EuroEAP 2016

6th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Helsingør, Denmark
14-15 June 2016

Technical programme

Book of abstracts

List of participants

EuroEAP 2016 sponsors

Contents

Conference venue

Beach Hotel Marienlyst****
Ndr. Strandvej 2
DK-3000 Helsingør
Denmark

Conference Chairperson

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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 referred 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 EuroEAP Society as a non-profit Association, whose main purpose is to contribute to and promote the scientific and technological advancement and the diffusion of Transducers and Artificial Muscles based on EAPs. In an effort to disseminate current advances in this emerging field of science and technology, gathering experts from all over the world, the Society 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 Chairperson for the valuable local organization of this new edition. I am sure that you will enjoy this event and will leave it with plans to attend the future annual editions that will be moving across Europe.

Federico Carpi
EuroEAP Society President

Conference committees

Organizing committee

The EuroEAP conference is steered by the conference committee of the EuroEAP Society:

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Edwin Jager, Linköping University (Sweden)

Members
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Anne Skov, Technical University of Denmark (Denmark)
Frédéric Vidal, University of Cergy-Pontoise (France)

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Anne Skov, Technical University of Denmark (Denmark)
Peter Sommer-Larsen, Danish Technological Institute (Denmark)

Tuesday, 14 June 2016

General programme of the day

Opening	8:45- 9:00	Welcome & introductory remarks **Anne Ladegaard Skov** DTU, Denmark
EAPlenary	Session 1.1 part I *Chair: Anne Ladegaard Skov, DTU, Denmark*	
	9:00- 9:30	Invited talk **Reimund Gerhard** Potsdam University, Germany
EAPodiums	Session 1.1 part II *Chair: Reimund Gerhard, Potsdam University, Germany*	
	9:30- 9:50	Invited talk **Geoffrey Spinks** University of Wollongong, Australia
	9:50- 10:10	Invited talk **Jinsong Leng** Harbin Institute of Technology, PR China
	10.10- 10.30	Invited talk **Andreas Richter** Technical University of Dresden, Germany
Break	10:30- 10:50	Coffee break
EAPills	Session 1.2 part I *Chair: Edwin Jager, Linköping University, Sweden*	
	10:50- 11:50	**Pill oral presentations** 10 presentations of research activities 5 presentations of prototypes/products (3 minutes each + 1 minute to change speaker)
Lunch	11:50- 12:50	Buffet lunch

EAPosters **EAPrototypes** **EAProducts**	Session 1.2 part II	
	12:50- 14:00	**Posters & exhibitions** 10 posters 5 prototypes/products Coffee served during the session
EAPills	Session 1.3 part I *Chair: Frédéric Vidal, University of Cergy-Pontoise, France*	
	14:00- 15:00	**Pill oral presentations** 16 presentations of research activities (3 minutes each + 1 minute to change speaker)
EAPosters	15:00- 16:10	**Posters & exhibitions** 16 posters Drinks and snacks served during the session (sponsored by LEAP Technology)
Social Tour	16:10- 18:00	Guided tour of Kronborg Castle (the castle of Hamlet)
Social dinner	18:30	Social dinner at the conference hotel (sponsored by TA Instruments)

Session 1.1

(abstracts are listed in the order of presentation)

1.1.1 Electro-mechanical and mechano-electrical transduction via electric charges or dipoles localised on or in dielectric polymers

Reimund Gerhard (1),

(1) University Of Potsdam, Institute Of Physics And Astronomy, Potsdam, Germany

Presentation given by Prof. Reimund Gerhard

In dielectric materials, localised or trapped charges and electrode charges, as well as fixed electric dipoles from pairs of such charges with opposite polarities can lead to useful electro-mechanical and mechano-electrical effects. The charges have to be properly arranged and stabilised, and the materials should have extremely low conductivities so that charge compensation can be avoided at least during the operation of an electro-active device. Furthermore, the materials or materials systems should be elastically heterogeneous with a non-affine deformation behaviour so that relative charge movements can be generated in them. Essentially, the (electrostatic) charges need to be fixed to the material, but for the desired electro-mechanical or mechano-electrical effects, the charges need to move along with the material to which they are fixed, i.e. the charges are at the same time static (trapped or fixed) with respect to the material and mobile together with the respective material. As a result, mechanical movements of or within the material can be detected or generated via the movement of charge. Furthermore, the coupling between localised charges or fixed dipoles and anisotropic mechanical properties may also give rise to pyroelectric and electrocaloric effects. A straight-forward charge-spring model for an intuitive semi-quantitative understanding of the observed phenomena will be introduced and discussed together with examples of proposed and implemented applications.

1.1.2 Actuating materials and fabrication strategies for soft robotics and wearable robotics

Geoffrey Spinks (1), Sina Naficy (1), Javad Foroughi (1), Shannon Bakarich (1), Danial Sangian (1), Nicolas Martino (1), Shazed Aziz (1), David Shepherd (1), Bidita Salahuddin (1),

(1) University Of Wollongong

Presentation given by Dr. Geoffrey Spinks

Soft robotic and wearable robotic devices seek to exploit polymer based artificial muscles and sensor materials to generate biomimetic movements and forces. A challenge is to integrate the active materials into a complex, three-dimensional device with integrated electronics, power supplies and support structures. Both 3D printing and textiles technologies offer attractive fabrication strategies, but require suitable functional materials. 3D printing of actuating hydrogels has been developed to produce simple devices, such as a prototype valve. Tough hydrogels based on interpenetrating networks of ionicially crosslinked alginate and covalently crosslinked polyacrylamide and poly(N-isopropylacrylamide) have been developed in a form suitable for extrusion printing with UV curing. Combined with UV-curable and extrudable rigid acrylated urethanes, the tough hydrogels can be printed into composite materials or complex shapes with multiple different materials. An actuating valve was printed that operated thermally to open or close the flow path using 6 parallel hydrogel actuators. Textile processing methods such as knitting and weaving can be used to generate assemblies of actuating fibres. Low cost and high performance coiled fibres made from oriented polymers have been used for developing actuating textiles. Similarly, braiding methods have been developed to fabricate new forms of McKibben muscles that operate without any external apparatus, such as pumps, compressors or piping.

1.1.3 Soft active polymers and composites: from fundamental to applications

Jinsong Leng (1),

(1) Harbin Institute Of Technology, Centre For Composite Materials And Structures, Harbin, China

Presentation given by Prof. Jinsong Leng

Soft active polymers are capable of changing shapes or sizes when subjected to an external stimulus, making them the promising materials for sensors, actuators and active deformable structures. As typical soft active materials, shape memory polymers (SMPs) and their composites (SMPCs) can deliver active properties and autonomic responding. They can not only remember multiple shapes but also respond diverse stimuli. In particular, their stiffness can change significantly when triggered by external stimuli. Recently, their applications in active deformable structures, like deployable structures, morphing wings, and smart mandrels, are developed. 4D printing has also been generated through adding another dimension, time-dependent shape change, to 3D printing. Dielectric elastomers are also representative soft active polymers and can deform sustainably subjected to a high voltage. Based on dielectric elastomers, various actuators and devices had been designed and investigated, such as soft robotics, Braille tactile display, energy harvester. Besides, for the guidance of structural design of these actuators and devices, the constitutive model, stability and failure of dielectric elastomers are also analyzed, considering nonlinear performances of dielectric elastomers. Soft active polymers could significantly accelerate the advancement of novel composites and structures that have excellent performances and could lead to revolutionary developments in some areas.

1.1.4 Stimuli-responsive hydrogels as active materials for microsystems: prospects and challenges

Andreas Richter (1) (2), Martin Elstner (2), Andreas Voigt (1) (2),

(1) Technische Universität Dresden, Lab Of Polymeric Microsystems, Dresden, Germany
(2) Technische Universität Dresden, Center For Advancing Electronics Dresden, Dresden, Germany

Presentation given by Prof. Andreas Richter

Microsystems technology lacks a diverse material with a comparable significance as silicon in microelectronics. Because of the huge diversity of microsystems, we will maybe never find such material. However, for a broad range of applications, stimuli-responsive hydrogels could take a similar place. Compared to other solid-state actuators, these hydrogels provide one of the highest energy densities and also the highest change of volume known from solid-state actuators. They can be monolithically integrated into microsystems and micro-structured with several lithographic techniques. Otherwise, the time behaviour of this active material is diffusion-controlled. In our talk, we want to discuss the chances, but also the challenges of this promising material in microsystems.

Session 1.2
(abstracts are listed in the order of presentation)

1.2.1 Complete band-gaps in soft dielectric fiber-composites

Roey Getz (1), Gal Shmuel (1),

(1) Technion, Faculty Of Mechanical Engineering/Technion - Israel Institute Of Technology, Haifa, Israel

Presentation given by Mr. Roey Getz

Dielectric elastomers (DEs) undergo large deformations and their properties are changed in response to electric stimuli. We characterize the static response of electrostrictive DE fiber-composites to a voltage drop along the fibers. We formulate the equations governing the in-plane motion propagating on top of the deformed state of the composite. These equations are solved semi-analytically, when the material law is specialized to the augmented Gent model, which accounts for the strain-stiffening in elastomers. We explore the dependency of the motion on the phases properties, volume fractions, and most importantly the bias electric field. We find ranges of frequencies, termed band-gaps, at which waves cannot propagate. Parts of these gaps coincide with the gaps found for the anti-plane motion, forming complete band-gaps in which propagation is forbidden at all propagation directions. We show how such gaps can be tuned by adjusting the applied voltage. Thus, our analysis further promotes the use of DEs as electrostatically tunable waveguides and isolators.

1.2.2 Mechanical performance of a dielectric gel

Bo Li (1),

(1) Xi"an Jiaotong University

Presentation given by Dr. Bo Li

Mechanical deformation of a dielectric gel is attributed to: the solvent diffusion, the electrical polarization and material hyperelasticity. A multi-field model,

coupling electrical, chemical and mechanical quantities, is established based in the thermodynamics. A set of constitutive relations is derived as equations of state for characterization. The model is applied to specific cases as an effective validation. Physical and chemical parameters affect the performance of the gel, and the model offers a guidance for engineering application.

1.2.3 Glycerol as high-permittivity liquid filler in dielectric silicone elastomers

Piotr Mazurek (1), Liyun Yu (1), Reimund Gerhard (2), Werner Wirges (2), Anne Ladegaard Skov (1),

(1) Danish Polymer Centre, Department Of Chemical And Biochemical Engineering, Technical University Of Denmark, Kgs. Lyngby, Denmark
(2) Applied Condensed-Matter Physics, Institute Of Physics And Astronomy, Faculty Of Science, University Of Potsdam, Potsdam-Golm, Germany

Presentation given by Mr. Piotr Mazurek

A recently reported novel class of elastomers was tested with respect to its dielectric properties. The new elastomer material is based on a commercially available polydimethylsiloxane (PDMS) composition, which has been modified by embedding glycerol droplets into its matrix. The approach has two major advantages that make the material useful in a dielectric actuator. First, the glycerol droplets efficiently enhance the dielectric constant which can reach very high values in the composite. Second, the liquid filler also acts as a softener that effectively decreases the elastic modulus of the composite. In combination with very low cost and easy preparation, the two property enhancements lead to a very attractive dielectric elastomer material. The main focus of this study lies on the electrical properties of the new composite - conductivity, dielectric loss and relative permittivity. PDMS, containing various amounts of glycerol, has been tested at increasing voltages in order to precisely characterize the influence of an electric field on the relevant material properties. Experimental permittivity data are compared to various theoretical models that predict relative-permittivity changes as a function of filler loading, and the applicability of the models is discussed. Furthermore, the influence of the diameter of the inclusions on the resulting dielectric constant of the glycerol-PDMS composites has been investigated.

1.2.4 Synthesis of pedot electrodes using vapor phase polymerization for

ionic eap-s

Kätlin Rohtlaid (1), Frédéric Vidal (1), Cédric Plesse (1), Tran Minh Giao Nguyen (1), Eric Cattan (2), Caroline Soyer (2),

(1) Université De Cergy-Pontoise, LPPI (Laboratoire De Physicochimie Des Polymères Et Des Interfaces)
(2) Université De Valenciennes Et Du Hainaut-Cambrésis, IEMN (Institut D"électronique De Microélectronique Et De Nanotechnologie)

Presentation given by Ms. Kätlin Rohtlaid

Synthesis and characterization of thin poly(3,4-ethylenedioxythiophene) (PEDOT) electrodes for ionic EAP applications are described. PEDOT electrodes are synthesized using vapor phase polymerization (VPP) directly on a substrate covered with spin-coated oxidant solution. Influence of synthesis parameters (rotation speed and composition of oxidant solution, VPP time and temperature) on final electrodes properties will be described. More specifically thickness, electronic conductivity and electroactivity are systematically determined to achieve best guidelines for synthesizing ionic EAP electrodes. Finally, electrodes are integrated into trilayer actuators prepared using layer-by-layer (LbL) synthesis and the resulting devices are swollen with ionic liquid. First actuation results of the trilayer devices will be described.

1.2.5 On the thermo-electro-mechanical modeling of electroactive materials

Markus Mehnert (1),

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

Presentation given by Mr. Markus Mehnert

This work presents a fully coupled thermo-electro-elastic continuum model for the material behaviour of isotropic electro-active elastomers under the influence of a temperature gradient. Electro-active polymers are composed of a rubber-like base material combined with electro-active particles resulting in a material behaviour that is sensitive both to the application of an electric field and a change in temperature. The derived coupled continuum model is implemented into a finite-element code in which the electro-mechanical and the thermal fields

are partitioned into individual subproblems. The decoupling is obtained by means of an isothermal operator-split. In order to validate the implementation we compare the results obtained from simulation with analytical results. As an example we investigate the behaviour of a thick walled cylindrical tube under inflation and stretch, which is a well established setup in the literature. The possibilities of the numerical simulation allow us to further expand on this example by including material effects that can not be described analytically or by implementing more complex material models.

1.2.6 Investigation of the field-distribution in a multilayer DE stack-transducer

Thorben Hoffstadt (1), Philip Meier (1), Jürgen Maas (1),

(1) Ostwestfalen-Lippe University Of Applied Sciences

Presentation given by Mr. Philip Meier

In most cases the electrical behavior of a dielectric elastomer transducer is modeled by an equivalent circuit with lumped electrical parameters. The capacitance is obtained under consideration of the active area of the whole DE transducer, while additional parallel and series resistances model the losses in the dielectric and the electrode respectively. However, in general a DE transducer has a certain spatial distribution depending on the design of the considered transducer. Thus, a model with lumped parameters might be inaccurate and does not take into account the field-distribution within the DE transducer. Since the electrostatic pressure and by this the actuation principle depends on the electrical field, the dynamics of the field propagation also influence the electromechanical coupling. Thus, within this contribution a multilayer DE stack-transducer is considered. The stacked DE films of such a transducer are connected in parallel via diagonal-edge contacts using a contacting film. Under consideration of these diagonal-edge contacts, within this contribution an electrical network model for the multilayer DE stack-transducer is presented that enables an investigation of the field-distribution in the transducer. This model takes into account the influence of the contacting of each transducer film as well as their electrical interaction and spatial distribution.

1.2.7 Enabling wearable soft tactile displays with dielectric elastomer actuators

Gabriele Frediani (1), Hugh Boys (2), Stefan Poslad (2), Federico Carpi (1),

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

Presentation given by Mr. Hugh Boys

Ongoing developments in our lab to develop wearable soft tactile displays made of electroactive smart elastomers are proposed, which have the benefit that they support multiple-finger interaction with virtual soft bodies, via soft electrically-deformable interfaces. The overall system consists of soft tactile displays arranged at the user's fingertips, which generate an electrically tuneable force according to information captured by an optical three dimensional finger tracking system, combined with a virtual environment that represents the position of the fingers. The tactile displays are based on an original design which uses the electromechanically active polymer transduction technology known as dielectric elastomer actuators. The paper presents our latest demonstrators, which allow users to probe a soft object with one finger, and describes ongoing development towards a multiple-finger system, based on a new compact design of the tactile displays.

1.2.8 A simple and compact high voltage breakdown detection system for dielectric elastomer actuators

Michele Ghilardi (1), Federico Carpi (1),

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

Presentation given by Mr. Michele Ghilardi

While working at the development of an art installation made up of many dielectric elastomer (DE)-based butterfly-like actuators, we needed a simple and effective solution to detect electrical breakdown of individual units in order to stop applying voltage to them for safety issues. Here we present a simple solution based on a voltage-divider configuration that detects the voltage drop at the DE actuator terminals and assesses the breakdown occurrence via comparison with a dynamic threshold. A microcontroller (Beaglebone Black single-board computer) is used with a Bela cape (an open-source embedded platform for real-time, ultra-low-latency audio and sensor processing developed at Queen Mary University of London) to both generate the control signal that drives the actuator and constantly monitor the functionality of the device, detecting any possible breakdown and discontinuing the supplied voltage accordingly, so as to obtain a safer controlled actuation.

1.2.9 Improving the stroke of dielectric elastomer actuators using magnets

Philipp Loew (1) (2), Gianluca Rizzello (1), Stefan Seelecke (1),

(1) Saarland University
(2) Zentrum Fuer Mechatronik Und Automatisierungstechnik

Presentation given by Mr. Philipp Loew

Dielectric Elastomers (DE) represent an attractive technology for the realization of mechatronic actuators, due to their lightweight, high energy density, high energy efficiency, scalability, and low noise features. In this work we propose a novel design solution which permits to significantly increase the performance of membrane DE Actuators (DEA). In order to produce a stroke, a DE membrane needs to be pre-loaded with a mechanical biasing mechanism. In our previous work, we compared the stroke achieved with different biasing mechanisms for a circular out-of-plane DEA, i.e., hanging masses and linear springs. In this work we propose an alternative design solution for the DEA biasing mechanism, based on permanent magnets. Compared to standard solutions based on linear springs, the magnets permit to achieve an improved displacement and to increase the bandwidth of the actuator. An additional advantage introduced by the magnets is the possibility to design more compact actuators. Furthermore, it is shown how the combination of the magnets with a linear spring allows to compensate for higher external loads, while maintaining a large stroke. This design solution makes then the actuator more tunable, allowing it to be used in a wider range of loading conditions.

1.2.10 Multifunctional shape memory electrodes for dielectric elastomer actuators enabling high holding force and low-voltage multisegment addressing

David McCoul (1), Nadine Besse (1), Samuel Rosset (1), Herbert Shea (1),

(1) Ecole Polytechnique Federale De Lausanne (EPFL), Microsystems For Space Technologies Laboratory (LMTS), Neuchatel, Switzerland

Presentation given by Dr. David McCoul

We present a novel configuration of a dielectric elastomer actuator (DEA) using electrodes made of a shape-memory polymer. DEAs are an efficient class of flexible electromechanical transducer. They have been incorporated into a variety of elegant devices, such as microfluidic devices, tunable optics, haptic displays, and minimum-energy grippers, to name a few. Dielectric elastomer minimum energy structures (DEMES) take advantage of the prestretch of the dielectric elastomer actuator to bend a non-stretchable but flexible component to perform mechanical work. DEMES grippers are capable of grasping objects, but with only small to moderate forces. We report on the use of a conductive shape memory polymer (SMP) as the electrode for a DEA gripper. The SMP electrodes allow the DEA to be rigid in the cold state, offering far greater holding force than a conventional DEA. Joule heating applied to the shape memory electrodes soften them, allowing for electrostatic actuation. Cooling then locks in the actuated position without the need for continued power to be supplied. Additionally, the Joule heating voltage is at least one order of magnitude less than electrostatic actuation voltages, allowing for addressing of multiple actuator elements using commercially-available transistors. The shape memory gripper incorporates this addressing into its design, enabling the three segments of each finger to be controlled independently.

1.2.11 Exhibitions of research prototypes and commercial products

1. Boys Hugh, Queen Mary University of London, United Kingdom
2. Ghilardi Michele, Queen Mary University of London, United Kingdom
3. Loew Philipp, Saarland University, Germany
4. McCoul David, EPFL, Switzerland
5. Sarban, Rahimullah, LEAP Technology, Denmark.

Session 1.3

(abstracts are listed in the order of presentation)

1.3.1 Self-priming circuits in load-driven Dielectric Elastomer Generators

Plinio Zanini (1) (2), Jonathan Rossiter (1) (2), Martin Homer (1),

(1) University Of Bristol, Department Of Engineering Mathematics, Bristol, UK
(2) Bristol Robotics Laboratory, Bristol, UK

Presentation given by Mr. Plinio Rodrigues De Oliveira Zanini

Dielectric Elastomer Generators (DEGs) are an emerging technology to convert mechanical into electrical energy. Despite many advantageous characteristics (lightweight, low cost and high energy density) there are still some issues to overcome, including the need for charging at every cycle to produce an electrical output. Self-priming Circuits (SPCs) are one way to avoid the issue, by storing part of the energy output of one cycle to supply as input for the next, producing a voltage boost effect. Until now, studies regarding SPCs typically consider the deformation in the DEG to be limited to two prescribed positions, maximum and minimum stretch, and neglect to consider how SPCs will affect the DEG when they are driven by an oscillatory load, bounded by a maximum and minimum force. In the present work we model this force-based actuation, including coupling between the DEG and SPC, in order to more accurately predict the dynamics of the system. In such cases, there is an actuation-like effect, consisting of the mechanical response by the material when electrically charged; as the voltage increases, the actuation-like effect increases the capacitance values that bound the cycle. We show how this yields a reduction in the capacitance swing of the DEG, due to the nonlinearity of the system, and how the resulting periodic orbit affects the performance of the SPC.

1.3.2 Polypyrrole-carbon nanotube composite/tape bilayer sensing-muscles: electrochemical and electrochemo-dynamical characterization at different sweep rates

Johanna Schumacher (1), Toribio F. Otero (2), Victor H. Pascual (2), Jose G. Martinez (2), Laura Valero (3),

(1) Arquimea Ingeniería, Leganés, Spain
(2) Technical University Of Cartagena, Laboratory Of Electrochemistry And Intelligent Materials, Cartagena, Spain
(3) Universidad Autónoma Del Estado De México, Engineering School, Toluca, Mexico

Presentation given by Ms. Johanna Schumacher

Bending bilayer artificial muscles constructed of a non-electroactive and an electroactive layer convert electrical into mechanical energy driven by electrochemical reactions of the electroactive layer. Solvent and ion exchange during redox reactions cause volume changes of the electroactive layer inducing bilayer bending. While moving the consumed electrical energy and the muscle potential evolution senses the working energetic (electrical, thermal, mechanical, chemical and so on) conditions. Those electrochemical artificial muscles are dual sensing-motors mimicking haptic muscles. The electrochemical and electrochemo-dynamical characterization of polypyrrole-dodecylbenzene-sulfonate-multiwalled carbon nanotube/tape bilayer muscles in terms of actuation and sensing is presented for different sweep rates (different electrochemical energies). The electrochemical responses and the angular position of the muscle during oxidation (shrinking) and reduction (swelling) indicate a prevalent cation exchange driven by the reaction. The muscle is a faradaic motor: the angular position is, in average, a linear function of the consumed charge. Osmotic insertion and expulsion of water, following the ion exchange, provokes minor deviations. The reaction senses the electrochemical energy: higher charges and energies are consumed at decreasing sweep rates. A double exponential function of the sweep rate fits the experimental results which indicate superior sensibility at low sweep rates.

1.3.3 The effect of humidity on carbon-based IEAP actuator

Alvo Aabloo (1), Andres Punning (1), Veiko Vunder (1), Urmas Johanson (1),

(1) IMS Lab, University Of Tartu

Presentation given by Prof. Alvo Aabloo

Ionic electroactive polymer (IEAP) actuators and sensors have proven their compatibility in various fields of adaptive soft robotics yielding from autonomous inchworm like robots down to micromanipulator arrays. Depending on the each particular application, the ambient conditions for the transducer can change drastically, which in turn might change the behavior and performance of the IEAP. In this work, a nanoporous carbon-based IEAP material is investigated in vacuum, in dry inert, and in natural air environments. In each environment, the actuator is subjected to a 2.5 V step input while the consumed current and displacement are constantly monitored. A gray-box model is used to differentiate the important characteristics in electrical and mechanical parameters. The results emphasize that in presence of humidity the rate of back-relaxation is rapidly increased whereas only marginal rate of relaxation was observed in dry inert and in vacuum environments. Furthermore, in normal pressure and in vacuum, the studied IEAP performed nearly identically.

1.3.4 Electrochemical reactions from conducting polymers sense available electrochemical energy: sweep rate influence.

Victor H. Pascual Carrion (1), Toribio F. Otero (1), Jose G. Martinez (1), Laura L. Valero Cozuelo (1) (2), Johanna Schumacher (3),

(1) Laboratory Of Electrochemistry And Intelligent Materials. Technical University Of Cartagena. ETSII. Campus Alfonso XIII, 30203, Cartagena, Spain
(2) B Engineering School, Universidad Autónoma Del Estado De México, Toluca 50000, Mexico
(3) Arquimea Ingeniería S.L., 28919, Leganés, Spain

Presentation given by Mr. Victor H. Pascual Carrion

One of the aims of the modern Science is the design and construction of motors sensing by themselves working conditions. If haptic muscles, nerves and brain originate proprioception, sensing-motors will support development of artificial proprioceptive systems. For that the electrochemical reactions of conducting polymers provide dual sensing-actuating properties and devices. Here a platinum electrode coated with a film of polypyrrole/dodecyl benzene sulfonate was subjected to potential sweeps at several scan rates to check if the reacting material senses those different electrochemical conditions. Both, the consumed electrical energy and the hysteresis corresponding to the parallel charge/potential loop show a relation with the scan rate consisting of the addition of two exponential functions (sensing equations). But while the energy decreases with the scan rate the hysteresis increases with it. The existence of two exponentials indicates two processes: reaction-driven conformational movements of the polymer chains, dominating the kinetics in low scan rates; and diffusion process, leading for the higher ones. There are then two different sensing ranges, one similar to biochemical conformational and allosteric sensors and another one similar to current amperometric electrochemical sensors.

1.3.5 A single electro-chemo-physical equation explains dual sensing and actuating properties of conducting polymer actuators: theoretical description of sensing-motors

Jose G. Martinez (1), Toribio F. Otero (1), Victor H. Pascual Carrion (1), Johanna Schumacher (3), Laura L. Valero Cozuelo (3),

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(3) Arquimea Ingeniería S.L., 28919, Leganés, Spain

Presentation given by Mr. Victor H. Pascual Carrion

Two-tool devices, sensing-actuators, based on electroactive (reactive) materials such as conducting polymers, carbon nanotubes or graphenes have been developed during the last years. They work in a similar way as mammal muscles do: by reaction of the constitutive material. They are physically uniform devices that use only two connecting wires to feed (actuate) the devices through the applied current or the consumed electrical charge and to sense, through the muscle potential or the consumed energy, mechanical, electrical, chemical or physical variables. A theoretical equation describing this dual behaviour is required to develop most intelligent tools and robots. Now, a model has been developed from basic electrochemical, chemical, polymeric and mechanical principles linking actuating and sensing magnitudes. The attained relationship includes, at any time: the muscle position and movement rate altogether the working conditions: temperature, electrolyte concentration, trailed mass, driving current. Cheaper, more reliable and anthropomorphic tools and robots can be envisaged using reactive dual sensing-actuators.

1.3.6 Instability of dielectric elastomers

Liwu Liu (1), Yanju Liu (1), Jinsong Leng (2),

(1) Harbin Institute Of Technology, Department Of Astronautical Science And Mechanics, Harbin, China
(2) Harbin Institute Of Technology, Centre For Composite Materials And Structures, Harbin, China

Presentation given by Prof. Liwu Liu

Dielectric elastomer is a kind of typical soft active material. It can deform obviously when subjected to an external voltage. When a dielectric elastomer with randomly oriented dipoles is subject to an electric field, the dipoles will rotate to and align with the electric field. The polarization of the dielectric elastomer may be saturated when the voltage is high enough. When subjected to a mechanical force, the end-to-end distance of each polymer chain, which has a finite contour length, will approach the finite value, reaching a limiting stretch. On approaching the limiting stretch, the elastomer stiffens steeply. Here, we develop a thermodynamic constitutive model of dielectric elastomers undergoing polarization saturation and strain-stiffening, and then investigate the electromechanical instability, snap through instability and voltage induced deformation of dielectric elastomers. Analytical solution has been obtained and it reveals the marked influence of the extension limit and polarization saturation limit on its instability. The developed thermodynamic constitutive model and simulation results would be helpful in future to the research of dielectric elastomer based high-performance transducers. We described the allowable area of dielectric elastomer on both equal biaxial and unequal biaxial circumstances, calculated temperature change and entropy change induced by electrical field of dielectric elastomer and electrocaloric materials.

1.3.7 Silicone elastomers with aromatic voltage stabilizers

Aliff H. A. Razak (1) (2), Anne L. Skov (1),

(1) Danish Polymer Center, Chemical And Biochemical Engineering, Technical University Of Denmark, 2800 Lyngby, Denmark
(2) Faculty Of Engineering Technology, University Of Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Presentation given by Ms. Aliff H. A. Razak

Electrical breakdown causes short-circuiting of dielectric elastomers (DEs) resulting in irreversible destruction of the DE. Numerous studies have been

performed in order to obtain elastomers with high relative permittivity and low Young's modulus in order to increase the actuation performance at a given voltage, but the optimised elastomers often possess relatively low electrical breakdown strength. On the other hand, increasing the electrical breakdown strength of DEs allows for larger actuation due to the possibility of utilizing larger electrical fields. Many studies on electrical breakdown of pre-strained DEs have been conducted, however less efforts have been focused on improving the electrical breakdown strength such as by blending in additives or by polymer structure modifications. In order to increase the electrical breakdown strength of polymers for e.g. the cable industry, additives like aromatic voltage stabilizers are used. Earlier works on using voltage stabilizers in polymers have mainly focused on polyethylene with the purpose of reducing power loss for high voltage insulation cables. As an alternative to utilise additives as voltage stabilizers, grafting aromatic compounds to silicone backbones may overcome the common problem of insolubility of the aromatic voltage stabilizer in the silicone elastomers due to phase separation. Preventing phase separation during preparation and during operation is a key requirement for long life-times of DEs.

1.3.8 Instabilities in dielectric elastomer plates

Hadrien Bense (1), José Bico (1), Benoît Roman (1), Etienne Reyssat (1), Miguel Trejo (1),

(1) ESPCI, PMMH, Paris, France

Presentation given by Mr. Hadrien Bense

Dielectric elastomers are part of a class of electro-active polymers that exhibit mechanical deformations when stimulated by an electric voltage. In most cases the elastomer is strongly stretched and clamped, or submitted to large dead loads before the voltage is applied. Here, we are interested in similar systems, but without any prestrain and investigate the effect of a spatially non uniform voltage. We find that the membranes under non-uniform load undergo mechanical instabilities. Such buckling-like instabilities are not observed in other studies because of large tensile loading, but they are common in thin plates with internal stresses. As a first step, we propose to study simple geometries, where the sample is only partially covered with the conductive coating. A disk where only the central zone or a peripheral annulus is growing would be a first example. These systems, despite their apparent simplicity, display surprising features. The threshold buckling is surprisingly high and the buckling pattern of the disk is strongly localized inside the active part. Secondary instability presenting radial wrinkles may even be observed for high voltages. Predicting the threshold of buckling and the main characteristics of the pattern is complex, even in simple geometries. A non-linear analysis is indeed necessary to capture, at least qualitatively, the behavior of such systems from the buckling threshold to the evolution of the observed patterns.

1.3.9 High breakdown strength composites based on silicone and ceramic nanotubes

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

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

Presentation given by Mr. Adrian Bele

It is well-known that, to be useful in actuators and generators, the dielectric elastomers should meet certain requirements such as increased dielectric permittivity, low dielectric losses, high elongation at break and breakdown strength. Besides natural rubber, acrylics, polyurethanes and other synthetic polymers, the silicones are often chosen for such purpose due to their outstanding characteristics, like high flexibility, weathering resistance, easy manufacturing. However, silicones show low dielectric permittivity values. Between strategies to minimize this disadvantage, the physical incorporation of high dielectric permittivity fillers, e.g., ceramics particles, within silicone matrix is included. But the effectiveness of this approach depends, besides the filler nature and dispersion uniformity within the matrix, on their surface contact with matrix. The use of fillers with high aspect ratio seems to be a promising way, although in some cases, the dielectric permittivity is improved for the detrimental of the breakdown strength. In this study, by using optimally surface treated titania nanotubes - based filler as dielectric permittivity enhancer for silicones, a breakdown strength higher that 60 kV/µm was obtained.

1.3.10 Ultra-thin stretchable silver electrodes as compared with PDMS-based electrodes designed for energy harvesting

Codrin Tugui (1), Cristian Ursu (1), Adrian Bele (1), Mihail Iacob (1), Maria Cazacu (1),

(1) "Petru Poni" Institute Of Macromolecular Chemistry

Presentation given by Mr. Codrin Tugui

Besides the already known available technologies, dielectric elastomers transducers (DET) offer a simple and low cost way to obtain electrical energy from free mechanical energy sources. Two types of soft capacitors were designed in order to compare the effectiveness of both metallic and PDMS-based electrodes. Ultra-thin silver layers of about 40 nm thickness were deposited through pulse laser deposition (PLD) on the silicon film surface, while the thin films of PDMS/carbon black-based electrodes were achieved by mixing a high molecular mass PDMS with carbon black and crosslinked with tetraethylorthosilicate. The highly effective till large strain obtained capacitors were well investigated from both morphological and electromechanical point of view.

1.3.11 Comparison of non-locking incompressible multi-field finite element models for dielectric actuators

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

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

Presentation given by Mr. Tristan Schlögl

The mechanical properties of commonly used polymers for dielectric elastomers are well covered by hyperelastic material models, where the stress-strain relation is derived from a strain energy function. Incompressibility is often approximated by a Poisson's ratio close to 0.5 or a very large bulk modulus. This, however, is like enforcing the incompressibility condition with a penalty method that, due to the spatial finite element discretisation, might lead to volume locking. As a result, the material is artificially stiffened, not leading to physically meaningful simulation results. In analogy to the three-field formulation for pure mechanical problems, in this work additional degrees of freedom are added to the electromechanically coupled material model, leading to a multi-field formulation. Combined with reduced spatial integration for the additional fields, also known as the mean dilatation method, volume locking for incompressible and nearly incompressible materials is avoided. Depending on the specific choice of additional fields, different formulations are obtained. In the framework of dielectric elastomer actuator simulation and structure preserving time integration, these formulations are compared in terms of achievable incompressibility, tendency to volume-locking and computational cost.

1.3.12 Processing line for stacked actuator modules

Michael Wegener (1), Miriam Biedermann (2), Sven-Oliver Seidel (1), Hartmut Krueger (2),

(1) Fraunhofer IAP, Sensors And Actuators, Potsdam, Germany
(2) Fraunhofer IAP, Polymers And Electronics, Potsdam, Germany

Presentation given by Dr. Michael Wegener

Dielectric elastomer actuators (DEAs) are widely studied due to their extraordinary properties. Research and development on DEAs is conducted in order to generate and optimize the elastomeric materials, flexible electrodes, preparation processes of films and layers as well as to build up film, roll and stacked actuators. A broad variety of applications is developed for different kind of actuators. Recently, huge developments were performed in stack actuators. Such actuators consist of several tens or hundreds of single elastomer layers with flexible electrodes which are processed or aligned on top of each other. Actuator modules with heights of e.g. some millimeters to centimeters are fabricated which provide a deflection in transversal direction in the range of some hundred micrometers to e.g. some millimeters. Here, we present the manufacturing of stack actuator modules which is performed in a semi-automatic processing line. The elastomeric layers are processed from the liquid phase by doctor-blading which allows the deposition of a homogeneous layer with a size of 20cm x 20cm. In the next step the elastomer is cured by thermal or UV treatment. Carbon-particle electrodes are deposited by an air-brush technique. This procedure is repeated in order to process stacked actuator modules with e.g. 10 layers which can be combined to larger stacked actuators. Finally, stacked actuators were characterized regarding their geometrical and electrical properties.

1.3.13 Fabrication of flexible nickel electrode for wireless self-propelling actuators

Eswaran Murugasen (1), Jalal Ghilane (1), Hyacinthe Randriamahazaka (1),

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Paris, France

Presentation given by Mr. Eswaran Murugasen

Herein, we are reporting a wireless self-propelling actuator made up of flexible nickel metal electrode upon nafion membrane by electroless deposition method. In this process, the nafion membrane is adsorbed by Pd^{2+} cations to immobilize nickel on its surface during electroless deposition in electrolyte bath containing nickel salt and reductant according to the following equation: $3Ni^{2+}$ + 3 R_2NHBH_3 + 6 H_2O give 3 Ni^0 + B + 3 $R_2NH_2^+$ + 2 $B(OH)_3$ + 9/2 H_2 + $3H^+$; This flexible electrode along with electrodeposited manganese dioxide layer has the potential to decompose H_2O_2 into water and oxygen. The electrodeposition of MnO_2 was done by CV from the aq. solution of $MnSO_4$ at pH-1.8 based on below equations: Mn^{2+} yields Mn^{3+} + e^-; Mn^{3+} + $2H_2O$ give MnOOH + $3H^+$; MnOOH gives MnO_2 + H^+ + e^- , The oxygen evolution of flexible electrode in 1mM H_2O_2 solution produce lot of bubbles on the surface of the electrode that act as propellant to induce movement. During this, H_2O_2 was first adsorbed on the active sites of MnO_2 surface, then the MnO_2 is reduced by H_2O_2 as mentioned below: $2MnO_2$ + H_2O_2 provide Mn_2O_3 + O_2 + H_2O; Then Mn_2O_3 will be oxidized back to regenerate MnO_2 by H_2O_2 as per the below equation: Mn_2O_3 + H_2O_2 give $2MnO_2$ + H_2O; With this results, the path towards realization of wireless self-propelling actuator will be acquainted.

1.3.14 Thin silicone-based dielectric elastomer actuators with soft and stretchable electrodes obtained by supersonic cluster beam deposition

Silvia Taccola (1), Andrea Bellacicca (2), Paolo Milani (2), Lucia Beccai (1), Francesco Greco (1),

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(2) Università Degli Studi Di Milano, Department Of Physics, Milano, Italia

Presentation given by Dr. Silvia Taccola

In order to enable widespread use of dielectric elastomers (DE) and their integration in devices, as actuators, strain sensors, haptic interfaces, and energy harvesting systems, a number of key challenges have yet to be optimized, such as operation at low voltage, miniaturization, and fabrication of compliant electrodes. In this work, we present new DE actuators based on thin films of polydimethylsiloxane (PDMS) onto which ultrathin, low-weight, and stretchable silver electrodes were implanted by Supersonic Cluster Beam Deposition (SCBD) of silver nanoparticles. The approach adopted here ensured to minimize the driving voltage by substantially reducing the thickness of the elastomeric membrane and reducing the elastomer mechanical stiffness. Stretchable patterned Ag-PDMS electrodes, able to withstand large deformation while preserving finite and reproducible electrical resistance, were successfully fabricated on top of 17 um-thick PDMS films. The electromechanical transduction performances of the actuators were characterized in pure shear configuration with an isotonic test on free-standing clamped actuators with applied uniaxial pre-strain. The attained combination of softness, small thickness, relatively low driving voltage and fast response speed demonstrate feasibility of the approach which, contrary to other electrode deposition techniques, is amenable to further reduction to even lower thickness of elastomeric membrane, down to the micrometer or submicrometer-scale.

1.3.15 Development of electroactive materials for wave energy harvesting

Sophie Iglesias (1), Sebastien Pruvost (1), Jannick Duchet-Rumeau (1), Sebastien Livi (1), Jean-François Gérard (1),

(1) University Of Lyon, INSA-Lyon, IMP, UMR CNRS 5223, Villeurbanne, France

Presentation given by Ms. Sophie Iglesias

The world is facing a delicate energetic situation, as the global energy demand increases and fossil resources are being exhausted. In this context, diversification of renewable resources is a real challenge and wave energy harvesting seems to be relevant. A prototype, soft structured and based on EAP has been developed by SBM Offshore. The active tube's shell is composed of a stack of compliant electrodes and electroactive layers. Our work will focus for now on the elastomer composite electrodes: PDMS matrix filled with different carbon fillers as graphite, graphite nanoplatelets (GNP) and carbon nanotubes (CNT). Numerous studies on compliant/stretchable electrodes with similar formulation have been undertaken and the literature is substantial on the topic. Electrical performances have been reported, such as volume conductivity, surface resistivity and conductivity evolution under mechanical stress (tensile test and cycles). We propose to bring these results a complement by measuring the DC volume conductivity depending on the current density, which, at the best of our knowledge hasn't been reported before. In order to investigate conduction mechanisms in the composite, the samples where tested at ambient temperature and at higher temperatures. Moreover DC volume conductivity measurements have been performed under mechanical deformation. Finally, we observed the microstructure of the electrodes by SEM.

1.3.16 Transparent dielectric elastomer actuator used as tunable optical grating

Xiaobin Ji (1), Samuel Rosset (1), Herbert Shea (1),

(1) Microsystems For Space Technologies Laboratory, Ecole Polytechnique Federale De Lausanne (EPFL), Neuchatel, Switzerland

Presentation given by Mr. Xiaobin Ji

In this work, a transparent dielectric elastomer actuator is integrated into a tunable transmission grating. A 13 micron-thick silicone membrane has been sandwiched between two 750 nanometer-thick transparent ionogel electrodes to fabricate a transparent dielectric elastomer actuator. By structuring the top transparent ionogel electrode into a sinusoid grating profile, with 2 µm period, the transparent dielectric elastomer actuator is transformed into a tunable transmission grating. The structured stretchable electrode plays both the role of electrical conductor and optical grating. When 1300V is applied between the two stretchable ionogel electrodes, the actuator presents a linear strain of 12.8 percent, which correspond to a 1.4 degree change in the first diffraction angle for green light. The transparent ionogel electrode also present the self-clearing property, thus further extending the lifetime of the actuator at high drive voltages. The ionogel electrodes maintain the accurate grating shape for several weeks, and could be patterned into the shape of any diffractive element.

Wednesday, 15 June 2016

General programme of the day

EAPlenary	Session 2.1 part I *Chair: Anne Ladegaard Skov, DTU, Denmark*	
	9:00- 9:30	Invited talk **Toribio Otero** University of Cartagena, Spain
EAPodiums	Session 2.1 part II *Chair: Toribio Otero, University of Cartagena, Spain*	
	9:30- 9:50	Invited talk **Gabor Kovacs** Empa and CT Systems, Switzerland
	9:50- 10:10	Invited talk **Tushar Ghosh** North Carolina State University, USA
	10.10- 10:30	Invited talk **Toshihiro Hirai** Shinshu University, Japan
Break	10:30- 10:50	Coffee break
EAPromises	Session 2.1 part III *Chair: Gabor Kovacs, Empa and CT Systems, Switzerland*	
	10:50- 11:10	Invited talk **Ingrid Graz** Johannes Keppler University, Austria
	11:10- 11:30	Invited talk **Ali Maziz** Linköping University, Sweden
EAPills	Session 2.2 part I *Chair: Ingrid Graz, Johannes Kepler University, Austria*	
	11:30- 12:40	**Pill oral presentations** 17 presentations of research activities (3 minutes each + 1 minute to change speaker)

Lunch	12:40-13:40	Lunch
EAPosters EAPrototypes EAProducts	Session 2.2 part II	
	13:40-14:50	**Posters & exhibitions** 17 posters
EAPills	Session 2.3 part I *Chair: Herbert Shea, EPFL, Switzerland*	
	14:50-16:00	**Pill oral presentations** 17 presentations of research activities (3 minutes each + 1 minute to change speaker)
EAPosters EAPrototypes EAProducts	Session 2.3 part II	
	16:00-17:20	**Posters & exhibitions** 17 posters Drinks and snacks served during the session (sponsored by Aura Scientific)
Best poster award	17:20-17:30	Announcement of the winner of the best poster award
Closing ceremony	17.30	Conference closure and handover to the next year's Chairman
EuroEAP Society's annual meeting	17:40	Annual meeting of the EuroEAP Society's General Assembly (open to members and non-members).

Session 2.1

(abstracts are listed in the order of presentation)

2.1.1 Mimicking haptic muscles and proprioception. Robust and reproducible electrochemical sensing-actuators: experiments, models and tools.

Toribio F. Otero (1),

(1) Technical University Of Cartagena. ETSII. Laboratory Of Electrochemistry, Intelligent Materials And Devices. Cartagena. Spain

Presentation given by Prof. Toribio F. Otero

Artificial muscles, actuators or soft motors giving reversible movements driven by reversible electrochemical reactions are robust, reliable and reproducible devices. The flowing specific current (current per unit of weight of the electroactive component) controls the displacement (linear or angular) rate. The sense of the current flow controls the sense of the movement. The consumed specific charge controls the displacement amplitude. The electrochemical control remains whatever the synthesis conditions of the electroactive material, the muscles dimensions or shape. The driving electrochemical reaction senses the mechanical, thermal, chemical or electrical working energetic conditions. One motor and several sensors work simultaneously in a physically uniform device driven by reactions/the reaction of the constitutive material. Actuating (current and charge) and sensing (potential and electrical energy) magnitudes are present at any time in the only two connecting wires. None parallel device exists in present technologies. Haptic muscles are also dual devices and develop, with brain and nerves, proprioception. A basic proprioceptive equation, attained from basic electrochemical, polymeric and mechanical principles describes experimental results. Artificial muscles are useful tools for the identification and quantification of: the driving reaction, the presence of parallel irreversible reactions, creeping effects, osmotic effects, cooperative or antagonist actuating effects.

2.1.2 From research to industrial production

Gabor Kovacs (1),

(1) Empa, Lab Of Mechanical Systems Engineering, Dübendorf, Switzerland

Presentation given by Dr. Gabor Kovacs

In the past decades the development of compliant dielectric materials, capable of storing high electric energy density, is the object of considerable research efforts for commercial applications. Compared to the widely used soft dielectrics as compliant insulators, only a small variety of commercially products based on dielectric polymer transducers are available on the market up to date. A whole bunch of research activities worldwide has created a lot of very useful knowledge; but many researchers have been faced to different demonstrators manufacturing issues. However, building handy demonstrators is one of the most relevant action in order to attract the leading managers of the interested industrial companies. Moreover, low cost manufacturing strictly requires very efficient production methods and facilities to become competitive on the market. This represents the ultimate requirement especially for very high output rates and is one of the major topic at most negotiations. All problems linked to this issue have been addressed only a little in the past R+D activities and are still widely not satisfactory solved. The present talk will provide an overview of the options for opening the door of industrial production of polymer transducers and the remaining obstacles to be solved for the next step. In particular, we will discuss the most relevant measures to be taken for enabling high capacity production at very low cost.

2.1.3 Anisotropic dielectric electroactive polymer with tunability

Tushar Ghosh (1), Krishna Bala Subramani (1), Xiaomeng Fang (1), Richard Spontak (1) (2),

(1) NC State University, Fiber & Polymer Science Program, Raleigh, NC, USA
(2) NC State University, Department Of Chemical & Biomolecular Engineering, Raleigh, NC, USA

Presentation given by Dr. Tushar Ghosh

Dielectric electroactive polymers (D-EAP) constitute a class of soft materials that deform in response to input electrical energy. The primary focus of research in D-EAPs has been aimed at improving actuation response using materials that deform isotropically. The directional actuation required in most applications, however, is obtained through complicated fabrication of the D-EAP based device. New design paradigms to produce significantly increased directional response will be presented. These include, dielectric elastomer matrix reinforced with unidirectionally aligned elastomeric fibers to form 1-3 type composites and unique carbon nanotube based electrodes. The all-polymer lightweight composite laminates exhibit improved dielectric behavior and excellent directional stress/strain behavior under an applied external electric field. The composite designs yield mechanically anisotropic materials that exhibit a broad range of composition-tunable electromechanical anisotropy. The experimental data reflects synergistic effects due to filler or electrode induced mechanical anisotropy, as well as improved permittivity, which together result in high linear actuation strains at significantly reduced electric fields.

2.1.4 Electrical actuation of dielectric gels and elastomers - Deformation by asymmetric charge distribution

Toshihiro Hirai (1),

(1) Fiber Innovation Incubator, Faculty Of Textile Science And Technology, Shinshu University

Presentation given by Prof. Toshihiro Hirai

This presentation includes from the polymer gels highly swollen with dielectric solvent, elastomers without solvent, and plasticized polymers. All of these polymeric materials can be actuated by asymmetric charge distribution which has some characteristic features: (1) Charge injection, (2) solvent migration by solvent drag or charge migration, (3) asymmetric charge distribution by discharging depression. These processes caused various actuations such as (1) bending, (2) crawling, (3) creeping, (4) folding, (5) tacking, and (6) vibration. All of these deformation or actuation can be induced by applying dc electric field. About vibration even PET films without any additives can be used. Common features of these soft polymer materials contain huge increase of dielectric constant at low frequency range. The colossal dielectric constant suggested us to the possibility of electro-optical and piezoelectric functions to these materials. These materials show the interesting functions of light deflection with huge Kerr effect and/or Pockels effect, and piezo-electric functions which depends remarkably on the composition of plasticizer or solvent. These results will provide new possibility of the conventional polymer materials as electrically active materials.

2.1.5 Harnessing mechanical instabilities for fast actuation

Ingrid M. Graz (1),

(1) Johannes Kepler University Linz, Soft Matter Physics, Altenbergerstrasse 69, 4040 Linz, Austria

Presentation given by Dr. Ingrid M. Graz

How do you eat when you can't move? Some plants solve this matter of life-and-death by harnessing mechanical instabilities. The Venus flytrap catches its prey employing a snap-buckling instability from concave to convex in a few tens of seconds. The also carnivorous bladderworts utilizes liquid-pressure differences to induces snap-buckling to operate its traps. Can we learn from plants how to build efficient and fast elastomer actuators? This talk will explore approaches to designing actuators inspired by plant movements. Balloon instabilities, mainly snap-trough instabilities from planar/convex to convex are used to achieve fast actuation. Liquids help to change the pressure and trigger these instabilities. Simple soft robotic gripper prototypes exploiting those concepts are presented.

2.1.6 Electromechanically active textiles for soft assistive devices

Ali Maziz (1), Alexandre Khaldi (1), Nils-Krister Persson (2), Edwin Jager (1),

(1) Linkoping University
(2) University Of Boras

Presentation given by Mr. Ali Maziz

There has been an increasing demand to make novel human-friendly robots capable of working alongside humans. Such soft robots need to be compliant, lightweight and equipped with silent and soft actuators. Conducting polymers (CPs) are smart materials that deform in response to electrical simulation and are often addressed as artificial muscles due to their functional similarity with natural muscles. They offer unique possibilities and are perfect candidates for such actuators since they are lightweight, silent, and driven at low voltages. We have developed novel generation of soft actuators that combine one of humankind oldest technology with one of the latest, that is to combine the textile techniques of weaving and knitting with CPs. The use of innovative textiles technology provide a more conformal and natural motion to soft robotics, prosthetics and exoskeletons. We have developed new CP based fibres and novel architectures employing parallel assembly of the CP fibres using advanced textile technology resulting in electroactive textile actuators. These will provide enhanced actuation strain, speed and stress, similar to natural muscles. We will present the fabrication and characterisation of these CP based textiles as well as their performance as linear actuators.

Session 2.2
(abstracts are listed in the order of presentation)

2.3.1 Multiphysics modelling of ionic polymer transducer with porous carbon electrode

Sunjai Nakshatharan S. (1), Urmas Johanson (1), Andres Punning (1), Alvo Aabloo (1),

(1) Intelligent Materials And Systems Laboratory, Institute Of Technology, University Of Tartu, Estonia

Presentation given by Mr. Sunjai Nakshatharan Shanmugam

Migration of ions under electric field is the phenomenon behind the mechanical deformation of ionic polymer actuators. This transport process is influenced by numerous factors depending on the physical, chemical and electrical properties of the ion channels in the type of material used. In this work, microstructural mathematical analysis of ion transport and mechanical deformation of the actuator with porous electrode is examined. A three dimensional Multiphysics model of tri layer actuator with porous carbon electrodes and ion conductive separator membrane is presented. Porous electrode theory considering the effects porosity and tortuosity in each of the layer are incorporated in the model. The actuator samples are prepared and experiments are conducted in order to measure the key parameters and also to verify the accuracy of the developed model. Chemo electro and mechanical response of the material are coupled together and solved numerically using finite element method. The result shows the theoretical model was able to well predict the behavior of chemo electro mechanical response of the actuator. It is shown that the conductivity and so the mechanical deformation is highly influenced by the porosity of the material. This study provides a comprehensive understanding of behavior of ion transport in actuators made of porous electrode.

2.3.2 Effect of electrical terminals made of copper to the IPMC actuators

Sunjai Nakshatharan S. (1), Urmas Johanson (1), Andres Punning (1), Alvo Aabloo (1),

(1) Intelligent Materials And Systems Laboratory, Institute Of Technology, University Of Tartu, Estonia

Presentation given by Mr. Sunjai Nakshatharan Shanmugam

In order to diminish the effect of terminals to IPMC, the electrical input terminals should be made of a noble metal - platinum or gold. Nevertheless, several published papers report about the results obtained with setups where terminals are made of copper. As a matter of fact, copper is electrochemically not stable enough, even at very low voltages. As soon as a voltage is applied between the terminals, the ions of copper formed in the process of oxidation migrate very fast into the IPMC. The bending of IPMC actuators is caused by the movement of cations in the applied electric field. In the region of electrical terminals the infiltrated cations of copper will participate in this process, giving additional effect. As a result, close to the input terminals the bending of the IPMC actuator is significantly amplified. With the help of a experiment we compare the bending of an aqueous IPMC material using terminals made of copper and made of gold. We demonstrate that copper contacts: a) Promote bending close to the terminals; b) Alter the composition of the IPMC between the terminals.

2.3.3 Synthetic approach to obtain silicone-based elastomers with improved electromechanical properties

Maria Cazacu (1), Codrin Tugui (1),

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

Presentation given by Dr. Maria Cazacu

An original polyurethane (PUUS) containing tetramethyldisiloxane moiety but also pendent carboxyl groups in structure has been prepared and mixed in different percentages with polydimethylsiloxanes of various molecular masses (70000, 230000 and 370000 g/mol). The mixtures were made into films and stabilized by simultaneously crosslinking of the two networks, the silicone by chemical crosslinking while the polyurethane by intermolecular interactions. The samples were studied in terms of mechanical and dielectric behaviour. Higher dielectric permittivity value besides moderate increasing in Young modulus is reflected in increase of electrically induced actuation, the best results being recorded in the case of the PDMS with molecular weight of 230000 g/mol interpenetrated with 10 wt% PUUS.

2.3.4 Carbide-derived carbon and polypyrrole soft microactuator

Zane Zondaka (1) (2), Yong Zhong (1), Edwin Jager (1),

(1) Linkoping University, Department Of Physics, Chemistry And Biology, Linkoping, Sweden
(2) University Of Tartu, Institute Of Technology, Tartu, Estonia

Presentation given by Ms. Zane Zondaka

Conducting polymer based actuators show good displacement and actuation. The most commonly used polymer in the field of actuation is polypyrrole (PPy). The addition of carbon based materials (e.g. carbide-derived carbon(CDC)), thus creating composite materials, may increase the conductivity of the polymers and improve the performance of PPy based actuators. However there are no reports yet of using these composite materials in microscale devices such as microactuators. Here we present our research to microfabricate and test PPy-CDC hybrid material based devices at the microscale. We have incorporated these novel hybrid materials in in-house developed microfabrication process. The hybrid material based microactuators show bending while actuated under 2V in an aqueous electrolyte solution. The PP-CDC microactuators function similar to pure PPy microactuators, and more detailed characterization is on-going.

2.3.5 Interpenetrated polymer networks based on commercial silicone elastomers and ionic networks with high dielectric permittivity and self-healing properties

Elisa Ogliani (1), Liyun Yu (1), Anne Ladegaard Skov (1),

(1) The Danish Polymer Centre, Department Of Chemical And Biochemical Engineering, Technical University Of Denmark, 2800 Kgs. Lyngby, Denmark

Presentation given by Ms. Elisa Ogliani

The dielectric elastomers (DEs) technology can be used in many advanced applications, such as actuators, generators and sensors, showing promising properties. However, the main disadvantage is the high driving voltage required for the actuation process. One method used to avoid this limitation is to increase the dielectric permittivity of the material in order to improve the actuation response at a given field. Recently, interpenetrating polymer networks (IPNs) based on covalently cross-linked commercial silicone elastomers and ionic networks from amino- and carboxylic acid- functional silicones have been designed. This novel system provides both the mechanical stability and the high breakdown strength given by the silicone part of the IPNs and the high permittivity and the softening effect of the ionic network. Interpenetrating systems show dielectric permittivity from 6,7 to 2000 at 0,1 Hz and the commercial elastomers RT625 and LR3043/30 provide the best viscoelastic properties to the systems, since they maintain low viscous losses upon addition of ionic network. The values of the breakdown strength in all cases remain higher than that of the reference pure PDMS network. In addition, the ionic part of the interpenetrating systems provides promising self-healing properties both upon mechanical rupture and upon electrical breakdown. This advantage achieved by the IPNs represents an encouraging step forward in the challenge of increasing the life-time of the DEs.

2.3.6 Fabrication of polypyrrole based dry state on-chip microactuators

Yong Zhong (1), Staffan Lundemo (1), Edwin W.H. Jager (1),

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

Presentation given by Mr. Yong Zhong

We have developed a microfabrication process to fabricate on-chip microactuators that can work in open air. The on-chip microactuators were fabricated using standard photolithographic techniques and wet etching, combined with special design processing to micropattern polypyrrole. By patterning a UV-polymerizable gel containing a liquid electrolyte on top of the electroactive polypyrrole layer, actuation in air is achieved. The resulting microactuators were able to move, although with reduced movement which we contribute to poor ionic conductivity. Further optimization of the processing is currently on-going. The result shows the possibility to fabricate complex microsystems such as microrobotics and micromanipulators based on these dry state on-chip microactuators.

2.3.7 On the actuation of multi-layer dielectric elastomer actuators interfaced to compressive loads via thick soft membranes

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(2) Queen Mary University Of London, School Of Engineering And Materials Science, London, UK
(3) Cardiff University, School Of Engineering, Cardiff, UK
(4) University Of Pisa, Research Centre "E. Piaggio", Pisa, Italy

Presentation given by Mr. Luigi Calabrese

Multi-layer planar Dielectric Elastomers Actuators (DEAs) are electromechanical transducers consisting of stacks of soft thin elastomeric films coated with compliant electrodes. For applications that require the stacked DEA to work under axial compressive loads, the device needs to be insulated from the external structures, both for electrical safety and mechanical protection. The insulation can be provided by interface layers, which inevitably introduce a constraining effect on actuation. Specific applications might require insulating layers that are not only non-rigid, but also softer than the DEA material. In such cases, effects on the actuation performance exerted by the coating layers, according to their thickness and stiffness, are non trivial. In this work, such effects are studied with both theoretical and experimental investigations, using acrylic-elastomer-based DEAs sandwiched between soft silicone layers of variable thickness and elastic modulus. Experiments and FEM modelling allowed for identifying optimum parameters to maximise the actuation performance. This study might help to improve the design of interfaces between DEAs and external loads.

2.3.8 A self-sensing algorithm for dielectric elastomer actuators with improved capacitance and resistance estimation at low sampling-to-signal frequency ratio

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(2) Department Of Electrical And Electronic Engineering, Politecnico Di Bari, Bari, Italy

Presentation given by Dr. Gianluca Rizzello

This paper presents a novel self-sensing algorithm for Dielectric Elastomer actuators. The method, based on online identification algorithms, permits to obtain accurate estimations of material capacitance and electrodes resistance. While the capacitance can be used to reconstruct the mechanical deformation of the membrane (self-sensing), the resistance can provide additional information on the actuator state, e.g., fatigue (self-monitoring). The main features of the algorithm are its relatively simple structure, which makes it suitable to be implemented on microcontrollers, and the requirement of voltage and current measurements only, which eliminates the need of designing additional charge or capacitance sensors. The new self-sensing method is presented and compared with a different algorithm previously developed by the authors. By means of several experiments, it is proved how capacitance and resistance predicted by the new algorithm are in agreement with the values measured with an LCR meter. Moreover, it is shown how the accuracy of the new method does not deteriorate when reducing the sampling-to-signal frequency ratio (the method is tested up to a ratio of 2.5). This result enables achieving reliable self-sensing without a significant amount of online computation effort.

2.3.9 Supersonic cluster beam deposition: a novel technique for the fabrication of compliant electrodes for dielectric elastomer transducers

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Presentation given by Mr. Andrea Bellacicca

One of the major challenge in the fabrication of dielectric elastomer transducers (DETs) and their integration in devices is the realization of compliant electrodes able to sustain very large number of deformations while remaining electrically conductive. These electrodes must adhere well to the soft elastomer without significantly increasing its stiffness, in order not to alter the elastic characteristic of the DETs. Here we present a novel technique called supersonic cluster beam deposition (SCBD) for fabrication of metal/polymer nanocomposites. With SCBD it is possible to implant neutral metal clusters inside elastomers polymeric matrix on a wide typology of polymers to produce stretchable metal/polymer nanocomposite electrodes with an excellent adhesion below the substrate surface. SCBD technique avoids both sample heating and charging and it is fully compatible with stencil mask micropatterning. The electrical properties of the nanocomposite can be fine tuned, they can sustain large deformations with a little loss in conductivity and they improve upon cyclical stretching tests. We also demonstrated that the mechanical properties of the nanocomposite can be maintained close to that of the bare elastomer for large metal volume concentrations producing a stretchable and patterned 17 um thin films Ag/PDMS DETs with very good electro/mechanical properties.

2.3.10 Novel printed linear actuators based on conducting polymer with activated carbon aerogel

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Presentation given by Ms. Inga Põldsalu

Bending tri-layer actuators are in general synthesized by depositing conducting polymers electrochemically in a sandwich arrangement with ion-conducting membrane separating working and counter electrode. When connecting the working and the counter electrode as one electrode, instead of bending, linear actuation can be performed in an electrolyte. Our aim in this work was to investigate the linear length change and force properties of printed tri-layer actuators comparing those of poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) and hybrid PEDOT:PSS- activated carbon aerogel (ACA) electrodes. Electro-chemo-mechanical-deformation (ECMD) measurements with cyclic voltammetric signal in the potential range 1.0 V to -0.6 V revealed that PEDOT:PSS tri-layer has nearly double the strain of PEDOT:PSS-ACA tri-layer while the stress is higher in the case of PEDOT:PSS-ACA. Characterization of the novel printed tri-layer actuators were performed applying infrared spectroscopy and scanning electron microscopy. This work shows for the first time the potential of printed form of conducting polymer- carbon hybrid actuators and printing as a technology applicable for fabrication of electromechanical actuators.

2.3.11 Development and optimization of a moving interface for in vitro models of epithelial barriers using an EAP

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Presentation given by Dr. Joana Costa

The physiological barriers of the human body are characterized by dynamic conditions such as flow and motion, exposing the epithelial cells to continuous mechanical stimuli. This study focuses on the development of a system for cell deformation using the EAP technology. In the future such a device can be used to develop a realistic in vitro model of different mobile biological interfaces. Our proposal is a DEA (dielectric elastomer) composed of a VHB membrane cast on a rigid frame - a central passive area is dedicated for the cell culture, while the surrounding circular active area is covered by compliant electrodes. In this work, several configurations with different ratios of passive to total area were tested in order to assess the ideal trade-off between maximum compression, minimum applied voltage and dimension. The purpose was to determine the best combination that allows the design of small DEA resembling the traditional cell culture systems. Aiming at compatibility with the cell culture environment, new electrodes consisting of a conductive silicon ink were developed by mixing PDMS with carbon black particles applied by aerosol deposition on the surface of the VHB membranes. The results indicate that the optimal ratio passive/total membrane area is between 20 and 40%. The actuation performance of the conductive silicon electrodes was excellent, allowing us to obtain between 8 and 10% of deformation using 4 kV at a frequency of 0,15 Hz.

2.3.12 Electronic board dedicated to conducting IPN actuators

Tien Anh Nguyen (1), Chia-Ju Peng (1) (2), Luc Chassagne (1), Adelyne Fannir (3), Kätlin Rohtlaid (3), Tran Minh Giao Nguyen (3), Cedric Plesse (3), Frédéric Vidal (3), Shih-Jui Chen (2), Barthélemy Cagneau (1),

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Presentation given by Dr. Cedric Plesse

In this work, we are interested in the design of an electronic board which can be used for sensing and actuating of conducting IPN actuators. The first prototype allows the user to generate custom signals for actuation purposes (steps, sine, triangle...). It allows also to record the deformations externally applied to the polymer by reading the voltage between the two electrodes. However, the voltage required for actuation is of a few volts while the measured voltages during sensing is only of a few millivolts. It is thus necessary to magnify the measured voltage with signal processing techniques. We explain how the board has been designed to process the signal and to design a convenient system for both sensor and actuator capabilities (components, filters, hardware specifications). The performances of the system are evaluated by providing first experimental results.

2.3.13 Harvesting human kinetic energy by electret-based soft generators

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Presentation given by Ms. Clara Lagomarsini

Harvesting human kinetic energy to produce electricity is an attractive alternative to batteries for applications in wearable electronic devices and smart

clothing. Dielectric elastomers generators (DEGs) represent one of the most promising technologies for these applications. One of the main disadvantages of these electrostatic generators is the necessity of an external polarization source to perform the energetic cycle. In order to overcome this problem, our research group worked on a hybrid and autonomous generator made by an elastomeric membrane coupled with an electret material. This device was able to scavenge an electrical energy density of theoretically 1,42mJ*g-1 and experimentally 0,55mJ*g-1 by charges reorganization between two opposite electrodes of a variable capacitor. In this work, we present a new prototype of our soft electret-based harvester used to exploit human kinetic energy during walking. As compared to the previous design realized with the same technology, the advantages of this new device are lower encumbrance and mechanical force necessary to deform the structure. The numerical simulations data derived from the electrical model of the structure will be compared with the experimental results obtained on the prototype. The performance of this device will be compared with the first results obtained on a new generator design which uses the electret to polarize a classic dielectric elastomer generator.

2.3.14 Development of a fatigue testing setup for dielectric elastomer membrane actuators

Marc Hill (1), Gianluca Rizzello (1), Stefan Seelecke (1),

(1) Saarland University

Presentation given by Mr. Gianluca Rizzello

Dielectric Elastomers (DE) represent a transduction technology with high potential in industrial application, due to their low weight, flexibility, and small energy consumption. For industrial applications, it is of fundamental importance to quantify the lifetime of DE technology, in terms of electrical and mechanical fatigue, when operating in realistic environments. This work contributes toward this direction, by presenting the development of an experimental setup which permits systematic fatigue testing for DE membranes. The setup permits to apply both mechanical and electrical stimuli to the membranes, and measure at the same time their mechanical (force, deformation) and electrical response (capacitance, resistance). In its final state, the setup will allow to test up to 15 DE membranes at the same time for several thousands of cycles. The control of the modules, the monitoring of the actuators, and the data acquisition are realized on a cRio FPGA-System running with LabVIEW. The setup is located in a climate chamber, in order to investigate the fatigue mechanisms at different environmental conditions, i.e., in terms of temperature and humidity. This will permit to quantify mechanical and electrical failure mechanisms and to understand how they affect the lifetime of DE membrane actuators.

2.3.15 Measurement setup for the characterization of the dielectric breakdown strength of thin elastic films in various ambient media

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Presentation given by Ms. Florentine Förster-Zügel

Dielectric Elastomer Transducers (DETs) can be used as actuators, sensors and generators. The dielectric breakdown field strength of the elastomer restricts the driving voltage. For an efficient operation of the DET the breakdown strength of the elastomer has to be known. For the fabrication of DETs, Wacker Chemie AG developed a thin PDMS film which exhibits high breakdown strength and low thicknesses down to 10 micrometers. Existing standards and methods for the measurement of the breakdown strength seem to be not applicable for such thin films. In this work a new setup for the measurement of the breakdown strength of thin elastic films in various ambient media is described. The main feature of the new measurement setup is that breakdown measurements in different ambient media (solids, liquids, gases) can be conducted. Furthermore, ten test points on one film sample can be investigated in one ambient media without changing the measurement setup which leads to a high comparability of the measured breakdown data. Breakdown measurement results of PDMS films (50 micrometers thick) in air, silicone oil and solid silicone material are compared. The results show that the measured breakdown strength of the PDMS film depends on the ambient medium. An ambient medium with a higher dielectric constant and a higher breakdown strength leads to a higher breakdown strength of the PDMS film during the measurements.

2.3.16 Development of a flexible sheet-like soft actuator using plasticized PVC gel fibers.

Ayumi Sakaguchi (1), Minoru Hashimoto (1),

(1) Shinshu University, Faculty Of Textile Science And Technology, Ueda, Japan

Presentation given by Dr. Ayumi Sakaguchi

In this study, two types of new actuators, which were prepared from plasticized PVC gel, were proposed for construction of a flexible sheet-like soft actuator. First, a woven sheet formed from conductive plasticized PVC gel fibers with a core-sheath structure. Second, a yarn-structured PVC gel actuator. Then, the characteristic of these two types of actuators was examined from a preliminary experiment as a flexible sheet-like soft actuator. The woven sheet actuator was formed by a plain weave using flat conductive plasticized core-sheath PVC gel fibers and aluminum foil tubes which were connected to the cathode and anode electrode, respectively. By applying a voltage of up to 500 V, the actuator was contracted with deformations along the anode surface of conductive plasticized PVC gel fibers. Contraction strain was increased with increasing of applied voltage, and it became about 20 % at 400V. On the other hand, a yarn-structured PVC gel actuator extended by applying a voltage. This result indicates that these structures of the woven sheet and yarn-structured actuator were able to drive in plane and axial direction, our proposal was demonstrated to be effective for development of a flexible sheet-like soft actuator.

2.3.17 Thermal breakdown in silicone elastomers

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(1) Danish Polymer Center, Chemical And Biochemical Engineering, Technical University Of Denmark, Kongens Lyngby, Denmark

Presentation given by Ms. Camilla M. Kjeldbjerg

Thermal breakdown occurs when the heat generated within the DE cannot be dissipated away rapidly enough. This causes elevated temperatures for the elastomer and can lead to breakdown. The elevated temperatures are often designated as a thermal runaway. The increase in temperature increases the conductivity of the polymer, which again increases the energy generation from Joule heating giving a positive feedback effect. The thermal breakdown is affected by different properties, e.g. changing the electrical conductivity for the DE changes the amount of heat generated. In addition, stacking the changing the number of layers also changes the amount of heat generated as heat dissipation is confined to the outer surface. The electrical conductivity is usually exponentially dependent on the temperature of the elastomer and therefore increasing the number of layers will increase the heat generated exponentially. The heat dissipated away from the elastomer due to free convection is described by the film theory, and depends only on the difference in temperatures between the surface of the elastomer and the surroundings and the area exposed to the surroundings. From the amount of heat generated and dissipated from free convection for elastomers it is possible to find the maximum numbers of elastomer layers for a given conductivity. Thermal breakdown will not occur as long as the power of energy generation is lower than the power for which energy is transferred by free convection.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 Challenges in gesture control of robots based on multi-degree of freedom movement recognition with dielectric elastomer sensors

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(1) Friedrich-Alexander-University Erlangen-Nuremberg, Institute For Factory Automation And Production Systems, Erlangen, Germany

Presentation given by Mr. Maximilian Landgraf

We present our current progress in the development of multi-degree of freedom (DOF) gesture based robot control within the Robot Operating System (ROS), our experiences from the user's point of view and also the challenges in robot control while using dielectric elastomer sensors (DES). Due to drawbacks of other well-established gesture recognition methods, such as vision based technologies, in our application the movement of the user's arm is recognized by DES attached to his/her arm. DES are lightweight, soft and flexible, which make them comfortable to wear, like already realized in a glove of StretchSense Ltd., which is able to recognize the fingers' movements. In future, DES could also be integrated in body fitting long sleeved shirts to be able to detect additional DOFs. Due to the limited variety in size and length of the commercially available sensors, the identification of suitable sensor positions for detection of different DOFs is impeded. Aspects such as material aging, inappropriate handling and deviations of sensor positions affect the quality of movement recognition by changes of the sensor capacity range, noise and mutual influence of the sensors. With the present sensor values only a simple control of a robot is possible. Actual solutions for the issues mentioned above are the implementation of a calibration process before each use, the software based reduction of the sensors' noise and simple mechanical protections against an overstretching of the sensors.

2.3.2 Biocompatible microfluidic systems based on dielectric electroactive actuators

Susana Solano Arana (1), Holger Mößinger (1), Helmut F. Schlaak (1),

(1) Technische Universität Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany

Presentation given by Ms. Susana Solano Arana

Microfluidic devices are nowadays widely investigated for applications in the field of biomedicine, analytical chemistry and for the lab-on-a-chip industry. Peristaltic micropumps can be used to replace biological organs, as a result of their pulsed and soft/delicate flow. Unlike other micropumps, in peristaltic micropumps the fluid only contacts the microchannels, and no other parts of the pump like valves or pistons. Therefore, contamination of the pumped fluid is avoided and lower damage is caused to cell membranes and to the pumped fluid. Different biocompatible materials have already been used to fabricate micropumps. One of the most promising materials is polydimethilsiloxane (PDMS), due to its lightness, biocompatibility, high flexibility and low cost. For medical applications, reducing the high voltage required for PDMS based dielectric elastomer actuators is however a major challenge. In this work, new biocompatible microfluidic devices based on Dielectric Electroactive Actuators (DEAs) are developed. The main goal is not only the reduction of the required voltage, but also the increase of the flow rate. During the course of the project within the European Project MICACT, actuators with different electrode materials and electroactive polymer materials will be designed.

2.3.3 Electrically shielded dielectric elastomer actuators for the study of the mechanical perturbation of cardiomyocytes

Matthias Imboden (1), Alexandre Poulin (1), Etienne de Coulon (2), Samuel Rosset (1), Stephan Rohr (2), Herbert Shea (1),

(1) Ecole Polytechnique Fédeérale De Lausanne (EPFL), Microsystems For Space Technologies Laboratory (LMTS), Neuchâtel, Switzerland
(2) Universität Bern, Institut Für Physiologie, Bern, Switzerland

Presentation given by Dr. Matthias Imboden

We present the development of a mechanically active bioreactor. Using dielectric elastomer actuators (DEA), we are able to mechanically perturb cell cultures in a controlled environment. With tailored pre-strain and compliant electrodes, it is possible to digitally control the strain state of the cell culture substrate and generate tensile strain exceeding 20%. This bioreactor enables new types of studies of cytomechanics. Specifically, we will use the bioreactor to study cellular mechanisms of cardiac arrhythmias that are related to mechanoelectrical feedback. DEAs require high electric fields to generate physiologically relevant strain levels of 10%. Typically, potentials up to 5 kV are applied to electrodes that are located a few tens of microns from the cells. Resulting electrical fields may adversely affect cell physiology and mask the mechanosensitive response under study. To circumvent this problem, we present a stacked DEA design where the HV-electrode is embedded between grounded electrodes. This design practically eliminates the cells' exposure to fringe fields. Compared to a two-electrode configuration, it is shown that stray fields can be suppressed by six orders of magnitude. Tests on cardiomyocytes indicate that this layout is sufficient to prevent unwanted electrical triggering of the action potential. The device presented demonstrates the ability to combine electrically sensitive cells with mechanically active DEA bioreactors.

2.3.4 Technologies to enable controlled fabrication and system integration of carbon nanotube based ionic actuators, as example: liquid handling for biomedical applications

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(2) Stuttgart University, Institute Of Industrial Manufacturing And Management (IFF)

Presentation given by Mr. Raphael Addinall

Technologies to enable controlled fabrication of electrode material for carbon nanotube based ionic actuators, as example: biomedical applications.Multiple variation of materials, dispersing methods and assembly processes have been adopted throughout the years with the aim to optimise not only performance (stress, strain and reaction rate), but also reproducibility of actuators. Current state of the art production methods are still in the domain of lab scale. The growing interest from multiple industry sectors has now created the need for the scientific community to come together and develop new or adapt existing manufacturing routes capable of mass production for the expected demand of the future. A focus on biomedical applications, fabrication control and system integration of the actuators to enable increased reproducible performance will be the aim of this work. From additive manufacturing technology enabling ease of system integration to the influence of electronic contacts on the reproducibility of actuator performance will be explored.

2.3.5 Bimodal condensation silicone elastomers as dielectric elastomers

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Presentation given by Dr. Liyun Yu

Most elastomers are prepared by end-linking, resulting networks are so-called unimodal networks there is one polymer only in the system. Bimodal networks where two polymers with different molecular weights are mixed with one crosslinker. Silicone rubber can be divided into condensation and addition type according to curing reaction. Condensation silicones are low cost, curing rate largely being independent of temperature, excellent adhesion and catalyst being nontoxic. Bimodal condensation elastomers were prepared by mixing different mass ratios (9:1, 8:2, 7:3, 6:4, 5:5, 4:6) between long and short PDMS chains. Elastomers were investigated by rheology, dielectric properties, tensile strength, electrical breakdown and thermal stability. Bimodal elastomers reinforce themselves at large strain and high electrical breakdown strength is obtained due both to low extensibility of short chains that attach strongly long chains and to extensibility of last ones that retards rupture process. Elastomers with the same mass ratio (7:3) between long and short PDMS chains were made at different humidity (90%, 70%, 50%, 30%, 10%) at 23 degrees. Dielectric and mechanical properties depend strongly on atmospheric humidity level. Top and bottom surfaces of elastomer (7:3) prepared at 23 degrees and 50% humidity were tested by water contact angle and optical microscope. Bimodal condensation elastomer possesses structural heterogeneity, which may lead to favourable properties for DE applications.

2.3.6 Largely improved actuated strain of homogeneous dielectric elastomers by grafting dipoles onto SBS using thiol-ene click chemistry

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(2) Beijing University Of Chemical Technology, College Of Materials Science And Engineering, Beijing, China

Presentation given by Prof. Ming Tian

Herein, we report an approach to the preparation of a homogeneous styrene-butadiene-styrene triblock copolymer (SBS) dielectric elastomer (DE) with dramatically improved actuated strain by using a photochemical thiol-ene click reaction. The stock SBS was grafted with dipoles (ester groups) to increase the polarizability of SBS. The grafting degree of dipoles on SBS can be controlled by irradiation time to control the electromechanical properties. The grafting degree of modified SBS increases with the increase of irradiation time, and a maximum 87.5% grafting degree can be achieved at a radiation time of 30min. After modification, the phase mixing of PB and PS block occurs and the size of PS domains largely decreases, leading to the obvious decrease in the tensile strength and elastic modulus (Y). However, the modified SBS still shows good tensile strength (>3MPa). More importantly, the dielectric constant (k) largely increases for modified SBS. The simultaneous increase in k and decrease in Y result in the large increase in electromechanical sensitivity, and thus the large increase in maximum actuated strain and the actuated strain at low electric field (e.g. 15kV/mm). In addition, the modified SBS shows consistently low dielectric loss. Our study provides a simple, effective and controllable chemical method to prepare homogeneous DE with high k, large actuated strain at low electric field, good mechanical strength, easy processibility, and recyclability.

2.3.7 Tailoring dielectric properties of polymer composites by controlling the alignment of carbon nanotubes

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Presentation given by Prof. Nanying Ning

We prepared hydrogenated butadiene-acrylonitrile (HNBR) elastomer composites with random orientation of carbon nanotubes (CNTs) and aligned CNTs by using a simple mechanical blending method, named as random composites and aligned composites, respectively. The CNTs are dispersed uniformly in the HNBR matrix in both composites. Interestingly, in the CNTs content of 1-2.5 vol.%, the dielectric loss of aligned composites increases slightly and the dielectric constant of aligned composites largely increase with increasing the content of CNTs, whereas both dielectric loss and dielectric constant of random composites largely increases with increasing the content of CNTs. As a result, a high dielectric constant (5000 at 1000 Hz) and a low dielectric loss (0.42 at 1000 Hz) was obtained in aligned composite with 2.5 vol.% of CNTs content, whereas a high dielectric constant and a high dielectric loss was obtained in random composite. The relationship between the micro-structure and dielectric properties was qualitatively analyzed by using percolation theory and intercluster polarization model. The mechanism for the achievement of dielectric composites with high dielectric constant and low dielectric loss was discussed. This study provides a guide to design micro-structures that yield composites with improved dielectric properties.

2.3.8 Developing a new technique for the fabrication of large dielectric elastomer stack actuators

Florian Klug (1), Florentine Förster-Zügel (1), Holger Mößinger (1), Helmut F. Schlaak (1), Georg Grötsch (2), Carsten Corneließen (2), Almuth Streitenberger (2), Moritz Eulenburg (2),

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Presentation given by Mr. Florian Klug

Many applications for dielectric elastomer stack actuators (DESA) have been in the focus of research for a long time. Some examples are peristaltic micro pumps, tactile interfaces and medical devices. At the moment, there are only a few institutions who can produce DESA in an automated process. In order to bring those applications to market a reliable and affordable production technology which can produce large actuators is required. This work focuses on developing an industrial fabrication technique for large DESA. The key feature is the fabrication of endless films which allows a fast production of large films on low costs. Furthermore, for using the actuators in medical applications, we are working on low dielectric layer thickness to reduce the driving voltage. In first experiments we achieved a two-layer compound with homogeneous dielectric layer thickness less than 10 micrometer and electrode thickness less than 1 micrometer by using water based materials. During the process the liquid materials are applied on top of each other and cured afterwards without intermixing. It is possible to apply up to four active layers in each process step. Patterning the electrodes in width enables electrical connection of all electrode layers.

2.3.9 Electrically tunable microcavity based on metallized and dye doped PDMS gel

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(2) Technical University Dresden, Institute Of Applied Photophysics, Dresden, Germany

Presentation given by Mr. Markus Franke

(Tunable) optical microcavities (MC) are essential systems for telecommunication, sensor or display application able to confine light in small volumes. Nowadays, many MC types exist in which the most common Fabry-Pérot (F-P) MC is an arrangement of two parallel mirrors that show a thickness dependent frequency spectrum. Combining a F-P MC with a dielectric elastomer actuator enables a feasible way to set up a tunable MC that has the edge over other microelectromechanical solution to tune optics. We present a F-P MC based on a metallized and ultra-soft PDMS gel that is able to vary the cavity layer thickness and frequency spectrum by electrical control. The MC is placed on a glass substrate with ITO electrode and distributed Bragg reflector as highly reflecting mirror on bottom. The cavity layer consists of the PDMS gel with a thickness of 14µm. Surface activation of the gel by oxygen plasma is necessary to create a reflective mirror and conductive electrode on top by PVD of silver. A homogenous deflection of the mirror is essential for a suitable working MC and is realized by reducing the lateral electrode dimension via structuring. We observe a cavity thickness decrease of 2.6µm (19%) at 70V by confocal microscopy. Additional doping of the PDMS with a pyrromethene dye allows a wavelength shift of 40nm at 70V in the emission spectra of the multimode MC. These results open the possibility to realize electrically tunable laser devices with low cost and easy processing.

2.3.10 Improving the manufacturing speed and the reproducibility of ionic CNT actuators by the use of screen printed electrodes

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Presentation given by Mr. Raphael Addinall

Electroactive polymer (EAP) actuators based on carbon nanotubes (CNTs) have found great interest in research and have the potential to be used in the field of soft robotics. They provide many advantages such as a low driving voltage, a noiseless movement and are lightweight. However, up to now ionic CNT actuators are not ready to be integrated into products that are ready-to-market. This is due to their moderate performance and their low reproducibility. In this poster the focus is on the reproducibility and the manufacturing speed of screen printed ionic CNT EAP actuators. The manufacturing of solution processed actuators can be divided into two steps. Firstly, the dispersion for the separator and the electrodes has to be made. Secondly, these materials have to be processed with different coating technologies. Commonly the dispersion is made by the use of a magnetic stirrer which in general is a slow dispersing method. In contrast an ultrasonic horn is used to reduce the time that is required to make the dispersion for the electrodes. Casting into a mould is mostly used to make the separation layers and the electrodes. With this technique thick layers can be realized, again however, solidification using this method is time consuming due to the large amount of solvent which has to evaporate. To reduce the manufacturing time of actuators and to improve the reproducibility, screen printing is used to print the electrodes of ionic CNT EAP actuators.

2.3.11 Tailoring electromechanical properties of thermoplastic elastomers with nanofillers for strain sensor applications

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Presentation given by Mr. Pedro Costa

Thermoplastic elastomers (TPE) are known for exhibiting high deformation capability and they are promising materials for the development of composites for sensors and actuator, due their excellent mechanical properties, such as large strain and easy recovery. These properties can be significantly modified by the addition of nanofillers [1]. Carbon nanotubes (CNT) are known to produce composites with superior electrical properties [1]. The CNT electrical properties [2] and the high aspect ratio allows that even at low concentrations they can strongly affect the composites electrical and piezoresistive properties [3]. TPE copolymer styrene-butadiene-styrene (SBS) is widely studied and used. SBS-based TPEs no need vulcanization, which is an advantage as it does not degrade their properties [4]. The application range of SBS, once suitably reinforced with CNT, can be tailoring to a variety of products: piezoresistive and piezocapacitive sensors, biomaterials for medical devices [5] or dielectric elastomer generators. Previous studies on CNT/TPE composites indicate that the final composites properties changes for different styrene/butadiene ratio [6]. The composites conductivity increase with CNT content and the percolation threshold is <1wt%. The composites mechanical properties with real time electrical tests show their possible use as piezoresistive sensors up to 50% of strain with the composites sensibility varying with CNT content, strain or pre-strain and can be up GF=120.

2.3.12 Multi-scale modeling EAP actuators using Bond Graph

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Presentation given by Mr. Ngoc Tan Nguyen

Trilayers structured from interpenetrating polymer network (IPN) sandwiched between two poly (3,4- ethylenedioxythiophene) (PEDOT) electrodes are promising actuators due to their excellent mechanical properties, high ionic conduction, low operation voltage, and open air function. For purpose of prediction the actuator behavior, modeling and simulation are the first requirement. In this work, a newly multi-scale model of trilayers actuators is derived and proposed using Bond Graph language. This model includes a physical sub system, a mechanical sub system, and the coupling matrix to transform the energy between both systems. Parameters of the model are either measured or compared to simulation and experimental results. The strain-to-charge ratio is verified to be varied as frequency and voltage input. Matching of simulation and measurement has confirmed that the combined model between RC equivalent circuit in electrical part and Euler-Bernoulli beam theory using modal-superposition in mechanical part succeeded in predict the displacement time response of actuators.

2.3.13 CNT embedded PAN/PPy nanofiber actuators synthesized by electrospinning method

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Presentation given by Ms. Atike Ince Yardimci

Among conducting polymers, polypyrrole (PPy) is appropriate to use in artificial muscles with its low actuation voltage and large stroke for an electrochemical actuation. However, it has a high viscosity, therefore, polyacrilonitrile (PAN) is used to improve low solubilitiy of PPy. In this study, PAN/PPy electroactive nanofibers with different PPy amounts were synthesized by electrospinning. 10 and 25 wt% PPy were investigated and the results showed that high concentration of PPy provided to obtain smaller electrospun nanofibers in diameter. In order to improve mechanical and electrical properties of PAN/PPy nanofibers, carbon nanotubes (CNTs) were incorporated into the nanofibers. Used CNTs were synthesized by chemical vapor deposition method on Co-Mo/MgO catalyst, were of high crystal quality single walled CNTs. Solution including 10 wt% PPy was found appropriate for used with CNT in electrospinning. When CNT was added into solution including 25 wt% PPy, nanofiber formation was not observed. CNT effects on PAN/PPy fibers including 10 wt% CNTs were observed by examining four different CNT concentrations, 1, 2, 3, 4 wt%. With increasing CNT concentration some beats and disordered sites were observed on the surface of fibers because of CNT agglomeration. It was observed that CNTs were aligned along the direction of nanofibers during electrospinning process due to high electrical field.

2.3.14 Flexible 1kV thin-film transistor driving out-of-plane dielectric elastomer actuator

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Presentation given by Mr. Alexis Marette

This work demonstrates dielectric elastomer actuators controlled by the world's first thin-film transistors on flexible substrate operating at 1kV, thereby enabling locally switching high-voltages on DEAs using a low control voltage. The high voltages required to drive DEAs limit their integration in complex systems, such as high resolution haptic displays and multiple-degree-of-freedom robotics. We report here a top-gate, thin-film transistor (TFT) with coplanar electrodes specifically designed to drive DEAs. The TFTs are fabricated on flexible polyimide, using solution-processed zinc-tin oxide, offset gate and thick dielectric bilayer of Alumina and Parylene. The TFT switches reliably at up to 1kV, outperforming on this metric all published high-voltage TFTs. The on-off current ratio ranges from 20 to 200, the saturation mobility is 0.1cm2/Vs, and the threshold voltage is 10V. Our DEAs are designed for maximal actuation strain at 1kV, to match the maximal voltage of the TFTs. The DEA is a diaphragm actuator: a suspended non-prestretched membrane with electrodes on both sides. The circular electrode has a 5 mm diameter and the silicone membrane is 17um thick. A backpressure of 50mbar is applied to the membrane. The TFT is wired in parallel with the DEA. A change of out-of-plane displacement of 350um is achieved with 30V applied to the gate, for a circuit bias voltage of 1.4kV. The TFT + DEA operate reliably for several weeks.

2.3.15 Conducting polymer microactuators with easy patterning and fabrication using soft-lithography

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Presentation given by Mr. Manav Tyagi

Fabricating polymer microactuators especially with different designs require multiple chromium photomask designs, as well as multiple photo-lithography steps on a silicon wafer. This adds to the complexity of process, and also the cost per device. We have developed an easy and cost-effective method for the patterning and fabrication of conducting polymer microactuators. We employ soft-lithography to pattern PDMS layers for use as construction element in actuator devices. Instead of fabricating using multiple photolithography steps with different chromium photomasks, we use a single design master to repeatedly obtain patterned PDMS layers, which are then specifically cut to obtain multiple device designs.

2.3.16 Design of high frequency trilayer conducting polymer actuators

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Presentation given by Ms. Saeedeh Ebrahimi Takalloo

Trilayer conducting polymer actuators are being considered for use as micro-actuators in Micro-Electro-Mechanical Systems (MEMS) due to their low-cost, low operating voltage, and down-scalability. However they typically suffer from relatively low force generation and slow actuation. Recent work has shown fast response, and here a strategy is proposed to guide the design of fast actuators, as well as to explore tradeoffs between speed, force and displacement. Being ionically electroactive, strain in conducting polymer actuators is directly proportional to charge. Hence, RC charging time constants due to the actuator capacitance, electronic and ionic resistances of the conducting polymer film as well as the separator layer can provide a guide towards the frequency response of the trilayer actuators. In this work, we introduce three RC time constants which depend on the critical dimensions of the trilayer actuator as well as the ionic and electronic conductivities of the films. These time constants and the structural resonance frequency are considered as the main indications of how fast the device can actuate. Considering a target frequency response or rise time, the maximum allowable value for the width and the length of the device, conducting polymer thickness and separator thickness versus the working frequency are computed. We evaluate our proposed approach by comparing the results obtained thought this method by the corresponding experimental data in the literature.

2.3.17 Aging setup for high cycle tests on dielectric elastomer actuators

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Presentation given by Dr. Christine Saint-Aubin (de)

To be implemented at the industrial scale, any dielectric elastomer actuator (DEA) must demonstrate long term reliability. For this purpose, a novel and fast DEA aging setup for high cycle tests has been developed. It monitors the in-plane strain and the change in electrode resistance of an expanding circle actuator (active area of approx. 10 mm^2) versus cycle number and drive voltage. A square voltage input signal of an amplitude up to 5 kV with resolution of 0.1% of full scale is applied to the tested actuator using a programmable high voltage supply, enabling fast switching at up to 1 kHz. The actuator mechanical output is recorded throughout the test via automated visual tracking of the edges of the top compliant electrode, from which long-time strain evolution can be inferred. The four-points-probe resistance of this electrode is measured simultaneously. This focus on the actuator electrodes allows studying their too often neglected behavior and influence on the whole DEA, as well as to optimize their formulation through comparisons between aging tests of actuators made with different electrode materials. Using this innovative, versatile, automated setup, actuator aging tests of a million of cycles can be easily performed overnight. This tool will enable dielectric elastomer actuators' industrial optimization to meet desired product technical specifications, but also in-depth academic understanding of their long-term behavior.

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