WorldWide ElectroActive Polymers EAP (Artificial Muscles) Newsletter

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

FROM THE EDITOR

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

Since the first SPIE conference on EAP that was held in March 1999, the field of Electroactive Polymers continued to emerge from its anonymity to the spotlight of the science and engineering community. The characteristics of inducing large displacements and the capability to emulate biological muscles are making EAP materials attractive for consideration in an increasing number of fields. Turning these materials into actuators-of-choice requires solidifying the technical foundations and identifying niche applications where their unique capabilities would provide the needed edge. The comprehensive coverage of the topic in the book entitled "Electroactive Polymers (EAP) actuators as artificial muscles" [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-book_outline.htm] published by SPIE Press as well as the established communication forums that include the SPIE and MRS conferences, the WW-EAP webhub: [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm] with links to the leading research and development labs worldwide [accessible via the JPL's NDEAA Technologies Webhub http://ndeaa.jpl.nasa.gov], and this WWEAP Newsletter are providing a wealth of information and cooperation opportunities for this multidisciplinary field. We are continuing to be at a distance from meeting the challenge of an EAP actuated robotic arm winning against human in a wrestling match. While it is a futuristic objective, significant progress has been made in advancing the critical elements of the field infrastructure.

A potential niche application for EAP material may be the development of *Braille* displays. The Editor received numerous inquiries in response to his concept described in the SPIE Press book on EAP (see Page 630). An example of related e-mail is presented in this issue on Page 2. Some of the organizations that reported the development of such displays include the University of Wollongong (see page 15) and SRI International.

While researchers and engineers are facing the challenges related to the implementation of EAP materials it would be productive to consider using hybrid materials and identifying applications where properties can be traded. Efforts in this direction are reported in this Newsletter issue and in presentations that are made at the annual SPIE's EAPAD and MRS's EAP Conferences.

The Editor believes that one of the areas that requires strengthening is the commercialization of low cost EAP materials that can available for purchase. It is becoming increasingly critical to have EAP materials as consumer products. The unavailability of such materials is hampering potential users and many students worldwide from being able to explore potential research, development or applications.

ABOUT THE EXPERTS

Liming Dai

In March, Liming Dai joined The University of Akron as Associate

Professor of Polymer Engineering in Akron University's College of Polymer Science and Polymer Engineering. Previously, he worked at the CSIRO Division of Molecular Science in Australia. At the University of Akron, Dr. Dai is continuing his research and development of novel conjugated polymers and carbon nanomaterials for device applications. His new E-mail address is: ldai@uakron.edu

LETTER TO THE EDITOR

Seeking Tactile Graphics Display for Blind Persons

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Hello Dr. Bar-Cohen, I have been reading your edited book entitled "Electroactive Polymers as Artificial Muscles - Capabilities, Potentials and Challenges[1]." This book was highly informative to me as I am blind person seeking to improve the tactile displays that are available commercially. I am a computer science student studying towards Master degree but I don't have the facility to produce the required devices. I would appreciate your assistance in addressing the technical issues that are related to making such devices[2]. Following are some of my suggested concepts:

Being blind, I have to rely on available devices to read visually presented information. The leading tools that currently exist include: Screen reader and Optical character recognition (OCR). These tools are useful for reading text, but there is no technology to feel graphics. There are some tactile printers that can present graphics, but they are like using a computer or seeing things with no printout. Also, there are some copy machines that can convert printed text to a swollen form, but they are expensive and are not practical for real time use.

I have been exploring methods of presenting tactile shapes of diagrams and other graphics just as they are visible on the screen. By "just as visible," I mean that one should be able to instantly sense changes on such screens. The device should be capable of presenting raised figures so that blind persons can touch them and feel presented graphics. At this point, I can thing of two possible approaches:

1. Paper that can be raised at different points. For example, to raise point X-100 by Y-200 the related location on the paper should be made to contract or expand using a computer signal. This may be possible to produce using electroactive polymers. The paper may swell at a point or at many points as desired. Similarly, lines and other figures may be drawn to present various graphic shapes acting like as an electronic paper for the vision impaired person. This may be done similar to the electronic paper that is produced by E-Ink and other companies which are used to read newspapers and other documents. The difference will be that this paper will need to show images in a tactile form. Such a paper display may be linked to a computer and present text, images and various graphics for use by blind persons.

[1] SPIE Press, Page 630
[2] See input from the U. of Wollongong, Australia

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2. Use of small pins made of conductive polymer that can expand and contract under electrical activation. These pins may be arranged like bristles of a toothbrush. Obviously, in this case the surface of the display will need to be in a useful size, i.e., standard A4 paper, and the resolution should be as high as possible. Such a display will allow presenting various shapes and can also be linked to computers and serve as a tactile monitor for use by blind persons.

Currently, graphic sensing is the major hurdle for the visually impaired persons in many areas including possible jobs and independent living. If we can develop this kind of a device, blind persons will have a lot more opportunities. Some of the potential applications of such a device may include the presentation of:

1. Mathematical diagrams
2. Maps and charts
3. Design diagrams in many engineering fields
4. Icons of computer screens
5. Internet images
6. Images of close friends and relatives
7. Hand written text with magnifiers
8. Present video images in real time

There are many more possibilities that may not be possible to list here, but they will evolve as such device become available. Can you please guide me about the technical feasibility in these areas and if it is possible can you connect me to researchers and engineers who are working on the development of such devices.

Regards
Dinesh Kaushal

GENERAL NEWS

The WW-EAP Webhub is continuing to be updated with information regarding the EAP activity Worldwide. This webhub is hosted at the JPL's NDEAA Technologies Website: http://ndeaa.jpl.nasa.gov

Navy SBIR Contract on EAP

The Navy issued a call for STTR proposals related to Artificial Muscle Technology and it was due in April 2002. The solicitation reference number was N02-T001 and the objective has been to develop electroactive polymers for flexible underwater propulsor blades. According to the latest news published in the Navy STTR website: http://www.navysbir.com/ three proposals were selected for further consideration and the proposers are:

- MicroFab Technologies, Inc., Plano, TX
- Molecular Mechanisms LLC, Somerville, MA
- Tao of Systems Integration, Inc., Williamsburg, VA

At JPL - New Android head Available as EAP Platform

To promote the development of effective EAP actuators, which could impact future robotics, toys and animatronics, two platforms were developed and were made available to the Editor of this Newsletter. The platforms are intended to support the worldwide development of EAP. These platforms include an Android head that makes facial expressions and a robotic hand with activatable joints. The head can be controlled to move the eyes and the lips, whereas the hand allows moving the index finger. Recently, a new head was produced that makes more realistic movements. The head (see Figure 1) was sculptured by D. Hanson U. of Texas, Dallas, who has jointly instrumented it with G. Pioggia, University of Pisa, Italy.

FIGURE 1: Andy the Android head making facial expressions (See more details on Page 14).

2002 SPIE EAPAD Conference

EAPAD is continuing to be the largest international conference that is being held on the subject of electroactive polymers. Overall, 66 papers were presented covering this emerging technology area. The conference was well attended by leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas.

The Keynote Speaker of the conference this year has been Cynthia Breazeal from MIT. In her presentation entitled "Biologically-Inspired Intelligent Robots," she described robots that respond and express emotion both verbally and facially. She showed examples of her Kismet robot (see Figure 2) performing such tasks by making various emotional expressions that personalized the robot to make it look "like a living creature". Using EAP as artificial muscles would significantly enhance the capability to produce robots that are biologically inspired. The topic of biologically inspired intelligent robots is the subject of a book that is currently being edited by Cynthia Breazeal and the Editor of this Newsletter. The book is expected to be published by SPIE Press before the end of 2002 [http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biomimetic-robots-outline.pdf].

FIGURE 2: The Keynote Speaker, Cynthia Breazeal, MIT, with her Kismet robot responding to her expressions (courtesy of MIT Press Office) [http://www.ai.mit.edu/people/cynthia/cynthia.html].

The presentations in this conference covered progress in various areas of the EAP infrastructure. The papers focused on issues that can forge the transition to practical use, including improved materials, better understanding of the principles responsible for the electromechanical behavior, analytical modeling, processing and characterization methods and considerations of various applications. The sessions about EAP materials were divided into the two principal groups that the Conference Chair defined: electronic, and ionic. The electronic ones are driven by electric forces and involve mostly with movement of electrons, whereas the ionic EAPs consist of electrodes and electrolytes and involve mobility of cations or anions. Papers in this conference covered the following topics:

- Electroactive polymers (EAP) and non-electro active-polymer (NEAP) materials
- Biological muscles and biomechanics as a model for EAP actuators
- Theoretical models, analysis and simulation of EAP and computational chemistry.
- Support technologies, including electroding, synthesis, processing, shaping and fabrication
- Methods of testing and characterization of EAP
- EAP scalability to small (MEMS, micro and nano) and large dimensions
- EAP as artificial muscles, actuators and sensors
- Design, control, intelligence, and kinematic issues related to robotic and biomimetic operation of EAP
- Under consideration, in progress or desired applications of EAP

The efforts described in these papers are showing improvement of the understanding of the materials electromechanical principles and better methods of addressing the challenges to the application of these materials. Researchers are developing analytical and theoretical models to describe the electro-chemical and -mechanical processes, non-linear behavior as well as methodologies of design and control. EAP with improved response were described including IPMC, dielectric, carbon nanotubes, liquid crystals, conductive polymers, electrostrictive and other types. Also, the use of composite electrostrictive polymers is showing promise towards reducing the need for high actuation voltage in the electronic group. Improved methods of materials fabrication and testing were reported. A review was given describing the application of EAP at the MEMS level for medical applications. Further, applications to robotically inspired robots, entertainment animatronics, and many other fields are continuing to be explored with encouraging results.

During the EAP in Action Session, the attendees were given an opportunity to see five demonstrations of EAP actuators and devices. This Session offered a forum of interaction between the technology developers and potential users as well as a "hands-on" experience with this emerging technology. The presentations included:

- Roy Kornbluh, Ron Pelrine, Qibing Pei, Jonathan Heim, Richard Heydt, Joseph Eckerle, Seajin Oh, Scott Stanford, Neville Bonwit, Philip von Guggenberg, and Don Czyzyk, SRI International, Menlo Park, California, USA, presented "Dielectric Elastomers: Stretching the Capabilities of Actuators, Generators and Sensors" with Halloween masks that make movement of various parts of the face (Figure 3- top).

- Kinji Asaka, National Institute of Advanced Industrial Science and Technology (AIST Kansai), Osaka, Japan presented "Polymer actuators composed of conductive polymers and an IPMC" (See Figure 3-bottom)
- C. Xu, and Minoru Taya, University of Washington, Seattle, WA, USA, presented their "Design of color changeable window based on electro-chromic polymer and counter-electrode"
- On behalf of Graham Whiteley, Sheffield Hallam University UK (currently at University of Bath, UK), Y. Bar-Cohen showed the "Robotic hand" that is a platform for EAP.
- Separately, on Thursday, David Hanson, University of Texas at Dallas, USA, presented a new "Android Head platform for EAP" that he constructed recently.

Also, an Open Discussion Session was held to debut the status of the field of EAP. Each of the panelists gave a short presentation of his views and the attendees were invited to express their thoughts and comments. This session was intended to stimulate ideas and thought with no attempt to reach a consensus. The general views have been that the field is moving in the right direction but we still have "a long way to go". The panel Moderator was the Conference Chair: Yoseph Bar-Cohen, JPL, and the panelist included: Rainer W. Gülch, Universitat Tübingen, Germany; James Jungho Pak, Dankook University, Korea; John D. Madden, MIT, Cambridge MA; Mohsen Shahinpoor, University of New Mexico, NM; Alberto Mazzoldi, University of Pisa, Italy; and Gordon Wallace, University of Wollongong, Australia (See Figure 4). The topics that were discussed at this session included:

- Weakness of the EAP technology infrastructure
- What is the gap between the needed and available EAP and how to bridge it?
- Do we see on the horizon a commercial EAP actuator or device?
- Future science and engineering directions

FIGURE 3: Attendees of the EAP-in-Action Session looking at the demonstration of the latest EAP materials and related devices. Top – SRI display of elastomeric-EAP actuators and devices; and Bottom - IPMC samples shown by Kinji Asaka, AIST, Japan.

FIGURE 4: Open discussion panelists from right to left Mohsen Shahinpoor, John Madden, Rainer W. Gülch, Gordon Wallace, Alberto Mazzoldi and James Jungho Pak.

2002 Transducing Materials & Devices Conference

From October 31 to November 1, 2002, the first Transducing Materials & Devices Conference is going to be held in Brügges, Belgium. Generally, transducing materials play an important role in our daily life enabling the functionality of many instruments and devices that are commonly used. Effective use of transducing materials requires understanding their behavior and assuring their robustness. These materials offer enormous potential to many fields and, to name few, one can list such important devices and mechanisms as single, multi-DoF and hybrid actuators, sensors, displays, MEMS, SAW, ultrasonic motors (USM), and reconfigurable robots. While there is a large body of science and engineering work that addressed the various transducing materials we are faced with many challenges. This conference is seeking to provide a forum for information exchange among the experts from the various related disciplines. The resulting interaction is hoped to lead to new initiatives and help existing technologies as well as forge new ones. This Conference will be held as part of the Optatech 2002 Symposium, Photonic Systems Europe. The Keynote speaker will be Carl Erik Skjølstrup, Senior Director, Platform, Development, LEGO System. The title of the presentation will be "Consumer mechatronics - A challenging play ground for Transducing materials and devices." The Conference information can be viewed on: http://www.spie.org/conferences/calls/02/epf/confs/PF11.html

9th International Seminar on the Technology of Inherently Conductive Polymers

This annual seminar includes tutorial lectures and up-to-date technical and commercial developments. The seminar is organized by Advanced Polymer Courses, Safety Harbor, Florida http://www.conductivepolymers.com. This year the Seminar was held at Monterey, CA, June 17-19, 2002. Application using conductive polymers, so-called synthetic metals, and their tests were described. Each of the applications is based on properties that are specific to these materials. Significant advancement was recently made with the development of several air-stable highly conductive polymers, such as polythiophenes, polypyrroles and polyanilines, and the fast entry of these products into the marketplace. Several applications have already been possible, and numerous others are going to be easily realized. The unique properties of inherently conductive polymers stem from (i) the possibility of fine-tuning the conductivity by adjusting the amount of dopant incorporated within the polymer, (ii) doping/undoping reversibility, and (iii) the optical and electromagnetic absorption characteristics in a wide frequency range. The list of applications includes batteries, capacitors, redox actuators, electrochromic devices, smart windows, LEDs, ink-jet printing, transistors, photovoltaics, microlithography, corrosion control, conductive adhesives and inks, static dissipation, EMI shielding, radar/microwave absorption, direct plating, electrostatic powder coating, clean room applications, sensors, and drug delivery systems. The status of commercial products and devices were described in this seminar. Further information about these annual seminars can be obtained by contacting Matt Aldissi at: maldissi@fractalsystemsinc.com

2003 SPIE EAPAD Conference

The call for abstracts to the 2003 SPIE EAPAD Conference is now available on the web http://spie.org/Conferences/Calls/03/ss/confs/SS03.html
The abstracts are due on July 31, 2002.

EAP ADVANCEMENTS

Composite Technology Development, Inc. (CTD)

Elastic Memory Composite (EMC) Applications

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Elastic Memory Composite material (EMC), under development by Composite Technology Development (CTD) in Lafayette, CO, is expected to significantly improve the reliability of space deployment mechanisms. EMC is a rigid deployable composite structure without motors or bearings, with the advantages of elegant simplicity, lightweight, and high strength and stiffness (Figure 5). Other EMC applications include composite rebar, medical devices, spoolable pipe, deployable shelters and MEMS actuators.

EMC uses a fully cured thermoset shape memory polymer, developed by CTD that enables EMC materials to achieve higher failure strains than traditional composites. CTD has determined how to incorporate fiber reinforcement, which provides improved stiffness and recovery force for shape memory polymers.

The unique properties of the matrix enable high packaging strains without damage. Strains are induced by elevating the temperature and then applying a mechanical force. The strains can be "frozen" by cooling. Deployment (i.e., shape recovery) is effected by elevating the temperature. The temperature at which these operations occur is adjustable. EMC devices are produced with conventional composite fabrication processes.

The first flight-qualified EMC components are likely to be improved versions of heritage structures, such as carpenter tape hinges. Drawbacks to the steel hinges are mass and deployment shock. Prototype EMC hinge elements weighed about 2 grams and were able to repeatedly deploy a 60-gram mass against gravity (Figure 5). The viscoelastic behavior provides for a gentle, shockless deployment. Only five Watts of power were required to deploy the hinge. It is anticipated that the capabilities of EMC materials will stimulate the development of entirely new deployable structures. EMC has the potential to achieve many of the goals sought with Electroactive Polymers (EAP). In addition, technology being developed for EAP may enhance the capabilities of EMC. EMC and EAP are two new exciting smart polymer technologies that may benefit from collaborative investigation.

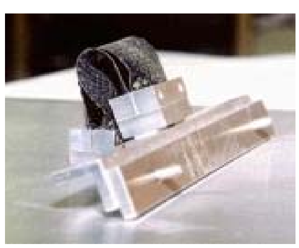

FIGURE 5. EMC hinge deployment

The Danish Polymer Centre, Denmark

Silicone elastomer as dielectric actuators

Peter Sommer-Larsen psl@polymers.dk,
Shridhar, M.H.

Dielectric elastomer actuators based on Wacker Elastosil 625 silicone rubber show up to 15% actuation when subjected to an electric field. At our lab, we studied these dielectric elastomer actuators that are made of silicone films with "smart" compliant electrodes [1, 2] (see Figures 6-8). The actuation properties of silicone elastomers with smart compliant electrodes have been tested. It was determined that the thickness of the actuator and silver electrode influences the compliance of the electrodes. The stress-strain measurement of these films indicates that the compliant electrode coating is efficient up to 25% extension. It was found that the optimal silver layer thickness is obtained between 75 nm and 100 nm, which what is normally used in our actuators.

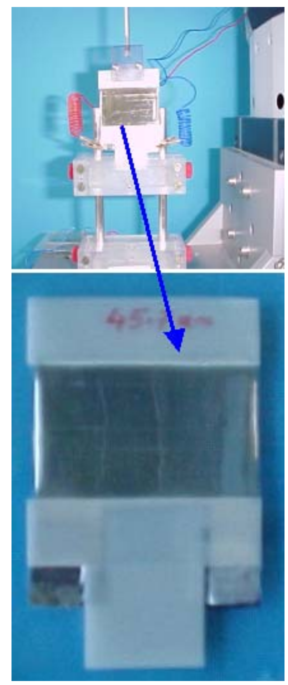

FIGURE 6: Silicone actuator of dimension 20x40mm and thickness 40 μm mounted on the electromechanical test bench. Strain at constant load is measured as a function of applied voltage.

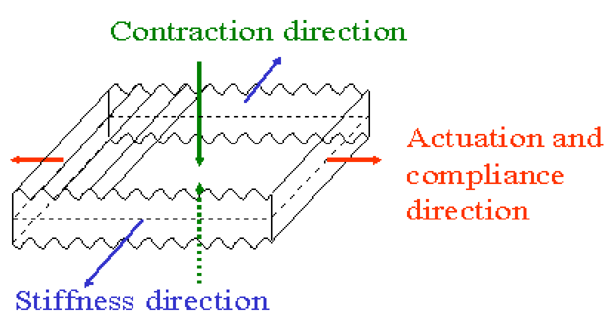

FIGURE 7: Smart Electrode: Elastomer with microstrucured corrugation. Silver is deposited on both sides of the structure.

References:

[1] M. Benslimane, P. Gravesen, P. Sommer-Larsen, "Mechanical properties of dielectric elastomer

actuators with smart metallic compliant electrodes”, *Proc. SPIE, Smart Structures and Materials 2002: Conference 4695 - Electroactive Polymer Actuators and Devices (EAPAD)* (2002)
[2] M. H. Shridhar, P. Sommer-Larsen, S. Hillersborg, G. Kofod, M. Benslimane, P.Gravesen, “Silicone elastomer as dielectric actuators”, *Proc. ACTUATOR 2002 annex, Bremen* (2002)

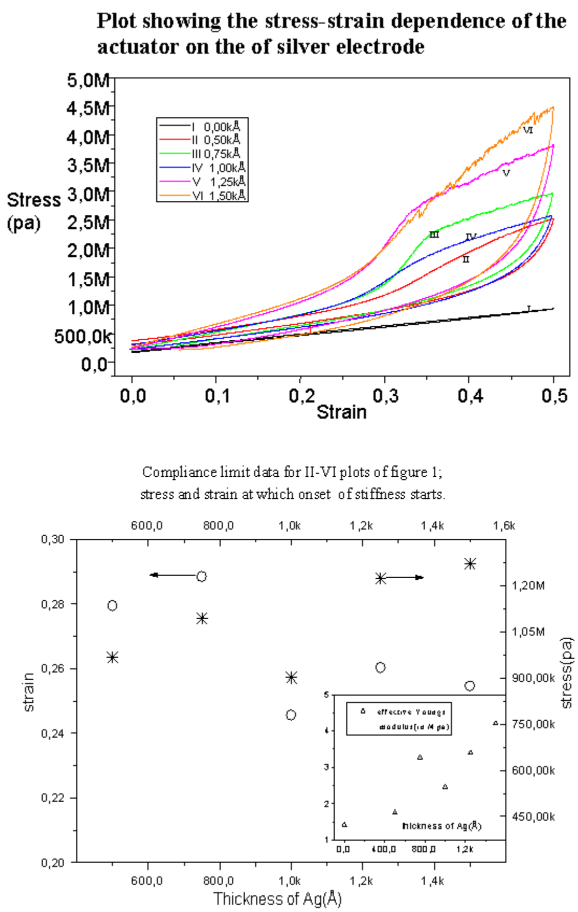

FIGURE 8: Test of actuator compliance for different thickness of silver electrodes. The stress-strain relationship is rubber like up to approximately 25% strain where the electrodes start stiffening. Beyond 30% strain, the electrodes are ruptured. The apparent Youngs modulus is fitted from the curves to the left at low strains.

Drexel University

Research on Nanofibers and Nanocomposites of Electronic Polymers

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Nanoscale fibrous materials are the fundamental building blocks of biological systems. From the 1.5-nm double helix strand of DNA molecules to sensory cells such as hair cells and the eye’s rod cells, nanoscale fibers form extracellular matrices for tissues and organs. These biological structures are invariably hierarchical and multiscale, with fibrils and fiber bundles organized in various orientations to form flexible and rigid composite structures. Many of these structures exhibit a complex combination of electro/chemo/bio-mechanical functions.

Inspired by the hierarchical and multifunctional, nanoscale nature of biopolymers and structures, the Drexel/Penn/UCLA research team is exploring various combinations of electronic polymers (EP), liquid crystalline polymers (LCP), carbon nanotube (CNT) and carbon nanoplatelet (CNP) reinforced polymeric matrices and carbon matrix composites. Conductive polymers were first discovered in the mid- 1970s and represent a particularly exciting class of conjugated polymers. These polymers have found applications in a broad range of technologies ranging from batteries and light emitting diodes to computer electronics. The importance of conductive polymers was recognized by awarding the Nobel Prize to Alan MacDiarmid and his collaborators in 2000. Collaborative research by Professors MacDiarmid, Ko and the research team demonstrated for the first time that blends of traditional polymers with conductive polyaniline polymers and nanofibers of pure conductive polymers can be electrospun. Additionally, in situ methods can be used to deposit 25 nm thick films of other conducting polymers on preformed insulating nanofibers. Professor Ko has successfully dispersed carbon nanotubes and ceramic as well as magnetic nanoparticles in polymer solutions and co-electrospun continuous nanocomposite fibrils (See Figure 9).

The combination of electronic polymer technology with the ability to produce strong and tough liquid crystalline and carbon nanotube and nanoplatelet based nanofibers will enable the development of a new generation of materials and structures for aircraft and re-useable space vehicles as well as interplanetary vehicles powered by solar sails and numerous other structural applications. This hybrid materials technology will also impact the emerging and rapidly growing field of nanoelectronics, information technology and biotechnology. Examples of areas that will benefit include nanofiber composites and membranes for the projected $1 trillion electronic textile/wearable electronic market; the $100 billion electronic packaging market; scaffolds for the $10 billion tissue engineering market projected by 2020; and the $5 billion automobile sensor and $1 billion biosensor market. Other areas that are expected to be impacted by nanofiber-based technology include drug delivery systems, wires, capacitors, transistors and diodes for information technology and systems for energy transport, conversion and storage, such as batteries and fuel cells. It is envisioned that the outcome of the scientific understanding and engineering development gained through these research activities will serve as "blueprints" for the fabrication of nanofiber based products and devices of immediate usefulness.

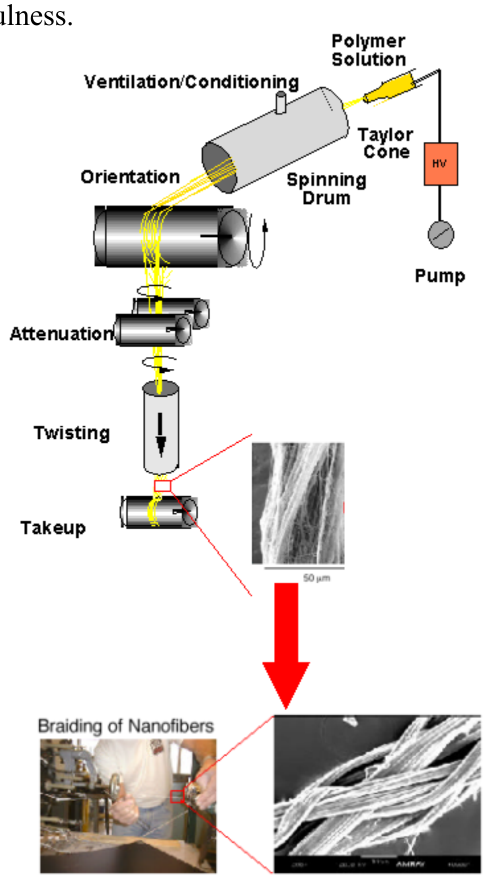


FIGURE 9: Electrospinning line for structures Nanofiber.

Jet Propulsion Laboratory (JPL)

EAP - the JPL's Spotlight for the month of June

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

In recognition of the technology potential for space applications, the field of EAP was selected as the JPL's Spotlight for this month. The topic appears under the title "Scientists 'Muscle' Sci-Fi into Reality" and details are on: http://www.jpl.nasa.gov/technology/features/muscles.html Also, this topic was covered in two open-to-the-public lectures as part of the JPL's von Kármán Lecture series. The lectures were given in February under the title "Electroactive Polymers as Artificial Muscles." A video of the lecture can be seen on:
http://www.jpl.nasa.gov/events/lectures/feb02.html

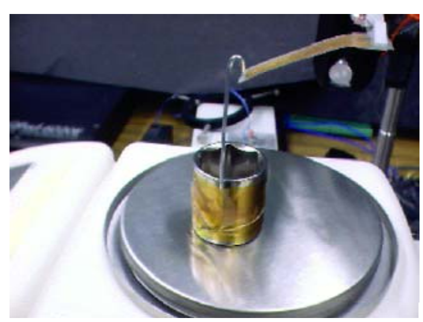
EAP surface wiper for biofouling and bubbles removal from Electrochemical sensors

Y. Bar-Cohen, yosi@jpl.nasa.gov, and X. Bao, JPL; and J. Su, NASA LaRC; and Tian-Bing Xu, ICASE

Recently, a pilot study has been initiated under the NASA NRA-00-HEDS-01 program, having potential for the use of EAP in space application. This study is part of the task entitled "Surface Control of Electrochemical Sensors for Water Reclamation." The goal of this project is to develop a wiper that is possibly actuated by EAP to ameliorate problems of biofouling and bubbles that obscure sensor surfaces in microgravity. In the previous issue of this Newsletter we reported the use of an IPMC strip with a miniature brush that was made to support the preliminary experiments and the proof of concept.

Recently, grafted elastomer EAP samples were considered as an alternative actuation material. This actuator was constructed a bimorph with an EAP layer bonded to a passive film. The strip size was 32.5x11x0.058 mm, weighing 90-mg and having active area of 30x9-mm. These strips were made relatively wide and therefore the lateral deformation caused rigidization affecting the longitudinal bending. The flexibility of these strips makes them bend when held horizontally as a result of gravity. The resulting actuation bending was determined to depend on the initial shape and therefore different deformation was induced when the strip were horizontal or vertical. Using a balance and activating the EAP at 2-kV upward a stall force at the level of 35-70 mg-f was measured (see Figure 10). The response to a step voltage is a quick movement followed by a slow motion.

FIGURE 10: Measurement of the stall force of a grafted elastomer EAP using a balance and activating the EAP upward.



LSU Eye Center (LSUEC), Jet Propulsion Laboratory (JPL), University of Maryland (UM), Massachusetts Institute of Technology (MIT)

Use of Dynamically Enhanced Electroactive Optic (DEEP) in image quality and restoration of sight in patients

A. Mallakin, amalla@lsuhsc.edu, Y. Bar-Cohen, E. Smela, and J. Madden

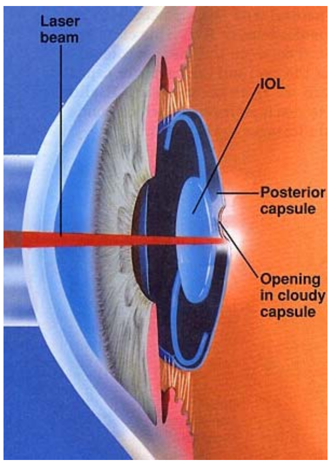


FIGURE 11: Schematic view of accommodation of an IOL in an eye and treatment of the eye after surgery by use of YAG laser for secondary cataract (American Academy of Ophthalmology).

Recently, an exploratory initiative has been taken to determine the potential application of electroactive materials to the development of active optics and ultimately for vision correction in patients. This study is entitled “Dynamically Enhanced Electroactive Optic (DEEP)” and the goal is to develop multilayered lens using transparent electroactive materials. The required fabrication process may draw on the recent development at Nanosonic Inc. using a novel self-assembly methodology to create highly thin layers. Success of this effort would allow developing electroactive optical devices and potential applications to vision correction (Actuated IOL) in patients with Cataract or blindness. Figure 11 shows an accommodation of a current IOL lens in an eye after a surgery and use of YAG laser in the treatment of patients with secondary cataract. The main challenge is to obtain transparent materials with electroactively controlled index of refraction. Suggestions of biomaterials or EAP materials with the total refracting power of 60-65 diopters and/or reversible index of refraction of ~1.0 to this initiative will be highly acknowledged.

Leeds University, UK

Increased actuator force output by combining multiple IPMC strips

R.C. Richardson menrr@leeds.ac.uk, K. Watterson, M.D. Brown, M.C. Levesley, J.A. Hawkes, and P.G. Walker.

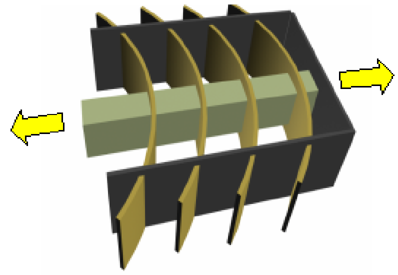


FIGURE 11: Actuator concept

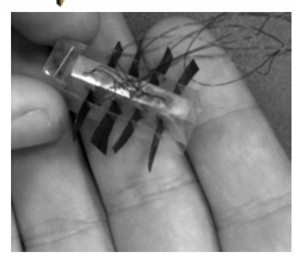


FIGURE 12: Actuator

IPMC’s have demonstrated immense potential as versatile, application specific actuators. However, the main drawback of these actuators is their small force output [1]. Research has been performed to develop IPMC’s with greater force output [2]. An alternative approach is to arrange strips of IPMC in series, creating a mini-actuator, thereby increasing the force output. A prototype actuator has been developed and the concept is shown in Figure 12. Four strips of IPMC jointly act to increase the force output of the actuator. The actuator has been fabricated by combining 4 strips of IPMC in a plastic casing (Figure 12). The actuator has demonstrated increased force output. Future work will investigate implementing force and position control on the actuator [3].

Acknowledgement

The authors would like to acknowledge the support of the National Heart Research Fund.

References

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Use of Laser Displacement Meter for the Characterization of Electrochemical Actuators Based on Polyaniline Integrally Skinned Asymmetric Membranes (PANI ISAMs)

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Electrochemical actuators with a novel monolithic configuration based on a single free standing "Polyaniline Integrally Skinned Asymmetric Membrane (PANI ISAM)" have been both developed and characterized. These membranes show an asymmetric configuration that consists of a skin side with a dense structure and a porous substructure. This novel asymmetric structure promotes a bending movement under both potentiostatic and galvanostatic conditions without the need of any additional layers (tape, polymer or thin sputtered metal layer).

The bending movement of actuators based on these membranes in HCl aqueous solutions was monitored in real time using a KEYENCE Laser Displacement Meter that includes the LK-503 Sensor Head and the LK-2503 Controller with a precision of 10 microns (Figure 13).

The Laser Displacement Meter gives a voltage signal that is proportional to the distance of the laser beam focused on the free end of the membrane. The voltage signal is converted to distance units by a VI Lab View program developed in our laboratory, synchronized with the electrical signal generated by a CHI660 Electrochemical Workstation. Curvature, angular displacement and angular velocity of the actuator are calculated in real time using the trigonometric relationships shown in Figure 14.

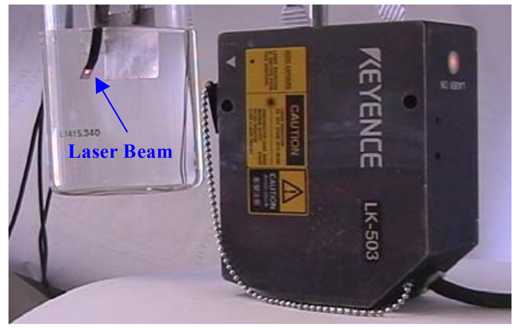

FIGURE 13: Laser Displacement Meter used to follow the movement of the PANI ISAM electrochemical actuator in real time.

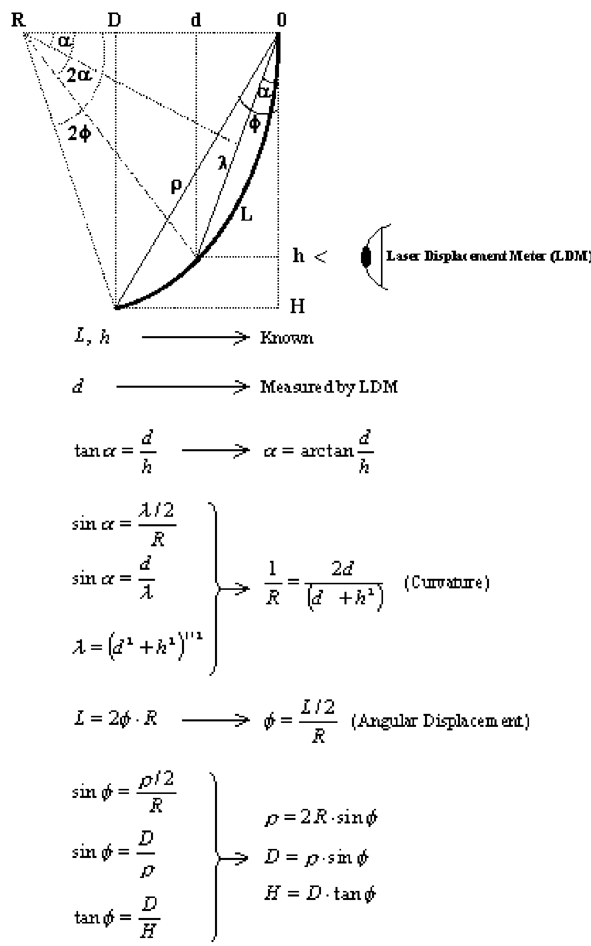

FIGURE 14: Trigonometric relationships used by the VI Lab View program to characterize the movement of the PANI ISAM electrochemical actuator in real time.

Figure 15 shows a typical graph where angular displacement and current are simultaneously plotted versus time. The consumed electric charge during the movement was obtained from the integral of the current versus time and the angular velocity was calculated from the slope of the angle versus time. A linear relationship for angular displacement versus consumed charge as well as for angular velocity versus applied current was obtained. Therefore, it can be concluded that it is possible to control the movement of the PANI ISAM actuator by controlling the applied electrical signal.

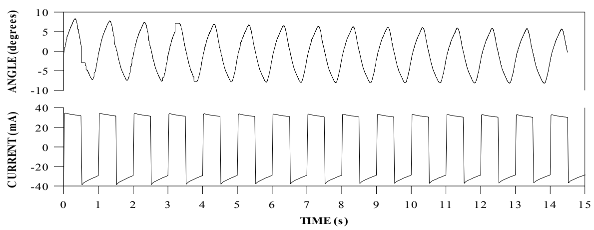

FIGURE 15: Simultaneous plots of both angular displacement and current versus time recorded from the potentiostatic movement (+/- 2 V vs. E_p = 0.4V) at 1 Hz frequency of a PANI ISAM electrochemical actuator in a 1.0 M HCl aqueous solution.

Acknowledgements

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Polytechnic University, New York

Electroactive Hydrogels on Nanometer Scale

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Hydrogels, as ionic reservoirs, can respond mechanically (swelling/shrinking) and/or electrochemically (accumulating/releasing ions) to environmental changes [1-8]. Recently, it seems attractive to use spherical nanoparticles (nanogels, liposomes, and lipobeads) as starting materials for fabrication of planar or hemispherical biosensors, actuators, and other nanodevices. Sensitivity of nanoparticles to physical or chemical stimuli allows one to enhance the functionality of the nanodevices. Nanoparticles responsive to environmental conditions can be readily identified under changes in external stimuli. In this context, new methods for preparation of nanoparticles and for fabrication of nanodevices are required. But the question is still open: How to characterize the nanoparticles and how to control the operation of nanodevices, including actuators, on the nanoscopic scale? Thus, the proper methods are necessary.

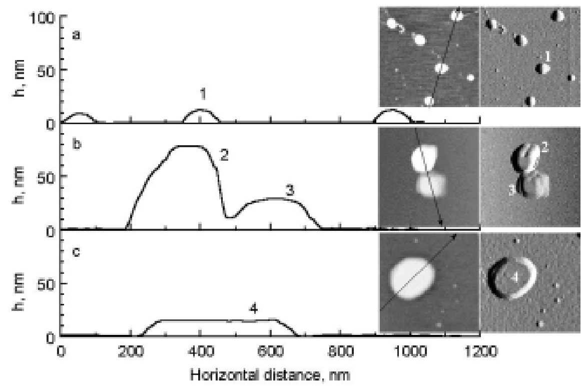

FIGURE 16: Tapping mode AFM height (left) and amplitude (right) imaging of PNIPA-VI nanogels after dialysis through 50 kDa membrane (a) at pH 6.5, (b) at pH 3, and (c) the same sample at pH 3 in 2 hours (frames 1×1 μm^2). Arrows show the direction of cross sectioning.

Light microscopy is not useful for identifying nanoparticles because the resolution is limited to the wavelength of the light source. Electron microscopy of soft nanoparticles is limited by the requirement of vacuum conditions during analysis. In addition, electron microscopy cannot provide information on biophysical properties of the nanoparticle surface. Atomic force microscopy (AFM) has unprecedented capabilities of imaging surface topography with nanometer lateral resolution under physiological conditions. Recent progress in AFM ("tapping" mode) made it possible to visualize the topology of a soft fluid-like matter, and even single macromolecules. Dynamic light scattering (DLS) is a conventional technique to characterize statistical parameters of nanoparticles in solution.

Ion-sensitive (electroactive) nanogels were prepared [9]. The liposomal interior was employed as a reactor for radical gelation by containing water-soluble hydrogel-forming components in the space surrounded by a closed lipid bilayer. Water-insoluble reactants were trapped within the lipid bilayer. The temperature and pH- and ion-sensitivity of nanogels thus prepared was studied by two of the most suitable techniques: DLS and AFM. For the first time, the electromechanical response of nanogels to environmental stimuli (pH) was directly shown by AFM imaging in free air (see Figure 16). Herein, the flat areas (~0.1-0.25 μm^2) of homogeneous hydrogels with uniform nanometer thickness of 10-15 nm were observed on a solid surface. This finding may pave the way for the fabrication of planar or hemispherical nanodevices (nanoactuators) using spherical nanoparticles, such as electroactive nanogels.

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SD School of Mines and Technology, JPL and Montana State University

Active Control of Gossamer Spacecraft

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The researcher team from SDSMT, JPL and MSU is developing techniques to actively control gossamer spacecraft (GS). The team's objective is to combine inherent features of GS with EAP and other active materials, through a rational design process. Gossamer spacecraft are ultra-lightweight systems with high packaging efficiency, that find particular advantage in applications where very large structures are desirable, such as in communication, imaging, and solar propulsion. By their very nature, GS have high structural compliance and insufficient inherent constraints, making active deployment and shape control a necessity in most cases. This research activity, funded by NASA, is comprised of the following main tasks:

- Definition of performance requirements
- The "Control Toolbox" design process
- Active material selection process
- Preliminary design of active GS
- Detailed design of active GS

Example of the research products includes an electro-rheological fluid (ERF) damper and an active seam antenna. ERF dampers would include spring members that could be wound or compressed for compact stowage during transport. The ERF based damper would keep the structures compacted and/or regulate the speeds with which the structures would spring out for deployment (Figure 17). After deployment, ERF based dampening mechanism could be used to rigidize the structure or damp its vibrations. An experimental ERF deployment controlled structure consisted of two metal tapes sandwiched together, held slightly apart by spacers, and placed in a bag filled with an ERF. The viscosity of the ERF varied with the voltage applied to the tapes, such that it was possible to hold the tapes in the wound condition or slow the speed with which they sprung from the wound to the straight condition. Several potential variations on the basic concept of an ERF-controlled structural members include compartmentalization of the interior volume to prevent total loss of the ERF in case of a leak and the use of multiple, individually addressable electrode pairs to enable more localized control.

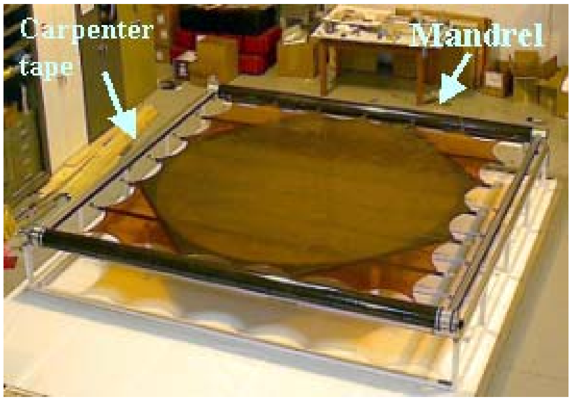

FIGURE 17: A photographic view of a deployable antenna produced at JPL. The black tubes are the mandrels over which the antenna is scrolled and the sidebars incorporate the carpenter tapes as a means of storing strain energy. ERF dampers would actively control the release of this stored energy.

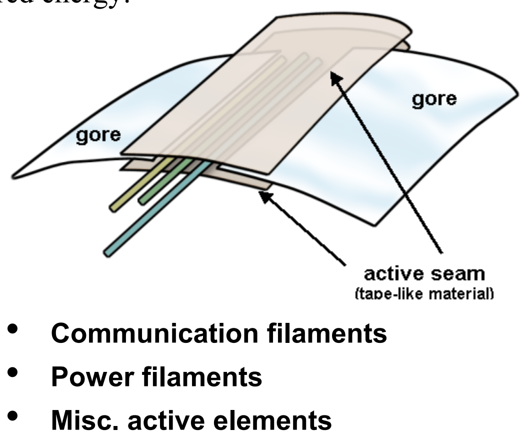

Figure 18. Concept of generic active seam where active "tapes" seam together major segments or gores.

In the active seam antenna, advantage is taken of the inevitable seams required in very large apertures (say, greater than 10 m in diameter). The seam "tapes" are EAP materials such as PVDF (Figure 18). Contained in the seam are other components, such as power and communication circuits, and other active components such as shape memory spines for deployment. In operation, the shaper memory spines would unfurl and deploy the antenna on orbit under the action of solar or supplementary heating (Figure 19). Once deployed, the active seam tapes could expand or contract in discrete locations to provide fine shape control, for example to smooth out wrinkles or remove hot-spot bulges. ABAQUS nonlinear FEM analysis has been conducted to show the efficacy of the concept.

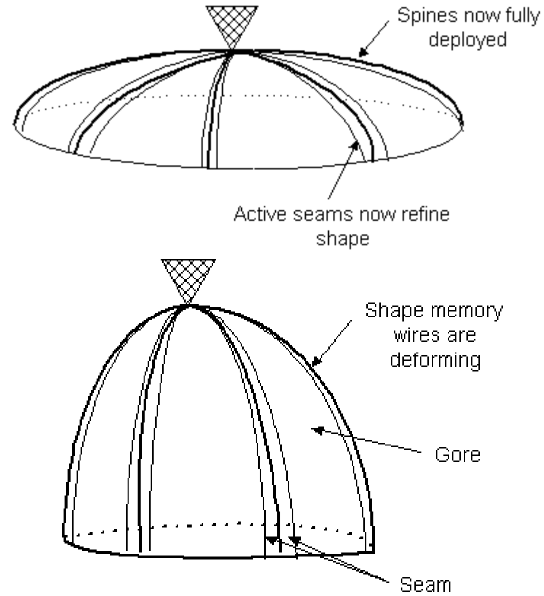

Figure 19. Active seam antenna concept. Antenna seen in partial deployment from the packaged state (left) and fully deployed (right).

Acknowledgement

The research activities will be reported in an upcoming NASA Technical Report.

University of Texas at Dallas and University of Pisa, Italy

Biologically Inspired Robotic Design for Aesthetic Expression (BIRDAE)

David Hanson dayofid@hotmail.com and G. Pioggia

Built at the Institute Interactive Arts and Engineering at the University of Texas at Dallas using servos and skull received from the University of Pisa in Italy, an Android head was produced (See Figure 20). This facial expression robot uses biomimetic structures, aesthetic design principles, and recent breakthroughs in elastomer material sciences to enact natural humanlike facial expressions. The facial expressions in this robot are very swift, taking less than 1-s to cycle through a smile. Moreover, the actuators used are low voltage (4.5-12 Volt) and low power (less than 1-A), making this approach to expressive robotics suitable to mobile robots.

Applications of expressive robotics will rise in relevance as humans and robots begin to have more face-to-face encounters in the coming years.

Potentially, artificial muscles could revolutionize the way robots express themselves, with applications ranging from medical (prosthetics or muscle replacements) to fun (toys and entertainment). My team and I are also working on imbuing our robot with several forms of interactive intelligence, including human-form and facial-expression recognition, and natural language interaction.

It is anticipated that such an integrated approach to biomimetic robotics, merging materials science, artificial intelligence, and design aesthetics will yield the most effective future robots.

FIGURE 20: Facial expressions of Android Head with and without hair.

Acknowlegement

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University of Wollongong and Quantum Technology, Australia

Electronic Braille Screen Technology

Gordon Wallace Gordon_Wallace@uow.edu.au and Tim Connell tconnell@quantech.com.au

The future of Braille displays lies in the development of compact refreshable screens operating with low power consumption. New polymer actuator devices developed at the Intelligent Polymer Research Institute* provide some unique opportunities in this regard. The actuators are configured in the device as shown in Figure 21.

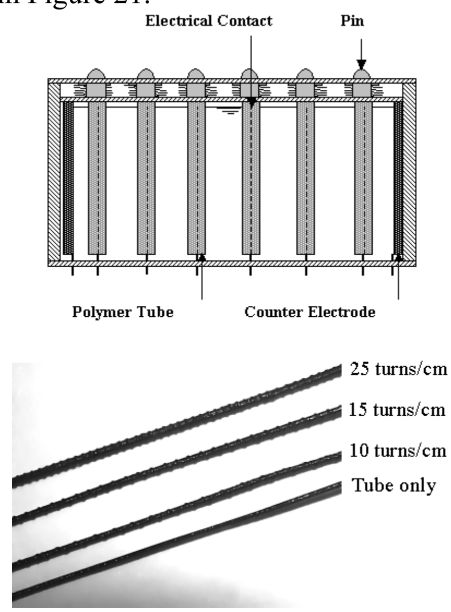

FIGURE 21: Polypyrrole fiber actuators with helical interconnects.

A prototype was constructed of a single pin prototype capable of 1.5% strain and a strain rate of 3.0% sec^{-1} in a simple 2-electrode system. This high level of performance was achieved by combination of a unique actuator design and the use of novel electrolytes as well as a carefully selected counter electrode composition and configuration.

The researchers that are involved with the development of this display include Quantum Technology, which is an Australian developer and manufacturer of technology solutions for people who are blind and vision impaired, and currently export their products to 30 countries around the world. Over the past two years the Intelligent Polymer Research Institute (University of Wollongong) and Quantum have developed an effective working partnership and, combined, they provide the expertise to further develop the design and engineering protocols needed to bring a commercial product to fruition.

The Research and Development team is keen to establish links with a third party capable of providing research funding, manufacturing

* Patent Pending

engineering expertise and/or commercialization expertise to further develop the electronic Braille screen.

Virginia Tech.

Center for Intelligent Material Systems and Structures

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<u>New Co-Reduction Process for Fabricating Ionic Polymer Transducers – Matthew Bennett</u>

A new process has been developed for reducing the amount of precious metals in the electrodes of ionic polymer transducers. The co-reduction process produces an alloy of copper and platinum at the surface of the polymer. A thin (~ 50 nm) gold overlayer is then deposited on the alloy to increase the conductivity of the electrode. Scanning electron microscopy reveals that the platinum loading in the first electrode layer is reduced by between 30 and 50% compared to platinum-only electrodes. Longevity tests indicate that samples produced by this method maintain greater than 90% of their free deflection for over 150,000 cycles when operated at 1.25 V (see Figures 22 and 23).

<u>Electromechanical Modeling Technique for Characterization of Ionic Polymers – Kenneth Newbury</u>

A technique based on linear piezoelectric theory has been developed for characterizing bidirectional energy conversion in ionic polymer materials. Measurements of blocked force, electrical impedance, and mechanical impedance are used to compute the elastic modulus, electric permittivity, and equivalent strain coefficient in strain / field. The model can be used to predict sensing and actuation using ionic polymer materials, and is scaleable with the geometry of the transducer. Material characterizations indicate that the induced strain coefficient of ionic polymer material is on the order of 20,000 to 30,000 pm/V. This value is two orders of magnitude larger than that obtained with piezoelectric materials. This is consistent with the fact that ionic polymers produce larger strains at lower electric fields than piezoelectric devices.

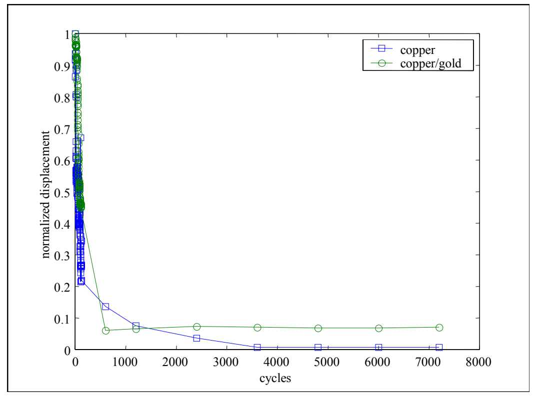

FIGURE 22: Normalized displacement over 7000 cycles for samples plated with a non-noble metal sublayer.

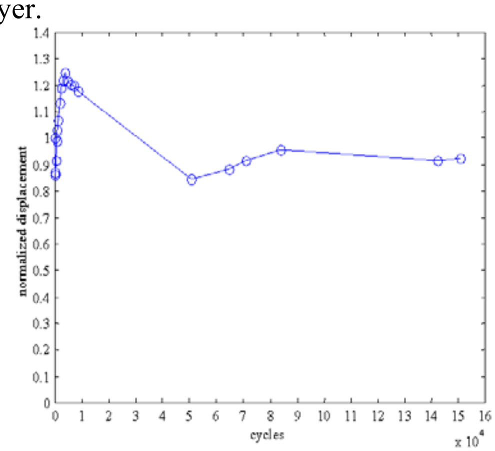

FIGURE 23: Normalized displacement over 150,000 cycles for samples plated with a copper-platinum sublayer.

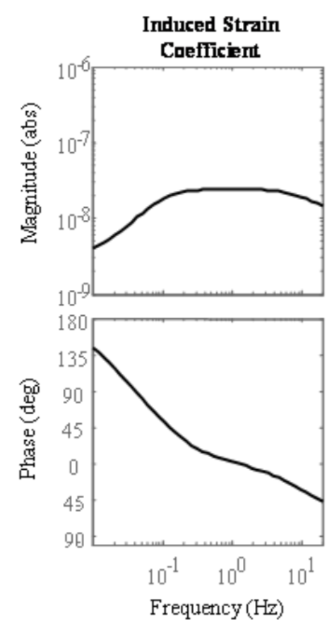

FIGURE 24: Measured induced strain coefficient for an ionic polymer bender.

<u>Multi-layer Ionic Polymer Transducers Fabricated and Characterized – Barbar Akle</u>

Limitations in force output and bandwidth of ionic polymer materials can be overcome, in part, by using multi-layer configurations. Transducers consisting of three to five layers in parallel (see Figure 25) and series have been packaged and tested to determine the sensing and actuation characteristics. As expected, these actuators provide more force than single-layer configurations and the actuation bandwidth is increased. Measurements on one, two, and three layer transducers demonstrate that the force increases linearly with the number of layers. Finite element modeling of the transducer is able to predict this increase in force output (see Figure 26).

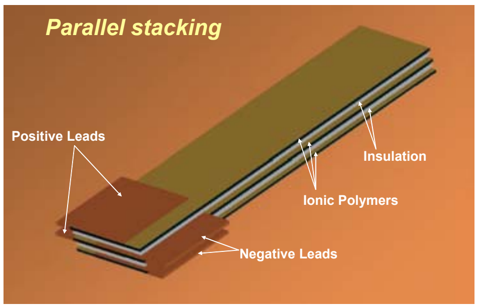

FIGURE 25: Multi-layer transducer configuration

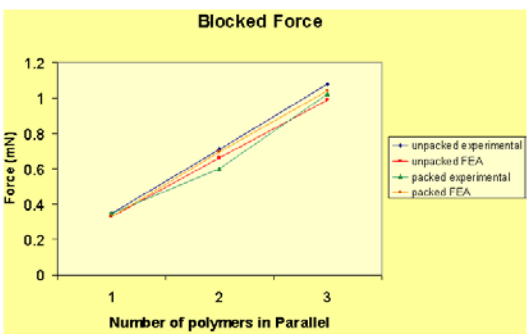

FIGURE 26: Blocked force for a one, two, and three-layer ionic polymer transducer.

BOOK REVIEWS

Electroactive Polymer [EAP] Actuators as Artificial Muscles - Reality, Potential, and Challenges

Recently, the Biomaterials Network, Biomat.net, published on its website a thorough review of the SPIE book entitled "Electroactive Polymer [EAP] Actuators as Artificial Muscles - Reality, Potential, and Challenges." The review can be accessed on http://www.biomat.net/biomatnet.asp?file=40

UPCOMING EVENTS

Oct. 31 – Nov. 1, 2002	Transducing Materials & Devices, part of Optatech 2002, Photonic Systems Europe, Belgium, SPIE, Y. Bar-Cohen, yosi@jpl.nasa.gov Information is available on http://www.spie.org/conferences/calls/02/epf/confs/PF11.html
Nov. 17-22, 2002	Adaptive Structures and Materials Symposium, ASME 2002, New Orleans, D. Leo, donleo@vt.edu
Dec. 9-11, 2002	Biomimetics and Artificial Muscles, Albuquerque, NM, M. Shahinpoor shah@unm.edu
March 2-6, 2003	EAPAD, SPIE's joint Smart Materials and Structures and NDE Symposia, San Diego, CA., P. Wight patw@spie.org Website: http://spie.org/Conferences/Calls/03/ss/confs/SS03.html
June 2003	10th International Seminar on the Technology of Inherently Conductive Polymers, Matt Aldissi at: maldissi@fractalsystemsinc.com

WorldWide Electroactive Polymers (EAP) Newsletter

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