

WorldWide ElectroActive Polymers



EAP

(Artificial Muscles) Newsletter

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FROM THE EDITOR

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

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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://ndea.jpl.nasa.gov>

Standard for EAP

A paper about the recently published standard for EAP materials has been posted on the internet and can be read at

<http://dx.doi.org/10.1088/0964-1726/24/10/105025>

EAP AND BIOMIMETICS MAGAZINES

INCOSE, INSIGHT April 2016

INSIGHT quarterly magazine featured articles on looking to Nature for design inspiration.

Lawrence Pohlmann, pohlmann@incose.org

The April 2016 issue of INSIGHT, which is published by International Council of Systems Engineering (INCOSE) [www.incose.org], has featured articles about biomimetics. The authoring of the articles was led by the INCOSE's Natural Systems Working Group (NSWG) [<https://sites.google.com/site/incosenswg/home>].

The goal of NSWG is to help the systems engineering community understand why, when, and how to ask: “What would Nature do?” Efforts are made to influence systems engineering processes to routinely and appropriately consider natural systems data and solution concepts as sources of design inspiration. Toward this end, the NSWG sponsored a Special Feature issue of the INSIGHT quarterly magazine for systems engineering practitioners (Figure 1). To facilitate communication among the systems engineering, biology, and design communities, the articles from this issue have been posted on the NSWG publicly accessible website: <https://sites.google.com/site/incosenswg/>



Figure 1: The cover page of the April issue of the INSIGHT magazine which featured topics of biomimetics.

NSWG Activities are structured to increase the systems engineering community’s awareness of this emerging, exciting, and current technical area. Its activities include:

- Sponsoring monthly webinars by various leaders in the BID (bioinspired design) field and making

presentation materials and recordings for availability on the website

- Creating guidance products - For example, a natural systems article for the Systems Engineering Body of Knowledge [[http://sebokwiki.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_\(SEBoK\)](http://sebokwiki.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_(SEBoK))]
- Developing white papers - For example, a series of papers on natural systems related reference architectures
- Seeking to partner with other INCOSE and industry working groups on topics and issues of mutual interest
- Having a range of small group meetings to discuss topics of interest, plans, progress, issues, and problems
- Identifying and documenting enhanced systems engineering process practices that enable effective and efficient ways to learn from nature.

For additional information or to get involved, please contact Curt McNamara, INCOSE NSWG Chair at: nswg-info@incose.org

UPCOMING CONFERENCES

2017 SPIE EAPAD Conference

The 19th SPIE’s EAPAD conference is going to be held from March 25 thru 29, 2017. The conference, which is part of the Smart Structures Symp., is going to be at Portland, Oregon. Specifically, at the Portland Marriott Downtown Waterfront [<http://www.marriott.com/hotels/hotel-photos/pdxor-portland-marriott-downtown-waterfront/>]. This hotel is located on the Willamette River in downtown Portland with lots of options for restaurants and tourist activities. This Conference is going to be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Jonathan Rossiter, University of Bristol, England. The Conference Program Committee consists of representatives from 32 countries. The call for papers is posted at: <http://www.spie.org/eap>

The papers 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.

In the 2017 EAPAD Conf. a Special Session is going to be focused on the “Use of EAP in the Form of Fibers and Textile”. The Session is going to be chaired by Elisabeth Smela, Univ. of Maryland, USA. Also, a Special Session is going to be held about “Artificial Muscle for Soft Robotics”. This subject is the objective of the NSF funded PIRE project (see further details in later pages of this issue of the Newsletter). This Session is going to be chaired by Kwang Kim, Univ. of Nevada, Las Vegas (USA) and Maurizio Porfiri, New York Univ. (USA)

For the record of the EAPAD conferences archive, the following is the list of the Co-chairs since the first one that was held in 1999 at Newport Beach, CA.

| Year | Co-chair | Country |
|------|--|-------------|
| 1999 | Mohsen Shahinpoor, U. of New Mexico | USA |
| 2000 | Steve Wax, DARPA | USA |
| 2001 | Danilo De Rossi, Univ. degli Studi di Pisa | Italy |
| 2002 | Yoshihito Osada, Hokkaido University | Japan |
| 2003 | Geoff Spinks, University of Wollongong | Australia |
| 2004 | Peter Sommer-Larsen, Risoe National Lab. | Denmark |
| 2005 | John D. Madden, U. of British Columbia | Canada |
| 2006 | Jae-Do Nam, Sung Kyun Kwan University | S. Korea |
| 2007 | Gabor Kovacs, EMPA | Switzerland |
| 2008 | Emillio P. Calius, Industrial Res. Limited | New Zealand |
| 2009 | Thomas Wallmersperger, Univ. Stuttgart | Germany |
| 2010 | Jinsong Leng, Harbin Institute of Tech. | China |
| 2011 | Federico Carpi, Univ. of Pisa | Italy |
| 2012 | Keiichi Kaneto, Kyushu Inst. of Tech. | Japan |
| 2013 | Siegfried Bauer, Johannes Kepler U. | Austria |
| 2014 | Barbar J. Akle, Lebanese American Univ. | Lebanon |
| 2015 | Gal deBotton, Ben-Gurion U. of the Negev | Israel |
| 2016 | Frédéric Vidal, U. de Cergy-Pontoise | France |
| 2017 | Jonathan Rossiter, University of Bristol | England |

1st Annual NASA Biomimicry Summit and Education Forum

The [1st Annual NASA Biomimicry Summit and Education Forum](#) is going to be held in Cleveland, Ohio from August 2 through August 4, 2016. This Summit is a groundbreaking event, bringing together aerospace, biology, paleontology, art and design. The bio-inspired topics include

- Materials Processing and Structures for Extreme Environments
- Physical and Life Sciences: Persistence of Life in Hostile Environments
- Guidance, Navigation & Communications
- Next Generation Aeronautics and In-space Propulsion
- Sustainable Energy Conversion and Power and featuring disruptive thinkers and special events at the Cleveland Metroparks Zoo and the Cleveland Museum of Natural History.

On August 4, networking session and workshop is going to be held to identify collaboration and funding opportunities for participants in support of NASA goals. This session will result in working groups and white papers and will feed into future NASA biomimicry summits. E-resources regarding this forum can be found at:

- The summit website (updated periodically): <http://www.tinyurl.com/Biomimicry2016>
- NASA’s biomimicry website: <https://www.grc.nasa.gov/vibe>

Questions regarding logistics can be addressed to Howard Thompson <howardthompson@oai.org>, OAI (Ohio Aerospace Institute).

RECENT CONFERENCES

2016 SPIE EAPAD Conference

The SPIE’s Electroactive Polymers Actuators and Devices (EAPAD) Conference is the leading international forum for presenting the latest progress and holding discussions among the attendees regarding the capabilities, challenges and potential future directions. The conference this year (Volume 9798, March 20-24, 2016) was Chaired by Yoseph Bar-Cohen, JPL/Caltech, and Co-Chaired by Frédéric Vidal, University de Cergy-Pontoise (France) and it included 128 presentations. The Conference was well attended by internationally leading experts in the field including academia, industry, and government participants from the USA and overseas.

This year, the Keynote speaker was Elisabeth Smela (**Figure 2**), University of Maryland, College

Park, MD and the title of her presentation was “Nastic actuators”. In her presentation, she covered the progress in developing actuators that are inspired by plants, namely the use of miniature hydraulic pumping mechanisms to deliver large forces and displacements. Devices are being developed using lamination of elastomer layers and encapsulating a fluid. Propylene carbonate has been demonstrated to be an effective fluid that does not generate gas bubbles. As example of an application that has been given at her presentation is the development of smart stents with adjustable diameters.



Figure 2: Elisabeth Smela, the Keynote Speaker in the 2016 SPIE EAPAD Conf.

Overall, the presented papers reported the significant progress that was made in each of the topics of the EAP field infrastructure. The topics included: theoretical modeling and analysis of EAP mechanisms; improved EAP materials, processes, fabrication (including 3D printing) and characterization techniques; emerging EAP actuators (including ionic, conducting, shape memory polymers, CNT and dielectric EAP); applications of EAP materials including power generation and energy harvesting, robotics, haptic, tactile, and other sensors. This year, the Special Session has been dedicated to “Celebrating the 10th Anniversary of the Dielectric Elastomer Minimum Energy Structures (DEMES)”.

The efforts described in the presented papers are showing significant improvements in understanding the electromechanical principles and better methods of dealing with the challenges to the materials applications. Researchers are continuing to develop

analytical tools and theoretical models to describe the electro-chemical and -mechanical processes, non-linear behavior as well as methodologies of design and control of the activated materials. EAP with improved response were described including dielectric elastomer, IPMC, conducting polymers, gel EAP, carbon nanotubes, and other types. Specifically, there seems to be a significant trend towards using dielectric elastomers as practical EAP actuators. Interesting presentations include the invited paper by Markus Henke and Iain A. Anderson, University of Auckland, New Zealand, describing autonomous artificial muscle robots without electronics. Also, a team that was led by Federico Carpi, Queen Mary, Univ. of London (United Kingdom) have reported the formation of standards for dielectric elastomer transducers. The formation of standards for the field of EAP is an important step towards a wide commercialization of the technology.

The 2016 EAP-in-Action Session included 9 demonstrations with presenters from China, Germany, Great Britain, New Zealand, Singapore, Switzerland, and USA. The Session highlighted some of the latest capabilities and applications of Electroactive Polymer (EAP) materials where the attendees were shown demonstrations of these materials in action (**Figure 3**). Also, the attendees were given an opportunity to interact directly with the presenters as well as have been given hands-on experience with the presented technology. The first Human/EAP-Robot Armwrestling Contest was held in 2005 during this session. In 2017, another EAP robotic arm is expected to be demonstrated.

The presenters consisted of professors and their students as well as engineers from companies. The demonstrations included innovative devices and potential new products that are driven by EAP and the following lists the demos by the country of the leading presenters:



Figure 3: A view of the presenters and the participants of the 2016 EAP-in-Action Session.

China

1. Tiefeng Li, Yuhan Xie, Guorui Li, Yiming Liang, Xuxu Yang, Yongbing Jin, Zhejiang University (China), “Soft robotics and smart SAM structures (Figure 4) - In this demonstration, soft robotics and smart structures driven by dielectric elastomer were shown to produce large actuation, fast response and integrated actuation-sensing (Figure 5). The demonstrated materials were thermally active tough hydrogel and the objective is to use them for bio-medical applications.



Figure 4: The team from Zhejiang University (China)

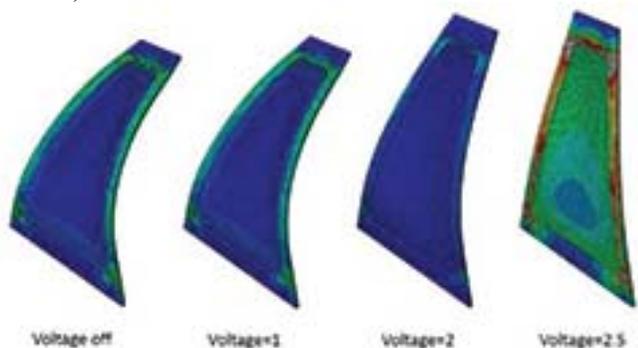


Figure 5: A model of a dielectric elastomer that produces large actuation, and fast response.

2. Liwu Liu, Jinrong Li, Fengfeng Li, Xiongfei Lv, Jinsong Leng, Harbin Institute of Technology (China), “Applications of smart polymers” (Figure 6) - This demonstration showed smart polymers in action taking advantage of their lightweight, fast response, and large deformation. These advantages make them attractive for applications in smart bionics, aerospace, biomedicine and other fields. The demonstration included application of shape

memory polymer (SMP) and dielectric elastomer EAP as actuators and deployable structures (Figure 7).



Figure 6: The team from Harbin Institute of Technology (China). From left to right: Qingqing Lu, Liwu liu, Jialiang Tao and Xiongfei Lyu



Figure 7: Soft robot and soft gripping device using DE Actuators

Germany

Steffen Hau, Alexander York, Saarland Univ. (Germany), “High force dielectric electroactive polymer (DEAP) membrane actuator” (Figure 8) - Energy efficiency, lightweight and scalability are key features to actuation applications such as valves, pumps or any portable system. DEAP technology is able to fulfill the requirements better than commonly used technology, e.g. solenoid, but it has limitations concerning force and stroke. This demo showed improvements that were made in increasing the force that is delivered by DEAP stack. Two different actuators were shown: The 1st lifted 10kg and the 2nd generate 66N force while acting against a spring load (Figure 9).



Left to right: Alexander York and Steffen Hau



Stefan Seelecke

Figure 8: The team from Germany

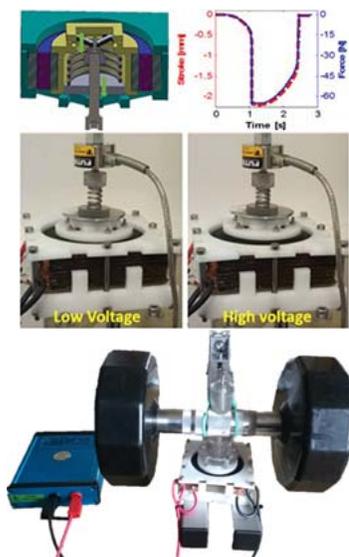


Figure 9: The two different DEAP actuators that were shown with an example of lifting 20 lbs.

New Zealand

Iain Anderson, Markus Henke, Patrin Illenberger, Andreas Tairych, Allan Veale, Chris Walker: “New technology from the Biomimetics Laboratory and StretchSense Ltd.” (Figure 10) - The Biomimetics Lab and its spinout company StretchSense Ltd. demonstrated EAP soft autonomous robots, wearable sensors, and energy harvesters.



Figure 10: From left to right: Allan Veale, Chris Walker, Andy Tairych, Markus Henke, Iain Anderson, Antoni Harbuz and Patrin Illenberger (Biomimetics Lab and StretchSense Ltd.)

The demos included:

- 1) Trevor the robot and Jule the Dragonfly – These EAP robots have no control electronics. By simply adding electric charge, Trevor crawls and Jule flaps its wings (Figure 11).





Figure 11: Trevor the robot

- 2) Wearable, stretch sensitive communication – An EAP glove for gesture-based communication and game control was demonstrated.
- 3) Wearable muscles with cyber-proprioception – Using soft wearable motion sensing, the team showed how to augment ones’ strength and get machines to follow gesture based commands.
- 4) Generate electricity using EAP – The lab’s spinoff company, Stretchsense, displayed an EAP starter kit that includes a polymer generator (that you squeeze) coupled to portable electrical charge management electronics. Further details are given in later pages of this Newsletter issue.

Singapore

Jian Zhu, Yuzhe Wang, Ujjaval Gupta, National Univ. of Singapore (Singapore), “Soft robots based on dielectric elastomer actuators” (**Figure 12**) - Artificial muscles were developed to mimic natural masseter muscles (superficial portion), using dielectric elastomer actuators. Soft actuators were installed onto a robotic skull, and were shown moving the jaw and the mimicking natural muscles’ displacement and velocity. Also, a worm-like robot driven by a dielectric elastomer actuator was shown (**Figure 13**).

Singapore and Great Brittan

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

Armrestling contest” (**Figure 14**) – Capabilities that are going to be used to produce an antagonistic system of a wrestling arm were described and shown. The concept of driving the arm is the use of a pair of elastomers that work against each other and are attached to a disc that forms the “shoulder” of the artificial arm, via (ideally) inextensible cords. Both elastomers are pre-tensioned by mechanical stretching. A wrestling arm is under development for potential demonstration at the 2017 EAP-in-Action Session.



Figure 12: The team from National University of Singapore.

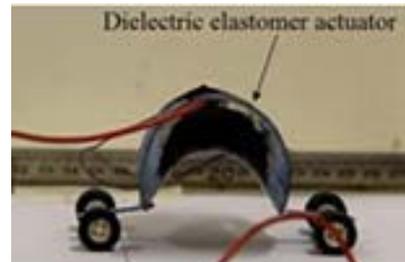


Figure 13: A demo and a video that were shown by the National University of Singapore.



Figure 14: Koh Soo Jin Adrian, National University of Singapore (NUS) on the left and Stoyan Smoukov, Cambridge University, on the right describing their armwrestling EAP actuator

Switzerland

Nadine Besse, Samuel Rosset, Alexandre Poulin, and Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (EPFL) (Switzerland), “Tactile display based on shape memory polymers” (**Figure 15**) - A fully latching and scalable 4x4 tactile display was demonstrated to have 300 mN holding force and 300 μ m 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 (**Figure 16**).

United States

1. Qi Shen, Sarah Trabia, Tyler Stalbaum, Choonhan Lee, Robert Hunt, and Kwang Kim, Univ. of Nevada, Las Vegas (United States), “Shape memory programmable and electrically controllable IPMC” (**Figure 17** and **Figure 18**) - 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-freedom that exhibited high maneuverability when controlled by two external inputs, allowing complex motions that are routine in nature.



Figure 15: In the top figure from left to right: Herbert Shea, Alexandre Poulin, Samuel Rosset, and Nadine Besse and on the bottom right Vanessa Leung

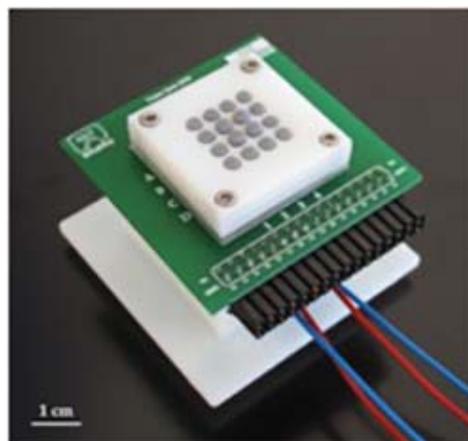


Figure 16: The fully latching and scalable 4x4 tactile display



Figure 17: The team from the University of Nevada, Las Vegas (United States)



Figure 18: Shape memory programmable and electrically controllable IPMC

2. Lenore Rasmussen (**Figure 19**), Eric Sandberg, Leila Albers, Simone Rodriguez, Ras Labs, “Synthetic Muscle™: shape-morphing EAP based materials and actuators” - EAP materials that contract upon activation and expand under a reversed electric input have been shown. A thin shape-morphing film of the material in the expansion mode produced raised surface zones in desired shapes. A thick shape-morphing pad can controllably contract or expand, which are being used to prototype self-adjusting prosthetic socket liners and other void-filling continual-fit applications. These EAPs can serve as sensors, which can be tied to biofeedback, and communicate impact and pressure. The material is currently being tested for radiation resistance on the International Space Center (ISS) (**Figure 20**).



Figure 19: Lenore Rasmussen, Ras Labs.



Figure 20: The Synthetic Muscle™ that is on the ISS.

ADVANCES IN EAP

Aerospace Engineering-Propulsion/ MEMS

DEA Compressor and TurboDEA

Babak Aryana, Independent Researcher/Inventor
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As stated in the previous issue of this Newsletter [Aryana, 2010], a new version of DEA compressor was introduced (**Figure 21**) [Aryana, 2016]. Further, a special gas turbine cycle, which the author names turboDEA, was configured to work with DEA compressor and was also introduced [Aryana, 2016].

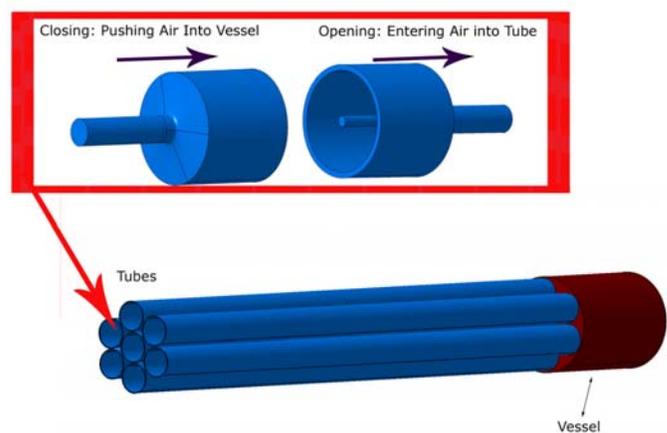


Figure 21: The compressor’s sections are shown schematically with two major sections: main tubes, and vessel. Also, the mechanism of compressor operation is indicated.

This novel gas turbine cycle works based on Brayton cycle, and its T-s and P-V diagrams are similar to conventional gas turbines. Configuration of a turboDEA is like a simple turbojet in main sections, but two important differences make it distinguished from a turbojet. TurboDEA is a hybrid cycle, in which the power transmission is indirect. There is no link between the turbine and the compressor, and a free turbine is linked to a generator that supplies the compressor with electricity. Additionally, exit flow from the combustion chamber is separated into two branches in which one is bypassed to the turbine and the other goes directly through the exit nozzle (Figure 22). However, the turboDEA special characteristic allows it to be reconfigured to serve as an alternative for other gas turbine cycles like turboshaft, turboprop, and turboprop as well.

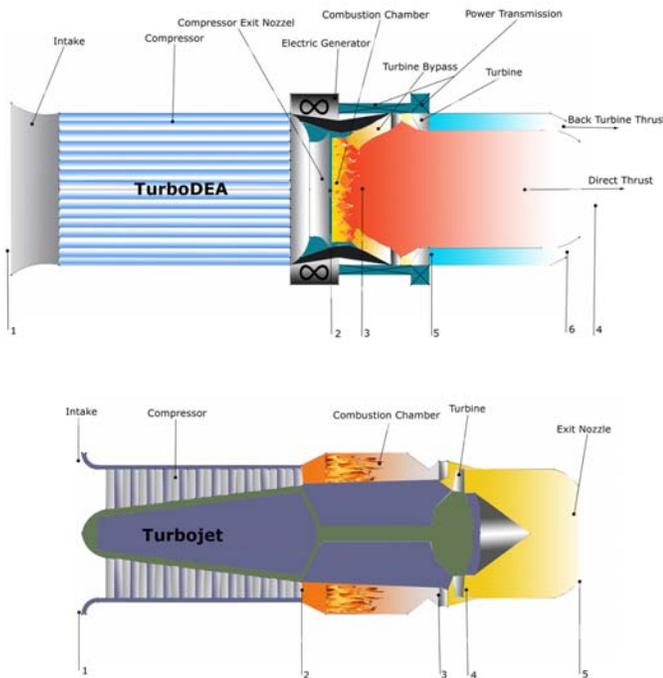


Figure 22: TurboDEA and Turbojet engines schematically depicted by their sections and zones

In this novel compressor, micro actuators made of DEA are used to reduce its energy consumption considerably. Two particular specifications of the DEA compressor, including low energy consumption and context-awareness, beside special

configuration of the turboDEA that creates gas turbine cycle with considerably low fuel consumption and higher flexible working envelope in comparison to conventional types (Figure 23) [Aryana, 2016].

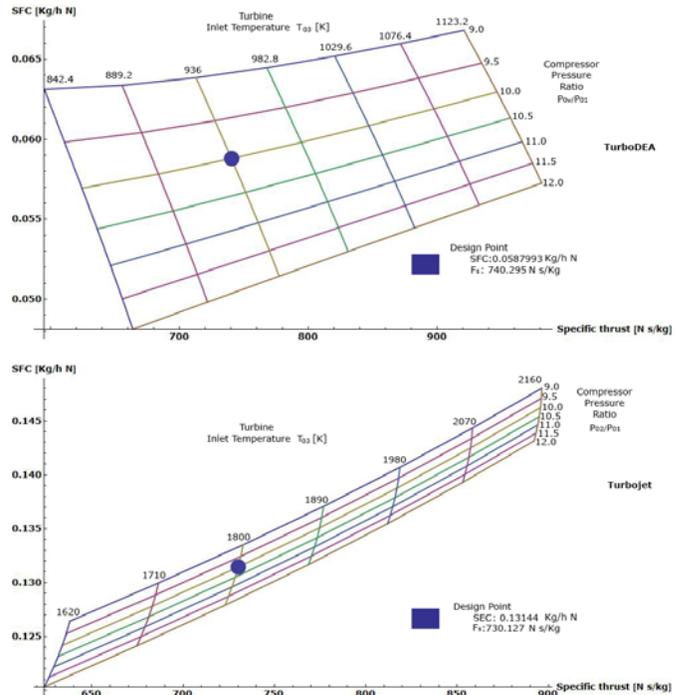


Figure 23: Comparison between Performance of a sample turbojet and its counterpart turboDEA (see [Aryana, 2016]). It shows that for a given design point, SFC (Specific Fuel Consumption) of turboDEA is more than 55% lower, its specific thrust is 1.4% higher and its performance map is wider than turbojet indicating its flexibility for variation of compressor pressure ratio.

References

Aryana B., "Implementing DEA to create a novel type of compressor," Materials Science and Engineering C, vol. 30, p. 42–49, 2010.
 Aryana B., "New version of DEA compressor for a novel hybrid gas turbine cycle: TurboDEA," Energy, vol. 111, pp. 676-690, 15 September 2016.

China

Property, actuation, and application of smart materials

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Optically transparent shape memory polyimide (TSMPI) is synthesized for the first time in Jinsong Leng's group at Harbin Institute of Technology. The polyimide possesses glass transition temperature (T_g) of 171°C, higher than T_g of other transparent SMPs reported. The 120 μ m thick polyimide film exhibits transmittance higher than 81 % in 450-800 nm (**Figure 24**). The transparent polyimide also showed nice thermomechanical properties and excellent shape memory performances, and it retained the high optical transparency after many shape memory cycles (**Figure 25**). This novel material has potentials in advanced optoelectronic and other common shape memory applications.

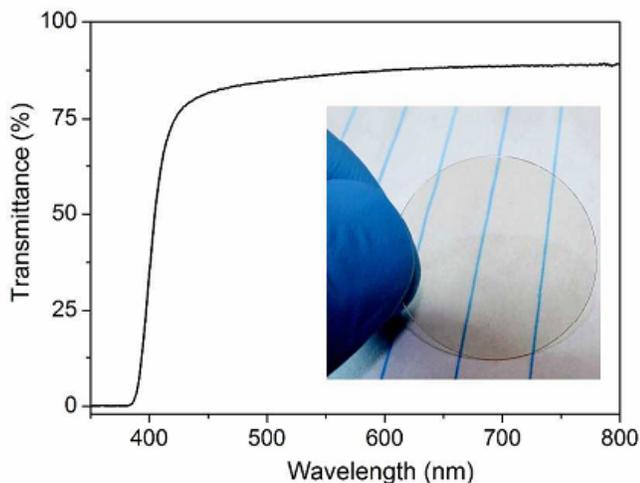


Figure 24: UV-Vis spectra of 120 μ m thick TSMPI film, and inset shows its optical photograph.

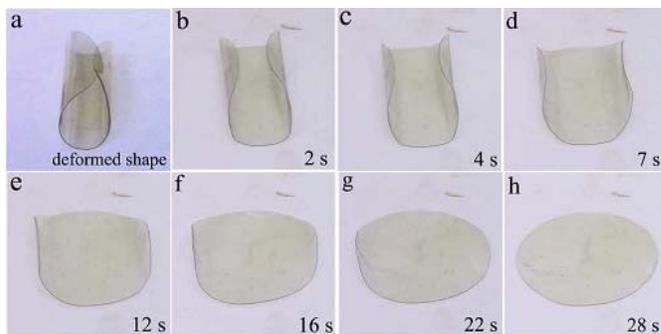


Figure 25: Deployable shape memory pattern of TSMPI. (a) deformed temporary shape and (b) - (h) shapes

Nonwoven fiber composite Nafion/Fe₃O₄ films can be programmed to adopt over 5 shapes, and several fast transformations in sequence are demonstrated using different intensities of the same stimulus (**Figure 25**). We used an alternating magnetic field to activate the transformations remotely and investigate the conditions for tunable actuation control. Since the heat is generated inside the shape-changing films, 80°C to 100°C temperatures are achieved, and their surface temperature can be kept below 40°C (**Figure 26**).

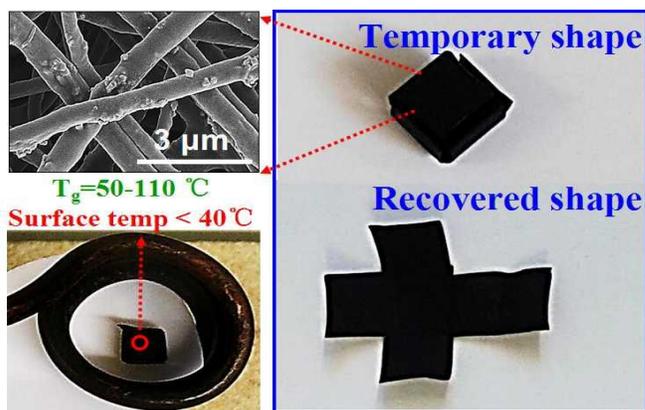


Figure 26: 3D shape recovery performance: magnetic field actuated shape recovery

The multicomposite styrene-based shape memory polymer (SSMP) can be selectively actuated by applying selective stimuli due to the selective remote heating properties of Fe₃O₄ (30 kHz alternating magnetic field) and multiwalled carbon nanotubes (13.56 MHz radio frequency field) nanofillers. Therefore, the multicomposite

SSMP possesses a well-controlled multiple temporary shapes recovery capability (**Figure 27**).

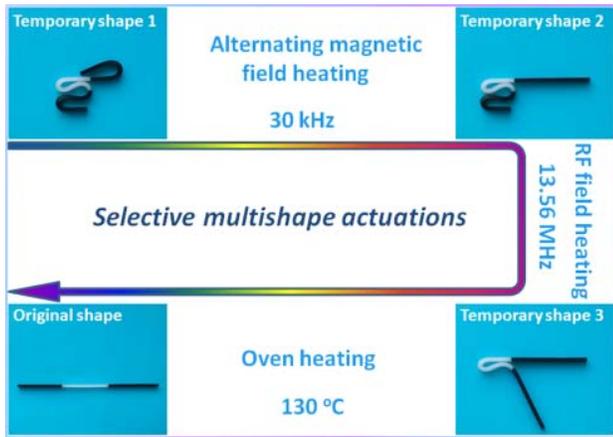


Figure 27: Demonstration of the selective shape memory recovery.

Dielectric elastomer has many advantages such as large deformation, fast response, light weight and easy synthesis. Subject to a high voltage, dielectric elastomer film will deform sustainably. These features make dielectric elastomer suitable for generators and actuators. In energy harvesting, the essence of DE is a variable capacitor. **Figure 28** shows a schematics and a photo of a wave power generator. Through the repeatedly compression of the dielectric elastomer transducers, the generator can convert mechanical energy to electric energy. Experiment validation shows its feasibility.

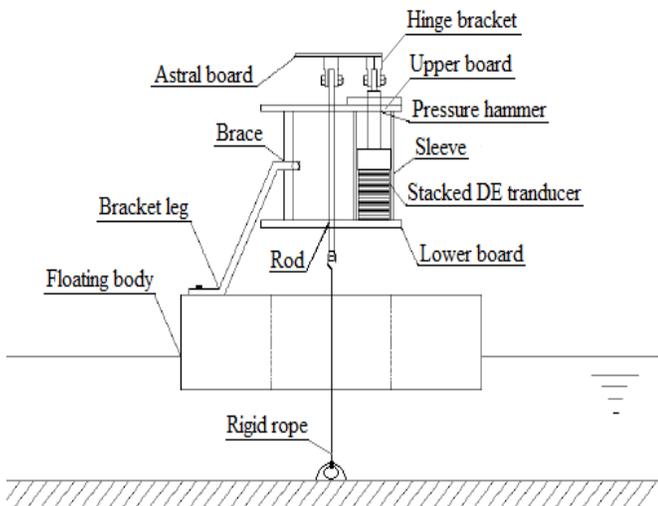
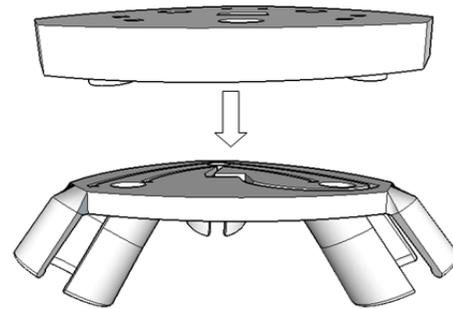


Figure 28: Schematic diagram and operating platform of wave power generator

A soft gripper that can grab objects without breaking them was made up of three dielectric elastomer spring-roll bending actuators and 3D printed rigid frame (**Figure 29**). The conductive wires were tethered inside. This could be used in space debris removal, space sampling, and so on.



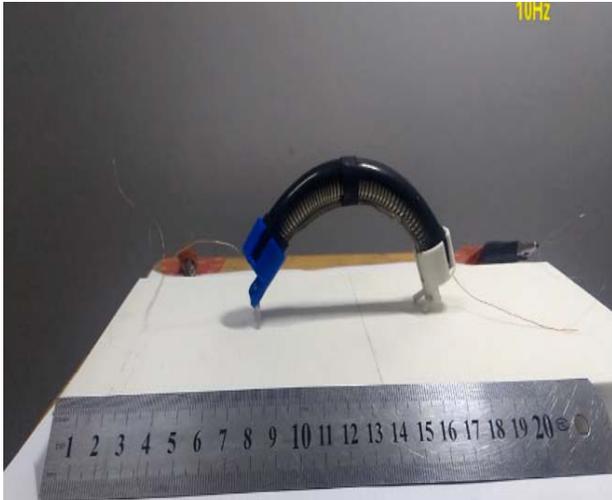


Figure 29: Soft robot and soft gripping device based on DE Actuators

References

- [1] Fenghua Zhang, Zhichun Zhang, J Luo, I-Ting Lin, Yanju Liu, Jinsong Leng and Stoyan K. Smoukov. Remote, fast actuation of programmable multiple shape memory composites by magnetic fields. *Journal of Materials Chemistry C*, 2015, 3(43): 11290-11293
- [2] Wenbing Li, Yanju Liu, Jinsong Leng. Selectively actuated multi-shape memory effect of a polymer multicomposite. *Journal of Materials Chemistry A*, 2015, 3(48): 24532-24539
- [3] Xiongfei Lv, Liwu Liu, Yanju Liu, Jinsong Leng. Dielectric elastomer energy harvesting: maximal converted energy, viscoelastic dissipation and a wave power generator. *Smart Materials and Structures*. 2015, 24(11): 115036
- [4] Yanju Liu, Liwu Liu, Zhen Zhang, Yang Jiao, Shouhua Sun, Jinsong Leng. Analysis and manufacture of an energy harvester based on a Mooney-Rivlin-type dielectric elastomer. *Europhysics Letters*, 2010, 90: 36004

Ireland (University College Cork), USA and India

Optical classification of morphological symmetries in natural photonic structures for bio-mimetic applications

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Morphological symmetries in the natural photonic architecture organization on the transparent wing surfaces of various insects have been evolving as a blueprint for their development and dictated by the energy minimization for multifunctional material related to macroscopic optical and bio-mechanical properties. High-symmetric photonic structures are very sensitive to structural deformation because of quite small bandwidth. Photonic structures with a hexagonal symmetry may not be as straight forward to fabricate in real life. This indicates that the modulation in degree of symmetry favor the manipulation of diffraction process from this structure is responsible for the optical properties, such as directionality, brightness variations, polarization and colors [Kumar et al., 2015; Arora et al., 2014; Kumar et al., 2014; Wang et al., 2016].

So, the identification and then modification of structural symmetry offers an exciting additional mechanism to control and manipulate the propagation of light via various complex optical effects like scattering, reflection, refraction, diffraction, interference.

We have classified optically various structural symmetries including, circular, triangular, hexagonal, random, and quasiperiodic in photonic structure organization on variety of insect wing surfaces via optical diffraction properties using monochromatic green laser and broadband

femtosecond laser pulses as shown in **Figure 30** [Kumar et al., 2015]. We find the particular symmetry coherently manipulates and controls light through these photonic structures at various length scales for multifunctional purposes as shown in **Figure 31**.

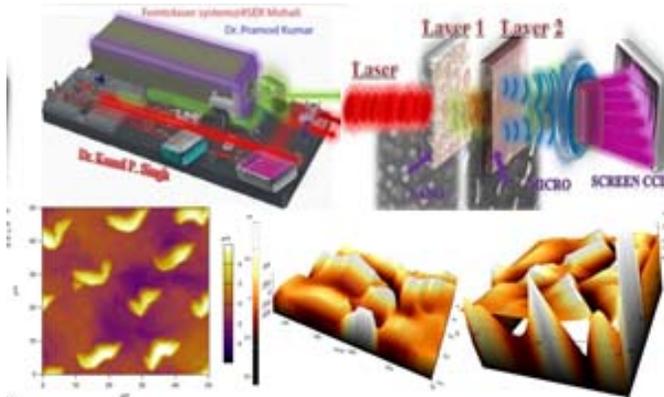


Figure 30: Top - A picture of the experimental setup using femtosecond laser at the IISER Mohali lab [Kumar et al., 2015]; Bottom - AFM images of the microstructure organization on various transparent insect wing surfaces (termite and Irish bumble bee) showing micro-grating arrays.

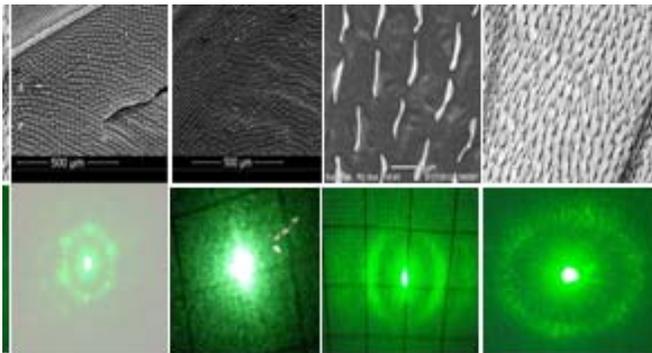


Figure 31: SEM Images of the various transparent insect wings surfaces (Irish bumble bee, wasp, termite, fruit fly) and corresponding optical diffraction patterns give the signature of morphological symmetries existence in microstructures organization [Kumar et al., 2015].

In conclusion, a detailed understanding of our observation about the classification of probed structural symmetries could provide a platform for

the development of novel photonic devices for bio-mimetic technological applications [Kumar et al., 2015; Arora et al., 2014; Kumar et al., 2014; Wang et al., 2016].

References

- Kumar P., D. Shamoon, D.P. Singh, S. Mandal and K. P. Singh, *Laser Phys. Lett.* 12, 025901 (2015)
- Arora A., P. Kumar, J. Bhagavathi, K. P. Singh and G. Sheet, *Appl. Phys. Lett.* 104, 063702 (2014)
- Kumar P., D. Shamoon, and K. P. Singh, *Proc. SPIE 9056, Electroactive Polymer (EAPAD)* 2014.
- Wang P., and I. M. Peters, *J. Appl. Phys.* 119, 083101 (2016).

StretchSense Ltd., New Zealand

Self-powered sensors and energy harvesting kit

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Website: www.stretchsense.com

StretchSense is a company of experts in soft sensors and generators for tackling tough problems in wearables. The company's long term goal is to develop self-powered sensors that provides precise motion information and are powered by movement only. The current products are described below and more information about the sensors and the energy harvesting kit can be found on the company's website: www.stretchsense.com or by directly contacting the team at: sales@stretchsense.com.

Stretch sensors (Figure 32): These are soft, lightweight and highly precise sensors for measuring the motion of soft objects like the human body. However, because the original silicone sensors were prone to being overstretched, the company has developed a new award-winning fabric version that is tougher and can be sewn into apparel and gloves.

Fabric sensors (Figure 33): These are sensors for sports and virtual reality applications. The photo in **Figure 33** shows five fabric sensors that were sewn into a glove to measure the fingers bending.



Figure 32: Stretch sensor.



Figure 34: Energy Harvesting Kit.



Figure 33: Fabric sensors

Energy Harvesting Kit (Figure 34): In addition to sensors, StretchSense is also making energy harvesting devices. They recently started marketing an EAP based Energy Harvesting Kit that can enable future wearable products to be powered by body motion without the need for batteries. The Energy Harvesting Kit is an R&D tool so that engineering teams can test this technology for specific applications. The kit generates electrical power at approximately 1Hz, using compression of its soft generator unit and it produces an outputs with a minimum power of 1 mW. The kit contains:

1. Soft Generator unit
2. StretchSense Energy Harvesting Circuit with a low voltage DC output
3. 9 V battery (provides an initial kick charge)
4. Power indicator LED light

The PIRE Team from the USA, S. Korea and Japan

Advanced Artificial Muscles for International and Globally Competitive Research and Education in Soft Robotics

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Maurizio Porfiri, New York University, USA

A team from the USA in partnership with S. Korea and Japan is working on soft robots powered by electroactive polymers. This multi-year Partnerships for International Research and Education (PIRE) program, funded by the US National Science Foundation (NSF), is working on enhancing the international robotics collaborators to create better performing artificial muscle. For more information see:

http://nsf.gov/discoveries/disc_summ.jsp?cntn_id=138883

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Review: The current state of silicone-based dielectric elastomer transducers

Frederikke B. Madsen, Anders E. Daugaard, Søren Hvilsted and Anne L. Skov, al@kt.dtu.dk

An extensive review of the research progress of research in silicone elastomers as electroactive polymers has been published recently in *Macromolecular Rapid Communications*, Vol. 37,5, pages 378–413, 2016. One of the most used materials for the elastomer membrane in dielectric elastomer transducers (DETs) is silicone elastomers which are promising materials due to superior properties such as high efficiency, reliability and fast response times. Silicone elastomers furthermore have many interesting and desirable properties that many other materials do not possess, namely they have very high thermal stability, hydrophobicity, transparency, high gas permeability, low glass transition temperature and low surface tension. For the DET technology to progress towards industrial implementation, a leap in material development is required, specifically targeting longer lifetime and higher elastomer energy densities to provide more efficient transduction at lower driving voltages. In this review, the current state of silicone elastomers for DETs is summarised and critically discussed. This includes the different material strategies that up till now has been used to improve silicone elastomers for DETs. The pros and cons of different approaches such as using commercial elastomers, composites, polymer blends, grafted elastomers and complex network structures are discussed and evaluated and recommendations for next steps in material development are suggested. Furthermore, material requirements and parameters for silicone DETs are given based on their chemical, physical and electrical properties. It was found that for the technology to be commercially viable in the future it is essential that all aspects of the elastomer are taken into account, namely dielectric losses, lifetime and the very often ignored polymer network integrity and stability.

NEW PUBLICATIONS

Ocean Innovation: Biomimetics Beneath the Waves

Authors: Iain A. Anderson, Julian Vincent, and John Montgomery

Published at the end of May, this book is part of the CRC Biomimetics Book Series, for which Yosi Bar-Cohen is the Editor.

Generally, biomimetics is the idea of creating new technologies abstracted from what we find in biology. The book “Ocean Innovation: Biomimetics Beneath the Waves” seeks that technological inspiration from the rich biodiversity of marine organisms. Bringing both a biological and engineering perspective to the biomimetic potential of oceanic organisms, this richly illustrated book investigates questions such as:

- How can we mimic the sensory systems of sea creatures like sharks, sea turtles, and lobsters to improve our ability to navigate underwater?
- What can we do to afford humans the opportunity to go unnoticed by marine life?
- How can we diffuse oxygen from water to enable deep diving without the risk of decompression sickness?

Each chapter explores an area where we, as divers and technologists, can benefit from understanding how animals survive in the sea, presenting case studies that demonstrate how natural solutions can be applied to mankind’s engineering challenges.



FUTURE CONFERENCES

| Date | Conference/Symposium |
|-------------------|--|
| 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 information see http://www.actuator.de/home |
| 14-15 June 2016 | EuroEAP 2016, the 6 th International Conf. on Electromechanically Active Polymer (EAP) transducers & artificial muscles' 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 held in Lisbon, Portugal during under the umbrella of the BioSciencesWorld 2016. For information see: http://www.iaria.org/conferences2016/BioSciencesWorld16.html |
| August 2-4, 2016 | 1stNASA Biomimicry Summit and Education Forum 2016. The forum is going to be held at the Ohio Aerospace Institute, Cleveland, Ohio. Further information can be see at: https://www.grc.nasa.gov/vibe |
| August 23 to 26, 2016 | EMN Meeting on Smart and Multifunctional Material, which will be held in Mövenpick Hotel Berlin, Germany. More details at http://emnmeeting.org/SMM/ |
| August 28 - September 1, 2016, | ASMM16, 2016 Int'l Conference on Advances in Structural Monitoring and Maintenance in Jeju Island, Korea. Further information is available at Structures16 website or from info@structures16.com |

| | |
|-------------------------|---|
| September 13 – 15, 2016 | Organized by Wessex Institute is the Design & Nature 2016, the 8th International Conference on Comparing Design in Nature with Science and Engineering, New Forest, UK. For information see http://www.wessex.ac.uk/conferences/2016/design-and-nature-2016 |
| September 12-14, 2016 | 3rd International Conference and Exhibition on Biopolymers and Bio plastics which is going to be held at San Antonio, USA. For information see: http://biopolymers-bioplastics.conferenceseries.com/ |
| November 2-4, 2016 | Complex Adaptive Systems Conference. Theme: Engineering Cyber Physical Systems - Applying Theory to Practice. The Conf. will be held in Los Angeles, California. Information can be seen at http://complexsystems.mst.edu/ |
| March, 25-29, 2017 | The 19th EAPAD Conf., SPIE's Smart Structures & Materials and NDE Symposia will be held at Portland, Oregon. For information see http://spie.org/eap or contact: Megan Artz megana@spie.org |

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>

Recipes: <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>

Armwrestling Challenge:

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

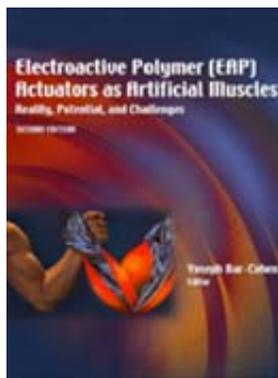
Books and Proceedings:

<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.



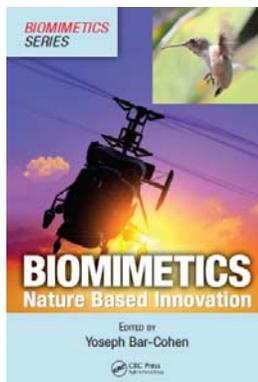
This book is intent to provide a reference about the subject, tutorial resource, list the challenges and define a vision for the future direction of this field. Observing the progress that was reported in this field is quite heartwarming, where major milestones are continually being reported.

Biomimetics 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

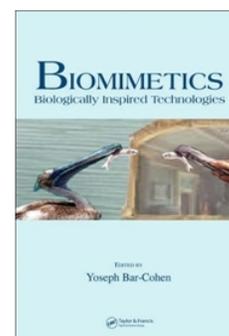


Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

<http://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



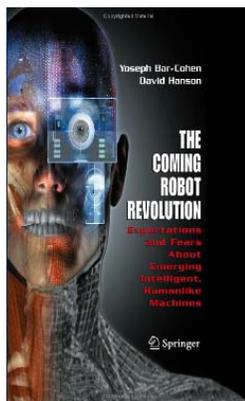
biomimetics in the future. This book is intended as a reference comprehensive document, tutorial resource, and set challenges and vision for the future direction of this field. Leading experts (co)authored the 20 chapters of this book and the outline can be seen on <http://ndea.jpl.nasa.gov/ndea-pub/Biomimetics/Biologically-Inspired-Technology.pdf>

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)

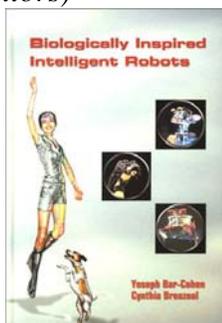
This book covers the emerging humanlike robots. Generally, in the last few years, there have been enormous advances in robot technology to which EAP can help greatly in making operate more lifelike. Increasingly, humanlike robots are developed for a wide variety of applications. These “smart” lifelike 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.

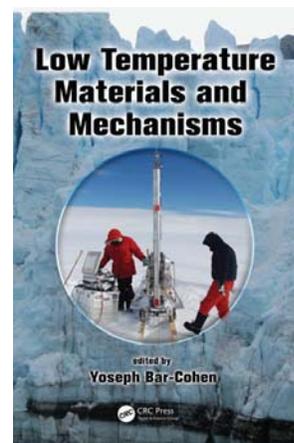
Other books

NEW: Low Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)

<https://www.crcpress.com/Low-Temperature-Materials-and-Mechanisms/Bar-Cohen/p/book/9781498700382>

Published on July 1, 2016, this book addresses the growing interest in low temperature technologies. Since the subject of low temperature materials and mechanisms is multidisciplinary, the chapters reflect the broadest possible perspective of the field. Leading experts in the specific subject area address the various related science and engineering chemistry, material science, electrical engineering, mechanical engineering, metallurgy, and physics.

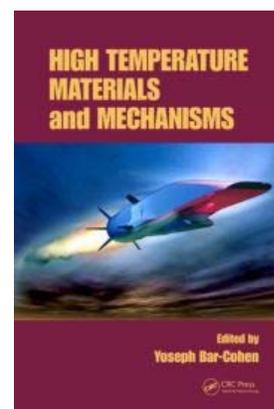


High Temperature Materials and Mechanisms

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.

WorldWide Electroactive Polymers (EAP) Newsletter

EDITOR: Yoseph Bar-Cohen, <http://ndea.jpl.nasa.gov/nasa-nde/yosi/yosi.htm>

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