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*

This issue reports the latest progress in the fields of Electroactive Polymers (EAP) and biomimetics.

LIST OF CONTENTS

ABOUT OUR EXPERTS

Siegfried Bauer is now an IEEE Fellow

In Nov., Siegfried Bauer has been elevated by IEEE to a Fellow. Bauer was born in Karlsruhe, Germany, in 1961. He received the master's and Ph.D. degrees in physics from Technical University in Karlsruhe, in 1986 and 1990, respectively, and the Habilitation degree from the University of Potsdam, in 1996. In 1992, he joined the Heinrich Hertz Institute for Communication Engineering, Berlin, Germany. In 1997, he became a Professor of Experimental Physics with Johannes Kepler University Linz, Austria. Since 2002, he has been the Head of the Soft Matter Physics Department. His interests are in the areas of electroactive polymers, flexible and stretchable electronics, energy harvesting, and soft machines. He is a member of the Austrian Physical Society and the Association of German Electrical Engineers. He received the European Research Council Advanced Investigators Grant in 2011.

GENERAL NEWS

The WW-EAP Webhub http://eap.jpl.nasa.gov is periodically being updated with information regarding the EAP activity worldwide. This Webhub is a link of the JPL's NDEAA Webhub of the Advanced Technologies Group having the address: http://ndeaa.jpl.nasa.gov

EuroEAP Society open to subscriptions

Federico Carpi, Queen Mary University of London, UK; Edwin Jager, Linköping University, Sweden; and Gabor Kovacs, Empa, Switzerland

Few years ago, as an outcome of the "European Scientific Network for Artificial Muscles", a group of European institutes decided to establish and fund the 'EuroEAP – European Society for Electromechanically Active Polymer Transducers & Artificial Muscles' (www.euroeap.eu) as a non-profit Association,, The main objective is to contribute to and promote the scientific and technological advancement and the diffusion of Transducers and Artificial Muscles based on Electromechanically Active Polymers (EAP).

The EuroEAP Society operates as an international organization and it welcomes members from any country worldwide. If you are interested in learning more about the Society, please visit the website www.euroeap.eu and subscribe to become a Member of this unique Association in the EAP field.

Standards for dielectric elastomer transducers

Federico Carpi[1*], Iain Anderson[2], Siegfried Bauer[3], Gabriele Frediani[1], Giuseppe Gallone[4], Massimiliano Gei[5], Christian Graaf[6], Claire Jean-Mistral[7], William Kaal[8], Guggi Kofod[9], Matthias Kollosche[10], Roy Kornbluh[11], Benny Lassen[12], Marc Matysek[13], Silvain Michel[14], Stephan Nowak[15], Benjamin O'Brien[16], Qibing Pei[17], Ron Pelrine[11], Björn Rechenbach[12], Samuel Rosset[18], Herbert Shea[18]

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[17] Department of Materials Science and Engineering, University of California, Los Angeles, USA
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The first standards for dielectric elastomer transducers have been published as a research paper in the journal "Smart Materials and Structures", vol. 24, 2015. These standards are the result of major cooperation among 18 leading international groups in the field. They present standardized methods for material characterisation, device testing and performance measurement.

The authors wish to encourage the dissemination of these standards within the interested research groups and companies, so as to ensure that students, research staff and industrial practitioners become aware of the standards and possibly adopt them while undertaking research and development activities, to the benefit of the entire field. These standards will be reviewed periodically. So, researchers and practitioners are encouraged to work for future improvements and extensions of the described protocols.

The published paper can be viewed at http://iopscience.iop.org/article/10.1088/0964-1726/24/10/105025 Also, a paper about these standards will be presented at the upcoming 2016 SPIE EAPAD Conference that is part of the Smart Structures Symposium that will be held in Las Vegas, Nevada, from March 20 to 24, 2016.

Wanted: Innovation in biomimetics

Start of submission for the International Bionic Award 2016 of German Association of Engineers (VDI) and Schauenburg Foundation

In 2016, it is time again: Every other year the German Association of Engineers (VDI) presents the International Bionic Award for outstanding scientific achievement in the field of product development in biomimetics. The Award is endowed with €10,000 by the Schauenburg Foundation and addresses young scientists. This is an international call for submissions. Young scientists who would like to be considered need to submit their papers in English by February 29, 2016 to the VDI Society Technologies of Life Sciences (TLS).

Biomimetics is an interdisciplinary scientific discipline in natural and engineering sciences. It belongs to the most important future technologies. Developments in biomimetics often provide innovative and novel solutions for technical problems inspired by nature.

The Award was launched in 2008 by the Schauenburg Foundation and the VDI, and was established to encourage start-ups as well as to open opportunities for young scientists in developing innovative products in biomimetics. This was proved impressively by the success of the past years awardees.

The Award is presented for outstanding work, for example in the form of a biomimetic/bionic product development or a doctoral/post-doctoral thesis that has been completed within the last two years before the submission deadline. Individuals as well as teams can participate. The winner or winners of this award are determined by an international judging team consisting of top-ranking scientists in biomimetics.

Further information and conditions for participation can be found at www.vdi.de/bionic2016 or can be requested by mail from the VDI-Society Technologies of Life Sciences (TLS), PO-Box 101139, 40002 Düsseldorf, Germany, or by e-mail: bionik@vdi.de

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The VDI – Spokespersons, designers, networkers

Engineers need a strong association that supports, promotes and represents them in their work. This task is performed by the VDI Association of German Engineers. For over 150 years it has steadfastly backed engineers. More than 12,000 honorary experts process the latest findings every year to promote our technology location. That's convincing: with over 155,000 members, the VDI is by far the largest engineering association in Germany. As the third largest standards organization we are also partner for the German business community and scientific organizations.

About the Schauenburg Foundation

The international Bionic Award has been endowed by the Schauenburg-Foundation since 2008. The Schauenburg-Foundation was established in 1986 by Hans-Georg Schauenburg, founder of the Schauenburg Group who has been in business in the Rhein-Ruhr area for over 50 years. The focus of the Schauenburg-Foundation, which is administered by the independent Stifterverband (Stifterverband is the business community's innovation agency for the German science system), reflects the close connection of the International Schauenburg Group to its roots and with scientific and technical innovation. The foundation mainly endorses academic projects in the area of engineering, economics and social sciences, as well as supporting young people in their vocational training.

UPCOMING CONFERENCES

2016 SPIE EAPAD Conference

The 18th SPIE's EAPAD conference is going to be held on March 20 to 24, 2016, in Las Vegas, Nevada. This Conference is going to be chaired by

Yoseph Bar-Cohen, JPL, and Co-chaired by Frédéric Vidal, University de Cergy-Pontoise, France. The Conference Program Committee consists of representatives from 32 countries. The call for papers is posted at: http://www.spie.org/eap

The Conference includes 122 papers and they will focus on issues that help transitioning EAP to practical use thru better understanding the principles responsible for the electro-mechanical behavior, analytical modeling, improved materials and their processing methods, characterization of the properties and performance as well as various applications.

At the EAPAD 2016, the Keynote Speaker is going to be Elisabeth Smela, University of Maryland, (**Figure 1**) and the subject of her presentation is "Nastic Actuators". These actuators mimic the capability of plants and they are based on hydraulic forces. They pump fluids by electroosmosis within microchannels in compliant material from one place to another. The hydraulic pressure causes the compliant material to deform.

Figure 1: Elisabeth Smela, University of Maryland, is the Keynote Speaker of the 2916 EAPAD Conf.

Elizabeth Smela is a Professor in the Department of Mechanical Engineering and the Institute for Systems Research at the University of Maryland, with affiliate appointments in Materials Science and Engineering and Electrical and Computer Engineering. She received a BS in physics from MIT and a PhD in electrical engineering from the University of Pennsylvania. Following her PhD she was a postdoc and then a researcher in Linkoping, Sweden, where she began developing conjugated polymer microactuators, LEDs, and sensors, and examining the volume change mechanisms. She continued this work as a senior researcher in Riso, Denmark, before moving to studies of actuation in spun polyaniline fibers as Vice President of Research and Development at Santa Fe Science and Technology. Her research at UMD has focused on polymer and biological microsystems, included basic understanding of conjugated polymer actuators, microfabricated dielectric elastomer actuators, and nastic actuators. Her group is also working on tactile skins for co-robotics, a bio-nose on a chip based on olfactory sensory neurons, and mapping the positions of nucleic acids in tissue sections.

In addition, in the 2016 EAPAD Conf. a Special Session is going to be held in celebrating the 10th anniversary of the Dielectric Elastomer Minimum Energy Structures (DEMES). The chairs of this Session are Siegfried Bauer, Johannes Kepler University, (Austria); and Herbert Shea, École Polytechnique Fédérale De Lausanne (EPFL), (Switzerland).

As in past years, an EAPAD course will be given on Sunday, March 20, 2016, and the EAP-in-Action Session will be held on Monday, March 21, 2016.

The invited papers in this Conference are:

Markus Henke, and Iain Anderson, "Autonomous artificial muscle robots without electronics", Session 1.

Richard J. Spontak, Krishna B. Subramani, Daniel P. Armstrong, Enes Cakmak, and Tushar K. Ghosh, "Fabrication strategies for exploring the anisotropic electroactuation of dielectric elastomers", Session 2.

Harold Park, "Computational modeling of electromechanical instabilities in dielectric elastomers", Session 3.

Liwu Liu, Yanju Liu, and Jinsong Leng, "Instability and thermodynamics of dielectric elastomers", Session 3.

Lenore Rasmussen, Charles Gentile, Lewis Meixler, and George Ascione, "Ras Labs-CASIS-ISS NL experiment for synthetic muscle: resistance to ionizing radiation", Session 5.

Reimund Gerhard, "From electrode charges on dielectric elastomers to trapped charges and electric dipoles in electrets and ferroelectrets: fundamental and applications-relevant aspects of diversity in electroactive polymers", Session 6A.

Hyacinthe Randriamahazaka, and Kinji Asaka, "General thermodynamic theory of the stress-composition interaction for bucky-gel electrochemical actuators", Session 6B.

Herbert R. Shea, Jun Shintake, Samuel Rosset, and Dario Floreano, "Cooking with DEAs: a compliant 1-gram gripper that easily picks up an egg", Session 8B

Jian Zhu, "Development of soft robots using dielectric elastomer actuators", Session 9A.

Jonathan M. Rossiter, Jonathan Winfield, and Ioannis Ieropoulos, "Here today, gone tomorrow: biodegradable soft robots", Session 9A.

The EAP-in-Action Session will include 9 demonstrating teams and the demonstrations will be as follows:

Canada

Yuta Dobashi, Mirza Saquib Sarwar, Saeedeh Ebrahimi Takalloo, Ali Rafiee, and John D.W. Madden, Department of Electrical and Computer Engineering, University of British Columbia, Vancouver BC, Canada

Description: Not available yet.

China

1. Liwu Liu, Jinrong Li, Fengfeng Li, Xiongfei Lv, Jinsong Leng, "Harbin Institute of Technology (HIT), Harbin China, "Applications of smart polymers"

Description: This demonstration will show smart polymer in action taking advantages of their being light weight, fast response, and large deformation. This advantages makes them attractive for applications in smart bionics, aerospace, biomedicine and other fields. The demonstration will include application of shape memory polymer (SMP) and dielectric elastomer EAP as actuators and deployable structures.

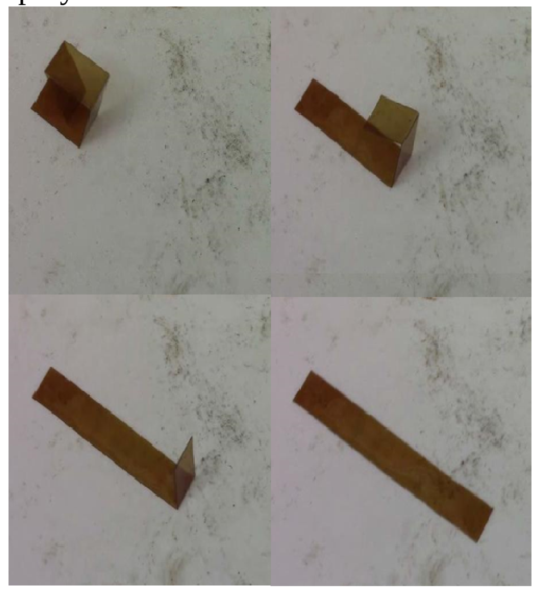

Figure 2: Unfolding of shape memory polymer film.

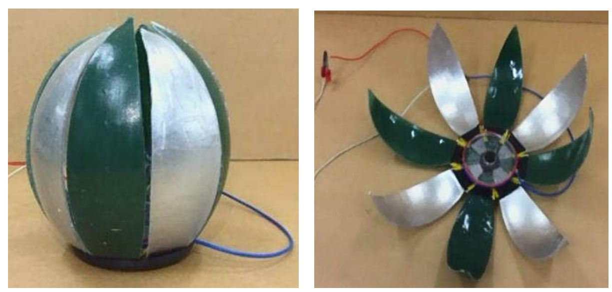

Figure 3: Deployment of sphere structure

Figure 4: Shape recovery process of SMP composites.

Figure 5: An "inchworm" based on dielectric elastomer

2. Tiefeng Li, Yuhan Xie, Guorui Li, Yiming Liang, Xuxu Yang, Yongbing Jin Soft Matter Research Center of Zhejiang University, "Soft robotics and smart SAM structures".

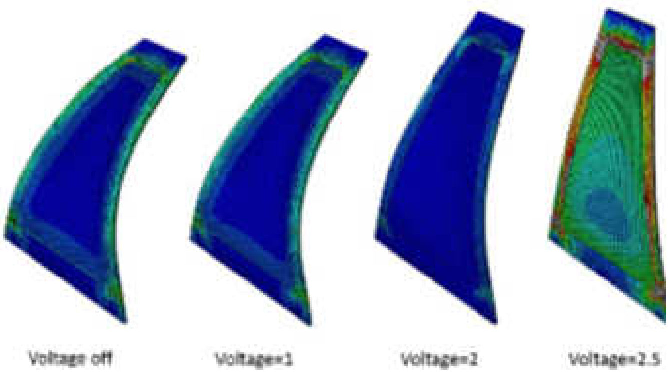

Figure 6: Temperature responsive tough hydrogel will be shown in large actuation tasks.

In this demonstration, soft robotics and smart structures driven by dielectric elastomer will be shown performing large actuation tasks, with fast response and actuating-sensing integrated capabilities. The materials are made of temperature responsive tough hydrogel and the objective is to use them for bio-medical applications.

Germany

Steffen Hau and Alexander York, Saarland University, Germany, "High force dielectric electroactive polymer (DEAP) membrane actuator"

Description: Energy efficiency, lightweight and scalability are key features for actuators in applications such as valves, pumps or any portable system. DEAP technology is able to fulfill these requirements better than commonly used technology e.g. solenoid, but has limitations concerning force and stroke. This demo will show the improvements that were made in increasing the force that is delivered by DEAP stack. Two different actuators are will be shown: The first is able to lift 10kg. The second can generate a force of 66N while acting against a spring load.

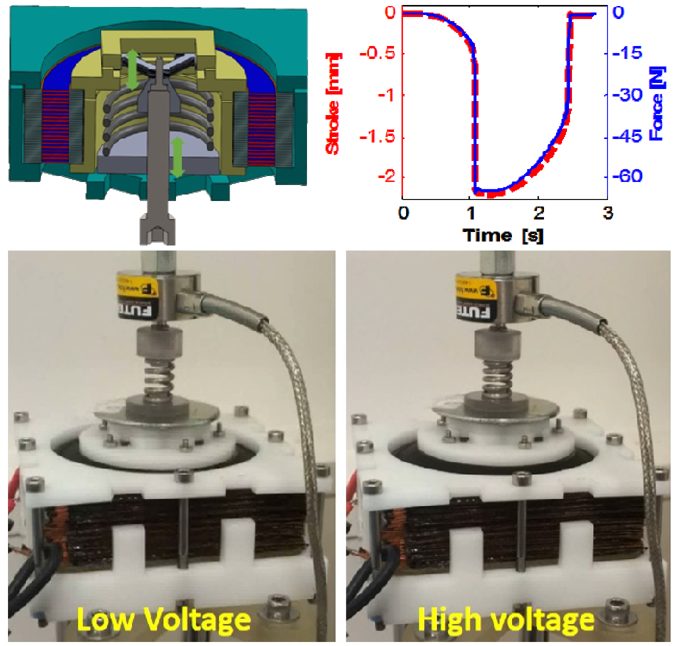

Figure 7: DEAP membrane actuator

New Zealand

Iain Anderson, Markus Henke, Andreas Tairych, Alan Veale, and Chris Walker, Biomimetics Laboratory and StretchSense Ltd, Auckland, New Zealand, "New technology for applications to autonomous robots, wearable sensors, and energy harvesters"

Description: EAP advances will be demonstrated having the potential to lead to an exciting future of autonomous robots, wearable sensors, and energy harvesters.

(1) Meet Trevor, the amazing EAP caterpillar with no control electronics! (**Figure 8**) - Trevor crawls by simply adding some DC charge to patterned conductor on the elastomer surface!
(2) Wearable, stretch sensitive communication – A demonstration will be of how to communicate with your partner, in the dark, and between rooms without talking.
(3) Giving wearable muscles cyber-proprioception - With soft wearable motion sensing we can augment our strength and get machines to follow our gesture based commands.

Figure 8: Trevor, the amazing EAP caterpillar with no control electronics

Singapore

1. Jian Zhu, Yuzhe Wang, Ujjaval Gupta, Dept of Mechanical Engineering, National University of Singapore, "Soft robots based on dielectric elastomer actuators",

<u>Description</u>: Artificial muscles were developed to mimic natural masseter muscles (superficial portion), using dielectric elastomer actuators. Soft actuators were installed onto a robotic skull, and will be shown moving the jaw and the mimicking natural muscles' displacement and velocity.

Also, a worm-like robot driven by a dielectric elastomer actuator will be shown.

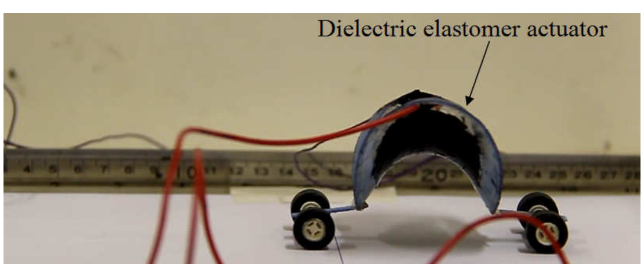

Figure 9: worm-like robot driven by a dielectric elastomer actuator

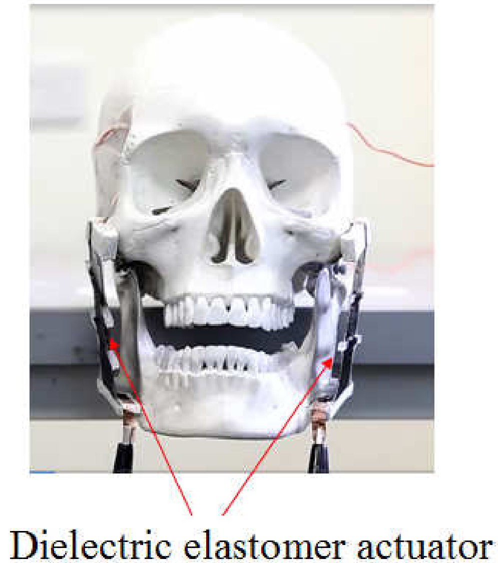

Figure 10: A jaw actuate by dielectric elastomer.

2. Koh Soo Jin Adrian, Stoyan Smoukov, Ang Marcelo H. Jr., Vy Khanh Vo Tran, Tan Hiok Yang, Christopher Tan, Zhang Jie, I-Ting Lin, and Tiesheng Wang, National University of Singapore (NUS) and Cambridge University, "An arm for the Arm-Wrestling contest",

<u>Description</u>: An antagonistic system of a wrestling arm will be demonstrated. A pair of elastomers that work against each other are attached to a disc that forms the "shoulder" of the artificial arm, via (ideally) inextensible cords, as illustrated below. Both elastomers are pre-tensioned by mechanical stretching. The main elastomer, depicted on the left, is for the actual arm wrestling, while the antagonist muscle is used to reset the arm to its original position (this can be made smaller).

During operation, a voltage is applied across the elastomer on the right, causing it to expand and "relax". The elastomer on the left contracts due to tension in itself, pulling on the disc and rotating the arm anti-clockwise. No voltage is applied across the left elastomer. The force exerted by the left elastomer is determined by the pre-stretching done mechanically.

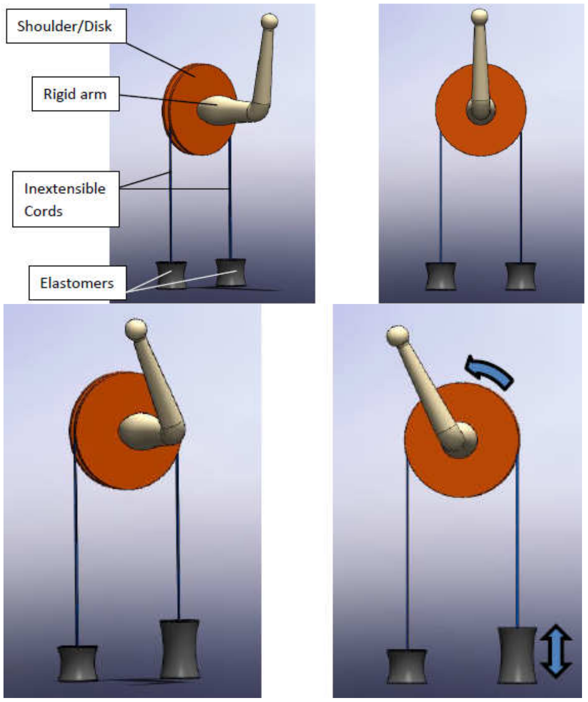

Figure 11: An antagonistic system of a wrestling arm

Switzerland

1. Vanessa Leung, Biomaterials Science Center, University of Basel, c/o University Hospital, 4123 Allschwil, Switzerland, "Apparatus for measuring the actuation forces of DEAs via cantilever bending"

Description: A compact, simple-to-operate apparatus for measuring the generated forces of planar dielectric elastomer actuators (DEA) will be demonstrated. DEA structures are fabricated on top of a cantilever substrate material with well-known mechanical properties such as PEN, PEEK, or Kapton film. When a DC-voltage is applied to the planar electrodes on either side of the elastomer layer, the resulting deformation of the incompressible elastomer bends the cantilever. The bending curvature is measured by the deflection of a laser beam reflected from the cantilever onto a position sensitive detector. This cantilever system can be used to evaluate the maximal strains of single- as well as multilayer DEAs.

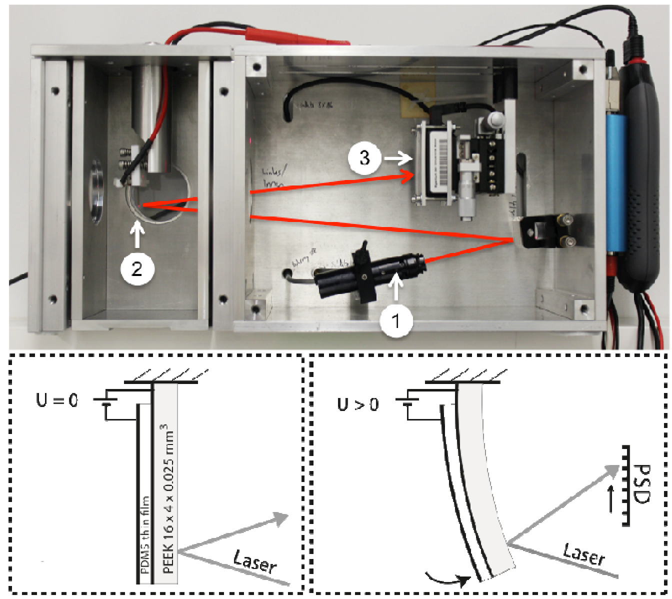

Figure 12: Light from a laser (1) reflects off from a DEA-based cantilever (2). When a DC-voltage is applied, the cantilever bends (bottom schematic). A position sensitive detector (3) measures the resulting deflection of the laser beam.

2. Nadine Besse, Samuel Rosset, Alexandre Poulin, and Herbert Shea, Microsystems for Space Technologies Laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL), Neuchâtel, Switzerland, "Tactile display based on shape memory polymers"

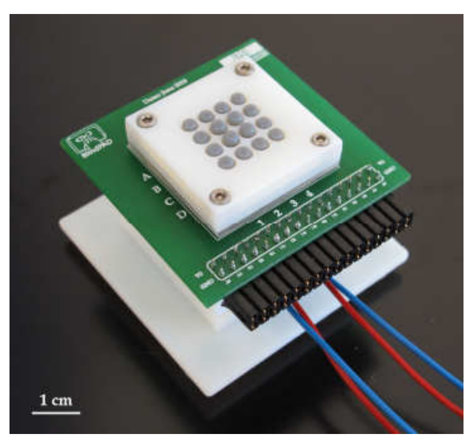

Figure 13: Latching and scalable 4x4 tactile display

Description: A fully latching and scalable 4x4 tactile display will be demonstrated to have 300 mN holding force and 300 μm motion per taxel (tactile pixel). The device, which is intended to provide graphical information to visually impaired users, consists of a shape memory polymer membrane, a compliant integrated heater per taxel, and a single common pneumatic actuation mechanism. Each taxel is individually addressable and the entire display can be refreshed in 5 seconds.

USA

1. Lenore Rasmussen, Eric Sandberg, Leila Albers, and Simone Rodriguez, Ras Labs, 300 Congress Street, Suite 405, Quincy, MA, "Synthetic Muscle™ – Shape-morphing EAP Based Materials and Actuators"

Description: Ras Labs electroactive polymer (EAP) based materials and actuators contract, and with reversed electric input polarity, expand. A thin shape-morphing film of the material in the expansion mode produces raised surface zones in desired shapes. A thick shape-morphing pad can controllably contract or expand, which are being used to prototype self-adjusting extremely comfortable prosthetic socket liners and other void-filling continual-fit applications.

Figure 14: Shape-morphing EAP Based Materials and Actuators were experimented on the International Space Station.

These EAPs can easily serve dual use as sensors, which can be tied in to automatic adjustment and biofeedback, and can communicate the number of impacts and severity of impact/pressure. Actuation can be performed underwater or on land with suitable elastomeric coatings. These robust EAPs (extreme temperature, high and low pressures) are being tested for radiation resistance on the International Space Center (ISS) National Laboratory. A protective cage with Ras Labs Synthetic Muscle™ EAP samples, similar to the hardware of the ISS experiment, will be also be presented.

2. Qi Shen, Sarah Trabia, Tyler Stalbaum, Choonhan Lee, Robert Hunt, and Kwang Kim Active Materials and Smart Living Laboratory, University of Nevada, Las Vegas (UNLV), USA www.kwangjinkim.org - Shape Memory Programmable and Electrically Controllable IPMC

Recently, the UNLV team successfully demonstrated an ionic polymer-metal composite (IPMC) actuator, having multiple-shape memory by two external inputs, electrical and thermal. This demonstration introduces a soft multiple-shape-memory IPMC actuator having multiple degree-of-freedoms that exhibited high maneuverability when controlled by two external inputs, allowing complex motions that are routine in nature.

Figure 15: Shape Memory Programmable and Electrically Controllable IPMC.

EuroEAP 2016 – the 6th International Conf. on EAPs

Anne Skov, Technical University of Denmark
Federico Carpi, Queen Mary University of London, UK

EuroEAP 2016, the 'Sixth international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles' (www.euroeap.eu/conference) will take place in Copenhagen, Denmark, on 14-15 June 2016 and will be chaired by Prof. Anne Skov (Technical University of Denmark).

The EuroEAP conference is annually organised by the EuroEAP Society. It is a highly multidisciplinary event with international breath. It is always held in Europe, in charming and easy-to-reach locations, and gathers participants and experts from all over the world. A unique format is conceived to facilitate interaction among participants. The entire event is condensed in two dense days, made of consecutive single-track sessions, consisting of oral and poster sessions. During the oral sessions, all the contributors (invited and not) present the significance of their work, in front of all the participants. For non-invited participants, the oral presentation is very short and it is aimed at anticipating in no more than 2 minutes key aspects of the work, which then has is presented more extensively with a poster, during a subsequent dedicated poster session. This allows all the contributors to gain full visibility of their work and all the participants to grasp the essence of all the works presented.

The invited oral presentations are given by world-leading scientists, young emerging researchers, as well as representatives of industry. The speakers invited to this edition are:

- Reimund Gerhard, University of Potsdam, Germany
- Toribio Otero, University of Cartagena, Spain
- Geoff Spinks, University of Wollongong, Australia
- Jinsong Leng, Harbin Institute of Technology, Harbin, PR China
- Tushar Ghosh, North Carolina State University, Raleigh, USA
- Andreas Richter, Technical University of Dresden, Germany
- Gabor Kovacs, Empa and CT Systems, Switzerland
- Jaehwan Kim, Inha University, Incheon, Korea
- Ali Maziz, Linköping University, Sweden
- Ingrid Graz, Johannes Kepler University, Linz

The oral sessions are intertwined by long poster sessions that facilitate discussions among participants in a friendly atmosphere. During these sessions, prototypes and products are shown by interested attendees, at no cost.

Discussions and networking continue also during the organised lunch on each day and the social dinner on the first day, whose costs are entirely included within the registration fees that are maintained competitively low by the non-for-profit approach taken in organising this unique event.

The conference is open to participants from any country worldwide. Detailed information, including abstract submission (note: no full paper required!), will be made available soon at www.euroeap.eu/conference.

ADVANCES IN EAP

Independent Researcher/Inventor

New Design for DEA Compressor, Computer Modeling of Actuator

Babak Aryana *Babak.Aryana@Gmail.com*

DEA compressor in this project is an improvement of concept compressor introduced in [1]. According to the project specifications explained in previous issues of this Newsletter, computer molding of DEA compressor is complete now. Dielectric elastomer considered for actuator (**Figure 16)** is made of 5 back-to-back sheets of Soft Silicon improved by Single Wall Carbone Nanotubes introduced in [2] with vinyl:hydride ratios 10:90. The actuator should elongate 20% of its actual length, and each sheet is under electric field separately as a DEA. Regarding analyses done by ANSYS, such an elongation needs 2100 V for each sheet with 5 mm length, 1 mm width, and 40 micrometer thickness. In the actuator model, all five DEA sheets are considered to act together as a single part simplifying the modeling process (**Figure 17**).

Analyzing the actuator, important factors of the DEA, namely stress and strain vs time and stress vs strain under electric field are calculated and drawn graphically in **Figure 18** and **Figure 19**.

Essentially, this concept compressor is aimed at two major targets, one advanced ability to adapt to environmental elements and users demand (Context-Awareness), and the other lower energy consumption. Special form and construction of the compressor made by DEAs satisfy these aims. Design and modeling of DEA compressor are explained in a paper that is submitted for publication.

Next step is preliminary design of a complete engine working by DEA compressor, whose specifications will discuss in next issue of this Newsletter.

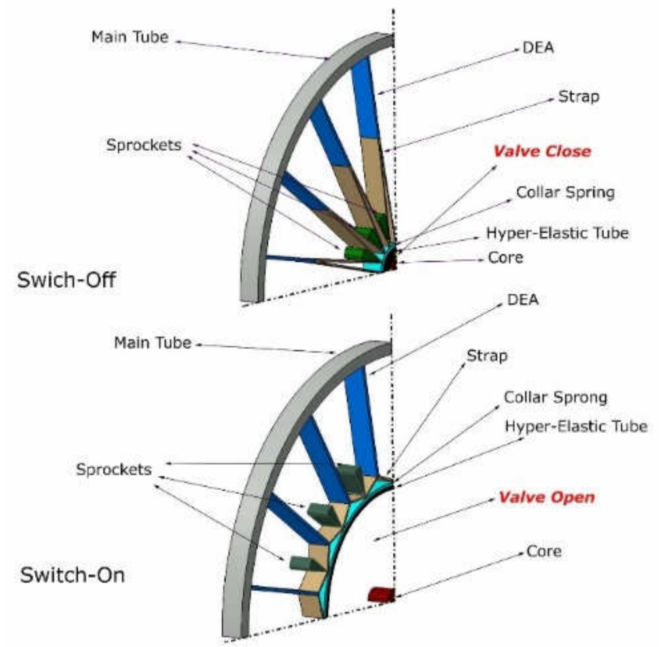

Figure 16: Schematic of a cell indicated in a 1/4th segment

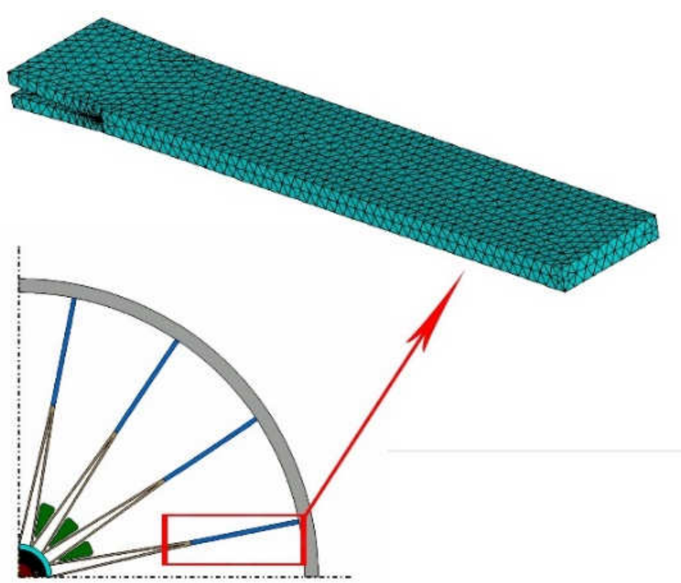

Figure 17: The cell actuator model

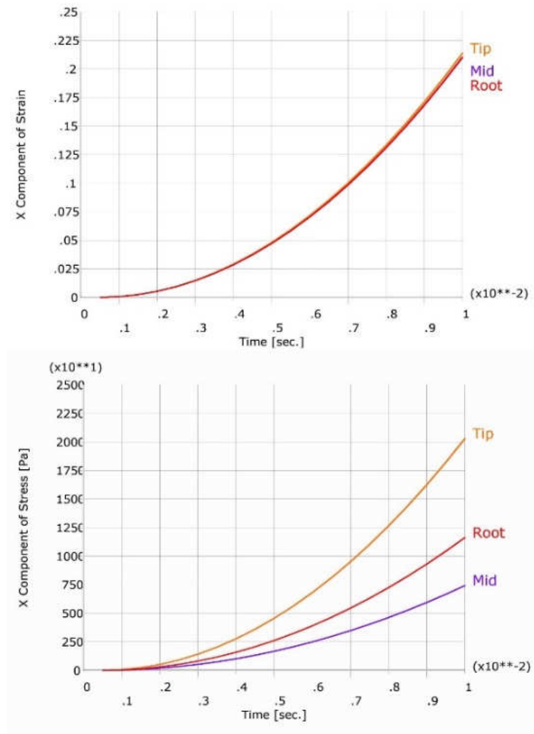

Figure 18: X component of strain and stress vs time

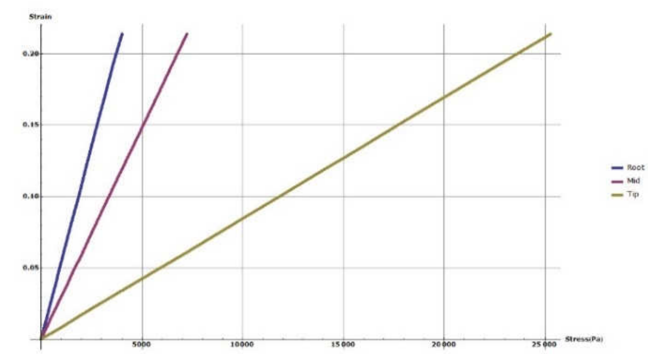

Figure 19: Stress-Strain curve of the DEA sheet under electric field

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India, Government of

Milind V. Kulkarni, *milind@cmet.gov.in* , *milindcmet@gmail.com*

Polyaniline Wrapped -Multiwalled Carbon Nanotubes (Pani-MWCNTs) Nanocomposite Coated Conducting Fabric / Electronic Fabric (E-Fabric) / Smart Fabric for Wearable Electronics Applications: Putting Functions into Fashion

There is strong interest in lightweight, flexible, and wearable electronics to convene the technological demands of modern society. Integrated energy storage devices of this type are a key area that is still significantly under development. 'Wearable electronics' represent a developing new class of materials with an array of novel functionalities, such as flexibility, stretchability, and lightweight, which allow for many applications and designs previously unachievable with traditional electronics technology. All these electronic applications require lightweight, wearable power conversion and storage devices. The fabrication of electronic systems onto substrates which are not only flexible, but also comfortable to the human body, represents a breakthrough in many areas of application, such as virtual reality, telepresence, ergonomics, teleoperation and rehabilitation engineering.

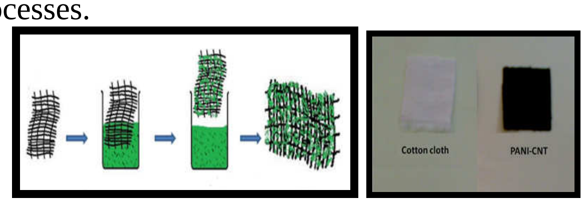
The possibility of realizing sensing textiles by coating traditional fabrics with smart materials (piezoresistive, piezoelectric, and piezocapacitive polymers) is pretty recent and has opened up a means of implementing a new type of man-machine interface technology. Wearable health monitoring systems typically include signal acquisition, processing systems and information feedback platform and so on. Fabric electrode with a textile structure is an indispensable material in signal acquisition process in which fabric electrode capable of receiving biological signals acts as a signal sensor. It not only used to monitor human biological signals constantly, but also will not irritate the skin-causing skin irritation, ulcers, etc. Fabric electrode has many advantages. Its comfortable, breathable, non-irritating properties are greatly favored by many researchers. The fabric sensors can be used for electrocardiogram (ECG), electromyography (EMG), and electro-encephalography (EEG) sensing; fabrics incorporating thermocouples can be used for sensing temperature; luminescent elements integrated in fabrics could be used for biophotonic sensing; shape-sensitive fabrics can sense movement, and can be combined with EMG sensing to derive muscle fitness.

Carbon electrodes integrated into fabrics can be used to detect specific environmental or biomedical features such as oxygen, salinity, moisture, or contaminants. With the development of health sector oriented toward miniaturization, intelligence and convenience, fabric electrode has become one of the hottest researches among researchers in this area. As a new generation of bio-signal acquisition material meeting the requirements of the development of modern medicine, fabric electrode has characteristics of comfort, intelligence, convenience, and accuracy, different from traditional conductive gel which is prone to cause skin allergies and has some other shortcomings. Recently, flexible energy storage devices (batteries and supercapacitors) and solar cells have also been fabricated using these e-fabrics.

Textile is a flexible and porous material made by weaving or pressing natural or synthetic fibers, such as cotton or polyester. Traditional textiles, both natural and synthetic, are almost always insulators. The interest in transforming them into conductors arises from the need to obtaining antistatic or electromagnetic shielding garments, or for the production of the revolutionary electronic "smart" textiles. The technologies utilized to make a textile conductive are based on the introduction of conductive agents, like metal nanoparticles, carbon nanotubes (CNTs), carbon black (CB), or conductive polymers, like polypyrrole, polyaniline, and polythiophene into the fabric. These conductive agents are introduced into fibers and fabrics using processes such as physical vapor deposition, dispersion into polymer followed by spinning or electrospinning, dip coating, vapor or solution polymerization of conductive polymers. These "electronic/smart textiles" are attracting increasing attention; they contain sensors, actuators and control units but still retaining the features necessary for comfortable clothing. They may be either passive, i.e. capable of sensing the surrounding conditions, and active, i.e. containing both sensors and actuators to respond/adapt to specific inputs.

In this communication, the fabrication of conducting polyaniline wrapped - Multiwalled Carbon nanotubes (MWCNTs) - nanocomposite coated conducting fabrics using an extremely simple ***'dipping and drying'*** process on the cotton cloth has been described. Also, the examination of the conducting properties of carbon nanotubes-polyaniline nanocomposite networks on a ''rough'' surface, exemplified by a non-conducting fabric is also discussed. We have reported the synthesis, characterization and successful applications of polyaniline and its nanocomposites in our previous publications [1, 2]. Recently, we have synthesized the stable and completely water dispersible, conducting Polyaniline wrapped - Multiwalled Carbon nanotubes (MWCNTs) - nanocomposite via ***'in situ'*** polymerization approach in an aqueous media and utilized successfully for optical pH sensing application [3].

The synthesized nanocomposite formulation with unique 'core-shell' like morphological structure was then used to prepare conducting fabrics using cotton cloth. The coating of the nanocomposite was performed with an extremely simple ***'dipping and drying'*** process on the cotton cloth using everyday textiles as the platform. Textile fibers, such as cellulose have a hierarchical structure complicated surface morphology, functional groups such as hydroxyl groups and high porosity. For example, each cotton fibers are composed of multiple individual cotton fibrils, which are in turn composed of multiple micro fibrils bundled together. These micro fibrils are made-up of poly-D-glucose chains, usually arranged in crystalline, domains, this structure allows the fibers to absorb large amount of water, which causes the fibers to swell when placed in such solutions. The textile investigated in this study include cotton cloth sheet. A highly conductive textile/fabric is achieved through the simple ***'dipping and drying'*** process presented schematically as **Figure 20**(a) while, the picture of bare cotton cloth and Pani-MWCNTs nanocomposite coated samples are represented as **Figure 20**(b). The commercial cotton cloth with pore size of (180 X 220 μm^2) was dipped in to the greenish-black, Pani-MWCNTs nanocomposite suspension. Because of the strong absorption, the textile is quickly get coated by the nanocomposite solution and subsequently dried ~120^0C for 10 min using hair dryer. This simple ***'dipping and drying'*** process was repeated to prepare the highly conductive textile. This highly conductive textile retains their texture, flexibility and structure after coating with nanocomposite and feels the same as the original. This fabrication process can be easily applied to other ink made up of nanostructured materials such as Graphene, CNTs, Silver and Gold and scaled up with roll-to-roll technique using slot-die or curtain coating processes.

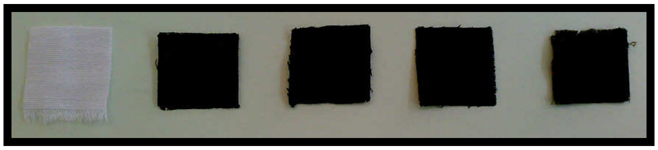


(a) **(b)**

Figure 20: (a) Schematic of simple "Dipping and Drying" process for the coating of cotton cloth and (b) the picture of cotton cloth and Pani-MWCNTs nanocomposite coated samples

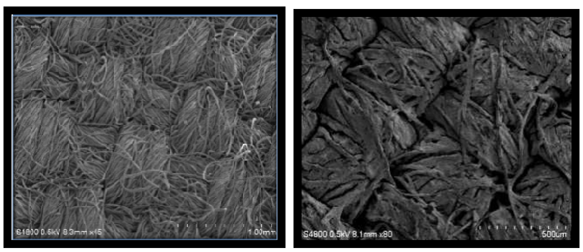
We also have prepared the conducting fabric with the varying concentrations of MWCNTs (0.1, 0.5 and 1.0 %) in the polyaniline-MWCNTs nanocomposites (presented as **Figure 21**) and studied its effect on the conductivity.

The FE-SEM images presented in **Figure 22** shows the macroporous structure of the cotton cloth before (a) and after (b) coating with the Pani-MWCNTs nanocomposite. From the FE-SEM micrographs, it is observed that there is a uniform coating of the Polyaniline-MWCNTs nano-composites on the cotton fabric (**Figure 22**b).



(a) (b) (c) (d) (e)

Figure 21: Polyaniline-MWCNTs Coated cotton fabrics with different concentrations of MWCNTs in the nanocomposite: (a) Cotton cloth; (b) pristine Pani coated; (c) Pani + 0.1% MWCNTs; and (d) Pani + 0.5 % MWCNTs (e) Pani + 1.0 % MWCNTs.



(a) (b)

Figure 22: FE-SEM images of Cotton cloth (a) before coating and (b) after coating.

Carbon Nanotubes have been proven to have large van der Waals interactions with many types of polymers and MWCNTs and cellulose fibers also exhibits the large van der Waals forces. Furthermore, acid treated MWCNTs have carboxyl functional group on the surfaces and the ends, which can form strong hydrogen bonds with the hydroxyl group of the cellulose fibers. Also, because of the mechanical flexibility of MWCNTs and the high surface area of cellulose fibers, together with the large water absorption of the fibers, surface contact between MWCNTs and cellulose fibers is maximized. Upon contact, large van der Waals forces and hydrogen bonding occurs, which binds the MWCNTs very tightly to the cellulose and makes these textiles highly conductive.

The as prepared Pani-MWCNTs coated cotton fabrics are electrically conductive with good air stability. The sheet resistance of the conducting cloth was measured by using multimeter (Two probe methods) and was found to be around few hundred ohms. Because of the high conductivity, flexibility and robustness the as made conductive textile or yarn can be used as conductive wires in electronic circuits. As a proof -of- concept, we have constructed a simple circuit by bridging a 9 V battery and one electrical contact of a blue or white LED with our conductive fabric or 1m long conductive thread (**Figure 23**). When the other contact between the LED and battery was made, The LED turned on immediately and illuminated for more than 5 min. until we disconnected the contact. The LED can be repeatingly switched 'ON' and 'OFF' by connecting and disconnecting the contact without loss of fidelity. The good conductivity achieved by this simple ***'dipping and drying'*** process has been demonstrated by the illumination of LED using 9V battery.

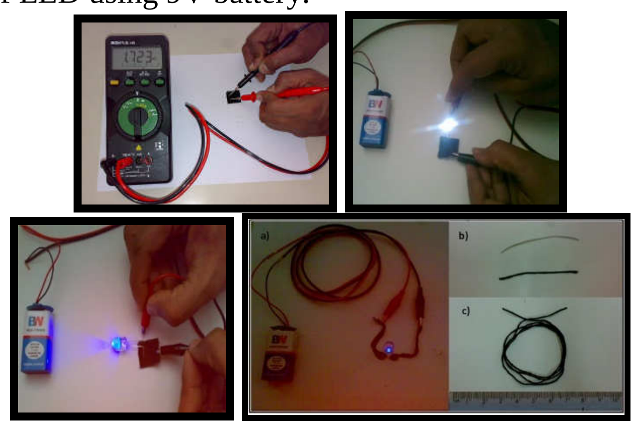


Figure 23: Demonstration of illumination LED using Conducting Fabric and 1 m long thread

Proof-of Concept: Illumination of LED using Electronic Fabrics/ Smart fabrics

Similarly, we have also developed conducting Polythiophenes and nanosized Polypyrrole coated 'Smart'/ 'Conducting' fabric for various electronics applications. This Lightweight, conducting, wearable fabric can be used for novel applications such as fabric/Textile based electrodes (Textrodes), High-performance sportswear, wearable displays, new classes of portable power, and embedded health monitoring devices as well as for microwave absorption, static charge dissipation, resistive and microwave heating, Electromagnetic Interference (EMI) Shielding and - in its patterned form-wearable antennas, and interconnects. Because of its conducting properties, this Smart fabric can be integrated into space suits, spacecraft, and space habitats for active radiation shielding. Functionalized carbon nanotubes have already been shown to operate as extremely sensitive sensors for the selective detection of both gases and biomolecules; these sensors will in the future be incorporated as wearable sensors that can be fabricated directly onto various fabrics.

References

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2) Tuning of morphology of conducting polyaniline via static, liquid-liquid interfacial polymerization process and its application for optical pH sensing, Sangita M. Thorat and Milind V. Kulkarni , *International Polymer Processing 2 (2015) 243-247*

3) Studies of Conducting Polyaniline-Wrapped Multiwalled Carbon Nanotubes (PANI-MWCNTs) Nanocomposite and its Optical pH Sensing, Milind V. Kulkarni and Bharat B. Kale, *Sensors and Actuators B: Chemical, 187 (2013) 407– 412.*

Hungary - Japan

EAP Polymer Rotor for Micro-Electromotor

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Novel polymer has been used to realize a side drive micromotor, based on the electro-rotation phenomena (**Figure 24**). EAP polymer disks, hollow cylinders and gears were prepared as rotors in few micrometer dimensions. The diameter varied between 100 to 500 microns with heights of 20 - 40 microns.

Electro-rotation of these submillimeter size tools was studied under uniform DC electric field. It was found that the rotational speed of micron-size polymer rotors can be conveniently tuned in wide range (between 300 – 3000 rpm) by the DC electric field intensity (**Figure 25**). All the measurements provide fundamental information on micro-motor characteristics which is important for further micro-engineering development.

(a) (b) (c)

Figure 24: A rotor was prepared from epoxy based EAP material. (a) disk, (b) hollow cylinder, and (c) gearwheel. The bar indicates 500 microns.

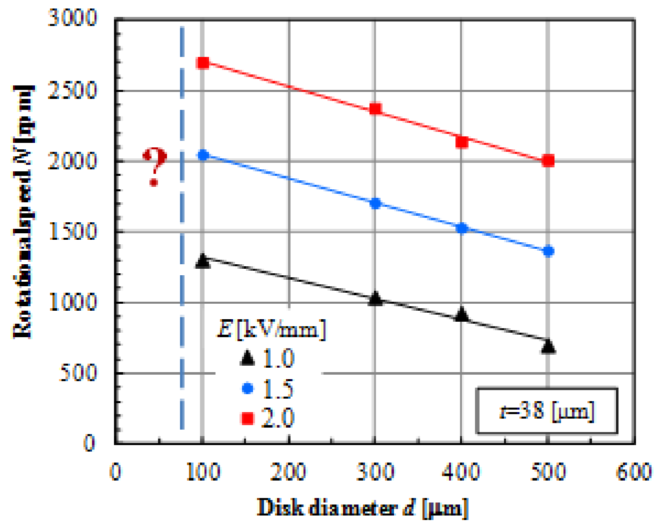

Figure 25: Dependences of rotational speed *N* on the diameter *d* of disk (thickness: *t*=38µm)

References

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Zrinyi M., M. Nakano, T. Tsujita, “Electrorotation of novel electroactive polymer composites in Uniform DC and AC electric field”, *Smart Mater. Struct.***21**, No. (2012) 1-6.

Bauer R., I. Kelemen, M. Nakano, T. Totsuka, M. Zrinyi, *Smart. Mater. Struct.* **24** (2015), 105010.

Switzerland - École polytechnique fédérale de Lausanne (EPFL)

Versatile soft grippers with intrinsic electroadhesion based on multifunctional polymer actuators

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We report a novel method to create soft and compliant grippers combining optimized dielectric elastomer actuation (enabling delicate gripping with mN forces) with an optimized electroadhesion (allowing for several Newton of shear force). This approach enables us to manipulate deformable, fragile objects of any shape with only a single control signal.

To illustrate the impressive abilities of our device, we developed a compliant gripper, weighing 1.5 g, shown below holding a strawberry. The two-fingered gripper easily and safely picks up objects that would be very challenging for conventional robotic manipulators. We can pick up a soft water-filled balloon (35 g), a flat sheet of paper (1 g), a Teflon block (80g), and a raw egg (61 g). The gripper opens and closes in 100 ms, thanks to the use of silicone elastomers and silicone-based electrodes. This highly-integrated multifunctional conformal gripper with high holding force and simplified control paves the way for sensitive grippers for soft robotics.

Figure 26: Versatile soft grippers with intrinsic electro-adhesion based on multifunctional polymer actuators

Reference
J. Shintake, S. Rosset, B. E. Schubert, D. Floreano and H. Shea., Advanced Materials, 2015 http://onlinelibrary.wiley.com/doi/10.1002/adma.201504264/abstract

Switzerland - Universität Basel

Low-voltage dielectric actuators based on nanometer-thin siloxane

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The Swiss research team *SmartSpincter* reached a first milestone within their nano-tera.ch-funded initiative. They used molecular beam deposition to realize single-layer dielectric elastomer actuators that provide 6 % strain applying 12 V. The 200 nm elastomer layer was grown from 6,000 g/mol vinyl-terminated PDMS within about 1 h. Subsequently, ultraviolet (UV) light polymerized the film. Contacts are 10 nm-thin, sputtered Au films. Placed on 25 µm-thick PEEK cantilevers, the bending characteristics gave evidence that the 200 nm actuator needs only 12 V to generate a strain comparable to a 4 µm-thick, spin-coated actuator at 400 to 500 V (see Figure). Here the maximal force of the 200 nm actuator was about 10^{-4} N. Thus molecular beam deposition of 10^4 layers is needed to reach the actuation force of a natural muscle.

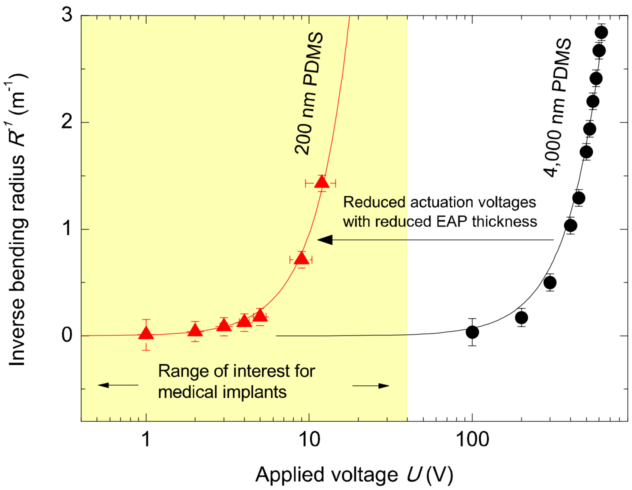

Figure 27: ***The 200 nm-thin, dielectric actuator reaches 5 % strain applying a voltage of 10 V [1]***

References
Töpper T., F. Weiss, B. Osmani, C. Bippes, V. Leung, B. Müller, Siloxane-based thin films for biomimetic low-voltage dielectric actuators, Sens. Actuators A: Phys. 233 (2015) 32-41.

UK - Laboratory for Matter Dynamics

A molecular description of mechanical actuation

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The readers are well aware of the large variety of mechanical "smart" actuators that are populating at present both the academic and commercial landscapes, proof of the high expectation created by artificial muscles, self-healing and even self-assembling systems at multiple length scales. This multiplicity is further convoluted by the possibility of various stimuli (thermal, optical, electrical, and chemical) as candidates to promote mechanical responses as well as by a wealth of material systems (liquid crystals, elastomers, carbon nanotube bundles, and also polymer nanocomposites).

The Laboratory for Matter Dynamics (LMD) focuses primordially on the later; CNT polymer composites that are responsive upon thermal or optical exposure. Despite a promising application space of these material systems, the technology is not yet mature to perform at commercial standards. A few factors hinder this development; namely, a lack of understanding between chemistry, processing, and resulting molecular configurations that yield optimal actuating conditions.

The LMD has pioneered the use of synchrotron technologies to address this correlation, and has produced a singular molecular map to describe both the needed molecular conformation between polymeric chains and CNTs, as well as the processing conditions conducive to a mechanical response, as shown in **Figure 28**left). Further, in situ actuation analysis also confirmed that CNTs underwent a torsional effect, promoting the macroscopic mechanical response.

Remarkably, a year after fabrication, these nanocomposites (EVA/Py-Chol/MWCNT) became inactive. Atomic force microscopy **Figure 28**right) suggested that the initially tightly wrapped polymeric chains in the vicinity of MWCNTs were in fact unlatching, which was also confirmed by synchrotron spectroscopy.

These findings highlight the importance of establishing a molecular map to correlate chemistry, synthesis, and property, as well as the usefulness of synchrotron spectroscopies in the study of soft matter.

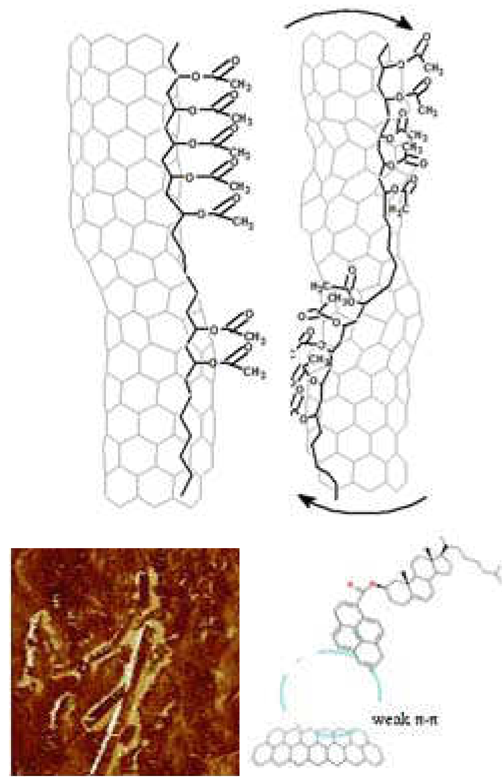
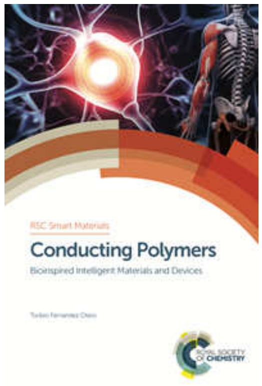


Figure 28: The molecular correlation between CNTs and surrounding polymer chains is highlighted in an active composite in the relaxed and active stages (left). Active composites undergo aging within a year of fabrication through polymer unlatching as suggested in AFM imaging and confirmed chemically by synchrotron spectroscopy (right).

NEW PUBLICATIONS

New Book: Conducting Polymers

Author: Toribio F. Otero, Technical university of Cartagena. Spain toribio.fotero@upct.es.



This book collects basic scientific and philosophical motivations altogether polymeric, mechanical, chemical and electrochemical principles to develop, using different electrochemical methodologies here described, electro-chemo-biomimetic devices mimicking natural organs. Among those devices electrochemical sensors and electro-chemo-mechanical actuators are presented and characterized. The facts that the same reaction drives both devices' families originate unique dual devices: those actuators sense, by themselves, mechanical, thermal, chemical or electrical working conditions, mimicking haptic muscles. Some sections from chapter 8 condensate very specific interest for our community: Artificial muscles; Bilayer and tri-layer bending devices; Electrochemo-dynamic characterization of artificial muscles; The driving current controls the angular movement of the polymeric motor; The consumed charge controls displacement and relative position; Artificial muscles are robust, reproducible, reliable and Faradaic polymeric motors; Dynamic hysteresis and creeping effects under cycling; Artificial muscles as a tool to clarify reaction-driven ionic exchanges; Artificial muscles as tools to quantify relative solvent exchanges; and Osmotic and electro-osmotic processes during actuation. Chapter 9 is devoted to Multi-tool actuator-sensors devices presenting empirical results and theoretical descriptions.

The reaction drives conformational movements (molecular motors), as biochemical reactions involving macromolecules do. Those soft, wet, ionic and reactive dense gels are used in chapter 7 as material model of biochemical reactions to investigate limits, and limitations, of present chemical models to describe biological functions and dis-functions, health or illnesses. A new chemical kinetic model is presented, including classical models. It describes results from conducting polymers, carbon nanotubes, graphenes, other electroactive (reactive) materials and biochemical reactions as enzymatic reactions.

The theoretical description of artificial proprioceptive devices paves the way to develop electro-chemo-conformational memories trying to understand, describe and mimic brain memory and other biological functions.

RCS link:
http://pubs.rsc.org/en/content/ebook/978-1-78262-315-1#!divbookcontent

FUTURE CONFERENCES

Date	Conference/Symposium
February 22 -25, 2016	Bio-inspired Materials 2016, International School and Conference on Biological Materials, Potsdam, Germany. Information about this conference can be seen at http://bioinspired.inventum.de/home/
March 20 - 24, 2016	The 18th EAPAD Conf., SPIE's Smart Structures & Materials and NDE Symposia, will be held in Las Vegas, NV. For information contact: Megan Artz megana@spie.org, Website: http://spie.org/eap
June 5 to 9, 2016	CIMTEC 2016 - 7th Forum on New Materials will be held in Perugia, Italy. Symposium H "Electroactive Polymers and Shape Memory Polymers: Advances in Materials and Devices". For information see: http://www.cimtec-congress.org/
June 13 to 15, 2016	Actuators 2016, International Conference and Exhibit on New Actuators and Drive Systems, Bremen, Germany. Organized by Messe Bremen. For further information see http://www.actuator.de/home
14-15 June 2016	EuroEAP 2016, the 6th International Conf. on Electromechanically Active Polymer (EAP) transducers & artificial muscles' will held in Copenhagen, Denmark. It is Chaired

	by Anne Skov, Technical University of Denmark. For information see www.euroeap.eu/conference
June 26 - 30, 2016	BIONATURE 2016 is scheduled to be held in Lisbon, Portugal during under the umbrella of the BioSciencesWorld 2016. Information about this conference can be seen at http://www.iaria.org/conferences2016/BioSciencesWorld16.html
September 13 – 15, 2016	Design & Nature 2016, 8th International Conference on Comparing Design in Nature with Science and Engineering, New Forest, UK. Organized by Wessex Institute. Information about this conference can be seen at http://www.wessex.ac.uk/conferences/2016/design-and-nature-2016

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

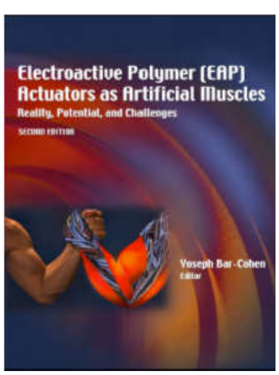
EAP Companies: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-material-n-products.htm

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)

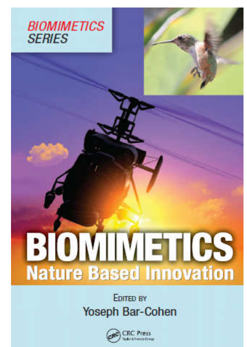


In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published. This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent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

Biomimetics books series

Biomimetics – Nature Inspired Innovation

Yoseph Bar-Cohen (Editor)



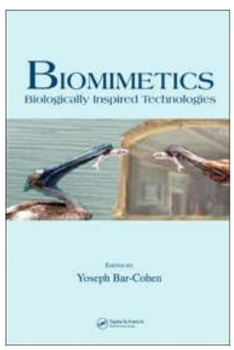
This book contains 20 chapters covering various aspects of the field of biomimetics including Nature as a source for inspiration of innovation; Artificial Senses & Organs; Bio-mimicry at the Cell-Materials Interface; Multiscale modeling of plant cell wall architecture and tissue mechanics for biomimetic applications; Biomimetic composites; EAP actuators as artificial muscles; Refreshable Braille Displays Actuated by EAP; Biological Optics; Biomimicry of the Ultimate Optical Device: Biologically Inspired Design: a tool for interdisciplinary education Enhancing Innovation Through Biologically-Inspired Design; Self-reproducing machines and manufacturing processes; Biomimetic products; Biomimetics for medical implants; Application of biomimetics in the design of medical devices; Affective Robotics: Human Motion and Behavioral Inspiration for Safe Cooperation between Humans and Humanoid Assistive Robots; Humanlike robots - capabilities, potentials and challenges; Biomimetic swimmer inspired by the manta ray; Biomimetics and flying technology; The Biomimetic Process in Artistic Creation; and Biomimetics - Reality, Challenges, and Outlook. Further information is available at:

http://www.crcpress.com/product/isbn/9781439834763

Architecture Follows Nature - Biomimetic Principles for Innovative Design
Authored by Ilaria Mazzoleni ***www.imstudio.us*** *info@imstudio.us in collaboration with Shauna Price* http://www.crcpress.com/product/isbn/9781466506077

The book entitled "Architecture Follows Nature - Biomimetic Principles for Innovative Design" has been published by CRC Press as part of the book series on Biomimetics for which Y. Bar-Cohen is the editor. The homepage of this book series is: http://www.crcpress.com/browse/series/?series_id=2719

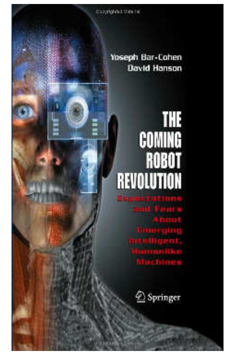
Biomimetics - Biologically Inspired Technologies



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

Books about robotics

The Coming Robot Revolution - Expectations and Fears about Emerging Intelligent, Humanlike Machines

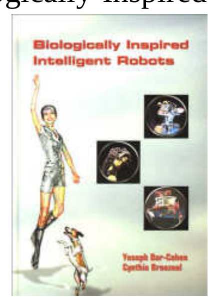


Yoseph, Bar-Cohen and David Hanson (with futuristic illustrations by Adi Marom), Springer, ISBN: 978-0-387-85348-2, (February 2009)

This book covers the emerging humanlike robots. Generally, in the last few years, there have been enormous advances in robot technology to which EAP can help greatly in making operate more lifelike. Increasingly, humanlike robots are developed for a wide variety of applications. These "smart" lifelike robots are designed to help with household chores, as office workers, to perform tasks in dangerous environments, and to assist in schools and hospitals. In other words, humanlike robots are coming and they may fundamentally change the way we live, even the way we view ourselves.

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.

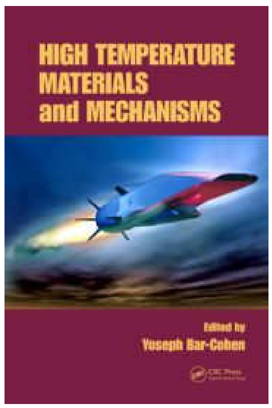
Other books

High Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)
http://www.crcpress.com/product/isbn/9781466566453

This book is addressing the growing interest in high-temperature technologies. This book covers technology related to energy, space, aerospace, electronics, metallurgy, and other areas. While some applications involve the use of materials at high temperatures, others require materials processed at high temperatures for use at room temperature.

Reflecting the multidisciplinary nature of the subject of high-temperature materials and mechanisms, the chapters bring as broad a perspective to the field as possible and are authored by leading experts in the specific subject. The book addresses the various related science and engineering disciplines, including chemistry, material science, electrical and mechanical engineering, metallurgy, and physics.



Happy New Year

WorldWide Electroactive Polymers (EAP) Newsletter

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