EuroEAP 2013

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

Duebendorf (Zurich), Switzerland
25-26 June 2013

Technical programme

Book of abstracts

List of participants

ESNAM
European Scientific Network for Artificial Muscles

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EUROPEAN SCIENCE FOUNDATION
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Conference venue

Empa Academy
Empa – Materials Science & Technology

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Local organization

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EMPA AKADEMIE
Zentrum für Wissenstransfer

Presentation of the EuroEAP conference series

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

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

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

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

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

Federico Carpi
ESNAM Chair

Conference committees

Organizing committee

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

President:
Federico Carpi, Queen Mary University of London (UK)

Vice-President:
Edwin Jager, Linköping University (Sweden)

Members:
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Marc Matysek, Technische Universität Darmstadt (Germany)
Mika Paajanen, VTT Technical Research Centre of Finland (Finland)
Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Frédéric Vidal, University of Cergy-Pontoise (France)

Scientific committee

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

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Danilo De Rossi, University of Pisa (Italy)

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

Tuesday, 25 June 2013

General programme of the day

Opening	8:45-9:00	Welcome & introductory remarks **Gabor Kovacs** (EMPA, Duebendorf, Switzerland)
EAPlenariess	Session 1.1 part I *Chair:* **Gabor Kovacs** (EMPA, Duebendorf, Switzerland)	
	9:00-9:30	Invited talk **Richard Spontak** (North Carolina State University, Raleigh, USA)
	9:30-10:00	Invited talk **Kwang Kim** (University of Nevada, Las Vegas, USA)
EAPodiums	Session 1.1 part II *Chair:* **Edwin Jager** (Linköping University, Linköping, Sweden)	
	10:00-10:20	Invited talk **Ilkwon Oh** (Korea Advanced Institute Of Science And Technology, Korea)
Break	10:20-10:50	Coffee break
EAPromises	Session 1.1 part III *Chai:* **Ingrid Graz** (Johannes Kepler University, Linz Austria)	
	10:50-11:10	Invited talk **Christoph Keplinger** (Harvard University, Cambridge, USA)
	11:10-11:30	Invited talk **Adrian Koh** (National University Of Singapore, Singapore)

EAPills	Session 1.2 part I *Chair:* **Marc Matysek** (Technische Universität Darmstadt, Darmstadt, Germany)	
	11:35-12:50	**Pill oral presentations** 18 presentations (3 minutes each + 1 minute to change speaker)
Lunch	12:50-14:00	Lunch
EAPosters **EAPrototypes** **EAProducts**	Session 1.2 part II	
	14:00-15:20	**Posters & exhibitions** 18 posters
EAPills	Session 1.3 part I *Chair:* **Mika Paajanen** (VTT Technical Research Centre of Finland, Tampere, Finland)	
	15:30-16:45	**Pill oral presentations** 19 presentations (3 minutes each + 1 minute to change speaker)
Break	16:45-17:15	Coffee break
EAPosters **EAPrototypes** **EAProducts**	Session 1.3 part II	
	17:15-18:45	**Posters & exhibitions** 19 posters
Dinner	19:00	Bus departure from EMPA to the social dinner place (with stop at Sorell Hotel Sonnental a few minutes after 19:00)

Session 1.1

(abstracts are listed in the order of presentation)

1.1.1 Electroactive polymers containing fibrous and continuous high-k constituents

Richard J. Spontak (1) (2) and Tushar K. Ghosh (3)

(1) Department of Chemical & Biomolecular Engineering, North Carolina State University, Raleigh, USA
(2) Department of Materials Science & Engineering, North Carolina State University, Raleigh, USA
(3) Department of Textile Engineering, Chemistry & Science, North Carolina State University, Raleigh, USA

Presentation given by Prof. Richard J. Spontak

Electroactive polymers (EAPs) continue to receive considerable attention due to the tremendous technological promise they afford because of their stimuli-responsive nature. Numerous recent advances in the design of EAPs have focused on achieving high electroactuation strains and high dielectric breakdown conditions. In this work, we provide three different systems wherein various types of elastomers have been modified with either fibrillar or continuous additives possessing a relatively high dielectric constant (k). The first system employs a conventional dielectric elastomer, namely, VHB, in the presence of a finite number of oriented polyurethane fibers. The resultant actuation of these systems clearly demonstrates an anisotropic response that exceeds the purely isotropic response. Upon comparison with various models, it is evident that the enhanced actuation is a combination of the stress field accompanying the oriented fibers and their elevated k. These results further indicate that the electromechanical efficiency can be improved upon incorporation of oriented fibers. The second system utilizes a fully acrylic thermoplastic elastomer gel (ATPEG) in the same fashion as our earlier studies of midblock-solvated styrenic triblock copolymers. In this case, however, a high-k midblock-selective solvent (dioctylphthalate) is employed. Due to the thermodynamic nature of the copolymer blocks, the ATPEGs must contain a higher copolymer concentration to remain sufficiently elastic, which therefore

limits the extent of actuation strain achievable to a little over 100%. However, a significant consideration in these more highly polar systems is that they do not require mechanical prestrain to reduce specimen thickness and, thus, the voltage required to induce actuation. The third system to be discussed is based on the same materials design as the TPEGs but introduces a midblock-sulfonated block so that highly polar solvents such as water or ethylene glycol can be used to improve electroactuation. In this case, we demonstrate that these materials can be fabricated into an entirely different EAP class as ionic polymer-metal composites (IPMCs). Performance characterization of these materials confirms that they perform equal to or better than comparable EAPs derived from Nafion, and they show no evidence of back relaxation while the voltage is applied. In all three cases, the nano/microstructure of the material systems plays a critical role in electroactuation.

1.1.2 Recent progress in IPMC

Kwang Kim (1)

(1) University Of Nevada, Las Vegas, USA

Presentation given by Prof. Kwang Kim

Ionic Polymer-Metal Composites (IPMCs) are a unique polymer transducer that when subjected to an imposed bending stress, exhibits a measurable charge across the chemically and/or physically placed effective electrodes. IPMCs are also known as bending actuators capable of large bending motion when subjected to a low applied electric voltage across the electrode. In this presentation, the basic principles of IPMC actuator/transducer and its manufacturing techniques for various new configurations will be discussed.

1.1.3 Graphene-based Electromechanically Active Polymers

Ilkwon Oh (1)

(1) Korea Advanced Institute Of Science And Technology, Korea

Presentation given by Prof. Ilkwon Oh

Here, we report a simple route for a high-performance ionic conducting nano-biopolymer membrane based on pendent sulfonated chitosan (PSC) and functionalized graphene oxide (GO) to develop a new type of low-cost, air working, eco-friendly electro-active biopolymer actuator with improved electro-chemo-mechanical properties. The amine group in the chitosan biomolecule was actively used to tune the degre-of-sulfonation of pendent sulfonated chitosan by controlled treatment with 1,3-propyl sultone in ambient conditions and reacted with functionalized graphene oxide. So, it can act as higher ionic-exchangable membrane because of the availability of propyl sulfonic acid groups that can strongly bind with free amines and with ionic liquid. Furthermore, electro-chemo-mechanical activities of PSC can be maximized by simply reinforcing with functionalized carbon nanomaterials. Therefore, functionalized graphene oxide was used to improve in-plane mechanical stiffness and electro-chemo-mechanical properties through strong ionic interactions and bonding with free amines and sulfuric acid groups of PSC biopolymer. The incorporation of GO enhanced multiple qualities such as mechanical strength and physicochemical properties like ionic exchangeable capacity, ionic conductivity and electrochemical impedance, resulting in a novel high-performance nano-biopolymer actuator that shows very large bending deformations under low input voltages in the dry environment.

1.1.4 Giant deformation of elastomers in electric fields

Christoph Keplinger (1) (2) (3),

(1) Harvard University, School Of Engineering And Applied Sciences, Cambridge, USA
(2) Harvard University, Department Of Chemistry And Chemical Biology, Cambridge, USA
(3) Harvard University, Kavli Institute For Bionano Science And Technology, Cambridge, USA

Presentation given by Dr. Christoph Keplinger

Dielectric elastomer actuators (DEAs) are developed for applications ranging from artificial muscles to electrically deformable lenses for tunable optics and Braille displays. The presented work is focused on the most conspicuous feature of DEAs: giant voltage-induced deformation of actuation. The deformation of elastic membranes induced by voltage is limited to about 60% in terms of area strain by an electromechanical instability usually leading to electric failure of the device. Two methods to exceed this limit are presented: Firstly, electrode free DEAs are introduced. They are operated with electrical charges, which are sprayed onto the elastomer surface originating from a high voltage corona discharge. This technique avoids the electromechanical instability. Experimental evidence of giant voltage-induced deformation is provided. The absence of electrodes allows for transparent designs and applications in optics, which is demonstrated with an electrically tunable lens. Secondly, a principle is introduced that allows for exceeding the deformation limits of the electromechanical instability with conventional voltage controlled actuators based on off-the-shelf materials. The developed principle of operation safely harnesses electromechanical instabilities. With a commercially available acrylic elastomer, voltage-induced expansion of area by 1692% is demonstrated, well beyond the largest value reported in literature.

1.1.5 Dielectric elastomer generators: from fundamentals to realization

Soo Jin Adrian Koh (1) (2), Christoph Keplinger (3), Rainer Kaltseis (4), Choon Chiang Foo (2), Siegfried Bauer (4), Zhigang Suo (3),

(1) National University Of Singapore, Department Of Civil & Environmental Engineering And Engineering Science Programme, Singapore, Singapore
(2) Agency For Science, Technology And Research, Institute Of High Performance Computing, Engineering Mechanics Department, Singapore, Singapore
(3) Harvard University, School Of Engineering And Applied Sciences, Cambridge, Massachusetts, USA
(4) Johannes-Kepler University, Department Of Soft Matter Physics, Linz, Austria

Presentation given by Dr. Adrian Koh

A dielectric elastomer reversibly transduces between its electrical and mechanical thermodynamic states, allowing it to be used as an actuator, sensor and generator. This talk focuses on the use of dielectric elastomer as a generator (DEG). Due to material non-linearity, electromechanical coupling and complex dissipative processes, realizing the full potential of a DEG remains a challenge. We tackle this challenge on three fronts: First, we use a thermodynamic model to estimate the maximum amount of energy that can be converted. This model enables us to compare and design different DEG systems. Second, we develop loss models based on experimental measurements of viscoelasticity, hysteresis, dielectric losses and current leakage. This model enables us to optimize operating conditions to give the highest conversion efficiency. Third, we design a simple experiment that allows repeatable and consistent measurements on the output yield of a DEG. Our theoretical model revealed that DEGs convert energy at a specific energy density of at least an order of magnitude higher than piezoelectrics and electromagnetic generators. Our experiments shows that natural rubber converts up to three times more energy than the commonly-used VHB, and is more durable against cyclic operation, less viscous and more efficient. Natural rubber also costs significantly less to produce, paving the way for portable and efficient high-performance generators to be commercialized.

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

1.2.1 EAPs for consumer electronics, a market perspective

Cathleen Thiele (1) (2),

(1) IDTechEx GmbH, Market Research, Berlin, Germany
(2) IDTechEx Ltd, Market Research, Cambridge, United Kingdom

Presentation given by Ms. Cathleen Thiele

Despite several decades of R&D and first applications, the EAP field is far from mature and several challenges, such as perfomance and long-term stability, still need further development to tailor their properties to the requirements of each application. Nevertheless, excellent sensor and actuator characteristics allow for highest potential in new sectors, namely haptics for touchscreens, medical and energy harvesting. Especially in the actuators segment vast R&D activity can be seen for specialized applications, such as medical devices and biomimetic-robotics. Finally, 2013 will see first commercial implementations mainly in the consumer electronics market with penetration being forcasted at USD1bn. Haptics for consumer portable touch screen devices and peripherals is going to be the next big application and potentially the first large-scale implementation of EAP actuators in general with an expected penetration of 60% for haptic feedback in mobile phones for 2018. Penetration of the touchscreen market will finally take the technology to the next level. The success will account for over 40% of the expected total EAP market revenue in 5 years. Other applications with great potential in +5 years include energy harvesting from see waves, medical applications, both invasive and non-invasive, large-area sensors, speakers etc. However, challenges remain and need to be addressed first.

1.2.2 Improved electromechanical characteristics in the TiO2/polydimethylsilicone nanocomposites by tuning flexibility

Zhi-Min Dang (1), Hang Zhao (1), Jun-Wei Zha (1),

(1) University Of Science & Technology Beijing, Department Of Polymer

Science And Engineering,Beijing, China

Presentation given by Prof. Zhi-Min Dang

Flexible polymer materials with obvious electrostriction characteristic display a significant application as novel potential actuators in the future. We report the advanced TiO2/polydimethylsilicone (TiO2/PDMS) nanocomposites with effective increased electroaction through a molecular flexibility tuning process. The rises of electromechanical sensitivity (increase by 550 %) and actuation strain (increase by 230 %) at a low electric field in the low elastic modulus TiO2/PDMS composites originate from the flexibility tuning process by introducing dimethylsilicone oil (DMSO). The DMSO is miscible with PDMS for the uniform composition in molecular level, which can significantly decrease the elastic modulus of dielectric elastomer composites from 820 kPa to 95 kPa. The experimental results are interpreted with swelling elastomers theory. It suggests that reducing elastic modulus could be a good strategy of improving actuation performance at low electric field.

1.2.3 Linear actuation and electronic properties of freestanding PPyDBS and chitosan-PPyDBS films

Rudolf Kiefer (1), Nihan Aydemir (2), James Parcell (2), Jadranka Travas-Sejdic (2), Alvo Aabloo (1),

(1) University Of Tartu, Institute Of Technology, Tartu, Estonia
(2) The University Of Auckland, School Of Chemical Sciences, Auckland, New Zealand

Presentation given by Dr. Rudolf Kiefer

An investigation is reported into the electrochemomechanical deformation (ECMD) of polypyrrole (PPy) doped with dodecylbenzenesulfonate (DBS) in the form of freestanding films and as depositions on conductive substrates (chemical fixed PEDOT) based on chitosan. Under isotonic (constant force) conditions the samples are tested in tetrabutyl ammonium trifluoromethanesulfonate (TBACF3SO3) in organic electrolyte (propylene carbonate) and tetramethylammonium chloride (TMACl) aqueous electrolyte. The goal of this study was to investigate the actuation response of linear actuators electrochemically polymerized on conductive chitosan materials relative to freestanding PPyDBS films. The examination looks into the changes of the electronic properties of chitosan-PPyDBS and freestanding PPyDBS films before and after actuation via scanning electronic microscopy (SEM) and Raman spectroscopy. This study involves a novel method of utilizing scanning ion-conductance microscopy (SICM) to accurately inspect electrochemical behavior of the surface of the linear actuator using micropipette tips on top of the films.

1.2.4 Sensing using piezoelectric chiral polymer fiber

Yoshiro Tajitsu (1),

(1) Kansai University, Electrical Engineering Department, Suita, Osaka, Japan

Presentation given by Prof. Yoshiro Tajitsu

Soft and flexible actuators fabricated from piezoelectric polymers are currently being studied actively because small, soft, and flexible actuators can be widely applied in new technologies in the mobile communication, medical, and biological fields. To realize a new polymer sensor fabricated from a piezoelectric chiral polymer fiber, we attempted to detect the response signal induced by the shear piezoelectricity of the chiral poly(L-lactic acid) (PLLA) under the application of stress and strain, and we confirmed that the piezoelectric response signal was sufficiently large for use as a sensor signal. We then prepared a left-hand helical torsion coil (PLLA fiber left hand coil), which was formed by drawing a PLLA fiber ten times. It was observed that, when twisted and released suddenly, the coil exhibited a torsion vibration, and we confirmed that the piezoelectric response signal followed the torsion vibration. Next, we prepared a system in which a PLLA fiber coil was linked to a personal computer used for simple image processing. The PLLA fiber left- and right-hand coils were placed on the arm of a subject, and the inward rotation and outward rotation of the forearm and upper arm were measured. Finally, using this system, we were able to visualize the rotation of the forearm and upper arm.

1.2.5 Dielectric properties of silver nanoparticles coated with silica shells of different thicknesses

Jose Enrico Quinsaat (1) (2), Frank NÃ¼esch (1), Heinrich Hofmann (2), Dorina Opris (1),

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(2) Ecole Polytechnique FÃ©dÃ©rale De Lausanne (EPFL), Materials Institute, Powder Technology Laboratory (LTP), 1015 Lausanne, Switzerland

Presentation given by Mr. Jose Enrico Quinsaat

Silver nanoparticles have attracted considerable attention due to their catalytic, electronic and optical properties which differ from bulk. The polyol synthesis has emerged as a convenient way of preparing silver nanoparticles and tuning their properties such as size and shape. Because of their high polarizability, the dispersion of silver nanoparticles into a polymeric matrix leads to an enhancement in the dielectric constant of the resulting material. This approach is considerably attractive for preparing dielectric elastomer actuators. In this work, silver nanoparticles were prepared and coated with a silica shell in order to prevent possible percolation thus leading to electric shortcuts. The silica shell was formed using a modified StÃ¶ber method which consists of the hydrolysis of tetraethoxysilane under basic conditions. These core-shell particles, where the silica shell thickness could be controlled by the amount of tetraethoxysilane added into the reaction mixture, were pressed into pellets and their dielectric properties measured. Prior to the potential use of these core-shell particles as filler in polymeric materials such as polydimethylsiloxane, the surface of the silica shell surrounding the silver cores require hydrophobic treatment in order to facilitate their dispersion into the hydrophobic polymer matrix.

1.2.6 Semi-automated test stand for standardized characterization of dielectric elastomer transducers

William Kaal (1), Sven Herold (1),

(1) Fraunhofer LBF, Department Of Structure Dynamics And Vibration Technology, Darmstadt, Germany

Presentation given by Mr. William Kaal

The electromechanical behavior of dielectric elastomer (DE) actuators is strongly frequency-dependent. In order to characterize such devices and develop suitable numerical models in a broad frequency range a semi-automated test stand was realized. It excites the actuator with a sinusoidal high voltage input signal and directly analyzes its mechanical response, taking into account the nonlinearity of the system. Depending on the set-up the test stand can determine the frequency-dependent blocking force or the frequency-dependent free displacement. The characterization process can take several hours due to the low frequencies that have to be considered, but the result is a high quality data set that can form the basis for a reliable modeling. The design of the test stand and its graphical user interface, the crucial algorithms that are implemented and some exemplary measurement results obtained with different DE actuators will be presented in this poster. The test stand is an extremely useful tool to easily analyze and compare DE actuators in a standardized way and thus forms an important step in the process of further advancing the exciting technology of dielectric elastomers.

1.2.7 Self-healing electrodes for dielectric elastomer actuators

Dorina Maria Opris (1), Silvain Michel (2), Frank A. NÃ¼esch (1), Andreas Borgschulte (3),

(1) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory Of Functional Polymers, Duendorf, Switzerland
(2) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory Of Mechanical Systems Engineering, Duendorf, Switzerland
(3) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory For Hydrogen And Energy, Duendorf, Switzerland

Presentation given by Dr. Dorina Maria Opris

Dielectric elastomer actuators are stretchable capacitors that elongate when charged. The elongation and the reliability of such actuators depend on the dielectric material as well as the electrode material used. While elastomers with low modulus of elasticity and increased permittivity allow actuations at lower electric fields, the electrode material can have a direct impact on the actuator lifetime and reliability as well as on the energy consumption. This poster presents a conductive printable and stretchable composite based on 20 wt% reduced graphite in silicone to be used as electrode in dielectric elastomer actuators. It has a sheet resistance of 0.1 k?/? and a low modulus of elasticity. Additionally, it is able to self-heal the actuator after a breakdown and thus increases significantly its lifetime and reliability. The actuator can suffer many breakdowns and is able to self-heal again and again without loss of performance.

1.2.8 Integrated polypyrrole and amorpous carbon hybrid films

Janno Torop (1), Alvo Aabloo (2), Edwin Jager (1),

(1) Biosensors & Bioelectronics Centre, Dept. Of Physics, Chemistry And Biology (IFM), LinkÃ¶ping University, LinkÃ¶ping, Sweden
(2) IMS Lab, Institute Of Technology, University Of Tartu, Tartu, Estonia

Presentation given by Dr. Janno Torop

Although electroactive materials based on conducting polymers have improved considerably during the last two decades, further improvement, especially with regards to strain and speeds are required. Here, we present a novel concept of synthesizing hybrid materials comprising polypyrrole (PPy) and carbonaceous materials in order to increase the performance. Hybrid electroactive films composed of nanoporous amorphous carbon and PPy were successfully electropolymerized. PPy and the carbon materials were integrated to form a continuous film without additional binder which is often an insulator and inevitably reduces the electrical and electrochemical performance. The incorporation of nanoporous carbon in film structure was verified using ATR-FTIR. The redox behavior of PPy/carbon hybrid and PPy films, as well as electrochemical capacitance properties were investigated using cyclic voltammetry and electrochemical impedance spectroscopy (EIS) methods. The conductive polymer-carbonaceous films exhibited good electrochemical reversibility during cycling. The surface morphology of the polymer hybrids were investigated with SEM. The porous structure of PPy/carbon hybrid considerably increases the area of the electrolyte/composite film interface, which is leading to higher electric double-layer capacitance and higher redox capacitance, and leaving adequate working space to assure facile electrolyte penetration and better faradaic utilization of the electroactive PPy.

1.2.9 Autofocus fluid lens device construction and actuator performance based on electroactive polymers (EAP)

Harti Kiveste (1), Alvo Aabloo (1), Rauno Temmer (1), Rudolf Kiefer (1),

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

Presentation given by Mr. Harti Kiveste

Autofocus fluid lens device as example developed by Phillips based on water/oil interfaces forming a spherical lens by the meniscus of the liquid that can be switched by applying high voltage to change from convex to concave divergent lens. In this work we construct a device to evaluate the performance of membrane actuators in later design applicable for autofocus fluid lens application. The membrane with hole in the middle separates the oil phase and electrolyte phase, forming a meniscus in the middle of the membrane between oil/electrolyte. If the membrane actuator shows certain force and displacement the meniscus between oil and electrolyte will change their form between concave and convex, applicable as fluid lens. The advantages for applying ionic EAP actuators based on conducting polymers (CP) and ionic polymer metal composites (IPMC) in this application relies on their low voltage supply, frequency up to 10 Hz and high displacement. EAP membrane actuators are less studied and their performance in view of bending size and force will be presented in this work.

1.2.10 Effect of crosslinking agents on the electromechanical properties of silicones

Adrian Bele (1), Maria Cazacu (1), Carmen Racles (1), Dorina Opris (2), Mircea Ignat (3), George Stiubianu (1), Valentina Musteata (1),

(1) "Petru Poni" Institute Of Macromolecular Chemistry, Iasi, Romania
(2) Empa, Swiss Federal Laboratories For Materials Science And Technology, Laboratory For Functional Polymers, DÃ¼bendorf, Switzerland
(3) National Institute For Research And Development In Electrical Engineering ICPE-CA , Bucharest, Romania

Presentation given by Mr. Adrian Bele

Five R-triethoxysilanes, with R: CH3, C6H5, (CH2)3NH2, (CH2)3Cl or (CH2)3CN were used as condensation crosslinking agents for two -OH terminated polydimethylsiloxanes with different molecular masses (Mw = 35000 g/mol and Mw = 125000 g/mol). The crosslinking was done at room temperature under the influence of the environmental moisture, in absence of any catalyst. After aging, the mechanical, dielectrical and thermal properties of the resulting films were investigated. Surface characteristics including water sorption, contact angle, roughness were evaluated by dynamic vapour sorption analysis, tensiometry and atomic force microscopy, while the distribution of in-situ formed silsesquioxanes was observed by scanning electron microscopy (cryo-fracture). The electromechanical response to an applied electric field was also investigated. The influence of type of R from crosslinking agent and polymeric chain length on the investigated properties are discussed.

1.2.11 Silicone composites with optimized properties for electromechanical actuation

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

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

Presentation given by Dr. Maria Cazacu

Polydimethylsiloxane-alfa, omega-diols with different well-established molecular masses were prepared and used as matrix to incorporate a surface treated ceramic active filler, in order to increase the dielectric permittivity. The composites were processed as films and crossllinked by condensation. After ageing, these were investigated by different methods, aiming to obtain information of interest for electromechanical actuation. Thus, the mechanical properties (stress-strain curves, cyclic tensile stress tests, Young modulus) and the dielectric behavior were correlated with thermal behavior (differential scanning calorimetry), surface properties (dynamic water vapor sorption analysis and contact angle) and morphology (by scanning electron microscopy) were studied. Strains of the order 500-800 % were obtained while the permittivity values ranged between 3 - 4 within a large frequencies domain. The effect of the polymeric matrix parameters, the content of the active filler, its characteristics and dispersion pattern on these properties were estimated based on the obtained results.

1.2.12 Synthesis and characterization of silicones containing cyanopropyl groups and their use in dielectric elastomer actuators

Carmen Racles (1), Maria Cazacu (1), Beatrice Fischer (2), Dorina M. Opris (2), Mihaela Alexandru (1),

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Presentation given by Dr. Maria Cazacu

Due to the low dielectric permittivity of polydimethylsiloxanes (PDMS), large electric fields are required to induce electromechanical actuation. By chemically modifying silicones with cyanopropyl groups, permittivity increase is expected. We synthesized siloxane copolymers containing repeat units with cyanopropyl groups from 3 to 23%, by different methods. The prepared polymers were cross-linked into thin films. The dielectric permittivity of these films increased from 2.4 (for the silicone matrix) to 6.5 for a film containing about 23% of cyanopropyl units. The most promising materials were further optimized to meet the requirements for actuators and their electromechanical properties were investigated. The best performance in this series was obtained with a blend of PDMS and cyanopropyl-modified silicone, which had a permittivity of 3.5 and higher modulus of elasticity as compared to the matrix. This material showed 10% actuation strain at 40 V/micrometer, which is a factor of 3.8 larger as compared to the matrix (2.6% actuation strain at the same voltage).

1.2.13 Development of polydiphenylamine/zeolite Y composites and electrical conductivity responses toward halogenated hydrocarbons

Tharaporn Permpool (1), Anuvat Sirivat (1), Darunee Aussawasathien (2),

(1) The Petroleum And Petrochemical College, Polymer Science/Chulalongkorn University, Bangkok, Thailand
(2) National Science And Technology Development Agency, National Metal And Materials Technology Center/Ministry Of Science And Technology, Pathumthani, Thailand

Presentation given by Ms. Tharaporn Permpool

Composites of polydiphenylamine (D PDPA) and zeolite Y with H+ as the cation (Y H+) have been fabricated to be used as a sensing material towards non-halogenated and halogenated solvents (hexane, dichloromethane, 1, 2-dichloroethane, chloroform). The composites can discriminate a non-halogenated solvent from halogenated solvents. They possess maximum electrical conductivity sensitivity values towards dichloromethane, but the composites do not respond to hexane. Generally, the sensitivity of the composites increases with increasing zeolite content and vapor concentration. To enhance the sensing properties of the composites, zeolite Y was modified by the dealumination process. The resultant dealuminated zeolite Y shows a higher sensitivity when exposed to those solvents than the pristine zeolite. An a Acid treatment time of 12 h provided the highest sensitivity. The optimal dealuminated zeolite content in the composites is 30 %v/v. The interaction between the polymer and the vapor is irreversible as confirmed by EFM technique. A mechanism for the interaction between the composites and the solvents is proposed.

1.2.14 Electromechanical properties of biocompatible gelatin as actuator

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(3) Faculty Of Science, Department Of Industrial Chmistry, Chiang Mai University, Chiangmai, Thailand

Presentation given by Mr. Thawatchai Tungkavet

Nanowire-Polypyrrole/gelatin hydrogels were fabricated by the dispersion of nanowire-polypyrrole into the gelatin aqueous solution followed by solvent casting. The electromechanical properties, thermal properties and deflection of pure gelatin hydrogel and nanowire-polypyrrole/gelatin hydrogels were studied as functions of temperature, frequency, and electric field strength. The 0.01, 0.1, 0.5, 1 %v/v nanowire-polypyrrole/gelatin hydrogels and pure gelatin hydrogel possess storage modulus sensitivity values of 0.75, 1.04, 0.88, 0.99 and 0.46, respectively, at the electric field strength of 800 V/mm. Stress relaxation functions of the uncrosslinked and crosslinked gelatin hydrogels were measured to study the effects of electric field strength and the crosslinking ratio. The characteristic relaxation time can be estimated by three methods; KWW; the dynamic crossover; and the relaxation time distribution spectrum H(?). For the uncrosslinked, 3 %v/v crosslinked and 7 %v/v crosslinked gelatin hydrogels, the relaxation times decrease with increasing degree of crosslinking and applied electric field strengths. The experimental shift factors can be thus obtained from either the stress relaxation functions or the storage and loss moduli. These approaches produce numerically the same shift factor values which successfully allow the time-electric field superposition of various related functions.

1.2.15 Influence of titanium dioxide particles on the mechanical and electrical properties of silicone films in dependence of titania (TiO2) surface treatment and content

Martin Bluemke (1), Michael Wegener (1), Bjoern Kussmaul (1), Holger Egger (2), Jens Krause (3), Hartmut Krueger (1),

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(2) Bayer Technology Services GmbH, Leverkusen, Germany
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Presentation given by Mr. Martin BlÃ¼mke

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. Recently, we offered a method to increase the permittivity of silicones simultaneously with stiffness reduction by dipole-grafting. Beside the use of organic dipoles, the permittivity generally can be increased by high-DK inorganic filler particles. The use of these fillers often results in an increase of mechanical stiffness. To avoid that and to achieve stable dispersions during film processing surface treatment of the nanoparticles can be important. In the present work we will compare the properties of silicones filled with different types of TiO2 nanoparticles. Furthermore we substitute the usually in a silicone embedded fumed silica step by step by TiO2, whereas the overall volume percentage of the particles was held constant. Different dispersion techniques were tested to determine their influence on the resulting film properties. To change the particle-silicone interaction, surface-modified TiO2 nanoparticles were prepared also and tested. The chemical, mechanical and electrical properties were characterized and will be discussed.

1.2.16 Plastic tests plastics: A toy brick based tensometer for the characterization of dielectric elastomers

Richard Moser (1), Christian Siket (1), Gerald Kettlgruber (1), Ingrid M. Graz (1), Michael Drack (1), Petr Bartu (1), Siegfried Bauer (1),

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Presentation given by Mr. Richard Moser

Knowledge of stress-strain curves of dielectric elastomers is important for the design of dielectric elastomer actuators and generators, usually displayed in work-conjugate plots. Measurements of stress strain curves are typically carried out with expensive commercial tensometers. Here we show how to use and upgrade toy bricks based on the Lego Mindstorms system for the construction of a lightweight, low-cost and easy to reproduce tensometer. The current design allows for stress-strain studies along with resistance over strain measurements, therefore being an ideal tool for mechanical characterization of common elastomers and performance studies of stretchable electrodes. We apply our system to mechanically characterize PDMS elastomers and compare results with measurements obtained on commercial equipment, with remarkable agreement. Additionally we show hot to use the set-up for the electomechanical characterization of stretchable electrodes, based on thin metal layers on ultrathin plastic substrates glued on pre-stretched dielectric elastomers.

1.2.17 New silicone systems as matrices in dielectric elastomer actuator applications

Yee Song Ko (1), Dorina Opris (1), Farnk Nueesch (1), Beatrice Fischer (1), Christian Walder (1),

(1) EMPA Dubendorf, Department Of Advanced Materials And Surfaces, Dubendorf, Switzerland

Presentation given by Mr. Yee Song Ko

Several polydimethylsiloxane elastomers were developed and investigated regarding their potential use as materials in dielectric elastomer actuators (DEA). A hydroxyl end-functionalized polydimethylsiloxane was reacted with different crosslinkers and the electromechanical properties of the resulting elastomers were investigated. The performance of the best performing silicone was further improved by using PDVB encapsulated PANI particles. These composites have enhanced properties including increased strain at break, higher dielectric constant as well as breakdown fields higher than that of the matrix. The composites are compared to the commercially available acrylic foil VHB 4905

(3M) which is currently the most commonly used elastomer for DEA applications. It was found that the composites have little hysteresis and can be activated at low voltages. For example, when the newly synthesized composite was 30% prestrained, a lateral actuation strain of about 12% at 40 V/?m was measured while half of this actuation strain at the same voltage was measured for VHB 4905 film that was 300% prestrained. Such composites are quite robust and survived more than 100 000 cycles at a frequency of 100 Hz and high electric fields close to the dielectric breakdown value. Such materials will find applications wherever small forces but large strains at low voltages are required.

1.2.18 Approaches to soft electronic skin

Ingrid M. Graz (1), Michael Drack (1), Roland AltmÃ¼ller (1), Martin Kaltenbrunner (1) (2), Tsuyoshi Sekitani (2), Takao Someya (2), Siegfried Bauer (1), Qibin Zhao (3), Jeremy J Baumberg (3),

(1) Soft Matter Physics, Johannes Kepler University
(2) Department Of Electrical And Electronic Engineering And Information Systems, The University Of Tokyo,
(3) Nanophotonics Centre, University Of Cambridge

Presentation given by Dr. Ingrid M. Graz

Skin is not only our largest organ, it is also a very complex ultra-conformable large-area sensor. Electronic skin inspired by its human equivalent now combines sensing and signal transduction, but still remains mechanically stiff or only flexible. New designs are taking the evolution of this electronic skin one step further towards a soft, stretchable system. Our approach employs the concept of wrinkling, also familiar from human skin, enabling large uni- and biaxial deformations without compromising the electrical functionalities. An ultrathin polymer foil supported by a thick rubber layer forms the platform for stretchable conductors and electronic circuits. We have demonstrated reliability of conductors and devices such as thin film transistors up to 10.000 stretching cycles. In a parallel approach the concept of adding visual and haptic feedback is explored. Here the inspiration is taken from animals such as the octopus that enlarges pigmented areas on its skin to change its colour. Polymer opals change their colour according to strain as the lattice spacing within the artificial photonic crystal is altered. These strain-sensitive opals are combined with phase-change driven actuators where a liquid is evaporated by means of resistive heating. Forces up to 6N result in both visual and haptic feedback of our soft electronic skin enabling the development of soft robotic limbs.

Session 1.3

(abstracts are listed in the order of presentation)

1.3.1 Towards reconfigurable RF devices based on dielectric elastomer actuators

Oluwaseun Araromi (1), Pietro Romano (2), Samuel Rosset (1), Julien Perruisseau-Carrier (2), Herbert Shea (1),

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Presentation given by Dr. Oluwaseun Araromi

Radio Frequency (RF) devices generate or control the transmission or reception of electromagnetic (EM) waves such as are used in mobile phones, WIFI etc. Devices based on millimeter-waves/microwaves are used widely in satellite communications. Reconfigurable millimeter-wave RF devices are in increasing demand due to their ability to dynamically change operation frequency, coverage and even directionality without the need to physically change the orientation of the receiver. However, there is an under-usage of such devices due to the complexity and cost of current technologies. Moreover, many of the current technologies suffer from higher EM losses compared to their non-reconfigurable counterparts. We present a design for a tunable RF phase shifter based on a planar dielectric elastomer actuator (DEA). The design operates by laterally displacing conductors strips suspended above a coplanar waveguide. DEAs are compact, lightweight and are capable of generating large strains, hence such as device promises several advantage over current methodologies, principally low costs, low complexity and compactness. The design is also optimized to reduce losses compared to current methods. The design requires a lateral displacement of approximately 500 microns to achieve optimal phase shifting, our actuator meets this requirement whilst remaining as compact as possible. The phase shifter is the first step in the realization of fully reconfigurable antenna based on DEAs.

1.3.2 Dielectric elastomers with photopolymerized interpenetrating

networks

Shigeki Tsuchitani (1), Satoshi Oda (2), Kunitomo Kikuchi (1), Hirofumi Miki (1),

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

Presentation given by Prof. Shigeki Tsuchitani

Mechanical prestrain of elestomers significantly enhances electromechanical performances of dielectric elastomer actuators. However, additional mechanical structures to maintain the prestrain are necessary. Interpenetrating polymer network (IPN) is an effective way to eliminate the additional structures since additive polymer network supports the prestrain. We present IPN elastomer actuators formed by photopolymerization which has advantages of controllability of polymerization rate and polymerization at room temperature. We used VHB 4910 films (3M) as base polymers. Additive networks were formed with three monomers: trimethylolpropane trimethacrylate (TMPTMA), trimethylolpropane triacrylate (TMPTA) and pentaerythritol triacrylate (PETA). After the VHB films were stretched 13.2 times in area, mixtures of the monomer, polymerization initiators and ethanol were sprayed on the stretched films and dried. Then, UV light was irradiated. The elastomers with 30wt% poly(TMPTMA), poly(TMPTA) and poly(PETA) had preserved prestrains of 730, 830 and 560%, respectively. In stress relaxation test, the stress of these elastomers and the VHB film decreased to 47, 30, 15 and 8% of the original one within 4s, respectively. The actuator using the elastomer with 30wt% poly(TMPTMA) had electrically induced thickness strain of -55% at 28MV/m and higher response speed than the one using the VHB film with 1320% prestrain.

1.3.3 A supercapacitor-like flexible laminate for harvesting energy from ambient moisture gradient

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Presentation given by Mr. Indrek Must

To date, the energy of ambient water vapor has not been widely considered as a source of electric energy. A supercapacitor-like ionic electromechanically active polymer laminate with carbide-derived carbon electrodes, Nafion membrane, and ionic liquid electrolyte responds to ambient humidity gradient by formation of voltage and electric current between the electrodes and therefore acts as a differential humidity sensor or, more importantly, as an energy harvester. When the laminate is placed between the environments with different relative humidity, sorption and diffusion of water is induced. The diffusing electrically neutral water molecules dislocate and reorientate the ionic liquid ions, in turn charging the electric double-layer. There is one especially unique property for the supercapacitor-like energy harvesters: they can store a considerable amount of harvested electric energy into the same lateral region of the material, where the energy is generated. The supercapacitor-like laminate can generate electric energy from the ambient humidity gradient during a long time period and give momentary bursts with high current and power. This new kind of energy harvester offers interest for powering wireless sensor network nodes, which work at very low duty cycle regime. Compared to the similar material working as a mechanoelectrical transducer, it can provide up to as much as 300000 times higher momentary power than as a result of mechanical bending.

1.3.4 Array of micro artificial muscles for investigation of cells mechanotransduction properties

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(1) Microsystems For Space Laboratory, Ecole Polytechnique FÃ©dÃ©rale De Lausanne, NeuchÃ¢tel, Switzerland

Presentation given by Mr. Alexandre Poulin

We present an array of micro artificial muscles developed for investigation of cells response to mechanical strain. Few technologies can be used to realise this type of study. However, in most cases a compromise is required and one must choose between high throughput and small population or single cell study. We previously reported the development of a device based on electro active polymer actuators which overcomes this limitation. Preliminary results however suggested a limited lifetime and some strain non-uniformity across the artificial muscles array. A new generation of devices was fabricated and the packaging was optimized in order to facilitate its use for biological experiments. Ion implanted electrodes were replaced by polymer-based electrodes in order to minimize their stiffening effect and to increase the strain uniformity. In addition, the device lifetime was studied in more detail. Multiple devices were tested in both normal working condition (with a cell culture medium covering the top side of the artificial muscle array) and air. This contribution aims to present a more comprehensive study of the device strain uniformity and lifetime. The latest advances in the device fabrication process and packaging will also be expounded.

1.3.5 Identification of parameters of zero-dimensional models for dielectric elastomer transducers based on three-dimensional visco-hyperelastic electromechanical models

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Presentation given by Mr. BjÃ¶rn Rechenbach

For dielectric elastomer transducers to be used in commercial applications, it is important to know their electromechanical response. The most advanced level of modeling is a three-dimensional (3D) finite element implementation of the transducer. However, with respect to computation time it is nowadays not feasible to model complicated systems, e.g. systems containing several transducers, by this approach. Therefore simpler zero-dimensional (0D) models are needed. Depending on transducer geometry and boundary conditions, the parameters of the simpler 0D models do not necessarily coincide with the material parameters measured on the pure dielectric elastomer material. In this work, finite element simulations of a 3D coupled electromechanical model of a dielectric elastomer transducer are presented as one option to obtain parameters for 0D models. Given a certain transducer geometry, a 0D fully coupled electromechanical model is derived on the basis of the 3D model and fitted to finite element simulations of the 3D model. The simulation results will be compared to measurements which Danfoss PolyPower A/S performs on a specific transducer prototype to validate the model. In a longer perspective, the presented finite element approach should enable the extraction of parameters of simple 0D models of dielectric elastomer transducers for which no prototype exists yet.

1.3.6 Conducting interpenetrating polymer network fibers for linear actuation in open air

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Presentation given by Ms. Fannir Adelyne

The field of electronic conducting polymer (ECP) based electrochemical actuators has received great attention in the last decades, due to their attractive properties, such as being lightweight and having low cost, high stress generation, and low operating voltages. However, even if a lot of progresses have been made, most ECP actuators with linear deformation described in the literature are working when immersed in an electrolytic solution. The laboratory presented few years ago a new design for electrochemical actuators, presenting linear strain and working in open air. These actuators are synthesized in the shape of hollow fibers presenting two concentric ECP electrodes made of poly(3,4-ethylenedioxythiophene) (PEDOT). The two linear electronic conducting polymer layers are separated by a solid polymer electrolytes which has been designed as an Interpenetrating Polymer Network: a poly(ethylene oxide) network, for ionic conductivity properties, and a rubbery network, for mechanical properties. Recent advances on the synthesis of linear actuators as well as their morphologies and actuation characteristics will be presented and discussed. A mechanical model will be proposed, as a basis of improvement of such architecture.

1.3.7 New mechanisms and concepts for exploiting electroactive polymers for wave energy conversion: PolyWEC EU-Project

Marco Fontana (1), Rocco Vertechy (1), Massimo Bergamasco (1),

(1) TeCIP Institute - Scuola Superiore Sant"Anna, Pisa, Italy

Presentation given by Dr. Marco Fontana

Wave energy has a great potential as renewable source of electricity. Studies have demonstrated that significant percentage of world electricity could be produced by Wave Energy Converters (WECs). However electricity generation from waves still lacks of spreading because the combination of harsh environment and form of energy makes the technical development of cost effective WECs particularly difficult. In November 2012, within the European Community FP7, the project PolyWEC (www.polywwec.org) has started a collaborative research on a new class of WECs, characterized by the employment of Dielectric Elastomers (DE) transducers. The main goal is to introduce a radical change in the traditional architecture of WECs by using converters characterized by deformable lightweight and low-cost polymeric elements. PolyWEC assumes a multidisciplinary approach that includes competencies on WEC design/tests, fluid dynamics, control/mechatronics and material science. The aim of the Project is to develop new knowledge and new technologies aiming at: (1) optimising materials for WEC applications, (2) conceiving new configurations for WECs, (3) studying the fluid-DE interaction through numerical simulations, (4) performing wave-tank tests of small scale prototypes, (5) providing economic and environmental assessment. This presentation introduces the general approach of PolyWEC project and provides an overview of preliminary analysis of different converter architectures.

1.3.8 Hyperelastic models for dielectric elastomers

Rocco Vertechy (1), Marco Fontana (1), Massimo Bergamasco (1),

(1) TeCIP Institute - Scuola Superiore Sant"Anna, Pisa, Italy

Presentation given by Dr. Rocco Vertechy

This presentation reviews different constitutive laws that can be used to capture the finite and deviatoric deformation response of dielectric elastomers. The considered laws are: the Neo-Hooke model, the Mooney-Rivlin model, the Ogden model, the Arruda-Boyce model, the Yeoh model, the augmented Gent model, the Gent-Thomas model, the Carroll model, the Isihara model, and the Swanson model. Models are fitted to different numbers of experimental data sets, which have been obtained by testing samples of acrylic elastomer membranes (VHB-4905 by 3M) with different biaxial pre-stretches in a "picture-frame" testrig. The capability of capturing the fitting data sets is shown for each model, together with the corresponding optimal constitutive parameters. Fitted models are compared in terms of their ability in: 1) predicting experimental data different than those used for the fitting procedure; 2) representing the effective biaxial stress-strain characteristics of the considered material.

1.3.9 Hybrid electret-dielectric elastomer generator

Claire Jean-Mistral (1), Thanh Vu-Cong (2), Alain Sylvestre (2),

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(2) G2Elab, Joseph Fourier University (UJF), G-INP, CNRS, Grenoble, France

Presentation given by Dr. Claire Jean-Mistral

Dielectric elastomers are flexible electrostatic generators working on capacitance variation to convert mechanical strain energy into electrical energy. They offer huge potential for applications involving human or fluid interaction. Nevertheless, they are passive materials requiring to be poled by a high external bias voltage or thanks to electronic power circuits. These power circuits drastically complex the system and slow down the development of dielectric elastomer generators. Recently, we have proposed to combine dielectric elastomer with an electret, providing a quasi-permanent potential, thus replacing the high voltage supply. We have developed a first proof of concept. Our structure is made of a dielectric elastomer (Polypower from Danfoss) and an electret developing a potential of -1000V (Teflon from Dupont). From an appropriate electromechanical analytical model, an energy density of about 1.48mJ.g-1 is expected on an optimal electrical load. Our autonomous dielectric generator can produce about 0.55mJ.g-1 on a resistive load. Here, we summarize and present a complete theoretical study on three modes of combination: "dielectric mode", "electret mode" and "egde mode". We focus on our recent development on original plane structures using electret to polarize a dielectric elastomer and able to scavenge few ÂµJ.g-1.

1.3.10 Effect of the pre-stretch and the temperature on the dielectric behaviours of polyacrylate film

Claire Jean-Mistral (1), Thanh Vu-Cong (2), Alain Sylvestre (2),

(1) LaMCoS, University Of Lyon, INSA, CNRS, Villeurbanne, France

(2) G2Elab, Joseph Fourier University (UJF), G-INP, CNRS, Grenoble, France

Presentation given by Dr. Claire Jean-Mistral

Dielectric elastomer generators (DEGs) are a promising solution to scavenge energy from human motion or fluid such as waves, due to their lightweight, high efficiency, low cost and high energy density. Performances of a dielectric elastomer used in a generator application are generally evaluated by the maximum energy which can be converted, and this energy depends deeply on the dielectric behaviour of the material. However, there is controversy on the dielectric constant (permittivity) of usual elastomer used for these applications: VHB 4910 (3M). We aim to investigate here the dielectric behaviour of this dielectric elastomer on a broad range of frequency (0.01Hz-1MHz) and temperature (-100Â°C - 100Â°C). We specially focus on the influence of pre-stretch in the change of the dielectric behaviour (permittivity, loss, conductivity) according to frequencies and temperatures. This pre-stretch is biaxial symmetric or non symmetric. Physic explanations of these variations leads to disagreements into the scientific community and we try to underline some potential phenomena occurring into the polymer. From the experiments, analytic equations were proposed to take into account the influence of the temperature and the pre-stretch on the permittivity. These analytic equations can be used to estimate and optimize the performances of the DEGs.

1.3.11 PANI nanofiber and nanoparticles based nanocomposites for artificial muscle applications

Shayan Mahraeen (1), Fevzi Ã‡akmak Cebeci (1) (2), Selmiye Alkan GÃ¼rsel (1) (2),

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(2) Sabanci University Nanotechnology Research And Application Center (SUNUM)

Presentation given by Prof. Selmiye Alkan GÃ¼rsel

Natural muscles are almost perfect systems in terms of their high strain, high efficiency, high energy density, ease of control of robustness and cycle life. Electroactive polymers, converting electrical energy into mechanical work, have been employed for the preparation of materials for artificial muscles. Although in the literature there are significant amount of studies to obtain those desired properties of natural muscles, the systems exhibiting all these properties still have not been achieved. In this study, novel materials, to be used in artificial muscles, that can serve as the alternative for the systems known in the literature, will be developed. For this purpose, new nanocomposites, containing polyaniline (PANI) nanofibers and nanoparticles, having the similar fibril structure as the natural muscles have been produced. PANI nanofibers and nanocomposites have been prepared by chemical polymerization method. Instead of using PANI nanofibers as the bulk, nanofibers have been included in small amounts in the chitosan (as a matrix) to form a percolation network so that the disadvantages of the conducting polymers will be avoided. The volume fraction of PANI in the nanocomposites, their electrochemical, electrical and thermal propeties have been investigated. It is expected that the produced nanocomposites will posses superior electrical, thermal and processability properties.

1.3.12 Nano-optical mechanical systems based on carbon nanotubes and elastomeric matrix

Matej Micusik (1), Klaudia Czanikova (1), Igor Krupa (1), Maria Omastova (1),

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Presentation given by Dr. Matej Micusik

Carbon nanotubes (CNT) excite both scientists and engineers interested in applications due to their high electrical/thermal conductivity and extraordinary mechanical properties. Ahir and Terentjev showed how CNT dispersed in an elastomer can lead to reversible volume change in response to infrared irradiation. This behaviour has interesting technological potential for a new approach to mechanical actuation. The mechanism of the actuation after irradiation of carbon nanotube-polymer composite is still not very clear and is under debate. Nanocomposites were prepared. Nanocomposites based on ethylene-vinylacetate copolymer (EVA) or styrene-isoprene-styrene copolymer (SIS) and various amount of modified CNT were tested as actuators. The photo-actuation measurements of the samples were performed using LED as light source. Pure non-stretched EVA matrix exhibited expansion when exposed to the light. On the other hand pure EVA matrix deformed by uniaxial stretching of the material above the melting point of the polymer matrix followed by cooling in cold water to freeze the structure showed contraction. This suggests that the alignment of the polymer chains plays an important role in the type of response of the material. This phenomenon was substantially increased when CNT was introduced to the system. Nanocomposites contracted upon illumination and modification of CNT together with good dispersion and orientation play important role.

1.3.13 High-frequency response of large-scale silicone dielectric elastomer planar actuators

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(2) Technische Universitaet Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany

Presentation given by Mr. Davide Gatti

Dielectric elastomer planar actuators were investigated mainly in a quasi-static regime, where they exhibit giant deformations thanks to highly soft viscoelastic materials not capable of fast actuation. However, most of applications of DEAs require fast and precise actuation while preserving their ability of reaching high strains. In the present work, the high-frequency response of 9 cm-square dielectric elastomer silicone membranes is studied. The effect of several pre-stretch ratios in the two in-plane directions and several payloads on the transient step-response of the actuator is measured by tracking dots with a high-speed camera at 7000 frames per seconds. A second-order system model, with an additional term to account for creeping, describes well the step response. We proved the presence of a longitudinal strain traveling wave, whose reflection on the boundaries is responsible for differences with model predictions and can determine the in-plane resonant frequency. The effect of pre-stretch and payloads on in-plane resonance is also studied with both high-speed camera and laser vibrometer, showing that certain pre-stretch ratios lead to resonant frequencies of about 200 Hz while preserving high active strains. The hyperelastic Gent model is fitted with pure-shear, bi- and uni-axial tensile tests and used to develop tools to predict the actuator performances.

1.3.14 Artificial muscles: the exchanged solvent is also important

Toribio F. Otero (1), JosÃ© Gabriel MartÃnez (1),

(1) Universidad PolitÃ©cnica De Cartagena

Presentation given by Prof. Toribio F. Otero

Bending bilayer (polypyrrole/isolating tape) artificial muscles were electrochemically and mechanically characterized in aqueous solutions having the same concentration of a different salt, with the same cation and different anions. The faradaic nature of the ovement was corroborated determined the number of exchanged anions and water molecules. Under flow of different currents the experimental described angles and the angular rates corroborate the faradic nature of those soft motors. The described angle is a linear function of the consumed charge and the rate of the angular movement is a linear function of the applied current.

1.3.15 Evaluation of driving characteristics of miniaturized ionic polymer actuator fabricated by a selective plasma treatment method

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

Presentation given by Dr. Kunitomo Kikuchi

Ionic polymer-metal composite (IPMC) is one of the most attractive soft actuators because it exhibits large strain under low application voltages. It consists of a polyelectrolyte membrane and thin noble metal electrodes formed on the both surface of the membrane. In conventional IPMCs, commercialized membranes were mainly used. So, it is difficult to fabricated miniaturized IPMC freely, because it is generally cut into small pieces mechanically. By combining IPMC fabrication technologies with micro machining technologies, we can make miniaturized IPMCs together with MEMS devices. There are many technological subjects to fabricate it. Formation method of the electrodes is one of the most difficult problems. Conventionally, the most reliable method is a chemical plating method. In this report, we present evaluation results of driving characteristics of miniaturized ionic polymer actuator fabricated by a selective plasma treatment method with 1 time gold plating. From a result, we could fabricate a strip-type actuator whose size was 0.4mm width and 10mm long, and succeed to operate it. The displacement at the tip of it exhibited about 0.02 mm, when a sinusoidal voltage, whose amplitude was 1V, was applied. Additionally, in this method, cutting process for electrical insulation between the electrodes is unnecessary.

1.3.16 Vibration of dielectric elastomer actuators

Bo Li (1), Zijie Zhao (1) (2), Zhenbo Lu (2), Yongdong Cui (2), Jian Zhu (1),

(1) National University Of Singapore
(2) Temasek Laboratories, Singapore

Presentation given by Dr. Jian ZHU

This paper focuses on one class of soft active materials: dielectric elastomers. When a membrane of a dielectric elastomer is subject to a voltage through its thickness, the membrane reduces thickness and expands area, possibly straining over 100%. Dielectric elastomer actuators may exhibit the following attributes: larger deformation, high energy density (order higher than ceramics), low noise, low density (density is close to water), fast response, etc. Recently, dielectric elastomers are being developed as transducers for broad applications, including soft robots, adaptive optics, Braille displays, electric generators, and acoustic equipments. In this paper, I will also discuss oscillation of dielectric elastomers, which is nonlinear due to large deformation and nonlinear electromechanical coupling. Natural frequencies and vibration modes of dielectric elastomers are analyzed. Interesting phenomena are found, such as hysteresis, superharmoincs, and subharmonics. It is shown that natural frequency of a dielectric elastomer is easy to tune. For example, its natural frequency may decrease as a voltage through the thickness of a dielectric elastomer membrane increases. Applications exploiting dynamic behavior of dielectric elastomers include loudspeakers, active vibration control, and frequency tuning. Active vibration control may have important applications in aerospace engineering.

1.3.17 Piezoelectric transformer based drivers for electro active polymer actuators

Martin S. RÃ¸dgaard (1), Anders R. Steenstrup (1),

(1) Noliac A/S, Kvistgaard, Denmark

Presentation given by Mr. Martin RÃ¸dgaard

Through resent years new high performing Electro Active Polymers (EAP's) have emerged, which can be utilized as actuators, demonstrating displacements of 1-2%. One of the main challenges of utilizing EAP actuators is the requirement of a high applied voltage, in order to fully exploit the materials potential. Furthermore the electrical load is highly capacitive, meaning that only a small fraction (1-5%) of the supplied electrical energy is converted to mechanical energy, giving the overall system a poor efficiency, if the electrical stored energy is not recovered. In this work it is shown how piezoelectric transformer (PT) based power converters can be utilized to drive EAP actuators. A simple but compact driver solution is presented, which converts energy from a 24V supply voltage and is capable of driving the actuator at voltages of up to 2.5kV. Moreover the driver is small enough to fit inside a 110x32mm cylindrical InLastor Push actuator, forming a "low voltage" EAP actuator. A more complex driver solution is also presented, with the major improvement of incorporating bi-directional power flow. This enables the driver to recover the electrical stored energy and hence greatly improves the overall system efficiency. The bi-directional driver relies on an advanced phase-shift control scheme, which shifts the conduction angle of the output rectifier, resulting in a negative output current that discharges the EAP actuator.

1.3.18 Harvesting maximal energy from a load-driven soft dielectric generator

Eliana Bortot (1), Roberta Springhetti (1), Massimiliano Gei (1), Gal deBotton (2),

(1) Dept. Of Civil, Environmental And Mechanical Engineering, University Of Trento, Trento, Italy
(2) Dept. Of Mechanical Engineering, Ben-Gurion University, Beer-Sheva, Israel

Presentation given by Prof. Massimiliano Gei

In recent years the interest in energy efficiency has greatly increased and several technologies emerged for harvesting energy from renewable sources. Mechanical energy can be converted to electrical one by dielectric elastomer generators. Taking into account the various modes of failure, we study a biaxial homogeneous generator that follows a four step cycle where the tensile load and the charge are alternately held constant. By fixing the in-plane ultimate stretch (lambda_u) and the voltage applied at high load, we maximize the theoretical energy extracted during a cycle that comply with these limits. In general, there are two possible regimes of work, defined by the maximum voltage point achieved when electromechanical instability coincides with the no-tension threshold, at low ultimate stretch, or electrical breakdown, at high ultimate stretch. Results show that for lambda_u=1.5 a specific energy of 0.610 J/g can be harvested, rising to 1.075 J/g for lambda_u=3 and up to 2.220 J/g for lambda_u=5. On the contrary, the efficiency of the cycles, which is the ratio of the gained electrical energy to the invested mechanical one, will drop from 0.426 at lambda_u=1.5 to 0.081 at lambda_u=5.

1.3.19 Fabrication and characterization of multi-layer actuators with electrostrictive polymer

Takuya Sawada (1), Shozo Ohtera (1),

(1) Research Center For Next Generation Technology, Murata Manufacturing Co., Ltd., Yasu, Japan

Presentation given by Mr. Takuya Sawada

Because of the high performance the electric-field driving type of electroactive polymer (EAP) is a promising material for the unique soft actuators. However, in general, the high driving voltage is one of the main obstacles for practical use. The driving voltage can be decreased by using thinner film of EAP. Lamination is an essential technology to put thin films into the shape of actuators. In this work, we have fabricated several types of multi-layer actuator including very thin actuator made of thin films of the electrostrictive polymer and evaluated the properties of actuation for each one. Furthermore we suggest applications for those multi-layer actuators.

Wednesday, 26 June 2013

General programme of the day

EAPlenary	Session 2.1 part I *Chair:* **Danilo De Rossi** (University of Pisa, Pisa, Italy)	
	9:00- 9:30	Invited talk **Gerald Pollack** (University of Washington, Seattle, USA)
EAPodiums	Session 2.1 part II *Chair:* **Toribio Otero** (University of Cartagena, Cartagena, Spain)	
	9:30- 9:50	Invited talk **Hidenori Okuzaki** (University of Yamanashi, Takeda, Japan)
EAPromises	Session 2.1 part III *Chair:* **Herbert Shea** (Ecole Polytechnique Fédérale de Lausanne, Neuchatel, Switzerland)	
	9:50- 10:10	Invited talk **Xiaofan Niu** (UCLA, Los Angeles, USA)
	10:10- 10:30	Invited talk **Florian Habrard** (Empa, Duebendorf, Switzerland)
Professional Organisations talks	10:30- 10:40	Invited talk **Gordon Attenborough** (The IET - The Institution of Engineering and Technology, Stevenage, UK)
Break	10:45- 11:15	Coffee break
EAPills	Session 2.2 part I *Chair:* **Frédéric Vidal** (University of Cergy-Pontoise, Cergy, France)	

	11:20- 12:40	**Pill oral presentations** 20 presentations (3 minutes each + 1 minute to change speaker)
Lunch	12:50- 14:00	Lunch
EAPosters **EAPrototypes** **EAProducts**	Session 2.2 part II	
	14:00- 15:20	**Posters & exhibitions** 20 posters
EAPills	Session 2.3 part I *Chair:* **Gabor Kovacs** (EMPA, Duebendorf, Switzerland)	
	15:30- 16:45	**Pill oral presentations** 20 presentations (3 minutes each + 1 minute to change speaker)
Break	16:45- 17:15	Coffee break
EAPosters **EAPrototypes** **EAProducts**	Session 2.3 part II	
	17:15- 18:45	**Posters & exhibitions** 20 posters
Closing	18:45- 19:00	Closing words & final remarks **Gabor Kovacs** (EMPA, Duebendorf, Switzerland)

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

2.1.1 The fourth phase of water: implications for electroactive polymers

Gerald Pollack (1)

(1) University Of Washington, Bioengineering, Seattle, USA

Presentation given by Prof. Gerald Pollack

School children learn that water has three phases: solid, liquid and vapor. But we have recently uncovered a fourth phase. This phase occurs next to water-loving (hydrophilic) surfaces. It is surprisingly extensive, projecting out from the surface by up to millions of molecular layers. A recent book describes this new phase: www.ebnerandsons.com. Of particular significance is the observation that this fourth phase is charged; and the water just beyond is oppositely charged, creating a battery that can produce current. We found that light recharges this battery. Thus, water can receive and process electromagnetic energy drawn from the environment - much like plants. The absorbed light energy can then be exploited for performing work, including electrical and mechanical work, as in the bending of electroactive polymers. Recent experiments confirm the reality of such energy conversion. The energy-conversion framework implied above seems rich with implication. Not only does it provide an understanding of how water processes solar and other energies, but also it may provide a foundation for simpler understanding natural phenomena ranging from weather and green energy all the way to biological issues such as the origin of life, transport, osmosis, tissue hydration and blood flow. The presentation will show evidence for the presence of this novel phase of water, and will consider its potentially broad implications for EAP and beyond.

2.1.2 Soft and flexible PEDOT/PSS films for applications to EAP actuators

Hidenori Okuzaki (1),

(1) University Of Yamanashi, Interdisciplinary Graduate School Of Medicine

And Engineering, Kofu, Japan

Presentation given by Prof. Hidenori Okuzaki

We have succeeded in fabricating elastic and highly conductive PEDOT/PSS films by addition of sugar alcohol (SA) and subsequent heating, where the PEDOT/PSS/SA film is no more brittle but flexible and stretchable, having an elongation at break as high as 25%. Interestingly, the electrical conductivity simultaneously increases by two orders of magnitude and attains as high as 300 S/cm. It is found that the sugar alcohols have two functions: one is to increase the elongation by preventing from hydrogen bonding between the colloidal particles which behaves as a plasticizer; and the other is to increase the electrical conductivity by improving the carrier transport due to crystallization of PEDOT and removal of insulating PSS from the surface of colloidal particles similarly to the ethylene glycol. The flexible and stretchable polyurethane gel containing ionic liquid was synthesized and sandwiched between the PEDOT/PSS/SA films. When an electric field was applied through PEDOT/PSS/SA electrodes, the gel quickly bent toward anode. Compared with other compliant electrodes such as carbon nanotube/ionic liquid composite and chemically plated gold or platinum, the PEDOT/PSS is much cheaper and high conductive electrodes can be fabricated by a wet-process such as spin-coating, bar-coating, and spraying. Therefore, the PEDOT/PSS can be used not only as the active material of novel EAP actuator but also as compliant electrodes of conventional ionic polymer actuators.

2.1.3 Material design for prestrain-free dielectric elastomers and bistable electroactive polymers

Xiaofan Niu (1), Wei Hu (1), Qibing Pei (1),

(1) University Of California, Los Angeles, Department Of Materials Science And Engineering, Los Angeles, USA

Presentation given by Dr. Xiaofan Niu

Current available acrylic elastomers (3M VHB) have a large electromechanical strain as well as energy density. Silicone elastomers are superior in temperature stability and frequency response. However, high actuation performance generally requires prestretching to overcome electromechanical instability. Prestretching complicates device fabrication and potentially decreases the device shelf lifetime. We report a new category of prestrain-free dielectric elastomers synthesized from commodity monomers, that can produce electromechanical strains larger than 100% and energy densities as large as 1.5 MJ per cubic meter. Electromechanical instability is suppressed in the material by tuning its crosslink density. The material features an easy processing that is potentially scalable and compatible with industrial processes. Buckling actuators and multilayer stack actuators have been fabricated to demonstrate the applicability of the material. Also reported is a bistable electroactive polymer with improved electromechanical performance and easy processing. Large-scale refreshable Braille display prototypes have been demonstrated and is under development for prototype Braille electronic reader applications.

2.1.4 Compliant sputtered metallic electrodes for electroactive polymer actuators

Florian Habrard (1), JÃ¶rg Patscheider (2), Gabor Kovacs (1),

(1) EMPA, Mechanical System Engineering Laboratory, Duebendorf, Switzerland
(2) EMPA, Laboratory For Nanoscale Material Science, Duebendorf, Switzerland

Presentation given by Dr. Florian Habrard

Electroactive polymer (EAP) actuators with straining values of 10% or more require electrodes capable of following these deformations without losing their electrical conductivity. In this work we describe deposition and characterization of silver electrodes deposited by magnetron sputtering. However, the use of metallic thin films as electrodes for EAPs is restricted by several limitations. First, Young's moduli of metals are 4 to 5 orders of magnitude higher than those of elastomers, implying that the stiffness of the metallic layers would hamper actuator deformation. Secondly, a sputtered metallic film can usually only sustain straining up to 2%, before mechanical rupture sets on and with it conductivity loss. We show that tuning microstructure and the grain size of silver films is an effective way to extend the stretching limit. The desired grain size reduction is obtained by deposition at high argon pressure. The impact of the argon pressure on the compliance of silver layers is evaluated by measuring the electrical resistance under stretching for different grain sizes, combined with different microscopic investigations. We observed that films with an open pores microstructure and small grains of 18 nanometers do not develop cracks that are observable by AFM and can maintain electrical con-ductivity at more than 10% stretching, while dense films with grains of ca. 25 nanometers develop crack networks causing conductive failure already at 4% strain.

2.1.5 Collaborative opportunities to benefit the EAP field between ESNAM and the Institution of Engineering and Technology (the IET)

Gordon Attenborough (1),

(1) The Institution Of Engineering And Technology, Stevenage, UK.

Presentation given by Mr. Gordon Attenborough

For over 140 years the IET has been inspiring, informing and influencing the global engineering community and supporting technology innovation. As a charitable membership organisation for engineers with more than 150,000 members worldwide in 127 countries, the IET's core purpose is to support and promote the engineering profession and advance engineering and technology for the benefit of society. The capabilities of the IET include: Education, accreditation, standards, professional registration and development, policy, events, publishing and Inspec a leading English language bibliographic information service for scientific and technical literature which recently indexed its 12 millionth record. The IET's five sectors provide a technical home for engineers and technicians to exchange knowledge, find relevant communities, join activities and access engineering intelligence across the IET and wider SET community. Each sector highlights new technologies and identifies key societal issues that can be benefited by advances in engineering. Through knowledge dissemination, industry and academic partnerships; the sectors create impact by generating greater insight, debate collaboration and innovation. The strategy and capabilities of the IET could be of great benefit to ESNAM and EAP as a technological field.

Session 2.2

(abstracts are listed in the order of presentation)

2.2.1 Improving the stroke of dielectric electro-active polymer actuators using a non-linear spring

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

(1) Saarland University, Multifunctional Material Systems Lab, Saarbruecken, Germany

Presentation given by Mr. Micah Hodgins

Dielectric electro-active polymers (DEAP) are an attractive material for use in actuator technologies due to their lightweight, high energy density, high energy efficiency, scalability and low noise features. This work focuses on experimentation and modeling of a small profile, scalable DEAP actuator system. In our previous work we compared different pre-strain, or biasing, mechanisms for a circular out-of-plane DEAP actuator, like hanging mass, linear spring and non-linear spring. We achieved an improved displacement and frequency behavior of the actuator using a non-linear spring. It was discovered that a linear spring can be added to the non-linear spring in order to compensate for higher external loads while yet maintaining the large stroke. This makes the actuator more tunable; allowing it to be used with a range of loading conditions.

2.2.2 Electrically driven dry-state actuators based on PEDOT:PSS nanofilms

Silvia Taccola (1), Alessandra Zucca (1) (2), Francesco Greco (1), Barbara Mazzolai (1), Virgilio Mattoli (1),

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

Presentation given by Dr. Silvia Taccola

"Dry" conjugated polymer actuators able to work in air have attracted considerable attention because they further expand the range of applications otherwise restricted to liquid environments. In this framework, the electrically induced dimensional change of PEDOT:PSS films through reversible sorption and desorption of water vapor molecules lends itself to the realization of novel actuatorws that operate in ambient air. The actuation principle lies in the reversible contraction of PEDOT:PSS films upon the application of an electric field due the desorption of water vapor sorbed in the films because of local joule heating. Recently, we proposed a novel fabrication process for obtaining freestanding ultra-thin conductive nanofilms made of the conjugated polymer PEDOT:PSS. These nanofilms, deposited by spin-coating, have the advantage of a well controlled and reproducible thickness ranging between few tens to several hundreds of nm. The present study deals with novel electrically driven actuators based on PEDOT:PSS nanofilms that operate in ambient air. Thanks to the nanometric thickness of the PEDOT:PSS nanofilms, such actuators allow for a rapid response. Here, we report the processing methods and a validation of the actuators' working principle. Two different actuator configurations have been tested: 1) nanofilms wrapped and twisted in the form of contractile fibers and 2) PEDOT:PSS/PDMS bilayer bending actuators with different designs e geometries.

2.2.3 Parylene insulation of bucky gel actuators

Alberto Ansaldo (1), Maurizio Biso (1), Davide Ricci (1),

(1) Istituto Italiano Di Tecnologia, Robotics, Brain And Cognitive Sciences, Genova, Italy

Presentation given by Dr. Alberto Ansaldo

Back gel actuators, thanks to their mechanical properties and low voltage operation, are very promising for applications where a flexible compliant actuator has to be placed in direct contact with the human body. Their use in catheters or flexible electrodes that have to be introduced in the human body and actively bent is particularly attractive. A major issue is to insulate the actuator from the surrounding environment (i.e., the human body and its biological fluids) and vice versa to avoid interactions with the electrolytic solutions and the release of nanomaterials or ionic liquids into the body. A possible approach is to encapsulate the devices with a biocompatible polymer, but feasibility and influence of the coating on the actuator performance have to be studied. We tested the influence of a parylene coating while varying its thickness. Preliminary data indicate that after coating the device with a thin layer of parylene (1 or 2 micrometres) the actuation improves, probably due to the contextual oxygen/humidity removal and encapsulation during the deposition process. It is reasonable to suppose that the presence of oxygen and moisture can play a strong role in the electrochemistry (hydrolysis, oxidation etc.) of the bucky gel actuator and thus the parylene coating should improve device lifetime. On the other hand, if the coating is too thick (4 micrometres), its stiffness results in inferior actuation performance.

2.2.4 Numerical simulation model of a dielectric elastomer generator

Florentine Foerster (1), Holger Moessinger (1), Helmut F. Schlaak (1),

(1) Technische UniversitÃ¤t Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany

Presentation given by Ms. Florentine Foerster

Dielectric elastomer generators (DEGs) produce electrical energy by converting mechanical to electrical energy. Efficient operation of multilayer DEGs requires homogeneous deformation of each single layer. Internal and external influences like supports or the shape of a DEG may cause an inhomogeneous deformation and hence negatively affect the amount of the generated electrical energy. Optimization of the deformation behavior leads to improved efficiency of the DEG and consequently to higher energy gain. In this work a numerical simulation model of a multilayer dielectric elastomer generator is developed using the FEM software ANSYS. The analyzed multilayer DEG consists of 49 active dielectric layers with layer thicknesses of 50 micrometers. The elastomer is PDMS. The compliant electrodes are made of graphite powder. In the simulation the real material parameters of the PDMS layers and the graphite electrodes are included. The numerical simulation of the DEG is carried out as coupled electro-mechanical simulation for the constant voltage and constant charge energy harvesting cycles. The derived numerical simulation model is validated by comparison with electro-mechanical characterization results of the real DEG and analytical calculations. The comparison of the determined results shows good accordance with regard to the deformation of the DEG. Based on this validated model it is possible to optimize the DEG layout for improved deformation behavior.

2.2.5 Qualifying dielectric elastomer actuators for usage in complex and compliant robot kinematics

Sebastian ReitelshÃ¶fer (1), Maximilian Landgraf (1), Tristan SchlÃ¶gl (2), JÃ¶rg Franke (1), Sigrid Leyendecker (2),

(1) Friedrich-Alexander-University Erlangen-Nuremberg, FAPS, Erlangen, Germany
(2) Friedrich-Alexander-University Erlangen-Nuremberg, LTD, Erlangen,

Germany

Presentation given by Mr. Sebastian ReitelshÃ¶fer

In our contribution we describe a new research project to facilitate the transition from fundamental research to the qualification of dielectric elastomer actuators (DEA) as regular control elements in complex and compliant robot kinematics. To initiate this step the four key research topics - automated manufacturing processes, lightweight power electronics, modelling and simulation and the development of a new set of efficient control hardware - are identified to actualize the adaptability of DEA within the basic methodologies of robotics. Besides an overview of the whole five year project, results from the first phase regarding automated manufacturing and lightweight power electronics are presented. The Aerosol Jet Printing process is described to generate homogeneous dielectric layers of RTV-2 silicones with a current thickness of 6 microns. The same process is used to print electrodes of CNT compounded RTV-2 silicones to realize stacked DEAs with nearly homogenous mechanical properties of the altering functional layers. Furthermore, to improve the overall specific power of a complex kinematic system, an approach is investigated to control the contraction of DEA with a principle based on pulse width modulation (PWM). Using PWM may permit the substitution of DC-DC converters for each actuator by single lightweight semiconductor elements like optocouplers, MOSFETs or insulated gate bipolar transistors which are compared and evaluated.

2.2.6 Active isolation mat based on dielectric elastomer stack actuators for mechanical vibration cancelation

Roman Karsten (1), Helmut F. Schlaak (2),

(1) Roman Karsten
(2) Helmut F. Schlaak

Presentation given by Mr. Roman Karsten

Nowadays, for active attenuation of mechanic vibrations on sensitive devices usually voice-coil, pneumatic or piezo-electric actuators are used. The main disadvantages of these actuator types are high complexity and costs. A promising alternative is the use of dielectric elastomer stack actuators (DESA). An active suspension based on DESA combines passive and active behavior. In the low frequency range up to 100 Hz the disturbing vibrations are canceled actively. Instead, higher frequencies are eliminated passively due to the material damping behavior. This paper describes the development of an active isolation mat for the cancelation of vibrations on sensitive devices with a mass of up to 500 g. Vertical disturbing vibrations are attenuated actively while planar vibrations are damped passively. The dimensions of the investigated mat are 140 mm x 140 mm x 20 mm. The mat contains 5 DESA. The design and the optimization of the active isolation mat are realized by ANSYS FEM software. The best performance shows a DESA with air cushion mounted on its circumference. The deployed DESA has 40 mm electrode diameter and 50 layers. In this application the planar strain of DESA is used. Within the mounting encased air increases static and reduces dynamic stiffness. Experimental results show that the vibrations with amplitudes up to 200 micrometers can be actively eliminated.

2.2.7 Electrostrictive microsensors based on the elastomeric polymers for medical rehabilitation procedures

Mircea Ignat (1), Gabriela Hristea (1), Maria Cazacu (1), Maria Cazacu (1) (2), Carmen Racles (1) (2), Adriana Sarah Nica (1) (2) (3),

(1) INCDIE CA
(2) Petru Poni" Institute Of Macromolecular Che-mistry
(3) University Of Medicine And Pharmacy, Carol Davila

Presentation given by Dr. Mircea Ignat

The paper presents some force microsensors based on a silicone elastomer-titania with application in the medical rehabilitation procedures and also the valuation by the rehabilitation procedures. The list of the medical experimental procedures with applications of this microsensors includes ; the successively microcompressions experiments, the finger contact stability, the gradual micropressure contact, the stability microforce of the hand or the fingers in time,etc. A microsensor matrix was mounted in special glove for a good simultaneously monitoring of the each finger of the hand. The electrostrictive signal field of this active microsensors was in the field ;0,5mV...4V and the field of microdisplacement ; 0,002- 1 mm. The authors realized also a collection of different medical disease for a medical generalization acting which is necessary for the clinical valuation process.

2.2.8 EAP enabled PC mouse as tactile feedback human interface device

Holger MÃ¶ÃŸinger (1), Henry Haus (1), Marc Matysek (1), Helmut F. Schlaak (1),

(1) Technische UniversitÃ¤t Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany

Presentation given by Mr. Holger MÃ¶ÃŸinger

EAP as tactile interfaces have been in the focus of research for quite some time. Examples are (vibro-) tactile keyboards, braille displays and similar devices. All these applications of EAPs aim on interfacing with the user's fingers or fingertips only - demonstrating the high spatial resolution. This contribution focuses on the enormous flexibility of EAP transducers allowing active free form surfaces in contrast. By using rapid prototyping techniques, a DEA driven active tactile interface is integrated into a PC mouse. The generated tactile information can be used to help the user in raising attention in certain directions, can be used to discriminate between different modes (like "pick" or "manipulate") as well as to tactile support the presentation of boundaries (boxes, active screens, etc.). The realized prototype incorporates four dielectric elastomer transducers on a pad resting in the users palm while operating the mouse. With these four transducers we are able to provide directional information for the directions up, down, left and right, to the user. The according configuration software on the PC allows customization of vibration patterns to test the influences of different tactile stimuli and provides an interface to firing the vibration patterns via a specific device driver.

2.2.9 Microfluidic device using new ferroelectric relaxor P(VDF-TrFE-CFE)

Alexandru Cornogolub (1), Pierre-Jean Cottinet (1), Jean-Fabien Capsal (1), Jeremy Galineau (1), Lionel Petit (1),

(1) University Of Lyon, INSA De Lyon - LGEF, Villeurbanne, France

Presentation given by Mr. Alexandru Cornogolub

The goal of the present study is to build a microfluidic pump and valves based on unimorph or bimorph diaphragm actuators, able to transport small quantities of liquid to specific locations. There have already been many researches on this subject and many types of pumps were developed. The problem with the present EAP based micropumps is that one need to apply very high electric fields in order to obtain the necessary deformations (?80MV/m). Recently the LGEF Lab developed a new type of polymer (P(VDF-TrFE-CFE)) which has very good actuating properties and the same performance is achieved by applying an electric field five times smaller than usual. So the idea is that using this new type of polymer (membrane of the valve) an important enhancement over existing techniques should be attained. The basic component of the desired system is the controlled valve as the pump is made of three such cascaded valves, sequentially opened and closed in the normal functioning mode. So the theoretical study and optimization work are focused first on the design of one valve in order to find the best parameters of the unimorph/bimorph polymer membrane. For the calculations MATLAB (simplified model), ANSYS and COMSOL (Finite Element Modeling) are used. An experimental validation is intended as well as a prototype.

2.2.10 Experimental analysis of the dual actuation and sensing capabilities of a dielectric electro-active polymer system

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

(1) Multifunctional Materials Systems Lab, Department Of Mechatronics.
Saarland University, Saarbruecken, Germany

Presentation given by Dr. Alexander York

Dielectric Electro-Active Polymer's (DEAP) are attractive material for actuator designs due to their low weight and energy consumption. Some application examples include proportional valve control units and pump drives. Furthermore, these actuators may be simultaneously used as sensors, which can then detect the respective actuator position. As a first step an actuator system is presented here which combines these two functions creating a dual actuation and sensing system. In this case a separate DEAP sensor is used to measure the position of a DEAP actuator. The DEAP actuator module is operated by a high voltage source, and allows a displacement of up to 3 mm. The DEAP sensor module is connected to the actuator, and they displace together when activated. The relationship between the change in capacitance of the sensing module and deflection was found to be non-hysteretic, and therefore suitable for measuring the position. Experiments were conducted for various combined actuator and sensor configurations and an analysis performed with a focus on optimizing the system for high actuation stroke and high sensing resolution.

2.2.11 Modeling and identification of a mass-spring biased EAP annular membrane actuator

Gianluca Rizzello (1), Alexander York (1), David Naso (2), Stefan Seelecke (1),

(1) Multifunctional Materials Systems Lab, Department Of Mechatronics.
Saarland University, Saarbruecken, Germany
(2) Department Of Electrical And Electronic Engineering, Politecnico Di Bari, Bari, Italy

Presentation given by Dr. Alexander York

This paper presents a dynamic model for a dielectric Electro-Active Polymer (EAP) actuator system consisting of a circular EAP membrane biased with a mass-spring mechanism. The model is capable of predicting both the actuator dynamic response and the nonlinearities of large material deformations. The principal physical phenomena involved in the actuation process are investigated and the main sources of nonlinearities are identified and described. The nonlinear material viscoelasticity is also included in the model using a free-energy approach. The model is then used to simulate the response of an experimental actuator prototype. The global identification is divided into individual sub problems, namely the identification of the parameters which affect the static and the dynamic response. The structure of the model equations allows for the use of a Least Mean Square (LMS) identification algorithm, which provides an optimal solution to the static calibration problem. This results in very high accuracy when simulating the system equilibrium under several loading condition. As a final step, numerous validation experiments show how the model predicts the actuator output for various excitation signals. The accurate knowledge of the system nonlinearities provided by the model can then be used as a first step towards the development of a high accuracy position control system.

2.2.12 New conductive hydrogels: elaboration and properties

Christo Jossifov (1), Darinka Christova (1), Krasimira Ivanova-Mileva (1), Sijka Ivanova (1), Mariya Kyulavska (1),

(1) Institute Of Polymers, Bulgarian Academy Of Sciences, Sofia, Bulgaria

Presentation given by Dr. Christo Jossifov

Electroconductive hydrogels (ECHs) are polymeric blends or conetworks that combine inherently conductive electroactive polymers (CEPs) with highly hydrated hydrogels. First described by Guiseppi-Elie [1] in 1995 and later by Wallace et al. [2], these polymeric materials synergize the advantageous features of hydrogels and organic conductors and have been used in many applications such as bioelectronics and energy storage devices, sensors, actuators etc. Polymeric hydrogels are able to absorb a large amount of water, and a very attractive property of these materials is their volume phase transition (shrinking, removal of most of water) triggered by a small change in environmental conditions. These environmental factors include temperature, pH, ionic strength and the presence of specific ions. Regarding the conducting polymers, they are also of great interest due to good conductivity, low operation voltage and good environmental stability. Here, we report the preliminary results on the synthesis and properties of a new conductive hydrogel based on semi-interpenetrating network (semi-IPN) comprising crosslinked poly[2-(acryloyloxy)ethyl trimethyl ammonium chloride] (PAETMAC) and polyaniline (PANI).

2.2.13 Modeling and simulation of electroviscoelasticity

Sara Thylander (1), Anna Ask (1), Andreas Menzel (1) (2), Matti Ristinmaa (1), Ralf Denzer (2),

(1) Lund University, Division Of Solid Mechanics, Lund, Sweden
(2) TU Dortmund, Institute Of Mechanics, Dortmund, Germany

Presentation given by Ms. Anna Ask

Reliable simulation techniques and advanced modelling related to the applications of electroactive polymers (EAP) is a growing and important area of research. Our work, related to electromechanical modelling of EAP, includes (i) electro-viscoelastic modelling of dielectric elastomers, (ii) an electromechanical micro-sphere framework and (iii) an inverse-motion based form finding method for EAPs. The theoretical framework is derived in a large strain setting and solved by means of the finite element method. Both hyper-elastic and hyper-viscoelastic constitutive models extended to include the electromechanically coupled behaviour are considered. While phenomenological macroscopic models have been fitted successfully to typical EAP materials, it is believed that a micromechanical approach may shed additional light and improve modeling accuracy as phenomena such as rubber-like elasticity is directly related to the microstructure.

2.2.14 Progress in material development for ElectroActive Polymers

Joachim Wagner (1), Jens Krause (1), Torsten Feller (1),

(1) BMS-AG

Presentation given by Dr. Joachim Wagner

Electroactive polymers are a research topic with globally ever increasing interest. Bayer MaterialScience is working on the development of materials for applications in actuators, sensors and energy converters since several years. Here we present testing data of an improved up-scalable generation of PU materials for the above mentioned applications.

2.2.15 Dynamic properties of a class of tensegrity elastomer structures

Ioannis A. Antoniadis (1), Demetrios T. Venetsanos (2), Fotis G. Papaspyridis (1),

(1) National Technical University Of Athens, School Of Mechanical Engineering, Athens, Greece
(2) Kingston University London, School Of Mechanical And Automotive Engineering, London, UK

Presentation given by Prof. Ioannis A. Antoniadis

Bars and tendons are structural members that can resist compression (C) and tension (T), respectively. A tensegrity structure is a bar-tendon con?guration in stable equilibrium, where the tendons are attached to the ends of bars. Tensegrity structures provide a promising paradigm for integrating structure and control design, which is essential in energy harvesting devices. The corresponding compressive members are either disjoint or connected with ball joints. This allows for large displacement and deployability, both beneficial for harvesting high amounts of ambient energy. Towards the direction of exploiting tensegrity structures for energy harvesting, the present work deals with the preliminary investigation of the dynamic behaviour of a four-bar-two-tendon (C4T2) structure with elastomer tendons. The normalized differential equation governing the response of this structure under a harmonic force excitation is developed and then solved providing not only the Frequency Response Curves but also the elastic forces developed in the tendons. The stiffness of the tendons, their pre-stress as well as their relative position is also examined. The contribution of the present work is the description of the dynamic properties of an entire class of tensegrity elastomer structures. In this manner, a whole new pathway for energy harvesting is opened since these structures may be used for scavenging energy from any source of ambient excitation.

2.2.16 Design, modeling and fabrication of DEAP roll-actuators with a polymer core

Thorben Hoffstadt (1), JÃ¼rgen Maas (1),

(1) University Of Applied Sciences, Hochschule Ostwestfalen-Lippe, Control Engineering And Mechatronic Systems, Lemgo, Germany

Presentation given by Mr. Thorben Hoffstadt

Actuators based on electroactive polymers use the electrostatic pressure to convert electrical energy into strain energy. Depending on the setup, stack- and roll-actuators can be realized, whereas this contribution deals with a new roll-actuator design consisting of a pre-compressed polymer core that is used to preserve the pre-stretch of the DEAP material winded up around the core, yielding to an axial elongation during actuation. Based on this actuator design an electromechanically coupled model for the dynamic behavior is presented, which consists of a non-linear mechanical model to describe the hyperelastic properties of the polymer and an electrical model to describe the electrostatic behavior. This model determines the actuator force depending on the actual stretch state of the actuator and the applied voltage. In order to proof the concept of the polymer core actuator, a handmade prototype was manufactured to validate the model. Finally, an automated process for winding up the pre-stretched DEAP material around the compressed core is presented. With this process polymer core actuators with better reproducible and homogeneous properties can be manufactured, compared to the handmade actuators.

2.2.17 Development of an automated manufacturing process for DEAP stack-actuators

Dominik Tepel (1), Thorben Hoffstadt (1), Christian Graf (1), Jens Krause (2), JÃ¼rgen Maas (1),

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(2) Bayer MaterialScience AG, EAP Research LEV, BMS-CAS-FF-R&D-EAP, Leverkusen, Germany

Presentation given by Mr. Dominik Tepel

Due to the influence of an electrical field, dielectric elastomers perform a large amount of deformation. Because single-layer actuator films are not suitable for the positioning applications, novel energy-efficient multilayer-actuators are utilized to enlarge the absolute displacement and force at a consistent high strain. In the multilayer-technology many actuator films are connected mechanically in series, building up a stack actuator, which elongates in the case of a charged EAP capacitance. This contribution deals with the development of an automated manufacturing process to build stack actuators. In contrast to known chemical stacking processes, thin DE-films are stacked mechanically in series ensuring a low driving voltage. In order to reach a modular and flexible construction the whole process is divided into several stations, which can be adapted separately to produce several actuator geometries. Due to the very thin DE-films, the films are folded to facilitate the handling in a first step. In the next steps the folded DE-films are stacked, cut, contacted and encapsulated. Applying this process stack actuators with reproducible and homogeneous properties can be manufactured.

2.2.18 Automated measurement of contact resistance in electrical interconnections of dielectric elastomer stack transducers

Henry Haus (1), Holger MÃ¶ÃŸinger (1), Marc Matysek (1), Helmut F. Schlaak (1),

(1) Technische UniversitÃ¤t Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany

Presentation given by Mr. Holger MÃ¶ÃŸinger

Electrically interconnecting the single electrode layers buried in silicone is still one major issue that needs to be solved to improve dielectric elastomer stack transducers (DEST). The interconnection needs to provide a mechanically stable and highly conductive electrical connection between the layers of graphite electrode of the DEST and an external metal wire. By now the interconnection is the main cause for failure of DEST. To improve the interconnections first it is necessary to be able to characterize their performance. In a second step one can compare different interconnection methods to find the best solution. Based on a measuring procedure close to the well known four-point measurement we present a fully automated measurement setup to evaluate the electrical contact resistance of dielectric elastomer stack transducers. To minimize the inaccuracies the test setup determines as many electrical parameters of the electrodes and interconnections as possible. Each tested cross-shaped DEST is connected with 12 interconnections. 23 relays allow to handle 54 different states and generate 702 measured values, increasing statistical robustness of the results. This data allows us to determine the electrode's sheet resistance and the contact resistance and thus compare different interconnection techniques more accurate. First measurements show the degradation of the electrical interconnection under different conditions.

2.2.19 Design and modelling considerations for the industrial application of dielectric elastomer actuators

Aaron Price (1),

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Presentation given by Dr. Aaron Price

Recent developments pertaining to dielectric elastomer actuator technology have primarily focussed on performance enhancement through novel materials and processes, electroding techniques, and alternative actuator design topologies. Concomitant gains in actuation performance have led to the proposal of a variety promising new use cases for dielectric elastomers, including the emergence of the first mass-produced consumer products based on these concepts. This investigation aims to bridge the gap between fundamental research activities and industrial technology development projects in a formalized manner by systematically examining the fundamental challenges and opportunities for the industrial application of dielectric elastomer actuators. Dielectric elastomer actuator design guidelines and associated modelling considerations are proposed with the goal of supporting the successful transfer of dielectric elastomer technology toward practical applications within the power and automation industries.

2.2.20 Electrically driven dry state actuators based on PEDOT:PSS nanofilms

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"Dry" conjugated polymer actuators able to work in air have attracted considerable attention because they further expand the range of applications otherwise restricted to liquid environments. In this framework, the electrically induced dimensional change of PEDOT:PSS films through reversible sorption and desorption of water vapor molecules lends itself to the realization of novel actuatorws that operate in ambient air. The actuation principle lies in the reversible contraction of PEDOT:PSS films upon the application of an electric field due the desorption of water vapor sorbed in the films because of local joule heating. Recently, we proposed a novel fabrication process for obtaining free standing ultra thin conductive nanofilms made of the conjugated polymer PEDOT:PSS. These nanofilms, deposited by spin coating, have the advantage of a well controlled and reproducible thickness ranging between few tens to several hundreds of nm. The present study deals with novel electrically driven actuators based on PEDOT:PSS nanofilms that operate in ambient air. Thanks to the nanometric thickness of the PEDOT:PSS nanofilms, such actuators allow for a rapid response. Here, we report the processing methods and a validation of the actuators' working principle. Two different actuator configurations have been tested: 1) nanofilms wrapped and twisted in the form of contractile fibers and 2) PEDOT:PSS/PDMS bilayer bending actuators with different designs e geometries.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 Supersonic cluster beam implantation: a novel approach for the fabrication of highly stretchable and patternable elastomeric electrodes

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Presentation given by Mr. Cristian Ghisleri

Compliant electrodes are fundamental ingredients for the fabrication of devices and systems based on Electromechanically Active Polymers (EAPs). The integration of EAPs on micro-devices requires the fabrication of micrometric electrodes, circuits and interconnections on soft and compliant polymeric substrates. To date, the standard approaches used for producing such structures on stretchable substrates have many drawbacks in terms of layer adhesion, electrical functionality under stretching, attainable lateral resolution, compatibility with ultra-thin substrates. Recently we developed a new method for the Supersonic Cluster Beam Implantation (SCBI) of neutral metal cluster, in the form of a supersonic beam produced by a Pulsed Microplasma Cluster Source (PMCS), in a polymer substrate at RT. This process avoids both sample heating and sample charging, enabling the metallization of ultracompliant and ultrathin soft polymeric materials. SCBI is a planar technology fully compatible with stencil mask micropatterning and lift-off technology. Stretchable macro- and micro-electrodes obtained by gold nanoparticle implantation in silicone polymers such as PDMS are able to withstand more than one million of uniaxial stretching cycles (at 20% strain) preserving finite and reproducible electrical resistance. At odd with electrodes obtained by standard approaches, the ones produced by SCBI experience no delamination even after severe deformation.

2.3.2 Highly conducting electrode materials for dielectric elastomers

Holger BÃ¶se (1), Detlev Uhl (1),

(1) Fraunhofer-Institut FÃ¼r Silicatforschung, Center Smart Materials, WÃ¼rzburg, Germany

Presentation given by Dr. Holger BÃ¶se

Dielectric elastomers are layered composites consisting of an elastomer film coated on both sides with thin electrodes. Generally, these smart materials can be used for various application fields such as actuation, sensing and energy conversion. Depending on the kind of application, special features are required not only for the elastomer dielectric, but also for the electrodes. Most relevant requirements concern the conductivity of the electrode material, the maintenance of a high conductivity upon stretch of the elastomer film and a low mechanical resistance of the electrodes. In this contribution, novel electrode materials with especially high conductivity are introduced. The electrodes consist of silver-coated particles with anisotropic shape which are embedded in silicone elastomer as binder. Electrodes with different concentrations of conducting particles and different thicknesses were prepared. Their electrical and mechanical properties were investigated and compared with those of reference electrode materials based on carbon particles. For the best electrode materials specific conductivities of 100 S/cm were achieved which surmount those of the reference materials by up to three orders of magnitude. High conductivities can be maintained also at very large stretch deformations up to 200 %. Finally, the stiffness of the silicone elastomer film carrying the electrodes was not markedly increased. This was confirmed by actuation measurements.

2.3.3 Electrostrictive response of P(VDF-TrFE-CFE) terpolymer doped with (2-ethylhexyl) phthalate

Jean-Fabien Capsal (1), Jeremy Galineau (1), Pierre-Jean Cottinet (1), Mickael Lallart (1), Daniel Guyomar (1),

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Presentation given by Dr. Jean-Fabien Capsal

Electroactive polymers (EAPs) show promising potential in various applications where electromechanical conversion is required, such as low-frequency energy harvesting or actuation (for instance micropumps or long stroke actuators).

These polymers reach large strain response to an electric field, making them good candidates as low frequency active actuators. Fluorinated terpolymer P(VDF-TrFE-CFE) is a semi-crystalline polymer which shows the highest level of conversion from electrical to mechanical energy thanks to its high dielectric permittivity and high mechanical modulus. However, large electrical field are required (E > 100V/Âµm) to reach sufficient strain levels (> 2%). In this work, fluorinated terpolymer P(VDF-TrFE-CFE) was doped with (2-ethylhexyl) phtalate (DEHP). This modified terpolymer shows a 28 fold increase of the longitudinal electrostrictive strain under low applied electric field and a 233 times increase in mechanical energy compared to the neat polymer. This simple chemical doping allows the use of the exceptional properties of the terpolymer at an electric field 5.5 times lower than that of the pure terpolymer. In addition, the modification we propose here is cheap, industrially used and could potentially break a technological lock as the performance recorded at low electric field are greater than any conventional electroactive polymer.

2.3.4 Development of large deformation sensors based on styrene-butadiene-styrene / carbon nanotube composites

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(2) Institute For Polymers And Composites IPC/I3N,Minho University, Portugal

Presentation given by Mr. Pedro Costa

Thermoplastic elastomer/carbon nanotube composites are studied for sensor applications due to their excellent mechanical and electrical properties. Piezoresisitive properties of tri-block copolymer styrene-butadiene-styrene (SBS)/ carbon nanotubes (CNT) prepared by solution casting have been investigated. Initial modulus of the SBS/CNT composites increases with the amount of CNT filler content present in the samples, without losing the high strain deformation on the polymer matrix (~1500 %). Further, above the percolation threshold these materials are unique for the development of large deformation sensors due to the strong piezoresistive response. Piezoresistive properties evaluated by uniaxial stretching in tensile mode and 4-point bending showed a Gauge Factors up to 100. The excellent linearity obtained between strain and electrical resistance makes these composites interesting for large strain piezoresistive sensors applications. Percolation threshold for SBS/CNT composites for different ratios butadiene/styrene is less than 1 wt% and gauge factor can be measure for several strains (since 1 to 50%) and speeds (1 to 50 mm/min). Gauge factor values depend of speed, strain and method of measure and can be near 100. These composites can be also processed in the form of nanofiber or extruded film or wire in industrial processes, increasing therefore the application potential of the materials for sensor applications.

2.3.5 Automated roll-to-roll-process for the fabrication of DEAP-stack-actuators

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(1) University Of Applied Sciences, Hochschule Ostwestfalen-Lippe, Control Engineering And Mechatronic Systems, Lemgo, Germany

Presentation given by Mr. Thorben Hoffstadt

Actuators based on electroactive polymers use the electrostatic pressure to convert electrical energy into strain energy. To either maximize the actuation force or absolute displacement of actuators for positioning applications, multilayer actuators are used. This contribution deals with an automated process for the fabrication of DEAP-stack-actuators. Here, a roll-to-roll-process known from the fabrication of capacitors is investigated and presented. In contrast to known chemical fabrication processes, the roll-to-roll-process describes a mechanical stacking process, which is used to facilitate the handling of the very thin DEAP films. The rolled up DEAP film is winded up on a second roll after several processing steps, like applying the electrode. Besides the setup of this process, control concepts for the utilized drives and the automated fabrication are presented.

2.3.6 Electromechanical transitions in pure shear dielectric elastomer actuators: giant stretches and failure modes

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Presentation given by Mr. Matthias Kollosche

For dielectric elastomers, one of the most striking attributes are large, voltage induced deformations. The electro-mechanical coupling in soft elastomer capacitors is well understood, however, the resulting actuation behavior and its intimate dependence upon the boundary conditions are not. Analysis is simplified when geometries with constant fields are employed - here, membranes of a dielectric elastomer are prepared in various pure shear states of pre-stretch, using rigid clamps and mechanical forces. A combination of experiment and theory shows that dielectric elastomers exhibit a complex interplay of nonlinear processes and that electromechanical instability can be avoided, enabling giant deformations with rich actuation behavior promoted by various transitions. Wrinkles appear above a certain applied voltage, leading to a snap-through transition and actuation strains up to 260% for VHB4905. Surprisingly, it was found that snap-through was not a cause of electrical failure, but may be caused instead by a local instability or intrinsic breakdown.

2.3.7 Large-strain detection using elastomeric sensors

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Presentation given by Mr. Matthias Kollosche

Electroactive polymers (EAP) and soft stretchable conductors have been studied for voltage-tunable dielectric elastomer actuators (DEA) that can achieve large deformations at low voltage. However, the advantages of this technology can also be used for strain-sensing solutions. While conventional strain sensors, e.g. made of piezoelectric materials, are limited to strains not exceeding 2 to 3% due to their mechanical properties, elastomeric sensors are able to detect both small and large strains. Furthermore, they offer the advantages of high sensitivity in the low-stress regime, fast response times, low power consumption, and weathering stability. The proposed sensor consists of a dielectric elastomer film sandwiched between highly stretchable electrodes. Its functional principle is based upon the coupling between mechanical deformations and changes in the sensor's capacitance. We present strategies to enable large reversible mechanical deformations as well as the use of ceramic/polymer nano-composites and molecular composites to adjust strain sensitivity and durability. One application is demonstrated on large-scale experiments: as a diagnostic tool for the structural health of infrastructural facilities.

2.3.8 Platform-based EAP components development

Rahimullah Sarban (1),

(1) Danfoss PolyPower A/S

Presentation given by Dr. Rahimullah Sarban

Research within the field of EAP has, so far, been mainly focused on material improvements, characterization, modeling and developing demonstrators. As EAP technology advances to higher technology readiness level, a more products oriented research is needed. This necessity is mainly driven by the need of commercializing the technology and its diffusion into products. Therefore EAP based products design and development is needed to the aforementioned commercialization needs. Product development can be based on an isolated design or platform design. In platform design the families of products exploits commonality of platform modules while satisfying a variety of different market segments. Platform based approach has the primary benefit of being cost efficient and short lead time to market when new products emerges. Products development based on EAP technology is challenging both technologically as well as from production and processing point of view. Both the technological and processing challenges need to be addressed before a successful implementation of EAP technology into products. Based on this need Danfoss PolyPower A/S has, in 2011, launched a EAP platform project. The aim of the project is to develop platform based designs and product family for the EAP components to be used in variety of applications. This paper presents the structure of the platform project as a whole and specifically the platform based designs of EAP transducers.

2.3.9 Bio-inspired concept of adaptive building envelope based on electroactive polymer actuators

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Presentation given by Dr. Pawel Zylka

Adaptive building envelope (ABE) is a subgroup of emergent adaptive systems that may be regarded - in architectural context - as building's bioinspired skin with inherited ability to manage building's interior climate. ABE is thus able to control and adjust transfer of various energy forms and carriers (i.e. temperature, humidity, lighting, airflow, etc.) between the internal and external building's environment. One of the novelty approaches in the ABE design is to base its adaptation mechanism on structures driven by electroactive polymers (EAPs). The poster presentation illustrates introductory experimental approach for developing discrete artificial aperture structures for controlled gas exchange, behaving similarly to stomata, a complex system of miniature pores responsible for vapor exchange process in plants. Dielectric elastomer actuator (DEA) and dimple arrangement were chosen as the initial scheme.

2.3.10 Electromechanical response in cellular and mesh ferroelectret structures

Agnieszka Okopna (1), Ryszard Kacprzyk (1), Pawel Zylka (1),

(1) Wroclaw University Of Technology, Department Of Electrical Engineering, Wroclaw, Poland

Presentation given by Dr. Pawel Zylka

Soft polymers with voided gaseous structure in which charges deposited on internal solid-gas interphases form dipole-like pattern exhibit piezoelectric effect characterized with d33 coefficient which may even exceed 1000 pC/N. Such structures demonstrate also inverse piezoelectric effect which may enhance their thickness change due to Maxwell stress and electrostriction. The electromechanical response of typical ferroelectret gas-expanded polypropylene voided foil is experimentally studied and compared to electromechanical effects occurring in multilayer polypropylene structure with solid outer sheets and nonwoven interlocked core.

2.3.11 Bucky gel actuators: the influence of the electrode resistivity

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Presentation given by Mr. Grzegorz Bubak

The bucky gel is considered as a promising material for muscle-like actuation. Bimorph dry electrochemical actuators prepared using bucky gel composite can operate at low voltage (2-5V) in air. We found out that one of the main issues that limits the effectiveness of these actuators is the voltage drop along the bucky gel electrode itself which results in a severe limitation of its frequency response and reduces the maximum force, especially in the case of long actuators. In order to quantify and verify this phenomenon, we measured the step response of our actuators while charging and discharging them, and we characterized the influence of different conductive layers deposited on the actuator surface by sputter coating to reduce the resistivity along the electrode. The conductivity of the electrodes surface was measured using 4 probe setup and the influence of the metal film thickness of coatings was investigated. Our last results on the influence of electrode resistivity on the force-displacement behavior of bucky gel actuators will be shown. The voltage drop-displacement/force relationships will be discussed.

2.3.12 Separation of metal ions by using conducting polymer membranes under electrical control

Ari Ivaska (1), Marceline Akieh-Pirkanniemi (1), Johan Bobacka (1),

(1) Process Chemistry Centre, Ãbo Akademi University, Turku/Ãbo, Finland

Presentation given by Dr. Ari Ivaska

The conducting polymer polypyrrole, PPy, was used as the active component of a cation exchange membrane for transferring a range of metal ions between two solutions by electrical modulation of the polymer between its conducting and non-conducting states. The cation exchange membranes consisted of platinum sputter-coated polyvinylidene difluoride (PVDF) which had been coated with polypyrrole doped with sulfonated calix[6]arene (PPy(C6S)). The experimental cell consists of two compartments separated by the PPy-composite membrane. The source solution contained the potassium and calcium ions as nitrates. The receiving solution was of distilled water. When the membrane was polarized sequentially between -0.8V and +0.6V a flux of cations through the membrane was observed. K+ was transferred through the membrane but no flux of Ca2+ through the membrane was observed. Transfer of several other cations through a selection of other membranes was studied as well. It was shown that applying an alternating potential in the range -0.8 V to +0.6 V a gradual but steady increase in metal ion concentration was detected in the receiving cell across the PVDF/Pt-PPy(C6S) membrane. The PVDF/Pt-PPy(C6S) composite membrane showed significant permeability towards metal ions such as Ca2+, K+ and Mn2+, with the flux for Ca2+ higher than that seen for this metal ion with any previously studied PPy films containing other complexing dopants.

2.3.13 Electrical breakdown in silicone elastomer films facilitated by sprayed network electrodes made of single-walled carbon nanotubes

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Presentation given by Dr. Dmitry Rychkov

Electrodes deposited onto elastomer films via spraying of single-walled carbon nanotubes (SWCNT) are one of the most suitable solutions for actuators and sensors. SWCNT electrodes are stretchable, conductive over a wide range of deformations, robust and even have self-healing properties. However, such electrodes can favour the injection of charges into the elastomer. Charge injection is an undesirable phenomenon that may lead to the build-up of charges, to early aging, to breakdown and to other processes that compromise the operation and the efficiency of the actuator. Here, we investigate the influence of SWCNT electrodes on the electrical breakdown in silicone elastomer films and compare them to metal electrodes. SWCNT were sprayed in the form of an isopropanol solution onto silicone films that had been prepared via drop-casting on glass substrates equipped with evaporated aluminium electrodes. Breakdown was induced by ramping up the voltage applied between the aluminium and CNT electrodes, while monitoring the current flowing through the sample. In the event of breakdown, the current will increase drastically, which will trigger the safety switch on the high-voltage amplifier. In each experiment, the highest applied voltage was recorded and recalculated into the electrical field strength at breakdown. It has been found that the samples with SWCNT electrodes experienced electrical breakdown at lower field strengths than the samples with all-metal electrodes

2.3.14 Electromechanical characterization of fingertip tactile display based on hydrostatically coupled dielectric elastomer actuators

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(2) University Of Pisa, Centre "E. Piaggio", Pisa, Italy

Presentation given by Dr. Gabriele Frediani

In a previous work we had proposed Hydrostatically Coupled Dielectric Elastomer Actuators (HC-DEAs) as a technology to develop tactile displays. The actuator includes an electromechanically active membrane and an electromechanically passive membrane which are hydrostatically coupled by an incompressible fluid. When a voltage is applied, the tension in the active membrane decreases, causing it to buckle outwards. As the fluid's volume is constant, the passive membrane buckles inwards accordingly. This principle allows for safe transmission of actuation from the active membrane to the passive membrane, which is in contact with the fingertip. The membranes are radially constrained by bonding them to a stiff support that is also shaped in order to hold the fingertip and keep it in contact with the passive membrane. Also, a plastic case is arranged in the support to integrate a miniaturized high-voltage DC/DC converter, so that the overall system is compact and portable. Here, we present the electromechanical characterization of the system in terms of static displacement and force, as well as stress relaxation.

2.3.15 Predictive stress-stretch models of dielectric elastomers up to the characteristic flex

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(2) University Of Trento, Department Of Civil, Environmental And Mechanical Engineering, Trento, Italy

Presentation given by Dr. Federico Carpi

Hyperelastic constitutive models are typically used to describe the characteristic non-linear stress-stretch curves of elastomers. Despite their descriptive ability, these models are not intrinsically predictive a priori, due to their parametric nature, which requires data fitting a posteriori. To overcome this limitation, here we present a simple predictive uniaxial law and hyperelastic model. They move from the experimental evidence that during uniaxial tensile loading of different soft elastomers the true stress has a linear dependence on the engineering strain, up to the characteristic oblique flex that shows up in the nominal stress vs engineering strain plot. We show that this behaviour is captured by a predictive hyperbolic stress-stretch law that requires just a single material constant (the Young's modulus), determinable from few data at very low strains. Also, we formulate a predictive hyperelastic constitutive model, able to describe the stress-stretch curve up to the flex, still by using the initial elastic modulus only. We present an experimental validation of these new models on three types of elastomers used for dielectric elastomer transducers. We show that the accuracy of the new predictive models is higher than that of the neo-Hookean equation, and we discuss the potentialities, as well as the limitations, of the derived laws as tools possibly useful to designers.

2.3.16 Stretchable device with electrically tuneable fluorescence and absorbance via dielectric elastomer actuation

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(2) Queen Mary University Of London, School Of Engineering & Materials Science, London, UK

Presentation given by Mr. Cormac Hanley

In this work we present the first proof-of-concept demonstration of a quantum dot (QD)-doped dielectric elastomer circular actuator as a possible optical device with electromechanically tuneable absorbance and fluorescence. A polyacrylate dielectric elastomer film with carbon grease electrodes was doped with organic-phase CdSe/CdS luminescent QDs. The idea is that actuation of the QD-doped elastomer varies the distances among each QD and its neighbours in the structure, modifying the volume and/or surface density of QDs, and thus leading to variable interactions among them, therefore changing the absorbance and fluorescence spectra of the QDs in the elastomer matrix. The system was studied by thermo-gravimetric analysis, absorption and emission (photoluminescence) spectroscopy, and fluorescence lifetime imaging microscopy. The QD doped actuator showed that a voltage-induced increase of the QD concentration per unit area can lead to increased UV-Vis absorption, shortened fluorescence lifetimes, and decreased photoluminescence intensity. This initial explorative work allowed us to assess basic potentialities and challenges of such systems, outlining the way for future developments.

2.3.17 The influence of barium titanate particles in silicone rubber based dielectric elastomers

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Presentation given by Mr. Liang Jiang

Previously, the impact of modifying the material properties of a silicone rubber based dielectric elastomer (DE) by including barium titanate ($BaTiO_3$) particles in the polymer has been studied for a specific particle volume fraction. In the research described here, volume fractions for $BaTiO_3$ were varied in increments between 0 and 20% and the influence on mechanical and electromechanical properties for the DEs was observed. Test samples for the modified electroactive polymers were pre-stressed biaxially to a stretch ratio of 1.7. Thereafter, a DC high voltage was applied across the 0.3 mm thickness of the material using a uniform coating of grease applied to the upper and lower faces of the samples which constituted the compliant electrodes on each surface. Both the dielectric strength and the biaxial tensile strain increased with an increase in the content of dielectric particles. The maximum biaxial strain of approximately 32% was achieved for the sample having a volume fraction of 10% BaTiO3. This strain corresponded to a dielectric strength of around 15V/Âµm. Dielectric tests carried out using wideband dielectric spectroscopy showed that the dielectric constant increased linearly as the volume fraction of Barium titanate increased. The elastic energy density (EL) and the electromechanical coupling efficiency (K2) were also calculated. For DEs with 10 vol% barium titanate, EL and K2 were 35.5 KJ/m3 and 50% respectively.

2.3.18 Dielectric elastomer and ferroelectret films for multifunctional electromechanical devices

Sebastian Raabe (1), Xunlin Qiu (1), Werner Wirges (1), Reimund Gerhard (1),

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Presentation given by Mr. Werner Wirges

As two groups of electromechanically active polymers, dielectric elastomers (DE) and ferroelectrets are extensively studied and are widely used in various applications. DEs are soft polymer materials exhibiting extremely large deformations under Maxwell-stress, while ferroelectrets are internally charged polymer foams showing large piezoelectricity combined with mechanical flexibility and elastic compliance. In this contribution, DE actuators and ferroelectret films are integrated into one device. The DEA was prepared by attaching a pre-stretched elastomer to a flexible plastic frame, to which a cellular polypropylene ferroelectret film or a tubular-channel fluoroethylenepropylene copolymer ferroelectret film system was mounted. The frame changed its shape upon release of the DE film from the pre-stretch, and finally formed a bending actuator with minimum-energy structure. The dielectric resonance spectra of the ferroelectret films were measured in-situ during the actuation of the DEA. It turns out that the anti-resonance frequencies (fp) of the ferroelectret film is a monotonic function of the bending angle of the actuator. Thus, the electromechanical device developed here possesses multi-functions: The actuation strain from the DEA can be used to modulate the fp of the attached ferroelectret and on the other hand, fp can also be evaluated for in-situ diagnosis and for precise control of the actuation of the DEA via feedback.

2.3.19 Electroactive scaffolds for cardiac tissue regeneration

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Presentation given by Ms. Amy Gelmi

Myocardial Infarction (MI), commonly known as a heart attack, is the interruption of blood supply to a part of the heart, causing heart cells to die. In order to restore function by-pass surgery or ultimately heart transplantation is needed. However, due to the shortage of organ donors and complications associated with immune suppressive treatments, development of new strategies to help regenerate the injured heart is necessary. Stem cell therapy can be used to repair necrotic heart tissue and achieve myocardial regeneration. This research is focused on developing implantable electroactive fiber scaffolds that will increase the differentiation ratio of mesenchymal stem cells into cardiomyocytes and thus increase the formation of novel cardiac tissue to repair or replace the damaged cardiac tissue after MI. Composite nanofibrous scaffold of poly(dl-lactide-co-glycolide) (PLGA) have been coated with biodoped polypyrrole to create an electroactive fiber scaffold, with controllable fiber dimensions and alignment. The electrical properties of the polymers are an integral factor in creating these 'intelligent' 3-D materials; not only does the inherent conductivity provide a platform for electrical stimulation, but the ionic actuation of the polymer can also provide mechanical stimulation to the seeded cells. The biocompatibility of the polymer, PLGA scaffolds, and coated PLGA scaffolds has been investigated using primary cardiovascular progenitor cells.

2.3.20 Overview and performance indicators of electroactive polymers (EAPs) and actuation materials integrated with large-deflection compliant rotational joints

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Smart materials can be used as actuators. They generate high forces and high energy densities. Compliant rotational joints can be compact, since they are made out of one piece of material. The integration of EAPs and actuation materials with compliant rotational joints potentially results in compact designs of actuators. They can be valuable for designers who are optimizing the volume and weight of their designs. Interesting applications could be active (medical) devices, such as robotics and prostheses. An overview of the material-actuated compliant joints does not yet exist. Furthermore, the performance of the designs is not well evaluated or compared. This literature study presents an overview of material-actuated compliant joints and performance indicators that evaluate the designs. The overview shows areas of potential designs based on preliminary calculations. A theoretical comparison study is done between two promising designs, a shape memory alloy and a dielectric elastomer configuration. The results show that a design with a shape memory alloy configuration generates higher stall torques and higher energy densities, while a dielectric elastomer configuration has a higher half cycle efficiency. Future work will focus on how to store elastic energy in EAPs and actuation materials and in the compliant rotational joints prior to actuation. This stored energy can be regained during actuation, which will increase the performances of the designs.

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