on his right is Seiki Chiba).

Actuator 2008

Peter Sommer-Larsen,
peter.sommer.larsen@risoe.dk

The 11th ACTUATOR, which is a biannual International Conference on new actuators, was held in Messe Bremen, Germany, on 9-11 June. This conference is a forum for the engineering community working with smart actuators to communicate their progress to a broad audience of professionals from industry and academia. The conference includes an exceptional exhibition with 35 companies presenting advanced actuator solutions. This year, ACTUATOR had 442 conference participants (incl. on-site registrations) from 30 countries.

The conference has three parallel tracks for all three days. A session dedicated to polymer actuators took place on June 9. The session comprised 6 oral presentations and 5 posters. In the medical devices session and in the microfluidics session, 1 oral and 2 poster presentations demonstrated application of IPMC and hydrogel polymer actuators. For EAP, the program committee members are R. D. Kornbluh, SRI International and P. Sommer-Larsen, Technical University of Denmark.

A review by Sommer-Larsen focused on applications of the different classes of polymer actuators. The presentations and posters indicated that the dielectric elastomer technology matures faster than other types of polymer actuators: two oral presentations demonstrated solutions in shape and position controls (F. Carpi, Univ. of Pisa) as well as vibration damping (P. Sommer-Larsen). One oral and two poster presentation dealt with automation of the production of contractile multilayer stacks of dielectric elastomers (M. Matysek, P. Lotz, Techn. Univ. Darmstadt) and another oral dealt with materials development for dielectric elastomer actuators (D. McCarthy, Univ. Potsdam). In addition, one poster (M. Randazzo, Italian inst. of technology) dealt with another fully automated fabrication of dielectric elastomer actuator stacks.

Two other classes of polymer actuators were presented: a multi-stable paraffin actuator (poster by M. Letho, Uppsala Univ.); whereas U. Kosidlo,

Frauenhofer Technologie-Entwicklungsgruppe (oral+poster) demonstrated stacked carbon nanotube based actuators operating in air with relatively large strain and force and driven only at a few Volts.

Further information about this Conference and the plan for ACTUATOR 2010 can be viewed at can be found at www.actuator.de.

CIMTEC 2008 Conf. on Smart Mat. and Structures

The 3rd International CIMTEC 2008 Conference on Smart Materials, Structures and Systems, was held at Acireale, Sicily, Italy from June 8 to 13, 2008 (Figure 11).



FIGURE 11: The 3rd International CIMTEC 2008 Conference on Smart Materials, Structures and Systems was held at Acireale, Sicily, Italy.

This conference was chaired by Pietro Vincenzini and it was organized as part of the CIMTEC series of international meetings that was established at the end of sixties. The conference was organized in an effort to provide a forum that covers the extensive research that is carried out worldwide for producing advanced materials, structures and systems. Progress in nano-technology and availability of multiscale computation models coupled with the exponential growth of computer capability are fuelling high rate of advancements. Also, this is increasingly taking advantage of emerging materials science and engineering with information derived from a deeper understanding of biological processes that are highly effective evolutionary solutions created by nature over million years. The conference consisted of five Symposia including

A. Smart materials and micro/nanosystems

- B. Smart optics Materials – Devices – Applications
- C. Emboding intelligence in structures and integrated systems
- D. Biomedical applications of smart materials, nanotechnology and micro/nano engineering
- E. Mining smartness from nature from bio-inspired Materials to Bionic Systems

A special focused session was dedicated to EAP and was held on June 10, 2008, as a joint session of Symposia A and E. The final program can be downloaded from http://www.cimtec-congress.org/2008/final_programme.pdf

UPCOMING CONFERENCES

2009 SPIE EAPAD Conference

The next SPIE's EAPAD conference is going to be the 11th one and it will be held again in San Diego, California, from March 8 - 12, 2008. This Conference will be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Thomas Wallmersperger, Univ. Stuttgart, Germany. With the recent addition of Maarja Kruusmaa from Estonia to the EAPAD Conference, the Program Committee now consists of representatives from 20 different countries.

As in past years, this conference will consist of 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.

In the EAPAD 2009, we are going to have a special session on Biomimetics that will be chaired by Silvain Michel, Swiss Federal Laboratories for Materials Testing and Research/Empa, Switzerland, and Iain Anderson, Auckland Biomimetics Laboratory Bioengineering Institute, New Zealand. This Session is intended to take advantage of the ability of EAP to emulate muscles for mimicking biological creatures and systems and potentially making lifelike devices and mechanisms.

As in past years, a Course will be given on Sunday, March 8, (<http://spie.org/x12234.xml>) and the EAP-in-Action Session will be held on Monday, March 9, 2007. Abstracts are due on August 24, 2007. Information about this SPIE conference, which is part of the Smart Structures and NDE Symposium, is available at:

http://spie.org/app/program/index.cfm?fuseaction=conferencedetail&export_id=x12536&ID=x12233&redir=x12233.xml&conference_id=869478&event_id=865450

2nd International Conf. on Smart Materials and Nanotechnology in Eng.

On July 8-11, 2009, the 2nd International Conference on Smart Materials and Nanotechnology in Engineering (SMN2009) is going to be held at Weihai, P.R. China. This conference is intend to serve as a platform for exchange of ideas and progress on the topics of Smart materials and Structures, Nanocomposite materials, Multifunction materials, Bio-Inspired materials, Shape-memory alloys and polymer, Electroactive Polymer, Piezo-materials, Electro and magneto restrictive materials, ER/MR fluids, Fiber optic sensor, MEMS sensors and actuators, Modeling and Control, Active and Passive Materials, Structural health monitoring, etc. For more information please contact:

smn2009@smart-nano.org, website: <http://smart-nano.org/smn2009>.

ADVANCES IN EAP

Michigan State University's Smart Microsystems Lab

Xiaobo Tan xbtan@msu.edu;
<http://www.egr.msu.edu/~xbtan>

The Smart Microsystems Laboratory (SML) at Michigan State University (MSU) was established in the Fall of 2004, with a goal to enable *smarter, smaller, integrated* systems by merging advanced modeling, control, and design methodologies with novel materials and new fabrication approaches. The research activities of SML are currently centered around electroactive polymers (EAP), including modeling and control of these materials, integrated sensory feedback for EAP actuators, and robotic applications of EAPs. The EAP materials

being investigated include ionic polymer-metal composites (IPMC's) and conjugated polymers.

The objective in EAP modeling is to develop models for EAP actuators and sensors that capture dominant dynamics and yet are amenable to real-time control design. By taking a control systems perspective, we explore approaches to the derivation of analytical models from governing partial differential equations (PDE's), with an attempt to bridge the gaps between complex physics-based models and oversimplified empirical models. For example, infinite-dimensional transfer function models have been developed for IPMC sensors and actuators by exactly solving the (linear) dynamics-governing PDE with appropriately imposed boundary conditions. Work is underway to extend these models to nonlinear regimes, by drawing on tools in nonlinear elasticity, perturbation analysis, and dynamical systems. This modeling work has been applied to model-based control, such as adaptive control and robust control, and implemented in real-time tracking control experiments.

Feedback is often necessary in order to ensure precise control of EAP actuators in the presence of model uncertainties and noises. Using external, bulky sensors, however, is undesirable, considering the size and weight constraints in targeted robotic or biomedical applications of EAPs. We have been exploring ways to realize compact sensory feedback for EAP actuators. For example, we have demonstrated feedback control of an IPMC actuator using integrated polyvinylidene fluoride (PVDF) films, shown in Figure 12. The integrated IPMC/PVDF sensory actuator is being explored for bio/micromanipulation applications, such as microinjection of *Drosophila* embryos (Figure 13).

SML is actively exploring robotic applications of EAP materials. One such application is biomimetic robotic fish, where IPMC actuators are used to propel and maneuver the robot. A recent prototype from the lab is shown in Figure 14.

The research on robotic fish is carried out at three different levels. First, at the material/device level, methods are investigated for monolithic fabrication of IPMC fins that are capable of complex, 3D deformations, and methods for

microfabrication of highly active IPMC flow sensors. Second, at the robot level, efforts are made to understand how biological principles can be exploited for the robotic fish to achieve maneuverability and efficiency. Third, at the group level, there is interest in developing robotic fish schools for environmental monitoring applications. The lab is expanding to house a large water tank, about $16 \times 16 \times 4 \text{ ft}^3$, for the study of robotic fish schools.

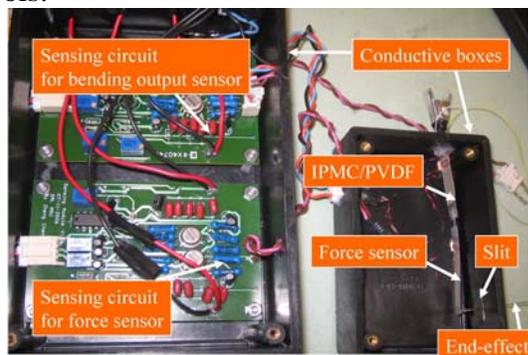


FIGURE 12: An integrated IPMC/PVDF sensory actuator that can monitor both the bending output and the force output of the actuator

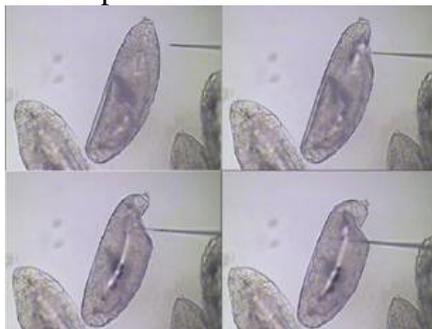


FIGURE 13: Application of IPMC actuator with integrated sensing to microinjection of *Drosophila* embryos.

SML is also using EAPs as an educational tool to inspire young students' interest in science and engineering. In collaboration with the Recruitment and K-12 Outreach Office of the College of Engineering at MSU, a robotic fish educational kit was developed, with which middle and high school students can learn how to build an IPMC-propelled robotic fish and get exposure to basic knowledge of robotics, artificial muscles, and circuits. A sociable robot, which uses IPMC strips to change expressions upon voice command, has also been popular in the outreach activities. Figure 15 shows

snapshots where EAP robots caught K-12 students' attention.

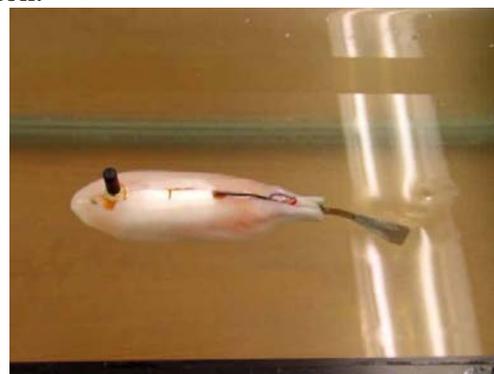


FIGURE 14: A recent prototype of robotic fish developed by SML. The free-swimming robot is propelled by an IPMC caudal fin, and contains onboard power, wireless communication, navigation, control, and sensing components.



(a) Students intrigued by an IPMC-propelled robotic fish during the MSU Grandparents University Program in 2007.

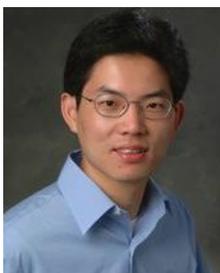


(b) Students interacting with IPMC-enabled sociable robot in the Summer of 2006.

FIGURE 15: EAP robots developed by SML are important tools of outreach.

SML's research and educational activities on EAP materials have been supported by a number of agencies and organizations, including National Science Foundation, Office of Naval Research, US Civilian Research & Development Foundation, SPIE, and MSU Intramural Research Grants Program.

More information about SML, including recent publications, can be accessed at http://www.egr.msu.edu/~xbtan/sml_index.html or by contacting Xiaobo Tan, Director of SML, Michigan State University, East Lansing, MI Email: xbtan@msu.edu; Web: <http://www.egr.msu.edu/~xbtan>



Innovative Research and Products (iRAP), Inc.

Electro-active polymer actuators and sensors to grow 50 times in five years

Tom Abraham <innoresearch@optonline.net>

According to a new market research study from Innovative Research and Products (*iRAP*) titled "Electro-active Polymer Actuators and Sensors – Types, Applications, New Developments, Industry Structure and Global Markets," the global market for EAP actuators and sensors reached \$15 million in 2007. This will increase to \$247 million by 2012. North America has about 66% market in 2007, followed by Europe at 21.3%, Japan at 9.3%, and rest of world at 3.3%. The AAGR growth rate is expected to be 71.3% to 91.8% for the four major regions surveyed for the period 2007 to 2012.

The demand for EAP actuators and sensors in 2007 comes mostly from laboratories for research and development in new application areas. There is large scale EAP-related R&D activity in university and institutional labs in North America, resulting in initial large scale demand for EAP devices in 2007. The sensors (as used in smart fabrics and high strain applications) constitute about 16% of the total EAP device market in 2007.

This *iRAP* (Innovative Research and Products, Inc.) study segmented markets into four

applications for electro-active polymer devices and products. These are medical devices, smart fabrics, digital mechatronics, and high strain sensing in construction. Manufacturers of electro-active polymers expect competition to persist and intensify in the future from a number of different sources. EAP devices are facing competition in a new rapidly evolving and highly competitive sector of the medical market. Increased competition could result in reduced prices and gross margins for EAP products and could require increased spending by research and development, sales and marketing, and customer support.

Medical devices will have the largest share in 2007, as much as 77.3%, followed by smart fabrics with 13.3%, digital mechatronics with 6.7%, and high strain sensing in construction as the remaining 2.7% of the market. While the medical devices will continue to maintain the lead in 2012, that sector will see the largest growth rate as well, as much as 92 % AAGR from 2007 to 2012.

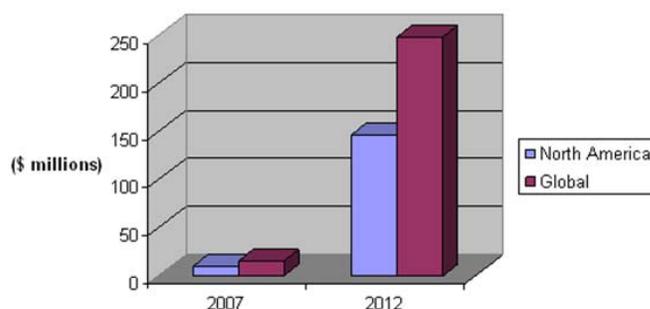


FIGURE 16: North American and global market for electro-active polymer actuators and sensors by application in 2007 and 2012 (Source: *iRAP*, Inc.)

TABLE 1: North American and global market for electro-active polymer actuators and sensors, 2007 and 2012 (Source: *iRAP*, Inc.)

	2007 (\$ Millions)	2007 (%)	2012 (\$ Millions)	2012 (%)	AAGR (%) 2006-12
North America	9.9	66	146	59.1	71.3
Global	15	100	247	100	75.1

More details of the report are available from Innovative Research and Products (*iRAP*), Inc., visit <http://www.innoresearch.net/Reports/ElectroActivePolymerActuators.doc> or marketing@innoresearch.net

According to the *iRAP* study, during 2007, there was a low key activity in the manufacturing of EAP devices. Companies are catering to specific orders of low to medium volumes. Low penetration of EAP technology in the fragmented market is partly due to lack of standardization of product specifications among manufacturers. Adaptation of EAP technology during the period of replacement of bulky conventional actuators by OEMs will depend upon, besides cost, reliability and durability of the EAP devices.

Central Mechanical Engineering Research Institute, Durgapur, West Bengal, India

Capabilities of IPMC based micro gripper for handling miniature parts

R K Jain, S Majumdar and G P Sinha
gopalpsinha@gmail.com

A compliant micro gripper using ionic polymer metal composite (IPMC) is shown in figure 17. The design consists of two compliant fingers using IPMC (size 30mmX6mmX0.2mm) as actuators. These fingers are operated independently through computer analog pulse which is controlled by digital analog card. When fingers are in operation, the maximum displacement is in the range of 5 mm. The maximum and minimum jaws opening for micro gripper are found to be 5 mm and 0.5 mm respectively (Figure 18). The fingers can hold the object having weight up to 10mg for a period of 5 second. The micro gripper has demonstrated handling capabilities for micro components likes pin (size ϕ 1mm and length 10mm, Mild Steel). However, this shows a tremendous potential for development of micro manipulation technology without usage of conventional means like micro motors and piezo motors etc. Although these devices have exhibited acceptable handiness, they could also perform handling of millimeter-scale components, required for complex fabrication and assembly.

Correspondence Address: R K Jain, Scientist,
Design of Mechanical System Group and Micro

Robotics Lab, Central Mechanical Engineering Research Institute (CMERI), Durgapur-713 209, West Bengal, India. Phone: +91-343-6452137, Email: rkjain@cmeri.res.in

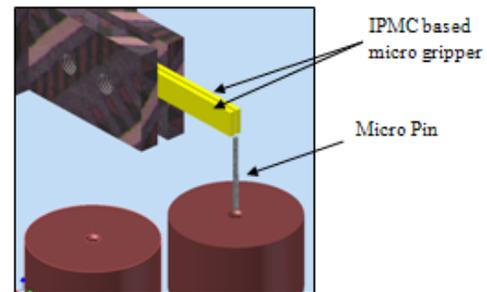


FIGURE 17: Schematic CAD model of micro gripper using IPMC



FIGURE 18: (a) Maximum jaw opening and (b) closing position of IPMC based micro gripper with handling capabilities of miniature components

Johannes Kepler University Linz

Electrical control method for dielectric elastomer actuators

Christoph Keplinger (christoph.keplinger@oeh.jku.at),
Martin Kaltenbrunner (mk27@gmx.at), **Nikita Arnold**, and **Siegfried Bauer**

Researchers from Johannes Kepler University in Linz, Austria, developed an electrical characterization technique for obtaining information about the transient strain in elastomer actuators and analyze the behavior of the actuator in safe and failure operation regimes. Additionally, the technique allows strain-dependent measurements of the electrode resistance. The current measurement based technique can be also applied for actuator control with feedback loops; an important direction of DEA research as it improves applicability.

The experimental setup for capacitive and optical analysis of extension rates is shown in Figure 19, where the optical part is only used to control and compare the capacitive data. For the capacitance in a circular symmetrically stretched DEA one can write

$$C = \epsilon_0 \epsilon (\lambda_r, \lambda_z) \frac{\lambda_r^2 A_0}{\lambda_z z_0} = \epsilon_0 \epsilon (\lambda_r, \lambda_r^{-2}) \frac{A_0}{z_0} \lambda_r^4$$

where λ_r and λ_z denote the radial and the axial stretch ratios with respect to the prestretched state. A_0 and z_0 are the initial area and thickness, ϵ_0 and ϵ denominate the vacuum permittivity and the dielectric constant (if necessary in dependence of the stretch variables).

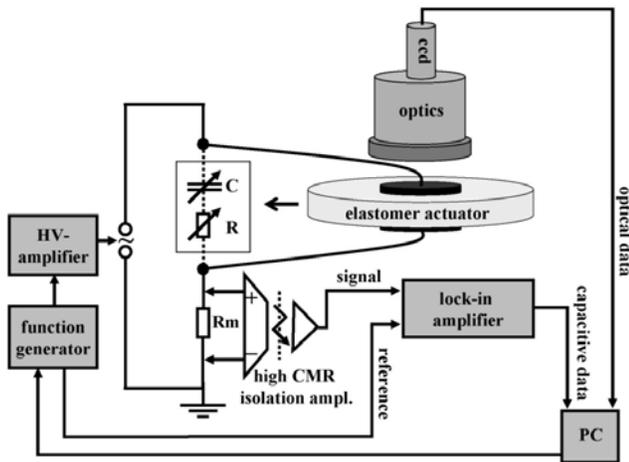


FIGURE 19: Electrical versus optical control of stretch ratios. Electrical control enables investigations in flat, wrinkled and instability regimes of actuator operation.

A clear handicap of optical control systems is the inability to correctly account for out-of-plane deformations (wrinkles). The discrepancy of the optical a20 19, where a circular actuator was driven into a wrinkled state. The optical method significantly underestimates the strain, whereas the capacitive setup delivers the right values.

An important task in DEA research is to improve the performance and reliability of compliant electrodes. The presented capacitive technique allows for *in situ* tracking of the electrode resistance which will accelerate material development.

Furthermore, the capacitive control of DEAs is not limited to planar geometries, but allows for characterization of arbitrary shaped actuators.

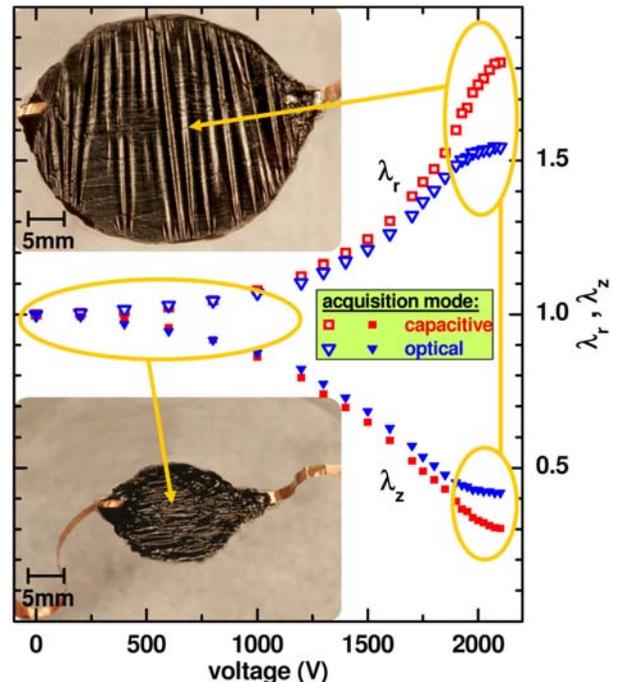


FIGURE 20: Electrical measurements of the extension rate can exceed optical measurements in wrinkled regimes of dielectric elastomer actuator operation.

References:

- S. Bauer and M. Paajanen, *Electromechanical characterization and measurement protocol for dielectric elastomer actuators*, Proc SPIE 6168 (2006).
- C. Keplinger, M. Kaltenbrunner, N. Arnold, and S. Bauer, *Capacitive extensometry for transient*

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Harbin Institute of Technology (HIT)

Analysis and application of dielectric elastomer actuators

Jinsong Leng lengjinsong@yahoo.com.cn
<http://smart.hit.edu.cn>

Dielectric elastomer actuators have been intensely studied in recent years. The electromechanical stability has been reviewed. We focused on the mechanical properties and the stability of the dielectric elastomer actuators based the theory of [Suo et al, 2007]. Using the large deformation theory hyperelastic model (model of Ogden, Yeoh, Mooney-Rivlin, Arruda-Boyer) we analyzed the mechanical properties of the planar actuator [Liu et al, 2008]. We considered the electromechanical coupling effect and used the nonlinear field theory analysis. We proposed an electric energy density function model with varying dielectric constant.

The dielectric elastomer film is very thin and therefore applied high voltage may result in an electrical breakdown. Based on the stability theory of dielectric elastomer actuator, we proposed a new method on the stability of the dielectric elastomer actuator using the strain energy function with two parameters [Liu et al, 2008] and the electric energy density function with varying dielectric constant.

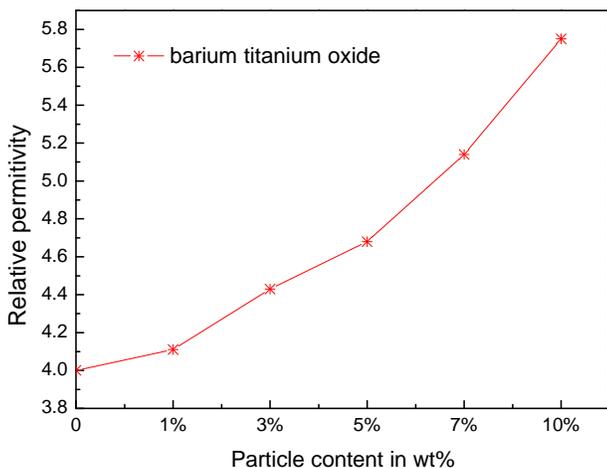


FIGURE 21: Permittivity of dielectric composites at varying particle content.

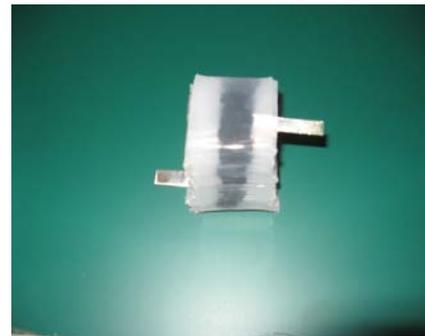
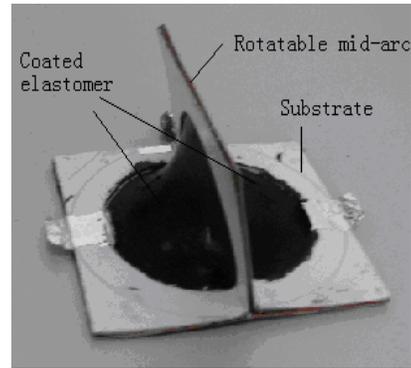


FIGURE 22: Inflated dielectric elastomer actuator and folded dielectric elastomer actuator.

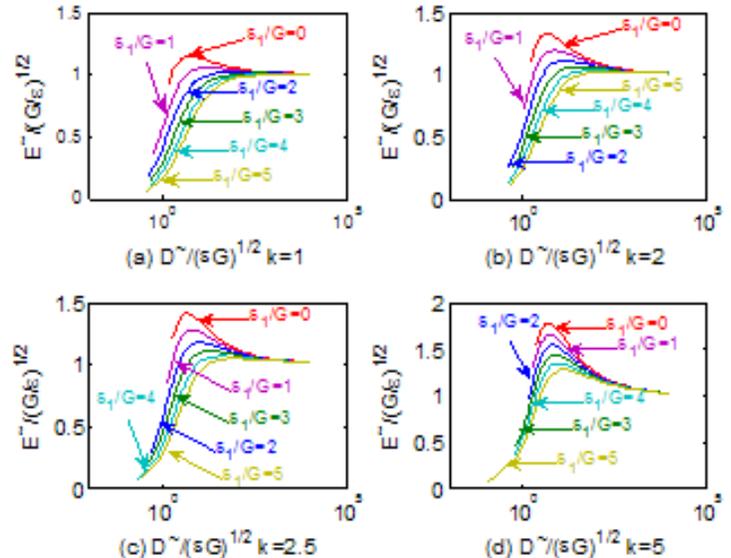


FIGURE 23: Analysis of stability of dielectric elastomer using strain energy function with two material constant, D^- , is nominal electric displacement, E^- , is nominal electric field, k , and G is material constant.

Using the acrylic film VHB 4910 (3M) we made planar actuator, wound roll dielectric elastomer

actuator and inflated dielectric elastomer actuator [Liu et al, 2007]. We tested the overall performance of these actuators and actuated an artificial muscle arms and artificial bio-mimetic eyeball respectively.

Based on the silicone elastomer (BJB, TC5005A/B-C) we fabricated a planar film actuator and folded dielectric elastomer actuator, and tested the performance of the actuator in terms of actuation strain, breakdown voltage and the deformation with different C content. A couple of agonist-antagonist actuators were studied to mimic the actions of the lateral rectus-type human ocular muscles, in order to enable bi-directional rotations of the eyeball around an axis.

Barium titanium oxide ferroelectric (BaTiO₃) powder [Zhang et al, 2007] was used to develop a particular composite based on a silicone elastomer matrix respectively, with improved dielectric permittivity. Tests of the physical and chemical properties of the dielectric elastomers are currently being conducted.

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Electro-activate shape-memory polymer composite

Jinsong Leng lengjinsong@yahoo.com.cn

Shape-memory polymers (SMPs) have been under intensive research in recent years, due to their many attractive properties and great potential. These materials by far surpass shape-memory alloys and shape-memory ceramics in many characteristics, e.g. easy manufacture, programming, high shape recovery ratio and low cost, and so on. However, they have not fully reached their technological potential, mainly since the actuation of shape recovery is driven by external heat. The focus of this discussion is on the electro-active SMP composites filled with conductive filler(s).

By adding carbon black and carbon short fiber, it is shown that the particulate additives are dispersed homogeneously within the matrix and served as interconnections between the fibers, while the fibrous additives act as long distance charge transporter by forming local conductive paths [Leng et al, 2007]. The electrical conductivity of the nanocomposite which contains 5 wt % carbon nanoparticles and 2 wt % short carbon fiber is 2.32 S/cm by four-point van der Pauw method, and can be induced by 24 V voltages.

Magnetic particles were also added into SMP. These particles formed chains by applying magnetic field in the cured process. Electrical resistance is significantly reduced in this way [Leng et al, 2008]. SEM images reveal that single chains start to be formed at 1 volume fraction percent of Ni. With the increase of Ni content, multi-chains (bundles) are resulted, and eventually no clear Ni chain can be recognized (Figure 25, left column). In addition, after five stretching-shape recovery cycles, the Ni chains still exist (Figure 25, right column).

Moreover, it was demonstrated to significantly reduce the electrical resistivity in polyurethane SMP filled with randomly distributed carbon black (CB). With an additional small amount of randomly distributed Ni microparticles (0.5 vol %) in the SMP/CB composite, its electrical resistivity is only slightly reduced. However, if these Ni particles are aligned into chains (by applying a low magnetic field on the SMP/CB/Ni solution before curing), the drop of the electrical resistivity is significant [Leng

et al, 2008]. Obviously, the remarkable reduction in the electrical resistivity is the result of the conductive chains, which serve as conductive channels to bridge those small isolated CB aggregations. This bridging effect is more significant in composites loaded with a low amount of CB in which the CB aggregates are relatively small in size and more isolated. As shown in Figure 26, almost full recovery is observed in 120 s.

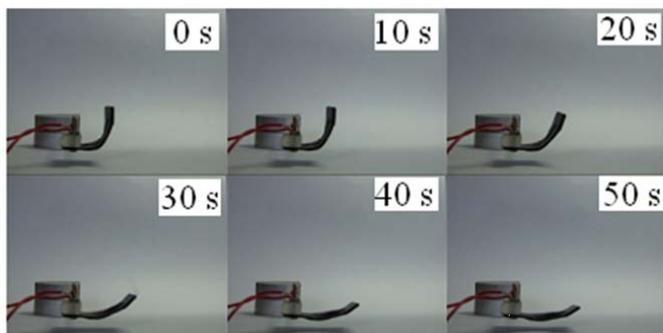


FIGURE 24: Electro-activate SMP filled with CB/SCF induced by applying 25 V of using chained SMPs for cyclic actuation.

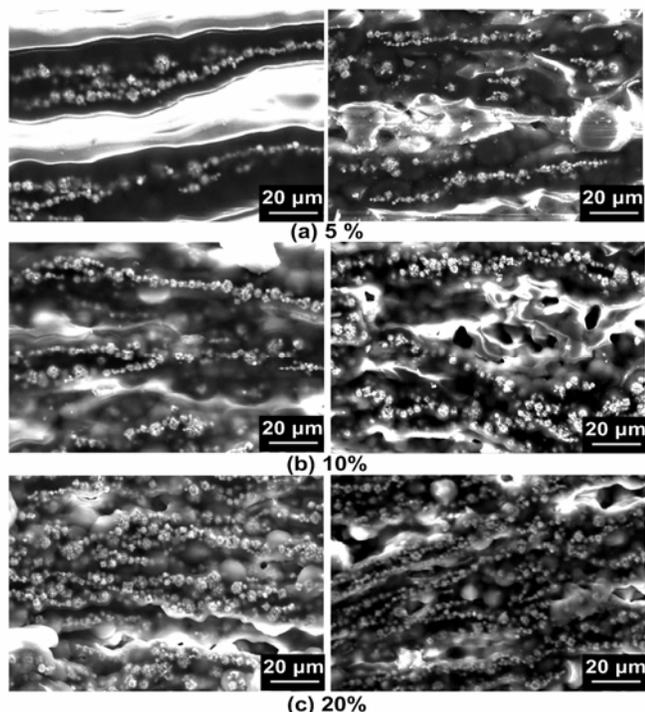


FIGURE 25: Typical SEM images before (left column) and after (right column) five stretching (at 50 percent strain) shape recovery cycles.

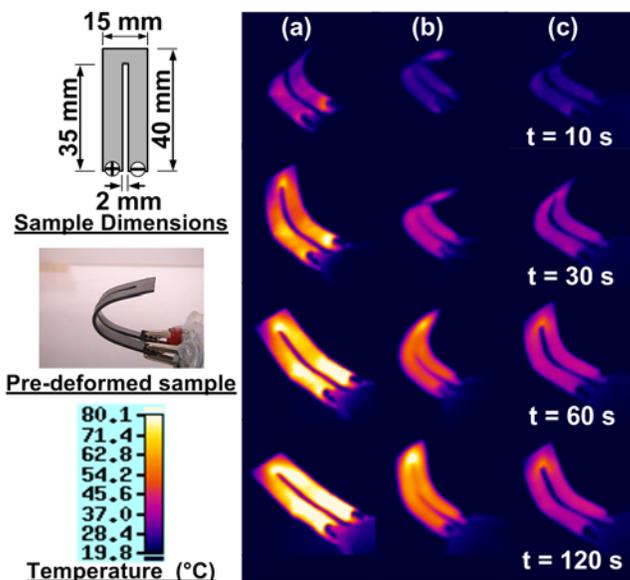


FIGURE 26: Sequence of recovery and temperature distribution. Top-left inset: dimensions of sample; middle-left inset: pre-bent shape; bottom-left inset: temperature bar (in Celsius degree). Sample (a) 10 volume fraction percent of CB, 0.5 volume fraction percent of chained Ni; Sample (b) 10 volume fraction percent of CB, 0.5 volume fraction percent of randomly distributed Ni; and Sample (c) 10 volume fraction percent of CB only. The tests were repeated for more than five times on each sample.

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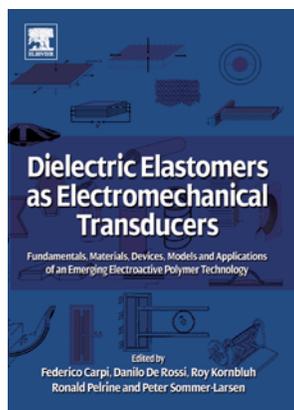
NEW BOOKS

Dielectric Elastomers as Electromechanical Transducers

Federico Carpi, Danilo De Rossi, Roy Kornbluh, Ronald Pelrine and Peter Sommer-Larsen

(Editors), Elsevier, ISBN-13: 978-0-08-047488-5, (Jan. 2008) 344 pages

This book describes dielectric elastomers as one of the most promising EAP classes for electromechanical transducers and “pseudo-muscular” actuation devices to be used in a very broad range of applications, spanning from robotics and automation to the biomedical field. Dielectric elastomer actuation is drawing a particular interest because of its promise of simple and robust low-cost devices with overall performance exceeding most conventional technologies, such as electromagnetics and piezoelectrics. In fact, dielectric elastomer actuators have demonstrated strain and energy density exceeding that of all high-speed field-activated actuation technologies. Further, in addition to actuation, dielectric elastomers have also been shown to offer unique possibilities for improved generator and sensing devices. Dielectric elastomer transduction was introduced during the 1990s, pioneered by SRI International. Although the field is still being explored and expanded extensively, a great deal of work has already been done, with encouraging results. This technology is enabling today an enormous range of applications that were not possible with any other EAP or smart-material technology until a few years ago. For interested readers, this book is expected to provide a comprehensive and updated insight on this technology. The book covers all the fundamental aspects, comprising a collection of chapters written by the fathers of this technology, along with the most renowned international contributors in the



field. The presented topics range from transduction principles, basic materials properties, design of devices, material and device modeling, up to possible applications and future research avenues. Such an extension of the covered topics is expected to make this text as the first reference handbook on dielectric elastomer transduction.

UPCOMING EVENTS

Date	Conference/Symposium
March 8 - 12, 2008	11th EAPAD Conf., SPIE's Smart Structures & Materials and NDE Symposia, San Diego, CA., For information contact: Rob Whitner, SPIE, mikes@SPIE.org Website: http://spie.org/smart-structures-nde.xml
July 8 – 11, 2009	2 nd International Conf. on Smart materials and Nanotechnology in Engineering, Weihai, China For information contact: Jingsong Leng, lengiinsong@yahoo.com Web: http://smart-nano.org/smn2009
June 14-16, 2010	ACTUATOR 2010 will be held at Messe Bremen. For further information contact Peter Sommer-Larsen peter.sommer.larsen@risoe.dk and see www.actuator.de

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://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/WW-EAP-Newsletter.html>

Recipe: <http://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-recipe.htm>

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

Arm wrestling Challenge:

<http://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm>

Books and Proceedings:

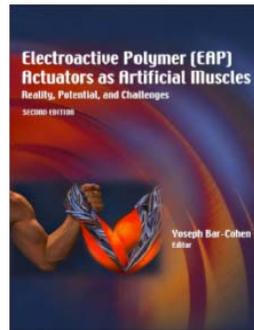
<http://ndea.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm>

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 heartwarming, where major milestones are continually being reported.

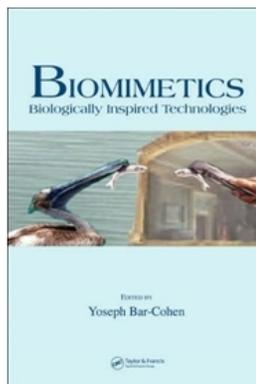


Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

<http://ndea.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



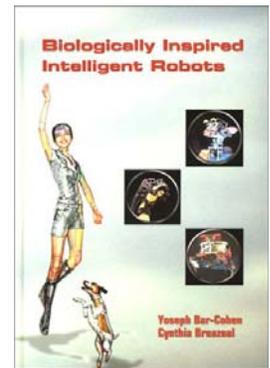
outline can be seen on

<http://ndea.jpl.nasa.gov/ndea-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.



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EDITOR: Yoseph Bar-Cohen, JPL, <http://ndea.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