EuroEAP 2014

4th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Linköping, Sweden
10-11 June 2014

Technical programme

Book of abstracts

List of participants

ESNAM
European Scientific Network for Artificial Muscles

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Contents

Conference venue

Scandic Frimurarehotellet

S:t Larsgatan 14
582 24 Linköping
Sweden

Latitude: 58.414622
Longitude: 15.623231

Conference chairman

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Local organization

Linköping University
Biosensors & Bioelectronics Centre
Dept. of Physics, Chemistry and Biology (IFM)
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www.liu.se and www.ifm.liu.se/biosensors

Presentation of the EuroEAP conference series

Electromechanically Active Polymers (EAPs) represent a fast growing and promising scientific field of research and development. EAPs are studied for devices and systems implemented with 'smart materials' inherently capable of changing dimensions and/or shape in response to suitable electrical stimuli, so as to transduce electrical energy into mechanical work. They can also operate in reverse mode, transducing mechanical energy into the electrical form. Therefore, they can be used as actuators, mechano-electrical sensors, as well as energy harvesters to generate electricity. For such tasks, EAPs show unique properties, such as sizable electrically-driven active strains or stresses, high mechanical flexibility, low density, structural simplicity, ease of processing and scalability, no acoustic noise and, in most cases, low costs. Owing to their functional and structural properties, electromechanical transducers based on these materials are usually refereed to as EAP 'artificial muscles'.

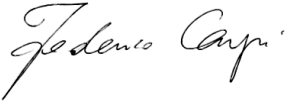
The two EAP classes (ionic and electronic) are studied for applications in several fields, including haptics, optics, acoustics, microfluidics, automation, orthotics, artificial organs, and energy harvesting.

The rapid expansion of the EAP technologies has stimulated in Europe the creation of the 'European Scientific Network for Artificial Muscles - ESNAM', established as a COST Action (MP1003) since 8 December 2010. The network gathers the most active European research institutes, industrial developers and end users in the EAP field (www.esnam.eu).

In an effort to disseminate current advances in this emerging field of science and technology, gathering experts from all over the world, the network organises and supports the annual EuroEAP conference, which is meant to be primarily driven by scientific quality and industrial impact.

I wish to express my gratitude to the conference chairman and local organizer, for the valuable organization that I am sure will allow you to enjoy this event and leave it with plans to attend the future annual editions moving across Europe.

Federico Carpi
ESNAM Chair



Conference committees

Organizing committee

The EuroEAP conference is steered by the conference committee of the '*European Scientific Network for Artificial Muscles*' (www.esnam.eu):

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Peter Sommer-Larsen, Technical University of Denmark (Denmark)
Frédéric Vidal, University of Cergy-Pontoise (France)

Monday, 9 June 2014

Registration desk open 15.00-19.00

Tuesday, 10 June 2014

Registration desk open 8.00-11.00

General programme of the day

Opening	8:45-9:00	Welcome & introductory remarks **Edwin Jager** Linköping University, Sweden
EAPlenary	Session 1.1 part I *Chair:* **Edwin Jager** (Linköping University, Sweden)	
	9:00-9:30	Invited talk **Gursel Alici** University of Wollongong, Australia
EAPodium	9:30-9:50	Invited talk **Cecilia Laschi** Scuola Superiore Sant'Anna, Pisa, Italy
Break	9:50-10:20	Coffee break
EAPromises	Session 1.1 part II *Chair:* **Ingrid Graz** (Johannes Kepler University, Linz Austria)	
	10:20-10:40	Invited talk **Alexandre Khaldi** Alexandre Khaldi, University of Cambridge, UK
	10:40-11:00	Invited talk **Benjamin O'Brien** StretchSense, New Zealand
EAPills	Session 1.2 part I *Chair:* **Samuel Rosset** (EPFL, Switzerland)	

	11:00- 12:10	**Pill oral presentations** 19 presentations (3 minutes each + 1 minute to change speaker)
Lunch	12:10- 13:30	Buffet lunch
EAPosters	Session 1.2 part II	
EAPrototypes **EAProducts**	13:30- 15:00	**Posters & exhibitions** 19 posters
EAPills	Session 1.3 part I *Chair:* **Gabor Kovacs** (EMPA, Duebendorf, Switzerland)	
	15:00- 16:10	**Pill oral presentations** 18 presentations (3 minutes each + 1 minute to change speaker)
Break	16:10- 16:30	Coffee break
EAPosters	Session 1.3 part II	
EAPrototypes **EAProducts**	16:30- 18:00	**Posters & exhibitions** 18 posters
Dinner	18:00- 22:00	Bus departure from conference hotel to the social dinner at Flygvapenmuseum

Session 1.1

(abstracts are listed in the order of presentation)

1.1.1 How ready are smart materials (e.g. electroactive materials) to establish soft robotic systems? A personal perspective to set up a bridge between materials research and robotics research

Gursel Alici (1) (2),

(1) University Of Wollongong, School Of Mechanical, Materials And Mechatronic Engineering, Australia
(2) ARC Center Of Excellence For Electromaterials Science, University Of Wollongong, Australia

One of the continuing research challenges in robotics is to create novel actuators, sensors and mechanisms with the aim of establishing novel robotic systems with behavioural diversity so that they can undertake tasks beyond the capabilities of current robotic systems. Nature or biological systems are one source of the inspiration to solve this challenge. Soft components may be intelligently hidden in a hybrid monolithic body with the capabilities of whole shape manipulation, built-in actuation, sensing and intelligence. Such a soft or hybrid monolithic body can generate soft movements to 'gently' interact with the environment while dealing with various contact scenarios. Soft materials, especially electroactive materials, can be the key to realising soft robotics systems such as surgical devices, prosthetic devices including wearables and exoskeletons, co-robots (i.e., assistive robots), robot manipulators and mechanical positioners. In this talk, we will try to answer the questions of (i) how ready the soft materials typified by electroactive polymers are to meet the requirements of a soft robotic system, and (ii) what should the characteristics of 'a dream material' and the combinations of such soft and hard materials be for soft robotics which is considered to be 'the new paradigm' to establishing novel robotic systems with behavioural diversity and bio-inspiration.

1.1.2 Soft Robotics and the challenges for soft actuation and sensing technologies

Cecilia Laschi (1), Matteo Cianchetti (1),

(1) The BioRobotics Institute, Scuola Superiore Sant"Anna, Pisa, Italy

Soft robotics, intended as the use of soft materials in robotics, is a young yet promising and growing research field. Using soft materials to apply forces on the environment, as expected in a soft robot able to locomote, grasp, and perform other tasks, poses new problems at the level of the different components, as well as at the whole system level. The technologies for actuating soft materials are one of the main challenges in soft robotics, and the same is true for sensors that can be embedded in soft materials. EAP technology can provide a very important contribution to the progress of soft robotics, providing essential enabling technologies. The scientific community of Soft Robotics is gathering around the ICT-FET Open RoboSoft Coordination Action, started in November 2013. A common forum helps soft robotics researchers to combine their efforts, to maximize the opportunities and to materialize the huge potential impact of soft robotics. RoboSoft is creating the missing framework for the soft robotics scientists, regardless of their background disciplines, and enabling the accumulation and sharing of the crucial knowledge needed for scientific progress in this field. RoboSoft is aiming not only to create and consolidate the soft robotics community, but also to establish effective links with relevant scientific communities potentially interested in exploiting soft robotics as case study, which is perfectly the case of the EuroEAP platform of the ESNAM COST Action.

1.1.3 Electro mechanical memory

Alexandre Khaldi (1), Stoyan Smoukov (1),

(1) AIM Laboratory, University of Cambridge, UK

Electro-mechanical memory material is an actuator whose ionic actuation response can be tuned or completely switched off by a mechanical programming, in a reversible fashion. This material combines functionalities of ionic actuators with those of a shape memory polymer. The temperature memory effect was also used to stores at two different temperatures two different shapes and actuation responses. The material is capable of bending ionic actuation in the 0-2 V range, shape-memory actuation to >100 % strain for programming/recovery in the 60-110°C temperature range. The ionic actuation amplitude decreases linearly with strain up to 70 %, and completely switches off for strain >100%. The effect is reversible, however, and ionic actuation is

restored upon shape-memory recovery of the material to strains >100%. Ionic Polymer actuators are a class of soft material which produces large impressive bending displacement under low voltage. They can find use for delicate manipulations of fragile objects or in mechanically sensitive medium. (e.g. biomedical and bio-mimicking devices). The incorporation of a large shape memory effect in ionic actuators will lead to the fabrication of smarter life-like materials and devices. We will also shows that the combining of the effects can be developed for a large class of materials.

1.1.4 The stretch sensor revolution

Benjamin O'Brien (1) (2), Todd Gisby (1) (2), Iain Anderson (1) (2) (3),

(1) StretchSense Limited, Auckland, New Zealand
(2) Biomimetics Lab Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand
(3) Department Of Engineering Science, University Of Auckland, Auckland, New Zealand

Stretch Sensors based on Dielectric Elastomer (DE) technology are revolutionary. They allow measurement of human body deformation in a precise, robust, unobtrusive and mobile manner. There are a number of companies and academic institutions - including our own - that are now actively bringing DE stretch sensors to the market. DE have been around for almost two decades and over much of this time it has been understood that stretch sensing modes were a possibility. Stretch sensing is the easiest application for DE technology - other modalities such as actuation and generation require high voltage which brings a range of commercial and safety issues. So if the technology is there, and it has robust demand, why has it taken so long? Our hypothesis is that the reduction of a DE system to a packaged, complete, ready-to-use form has been lacking. In the case of stretch sensors this took time and we believe it was the more interesting academic challenges of actuation and generation that provided the practical knowhow to make it possible. In parallel these technical developments have been matched by increasing market pull as awareness of the technology spreads for high value, low volume applications. For example: Health and rehabilitation; motion capture for animation, gaming, and augmented reality; and sports training and performance monitoring. The revolution has begun and has reached the tipping point; expect to see stretch sensors everywhere.

Session 1.2

(abstracts are listed in the order of presentation)

1.2.1 Self - Sensing Ionic Polymer Metal Composite

Parisa Bakhtiarpour (1), Masoud Amirkhani (1), Othmar Marti (1),

(1) Ulm University, Institute of Experimental Physics, Ulm, Germany

Integration of sensor and actuating properties of Ionic Polymer Metal Composite (IPMC) have attracted a lot of interest in recent decades. The electrical response of IPMC to the bending can be used for self-sensing. However, using the self-sensing mechanism of patterned IPMC results into cross talk between sensing and actuating part, which even with shielding cannot be avoided entirely. Additionally, two sections are correlated in which the maximum efficiency on one part lead to the minimum efficiency on the other part. We solve these problems by using a high-frequency and a low-frequency voltage as sensing and actuating signal respectively, on an unpatterned sample. IPMC in the high-frequency can be considered as a variable resistance and in the low-frequency works like an actuator.

1.2.2 Energy Harvesting Using Electroactive polymer

Nitin Singh (1),

(1) Indian Institute of Technology, Patna, India

This project article describes the energy harvesting set-up. It also describes electrical modeling and simulation results using PSpice software in order to scavenge energy. Dielectric elastomers are mainly known for its applications as an actuator, but these materials rapidly using as a generator also. Scientists in this area have received great attention and, several prototypes were invented like ocean wave power and human cranked power generators to describe the overall procedure. This report presents how electrical energy can be harvested using electroactive polymer and compares different theoretical results with experimental data obtained by hardware model of energy harvesting ciruit. Electroactive polymers are plastic materials that change shape and size on

applying voltage and also generate voltage on applying mechanical force. Electroactive polymer shows very large deformation and has many advantages over traditional polymer such as piezoelectric materials which make them better for scavenging energy. Different small scale models of energy harvesting devices, like SRIs wind and wave-power generators have been tested. The use of polymers with electroactive response has only revealed in this decade with the introduction of EAP materials, having significant deformation levels. However the theoretical limits and practical implementation still is a big challenge.

1.2.3 Effects of fillers on the properties of liquid silicone rubbers (LSRs)

Liyun Yu (1), Sindhu Vudayagiri (1), Shamsul Zakaria (1), Anne Ladegaard Skov (1),

(1) Technical University of Denmark, Department Of Chemical and Biochemical Engineering/ The Danish Polymer Centre, Lyngby, Denmark

Dielectric electro active polymers change their shape and size under a high voltage or reversibly generate a high voltage when deformed. To make their performances more efficient, certain properties of the polymers like dielectric permittivity, electrical breakdown and Young's modulus have to be modified. One such prominent method is by adding suitable fillers. Liquid silicone rubbers have relatively low viscosities when compared with thermoplastics, which is favorable for loading of inorganic fillers. In this study commercially available fillers, such as fumed silica, titanium dioxide, barium titanate, copper calcium titanate, multi-walled carbon nanotubes were added into the LSRs. Fumed silica reinforces the networks with no increase in permittivity. Barium titanate possesses high dielectric constant but its heavy density deteriorates the lightweight advantage of the DEAPs. Micron-sized giant dielectric constant CCTO decreases the mechanical performances of the composites. The inhomogeneous compatibility of the unmodified MWCNTs causes the risk of electric conductivity. The use of multiple titanium dioxides as filler potentially suits to special applications. A series of TiO2 fillers were blended into LSRs, such as hydrophilic/hydrophobic, micro/nano, anatase/rutile, sphere/core-shell. The results indicate that the hydrophobic rutile TiO2 nanofiller is a good candidate for achieving higher permittivity and breakdown, as well as favorable elastic modulus of the elastomers.

1.2.4 Bilaterally micro structured thin polydimethylsiloxane film production

Sindhu Vudayagiri (1), Liyun Yu (1), Suzan Sager Hassouneh (1), Anne Ladegaard Skov (1),

(1) The Danish Polymer Centre, Department Of Chemical and Biochemical Engineering, DTU, Kgs. Lyngby, Denmark

Thin PDMS films with complicated microstructures are used in making dielectric electro active polymer (DEAP) actuators, sensors and generators to protect the metal electrode from large strains and for controlled actuation. The current manufacture process in Danfoss Polypower produces a film with only one micro structured surface. It is advantageous to produce a film with both the surfaces micro structured as it increases the films' efficiency further. An economic large-scale manufacture process for producing a monolithic bilaterally micro structured thin PDMS film is therefore necessary. Bilaterally micro structured films of two different liquid silicone rubber (LSR) formulations namely, 1) pure XLR 630 and 2) XLR 630+ TiO2 filler are successfully made with the new technique. The LSR films (~ 70 µm) are made on a carrier web substrate. The carrier web has a sinusoidal corrugation of height 7 µm and period 7 µm on its surface. The carrier web with elastomer film is preheated to the gel point and then embossed between the rolls of a gravure lab coater. For the LSR systems used, the optimum conditions for preheating are 110 oC for 7-10 s and for embossing 110 oC with 25 psi pressure between the rolls and at a speed of 1.4 rpm. The bottom surface of the film gets the microstructure from the substrate and the top surface from the embossing roll. The SEM images confirm the formation of microstructures on both surfaces of the film.

1.2.5 A metallic substrate may reduce artificial muscles lifetimes

Jose G Martinez (1) (2), Toribio F Otero (1), Edwin W H Jager (2),

(1) Universidad Politécnica De Cartagena, Center for Electrochemistry and Intelligent Materials (CEMI), Cartagena, Spain
(2) Linköping University, Department Of Physics, Chemistry and Biology, Biosensors and Bioelectronics Centre, Linköping, Sweden

Researchers use to consider that a metallic substrate or backing (metal foil electrode or sputtered metal) guarantees a uniform electric field to organic and

carbon based electrodes and their applications to different devices. Here the effect of both Pt and Au substrates on the properties of actuators based on conducting polymers is considered when water or water contamination is present. The presence of slow irreversible hydrogen evolution, in parallel to those film reactions driving the muscle actuation, was detected from coulo-voltammetric (charge/potential) responses. The hydrogen release occurs at the metal-electrolyte interface: it disappears from a full polymeric muscle or organic solvents are used. For the same potential gradient the irreversible charge is higher in Au electrodes than in Pt coated with the conducting polymer film, promoting a faster degradation of the polymer electroactivity. The lifetime of the actuator drops in presence of the parallel reaction and increases when the parallel reaction is absent. Reactions on metallic back contacts must be avoided to get long actuator's lifetimes.

1.2.6 Energy harvesting: electro-viscoelastic modelling and circuitry analysis of a soft generator

Bortot Eliana (1), Ralf Denzer (2), Andreas Menzel (2) (3), Massimiliano Gei (1),

(1) University Of Trento, Italy
(2) TU-Dortmund, Germany
(3) Lund University, Sweden

This talk is concerned with modelling of soft Dielectric Elastomer Generators (DEGs). From an electrical viewpoint, a realistic model of the generator has to take into account the electrical resistance of the electrodes and conductivity current through the dielectric film. These dissipative effects can be represented respectively by a resistor in series and one in parallel with the variable capacitor. Therefore, a simple electrical circuit for energy harvesting is realized by connecting the DEG, stretched periodically by a source of mechanical work, in parallel with a battery through a diode and with an electrical load, in this case an external resistor consuming the energy produced. Since these devices undergo a high number of electro-mechanical loading cycles at large deformation, the time-dependent effects must be carefully taken into account as they strongly affect the generator performance. To this end, the viscoelastic behaviour of the polymer and the electrostrictive effects are analysed by means of a newly proposed coupled electro-viscoelastic constitutive model, calibrated on experimental data available in the literature for an incompressible electrostrictive polyacrilate elastomer (3M VHB4910). Numerical results will be

presented for different loading conditions, namely equibiaxial and uniaxial, showing the importance of time-dependent assumptions in the evaluation of the performance of these devices.

1.2.7 Abstract withdrawn

1.2.8 Abstract withdrawn

1.2.9 New insights into tailoring dielectric properties of silicones by chemical modification

Carmen Racles (1), Mihaela Alexandru (1), Adrian Bele (1), Valentina Musteata (1), Maria Cazacu (1), Simon Dunki (2), Dorina M. Opris (2),

(1) Petru Poni Institute of Macromolecular Chemistry, Iasi, Romania
(2) Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Functional Polymers, Dübendorf, Switzerland

Silicone-based materials with properties suitable for applications in dielectric elastomer transducers are prepared by modifying polysiloxanes with polar groups to increase their dielectric permittivity (k). For attaching the polar groups, poly(dimethyl-co-methylhydro)siloxanes with different compositions and a poly(methylhydro)siloxane were modified by hydrosilylation with allyl cyanide. The amount of polar groups was tuned in a wide range either by using copolymers containing different mol % of Si-H groups (series A) or by adjusting the allyl cyanide/hexene groups ratio in poly(methylhydro)siloxane hydrosilylation (series B). The dielectric properties of the prepared copolymers were investigated as function of cyano group content. An increase in permittivity with increasing the amount of polar groups was observed, with a maximum k= 15.9 (@10kHz) for a copolymer containing 18.6 wt% cyano groups. The incomplete conversion of Si-H groups in hydrosilylation opens up the intriguing possibility of using the prepared polymers as crosslinkers and allowed preparation of homogenous thin elastomeric films. The morphology, dielectric and mechanical properties of thin films obtained with these copolymers and high Mw PDMS were investigated by a combination of techniques: SEM, DSC, DMA, impedance spectroscopy, tensile measurements. The actuation properties were also evaluated.

1.2.10 A dual strategy for improving the electromechanical properties of silicones

Adrian Bele (1), Maria Cazacu (1), Mihaela Alexandru (1), Valentina Musteata (1), Dorina M. Opris (2), Carmen Racles (1),

(1) Petru Poni Institute of Macromolecular Chemistry, Iasi, Romania
(2) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory For Functional Polymers, Ueberlandstr. 129, CH-8600, Dübendorf, Switzerland

Two pathways were explored for increasing the dielectric characteristics of silicones. Polar groups were attached: (1) to polysiloxane chains and (2) to silica nanoparticles surface. The functionalized polysiloxane was used as cross-linker while the functionalized silica as reinforcing filler in interconnected networks with PDMS. Thus, a poly(methylhydrosiloxane) was modified by hydrosilylation with allyl cyanide while the silica nanoparticles were treated with organotrialkoxysilane containing polar groups. Next, different amount of polar silica particles and polar silicone were blended in a HO- terminated PDMS and cross-linked in the presence of tetraethoxysilane. The resulting films were investigated regarding their mechanical and dielectric as well as the water vapor sorption properties. Increased values for the dielectric constants were registered (~ 8) while the mechanical properties remained satisfactory.

1.2.11 Strategies and own results on the development and optimization of silicone materials for electromechanical applications

Maria Cazacu (1), Carmen Racles (1), George Stiubianu (1), Adrian Bele (1), Codrin Tugui (1),

(1) "Petru Poni" Institute Of Macromolecular Chemistry, Aleea Gr. Ghica Voda 41A, 70487, Iasi, Romania

In order to be useful in electromechanical devices (actuators, harvesters, sensors), the material must have adequate mechanical (elongation, Young modulus) and dielectric characteristics. When silicone materials are concerned, there are some parameters which can be handled to tune them: .molecular weight of the polysiloxane; .chemical structure (homopolymer or copolymer); .the microstructure of the copolymer (content of the co-monomer units and their distribution pattern along the chain; .nature of the second organic group attached to the silicon (polarity, length and bulkiness); .crosslinking system which is used: transversal or through the ends of the chain, and its chemistry (radicalic,

addition, condensation in presence or not of catalyst); .the use or not of the fillers; .type and amount of the filler used; .size and morphology of the filler nanoparticles and their dispersability within the matrix; .compatibility of the filler with the polymeric matrix. Some conclusions regarding the influence of these factors on the basis of own studies are presented.

1.2.12 Effects of shape and size of the ceramic filler particles on the electromechanical properties of the silicone composites

Adrian Bele (1), Maria Cazacu (1), George Theodor Stiubianu (1),

(1) "Petru Poni" Institute Of Macromolecular Chemistry, Iasi, Romania

A high molecular weight polydimethylsiloxane synthesized in house was used as matrix for silicone nanocomposites. Barium titanate nanoparticles with well-defined, either cubic or nanotube shapes were obtained by hydrothermal procedure and used as fillers after the surface treatment. A highly reactive trifunctional silane was used as crosslinking agent in presence of an organometallic catalyst. The simple crosslinked polymer and one filled with commercial barium titanate were prepared and used as reference to evaluate the influence of the barium titanate nanoparticles presence, their size and shape on some characteristics of the resulted crosslinked composites: morphology, thermal behavior, moisture sorption, mechanical and dielectric parameters. The electromechanical sensitivity was calculated on the basis of the proper experimental data to estimate the potential of the composites for future electromechanical applications.

1.2.13 Full silicone interpenetrating bi-networks with different organic groups to the silicon atoms

Codrin Tugui (1), Maria Cazacu (1), Stelian Vlad (1), Cristian Ursu (1),

(1) Institute Of Macromolecular Chemistry "Petru Poni"

Polydimethylsiloxane-alpha,and omega-diol of high molecular masses and siloxane copolymers having organic groups with various polarities attached to the silicon atom were prepared, characterized and used to obtain full interpenetrated bi-networks. The materials were processed as films, which have been stabilized through sequential cross-linking using separate chemical pathways: condensation in the case of the polydimethylsiloxane network and

addition for its copolymers. The morphology of the resulted materials was studied by scanning electron microscopy. The crosslinking and mixing degrees of the two networks were estimated on the basis of the differential scanning calorimetry traces. The obtained films were characterized from point of view of the properties of interest for electromechanical applications: mechanical testing, dielectric spectroscopy and electrical breakdown experiments. The influence of the molecular mass of the polymers, nature and content of the polar groups attached on the silicon atom as well as networks preparation mode proved to influence these characteristics.

1.2.14 Novel method to prepare multiwalled carbon nanotube/poly(dimethyl siloxane) (MWCNT/PDMS) non-conducting composites

Kaustav Goswami (1), Anders Egede Daugaard (1), Anne Ladegaard Skov (1),

(1) Technical University Of Denmark, The Danish Polymer Centre, Department Of Chemical And Biochemical Engineering, Kgs. Lyngby, Denmark

In this study a new method of carbon nanotube (CNT) incorporation was employed for the preparation of ultraviolet (UV) curable CNT filled poly (dimethyl siloxane) (PDMS) composites. The composites were designed to contain loadings of CNT above the percolation threshold without becoming conductive due to a localized distribution of CNT. Ultrasonicated and dispersed multiwalled CNTs were mixed with short chain ?,?- vinyl terminated PDMS. When the whole mixture containing dispersed CNT and short chain PDMS was irradiated with UV radiation in presence of deficient amount of hexa functional thiol PDMS crosslinker and a photoinitiator, hyperbranced PDMS layer was formed over the CNTs. The prepared hyperbranched CNTs were mixed in different weight ratios (0.33%, 0.66%, 1%) with long chain ?,?- vinyl terminated PDMS and crosslinked subsequently with the same hexa functional thiol PDMS via UV photoinitiated thiol-ene chemistry to obtain the networks. Rheology of the prepared networks showed a gradual decrease in storage modulus (G') in the entire frequency range as the amount of CNT was increased due to a reduction in crosslinking density imposed by the CNTs. Dielectric spectroscopy measurements showed an increasing trend in permittivity in all the composites with increasing CNT loadings and AC conductivity measurements confirmed non-percolating behavior of the prepared composites.

1.2.15 Electrostatic-elastodynamic finite element modelling of stacked

dielectric actuators

Tristan Schloegl (1), Sigrid Leyendecker (1),

(1) University Of Erlangen-Nuremberg, Chair Of Applied Dynamics, Erlangen, Germany

In electronics, electrostriction generally describes the deformation of a dielectric material caused by an electric field, due to the interaction between charges. Considering the sandwich structure of a dielectric elastomer actuator (DEA), charges can be found on the electrodes as free charges and in form of polarisation within the elastomer as bound charges. In 1998, using a simplified one-dimensional model, Pelrine showed that for incompressible elastomers, the resulting electrostatic pressure is twice the pressure present in a rigid plate capacitor. Motivated by inconsistent experiments and finite element analyses, in 2007, Wissler introduced a new physical interpretation of Pelrine's equation, distinguishing in-plane and out-of-plane stresses. Generally, the three-dimensional behaviour of DEAs is covered by the Maxwell equations and the balance of momentum as shown by Dorfmann 2005. Building on a variational finite element formulation of the static coupled problem introduced by Vu 2007, in this work inertia terms are added in order to obtain a description of the deformation process depending on time. This allows for a structure preserving time integration of fully three-dimensional DEAs. The obtained scheme is used to simulate stacked actuators at finite strains. A method is introduced that allows for the simulation of thin single layers of 10 micrometer at low computational cost.

1.2.16 Shaping and patterning of electrically driven soft PEDOT:PSS bilayer actuators

Silvia Taccola (1), Francesco Greco (1), Alessio Mondini (1), Barbara Mazzolai (1), Virgilio Mattoli (1),

(1) Center For Micro-BioRobotics @SSSA, Istituto Italiano Di Tecnologia, Pontedera, Italy

The cooperation between the electrical conductivity and the hygroscopic nature of conductive polymers such as PPy and PEDOT:PSS has recently led to the development of a new class of CP actuators working in ambient air. The actuation principle lies in the reversible contraction of the films upon the

application of a current, ascribed to desorption of water vapor sorbed in the films because of local Joule heating. Here, we present a new bilayer bending actuator made of a soft silicone elastomer, poly(dimethylsiloxane) (PDMS), acting as the passive substrate onto which the active PEDOT:PSS layer was deposited by spin coating. The isotropic volume change of the PEDOT:PSS film through reversible sorption and desorption of ambient moisture is thus converted into a bending motion. We report a simple, low-cost, rapid, and mask-free approach for fabricating actuators with different shapes and circuit patterns, based on the direct machining of PDMS/PEDOT:PSS structures using a commercial CO2 laser cutting system. By varying the settings of the laser, we were able to cut or pattern in the form of electric circuits the surface of the actuators. This allowed to drive the current flowing between the electrodes along specific paths thus inducing the individually addressable bending of selected portions of the structure. Site specific actuation of these materials was demonstrated with a patterned bilayer film cut in the shape of a hand with individually addressable fingers.

1.2.17 Grafting organic dipoles to silicone networks: Chemical strategies and physical pre-conditioning methods for enhanced dielectric elastomer actuators

Matthias Kollosche (1), Martin Bluemke (2), Stefan Best (1), Gunnar Gideon (1), Huelya Ragusch (1), Hartmut Krueger (2), Reimund Gerhard (1),

(1) University Of Potsdam, Institute Of Physics And Astronomy, Potsdam, Germany
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The preparation of elastic silicone elastomers that are grafted with strong organic dipoles was developed recently [Kussmaul et. al. 2011] and proposed for dielectric elastomer actuators (DEAs). Grafting of functionalized organic dipoles to cross-linker molecules and subsequent polymerization and network formation helps to prevent severe agglomeration and allows for homogeneous dielectrics. In this contribution, the simultaneous positive effects of permittivity enhancement and stiffness reduction are studied together with the additional and often beneficial influence of a mechanical pre-stretch. Dielectric, mechanical and breakdown experiments are employed to confirm the improvement of the elastomer material itself, while constant-force and constant-strain experiments on free-standing clamped membranes are carried out to demonstrate the enhanced performance of the elastomer under high electric fields. In conclusion,

a significant reduction of the driving voltage required for dielectric elastomer actuators can be achieved with a suitable combination of materials enhancement (chemistry) and mechanical pre-conditioning (physics).

1.2.18 Two-colours switching device using dielectric elastomer actuation

Hediyeh Zahabi (1), Martyn Bennett (2), James Busfield (1), Federico Carpi (1)

(1) Queen Mary University Of London, School Of Engineering And Materials Science, London, UK
(2) ARTIS, UK

Soft, thin, lightweight and cost effective electrically tuneable systems able to create colour changes are needed for biomimetic systems, architectural aesthetic design and visual display systems in general, and new technologies are being sought in order to address this need. Dielectric elastomer actuators offer high strains, high energy output, silent operation, are lightweight and low cost. Thus, they might represent a suitable technology to satisfy such a need. Here, we present the use of dielectric elastomer actuators to create a simple device switching between two colours. The proposed concept relies on the use of a planar dielectric elastomer actuator coated with an array of colour spots and masked by a frame with an array of holes. The holes are aligned with the colour spots, such that when voltage is switched from off to on the colour spots move, becoming visible or hidden through the holes of the mask. Thus, the device behaves as a positioner of colour spots, so as to make them visible or not. The resulting effect is that the whole device switches its overall colour. This work shows ongoing activities to characterise the electromechanical behaviour of the device in terms of displacement of the colour spots as a function of the applied voltage.

1.2.19 In-situ impedance characterization of filled rubber at small strain

Menglong HUANG (1), Hediyeh Zahabi (1), James Busfield (1)

(1) Queen Mary University Of London, School Of Engineering And Materials Science, London, UK

Nano composites have been used for many years in industry. Although it is known that nano fillers can enhance the mechanical, electrical and thermal properties of the products, the nature of the filler networks inside the composites

is still unknown. Here impedance spectroscopy (IS) is applied to investigate changes of filler structure in elastomer composite materials under strain when filled by silica or carbon black. A Dynamic Mechanical Analyser (DMA) is used to provide mechanical deformation whilst the dielectric behaviour is being monitored in situ. Dramatic changes of permittivity are observed with strain with the exact nature of the changes being dependent upon the nature of fillers' structure. We show that the electrical signal is only sensitive to the filler-filler interaction which allows it to be a very useful tool to characterise filler network structures.

Session 1.3

(abstracts are listed in the order of presentation)

1.3.1 Favorable electrical breakdown strengths of prestretched elastomers with and without sample volume conservation

Shamsul Zakaria (1), Peter H. F. Morshuis (2), Benslimane Mohamed Yahia (3), Liyun Yu (1), Anne Ladegaard Skov (1),

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(2) Faculty Of Electrical Engineering, Mathematics And Computer Science, Technology University Of Delft, The Netherland
(3) Danfoss Polypower A/S, Nordborg, Denmark

The breakdown strength determines the performance of a dielectric elastomer for its use in actuators and generators. A thorough understanding of the mechanism behind the electrical breakdown of a dielectric elastomer can help develop the improved devices. Two experimental configurations for the measurement of the stretch dependence of the breakdown strength on the polydimethylsiloxane (PDMS) dielectric elastomers have been successfully applied in this study. Further, the breakdown strengths for samples with and without volume conservation were thoroughly evaluated. The applied electric field at breakdown, EB, is found to depend on the stretch ratio and the deformed thickness. Experimental data also fit with the hypothesis where the breakdown strengths for samples with volume conservation underperformed the samples without volume conservation at all stretch ratios. Therefore the results suggest that the sample volume in breakdown measurements strongly influences the breakdown strength of prestretched elastomers.

1.3.2 Actuating electroactive scaffolds for cardiac tissue regeneration

Amy Gelmi (1), Monika K Ljunggren (1), Mehrdad Rafat (1), Edwin Jager (1),

(1) Linkoping University, Department Of Physics, Chemistry And Biology, Biosensors And Bioelectronics Centre, Linköping, Sweden

We are developing novel implantable electroactive nanofiber scaffolds for cardiac tissue engineering, as stem cell therapy can in theory aid regeneration of damaged cardiac tissue that results from a myocardiac infarction. Our electroactive nanofiber scaffold will mimic the extracellular matrix, provide a controllable stem cell niche microenvironment, to increase the differentiation ratio of stem cells into cardiomyocytes and thus regenerate new tissue. Electrospun nanofibrous scaffolds of PLGA with controllable fiber dimensions and alignment have been fabricated and thereafter coated with the conducting polymer polypyrrole. The electrical properties of polypyrrole are an integral factor in creating these intelligent 3-D materials; not only does the inherent conductivity provide a platform for electrical stimulation, but the ionic actuation of the polymer will also provide mechanical stimulation to the seeded stem cells. Electrical and mechanical stimulation have been shown to be important external stimuli to stem cell differentiation. The biocompatibility of coated and non-coated PLGA scaffolds has been investigated using primary cardiovascular progenitor cells, and excellent biocompatibility was achieved. The mechanical actuation of the scaffolds has been observed as well, with cyclical stimulation applied to the material. We will present the biocompatibility results as well as the electrochemical and electromechanical characterization of the electroactive scaffolds.

1.3.3 Novel Electroactive Polymer for Micro-motor Development

Miklos Zrinyi (1), Rita Bauer (1), Loránd Kelemen (2), Masami Nakano (3),

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(2) Biological Research Centre, Hungarian Academy Of Sciences, Szeged, HUNGARY.
(3) Intelligent Fluid Control Systems Laboratory, Institute Of Fluid Science, Tohoku University, Sendai, JAPAN

Epoxy based polymer has been developed for novel electric micro-motor construction. Polymer disks and hollow cylinders were prepared in few micrometer dimensions as rotors. Electrorotation of these micro tools was studied under uniform DC electric field. The effect of shape, size and thickness were investigated. Here, we present the first experimental observation, that novel epoxy based micro devices show intensive spinning in uniform DC electric field. The rotational speed of micron-sized polymer rotors can be conveniently tuned in wide range (between 300 - 2000 rpm) by the electric field

intensity

1.3.4 Actuator studies of conducting polymers deposited on non-metalic coatings

Rudolf Kiefer (1), Jose G. Martinez (2), Toribio F. Otero (2), Friedrich Kassik (1), Alvo Aabloo (1),

(1) University Of Tartu, Institute Of Technology, Tartu, Estonia
(2) Universidad Politnica De Cartagena (UPCT), Electrochemistry Intelligent Materials And Devices,Cartagena, Spain,

The construction of conducting polymer actuators requires a conductive surface on a film to obtain, by electrochemical polymerization, a uniform conducting polymer film. Bending actuators, as trilayer, are usually supported by a non-conductive and flexible non-conductive membrane (such as PVdF) with arrangement on both sides of conductive coatings required to support the electropolymerization of the conducting polymer layer. Our aim was to investigate the actuation properties of conducting polymers (polypyrrole doped with dodecylbenzoesulfate) deposited electrochemically on CDC-PVdF-CDC and PPy(chem.)-PVdF-PPy(chem.) to obtain PPyDBS-trilayer devices. Subsequent studies of the PPyDBS-trilayers in different solvents (aqueous, acetonitrile, propylene carbonate and ethyleneoxide) but in same electrolyte (0.5 M LiClO4) been made under steady state condition (charging/discharging in balance) to evaluate solvent and electrolyte exchange effects. The full charged cycle under cyclic voltammetric method shows that in aqueous and ethyleneglycole solvent cation mobile (Li+) bending actuation of PPyDBS-CDC-PVdF-trilayer takes place. Changing to organic solvent the trilayer bends in opposite direction that relays on anion mobility (ClO4-) during reversible redox reaction with also much higher bending angle 60 degree in comparison to aqueous solution (20 degree).

1.3.5 Design and preparation of new dielectric elastomers for micro-actuators

Ming Tian (1) (2), Nanying Ning (1) (2), Qin Ma (2), Dan Yang (2), Yonglai Lu (1) (2), Xiuying Zhao (1) (2), Hua Zou (1) (2), Yiqing Wang (1) (2), Liqun Zhang (1) (2),

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(2) Beijing University Of Chemical Technology, College Of Materials Science And Engineering, Center Of Advanced Elastomer Materials, Beijing, P.R. China

Dielectric elastomers (DEs) can convert electric energy to mechanical energy without gearing and work efficiently over a broad frequency range. Owing to its low modulus, large strain, fast response, lightweight, reliability, and high energy density, DEs find many applications in industry such as artificial muscles, sensors, and micro-robotics. A key for the preparation of DE with high actuated strain at a low electric field is to design and develop elastomers with high dielectric constant and low modulus. In this work, some new methods are used for the design and preparation of high performance DEs. The first one is the preparation of DE with large actuated strain at a low electric field by the ionic conductivity of polyethylene glycol (PEG) and the disruption of hydrogen bonds in thermoplastic polyurethane (TPU) chains. The second one is the preparation of an interlock structured all-organic dielectric elastomer with large actuation strain under ultralow-voltage and high mechanical strength. The third one is the design and preparation of the slide-ring DE materials with high dielectric constant, low elastic modulus and high actuated strain at a safe electric field. The mechanisms of these new methods, the dielectric properties of the as-prepared DE materials, and the structure-property relationship are carefully investigated.

1.3.6 Paper-Based Electroosmotic Device

Deepa Sritharan (1), Matthew Bleakney (2), Elisabeth Smela (1),

(1) University Of Maryland at College Park, USA
(2) Atholton High School, Columbia Maryland, USA

We present an electroosmotic pump fabricated from silicone and paper. There are significant advantages to employing paper to form the pumping microchannels: it results in the rapid and straightforward creation of a 3-dimensional network of small-diameter channels, which is desirable because pumping velocity increases with cross-sectional area and pumping force is inversely proportional to channel diameter. The pump has two expandable/contractable reservoirs connected through the pores in the paper. The reservoirs and microchannels are filled with propylene carbonate, the pumping liquid. When an electric field is applied across the fluid-filled paper,

the liquid is pumped from one reservoir to the other. The field is applied using flexible carbon electrodes integrated into the silicone device using a squeegee technique. These electroosmotic pumps could in principle be integrated with other paper-based microfluidic technology, and also hold potential for the development of fluidic displays and soft robotics.

1.3.7 Preparation of high performance graphene based dielectric elastomers by using some new methods

Nanying Ning (1) (2), Qin Ma (2), Yonglai Lu (1) (2), Xiuying Zhao (1) (2), Liqun Zhang (1) (2), Ming Tian (1) (2),

(1) Beijing University Of Chemical Technology, State Key Lab Of Organic-Inorganic Composites, Beijing, P.R. China
(2) Beijing University Of Chemical Technology, College Of Materials Science And Engineering, Center Of Advanced Elastomer Materials, Beijing, P.R. China

Owing to its reliability, low modulus, fast response, lightweight, large strain, and high energy density, dielectric elastomers (DEs) find many applications in industry. In this work, some new methods are used for the design and preparation of high performance DEs. The first one is the preparation of thermoplastic polyurethane (TPU) DE with high dielectric constant and low dielectric loss by using the combined technique of disrupting hydrogen bonding between TPU chains and in-situ thermal reduction of graphene oxide nanosheets (GONS). The second one is the preparation of carboxylated nitrile rubber (XNBR) DE with extremely high dielectric constant at quite a low percolation threshold. The third one is the preparation of XNBR dielectric composite with large actuated strain at a low electric filed by the latex compounding of XNBR and GONS-encapsulated carbon nanosphere (GO@CNS) hybrids. The mechanisms of these new methods, the dielectric properties of the as-prepared DE materials, and the structure-property relationship are carefully studied.

1.3.8 Design of ultrafast conducting polymer microactuators

Cedric Plesse (1), Ali Maziz (1) (2), Caroline Soyer (2), Eric Cattan (2), Frederic Vidal (1),

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Valenciennes Cedex 9, France

This presentation will reports results on ionic EAP micromuscles converting electrical into micromechanical response in open-air. Translation of small ion motion into large deformation in bending microactuator and its amplification by fundamental resonant frequency are used as tools to demonstrate that small ion vibrations can still occur at frequency as high as 1000 Hz in electrochemical devices. These results have been achieved through the microfabrication of ultrathin conducting polymer microactuators. First the synthesis of robust interpenetrating polymer networks (IPNs) has been combined with a spincoating technique in order to tune and drastically reduce the thickness of conducting IPN microactuators using a so-called "trilayer" configuration. Patterning of electroactive materials as thin as 6 µm is demonstrated with existing technologies, such as standard photolithography and dry etching. Electrochemomechanical characterizations of the micrometer sized beams are presented and compared to existing model. Moreover, thanks to downscaling large displacements under low voltage stimulation (+/- 4V) are reported at a frequency as high as 930 Hz corresponding to the fundamental eigenfrequency of the microbeam. Finally conducting IPN microactuators are then presenting unprecedented combination of softness, low driving voltage, large displacement and fast response speed which are the keys for further development to develop new MEMS.

1.3.9 A multi-scale analysis of the electro-mechanical response of polymer networks with long-chain molecules

Noy Cohen (1), Gal deBotton (1),

(1) Ben-Gurion University

The coupled electro-mechanical response of polymer networks with long-chain molecules is analyzed in terms of the local response and distribution of the dipolar monomers. A comparison between two variational statements for a continuous and a discrete systems leads to an estimate for the coupled electro-mechanical energy-density function of the polymer. Next, two types of dipolar monomers are considered, and the resulting variations in the macroscopic response of polymers with randomly distributed long chains are determined. Lastly, the polarization for the simple case of uniaxial stretch in the direction of the electric field is solved, and analytical predications for the susceptibility of the polymer are compared with recent experimental data.

1.3.10 High level implications of commercializing EAP technology

Rahimullah Sarban (1),

(1) LEAP Technology, Denmark

Relative to the academic efforts of improving the performance of Electroactive Polymer (EAP) technology, very little dissemination has been made related to the commercial performance of the technology. This poster lays out the high level implications of commercialisation based on observed needs within the supply chain, and theory relating to new technology introduction to the marketplace. We have identified that although EAP material can now be readily purchased and that there is clear and justifiable interest from industry. Despite this, creating components and products derived from EAP is seldom seen due to the significant efforts required to develop products. Many obstacles are largely regulatory, but satisfying them needs specialist knowledge and experience with respect to the technology. Other technology specific barriers are related to product design where, for example, handling of high voltages or interfacing soft and stiff materials are needed. Possible ways of bridging this gap in the value chain and advancing EAP materials into real commercial products are described.

1.3.11 Dielectric elastomer actuators using Slide-Ring Material with increased permittivity

Shigeki Tsuchitani (1), Tokiharu Sunahara (2), Hirofumi Miki (1), Kunitomo Kikuchi (1),

(1) Wakayama University, Faculty Of Systems Engineering, Wakayama, Japan
(2) Wakayama University, Graduate School Of Systems Engineering, Wakayama, Japan

In dielectric elastomer actuators (DEAs), inclusion of high dielectric constant nanoparticles in elastomeric materials is one of promising methods to achieve large strain and to generate large work density at relatively low applied voltages. However, the addition of the nanoparticle tends to increase the stiffness of the elastomer and disturbs the actuation of the DEA. This is attributed to the restriction of the chain motion in the elestomer by nanoparticles which act as physical cross-linking sites. Slide-Ring Material (SRM) is a cross-linked polymeric material with freely movable cross-linking sites. For this special

structure, internal stress are dramatically homogenized by the pulley effect. So, the restriction of the chain motion due to the existence of the nanoparticles is expected to be remarkably reduced. We used SRM (Advanced Softmaterials Inc.) as a host elastomer of DEA and added barium titanate (BaTiO3) nanoparticles as a ferroelectric filler. The effects of the addition of BaTiO3 on permittivity, stiffness and actuation strain of the DEAs using SRM were evaluated. Permittivity of the SRM composite increased linearly with wt. concentration of BaTiO3 and reached 3.7 times of that of pure SRM at 50wt.%. Elastic modulus was almost constant up to a concentration of 20wt.% and decreased above this concentration. The actuation strain of the DEA using the SRM including 50wt.% BaTiO3 was four times larger than that of the DEA using pure SRM.

1.3.12 Tailoring SBS-based materials for sensor, actuator and biomedical applications

Pedro Costa (1), Armando Ferreira (1), Vitor Senscadas (1), Sylvie Ribeiro (1), Clarisse Ribeiro (1), Vitor Correia (1) (2), Gabriela Botelho (3), Júlio Viana (4), Senentxu Lanceros-Mendez (1),

(1) Centro/Departamento De Física Da Universidade Do Minho, Campus De Gualtar, Braga, Portugal
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(4) Institute For Polymers And Composites IPC/I3N, University Of Minho, Guimarães, Portugal

Thermoplastic elastomers (TPE) are important material for device applications due to their large deformation with low mechanical hysteresis. These materials exhibit excellent mechanical properties but are electrical insulator. Carbon nanotubes (CNT) are thus used to provide electrical properties to TPE. The electrical percolation threshold depends on the matrix, reinforcement materials, processing method. Copolymer styrene-butadiene-styrene (SBS) have similar properties than rubber without need vulcanization step. Butadiene/styrene ratio and architecture influences the material morphology, mechanical, electrical and thermal properties. SBS do not find wide use in biomedical applications due to biostability problems, but poly(styrene-(ethylene-co-butylene)-b-styrene) (SEBS) shows oxidative stability, allowing biomedical applications. CNT/SBS-

based composites have been processed with maximum strain larger than 1000% for CNT contents up to 8 wt%. Have been processed both with lab-scale to up-scalable processes including extrusion and electrospinning. These materials have been used to development of large deformation sensors with proper piezoresistive response at low (1%) and large (50%) deformation. Gauge Factor (GF) increase with CNT content close to the percolation threshold and under application of pre-stress. For extruded wire composites (8wt% CNT) the GF~30 for 20% of strain. Some applications, including sensor and tissue engineering application, will be presented.

1.3.13 A new dielectric elastomer of high deformation fabricated by silicone rubber and dopamine coated barium titanate

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(1) Centre For Elastomer Research, Focas Institute, Dublin Institute Of Technology, Dublin, Ireland
(2) Dublin Institute Of Technology, Applied Electrochemistry Group, Dublin, Ireland
(3) Dublin Institute Of Technology, Department Of Mechanical Engineering, Dublin, Ireland

A Dielectric Elastomer (DE) was fabricated by embedding barium titanate particles coated with dopamine in a silicon rubber (SR) matrix. Coated particles were used in an attempt to enhance the electrostriction properties of the material. Electromechanical test results showed that the maximum area strain was approximately 56% for the DE filled with 20 wt% uncoated barium titanate under a high electric field (up to 44 volts per micrometer), corresponding to an electromechanical coupling efficiency of approximately 60%. However, an SR composite containing 20 wt% dopamine coated barium titanate achieved a maximum area strain of 78% when an electric field strength of 35 volts per micrometer was applied. This composite can theoretically convert 68% mechanical work to electrical energy. Thus a DE fabricated from an SR with dopamine coated barium titanate achieved a higher electromechanical efficiency than the material with uncoated particles, for the application of a lower electric field strength. Ultimately, such DE materials may act as electrical energy generators.

1.3.14 Ultra-actuation of acrylic-based artificial muscles

Yu Feng Goh (1) (2), Yee Siang Poon (3), Samin Akbari (4), Herbert Shea (4), Soo Jin Adrian Koh (1) (2) (5),

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(2) National University Of Singapore, Engineering Science Programme, Singapore
(3) National University Of Singapore, Department Of Civil & Environmental Engineering, Singapore
(4) École Polytechnique Fédérale de Lausanne EPFL, Microsystems For Space Technologies Laboratory, Neuchatel, Switzerland
(5) Institute Of High Performance Computing, Singapore

Electromechanical actuation of dielectric elastomer actuators (DEA) is limited by electromechanical instability (EMI). Previous works have demonstrated giant linear actuation of 323% linear actuation strain, by harnessing such instabilities. We found that, by applying an appropriate level of prestretch, and then laterally clamp a DEA, we suppress EMI, enhance the breakdown limit of a DEA, and thereby, achieve a beyond-giant actuation, we term ultra-actuation. This is achieved without a need to harness electromechanical instability. We show experimentally, that a maximum possible linear actuation strain of 500% is achievable. Such a level of electrical actuation approaches the mechanical strain capacity, which was previously thought to be unachievable. The performance and durability of the DEA was tested under cyclic loading conditions with different speeds of voltage ramping. At a fast speed of 1000 V/s, the DEA survives more than 400 cycles with maximum 50% cyclic strain. At a slow rate of 50 V/s, it survives 21 cycles, with a maximum of 140% actuation strain. At a moderate rate of 250V/s, the DEA survives 222 cycles, with 100% maximum actuation strain. A combination of mechanical and electrical aging affects the cyclic durability of the DEA. The setup is then manifested in a practical design of a rolled actuator, and 200% actuation strain was demonstrated.

1.3.15 Effects of repeated plating process on electro-mechanical response of a perfluorocarboxylic ionic polymer actuator containing ionic liquids

Kunitomo Kikuchi (1), Changhon Kim (2), Daichi Morioka (2), Hirofumi Miki (1), Shigeki Tsuchitani (1),

(1) Wakayama University, Faculty Of Systems Engineering, Wakayama, Japan
(2) Wakayama University, Graduate School Of Systems Engineering, Wakayama, Japan

Ionic polymer-metal composite (IPMC) is one of the most attractive soft actuators because it exhibits large strain under low applied voltages. IPMC consists of a polyelectrolyte membrane and thin noble metal electrodes formed on the both surface of the membrane. Driving characteristics of IPMC are affected by physical and chemical factors such as type of polyelectrolyte, form of electrode and type of counter ion. Generally, reliable IPMCs have dendrite electrodes formed by using a repeated plating process and it is known that electrodes influence the joint strength, electrical double layer capacitance and stiffness of IPMC. In order to develop a high performance IPMC with a large strain, we measured the step responses of perfluorocarboxylic IPMCs containing ionic liquids and characterized the effects of repeated plating process for fabricating them. The impedances of IPMCs were evaluated using A.C. impedance method and equivalent circuits of IPMCs were extrapolated. As a result, IPMC which have lower charge transfer resistance tended to exhibit a larger initial response of curvature. In this poster, our latest results on the effects of repeated plating process to the properties of IPMC such as the displacement behavior, stiffness and electric characteristics will be reported. The relationship between the charge transfer resistance and initial response of curvature of IPMC will be discussed.

1.3.16 Phase-transition actuators for robotic elements

Paul Hofer (1), Ludwig Birklbauer (1), Jürgen Kratochwil (1), Roland Altmüller (1), Ingrid Graz (1),

(1) Soft Matter Physics, Johannes Kepler University, Linz, Austria

Phase transition actuators present a low-voltage alternative to dielectric elastomer actuators. Instead of utilizing the Maxwell stress, the large volume changes due to liquid-gaseous phase transitions are employed. The phase transition in the liquid is induced by Joule heating. Low voltage operation is guaranteed, since the deformation relies on the heating of a liquid, albeit with larger power consumption in comparison to DEA's. Here we apply this principle to build a simple gripper. Further we investigate monitoring the motion of the actuator by means of stretchable electrodes. Thin gold films on elastomeric

substrates act as strain sensors. By allowing the sensor to move along with the soft robotic elements the bending motion of the individual arms of the gripper can be tracked

1.3.17 Charge transport in silicone elastomer films with network electrodes from single-walled carbon nanotubes - investigated by means of dielectric resonance spectroscopy

Dmitry Rychkov (1), Media Ghasem Zadeh Khorasani (1), Werner Wirges (1), Reimund Gerhard (1),

(1) Applied Condensed-Matter Physics, Department Of Physics And Astronomy, Faculty Of Science, University Of Potsdam, Germany

Single-walled carbon nanotubes (SW-CNTs) sprayed onto the surfaces of elastomer films are widely used as electrodes for dielectric elastomer actuators (DEAs). SW-CNTs fulfill the most stringent requirements for compliant DEA electrodes, as they are stretchable, conductive over a wide range of deformation, robust and even self-healing. One problem, though, has been identified only recently - charge injection. It has been found that SW-CNT electrodes facilitate charge injection into the elastomer which may lead to the accumulation of charges, to early aging, to electrical breakdown and to other processes that compromise the operation and the efficiency of the actuator. Here, we investigate the influence of SW-CNT electrodes on the charge-transport processes in silicone-elastomer films and compare them to metal electrodes. Silicone films were prepared via drop-casting from hexane solution, and the electrodes were subsequently deposited either using vacuum evaporation (silver electrodes) or spraying with an airbrush (nanotubes). Charge-transport processes were investigated by means of dielectric resonance spectroscopy. The dielectric spectra were obtained using low- and high-voltage dielectric analyzers from Novocontrol. Experimental results indicate that there is a considerable difference between the two types of electrodes. For example, samples with SW-CNT electrodes exhibit much higher conductivities, which may be due to higher charge-carrier concentrations.

1.3.18 Inkjet printed carbon aerogel-PEDOT:PSS actuators

Inga Põldsalu (1), Anna-Liisa Peikolainen (1), Friedrich Kaasik (1), Veiko Vunder (1), Francesco Greco (2), Alvo Aabloo (1)

(1) University Of Tartu, Institute Of Technology, Tartu, Estonia
(2) Italian Institute Of Technology, Centre For Micro-BioRobotics IIT@SSSA, Pontedera, Italy

Polymer-based actuators are inherently lightweight and compliant, and offer an appealing alternative to more conventional actuators in areas like microelectromechanical systems (MEMS), microrobotics and personal medicine and diagnostics like for Lab-on-Chip (LOC) devices, etc. Ionic electroactive polymer composites (iEAP) in the form of bimorph microactuators enable a new broad range of applications for these low voltage operating devices. In the current work activated carbon aerogel (ACA)-conducting polymer composite microactuators were fabricated by inkjet printing method. Microprinting allows direct assembly by dispensing the electrode suspension directly onto the membrane. The size of the nozzle of the inkjet dispensing device is ideal for producing miniature patterns of electrodes. The electrodes of ACA-PEDOT:PSS were printed directly onto 100um thick PVDF membrane. It was expected that combining carbon aerogel characterized by high specific surface area (760 m2/g) with conducting polymer would increase strain and capacitance while improving the actuation speed due to conducting polymer enhancing electronic conductivity throughout the electrode layer. The fabrication of the electrodes will be described and the obtained PEDOT:PSS and ACA-PEDOT:PSS based actuators are compared and characterized using optical and scanning electron microscopy. Laser displacement and impedance measurements were carried out to evaluate electromechanical properties.

Wednesday, 11 June 2014

General programme of the day

EAPlenary	Session 2.1 part I *Chair:* **Frédéric Vidal** (University of Cergy-Pontoise, Cergy, France)	
	9:00- 9:30	Invited talk **Qiming Zhang** Pennsylvania State University, USA
EAPodium	9:30- 9:50	Invited talk **Seon Jeong Kim** Hanyang University, Korea
Break	9:50- 10:20	Coffee break
EAPromises	Session 2.1 part II *Chair:* **Federico Carpi** (Queen Mary University of London, UK	
	10:20- 10:40	Invited talk **Samuel Rosset** EPFL, Switzerland
	10:40- 11:00	Invited talk **Xuanhe Zhao** Duke University, USA
EAPills	Session 2.2 part I *Chair:* **Alvo Aabloo** (University of Tartu, Estonia)	
	11:00- 12:10	**Pill oral presentations** 18 presentations (3 minutes each + 1 minute to change speaker)
Lunch	12:10- 13:30	Lunch
EAPosters **EAPrototypes** **EAProducts**	Session 2.2 part II	
	13:30- 15:00	**Posters & exhibitions** 18 posters

EAPills	Session 2.3 part I *Chair:* **Helmut Schlaak** (TU Darmstadt,Germany)	
	15:00- 16:10	**Pill oral presentations** 18 presentations (3 minutes each + 1 minute to change speaker)
Break	16:10- 16:30	Coffee break
EAPosters	Session 2.3 part II	
EAPrototypes **EAProducts**	16:30- 18:00	**Posters & exhibitions** 18 posters
Closing	18:00- 18:15	Closing ceremony & final remarks **Edwin Jager** Linköping University, Sweden

Session 2.1

(abstracts are listed in the order of presentation)

2.1.1 Electroactive Polymers as Self-Assembled Nanocomposites with High Electromechanical Responses

Qiming Zhang (1),

(1) The Penn State University, USA

We show that exploiting the molecular and nano-structure engineering can lead to electroactive polymers (EAPs) with large electromechanical responses. For the field active EAPs, defects modifications convert the macroscopic ferroelectric domains into nano-polar regions, inducing relaxor ferroelectric behavior with high dielectric response. The field induced nano-polar-non-polar transformation leads to giant electrostriction with high elastic energy density. This talk will review briefly the molecular mechanism responsible for the large electrostrictive response and the advanced device applications. Direction to further enhance the electromechanical responses will be presented. In contrast to the field actuated EAPs, the ionic EAPs such as ionic polymer metal composites whose actuation mechanism is based on the excess ion accumulation/depletion at the electrodes, suffer low actuation speed and efficiency. The very low operation voltage, often below 5 volts, of i-EAPs is very attractive. In the past several years, we have been investigating approaches to significantly enhance the electromechanical response of i-EAPs. For example, we developed a class of graphene based-composites that exhibit a high strain response (high than 50 percent strain) with an exceptionally high elastic energy density larger than 1.5 J/cm3 with a high efficiency. These results point out the potential of EAPs in achieving high performance by exploiting nano-structure engineering.

2.1.2 Biofuel cell energy for artificial muscle

Seon Jeong Kim (1),

(1) Hanyang University, Seoul, Korea

Some energies such as electric, photonic and thermal powered sources are needed to operate artificial muscles. Enzymatic biofuel cells that generate electricity from glucose in blood are promising for powering artificial muscles or biomedical devices such as cardiac pacemakers, nerve-stimulators, and drug-delivering pumps. Immobilizing interconnected enzyme and redox mediator in a highly conducting, porous electrode maximizes their interaction with the electrolyte and minimizes diffusion distances for fuel and oxidant, thereby enhancing power density. Here, Enzymatic biofuel cells is fabricated that deploy strong biscrolled carbon nanotube yarn electrodes. Twist-based yarn spinning traps redox mediators and enzymes within scrolled yarn corridors. When used for glucose energy harvesting, these separator-free biofuel cells provide power density. The biscrolled yarn biofuel cells were woven into textiles having the mechanical robustness needed for implantation for glucose energy harvesting.

2.1.3 Small, fast and tough: an overview of our silicone-based actuators

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At the Microsystems for Space Technologies Laboratory, EPFL, we design and manufacture miniaturised silicone-based dielectric elastomer actuators (DEAs). We love silicone, because even though the achievable strain is generally smaller than what you can get with acrylic elastomers, they lead to fast devices, which are reliable and have a long lifetime. Because silicones can be bought in their uncrosslinked state and are available in a broad range of Shore hardness, they offer unlimited design flexibility, as they can be casted to any desired thickness. Over the years, we have developed a mature DEA fabrication process, including silicone membrane casting on high quality PET foil coated with a sacrificial layer, followed by the release of the membrane in a water bath and its prestretching, as well as electrode application. For small-size devices (electrodes typically smaller than 10mm), it is important to be able to precisely pattern the electrodes on the dielectric membrane. Two methods will be discussed: 1) Gold ion implantation for high-conductivity compliant electrodes that can be patterned down to 100 um with a shadow mask, or down to 1 um with a lift-off process, and 2) Stamped conductive rubber, for electrodes that can be very rapidly and precisely applied on an elastomeric membrane. Finally different applications using this fabrication technology will be presented, such as a rotary motor, a rolling robot, an energy-harvesting device, and tuneable lenses.

2.1.4 Beyond Artificial Muscle: New Working Modes and Functions of Dielectric Elastomers

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Subject to a voltage, a layer of a dielectric elastomer reduces in thickness and expands in area, giving actuation stress and strain similar to those of human muscles. Over the last decade, dielectric elastomers have been intensively investigated as candidates for artificial muscles. In this talk, we will present novel non-conventional applications of dielectric elastomers as transformative skin and microlens. The working mechanism for the new applications is based on new modes of voltage-induced deformation and instability in dielectric elastomers recently discovered in our group. Subject to an electric voltage, a substrate-bonded polymer film initially maintains flat and smooth. Once the voltage reaches a critical value, regions of the polymer surface locally fold against themselves, giving a variety of patterns including creases, craters and lines. The dynamic interactions of the patterns with environment can lead to novel applications as transformative skins for antifouling, transfer printing and camouflage. In addition, electric voltages can deform micro-droplets encapsulated in dielectric elastomers into ellipsoidal and tube shapes, giving the electrocavitation instability. The deformation and instability can be used to tune the micro-droplets as microlenses for various applications. Inspirations from biological systems are particularly helpful in designing the transformative skin and microlens, and will be shared with the audience.

Session 2.2

(abstracts are listed in the order of presentation)

2.2.1 Actuators based on carbon nanotubes and elastomeric matrix

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Enormous efforts of researcher are focused on the exploitation of carbon nanotubes (CNT) in many applications as nanocomposites, sensors and actuators, field emission displays, nanoelectronics, etc. Tactile actuators based on polymer/CNTs composites are promising materials for the development of new types of visual-aid tablet for visually impaired people. However, when CNT are used as the nanofiller in polymeric matrices, problems appear with dispersion and agglomeration of CNT and compatibility with the polymeric matrix during the processing. One way to solve these problems is the surface modification of CNT which can be covalent or non-covalent. In this work the surface of multiwall carbon nanotubes (MWCNT) was modified by non-covalent approach. The surface chemical composition and extent of modification of MWCNT were studied by XPS. SEM and TEM as complementary techniques were employed. When composites in the form of strips are uniaxial pre-stretched more than 20 % of their original length, composites showed contraction when illuminated by LED. EVA nanocomposite containing 0.1 wt.% modified MWCNT showed the best results, exhibiting stresses between 33 to 165 kPa as a function of the light intensity and irradiation time. Very good repeatability of photo-actuation process up to 100 cycles was observed. High optical-to-mechanical energy conversion factor of 55 MPa W?1 for EVA nanocomposite containing 0.1 wt.% MWCNT during illumination by red light-emitted diode was found.

2.2.2 Modelling of soft generator combining electret and dielectric elastomer

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Dielectric elastomer generators (DEGs) are a promising technology for soft applications involving fluid or human interactions thanks to their high energy density and ability to couple directly on mechanical ambient sources. Light, compliant, silent energy scavengers, they can easily be incorporated into clothing where they could scavenge energy from the human kinetic movements for biomedical applications. Nevertheless, scavengers based on dielectric elastomers are soft electrostatic generators requiring a high voltage source to polarize them and high external strain, which constitutes the two major disadvantages of these transducers. We have proposed to use electret to replace the high external voltage source necessary to this electrostatic generator. These soft hybrid generators require thus a reliable non-linear multi-physic models to estimate their performances and to design new innovative structure. The model presented here is related to hybrid generator working on electret mode. It is based on numerical simulations computing the variation of the capacitance of the device during a cycle. Thanks to the knowledge of this variation, output characteristics of the device such as voltage and power can be calculated by solving analytic coupled laws.

2.2.3 Increasing the permittivity of silicone films with high stiffness through dipole-grafting

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Dielectric elastomer actuators (DEAs) enable a wide range of interesting applications since they are soft, lightweight, low-cost and have direct voltage control. However, one of the main obstacles to their wide-spread implementation is their high operating voltage, which tends to be several thousand volts. The operating voltage can be lowered by reducing the thickness, increasing the permittivity or lowering the stiffness of the elastomer. Recently, we offered a method to increase the permittivity of silicones simultaneously with stiffness reduction by dipole-grafting. For some applications it might be beneficial to work with higher stiffness, the usage of high-DC inorganic filler particles can already accomplish this. Therefore we developed a concept to increase the permittivity at a high elastic modulus, through the usage of dipole-grafting. The organic dipole molecule N-allyl-N-methyl-4-nitroaniline was used

and silicone films with different dipole concentrations were produced. Also, a molecule with a high similarity to N-allyl-N-methyl-4-nitroaniline but lower dipole moment was synthesized and incorporated. This allows the production of films with the same molecular ratio, but with a lower permittivity. So it is possible to investigate the permittivity effect at constant stiffness. The chemical, mechanical, electrical and electromechanical properties were thoroughly characterized and will be discussed.

2.2.4 Elastomer electret converter for large scale energy harvesting

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Parallel plate capacitors with variable plate distance can be used for the conversion of mechanical into electrical energy. Here we report on experiments with an experimental arrangement consisting of an electret based electrostatic converter with an elastomer membrane suitable for large scale applications. The converter is a capacitive charge pump capable of working at low frequency (< 1 Hz) with a very low mechanical input power and high conversion efficiency. With a charged electret-like elastomer membrane the demonstrator can operate without an initial supply of electric energy. First tests with a simple proof of concept demonstrator resulted in a mechanical input energy of 1.4 mJ (38 μJ/cm²) and a converted electric energy of 124 μJ (3.6 μJ/cm²) per cycle. This gives a total conversion efficiency of 9%. The work provides clear guidelines for reasonable improvements towards low-power converters with much enhanced efficiency.

2.2.5 Development of a lightweight hardware for controlling multiple dielectric elastomer actuators

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We present our current progress in the development of a lightweight hardware for the supply and control of multiple dielectric elastomer actuators (DEAs) with

one central power source. Since this kind of actuator represents an electromechanical system with inertia the concept of pulse width modulation (PWM) is used to drive multiple DEAs independently. The developed lightweight control hardware is structured in three parts, which are control logics, safety precaution part and a high voltage part. The main core of the control logics is a PWM driver that acquires data from an Arduino Nano board, which depicts the communication interface between the actuators and e.g. a CPU or sensors. The variable PWM signal has a constant frequency of 1 kHz. Since the control hardware is designed to supply DEAs with a high voltage up to 4 kV the high voltage circuit and the control logics are galvanically isolated from each other by the safety precaution part. Here the low voltage pulse width modulated signal is transmitted to the high voltage part, specifically to the semiconductor switching devices (MOSFETs of type IXTA-02N450HV) within the high voltage part. A transformer of type EMCO FS-40-15 is used as high voltage power source, which can deliver a constant voltage up to 4 kV to supply multiple DEAs with the control concept based on PWM. Our demonstrator shows the concept of driving more than one DEA individually depending on the input signals from commercial dielectric elastomer sensors.

2.2.6 Effect of the electrolyte concentration on artificial muscles

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The effect of the electrolyte concentration (NaCl aqueous electrolyte) on the dimensional variations of films of polypyrrole doped with dodecylbenzenesulphonate PPy(DBS) on Pt and Au wires was studied. The NaCl concentration of the electrolyte, when studied by cyclic voltammetry or chronoamperometry, has a strong effect on the performance. A maximum expansion was achieved in 0.3 M NaCl aqueous solution. The consumed oxidation and reduction charges control the fully reversible dimensional variations: PPy(DBS) films are faradaic polymeric motors. Parallel to the faradaic exchange of the cations, osmotic, electrophoretic, and structural changes play an important role for the water exchange and volume change of PPy(DBS).

2.2.7 Optimal energy-harvesting cycles for load-driven soft dielectric generators

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(1) University Of Trento, Italy
(2) Ben-Gurion University, Israel

Optimization of a plane, soft dielectric elastomer generator is performed in this work. The configuration is of a thin dielectric film coated by stretchable electrodes at both sides that is first stretched, then charged, released, and finally the charge is harvested at a higher electric potential. The amount of energy extracted by this cycle is bounded by the electric breakdown and the ultimate stretch ratio of the film as well as by structural instabilities due to loss of tension and electromechanical instability. To identify the optimal cycle that complies with these limits we formulate a constraint optimization problem and solve it with a dedicated solver for two typical classes of elastic dielectrics. As anticipated, we find that the performance of the generator depends critically on the ultimate stretch ratio of the film. However, more surprising is our finding of a universal limit on the dielectric strength of the film beyond which the optimal cycle is independent of this parameter. Thus, we reveal that, regardless of how large the dielectric strength of the material is, there is an upper bound on the amount of harvested energy that depends only on the ultimate stretch ratio. We conclude the work with detailed calculations of the optimal cycles for two commercially available soft elastomers.

2.2.8 Actuation behavior of chitosan/PANI nanocomposites

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Since the discovery of high electrical conductivity in polyaniline (PANI), it attracted attention of many researchers worldwide to investigate and utilize high conductivity of PANI in a variety of fields including actuators and artificial

muscles. In this work, PANI has been synthesized using oxidative polymerization of aniline with ammonium persulfate as the initiator in hydrochloric acid media. High aspect ratio nanofibers of PANI with a thickness less than 80 nanometers were achieved, according to SEM and TEM micrographs. Conductivity of dried as-synthesized PANI powders was measured 0.2 siemens per centimeter using four-point probe technique. It is believed that forming an effective percolation network is achievable using a small amount of high aspect ratio PANI nanofibers which lessens adverse effect of conductive polymers in an artificial muscle. Making a conductive film, PANI nanofibers and chitosan were blended and gelatin was added as the plasticizer. The blend was cross-linked, casted in a Teflon mold and dried at different conditions. DMA results of film showed acceptable flexibility and mechanical strength. Actuation results of a bilayer made of fabricated conductive nanocomposite and a non-conductive layer shows the bending movement at low DC voltages and low frequencies.

2.2.9 Preparation of graphene based actuators via electrospinning

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Electroresponsive actuators based on different graphene derivatives and polyaniline (at emeraldine salt state) and poly (vinyl acetate) (PVAc) was prepared via electrospinning. PVAc was used as the hydrophobic binding matrix during the process. Graphene oxide (GO) prepared via an improved method with a high level of layer exfoliation and thermally reduced graphene oxide (RGO) obtained via thermal reduction of GO were used as the electrically conducting additive material. The effect of graphene derivatives, in terms of their type and concentration, on conductivity and actuation performance of the materials was studied. Morphology and surface texture of the electrospun fibers were investigated via both optical microscopy and scanning electron microscopy which showed that the fiber diameters were about a few micrometers. Structural characterization of prepared additive materials was performed by means of X-ray diffraction and raman spectroscopy reporting the desirable formation of materials of interest. 4-point probe method and cyclic voltammetry were performed to measure the electrical conductivity and redox performance of the

prepared materials under applied DC voltage, respectively. It has been observed that high electrical conductivity as well as desirable mechanical properties of graphene derivatives adding up with electroresponsiveness ability of PANI resulted in a synergistic effect in actuation performance of the prepared devices.

2.2.10 Self-standing and ultrathin C-IPN microactuators operating in air

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We report a new process for the fabrication of ultra-thin Conducting Interpenetrating Polymer Network (IPN) microactuators operating in open-air. Compared with previously described methods, this process deals with a novel and tunable «Layer-By-Layer» (LBL) assembly combining LBL spin-coating method and bulk crosslinking of the conducting IPNs. This new approach avoids any manual handling during the microactuator fabrication and allows individual control of each layer thickness. The resulting ultra-thin conducting IPNs present a pseudo trilayer configuration as thin as 2 µm with a host matrix playing the role of ion reservoir sandwiched between two interpenetrated electrodes made of highly conductive Poly(3,4-ethylenedioxythiophene) (PEDOT). The host matrix is based on an IPN architecture combining the rubbery properties of Nitrile Butadiene Rubber (NBR) and the ionic conduction properties of poly(ethylene oxide) (PEO). After the LBL assembly process, these electroactive materials are micro-sized using dry etching process. Then after actuator lift-off and ionic liquid incorporation a micro-beam actuator operating in open air is fabricated. The obtained results open up numerous prospects in the field of integrated micro-actuators requiring collective fabrication, low operating voltages, large displacements and flexible substrates, able to operate in liquid, in air or under low vacuum.

2.2.11 Thermal effects in ionic electroactive polymer actuators

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The high spatial, temporal, and thermal resolution of the thermal imaging system Optotherm EL InfraSight 320 is used for investigation of thermal effects in the ionic electroactive polymer (IEAP) actuators. The resolution of 10-20 pixels in the direction of their thickness is close to the theoretical limit restrained by the infrared light wavelength registered by the imaging system. Experiments with the thermal imaging system show that the IEAPs, applied with the voltages close or exceeding the electrochemical window of the electrolytes used in the IEAPs, overheat to the temperatures of up to 50-80ºC within seconds only. This, in turn, a) affects the mechanical rigidity of the actuators; b) affects the electrochemical properties of the system; c) evaporizes the volatile electrolyte. The long-term goal of this work is creating a 2D or 3D FEM model of an electrically induced IEAP actuator, taking into account the thermally induced mechanical and electrochemical effects.

2.2.12 DEA-based deformable cell culture system

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We present a deformable cell culture system based on dielectric elastomer actuator (DEA). Understanding how the mechanical environment can affect cells functions could lead to significant advances in diseases diagnosis and drug development. Most available technologies offer low screening throughput, an important limitation considering the statistical nature of cellular studies. We previously reported an array of micro-DEAs for cell stretching application. Our DEA-based solution has the potential to replace current technologies and overcome the high screening throughput limitation. In this contribution we will present a new generation of devices, developed to better address cell biologists requirements. Two different devices were developed to apply periodic (1-5Hz) compressive or tensile strain greater than 10% on a 2mm x 2mm biological sample. Their original designs exploit non-equibiaxial prestretch of a silicone membrane and stress induced in passive regions of DEAs. Our technology is now compatible with high resolution optical microscopy for real time monitoring of morphology and chemical activity of the biological sample. This new generation of devices also significantly improves the electric field confinement and provides a fully biocompatible environment. In addition to

design improvements, advances in the fabrication process will be presented as well as their impact on the device strain stability over periodic actuation.

2.2.13 Characterization of carbon-polymer composite actuator in different environments

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Carbon-polymer composite (CPC) micro-actuators were studied in three different environments: in vacuum using a scanning electron microscope, in an oxygen- and humidity-free atmosphere under ambient pressure, and in ambient environment. The constructed CPC actuators are composed of boron carbide-derived carbon as an active electrode material, 1-ethyl-3-methylimidazolium tetrafluoroborate as an electrolyte and polyvinylidene fluoride-co-hexafluoropropylene as an electrode binder and a separator. The results demonstrate that despite some differences in their charge consumption depending on the environment, the CPCs with ionic liquid as the electrolyte are fully operable in high vacuum. Consequently the door towards space and lab-on-chip applications is opened for the CPC actuators. Additionally, scanning electron microscope isa valuable tool for characterizing actuation of CPCs with sub-millimeter dimensions - a typical size range of actuators desirable for medical or lab-on-chip applications.

2.2.14 The electrical and mechanical properties of ionic liquid-mediated carbon nanotubes dispersed in PDMS

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Carbon nanotubes (CNTs) have attracted much attention due to their

mechanical, electrical and thermal properties. These properties can be utilized to make conductive polymers. However, the dispersion of CNTs in polymer matrices can be challenging due to the very large specific surface area, which leads to agglomerations. It has previously been found that adding imidazolium type ionic liquids (ILs) improve the electrical properties of CNT-elastomer composites. Another advantage of using ILs is that CNTs are easier to disperse in the matrix as the ILs exfoliates the CNTs and works as a plasticizer for the elastomer. The aim of this study is to investigate the electricak and mechanical properties of IL-mediated CNTs dispersed in Polydimethylsiloxane (PDMS). Multi-walled carbon nanotubes (MWCNT) and ionic liquid 1-ethyl-3-methyl imidazolium bis (triflouromethanesulfonyl)imide ([EMIM][TFSI]) are dispersed in the Elastosil RT625 PDMS matrix. Different concentrations of CNT and IL are investigated.

2.2.15 Ar plasma induced functionalization for improved membrane - conducting polymer adhesion in artificial muscles

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Poly(3,4-ethylenedioxythiophene) doped with poly(4-styrenesulfonate) (PEDOT/PSS) and polyvinylidene difluoride (PVDF) membranes are commercially available building blocks for cheap and simply-made conducting polymer artificial muscles. Nevertheless, due to hydrophobicity of PVDF, it is difficult to achieve strong adhesion between these two materials, which leads to delamination of components and, consequently, to short cycle-life. Our strategy is to decrease hydrophobicity of PVDF membranes by using argon plasma-induced polymerisation to functionalize PVDF membrane's surface with hydrophilic polyethyle glycol (PEG). We show that even small grafting density significantly decrease hydrophobicity of the membrane that leads to improvement in adhesion strength between PVDF and PEDOT/PSS. We also suggest using spray coating as a deposition technique for a precursor (polyethyle glycol methacrylate (PEGMA)). By spray coating PEGMA is deposited only on the surface of the membrane, therefore bulk of the membrane is kept hydrophobic and occasional short circuits are avoided. Grafting densities as well as the functionalization depth and the penetration depth of PEDOT/PSS can be varied by changing precursor's deposition parameters. Finally, functional

actuators can be made and actuated in air. Further research is needed to characterise the cycle-life of such actuators and to determine the influence of the interfacial layer on the performance of the artificial muscles.

2.2.16 Capacity sensing of dielectric elastomers

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Dielectric Elastomers (DE) are electrically compliant capacitors. In order to use DEs as sensors or to control them as actuators, the feedback of its mechanical and/or electrical state is crucial. A very interesting approach is to measure the electrical capacity of the DE and by using the electro-mechanical coupling relation to monitor the mechanical deformation state therewith. While the theoretical capacity can be calculated very easily, the measurement of the effective capacity is not a simple task. In this contribution it is shown, that the effective capacity differs significantly from the theoretical value in most important cases of practical significant use. That the effective capacity is voltage, frequency and time dependent is shown with the results from measurements done on different sized rolled actuators as well as large stack actuators. Various measurement methods are discussed.

2.2.17 Novel dielectric elastomer compression sensors

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Beside various applications in actuation and energy conversion, dielectric elastomer films can also be used as mechanical sensors for the detection of stretch and associated stress. However, under compression load onto the elastomer film, the measurable change of the capacitance is very limited, due to the extreme aspect ratio of thin films and the volume incompressibility of elastomers. In this paper, novel approaches for dielectric elastomer sensors (DES) with strongly enhanced sensitivity to be used under compression load are

introduced. These DES contain special profiled elastomer surfaces which stretch the elastomer film under compression. Moreover, the electrode layers may be arranged in different positions leading to several distinct sensor designs. The elastomer film and the profiles were made from silicone rubber and the electrode layers contain carbon black particles embedded in silicone. Depending on the special design of the DES, the detectable capacitance change may reach more than 100 %. The sensitivity of the sensor is determined by the sensor design as well as the hardness of the silicone. These compressible sensor mats offer a high potential for a multitude of applications such as seat occupation surveillance or pressure distribution monitoring for medical purposes. Optionally, the sensor mat can also be equipped with electrode patterns, in order to measure the pressure distribution with local resolution.

2.2.18 Fabrication of high adhesion cm-scale compliant electrodes for dielectric elastomer transducers using O2 plasma activation

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We present a novel methodology for the production of PDMS-carbon powder electrodes with high adhesion for dielectric elastomer (DE) transducers. DE transducers have received significant interest in recent years due to their potential as stretchable-flexible actuators, sensors and energy harvesters. As the field matures, the need for mechanically resilient devices able to perform in "real-world" conditions, not just laboratory environments, increases. Our methodology produces electrodes of various thicknesses using a blade casting technique. The electrodes are subsequently laser cut to the desired shape, the electrode and dielectric membrane activated in oxygen plasma and finally placed in contact to achieve bonding. In this way we are able to produce large area (up to several cm in length) compliant electrodes with impressive adhesion qualities. Electrode adhesion is qualitatively evaluated using the "scotch-tape" method. We also produced multi-segment dielectric elastomer minimum energy structure actuators using this fabrication procedure, validating its ability to produce functional DE devices.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 Enhancement of Electro-mechanical Actuation Performance of Silicone Rubber by Filling with Polyaniline Nanorods

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Novel nanocomposites using silicone rubber as matrix and conductive polyaniline nanorods as filler were fabricated and their electro-mechanical actuation performance was carefully investigated. The nanocomposites displayed a typical insulator-to-conductor transition as the content of polyaniline nanorods increased. The percolation threshold was observed to show a relatively low value of 4.51 vol%, which should mainly ascribed to the one-dimensional structure of the nanorods. As the concentration approached to the percolation threshold, the electro-mechanical actuation strain of the elastomer films was significantly enhanced. The actuation coefficient of nanocomposite with 4.0 vol% of polyaniline nanorods was about 5 times higher than that of pure silicone rubbmer matrix.

2.3.2 Processing technology of bio-inspired artificial muscle

Vaclav Bouda (1),

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Mammalian skeletal muscle cell includes two kinds of protein filaments - actin and myosin with globular myosin heads. In the classical model, the stream of calcium ions induces the swing of the heads that drag the two kinds of filaments past one another and the cell contracts. Our new bio-inspired artificial muscle has similar structure, but the stream of ions is replaced by the stream of electrons in conductive polymeric filaments. The heads play the role of

insulators and dividers. The distribution of filaments and heads has been patented in Russian Federation, Kazakhstan, USA, Japan and EU (pending). Only nano-filaments enable effective function of this kind of artificial muscle. So, nanotechnology has to be applied for the production of the usable bio-inspired artificial muscles. 3D print in nano-scale definition is wanted.

2.3.3 Dry deposition sequential process for DEAP multilayer stack-actuators

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Due to the influence of an electrical field, dielectric elastomers perform a relatively high amount of deformation with considerable force generation. Because single layer polymer films are very thin (micrometer range) in order to realize high electric fields with a limited voltage level, novel multilayer actuators are utilized to increase the absolute displacement and force. To fabricate these stack-actuators with reproducible and homogeneous properties an automated manufacturing process is required. In contrast to known wet deposition processes for multilayer actuators, this contribution deals with the development, design and realization of a dry deposition sequential process to fabricate these stack-actuators based on dielectric electroactive polymers (DEAP). In order to obtain a modular and flexible construction, the whole process is divided into several sub-processes, which can be adapted individually in order to produce various actuator geometries. The main idea of the manufacturing process is based on the folding process to facilitate the handling of the very thin DEAP-films. This sub-process, the following stacking and cutting process and the development of the contacting of the actuator as well as the equipment of the manufacturing process are presented in detail. Finally, first DEAP actuator modules fabricated by mentioned process are validated experimentally.

2.3.4 Comparison of uni- and bidirectional power electronics for feeding DEAP transducer

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Transducers based on dielectric eletroactive polymers (DEAP) use the electrostatic pressure to convert electrical energy into mechanical energy or vice versa. Besides an intelligent setup of the transducer depending on the application, high voltage power electronics are indispensable. Due to the capacitive behavior of the DEAP DC/DC converter with current feeding are required. The flyback-converter is a promising converter topology for output powers up to several 100 of Watts, what is sufficient for the most actuator applications. Besides the capability to charge a DEAP transducer, the utilized converter also has to discharge the transducer in order to enable a continuous voltage adjustment. Thus, on the one hand a unidirectional flyback-converter with active discharging circuit can be used. In this case the energy is dissipated during discharging. On the other hand a flyback-converter with bidirectional energy flow is appropriate to feed the energy stored in the DEAP back to the DC-link. Although the bidirectional flyback-converter provides a higher efficiency, the unidirectional one can be realized with lower effort, e.g. concerning the specifications of the utilized components. Therefore, depending on the application different topologies are advantageous. Within this contribution a bidirectional and unidirectional flyback-converter with a novel active discharging circuit are explained and compared to each other theoretically and by measurements.

2.3.5 Self-oscillation reactions of an interpenetrating composite based on polyaniline / prussian blue / manganese oxide driven by H2O2

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Energy (or power) harvesting or (scavenging) is without a very attractive technique for a wide variety of self-powered microsystems.We will develop a novel bio-inspired concept of actuator based stimuli-responsive materials.These soft actuators are today broadly used for several types of smart materials,actuation devices and bioinspired and biomimetic systems,as well as systems to convert mechanical energy into electrical energy for sensing and

energy harvesting.Chemomechanical actuators can generate motion when chemicals cause a change in a material property such as modulus or stress.We will develop active materials which actuation properties are driven by the self-oscillation of pH or potential.Preliminary experiments showed that interpenetrating composite materials based on polyaniline/prussian blue/manganese oxide exhibit self-oscillating reactions in the presence of H2O2 under controlled hydrodynamic regime.The biomimetic approach will be developed by combining an enzymatic generation able to generate in-situ H2O2 and self-oscillating reactions inducing potential regulation.Here,we show that a rotating disk modified electrode,polyaniline/prussian blue/manganese oxide, exhibits potential self-oscillation in the presence of H2O2 in the aqueous solution containing 100 mM KCl.We have investigated the mechanisms of the chaotic behavior,and the parameters that control the amplitude and the frequency of the self-oscillating reactions (concentration,and hydrodynamic regime).

2.3.6 Structured electrode design for DEAP transducer with integrated safety mechanisms

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Using transducers based on dielectric eletroactive polymers (DEAP) in an application, first of all an appropriate transducer topology has to be chosen matching the specifications. To increase the force and absolute displacement of a DEAP actuator or the energy gain of a DEAP generator, multilayer technologies should be used. For instance DEAP stack- or roll-actuators are a common approach to realize either pull- or push-actuators. Besides the general design of the actuator further functionalities like integrated DEAP-based sensors or safety mechanisms can be implemented. For this purpose, the design of a stack-actuator is considered. This actuator consists of several single DEAP actuator films which are mechanically connected in series so that the deformations of every actuator film add up to the absolute deformation of the overall actuator. By electrically connecting these stacked films in parallel the functionality of this particular actuator is ensured. However, due to the connection in parallel a dielectric breakdown in one actuator film yields to a failure of the whole actuator. To avoid this electrical failure integrated safety

mechanisms are presented. In particular this means that the contacting of every single actuator film can be realized in such a way that additionally a safety fuse is integrated that melts in case of a short circuit. For this purpose actuator films with structured electrodes as well as design rules for the safety mechanism are presented.

2.3.7 Effects of electrolyte ionic mobility on the performance of bimorph bucky gel actuators

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Bucky gel is a physical gel made by grinding an imidazolium ionic liquid with carbon nanotubes, which can then be incorporated in a polymeric composite matrix to prepare the active electrode layers of linear and bending actuators. A typical bending actuator is a supercapacitor made by sandwiching a solid electrolyte between two active electrodes. Many conflicting factors influence the actuator performance: a large mechanical stiffness is preferable to produce a high force but limits the displacement; a big active electrode allows to produce a large force but thick actuators are slow because electrode charging is diffusion limited; a thin electrolyte allows increasing charging speed but pinholes and device failures may occur. In this paper we will present how different approaches in electrolyte preparation can influence actuator performance and properties, with special attention to the electrolyte ionic conductivity and the mechanical coupling between the electrodes.

2.3.8 Redox active poly(ionic liquid) by surface-initiated atom transfer radical polymerization towards linear electrochemical actuator

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We aim to develop linear electrochemical actuators based on redox active poly(ionic liquids) (PILs). Here, we present preliminary results in which we

investigate the formation of a redox active PILs onto glassy carbon electrode surface using surface-initiated atom transfer radical polymerization (SI-ATRP).The selected ionic liquid monomer is 1-ferrocenylethyl-3-vinylimidazolium bis(trifluoromethyl-sulfonyl)imide. Surface and electrochemical characterization indicate the success of SI-ATRP of ionic liquid monomer. Then, the immobilized PIL was characterized using cyclic voltammetry in different media. SI-ATRP is promising since functionalized redox active PILs derivatives are relatively easy to synthesize, e.g. ferrocene or anthraquinone. Ideally, the volume change during the electrochemical redox process may take place when designing ferrocenyl materials associated with anthraquinone. The asymetric configuration of the system may generate linear actuation. Indeed, an uptake of anion occurs during the oxidation of the ferrocene group at the anode and an uptake of cation takes place during the reduction of anthraquinone group at the cathode that will induce a volume increase of both the anode and cathode leading to a linear actuation. Under such circumstance, the immobilization of redox active PILs promises some important applications in advanced intelligent materials such as electrochemical actuators applied in artificial muscles domain.

2.3.9 Dynamic Modeling and Experimental Validation of a Bistable DEAP Annular Membrane Actuator

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This paper presents a dynamic electro-mechanical model for a bi-stable actuator system based on a Dielectric Electro-Active Polymer (DEAP) membrane. The motion is generated by the deformation of the membrane caused by the electrostatic, compressive force between two compliant electrodes applied on the surface of the polymer. A bi-stable spring is used to pre-load the membrane, allowing high stroke but also resulting in strong non-linear behavior. The development of mathematical models which accurately describe this non-linear behavior is a fundamental step in order to design model-based, high-precision position control algorithms. This work investigates the principal physical phenomena involved in the actuation process, and for each of them the main sources of nonlinearities are identified and modeled. The model is then validated

on an experimental actuator prototype. A procedure is presented for the systematic identification of the model parameters. Numerous validation experiments show how the model predicts the actuator output for different kinds of input signals. The model is also capable of predicting the dynamic behavior of the DEAP when coupled with alternative biasing elements such as constant mass or linear spring, and can therefore be used both for actuator simulation and design optimization.

2.3.10 Experimental Testing and Analysis of a Circular Dielectric Electro-Active Polymer Actuator Operating against Various Loads

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Dielectric Electro-Active Polymers (DEAP) are an attractive material for use in actuator technologies due to their lightweight, high energy density, high energy efficiency, scalability and low noise features. This work focuses on experimentation of small profile, scalable DEAP actuator system. In our previous work we compared different pre-strain, or biasing, mechanisms for a circular out-of-plane DEAP actuator, like hanging mass, linear spring and non-linear spring. We achieved an improved displacement and frequency behavior of the actuator using a non-linear spring. It was discovered that a linear spring can be added to the non-linear spring in order to compensate for higher external loads while maintaining the large stroke. Some examples of external loads are the forces to move a pump, valve or micro-positioning stage. This paper presents the results of a DEAP actuator system working against loads of various types. The results will give better understanding as how to design a DEAP actuator which can be applied in real devices.

2.3.11 Circular Dielectric Electro-Active Polymers (DEAP) with adapted Geometries to Specific Applications

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Dielectric electro-active polymer (DEAP) technology holds promise enabling

lightweight, energy efficient, and scalable sensors and actuators. The circular DEAP configuration (also known as cone or diaphragm actuator) in particular shows potential in applications such as pressure and weight sensors, pumps, valves, mico-positioners and loudspeakers. Geometric parameters dictate the stroke, force and work output performance of DEAP actuators and the sensitivity and resolution of DEAP sensors. The scalable geometric design allows DEAP actuators and sensors to be adapted to a variety of different applications.This Poster presents the adaption of DEAP actuators (force and stroke) to specific applications, by tailoring the geometry (such as the size of the inner and outer diamater) of the DEAP and the biasing mechanism. Therefore, measurements such as force, displacement, capacitance, resistance, power as well as modeling results are used. The DEAP's consist of a silicone based elastomer and a carbon ink based electrode held together with a stiff frame.

2.3.12 Wearable fingertip tactile display for virtual interactions with soft bodies: preliminary psychophysical test

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In previous works we described a wearable, compact and lightweight tactile display, able to mechanically stimulate the fingertip. The tactile element was based on the so-called hydrostatically coupled dielectric elastomer actuators. This technology relies on an incompressible fluid that hydrostatically couples a DEA-based active membrane to a passive membrane interfaced to the user' s finger. The actuator was arranged at the fingertip and integrated within a plastic case, which also hosted a compact high-voltage circuitry. present Aimed at assessing the ability of the system to deliver different levels of forces a psychophysical test was performed. The forces were perceived by users as a contact with virtual surfaces. Volunteers interacted via their fingertip with these virtual surfaces, and they were asked to report on the perceived stiffness, which was changed randomly. Results show that tactile stimuli are properly discriminated. The proposed device might find useful applications in virtual reality systems aimed at mimicking, for instance, interactions with biological tissues for surgical training (e.g. palpation of soft tissues) or robot-assisted minimally invasive surgery.

2.3.13 Electrically tuneable fluorescence device based on transparent dielectric elastomer actuators

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We report the first proof-of-principle demonstration of a quantum dot (QD) doped transparent dielectric elastomer actuator, as a device with electrically tuneable fluorescence. A silicone gel was loaded with organic-phase CdSe/CdS luminescent QDs and then was confined between two transparent dielectric elastomer membranes made of the 3M VHB film, forming a lenticular structure. The external surface of each elastomeric membrane was coated with a spray-dried PEDOT:PSS conducting polymer, so as to obtain compliant electrodes with an optical transparency of up to 90% at 550nm. The application of a voltage difference between the electrodes displaced the QD-loaded gel in the central region of the structure, leading to an enhancement of fluorescence. This concept might find application for compact and stretchable devices with electrically controllable fluorescence.

2.3.14 Assessment of a wave energy converter based on dielectric elastomers via hardware in the loop simulations

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Dielectric Elastomers Generators (DEGs) are a very promising technology for the development of energy harvesting devices based on the variable-capacitance electrostatic generator principle. As compared to other technologies, DEGs are solid-state energy conversion systems which potentially feature: 1) large energy densities; 2) good energy conversion efficiency that is rather independent of cycle frequency; 3) easiness of manufacturing and assembling; 4) high shock resistance; 5) silent operation; 6) low cost. One of the most promising fields of application for DEGs is in the ocean energy sector, where they could be used to replace traditional Power Take Off (PTO) systems of Wave Energy Converters (WECs) that are based on conventional hydraulic and electromagnetic

machinery. To date, the performances of DEGs have mostly been studied in ideal conditions by coupling them to an external mechanical source with infinite impedance. However, the practical energy that can be converted by a DEG significantly depends on the inertia, damping and springy properties of the external source. In this context, the paper investigates the experimental performance of a DEG PTO via a properly predisposed Hardware-In-the-Loop (HIL) simulation test-bench of a practical WEC, in realistic sea wave conditions. The HIL system is coupled to the considered DEG PTO via sensors and actuators, and is employed as an external energy source with variable impedance mimicking that of WEC-wave hydrodynamics.

2.3.15 Simulation and design optimization of low-voltage switchgear driven by dielectric elastomer actuators

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Although the functionality of dielectric elastomer actuators (DEAs) has been demonstrated through the first niche consumer products, several critical barriers remain that must be addressed before widespread adoption of these actuators can be realized. These constraints are particularly stringent in the case of high-performance industrial automation products where long-term stability and complete system reliability are of paramount importance. The DIELASTAR research consortium has been established to address these concerns and advance the state of technology for DEAs in industrial applications over a three-year period beginning in 2012. In this investigation, we evaluate the feasibility of DEAs for low-voltage switching products through the development of fully-integrated software tools that enable the automatic generation and evaluation of high-performance DEA enabled switchgear design candidates. Results obtained through the application of this toolchain indicate optimal actuator and mechanism attributes for the specific switchgear application under consideration, and in so doing facilitate the rapid and economical specification of physical prototypes. This approach demonstrates how simulation and virtual prototyping can be harnessed to streamline the design specification of novel high-performance DEA enabled systems, and brings us one step closer to realizing DEA based products for the power and automation industries.

2.3.16 Polypyrrole/Carbide-derived carbon-based electroactive hybrid films for bending and diametrically expanding actuators

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Despite the fact that electroactive materials based on conducting polymers have attracted noticeable attention during the last two decades, a further development is still required especially with regards to strain, speed, efficiency and stability. Here we demonstrate successful incorporation of highly porous carbon in a conductive polymer (polypyrrole) matrix in order to prepare actuators with diametrical- and bending strain properties with increased the actuation efficiency. Polypyrrole/Carbide-derived carbon (PPy(DBS)CDC) composites were prepared by an in-situ synthesis of nanoporous carbide-derived carbon powder and pyrrole monomers using simple electrochemical polymerization. This one-step electrochemical synthesis method provides supplementary, simple and efficient alternative for current tape-casting and inkjet printing technologies to produce carbon powder-based electroactive composites. In electroactive films the polypyrrole assists as highly conductive and electromechanically active binder to support the electromechanical actuation. The maximum diametrical strain of the hybrid PPy(DBS)CDC film increased tenfold compared to pure CDC film with nonconductive polymer binders. Although, the overall thickness change of hybrid material was slightly lower compared to PPy(DBS) films, the PPy(DBS)CDC hybrid films demonstrated a doubled efficiency (swelling per charge inserted).

2.3.17 Actuation scheme for electrodeless DEA actuator

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Highly compliant and durable electrodes with elevated electrical conductivity, which do not constraint extension of the underlying electroactive polymer are a must for effective actuation of dielectric elastomer actuators (DEA). Several approaches has been explored so far, including grease and dust-deposited electroconducting layers, sprayed carbon nanotubes, implanted heavy ions, corrugated metallic films and conducting polymers, just to name a few;

however, they still poses many disadvantages. Recently studied electrodeless actuation approach, relaying on direct deposition of HV-corona-produced ions on the DEA surface seems to overcome many of the problems related to physical firm electrodes. However, control of the actuation extent as well as dynamic actuation using electrodeless corona method requires excitation strategy which is different from exploited in conventional electroded DEA. The poster illustrates the methodology useful in dynamic control of the electrodeless DEA actuator extension.

2.3.18 Electro-mechanical modelling of a dielectric elastomer driven soft robot

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Compliant polymeric actuation technologies such as dielectric elastomers (DEs) enable a new generation of fully soft mobile robots to be developed that can operate in complex, constricted environments. These technologies have the potential to greatly improve performance in application domains such as minimally-invasive surgery and machine inspection since soft robots can actively and/or passively deform to reduce stresses in surrounding structures. However, this compliance adds significant complexity to the challenge of predicting their behaviour. In this work a hyperelastic electro-mechanical model is developed for a soft inchworm robot that incorporates pneumatically coupled DE membranes. The non-linear model has been validated against experimental data of inchworm segments with VHB 4905 DE actuators and demonstrates good correlation across a range of drive parameters. The model can also illustrate and characterize the complex non-linear relationship between drive voltage, pneumatic pressure and active stroke, which fundamentally underpins locomotion performance of the soft inchworm robot. Finally, the model is used to predict future performance limits of a two-segment soft robot, which has experimentally demonstrated a locomotion speed of 2.5 body lengths per minute.

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