EuroEAP 2015

5th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Tallinn, Estonia
9-10 June 2015

Technical programme

Book of abstracts

List of participants

Contents

Conference venue

Meriton Grand Conference & Spa hotel

Paldiski road 4, 10149
Tallinn

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http://www.meritonhotels.com/conference-spa-hotel-tallinn/

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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 Chairman 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

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

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Peter Sommer-Larsen, Danish Technological Institute (Denmark)

Tuesday, 9 June 2015

General programme of the day

Opening	8:45-9:00	Welcome & introductory remarks **Alvo Aabloo** University of Tartu, Estonia
EAPlenariess	Session 1.1 part I *Chair:* **Alvo Aabloo**, University of Tartu, Estonia	
	9:00-9:30	Invited talk **Keiichi Kaneto** Osaka Institute Of Technology, Japan
EAPodiums	Session 1.1 part II *Chair:* **Keiichi Kaneto**, Osaka Institute Of Technology, Japan	
	9:30-9:50	Invited talk **Kinji Asaka** National Institute Of Advanced Industrial Science And Technology (AIST), Japan
	9:50-10:10	Invited talk **Hyouk Ryeol Choi** Sungkyunwan University, South Korea
Break	10:10-10:40	Coffee break
EAPromises	Session 1.1 part III *Chair:* **Elisabeth Smela**, University Of Maryland, USA	
	10:40-11:00	Invited talk **Cedric Plesse** University Of Cergy-Pontoise, Cergy, France
EAPills	Session 1.2 part I *Chair:* **Frédéric Vidal**, University Of Cergy-Pontoise, France	
	11:00-12:15	**Pill oral presentations** 17 presentations (3 minutes each + 1 minute to change speaker)

Lunch	12:15-13:15	Buffet lunch
EAPosters EAPrototypes EAProducts	Session 1.2 part II	
	13:15-14:45	**Posters & exhibitions** 17 posters
EAPills	Session 1.3 part I *Chair:* **Jonathan Rossiter**, University of Bristol, UK	
	14:45-16:00	**Pill oral presentations** 17 presentations (3 minutes each + 1 minute to change speaker)
Break	16:00-16:30	Coffee break
EAPosters EAPrototypes EAProducts	Session 1.3 part II	
	16:30-18:00	**Posters & exhibitions** 17 posters
Excursion	18:00	Old town excursion will start from conference hotel
Social dinner	20:00	Dinner will be served at medieval-themed restaurant Olde Hansa.

Session 1.1

(abstracts are listed in the order of presentation)

1.1.1 Novel features of conducting polymer actuators

Keiichi Kaneto (1)

(1) Osaka Institute Of Technology, Department Of Biomedical Engineering, Osaka, Japan

Presentation given by Prof. Keiichi Kaneto

Electrochemomechanical actuation using conducting polymers such as polypyrrole, polyaniline and PEDOT films have been studied. The strain, stress and cycle stability of the actuation were measured under tensile loads. Interesting features like memory and training effects are observed along with creeping phenomenon. It will be reported that memory and training effects are closely related to the electrochemical creeping, and the mechanism will be explained.

1.1.2 Studies of Electromehanical Coupling of Bucky Gel Actuators based on Ion Movements

Kinji Asaka (1), Karl Kruusamaee (1), Takushi Sugino (1), Ken Mukai (1)

(1) National Institute Of Advanced Industrial Science And Technology (AIST)

Presentation given by Dr. Kinji Asaka

In this paper, we have developed electromechanical modelling of a bukcy-gel actuator which is composed of an ionic liquid (IL) gel electrolyte layer sandwiched by electrode layers based on single-walled carbon nanotubes (SWNTs) and ILs. The electromechanical effect is considered to be based on ion movement in the electrode layers, which was studied by precise displacement and genetated force measurement techniques. In addition, we studied the electrochemical impedance and mechanical properties of the bucky gel actuiators and considered the electromechanical coupling due to ion movement in the electrode layers of the bucky gel actuators. The model was compared with the experimental results of the bucky-gel actuators.

1.1.3 Dielectric Elastomer Actuator for Soft Robotics

Hyouk Ryeol Choi (1)

(1) Sungkyunwan University

Presentation given by Prof. Hyouk Ryeol Choi

For last decade, Dielectric Elastomer Actuator(DEA) has experienced great progress and come to the right end of applications. Dry and ease of handling with considerable output force appear to be more attractive than the other EAPs. As the results, robotic researchers start to adopt DEA for actuation of robots. However, DEA for robots needs to resolve several issues such as lack of meaningful force output, difficulty in seamless integration with the related components, fabrications with prestrain etc. In this talk, I would like to introduce a series of DEA applications performed by myself for the soft robotics up to now. Excluding the fundamentals of DEA, I will address how to apply DEA for driving robots mainly focused on practical implementation. Robots and devices such as inchworm, walking robot, robot hand, haptic display are presented including the brand new hexapod robot. I will cover up the issues from the design, control to the fabrication methods. In addition, the utilization of polymeric material for sensing is also explained shortly, which is mainly focused on the sensing of force. Finally, the perspective of DEA for the soft robotics is summarized.

1.1.4 Demonstrating kHz electromechanical response of ionic microactuators

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

(1) LPPI, University Of Cergy-Pontoise, Cergy, France
(2) IEMN, CNRS , Villeneuve D"Ascq, France

Presentation given by Dr. Cedric Plesse

Ionic EAP micromuscles converting electrical energy into micromechanical response in open-air are presented. Translation of small ion motions into large deformations in bending microactuator and its amplification by fundamental resonant frequency are used as tools to demonstrate that small ion vibrations can still occur at frequency as high as 1kHz in electrochemical devices. These results have been achieved through the microfabrication of ultrathin conducting polymer microactuators. First the synthesis of robust interpenetrating polymer networks (IPNs) has been combined with a spin-coating technique in order to tune and drastically reduce the thickness of conducting IPN microactuators. Patterning of electroactive materials as thin as 6 µm is demonstrated with existing technologies, such as standard photolithography and dry etching. Electrochemomechanical characterizations of the micrometer sized beams are presented and compared to existing model. Moreover, thanks to downscaling large displacements under low voltage stimulation (+/- 4V) are reported at a frequency as high as 930 Hz corresponding to the fundamental eigenfrequency of the microbeam. Conducting IPN microactuators are then presenting unprecedented combination of softness, low driving voltage, large displacement and fast response speed which are the keys for further development of new MEMS. Finally, new considerations on process, contact positioning and direct integration will be discussed.

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

1.2.1 PDMS-based DEA materials incorporating covalently attached softening agents

Miriam Biedermann (1), Martin Bluemke (1), Michael Wegener (1), Hartmut Krueger (1)

(1) Fraunhofer Institute For Applied Polymer Research, Potsdam, Germany

Presentation given by Dr. Miriam Biedermann

The use of polydimethylsiloxane (PDMS) materials for the processing of dielectric elastomer actuators (DEAs) is a field of research that gained much in interest particularly in recent years. Up to now a significant limitation to the application of DEAs is their high operation voltage in the range of several thousand volts. There are various approaches to face the challenge of lowering the required voltage and, thus, making these materials even more attractive for versatile applications. Promising concepts to overcome this restriction are the reduction of the film thickness, the increase of the permittivity or the lowering of the mechanical stiffness. The object of this work is to improve the actuation properties of PDMS-based DEA materials by decreasing their Young's modulus. Therefore asymmetric low-molecular PDMS chains are incorporated covalently into the PDMS network. They form loose chain ends during the network formation and act as a kind of softener within the PDMS network. PDMS materials featuring a broad range of Young's moduli Y were manufactured by varying the amount of the low-molecular PDMS additive between 0wt% and 50wt%. Our concept allows for the precise adjustment of the elastomer's stiffness from about Y = 2.7 MPa (0wt% softener) down to circa Y = 200 kPa (50wt% softener) starting from one and the same set of basic components. The chemical, mechanical, electrical, and electromechanical properties of these novel materials are presented in detail.

1.2.2 High permittivity silicones for dielectric elastomer actuators

Simon J. Dünki (1) (2), Frank A. Nüesch (1) (2), Dorina M. Opris (1)

(1) Swiss Federal Laboratory For Materials Science And Technology (Empa), Laboratory For Functional Polymers, Dübendorf, Switzerland
(2) École Polytechnique Fédérale De Lausanne (EPFL), Institut Des Matériaux, Lausanne, Switzerland

Presentation given by Mr. Simon Dünki

Dielectric elastomer actuators (DEA) are elastic capacitors that can be used to convert electrical into mechanical energy. Silicone elastomers have many advantageous properties for DEA application, but their low permittivity - typically below 3 - inherently diminish the actuator performance. Blending high permittivity ceramic or metal fillers into the silicone is usually accompanied with a stiffness increase and phase separation of the material. Chemical modification of silicone with polar groups evades these issues. In the presented work, a permittivity increase in silicone is achieved by modifying the siloxane backbone with polar side groups. The thiol-ene reaction was used for fast and quantitative conversion of the vinyl side-groups of a high molecular polymethylvinylsiloxane with mercaptopropanenitrile. Crosslinking of the polar silicones via condensation reactions had limited success. However, by using a simple one-step process which allows dipole grafting and crosslinking simultaneously, soft high permittivity silicone films with suitable elastic properties for DEA were achieved. Such films show lateral actuation strains up to 20.5% at 10.8 Volt per micrometer.

1.2.3 Soft strain sensors from Electroactive Interpenetrating Polymer Networks

Vincent Woehling (1), Giao T. M. NGUYEN (1), Cédric Plesse (1), Nicolas Festin (1), John Madden (2), Frédéric Vidal (1)

(1) University Of Cergy Pontoise, Laboratoire De Physico-Chimie Des Polymères Et Des Interfaces, Cergy Pontoise, France
(2) University Of British Columbia, Electrical And Computer Engineering, Vancouver, Canada

Presentation given by Dr. T. M. Giao NGUYEN

Electronic Conducting Polymers (ECP) have been widely studied in a tri-layer configuration as soft actuator. They are typically built with two ECP electrodes separated by an ionic conducting medium. Under low voltage oxidation/reduction of the ECP induces counter-ions expulsion/inclusion resulting in opposite volume changes of the two electrodes, thus a bending deformation. Electroactive Interpenetrating Polymer Networks (IPN) actuators were developed in order to solve delamination problem of the previous multi-layer systems. They are composed of an ionic conducing membrane designed as an IPN sandwiched between two interpenetrated ECP electrodes made of poly(3,4-ethylenedioxythiophene) (PEDOT). This original architecture allows the development of mechanically robust and electrically stable actuators after millions cycles without any delamination. Wu et al. have demonstrated that polypyrrole tri-layer actuators could present reverse behavior and generate electrical output signal when submitted to a mechanical strain due to a "Deformation Induced Ion Flux". In the present work sensing ability of electroactive-IPN will be described. When submitted to a mechanical bending, open circuit voltage (Voc) varies in the range of 10-1 millivolt can be measured. Values and sign of the Voc changes are directly related to the direction and to the amplitude of the mechanical stimulation. Effect of electrolyte, sample geometry as well as stimulation frequency will be discussed.

1.2.4 Silicone films by crosslinking of polymethylhydrosiloxanes with N,N-diallyl-4-nitroaniline

Martin Bluemke (1), Michael Wegener (1), Hartmut Krueger (1)

(1) Fraunhofer Institute For Applied Polymer Research, Potsdam, Germany

Presentation given by Dr. Hartmut Krueger

Dielectric elastomer actuators (DEAs) enable a wide range of interesting applications since they are soft, lightweight, low-cost and have direct voltage control. However, one of the main obstacles to their wide-spread implementation is their high operating voltage, which tends to be several thousand volts. The operating voltage can be lowered by reducing the thickness, increasing the permittivity or lowering the stiffness of the elastomer. Recently, we offered a method to increase the permittivity of silicones from 3 to 6 via dipole-grafting simultaneously accompanied by significant stiffness reduction (Kussmaul et al., Adv. Funct. Mater. 2011, 21, 4589-4594). During network formation the used dipole N-allyl-N-methyl-4-nitroaniline and divinyl-terminated polydimethylsiloxane compete to bind covalently to the polymethylhydrosiloxane crosslinker. Therefore, the dipole is connected only as a side-group to the crosslinker. Here we present a new approach using the difunctional dipole N,N-diallyl-4-nitroaniline as crosslinker for polymethylhydrosiloxanes. The Pt-catalyzed crosslinking reaction is optimized to obtain qualified silicone films with different dipole concentrations varying from 0.5 wt% to 1 wt%. The mechanical properties, the permittivity and the electromechanical properties of the films were characterized depending on the nitroaniline content. For these novel elastomer materials an actuation strain of 13 % was measured at 40 V/micrometers.

1.2.5 A small, powerful, light and fast hydraulic mcKibben muscle system

Danial Sangian (1)

(1) Intelligent Polymer Research Institute, ARC Centre Of Excellence For Electromaterials Science, AIIM Facility, University Of Wollongong, Wollongong, NSW 2522, Australia

Presentation given by Mr. Danial Sangian

Fluidic McKibben artificial muscles are one of the most popular biomimetic actuators, showing similar static and dynamic performance to skeletal muscles. In particular, their pneumatic version offers unique performances such as high-generated force, high speed and high strain in comparison to other actuators. In some alternative way, this paper investigates the development of a small-size, fully enclosed, hydraulic McKibben muscle powered by a low voltage pump. During this research, hydraulic McKibben muscles were miniaturized to an outside diameter of 6 mm and a length ranging from 35 mm to 80 mm. These muscles are able to generate forces up to 26 N, strains up to 23%, power to mass of 30 W/kg and tension intensity of 1.78 N/mm2 at supply water pressure of 2.5 bar. The effects of injected pressure, braid material and inner tube stiffness on the actuation strain and force generation were studied and a simple model introduced quantitatively estimate force and stroke generated for a given input pressure. This unique actuation system is lightweight and can be easily modified to be employed in small robotic systems where usually large movements in short time are required.

1.2.6 Conjugated polymer microactuators fabricated using soft lithography

Alexandre Khaldi (1), Daniel Falk (1), Ali Maziz (1), Edwin Jager (1)

(1) Dept. Of Physics, Chemistry And Biology, Linkoping University,Biosensors And Bioelectronics Centre, Linkoping, Sweden

Presentation given by Dr. Alexandre Khaldi

Conjugated polymer actuators operating in air presenting large and fast bending deformation under small applied potential have been recently described. However, the applications of these materials within the area of microbotics are still limited since the method of fabrication does not allow the individual control of different microactuators in the same device. To overcome this problem, we are developing a new bottom-up fabrication method based on soft lithography. This method will allow the individual patterning of several conjugated polymer actuators without the addition of extra steps of lithography and etching in the fabrication process. We will present this new fabrication procedure as well as the resulting devices and their performance.

1.2.7 Piezoelectric Fabric and its Application to Control of Humanoid Robot

Yoshiro Tajitsu (1)

(1) Kansai University, Faculty Of Science And Engineering, Suita, Osaka, Japan

Presentation given by Prof. Yoshiro Tajitsu

We have developed a piezoelectric fabric for sensing applied stress and strain using poly(l-lactic acid) (PLLA) fibers, and tailored clothing having the function of sensing complex motion using the piezoelectric fabric. First, we analyzed the motion of a yarn in the fabric with plain, satin, and twill weaves by simulation based on the infinite element method. The following result was obtained. A yarn in a twill weave was markedly bent when the fabric edge was folded onto itself. In contrast, a yarn in plain and satin weaves was hardly deformed. Also, large bending of a yarn in a satin weave was obtained when the fabric was twisted, whereas each yarn in plain and twill weaves did not deform in this case. On the basis of the simulation results, the PLLA clothing was produced using the technique for sewing Japanese kimonos, for the purpose of accurately detecting the twisting, bending, and elongation motion of the PLLA clothing itself. Finally, we developed a prototype system that allows human motion detected through the motion sensing of the PLLA clothing to be linked with that of a humanoid robot. At present, simple procedures such as bending of the arms and twisting of the wrists can be replicated in the humanoid robot. In the future, our aim is to enable the handling of complex movements after increasing the detection accuracy of the PLLA clothing. We would like to thank Teijin Co., Ltd., for kindly preparing the PLLA fabrics and clothing.

1.2.8 Silicone elastomers with superior softness and dielectric properties

Liyun Yu (1), Frederikke Bahrt Madsen (1), Shamsul Bin Zakaria (1), Anne Ladegaard Skov (1)

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

Presentation given by Dr. Liyun Yu

Dielectric elastomers change shape and size under a high voltage or reversibly generate a high voltage when deformed. Driving voltage can be lowered by decreasing Young's modulus and increasing dielectric permittivity of elastomers. In this work, three liquid additives - inert silicone oil, chloropropyl-functional silicone oil, and synthesized chloropropyl-functional copolymer - were blended into commercial silicone elastomers. The functional groups and morphologies were investigated by NMR and optical microscopy. The resulting elastomers were evaluated by dielectric permittivity, tear and tensile strengths, and electrical breakdown. The breakdown strength increased at low amounts of additives whereas it decreased at larger amounts. The elastomers became increasingly soft with increasing additions. Silicone oils enhanced molecular motions of network substructures via dynamic dilution effects but viscous losses also increased. Cross-linkable chloropropyl-functional copolymer offered a high level of mechanical integrity of blended elastomers thus consequent low viscous losses. The dielectric permittivity of chloropropyl-functional blended elastomers increased greatly compared to the pristine commercial elastomer, while dielectric losses remained at a low level. The increase in dielectric permittivity stemmed from the high dipole moment of the chloride groups. Alkyl chloride units yielded a larger free volume resulted in a less dense material with a lower Young's modulus.

1.2.9 New textile-based electroactive polymer actuators

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

(1) Biosensors And Bioelectronics Centre, Dept. Of Physics, Chemistry And Biology, Linköping University, Linköping, Sweden
(2) Smart Textiles, University Of Borås, Borås, Sweden

Presentation given by Mr. Ali Maziz

The emerging field of soft robotics represents one of the most motivating and challenging research topics in robotics. There is a strong growth in demand for

novel soft robots that can interact and work closely with humans. Such robots need to be compliant, lightweight and equipped with silent and soft actuators. Electroactive polymers such as conjugated polymers (CPs) have attracted attention because of their promising electronic, optical and electromechanical properties. These smart materials are distinguished by their possible dimensional changes due to the counter-ions and solvent molecules expulsion/insertion during oxidation or reduction processes. This behaviour makes them particularly interesting for such actuators since they are lightweight, silent, and driven at low voltages. Our goal is to develop soft and silent linear actuators to provide natural motion to robots and also exoskeletons and prosthetics. To achieve this we employ advanced textile technology to assemble CP fibres or yarns into new architectures. We have developed new CP based fibres and novel architectures employing parallel assembly of the CP fibres using knitting and weaving resulting in electroactive textile linear actuators with enhanced performance. Textile manufacturing allows efficient large scale manufacturing. We will present the fabrication and characterisation of these CP based textiles as well as their performance as linear actuators.

1.2.10 Influence of the static pre-stretching on the mechanical ageing of filled silicone rubbers for dielectric elastomer applications

Shamsul Zakaria (1) (3), Liyun Yu (1), Guggi Kofod (2), Anne L. Skov (1)

(1) Danish Polymer Center, Department Of Chemical And Biochemical Engineering, Technical University Of Denmark, Kgs. Lyngby, Denmark
(2) InMold A/S, Kgs. Lyngby, Denmark
(3) Faculty Of Industrial Science And Technology, Universiti Malaysia Pahang, Gambang, Pahang, Malaysia

Presentation given by Mr. Shamsul Zakaria

Pre-stretching of dielectric elastomers (DEs) is a key for better actuation performance as it helps preventing electromechanical instability at high voltage as well as the pre-stretching usually lowers the Young's modulus. The pre-stretched DE is not only susceptible to high risk of tearing and formation of mechanical defects, but films with a sustained large strain may be subjected to mechanical degradation. In this study a long term mechanical reliability study of DE is performed. Young's modulus of commercial silica filled polydimethylsiloxane (PDMS) contained additional 35 percent titanium dioxide was determined and was found reduced by factor of ~4 after static pre-stretched for 3 months. Mechanical ageing exacerbates with incorporation of permittivity enhancing fillers compared to a pure PDMS matrix. Furthermore, a detrimental impact on the mechanical ageing of filled PDMS films can be found for coupled effects of relatively thin and large prestrain of films. Also the electrical breakdown of the pre-stretched elastomer was shown to decrease over time. On the other hand, the storage permittivity of the elastomer was shown to increase after 3 months of static pre-stretched. These observations give clear indication of the long-time pre-stretching altering the films significantly.

1.2.11 Enhancing relative permittivity by incorporating PDMS-PEG multi block copolymers in binary polymer blends

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

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

Presentation given by Ms. Aliff H A Razak

Polydimethylsiloxanes (PDMS) are well-known to actuate with relatively large strains due to low modulus, but they possess low permittivity. Contrary, polyethyleneglycols (PEG) are not stretchable but possess high permittivity. Combination of the two polymers in a block copolymer depicts a possibility for substantial improvement of properties such as high permittivity, stretchability and non-conductivity - if carefully designed. The objective is to synthesize PDMS-PEG multiblock copolymer assembling into discontinuous morphologies in PEG based on variation of volume fractions of PDMS. The utilized synthesis of PDMS-PEG multiblock copolymer is based on hydrosilylation reaction, which is amended from Klasner et al.1 and Jukarainen et al.2 Variation in the ratio between the two constituents introduces distinctive properties in terms of dielectric permittivity and rheological behaviour. PDMS-PEG multiblock copolymers are, however, shown to be conductive (figure 1.a) and thus not capable of actuating. By incorporating conductive PDMS-PEG multiblock copolymers into commercial PDMS elastomer, the discontinuity in PEG can be obtained and the relative permittivity (?') is significantly enhanced 60% with 5wt% of PDMS-PEG block copolymer incorporated in the PDMS network (figure 1.b).

1.2.12 Cooperative and antagonist dynamics from asymmetric bilayer

artificial muscles

Toribio F. Otero (1), José Gabriel Martínez (1), Masaki Fuchiwaki (2)

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(2) Kyushu Institute Of Technology, Department Of Mechanical Information Science And Technology, 680-4 Kawazu, Iizuka(Fukuoka), 820-8502, Japan

Presentation given by Prof. Toribio F. Otero

The actuation of each layer from asymmetric polypyrrole-paraphenolsulfonic acid/polypyrrole-dodecylbenzensulfonic acid (PPy-HpPS/PPy-DBS) asymmetric bilayer artificial muscles is studied in NaCl aqueous solution in order to get large actuation. When both layers from the asymmetric bilayer follow complementary volume changes (swelling/shrinking, or shrinking/swelling) due to complementary ionic entrance/expulsion driven by the reaction charge, a cooperative dynamic actuation occurs: the bending amplitude of the angle described by the asymmetric bilayer muscle is one order of magnitude larger than those attained from each of the conducting polymer/tape muscles in the same electrolyte. Antagonist dynamic actuation emerges when the two films swell, or shrink, simultaneously. Antagonist actuation originates narrower angles described per unit of consumed charge and improves creeping effects. Some general criteria to get high efficient asymmetric bilayer muscles are stated.
The authors acknowledge the financial support from the Kyushu Institute of Technology and the Spanish Government (MCINN) Projects MAT2011-24973. J.G. Martinez acknowledges Spanish Education Ministry for a FPU grant (AP2010-3460).

1.2.13 Hysteresis cycle and creeping from asymmetric bilayer muscles

Toribio F. Otero (1), Jose´ Gabriel Martínez (1), Masaki Fuchiwaki (2)

(1) Univ. Politécnica De Cartagena, Lab Of Electrochemistry Intelligent Materials And Devices, Cartagena, Spain
(2) Kyushu Institute Of Technology, Department Of Mechanical Information Science And Technology, 680-4 Kawazu, Iizuka(Fukuoka), 820-8502, Japan

Presentation given by Prof. Toribio F. Otero

The actuation of each layer from asymmetric polypyrrole-paraphenolsulfonic

acid/polypyrrole-dodecylbenzensulfonic acid (PPy-HpPS/PPy-DBS) asymmetric bilayer artificial muscle is studied in NaPF6 aqueous solution in order to get large actuation. The PPy-HpPS film exchanges anions during reactions and the PPy-DBS exchange cations during redox reactions, as deduced from coulodynamic responses from the CP/tape bilayer muscles. Both layers from the asymmetric bilayer follow complementary volume changes (swelling/shrinking, or shrinking/swelling) due complementary ionic exchanges (entrance/expulsion) driven by the same reaction. The cooperative actuation almost eliminates creeping effects. However, a large dynamic hysteresis is observed per cycle attributed to an irreversible reaction (hydrogen evolution). Some general criteria to get high efficient asymmetric bilayer muscles with low creeping and hysteresis effects are stated. The authors acknowledge the financial support from the Kyushu Institute of Technology and the Spanish Government (MCINN) Projects MAT2011-24973. J.G. Martinez acknowledges Spanish Education Ministry for a FPU grant (AP2010-3460).

1.2.14 Highly stretchable and compliant PDMS/carbon-based electrodes for artificial muscles applications

Adrian Bele (1), Mihai Gabriel Asandulesa (1), George Stiubianu (1), Maria Cazacu (1)

(1) "Petru Poni" Institute Of Macromolecular Chemistry, Aleea Gr. Ghica Voda 41A, 700487 Iasi, Romania

Presentation given by Mr. Adrian Bele

Among other renewable technologies, energy harvesting using dielectric elastomers is a relatively new technology with a great potential. This technology is based on stretchable "artificial muscles" coated on both sides with compliant electrodes, thus forming a variable capacitor. Regarding the issues of this technology, electrodes present major difficulties by means of compliance, conductivity at large deformation or surviving lots of cycles (>50 millions). In this study we present three types of chemically bonded PDMS/carbon-based electrodes, which maintain large deformations (200%) without losing conductivity even after 1300 cycles.

1.2.15 Modelling and simulation of dielectric elastomer actuated multibody systems

Tristan Schlögl (1), Sigrid Leyendecker (1)

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

Presentation given by Mr. Tristan Schlögl

An important field for dielectric elastomer (DE) actuators is the use as artificial muscles in humanoid robots. DE actuated systems allow for flexible kinematics and safe and natural motions. In contrast to pneumatic and hydraulic systems, artificial muscles facilitate the design of autarkic systems. Besides the automated manufacturing and lightweight power electronics, the simulation of DEs is investigated within the collaborative research project bionicum. A three dimensional finite element model covers the time dependent behaviour of dielectric actuators. A hyperelastic Neo-Hookean material model is fully coupled with electrostatics. Viscoelastic stresses account for damping effects. A structure preserving time integration scheme provides accurate simulation results for energetic investigations. The actuated multibody system is modelled using rigid bodies. A redundant set of state variables avoids rotational degrees of freedom and provides a robust and generic formulation. The finite element model is coupled with the multibody system by constraints formulated at position level. Lagrange multipliers take coupling forces into account. The structure preserving integration scheme allows for the numerically exact fulfilment of constraints without index reduction. The coupled model serves as a basis for future work regarding optimal control of DE actuated robots.

1.2.16 Polar-nonpolar interconnected elastic networks with increased permittivity and high breakdown fields for dielectric elastomer transducers

Mihaela Dascalu (1), Adrian Bele (1), Valentina Musteata (1), Maria Cazacu (1), Simon Duenki (2), Dorina Opris (2), Carmen Racles (1)

(1) Petru Poni Institute Of Macromolecular Chemistry, Aleea Grigore Ghica Voda 41A, Iasi, 700487, Romania
(2) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory For Functional Polymers, Ueberlandstr. 129, CH-8600, Dübendorf, Switzerland

Presentation given by Dr. Mihaela Dascalu

Elastic materials with increased permittivity were obtained in a three steps process starting from hydroxyl end-functionalized polydimethylsiloxane

(PDMS) of high molecular weight, trimethylsilyl-end blocked silicones that carry hydrosilane, cyanopropyl and hexyl groups Px (where x represents the mol% of cyanopropyl groups), and tetraethoxysilane (TEOS). The hydrosilane groups of Px were first hydrolysed and the formed hydroxyl groups were subsequently reacted with partially hydrolysed TEOS and further used as high permittivity component, cross-linker, and reinforcing agent for the PDMS matrix. A high wt% of polar component was incorporated into the un-polar PDMS matrix by forming interconnected networks. The thermal (DSC, DMA) and morphological (SEM) investigations showed the biphasic morphology of the networks. The dielectric, mechanical, and electromechanical properties of the films were investigated. Materials with good elastic properties, increased permittivity, and high breakdown field (Eb) were obtained.

1.2.17 Transduction performance of polar-nonpolar silicone materials: interconnection versus blending

Mihaela Dascalu (1), Adrian Bele (1), Maria Cazacu (1), Dorina Opris (2), Carmen Racles (1)

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Presentation given by Dr. Mihaela Dascalu

Polar silicones have been synthesized by co-hydrosilylation of poly(methylhydrogen)siloxane with allyl cyanide and 1-hexene. The unreacted Si-H groups were used as anchoring points to the hydroxyl terminated PDMS, via a complex hydrolysis-condensation process. The resulted materials are polar-nonpolar interconnected networks that show micro-phase separation. Additionally, cross-linked submicron polar particles were formed in presence of an appropriate surfactant. These particles were further used as filler in a PDMS matrix, thus blends with similar composition were obtained. This contribution shows the properties of the two types of materials, with emphasis on their mechanical and electro-mechanical behavior. The influence of the materials microstructure, the PDMS matrix molecular weight, and the cross-linker amount is discussed.

Session 1.3
(abstracts are listed in the order of presentation)

1.3.1 Dielectric silicone elastomers filled with in situ generated polar silsesquioxane

Adrian Bele (1), Carmen Racles (1), Mihaela Dascalu (1), Elena Perju (2), Dorina Opris (2), Maria Cazacu (1)

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Presentation given by Mr. Adrian Bele

Polydimethylsiloxanes of different molecular weights were cross-linked with different amounts of (3-chloropropyl)-trimethoxysilane (CPTMS), from stoichiometric to 15 wt% reported to the polymer mass. In addition to cross-linking, the excess of silane generates in situ silsesquioxane structures (SSQ) containing chloropropyl groups. Due to the relatively high dipole moment of the chloropropyl group, the dielectric permittivity of the resulted materials increase, while the formed SSQ functions as a filler and improve the mechanical properties of the formed materials. Thus, this presentation show the influence of the amount of CPTMS used on the dielectric, mechanical and electromechanical properties.

1.3.2 Bimodal silicone networks as dielectric elastomers

Codrin Tugui (1), Mihail Iacob (1), George Stiubianu (1), Cristian Ursu (1), Cristian-Dragos Varganici (1), Maria Cazacu (1)

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

Presentation given by Mr. Codrin Tugui

Due to their unique properties such as high flexibility exhibited within a wide

range of temperature, moisture or frequency, silicones have attracted great interest in developing new DE's materials. Different strategies have been addressed (i.e., incorporation of ceramic material as fillers or chemical modification by attaching polar groups) to adapt their other properties, especially dielectric permittivity, to the requirements for such applications. But besides the expected improvements, some disadvantages are encountered to each approach. Therefore, still looking for new ways to optimize properties. Bimodal silicone interpenetrating networks have been only recently approached from this perspective. The availability of a wide variety of functional silicones and cure chemistries for them offerrs large opportunities for this. Taking into consideration these aspects, we prepared a series of bimodal siloxane IPNs by using two common silicone polymers but, different from other reports, with a great difference between their molecular masses, which were mixed in different ratios and sequentially crosslinked by different mechanisms from each other. A pre-stretch was applied to the "host" network after its formation followed by the thermal treatment for the second curing. The electromechanical measurements, such as electrical breakdown or actuation tests, have revealed that these very simple and homogeneous materials are suitable for use as DET's.

1.3.3 Development of Cardiovascular devices using IPMC for Pediatrics

Moutaz Hamdan (1), Terry Gourlay (1)

(1) Department Of Biomedical Engineering, University Of Strathclyde, Glasgow, UK

Presentation given by Mr. Moutaz Hamdan

Heart disease, in all of its various clinical manifestations is now the primary cause of premature death throughout the world. In children born with cardiac lesions treatment is complex and challenging, due to the small size and lack of donors. IPMC actuators could be used to support the cardiovascular system in different ways; such as heart valves, and ventricular assist devices. In this project we are developing IPMC that is suitable for several cardiovascular applications, which has a low power consumption, and able to produce enough mechanical power. These devices will be custom made for each case, where a 3D model of the anatomy will be created from CT and MRI images, this model will be used to design and test the device using Mimics. The objective is to develop a device that is totally implantable and powered via physiological mechanisms.

1.3.4 Accelerated aging behaviour of dielectric silicone elastomers under controlled conditions

Maria Cazacu (1), Adrian Bele (1), George Stiubianu (1), Lavinia Matricala (1), Stelian Vlad (1)

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

Presentation given by Dr. Maria Cazacu

Well defined silicone composite series, of interest as dielectric elastomers for application in energy harvesting devices, were aged by their immersion for one year in artificial seawater followed or not by UV irradiation in normal environmental conditions. Changes occurred in morphology as in the dielectric and mechanical characteristics of the samples due to their exposure under these conditions were followed by adequate techniques (scanning electron microscopy, differential scanning calorimetry, dielectric spectroscopy and tensile tests). It was assessed how some structural parameters of composites (molecular weight of the matrix polymer, filler content, the amount of surfactant, etc.) influence the aging behavior of the samples in these circumstances.

1.3.5 Beam actuator with patterned electrodes - investigation of the frequency response

Dmitry Rychkov (1), Gunnar Gidion (1), Reimund Gerhard (1)

(1) University Of Potsdam, Applied Condensed Matter Physics, Potsdam, Germany

Presentation given by Dr. Dmitry Rychkov

Dielectric elastomer actuators come nowadays in different forms and designs, but the most common arrangement is the planar actuator in pure shear configuration. Even though other configurations attract less attention in the EAP community, they are capable of different modes of motion - for example bending and rotary motion. Here we investigate bending of an actuator with electrodes specifically patterned to achieve this kind of motion. The actuator consists of an acrylic VHB layer coated on one side with continuous golden electrode while on the other side the electrode is patterned to form perpendicular stripes with inactive areas in between. The side with continuous electrode is

attached to a polyethylene terephtalate liner and, thus, is not allowed to expand when the voltage is applied. Such an arrangement results in bending motion which can be then tracked with a laser motion detector. The actuator is driven with a high voltage sine signal from a function generator and the data from the motion detector is processed by an audio network analyzer. The observed frequency response function is evaluated to determine relevant parameters of the actuator such as fundamental frequency, damping behavior and elasticity.

1.3.6 Dry etching and process for micro transducer based on conducting interpenetrated polymer network

Mohamed Bentefrit (1), Adelyne Fannir (2), Ali Maziz (2), Caroline Soyer (1), Cédric Plesse (2), Eric Cattan (1), Frédéric Vidal (2)

(1) IEMN, UMR-8520, UVHC, Valenciennes, France
(2) LPPI, EA 2528, UCP, Cergy-Pontoise, France

Presentation given by Mr. Mohamed Bentefrit

Due to their rigidity and high manufacturing temperatures, classic micro-transducers are unsuitable for fabrication of soft microsystems on flexible substrates, thus leaving the door open for the development of electroactive polymers operating as actuators or sensors. The aim of this work is to develop some reliable processes in order to shape ionic electroactive polymer (IEAP) filled with an electrolyte. Reactive ion etching is suitable for making collective fabrication, a required criteria for MEMS integration. However it has some limitations for IEAP: ionic liquid can not be inserted into the structure before etching, etching is almost purely isotropic, material thickness can not exceed 15 µm because of the poor selectivity with the photoresist mask. Another patterning way was to use laser ablation. It gave us a more anisotropic etching and possibility to insert ionic liquid before etching. No mask is needed, a single etching step can cut simultaneously different materials (gold electrode, polymer and substrate) and a high etching rate reached make possible the ablation of 250 µm thick structure. However removal of large material surfaces is delicate, partial etching is hardly manageable and the narrowness of etched lines is lesser. Both etching ways will be exhibit, compared and suitable process was developed in order to manufacture micro transducers. Co-integration of resulting micro transducers on soft substrate and with bottom and top gold electrode will be shown.

1.3.7 Engaging the public and the art and design community in EAPs via

biomimetic artistic installations

Michele Ghilardi (1), Astrid Bin (2), Federico Carpi (1)

(1) Queen Mary University Of London, School Of Engineering And Material Science, London, United Kingdom
(2) Queen Mary University Of London, School Of Electronic Engineering And Computer Science, London, United Kingdom

Presentation given by Mr. Michele Ghilardi

EAP s and other smart materials are expected to permeate future engineering systems and a growing role for them is anticipated also in art and design. However EAP and technologies are mostly unknown to the general public and the art and design community. As a first attempt to reduce that gap, Queen Mary University of London is supporting a public engagement project ('PauseInMotion') aimed at developing an artistic installation based on biomimetic systems made of EAPs. Taking inspiration from nature, PauseInMotion aims to bring EAP technologies to the public mimicking resting dynamics of migrating butterflies, which travel long distances and rest together in swarms. PauseInMotion expresses not only a pause between locations mid-migration, but also a pause on the continuum between the natural and technological worlds. A swarm of artificial butterflies made of Dielectric Elastomer Minimum Energy Structures (DEMES) will be displayed at the Barbican Gallery (London, UK). They will gently and silently move their wings like resting butterflies . The contrast between the realistic movement of the butterflies and their plastic construction will showcase the beauty and potential of smart materials, and the way that engineering research is inspired by - and evolves to imitate - nature (biomimicry). This presentation reports progress and challenges of this project.

1.3.8 Investigation on electrical breakdown of dielectric elastomer materials

Bin Chen (1), Matthias Kollosche (2), Mark Stewart (3), James Busfield (1), Federico Carpi (1)

(1) Queen Mary University Of London
(2) University Of Potsdam
(3) National Physical Laboratory

Presentation given by Mr. Bin Chen

Dielectric elastomer actuators (DEAs) are a kind of deformable capacitors that can undergo large voltage-induced deformations higher than 100% in area. Subject to an electric field, the layer of the dielectric elastomer film reduces in thickness and expands in area. Large-strain, fast and efficient actuation properties are attractive for a wide range of possible applications, such as artificial muscles, tuneable optical devices and tactile displays. Performance of DEAs is limited by electrical breakdown. Therefore, studying dielectric breakdown is highly important to gain insights on how to improve performance. In order to measure the electrical breakdown strength of dielectric elastomers, a bespoke set-up was built. This presentation shows preliminary results of an ongoing campaign of extensive characterisation tests on the acrylic elastomer film VHB 4905 from 3M.

1.3.9 Fish-skeleton visualization of bending actuators

Andres Punning (1), Sunjai Nakshatharan (1), Alvo Aabloo (1)

(1) University Of Tartu, Institute Of Technology, IMS Lab

Presentation given by Mr. Andres Punning

We present a new approach for qualitative visualization and quantitative characterization of the time-dependent behavior of bending ionic electroactive polymer (IEAP) actuators. The thin fibers, attached to the actuator, represent the surface normals at the given points of the particular sample. Comparing the directions of the surface normals, recorded by a video camera, allows to identify the strain of the actuator at the given point with excellent accuracy. On the other hand, the structure, formed by the skeleton of many adjacent fibers, amplifies the visual overview about the whole actuator, especially when observing a series of recorded images, e.g. a video. The developed handicraft technique of attaching the fibers does not require considerable skills. It has been tested upon many types of IEAP materials, while the attached fibers do not hinder even the actuators, operating in a liquid environment.

1.3.10 Screen printing electrodes on silicone film: influence of screen dimensions and multiple-layer-prints on resistivity

Bettina Fasolt (1) (2), Micah Hodgins (1), Alexander York (1), Stefan Seelecke (1) (2)

(1) Department Of Mechatronics, MMSL Multifunctional Materials And Systems Lab, University Of Saarland, Germany
(2) Zema Zentrum Für Mechatronik Und Automatisierungstechnik, Saarbrücken, Germany

Presentation given by Ms. Bettina Fasolt

Screen printing is used as a method for printing electrodes on silicone thin films for the fabrication of membrane Dielectric Electro-Active Polymers (DEAP). This method can be used to manufacture a multitude of patternable designs for actuator and sensor applications, implementing the same method for prototyping as well as large-scale production. The fabrication of DEAPs does not only require the development of a flexeble, highly conductive electrode material, which adhers to a stretched and unstreched silicone film, but also calls for a thorough understanding of the effects of the different printing parameters. This work investigates the influence of screen dimensions on the basis of a parameter 'open area to mesh thickness' as well as the influence of multiple layer printing on the resistivity in unstretched and stretched conditions. Magnified pictures of the electrodes will additionally illustrate the effects of the different printing parameters.

1.3.11 Wearable system for multi-finger tactile interactions with virtual soft bodies based on 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 Dr. Gabriele Frediani

Wearable human computer interfaces capable of providing users with tactile feedback while interacting with virtual bodies are becoming increasingly more relevant in a number of fields, such as training for medical operators, teleoperation, computer aided design and 3D modelling. However, commercially available wearable tactile displays are not portable, due to their complex mechanisms. Moreover, to the best of our knowledge, no tactile devices are currently available to mimic contact with soft bodies, via soft interfaces. Here, we report ongoing progress in our approach to develop such a

type of system using a technology known as Hydrostatically Coupled Dielectric Elastomer Actuators (HC-DEAs). Those actuators rely on an incompressible fluid that hydrostatically couples a DEA-based active membrane to a passive membrane that provides the user with a tactile stimulus. We report on recent advances on the software architecture and hardware system that are aimed at allowing users to interact with virtual soft bodies via multiple fingers. This is done by using a three dimensional finger tracking system combined with a virtual environment. By using multiple finger interaction, users are expected to explore virtual soft body objects in an intuitive, natural and accurate fashion. Ongoing development and testing of the whole system are here described.

1.3.12 Soft shape-adaptive gripper made of ionic capacitive laminate

Edgar Hamburg (1), Veiko Vunder (1), Friedrich Kaasik (1), Inna Baranova (1), Alvo Aabloo (1)

(1) University Of Tartu, Institute Of Technology, IMS Lab, Tartu, Estonia

Presentation given by Mr. Edgar Hamburg

In this study, we present a multifunctional four-finger gripper for soft robotics. The gripping as well as the lifting mechanism are made of a single smart material - ionic capacitive laminate (ICL) that changes its shape and size in response to electrical input stimulus. The device is able to adapt the complex shapes of objects and allows grasping multiple objects simultaneously without damage. The performance of the gripper is evaluated in two different configurations: a) the ultimate grasping strength of the gripper was tested by lifting the gripping head with a DC motor; and b) the lifting and gripping functionalities were realized with two ICL actuators.

1.3.13 Systematic experimental investigation of planar dielectric electro-active polymer actuators using a custom-built uniaxial tensile test rig

Micah Hodgins (1), Alex York (1), Stefan Seelecke (1)

(1) Multifunctional Materials And Systems Lab (MMSL), Department Of Mechatronics, Saarland University, Saarbrücken, Germany

Presentation given by Mr. Micah Hodgins

New materials for potential use as Dielectric Electro-Active Polymers (DEAPs) are developing quickly as the technology grows. A systematic comparison of these materials' properties is a necessary investigation in order to make use of their full potential in possible actuator and sensor applications. In this work, an experimental test setup with a procedure to systematically test DEAP actuators in a standardized manner is designed, fabricated and built. The testing rig is used to benchmark dielectric elastomer films and DEAP actuator performance by studying the mechanical and electromechanical response in a pure-shear configuration. A sample length-to-width ratio of at least 1:5 is maintained in order to minimize any special variation in strain and electric field over the sample. Also by having a large active-to-passive area ratio the mechanical resistance due to the uncoated elastomer film is lessened. Optical film-thickness measurements are performed to provide an accurate estimation of the applied electric field. The work summarizes the tester design and presents preliminary test results of straining dielectric elastomer film samples with and without electrodes. Future work will seek to exploit the test setup by performing comparative investigations of dielectric elastomer films and their applicability for use as DEAP actuators.

1.3.14 Improved temperature-dependent electro-mechanical sensitivity in stiffness-tunable nanoceramics/polydimethylsiloxane dielectric elastomer composites

Hang Zhao (1) (2), Jinbo Bai (1)

(1) Laboratoire de Mecanique des Sols, Structures et Materiaux, CNRS UMR8579, Ecole Centrale Paris,Chatenay-Malabry Cedex, France
(2) Laboratory of Dielectric Polymer Materials and Devices,University of Science and Technology Beijing, Beijing, People’s Republic of China

Presentation given by Mr. Hang Zhao

Stiffness-tunable BaTiO3/polydimethylsiloxane (BT/PDMS) dielectric elastomer composites using dimethylsilicone oil (DMSO) as the stiffness tuner were prepared. Significant improvements in both actuation areal strain and electromechanical actuation sensitivity can be observed from BT/PDMS samples with DMSO, which should be mainly contributed to the physical swelling behavior. Under wide testing temperature range, the stiffness-tuned BT/PDMS composite exhibited an excellent thermal stability of both dielectric and mechanical performance. The electromechanical sensitivity of BT/PDMS composite can be effectively tuned higher than that of VHB 4910 acrylics via the addition of DMSO under in vivo temperature range. This simple way endows PDMS-based composites the higher performance for being applied as implantable dielectric elastomer materials.

1.3.15 Polymerized ionic liquid membranes for electrochemical actuator and sensor applications

Arko Kesküla (1), Sandra Kuusik (1), Anna-Liisa Peikolainen (1), Uno Mäeorg (2), Alvo Aabloo (1)

(1) University Of Tartu, Institute Of Technology (IMS Lab), Tartu, Estonia
(2) University Of Tartu, Institute Of Chemistry, Tartu, Estonia

Presentation given by Mr. Arko Kesküla

Ionic liquids (IL) are a diverse group of salts that have melting points near room temperature. ILs have been a subject of intense research as a customizabe replacement for the conventional organic solvents used in industry and academia. Recently polymeric forms of ILs (PILs) have attracted attention. Typical characteristics of ILs combined with mechanical durability of polymers make PILs a key material for development of wide range of emerging technologies, like actuators, batteries, fuel cells and sensors. The main focus of the research is set on the preparation of fully plastic actuators with polymeric ionic liquids as membranes, and exploring the electromechanical and electrochemical limits of PIL-s in these applications.

1.3.16 Reduced size multichannel driving electronics for small scale dielectric elastomer actuator applications

Holger Mößinger (1), Henry Haus (1), Muhammad Bilal Saif (2), Klaus Hofmann (2), Helmut F. Schlaak (1)

(1) Technische Universität Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany
(2) Technische Universität Darmstadt, Integrated Electronic Systems Lab, Darmstadt, Germany

Presentation given by Mr. Holger Mößinger

As applications of DEA are moving closer to market matching driving electronics become more and more crucial. Commercially available components

for building customized driving electronics, such as switching transistors, coils, etc. are typically either available for low voltage and low power or for high voltage and high power circuits. For large scale DE-actuators and applications the size of the electronics is less important and component size is not a limiting factor. Meanwhile small scale DEA applications require rather high voltages of about 1 kV but are very limited in power. For application using small and micro scaled DEA, such as miniaturized fluidic valves and pumps , tactile interfaces such as braille displays and similar tactile surfaces, the size of the components required for building driving electronics becomes a limiting factor. This results in the driving electronics being about the same size as the actuators, or even several times larger. Energy efficiency is also limited. To overcome these limitations an application specific integrated circuit (ASIC) capable of generating high voltage driving signals for four DE-actuators with a size of 4 mm x 5 mm x 1 mm was developed. From an input of 700 volts the ASIC generates four modulated switching signals with frequencies up to 40 kHz. The use of this ASIC allows significant reduction of driving electronics size, especially for multi-channel applications such as DEA matrices in tactile displays.

1.3.17 Observer control of deflection and force acting on a dielectric elastomer actuator based on driving voltage and current

Holger Mößinger (1), Ralf Turzer (1), Helmut F. Schlaak (1)

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

Presentation given by Mr. Holger Mößinger

For using dielectric elastomer actuators (DEA) in tactile interfaces their inherent self-sensing capability is of interest. Self-sensing allows monitoring the actuators deflection and assessing external forces, such as the pressure applied by a human finger when pushing a tactile button. Several methods for self-sensing are already published. Some methods work with specialized driving waveforms, some work by applying additional sensing signals to the actuator or similar measures. In this publication a different approach, based on an observer control, for sensing deflection and force of a DEA is presented. The observer control comprises a model of the DEA describing electrical and mechanical parameters, including a description of relaxation and creeping effects. The implementation of the observer control is based on an Extended Kalman filter. Inputs to the observer control are the electrical driving voltage and driving current of the DEA. The influence of an external force acting on the DEA is modelled as disturbance. Different electrical driving signals, as well as the influence of measurement noise and changes in electrical parameters are tested to assess the accuracy of the observer control. The observer allows estimating the deflection and the external force acting on the DEA with high precision and shows good noise rejection. It might be a suitable approach for self-sensing of DEA, without the need for specialized driving signals or additional sensing signals.

Wednesday, 10 June 2015

General programme of the day

EAPlenary	Session 2.1 part I *Chair:* **Alvo Aabloo**, University of Tartu, Estonia	
	9:00- 9:30	Invited talk **Elisabeth Smela** University Of Maryland, USA
EAPodiums	Session 2.1 part II *Chair:* **Kinji Asaka**, National Institute Of Advanced Industrial Science And Technology (AIST), Japan	
	9:30- 9:50	Invited talk **Edwin Jager** Linköping University, Sweden
	9:50- 10:10	Invited talk **Jonathan Rossiter** University of Bristol, UK
Break	10:10- 10:40	Coffee break
EAPodiums	Session 2.1 part III *Chair:* **Hyouk Ryeol Choi**, Sungkyunwan University, South Korea	
	10:40- 11:00	Invited talk **Ming Tian** Beijing University of Chemical Technology, China
EAPills	Session 2.2 part I *Chair:* **Cedric Plesse**, University Of Cergy-Pontoise, Cergy, France	
	11:00- 12:00	**Pill oral presentations** 15 presentations (3 minutes each + 1 minute to change speaker)
Lunch	12:00- 13:00	Lunch

EAPosters **EAPrototypes** **EAProducts**	Session 2.2 part II	
	13:00- 14:00	**Posters & exhibitions** 15 posters
EAPills	Session 2.3 part I *Chair:* **Edwin Jager**, Linköping University, Sweden	
	14:00- 15:00	**Pill oral presentations** 14 presentations (3 minutes each + 1 minute to change speaker)
Break	15:00- 15:30	Coffee break
EAPosters **EAPrototypes** **EAProducts**	Session 2.3 part II	
	15:30- 16:30	**Posters & exhibitions** 14 posters
Closing	16:30	**Closing ceremony**

Session 2.1
(abstracts are listed in the order of presentation)

2.1.1 Hydraulic electroactive polymer actuators

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

(1) University Of Maryland, Department Of Mechanical Engineering, College Park, USA
(2) University Of Maryland, Institute For Systems Research, College Park, USA

Presentation given by Prof. Elisabeth Smela

Electro-osmotic fluid pumping occurs in micro-scale channels when an electric field is applied, allowing fluid to be transported from one area to another. Such hydraulic actuators can deliver both reasonable displacements and forces. Devices are fabricated by lamination of multiple layers. Electrodes are formed from a conductive, stretchable composite of silicone and carbon nanoparticles, while micro-channels are created from paper. Propylene carbonate is used as the pumping fluid because, unlike water, it does not produce gases due to electrolysis. Upon application of a voltage, the fluid is pumped to an area under a membrane, causing the membrane to bulge outward, with deflections of tens to hundreds of micrometers. We are pursuing a potential biomedical application of these actuators to control the flow of blood through a blood vessel or stent.

2.1.2 Electroactive polymers for bioelectronics and mechanostimulation

Authors: Edwin Jager (1),

(1) Linköping University, Dept. Of Physics, Chemistry And Biology (IFM)

Presentation given by Prof. Edwin Jager

Conducting polymers (CPs) are interesting materials to interface with biology. CPs can alter their surface properties dynamically, exchange ions with the surrounding environment, deliver electrical signals as well as exert mechanical forces. We have developed a variety of electroactive surfaces and devices that

interface with cells: Planar surfaces to electronically control the cell adhesion; Electrospun 3D scaffolds to electrically stimulate nerve cells; and small chips with microactuators to provide mechanical stimulation to cells. Recently, we developed an electroactive polymer scaffold for tissue engineering aimed at cardiac repair. The CP scaffold mimics the extracellular matrix and provides a 3D microenvironment that can be easily tuned during fabrication. It provides both electrical and electromechanical stimulation to the stem cells which are important external stimuli to stem cell differentiation. This stimulation will increase the differentiation ratio of stem cells into cardiomyocytes, increasing the formation of cardiac tissue. Excellent biocompatibility was achieved using primary cardiovascular progenitor cells. We present the fabrication, electrochemical and electromechanical characterisation as well as the response of the stem cells to the scaffolds and to the stimulation.

2.1.3 Electroactive polymers for soft robotics - meeting the challenge

Jonathan Rossiter (1)

(1) University Of Bristol

Presentation given by Dr. Jonathan Rossiter

Soft robotics is the growing area of research which focuses on the development of compliant active systems that go beyond current rigid robotics. The potential of this approach is huge: if a building falls down in an earthquake a worm-like soft robot can squirm its way into the rubble to find survivors; if a patient suffers from cancer a soft robotic implant can restore body function following tumour surgery; if an elderly person is becoming weak and unsteady on their feet wearable soft robotic assist clothing can give them power to move around comfortable and safely. Recently a range of soft robots have been presented which employ conventional actuation mechanisms including pneumatics and shape memory alloys. At the same time there has been notable progress in electroactive polymers (EAPs) for soft robotics, including grippers, multi-DOF actuators and active skins. Unfortunately the exploitation of EAPs in soft robotics is limited by a number of technology barriers that have yet to be fully overcome. In this presentation we will highlight the needs of key soft robotics applications and assess current EAPs technologies in this context. We will highlight efforts to overcome some of these barriers and highlight aspects of EAPs that have not yet received our full attention. These will include power density, bio-mechanical interfacing, fabrication, biocompatibility, biodegradability, safety and aesthetics.

2.1.4 Improving the electromechanical properties of dielectric elastomers through the disruption of hydrogen bonds

Nanying Ning (1) (2), Bingyue Yan (1), Yang Yao (1), Zhifei Wang (1), Liqun Zhang (1) (2), Ming Tian (1) (2)

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

(2) Beijing University Of Chemical Technology, State Key Lab Of Organic-Inorganic Composites, Beijing, China

Presentation given by Porof. Ming Tian

Dielectric elastomer actuators (DEAs) can give rise to surprisingly large deformations by applying an electric field, thus have been receiving much attention in the past two decades. Getting a large actuated strain at a low electric field is the biggest challenge for DEs. In this study, some methods were used to disrupt hydrogen bonds of elastomers to improve the actuated strain at a low electric field of DEs. The first one is to disrupt the hydrogen bonds between thermoplastic polyurethane (TPU) chains by adding diaminonaphthalene (DAN) into the TPU matrix, resulting in the increase in the dielectric constant (k) of TPU and the decrease in the elastic modulus (Y) , and a 500% increase in actuated strain at a low electric field of DEs (20 V/μm). The second is to disrupt the hydrogen bonds between TPU chains by adding polyethylene glycol (PEG) oligomer. The k of TPU obviously increases by adding PEG owing to the combined effect of the ionic conductivity of PEG and the disruption of hydrogen bonds of TPU chains. Meanwhile, the Y of TPU obviously decreases. The simultaneous increase in k and decrease in Y results in 7500% increase in actuated strain at 3 V/?m. The third one is to disrupt the hydrogen bonds of gelatin/glycerin (GG) elastomer by adding cellulose nanocrystals (CNCs). The k of GG elastomer obviously increases by adding 5wt% of CNCs, leading to a 230% increase in the actuated strain at low electric field of GG.

Session 2.2

(abstracts are listed in the order of presentation)

2.2.1 Silicone elastomers with self-healing properties

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(1) DTU-Chemical Engineering

Presentation given by Prof. Anne Ladegaard Skov

Self-healing elastomers are prepared from interpenetrating networks (IPNs) of a commercial silicone elastomer as well as an ionic network. Ionic networks have previously been shown to possess very high permittivities [1, 2] but low mechanical stability due to the lower strength of the ionic bonding. Coupling of the ionic networks with robust and non-conductive silicone elastomers leads to novel dielectric elastomers with high dielectric permittivity, relatively high dielectrical breakdown strength as well as mechanical robustness. Furthermore the IPNs possess self-healing properties both after rupture as illustrated below where an IPN is cut in two pieces and assembled in two different configurations. The IPNs can also self-heal after electrical breakdown. This type of material opens up for materials with significantly longer life-time than current elastomer-based solutions where e.g. metal oxides or dipoles are added to increase the dielectric permittivity.

2.2.2 Pad printing 1-10 µm thick elastomer membranes for DEAs

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Presentation given by Mr. Alexandre Poulin

We present a technique for stamping patterned silicone elastomer membranes

with thicknesses ranging from 1 to 10 um. Silicone elastomers are becoming the material of choice for dielectric elastomer transducers. The variety of readily available materials, their versatility in terms of film thicknesses and their excellent mechanical properties have made them a very appealing alternative to the widely used acrylic elastomer VHB from 3M. Silicone films are typically blade casted or spin coated, two complementary techniques allowing for large-area (> 10 cm x 10 cm) and ultra-thin (< 1 µm) membranes respectively. By comparison, membranes up to 5 cm x 5 cm in area and with thicknesses ranging from 1 to 10 µm can be fabricated with a stamping technique. Unlike blade casting and spin coating this technique can be used to directly pattern (in-plane) the membrane to any desired shape, thus providing great design flexibility. We demonstrated in prior work that stretchable electrodes can also be patterned by stamping. Combined with the ability to pattern silicone membranes, it enables the stamping of functional structures such as dielectric elastomer actuators (DEAs) with high level of integration (vertical integration). In this contribution we detail our fabrication process and highlight the important parameters. As a proof of concept we characterized a stamped DEA, as well as a stamped vertical electrical connection for layers interconnection.

2.2.3 Electrolyte and solvent effects in PPyDBS linear actuators

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Presentation given by Dr. Rudolf Kiefer

An important question with conducting polymer linear actuators concerns the processes that occur once the electrolyte is changed. To address this question, a series of electro-chemo-mechanical deformation (ECMD) measurements on electrochemically prepared free-standing films of polypyrrole doped with dodecylbenzenesulfonate (DBS) were investigated under isometric (constant force) conditions in an organic solvent- and in aqueous based- electrolytes during cyclic voltammetric and square wave potential step experiments. The same film was actuated first in propylene carbonate electrolyte (0.1 M TBACF3SO3), where cation-driven actuation (12% strain) was observed. The film was then exposed to an aqueous electrolyte (0.2 M TMACl) where the actuation changed to anion-driven (7% strain). The same film was then returned to the propylene carbonate electrolyte, where anion-driven actuation (10% strain) was observed rather than the original cation-driven actuation. The mechanism and reasons for the observed behaviour are proposed.

2.2.4 Surface activation as adhesion promoter in the fabrication of large scale dielectric elastomer stack actuators (DESTs) made of pre-fabricated dielectric films

Tanja Grotepaß (1), Henry Haus (1), Holger Moessinger (1), Florentine Foerster-Zuegel (1), Helmut F. Schlaak (1)

(1) Technische Universität Darmstadt, Institute Of Electromechanical Design

Presentation given by Ms. Tanja Grotepaß

Traditionally multilayered dielectric elastomer stack transducers (DESTs) are produced by repeatedly cross-linking a liquid elastomeric pre-polymer. Our recent research focusses on a novel fabrication method for large scale stack transducers with a surface area over 200 x 300 mm by processing pre-fabricated elastomeric thin films of less than 50 µm thickness. Prefabricated dielectric films have many advantages, one being the constant thickness of the pre-fabricated foils. To build a large scale DEST adhesive forces have to be established between two elastomeric layers or between the dielectric and the electrode layer. These forces prevent delamination of the transducer while being fabricated or during its lifetime. The very low Young's modulus of the dielectric prevents the use of an adhesive, for it will decrease the elasticity of the whole stack. This work evaluates surface activation methods for their capability to increase adhesion between two layers of elastomeric material. The activation methods are low pressure plasma, corona treatment and UV-radiation. To investigate the adhesion between the layers of elastomer foil, a 180° peel-experiment is used. The resulting peel-resistance of treated and untreated elastomer material is compared and a conclusion is drawn.

2.2.5 Continuous aerosol-jet-printing of silicone layers for dielectric elastomer actuators

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(1) FAPS, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Presentation given by Mr. Sebastian Reitelshöfer

In our contribution we describe recent findings of our efforts to qualify the Aerosol-Jet-Printing process for manufacturing stacked dielectric elastomer actuators. With the Elastosil P 7670 a RTV-2 silicone is used. A new system design allows the synchronous generation of separate aerosol streams of the two Elastosil components A and B. The two aerosol streams are mixed in one printing nozzle with the necessary mixing ratio of 1:1. With this setup, for example, round silicone structures with a diameter of one centimetre and a layer thickness of 10 microns can be printed in 12 seconds. The internal shutter system allows the interruption of the process to print several structures sequentially in different locations or on top of each other. The process up to now is stable over a time span of five hours with a continuous output of 20mg/min of the mixed components A and B for printing silicone layers. A second printing nozzle is integrated in the system to realize the printing of carbon nanotube inks in-between dielectric silicone layers.

2.2.6 Upscalable method for producing ionic artificial muscles

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Presentation given by Ms. Inna Baranova

The ionic and capacitive laminates (ICLs) are promising candidates for use as actuators in the emerging field of soft robotics. For the past quarter of century,the widespread use of ICLs has been constrained by small batch sizes and poor repeatability. We have made significant improvement in the ICL manufacturing process by introducing an inert mesh layer as the centermost layer of ICL. ICL is built by spraying electroactive membrane and electrode layers on both sides of an inert mesh structure. The tautened mesh supports the ICL during its fabrication and results in increased repeatability in the ICL fabrication.It is possible to use the same electroactive materials as used previously in ICL fabrication: carbon derived from metal carbides as the active electrode material, PVdF-HFP copolymer as the binder and membrane material, and EMITFS ionic liquid as the electrolyte. After the ICL of desired thickness is reached by carrying out consecutive spray-coating cycles, the ICL is covered from both sides by thin sheets of gold current collectors - the current collectors are the only functional layers that currently are not applied by spraypainting.Contrarily to the previous manufacturing methods, e.g. layer-by-layer casting method, the newly developed method shows increased repeatability in larger batch sizes, which clearly suggests that large-scale manufacturing of ICLs,and their prototyping in soft robotics, is finally made possible.

2.2.7 Design and manufacturing of a compact high performance stacked diaphragm DEAP actuator

Steffen Hau (1), Alexander York (1), Stefan Seelecke (1)

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Presentation given by Mr. Steffen Hau

Dielectric electro-active polymer (DEAP) technology holds promise enabling lightweight, energy efficient, and scalable actuators. The circular DEAP configuration (also known as cone or diaphragm actuator) in particular can produce a large stroke when coupled with an appropriate biasing mechanism. The force and stroke output of these actuators was also previously shown to be strongly influenced by their geometry. This work investigates high force actuator systems by stacking single diaphragm DEAPs. Modeling results of such stacked actuator systems show that they are able to compete with solenoid or even pneumatic cylinder actuators. The design and manufacturing process of such actuator systems, consisting of a stack of double layered diaphragm DEAP modules as well as a specially tailored biasing mechanism, is presented and discussed. For a compact overall actuator size the biasing mechanism is mounted into the inactive center of the DEAP stack. A novel folding process for manufacturing double layered DEAP modules is also introduced. This folding process includes a new highly conductive connection method for stacking diaphragm DEAP modules.

2.2.8 Key value propositions in applications for dielectric elastomer actuators

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Presentation given by Mr. Asger Lautrop

This work identifies and clarifies tendencies in the performance metrics of dielectric elastomer actuators with respect to different application requirements. The study is based on real proposed applications and therefore not only highlights the properties in which DEA provides value, but also brings new opportunities for applications. This investigation collects and compares a variety of applications for DEA actuators and the proposed value in EAP is recorded. From these examples we build a comparison showing the most important performance metrics from the point of view of the application. As a result, the comparison gives a new perspective on what the tendencies are in this area of research. The comparison is validated by objectively comparing the technologies to those presently used in the application described. Finally, we will use the conclusions to present which DEA specific characteristics typically offer most value in applications. This leads to suggestions for further work to support commercial interest in efficiently identifying future products and components that can significantly benefit from DEA based actuators.

2.2.9 Hybrid actuators based on conducting polymer, nanoporous carbon and interpenetrating polymer networks

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Presentation given by Dr. Anna-Liisa Peikolainen

The aims of the study were fabrication of homogeneous composites of interpenetrating polymer networks (IPN) of nitrile butadiene rubber and poly(ethylene oxide) with carbide derived carbon (CDC), and applying of these composites as solid polymer electrolytes in pseudo tri-layer electromechanical actuators with conducting polymer electrodes. Nanoporous carbon in conducting polymer based actuator was expected to contribute to capacitive properties of the actuator. A modified procedure for fabrication of CDC-IPN composites was proposed, since addition of CDC affects the viscosity and polymerization of IPN monomers. The mechanical properties of the composite films were analysed. For actuation tests, a pseudo tri-layer actuator was formed by chemical polymerization of conducting polymer electrodes on both sides of the CDC-IPN film. Electromechanical properties of the actuators saturated either by 1 M bis(trifluoromethane)sulfonimide lithium (LiTFSI, in propylene carbonate (PC)) or 1-ethyl-3-methylimidazolium-bistrifluoromethanesulfonylimide (EMITFSI) were analysed. Upon applying a square wave voltage from +2V to -2V at frequency 10 mHz, the strain difference of 4.1% was achieved in the case of 1 M LiTFSI as an electrolyte. The improvement in specific capacitance with 5% of CDC was determined.

2.2.10 Low-voltage dielectric elastomer actuators for artificial muscle sphincters

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Presentation given by Dr. Vanessa Leung

Sphincter implants for treating incontinence are currently based on mechanical systems with high failure rates, requiring revision after 3 to 5 years. To advance artificial sphincter technology, we are developing an artificial muscle sphincter based on bio-mimetic dielectric elastomer actuators (DEA). DEAs suitable for medical implants require polymer films that are nanometer-thin, allowing actuation below 42 V, and stretchable electrodes that remain conductive at strains of 10 %. The first of these challenges lies in the realization of uniform thin films on the nano-scale. We will report on our fabrication process based on vacuum deposition of EAP sandwich stacks, which has so far allowed us to produce 250 nm PDMS films and 5 nm gold films. We present our next-generation molecular deposition system, which will be used to deposit multilayered organic and metallic thin films in the nanometer thickness regime. The second challenge for the fabrication of EAP actuators is the stiffness of conventional metallic electrode layers. We will present our results on flexible electrodes, involving a combination of material choice and mechanical processing.

2.2.11 Effect of network structure on mechanical and electrical properties of silicone-based dielectric elastomer

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Presentation given by Ms. Mengjia Zhang

Silicone-based elastomer is promising material for future dielectric elastomer actuators. In order to ensure an optimum performance and the long-term reliability of the actuators, a fundamental understanding about the elastomer network structure and its correlation with the mechanical and electrical characteristics of the material needs to be established. In this work, we investigated the effects of variation of network structure on the mechanical and electrical properties. A series of silicone elastomer films with different cross-linking density were prepared using varied stoichiometric ratio of pre-polymers. The network structure was analysed in terms of cross-linking density and crystallization behaviour, which was correlated afterwards with the observed tensile properties, mechanical fatigue life, permittivity and dielectric breakdown strength. We found that an increasing stoichiometric ratio leads to the expected increase in cross-linking density and reduction in mobility of the polymer chains. A correlation was detected between higher cross-linking density and higher elastic modulus and longer fatigue life, whereas a reduced permittivity was observed due to the lower chain mobility. Increasing dielectric breakdown strength of the silicone elastomer was also found to be associated with the change in stoichiometric ratio. Its variation with the measured elastic modulus and permittivity agrees well with the Stark-Garton model based on the electro-mechanical instability.

2.2.12 Semi-industrially produced ionic electroactive polymers based on polyethylene and carbide derived carbon

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Presentation given by Mr. Madis Harjo

Ionic electroactive polymers are materials where actuation is caused by displacement of ions. Polyethylene (PE), carbide derived carbon (CDC) and multi walled carbon nanotubes (MWCNT), with 1-ethyl-3-methylimidazolium tetrafluoroborate (EMIBF4) as an electrolyte, were successfully combined to produce a tri-layered bending actuator. Ion-permeable PE membrane was produced by mixing PE and a porogen in a twin-screw micro-compounder. Hot roll-pressing was used for obtaining the films of electrodes and membranes as well as for assembling the tri-layered actuators with membrane between carbon based electrodes. Actuation occurred at low voltages: as given on Figure 1 in the potential range from -4 to 4 V. As a result of the study, the displacement dependence on frequency, relative humidity, membrane and electrode thickness, and CDC and MWCNT content in the electrodes were determined. Displacement was calculated using camera and vector representation of an actuator.

2.2.13 Position Control of A Dielectric Electroactive Polymer Circular Actuator Via Self-Sensing Feedback

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(2) Department Of Electrical And Electronic Engineering, Polytechnic University Of Bari, Bari, Italy

Presentation given by Mr. Gianluca Rizzello

This paper investigates the concept of "sensorless" control for Dielectric Electro-Active Polymer (DEAP) actuators. The deformation of the DEAP can be reconstructed by measuring voltage and current during the actuation and exploiting the "self-sensing" feature of the DEAP. The estimated deformation can be eventually used as a feedback signal for closing a position control loop. The resulting actuator device is then capable to operate in closed loop without requiring additional electromechanical transducers. The goal of this paper is to show that the self-sensing algorithm presented in the author's previous works can be successfully employed for position control. This controller is capable of stabilizing a bi-stable circular DEAP actuator system which used as a case of study to validate the proposed control architecture. The chosen control law is a PID cascaded with a square root. Several experiments are performed to compare the closed loop displacement response in two distinct cases. The first case has the feedback loop closed with an accurate high-end laser displacement sensor and the second case has it closed with the self-sensing feedback. The performance and limitations of the overall sensorless scheme was evaluated by comparing these two cases.

2.2.14 Limb compression band made of dielectric elastomer actuators

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(2) Queen Mary University Of London, School Of Engineering And Material Science, London, UK
(3) University Of Trento, Department Of Civil Environmental And Mechanical Engineering, Trento, Italy

Presentation given by Mr. Luigi Calabrese

Within the international space station environment, weightlessness has negative effects on astronauts' health, shifting blood flow and reducing muscular mass and bone density. To mitigate these effects, an approach would be to develop special astronauts' suit able to apply controllable mechanical counter measures to avoid physiological problems. Here, we propose the concept and preliminary experimental investigations and modelling on the development of a smart band capable of electrically controllable limb compression via embedded actuation. In particular, we present an electrically driven dielectric elastomer band actuator, consisting of a pre-stretched multi-layer structure. In order to define the best performing material and geometry, an extensive preliminary investigation was carried out by building and testing several proof-of-concept samples. Prototypes of the band, with increasing thickness of its layers, were built and tested by wrapping them around a pressurized air chamber, which mimicked a human limb. The electrically controllable variation of pressure was measured by a pressure gauge, experimentally identifying optimal geometrical parameters. While the study showed that dielectric elastomer actuation is a promising technology for the intended use, it also revealed the challenges to be addressed for the development of the application.

2.2.15 FEM analysis of electroactive nanocomposites

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Presentation given by Ms. Agata Nicolau-Kuklinska

A class of smart materials which are able to respond to electrical stimulation with a significant shape or size change, appropriate for spaces application, was attempted to obtain. A nanocomposites with electrical conductivity based on silicones and multi-walled carbon nanotubes (NC 7000, Nanocyl, Belgium) were prepared. Liquid silicone was mixed with 0.5-3 weight percent of carbon nanotubes using calendaring method. First and foremost, influence of calender rolls velocity on electrical conductivity of nanocomposites was investigated. Microscopic observations were made using Transmission and Scanning Electron Microscope and good distribution of nanofiller was confirmed. Afterwards, the wavy strips FEM analysis was performed to simulate elongation of Sylgard 170 material (used in nanocomposite) under different value of voltage compressible stress. Influence of different geometries of the wavy strips: number of waves and length of curved on elongation was investigated. Results of numerical simulation of deformation of wavy strips shows that increasing of number of waves decrease the elongation during operation. On the other hand increasing the amplitude of wave on strip results in higher elongation.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 Fabrication and characterization of an ionic actuator with 3D printed PEDOT:PSS electrodes

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Presentation given by Ms. Inga Põldsalu

Electroactive polymers (EAPs) show interesting properties: high mechanical flexibility (compliance), low specific gravity, and high grade of tractability, scalability and low cost. These properties make EAPs appealing alternative to conventional actuators in areas like micromechanical systems (MEMS), microrobotics, personal medicine and diagnostics like for Lab-on-Chip (LOC) devices, etc. Since these devices demand small parts, the actuators themselves have to be small. 3D microprinting enables fabrication of small and well-defined devices. In the current work PEDOT:PSS (poly(3,4-ethylenedioxythiophene)-poly(styrene sulfonate) conducting polymer microactuators were fabricated by 3D microprinting. Compared to layer-by layer method, where the electrode layers and the membrane are prepared separately and assembled by hot-pressing, microprinting allows direct assembly by dispensing the electrode suspension directly onto the membrane. Repeated printing of a layer allows the controlling of electrode thickness. The nozzle size of the inkjet dispensing device is ideal for producing miniature patterns of electrodes. The electrodes were printed directly onto polyvinylidene fluoride membrane. Electrode fabrication will be described; the obtained PEDOT:PSS based actuators are characterized using optical and scanning electron microscopy (SEM). Cyclic voltammetry, impedance and laser displacement measurements were carried out to evaluate electromechanical properties.

2.3.2 Development and experimental validation of a valve driven by a dielectric electro-active polymer actuator

Marc Hill (1), Alexander York (1), Stefan Seelecke (1)

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Presentation given by Mr. Marc Hill

Dielectric Electro-Active Polymer (DEAP) actuators are lightweight, high energy density systems which show promise for improving the performance of pumps and valve control units. Particularly the use of EAPs as valve control units offer advantages over traditionally used solenoid valves. Unlike solenoids which draw current continuously when activated, the EAP-system draws current only during its initial motion, aside from some very small leakage currents. This means that the EAP will use significantly less energy for holding a valve in position than a solenoid would performing the same action. The EAP also generates very low heat and runs virtually silent. This work presents a valve which is driven by an EAP-system consisting of a diaphragm, or circular, EAP and a linear spring. The valve is designed for pressured air and allows a similar volume flow at various pressure drops to industrial valves. An experimental investigation of the performance of the EAP valve is conducted demonstrating an improvement over an equivalent output solenoid valve.

2.3.3 FE analysis of the stretch-force characteristic of multilayer DEAP stack-actuators

Thorben Hoffstadt (1), Dominik Uhlenbusch (1), Jürgen Maas (1)

(1) Ostwestfalen-Lippe University Of Applied Sciences

Presentation given by Mr. Thorben Hoffstadt

Multilayer transducers based on dielectric electroactive polymers (DEAP) are an interesting opportunity to realize energy efficient and lightweight actuators that offer a considerable amount of work output. Amongst other, especially a DEAP stack-actuator is an advantageous topology since it consists almost entirely of active material. This results in a comparatively high energy density. During actuation the electrostatic pressure compresses the stack-actuator and generates a pulling force. If interfaces for the mechanical integration into an application are applied, such an actuator can be used e.g. to lift a weight or actuate a pneumatic valve or electrical switch. For these applications, the stretch-force characteristic of the stack-actuator is decisive. By neglecting boundaries and constraints like inactive areas or the influence of the mechanical interfaces this characteristic can be derived analytically. However, inactive areas are mandatory to prevent electrical arcing and the interfaces are required to transmit the generated pulling force. To consider these boundaries an electromechanically coupled finite element (FE) model is proposed that can be used to determine the stretch-force characteristic depending on the applied voltage. Based on this FE model various simulations are performed to analyze the influence of different design parameters on the generated force and deformation of the actuator.

2.3.4 Estimation of Young's modulus of EAP materials using finite element analysis based parameter estimation

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Presentation given by Mr. Veiko Vunder

Electroactive polymer (EAP) materials are composites that exhibit changes in shape and/or size in response to an applied electric field. One of the critical factors at estimating the behavior of EAP sample is its effective Young's modulus. However, since the composite is very soft, accurate measurements of the Young's modulus are difficult. Moreover, several different approximations for calculating the Young's modulus are available, all of them leading often to different results. In current work we aim to overstep these limitations. We apply Finite Element Method (FEM) to estimate the shape behavior of EAP strip, by using applied voltage dependent volumetric changes of the electrodes. Since typical behavior of EAP samples includes large deformations, accurate mechanical behavior of the system is simulated using linear elastic material approach, utilizing finite strain approach (Lagrange strains). The Young's modulus of the EAP strip is thereafter obtained by solving an optimization problem, consisting of material parameter estimation. The FEM model, presented in current study captures accurately qualitative behavior of the simulated the EAP system and is suitable for analyzing EAP samples under investigation. Moreover, the methodology presented provides an attractive approach to evaluate the Young's modulus of the samples with arbitrary geometrical shapes.

2.3.5 Characterization and magnetic properties of cobalt ferrite -pzt/pvdf-trfe nanofibers obtained by electrospinning

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Presentation given by Dr. San Sebastian Maria

$CoFe_2O_4$-PZT/PVDF-TrFE nanofibers were prepared by Electrospinning method. The X-Ray diffraction data the composites showed crystalline structures of inorganics and beta-phase electroactive presence of PVDF-TrFE. The differential scanning Calorimetry (DSC) of composites showed a melting point of 160 C degrees. Atomic Force Microscopy (AFM) and scattering electron microscopy (SEM) images revealed that the nanofibers are well aligned and less than 180 nm. The nanocomposite obtained displayed a ferromagnetic hysteresis loop, with coercivities of 0.1 Tesla and a remnant magnetization of 1.6 emu per grame were obtained at room temperature. The piezoelectric coefficient (-d33 value) was measurement in a d33 meter, a value of 54pC per N was obtained for a fiber mat of 50 micrometers thick. This ferromagnetic behavior and -d33 value indicate that this hybrid material has potential to manufacture multiferroic devices.

2.3.6 Low voltage DEAs based on ultrasoft PDMS gels for tunable optical cavities

Markus Franke (1), Irma Slowik (2), Georgi Paschew (1), Hartmut Fröb (2), Andreas Richter (1), Karl Leo (2)

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(2) Technische Universität Dresden, Institut Für Angewandte Photophysik, Dresden, Germany

Presentation given by Mr. Markus Franke

In the research field of dielectric elastomer actuators (DEA) many interesting devices were developed in recent years. This includes actuators for shape changing devices, valves, loudspeakers or tunable optical elements. One of the main drawbacks to introduce DEA products into the market is the necessity of a high voltage power supply which goes up to several thousand volts. This operation voltage can be significantly decreased by using ultrasoft PDMS gels with enormous reduced mechanical stiffness (storage modulus ~1kPa) as dielectric elastomer material. Here we present a new platform of ultrasoft PDMS gel based DEA for tunable optical devices that are operating with comparable low voltages. The device consists of a transparent PDMS gel film with metallic mirror electrodes on top and bottom. Since the metallic electrodes also work as mirrors, inside of the DEA device an optical cavity is created. By applying a voltage to the electrodes the electrical field force squeezes the optical cavity and thus alters its size. Depending on the applied voltage of several hundred volts we observed a reversible change in thickness of more than 20 percent. Investigations by LCR meters verify the results by a tunable capacitance. Replacing the bottom metallic electrode by a transparent ITO electrode and a distributed bragg reflector (DBR) forms a tunable optical cavity for a DBR lasing system which is still under investigation.

2.3.7 2DOF ionic electroactive polymer micromanipulator

Ingvar Drikkit (1), Friedrich Kaasik (2), Veiko Vunder (2), Andres Punning (2), Alvo Aabloo (2)

(1) Tartu Raatuse School
(2) University Of Tartu

Presentation given by Mr. Ingvar Drikkit

We report on an accurate millimeter-size 2DOF micromanipulator with a working range of nearly 0.5 mm in two directions. Its components - two actuators, are realized with a single patterned strip of ionic electroactive polymer (IEAP) material. It is able to work in ambient air as well as under scanning electron microscope (SEM) (i.e. in deep vacuum and under ? radiation). The actuator consists of two electrode layers separated by a membrane layer. The electrodes consist of porous carbon (derived from titaniumcarbide) as an active material, polymer binder (Polyvinylidene di fluoride-co-hexafluoropropylene) and ionic liquid (1-ethyl-3-methylimidazolium tetrafluorobroate) as an electrolyte. Its fabrication is straightforward: first, a membrane was made onto a tautened inert mesh. Then a mask was applied, and the patterned electrodes were formed directly to the membrane. Finally the micromanipulator desired size and shape was cut out, and attached between two pairs of input clamps. The fabricated device was tested under optical microscope and under SEM.

2.3.8 Dielectric elastomer compression sensors with variable design and material properties

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Presentation given by Dr. Holger Böse

Dielectric elastomer sensors (DES) are a simple and effective means to measure large deformations and low forces with a capacitive work principle. As pure elastomer films coated by soft electrode layers, they are very sensitive for stretch but insensitive for compression loads. In order to fill this gap, new dielectric elastomer compression sensors (DECS) have been introduced recently. They consist of two parallel elastomer films with complementary profiled surfaces, between which a flat dielectric elastomer film is confined. The electrode layers are located on the inner elastomer film and/or on the profiled surfaces. Upon compression of this sandwich configuration, the profiled surfaces approach each other and the inner film is stretched simultaneously. Compression sensors with different designs were manufactured and investigated. They differ in the shape of their profiles and in the locations of the electrode layers. All elastomer components were made with silicone and the electrode layers with carbon black in silicone. Furthermore, the mechanical properties of the elastomer components were varied by modifying the stiffness of the silicone. Three different profile shapes, wave, bar and knot patterns, were used for the compression sensors. In combination with the electrode layer locations, different mechanisms of capacitance enhancement are active. The impact of the design and material parameters on the characteristics of the compression sensor is shown in the contribution.

2.3.9 Influence of pre-strain on the actuation performance of silicone dielectric elastomer film actuators

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Presentation given by Dr. Holger Böse

A common configuration of dielectric elastomer actuators (DEA) consists of an elastomer film which is pre-strained and attached to a rigid frame. If only a part of the pre-stretched elastomer film area is coated by electrodes, the electrode area expands in the electric field at the cost of the area not coated by electrodes. It is known that the actuation of such DEA in terms of the electrode expansion is enhanced by the pre-strain of the elastomer film. In order to obtain quantitative data on the influence of the pre-strain on the actuation of silicone elastomer films, systematic investigations were performed. For this purpose, circular film actuators with circular electrodes with variable diameter in the center were prepared. The silicone films were radially pre-stretched by between 50 and 200 %. Furthermore, the stiffness of the silicone film was varied by adding different concentrations of silicone oil as plasticizer. With increasing pre-strain, the actuation at fixed electric field strength decreases, but the breakdown field strength is considerably enhanced due to the stiffening of the silicone elastomer. The softening of the silicone by a higher concentration of plasticizer leads to a higher actuation at the same field strength. Further results are presented in this contribution.

2.3.10 Pedot as host of organic-inorganic hybrid materials for sodium batteries to store energy

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Presentation given by Dr. San Sebastian Maria

Since the discovery of polyacetylene as the first conjugated polymer, electro-conductive polymers with pi-conjugated bonds have been attracting much attention as electroactive materials for sensors, batteries, electrochromic devices, supercapacitors, etc. In 1980s, a new polythiophene derivative, poly(3,4-ethylenedioxythiophene) (PEDOT) was developed and it has been considered one of the most successfully conjugated polymers due to its high conductivity and excellent environmental stability. The PEDOT doped by a low mobile anion, PSS, has been exploited in applications such as coatings and electrode materials in organic semiconductor devices and electrical connections. In this work we propose the use of PEDOT/PSS in cathode as host of organic-inorganic hybrid materials for sodium batteries to store energy. First of all it was proved that neat PEDOT does not present relevant electrochemical activity in a sodium cell, so this material will only contribute to the conductivity of the cathode, not interfering with the cathode operation. Different processes to make hybrid electrodes were used: electropolymerization in the presence of the fluorophosphates and coating of prefabricated electrodes with PEDOT/PSS. The effect of this conductive polymer on the electrochemical performance of the fluorophosphate active material will be analyzed.

2.3.11 Non-back-drivable binary bistable DEA device

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Presentation given by Mr. Andrew Hinitt

Research into soft actuator technologies has rapidly expanded due to the inherent compliance of the active materials and the opportunities this offers. Bi-stability has been actively explored, where the controllable elasticity of the actuator can enable the transition of an end effector. However, it is still necessary in some cases for these actuators to interact with rigid objects, which can lead to challenging dynamics due to the soft elastic materials used. A non-back-drivable binary bi-stable actuating device is presented to overcome this issue. A combined bistable mechanism and antagonistic DEA (dielectric elastomeric actuator) provide a method for generating rigid position control using soft actuation. The alternate relaxation of each DEA within the antagonistic pair configuration provides bi-directional linear translation. This translation is used to move a rotating locking pin between two zero-energy states. The locking pin can be utilised as a general-purpose end effector with bi-stable position control. Note that energy is only consumed during state transition. The bistable non-back-drivable mechanism is based on a rotating ratchet. This device has many applications where high loads must be accommodated, but where movement can occur in periods of low loading. This is commonly the case with robotic and state-switching engineering applications.

2.3.12 Improving the electromechanical performance of graphene based dielectric elastomers by using some new methods

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Presentation given by Prof. Qin Ma

Dielectric elastomers (DEs) can can give rise to surprisingly large deformations by applying an electric field. 1-3 Because of the lightweight, large strain, and high energy density etc., DEs find many applications in industry such as artificial muscles and sensors. Among various DEs, graphene based DEs have attracted much attention because of its high dielectric constant (k) and unique layered structure. In this study, some new methods were used to improve the electromechanical performance of graphene based DEs. First, we prepared thermoplastic polyurethane (TPU) DE with high k and low dielectric loss by disrupting hydrogen bonding between TPU chains and in-situ thermal reduction of graphene oxide nanosheets (GONS). Second, we prepared carboxylated nitrile rubber (XNBR) DE with extremely high k at quite a low percolation threshold via the distribution of GONS around XNBR latex particles and the in-situ thermal reduction of GONS. Third, we prepared GONS-encapsulated carbon nanosphere (GO@CNS) hybrid/XNBR dielectric composite with high k, low dielectric loss and large actuated strain at a low electric filed by latex compounding. In addition, we prepared poly (dopamine) encapsulated GONS/elastomer composites with low dielectric loss and improved breakdown strength and actuated strain at a low electric field. The improvement in the electromechanical performance of graphene based DEs facilitates the wider application of DEs.

2.3.13 EAP actuator as a dynamic in vitro model of the intestinal epithelium

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Presentation given by Dr. Giulia Gori

This study focuses on the development of a bioreactor for dynamic cell culture, designed in order to mimic a pulsatile physiological interface in an in vitro model. Our efforts aim at overcoming the intrinsic limitations of traditional static models of the intestinal barrier, with the future purpose to test more effectively drugs, nanoparticles and other substances. To this aim, we are developing and testing a system based on dielectric elastomer actuators (DEAs). The greatest potential of this emerging technology for such an application is represented by the good match between versatility, high performance and low cost. The device consists of an annular DEA with ionogel electrodes and is designed to stretch and release a central perforated soft well that hosts cultured cells. Morphological analyses from in vitro tests demonstrated the possibility of culturing Caco-2 cells on the central well for 21 days and their capability to form a confluent epithelial stratum. Preliminary electromechanical tests showed that the device was able to retain proper functionality after 24 hours of exposure to environmental conditions required for the storage in incubator of the cells, i.e. a temperature of 37 °C and a humidity of 95%.

2.3.14 On the way to high permittivity elastomers

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Presentation given by Dr. Dorina Maria Opris

The dielectric permittivity of an elastic material can be significantly increased when blended with conductive fillers at concentrations approaching percolation threshold or when modified with polar groups. However, the access to such materials is after decades of research still a major challenge. This presentation will show the advantages and disadvantages of the two strategies we have been following and will provide an assessment of their future potentials.

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