EuroEAP 2017

7th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Cartagena, Spain
6-7 June 2017

Technical programme

Book of abstracts

List of participants

EuroEAP 2017 sponsors

Contents

Local organization

Conference Chairperson

EuroEAP 2017 is chaired by:
Prof. Toribio Fernández Otero
Technical University of Cartagena,
Technical School of Industrial Engineers,
Laboratory of Electrochemistry, Intelligent Materials and Devices
email: toribio.fotero@upct.es
Ph: +34 968 325519

Local organizing institution

EuroEAP 2017 is organized by
Technical University of Cartagena,
Technical School of Industrial Engineers,
Laboratory of Electrochemistry, Intelligent Materials and Devices,
Campus Alfonso XIII,
30203, Cartagena, Spain

Contact information

For any information about EuroEAP 2017 please contact
Prof. Toribio Fernández Otero
e-mail: toribio.fotero@upct.es
Ph: +34 968 325519

Presentation of the EuroEAP conference series

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

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

The rapid expansion of the EAP technologies has stimulated in Europe the creation of the EuroEAP Society as a non-profit Association, whose main purpose is to contribute to and promote the scientific and technological advancement and the diffusion of Transducers and Artificial Muscles based on EAPs. In an effort to disseminate current advances in this emerging field of science and technology, gathering experts from all over the world, the Society organises and supports the annual EuroEAP conference, which is meant to be primarily driven by scientific quality and industrial impact.

I wish to express my gratitude to the conference Chairperson for the valuable local organization of this new edition. I am sure that you will enjoy this event and will leave it with plans to attend the future annual editions, which will be moving across Europe.

Federico Carpi
EuroEAP Society President

Conference committees

Organizing committee

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

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

Tuesday, 6 June 2017

General programme of the day

Opening	8:45- 9:00	Welcome & introductory remarks **Toribio Fernández Otero** Technical University of Cartagena, Spain
Session 1.1 *Chair: Toribio Fernández Otero, Technical University of Cartagena, Spain*		
EAPlenaries	9:00- 9:30	Invited talk **John Madden** Univeristy of British Columbia, Vancouver, Canada
	9:30- 10:00	Inspirational talk **Aurélie Mosse** Ecole Nationale Supérieure Des Arts Décoratifs, France
Session 1.2 *Chair: John Madden, Univeristy of British Columbia, Vancouver, Canada*		
EAPodiums	10:00- 10:20	Invited talk **Frédéric Vidal** University of Cergy-Pontoise, France
	10:20- 10:40	Invited talk **Takushi Sugino** AIST, Japan
Break	10:40- 11:00	Coffee break
Session 1.3 *Chair: Frédéric Vidal, University of Cergy-Pontoise, France*		
EAPitches	11:00- 12:00	**Pitch oral presentations** 20 presentations of research activities, followed by presentations of prototypes/products (2 minutes each + 1 minute to change speaker)
Session 1.4 *Chair: Luigi Calabrese, University of Trento, Italy*		
EuroEAP Society	12:00- 12:30	**Challenge pitch oral presentations** 6 presentations

Challenge project pitches		(3 minutes each + 1 minute to change speaker)
Lunch	12:30-14:00	Buffet lunch
EAPosters **EAPrototypes** **EAProducts**	14:00-15:00	**Posters & exhibitions** 20 posters, together with prototypes/products
Session 1.5 *Chair: Takushi Sugino, AIST, Japan*		
EAPodiums	15:00-15:20	Invited talk **Leonid Ionov** University of Georgia, USA
EAPromises	15:20-15:40	Invited talk **Francesco Greco** Italian Institute of Technology, Italy
EAPhDs	15:40-15:50	Invited talk **Zane Zondaka** University of Tartu, Estonia
Session 1.6 *Chair: Francesco Greco, Italian Institute of Technology, Italy*		
EAPitches	15:50-16:50	**Pitch oral presentations** 20 presentations of research activities (2 minutes each + 1 minute to change speaker)
EAPosters **EAPrototypes** **EAProducts**	16:50-17:40	**Posters & exhibitions** 20 posters, together with prototypes/products Coffee break served during the session
EuroEAP Society's annual meeting	17:40-19:30	Annual meeting of the EuroEAP Society's General Assembly (open to members and non- members).
Social dinner	19:30	Dinner at the conference hotel

Session 1.1
(abstracts are listed in the order of presentation)

1.1.1 Ionic skin and other ionic devices

John D.W. Madden (1), Mirza Saquib Sarwar (1), Yuta Dobashi (1), Saeedeh Ebrahimi Takalloo (1), Graham Allegretto (1), Eric Cattan (3), Sébastien Grondel (3), Frédéric Vidal (2), Cédric Plesse (2), Tran Minh Giao Nguyen (2), Ngoc Tan Nguyen (1) (3),

(1) Electrical & Computer Engineering And Advanced Materials & Process Engineering Lab, Univeristy Of British Columbia, Vancouver, Canada
(2) Laboratoire De Physicochimie Des Polymères Et Des Interfaces, University Of Cergy-Pontoise, Neuville Sur Oise, France
(3) IEMN, Université De Valenciennes, Le Mont Houy, Valenciennes, France

Presentation given by Prof. John Madden

If we are to make stretchable and foldable phones and tablets they will require deformable touch interfaces. Ionic skins composed of highly extendable hydrogels surrounded by rubber show promise. The hydrogels contain salt water and form transparent electrodes. Silicone rubber forms a transparent dielectric that surrounds and separates the gel electrodes. The resulting capacitive sensor is able to detect proximity and touch. By making the rubber more compliant, and adding air bubbles, stretch and pressure are also detectable. Sensing can also be achieved by pressure induced ion transport - in which voltages are generated in response to deformation of a salty gel - and by change in double layer area of metal contact with electrolyte. The next stage is to add energy storage and actuation. Recent advances in conducting polymer actuators have demonstrated excellent frequency response from clean room compatible processes - so adding tactile feedback may be possible.

1.1.2 Gossamer timescapes: a design-led investigation into electro-active and light responsive textiles for the home

Aurélie Mossé (1),

(1) Ecole Nationale Supérieure Des Arts Décoratifs, Soft Matters Research Group, Ensadlab, Paris, France

Presentation given by Dr. Aurélie Mossé

This lecture introduces Gossamer Timescapes, practice-based and design-led experimentations exploring how the design of self-actuated textiles can inform new poetical and cultural possibilities for smart technologies. More specifically, the research focuses on the role three-dimensionally dynamic textiles can play in shaping a culture of interconnectivity within the context of the Western home. In other words, how smart textiles can encourage interactions as a holistic culture in which nature, humans and their technologies belong to the same contexture. Developed as interdisciplinary collaborations at the intersection of textile design, architecture and material sciences, the research relies on the appropriation of three polymer technologies: thin film photovoltaics, light-responsive liquid crystals and dielectric elastomers. The Photovoltaic Mashrabiya -a textile membrane changing shape and producing electricity in response to solar patterns-, Photokinetic textiles - the probing of light-induced shape-changing textile swatches and Reef -a self-actuated ceiling changing with the wind- embody the outcome of this research. Together they not only suggest new opportunities for smart technologies but also demonstrate the value of interdisciplinary collaboration at the cross of science and design.

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

1.2.1 Title Conducting interpenetrating polymer networks: an easy route to shape actuators

Frédéric Vidal (1), Vincent Woelhing (1), Cédric Plesse (1), Giao T.M. Nguyen (1), Thomas Kerr-Phillips (2), Jadranka Travas-Sejdic (2), Meisam Farajollahi (3), John DW Madden (3),

(1) Laboratoire De Physicochimie Des Polymères Et Des Interfaces, Université De Cergy-Pontoise, France
(2) Polymer Electronics Research Centre, University Of Auckland, New Zealand
(3) Electrical & Computer Engineering And Advanced Materials & Process Engineering Lab, University Of British Columbia, Vancouver, Canada

Presentation given by Prof. Frédéric Vidal

In previous works, we have shown that the synthesis of electronic conducting Interpenetrating Polymer Networks (IPN) allows designing beam-shape actuators with tailored properties. For instance, robust or fast actuators can be fabricated at the macro and micro-scale. Besides tailoring the material's physico-chemical properties, actuators with particular shape can be prepared too. First, the synthesis of the artificial muscles with tubular shape mimicking an electro-active catheter will be described. The electroactive material is made of poly(3,4-ethylenedioxythiophene) (PEDOT) as Electro-Active Polymer in the presence of poly(ethylene oxide) (PEO), polystyrene (PS) and Nitrile Butadiene Rubber (NBR) within an IPN macromolecular architecture. Thus, a hollow, flexible, stretchable NBR-PEO-PS-PEDOT active catheter, with uniform thickness and showing a stiffness gradient has been prepared in order to solve the various problems associated with the catheter geometry. In a second part, electroactive elastomer microfiber mats were prepared by electrospinning. These porous, stretchable and robust materials showed reversible pore size variations in electrolytes. The synthesis and the main results will be described during the presentation.

1.2.2 Effect of carbon nanohorns on the actuation of nanocarbon polymer actuators

Takushi Sugino (1), Kinji Asaka (1),

(1) National Institute Of Advanced Industrial Science And Technology (AIST), Inorganic Functional Materials Research Institute/Hybrid Actuator Group, Osaka, Japan

Presentation given by Dr. Takushi Sugino

Electrically active polymers (EAPs) are promising key materials as sensors and actuators in the coming IoT (Internet of Things) society. Especially, low-voltage-driven EAP actuators are expected for their wearable applications. From these points of view, we have studied ionic EAP actuators consist of carbon nanotubes, ionic liquids, and a base polymer called as nanocarbon polymer actuators. The nanocarbon polymer actuators have a three layered structure, that is, one electrolyte film composed of ionic liquid and base polymer is laminated by two electrode films made from carbon nanotube, ionic liquid, and base polymer. In this talk, we would like to introduce you our recent research progress in order to improve the actuation of nanocarbon polymer actuators, especially by using carbon nanohorns in the electrodes. We will also introduce you our application challenges of nanocarbon polymer actuators.

Session 1.3

(abstracts are listed in the order of presentation)

1.3.1 Electroactive textiles for exoskeleton-like suits

José Martinez (1), Ali Maziz (1), Jonas Stålhand (1), Nils-Krister Persson (2), Edwin Jager (2),

(1) Linköping University
(2) University Of Borås

Presentation given by Dr. José Martinez

There is a need for soft assistive robotic devices such as prosthetics, exoskeletons and robot assistants. One particular area of interest is robotic exoskeletons to support the movement of body parts, e.g. assisting or enhancing walking and rehabilitation. Although technologically advanced, current exoskeletons are rigid and driven by electric motors or pneumatic actuators making them noisy, heavy, stiff and non-compliant. Ideally, assistive devices would be shaped as an exoskeleton suit worn under clothing and well-hidden. By merging one of humankind oldest technology with one of the latest, that is by combining knitting and weaving with novel electroactive polymers, we have developed soft textile actuators ("Knitted Muscles"). In this paper we will present the textile actuators in more detail as well as share the latest progress in the development of textile actuators for soft robotics.

1.3.2 Scalable actuator material for soft robotics

Alvo Aabloo (1), Friedrich Kaasik (1), Indrek Must (2), Inna Baranova (1), Inga Põldsalu (1), Enn Lust (3), Urmas Johanson (1), Andres Punning (1),

(1) Intelligent Materials And Systems Lab, Institute Of Technology, University Of Tartu, Nooruse 1, 50411 Tartu, Estonia
(2) Center For Micro-BioRobotics, Istituto Italiano Di Tecnologia (IIT), Viale Rinaldo Piaggio 34, 56025 Pontedera, Italy

(3) C Institute Of Chemistry, University Of Tartu, Ravila 14A, 50411 Tartu, Estonia

Presentation given by Prof. Alvo Aabloo

The development of soft shape-morphing robots is in demand of flexible and electrically reconfigurable actuators. Soft robotics poses some crucial expectations to the suitable actuators: their fabrication must be reproducible, a long lifetime is appreciated and the simplicity of driving the actuator is in interest. One type of materials that meets the requirements of soft robotics is called ionic and capacitive laminates - the materials that can be seen as actuators, sensors as well as electrical double layer capacitors. A novel ionic and capacitive laminate fabrication method is introduced; the electroactive layers (the membrane and the electrodes) are deposited layer-by- layer around a woven fabric substrate, which is pertained as the centermost layer of the laminate. The improved production method increases the reproducibility of the actuators: electroactive laminates can be produced with an outstanding uniformity in thickness and in areal capacitance. Simple galvanostatic driving is suitable and optimal for driving this kind of actuators, because the generated strain has a linear dependence to the injected charge. Furthermore, the new textile-incorporated actuating laminates stand out for their impressive lifetime of more than ten thousand cycles, which enables the use of these actuators in practical scenarios.

1.3.3 Climate chamber for testing ionic electroactive polymer actuators

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

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

Presentation given by Mr. Sunjai Nakshatharan Shanmugam

The ionic electroactive polymer (IEAP) actuators with carbonaceous electrodes and ionic liquid electrolytes are distinguished by their ability for operation in open air. Nevertheless, their behavior is influenced by at least two parameters of the ambient environment - temperature and humidity. This work describes the design of an instrumental arrangement and outline of the measurement procedure to characterize the temperature and humidity dependence of the ionic

EAP actuators. The design of the test setup is an inexpensive alternative to a complicated laboratory climate chamber. The humidity in an about one liter volume vessel is mantained with the saturated salt solutions or an humidity generator, while the temperature is controlled by sinking the vessel into a thermostat-controlled liquid. Tip displacements of several concurrent samples are detected by a single 2D laser scanner. National Instruments data acquisition system along with the LabVIEW software is used for monitoring, visualisation and post processing of the electromechanical and electrochemical response of up to nine IEAP actuators characterized all at once. This arrangement is capable providing stable level of relative humidity ranging from 0% to 90% and temperature in the range from -40 ºC to +90 ºC.

1.3.4 Mimicking muscle fatigue sensing. The cooperative actuation of multistep electrochemical molecular machines senses the electrolyte concentration.

Samuel Beaumont (1), Toribio F. Otero (1),

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

Presentation given by Mr. Samuel Beaumont

After long working times our muscles feel, and communicate to brain, their fatigue state due to the low available concentration of ATP and oxygen. Here we tray to investigate if some artificial reactions involving dense biomimetic gels can respond to concentration variations. Electrochemical reactions from films of conducting polymers include the cooperative actuation of multistep molecular (polymeric) machines generating the required volume to incorporate, or expel, balancing counterions and solvent. We have studied the evolution of the reversible voltammetric charge in different concentrations of NaCl aqueous solutions from polypyrrole films. Rising concentrations shift the reversible electrochemical reactions to deeper oxidation/reduction states with the concomitant increase of: the redox charge, the free volume generated/destroyed inside the film and the amount of exchanged counterions and solvent. The process is full reversible. Under constant temperature, pressure and electrical conditions the extension of the reaction (the consumed charge) decreases for decreasing concentrations. Translated to natural muscles that means that in order to do the same work (by consumption of the same charge) higher efforts should

be required in lower concentrations. Alternatively, for conducting polymers, the charge consumed during the driving reaction senses the available chemical energy: the reactant concentration. A theoretical description is proposed.

1.3.5 How muscles from cold-blooded animals work? The cooperative actuation of multistep electrochemical molecular machines from polypyrrole senses the temperature.

Samuel Beaumont (1), Toribio F. Otero (1),

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

Presentation given by Mr. Samuel Beaumont

The environmental temperature has a strong influence on the metabolism of any cold-blooded animal (ectotherm) muscles. By electrochemical reactions in liquid electrolytes conducting polymer become dense and reactive gels. There every chain acts as a multistep molecular machine, mimicking the intracellular matrix of the sarcomere in natural muscles. Here we have studied, through potentiostatic or galvanostatic pulses, how the temperature influences those reversible electrochemical reactions. The cooperative actuation during reactions of the constitutive polymeric machines generates/destroys the required free volume to incorporate, or expel, balancing counterions and solvent: the material swells and contracts. Under constant chemical, mechanical and electrical energetic conditions, at increasing temperatures (rising thermal energy) the evolution of both, the material potential and the consumed energy shifts to lower values. When the thermal energy of the ambient increases the reaction consumes lower energies to occur in the same extension. Furthermore, those reactions involving molecular machines act as sensors (through the material potential or the reaction energy) of the working temperature. Muscles from cold-blooded animals working at lower temperatures sends to the brain decreasing potential, demanding signals to produce higher efforts in order to do the same work. A theoretical description of those reaction-driven temperature sensors is proposed.

1.3.6 Laser patterned PEDOT:PSS microactuators based on LbL synthesis

Kätlin Rohtlaid (1), Cédric Plesse (1), Tran Minh Giao Nguyen (1), Caroline

Soyer (2), Eric Cattan (2), Frédéric Vidal (1),

Presentation given by Ms. Kätlin Rohtlaid

Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) has attracted more and more interest in the field of conducting polymer actuators due to its softness, flexibility, biocompatibility and easy processing. In this work synthesis and characterization of PEDOT:PSS based microactuators will be described. Microactuators were fabricated using custom fit Layer-by-Layer (LbL) process, where vapor phase polymerization was replaced by drop casting. The electrochemical properties of the PEDOT:PSS electrodes dependent on glycol based monomers will be described. Actuation, blocking force, Young's modulus and first sensing results of the laser patterned microactuators will be presented.

1.3.7 Electrochemical inmunosensor based on carbon nanotubes decorated with gold nanoparticles for the detection of prostate specific antigen (psa).

Andres Felipe Quintero Jaime (1) (2) (4), Angel Berenguer Murcia (2) (3) (4), Emilia Morallón Nuñez (1) (2) (4), Diego Cazorla Amorós (2) (3) (4),

(1) Departamento De Química Física
(2) Instituto Universitario De Materiales
(3) Departamento De Química Inorgánica
(4) Universidad De Alicante

Presentation given by Mr. Andres Felipe Quintero Jaime

Detection and quantification of chemical species in biological levels have been of high interest due to the wide variety of medical conditions, diseases and human being disorders, as cancer, which are associated with the presence or the increase of concentrations of those analytes. In this research, an electrochemical biosensor has been developed using functionalized multi-wall carbon nanotubes (fMWCNT) and decorated with gold nanoparticles (AuNPs) with a size distribution controlled during the chemical synthesis. In this way, an increase in the peak current associated with the redox process is observed when nanoparticles with a small particle size are used. Afterwards, fMWCNT decorated with AuNPs and modified with monoclonal antibodies promote the

bio-recognition, with high selectivity, of the Prostate Specific Antigen (PSA), associated with prostate cancer. Once the inmuno-reaction between antibody and antigen takes place, a decrease in the redox current occurs related with the concentration of the PSA in the sample, given that this inmunocomplex acts as a diffusional barrier to the electrochemical reaction. In this way, it has been possible quantify the concentration of PSA, as an alternative to the current methods for prostate cancer detection.

1.3.8 Micropatterning of solid polymer electrolytes using photolithography

Yong Zhong (1), Giao TM Nguyen (2), Cédric Plesse (2), Frédéric Vidal (2), Edwin W.H. Jager (1),

(1) Sensor And Actuator Systems (SAS), Department Of Physics, Chemistry And Biology (IFM), Linköping University, Linköping, Sweden
(2) Laboratoire De Physicochimie Des Polymères Et Des Interfaces, Institut Des Matériaux, Université De Cergy-Pontoise, Cergy-Pontoise Cedex, France

Presentation given by Mr. Yong Zhong

A solid polymer electrolyte (SPE) is an essential layer of conducting polymer based actuators to allow operation in air. To miniaturize this type of actuators, micropatterns of solid polymer electrolyte are desired. Here we presented a novel type of solid polymer electrolyte that can be patterned with standard photolithography and soft imprinting lithography. The SPE is prepared in situ by UV-initiated free-radical polymerization of thiol-acrylate precursors in the presence of ionic liquid (EMIM TFSI). The resulting SPE film is very flexible with a low Young's modulus (as low as 0.23 MPa) and shows a very high ionic conductivity (up to 2.4×10-3 S/cm with 75wt% ionic liquid incorporated) and has a reactive surface due to the excess thiol groups. Micropatterns of SPE are obtained by using the thiol-acrylate precursors - ionic liquid mixture as an ionic conducting photoresist with standard photolithography. Water, a solvent immiscible with ionic liquid, is used as the photoresist developer to avoid complete removal of ionic liquid from thin solid electrolyte micropatterns. By taking advantage of the reactive surface of solid polymer electrolytes and the photopatternability, SPEs with complex 3D microstructure are developed. The surface of the solid electrolytes can be easily patterned with UV-assisted imprinting lithography. This new type of SPEs opens up for building high-performance solid state microactuators and other electrochemical micro devices.

1.3.9 PPy/DBS films for artificial muscles: Dependency of the mechanical properties with the oxidation state

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

(1) Technical University Of Cartagena
(2) Arquimea Ingenieria

Presentation given by Mr. Victor H. Pascual

Nowadays, many scientists are engaged into a quest to develop biomimetic systems that would allow the growth of a new technological world where man-made devices would reach the full potential of biological organs. The first step to achieve this goal would be finding materials that resemble those originating biological functions in cells. For this purpose, conducting polymers have been widely studied: when they are immersed in an electrolytic solution they become dense reactive gels mimicking the intracellular matrix of functional cells. Under electrochemical reactions they work as dual sensorimotors (sensing-actuator) mimicking haptic muscles. Polypyrrole/dodecylbenzenesulfonate (PPy/DBS) films exhibit this dual behavior. In previous works it has been reported how, through the energy consumed during the driving reaction, the electrochemical reaction detects any change of the electrolyte concentration or temperature during actuation. Now, we report how the mechanical properties of PPy/DBS films display a clear dependence with the oxidation state of the material, the electrogeneration parameters and the film thickness. Those facts could lead to the design of materials with tailor-made mechanical properties to be used in dual sensing-actuator devices such as artificial muscles.

1.3.10 Monolayer saves extra energy required for polymeric artificial muscles

Laura Luz Valero Conzuelo (1) (2), Toribio Fernández Otero (2), Victor Hugo Pascual (2),

(1) Universidad Autónoma Del Estado De México, Engineering School, Toluca, México

(2) Universidad Politécnica De Cartagena, Laboratory Of Electrochemistry, Intelligent Materials And Devices, Cartagena, Spain

Presentation given by Ms. Laura Luz Valero Conzuelo

Conducting polymers allow the development of electrochemical: actuators (motors), sensors and actuators sensing by themselves, the mechanical, thermal or chemical conditions. They are Faradaic motors: the flowing current controls the movement rate and the charge consumed per weight unit of the conducting polymer controls the device displacement. They translate the reaction-driven cooperative conformational movements (molecular motors) of the polymeric chains and the concomitant volume variations into macroscopic movements through bilayer or multilayer bending devices. Here we present a bending monolayer artificial muscle. It presents the highest coulo-dynamic efficiency (mC g-1 per described degree) described at present for artificial muscles. A transversal cross-linking gradient attained during the film electropolymerization is identified as origin of the reaction-driven muscular movement. This monolayer artificial muscle saves extra energy required to bend and trail inactive layers (metal, tape, paper, other polymers) from bilayer or multilayer classical structures, which are required to transduce reaction driven reversible length variations of the conducting polymer film into transversal stress gradients and macroscopic bending movements. The use of bending self-supported films of conducting polymers should decrease the power consumption simplifying the design for tools or robotic applications.

1.3.11 Cooperative Actuation of Asymmetric Bilayer Muscles based on Polypyrrole

Masaki Fuchiwaki (1), Toribio Fernandez Otero (1) (2),

(1) Kyushu Institute Of Technology
(2) Universidad Politcnica De Cartagena

Presentation given by Dr. Masaki Fuchiwaki

Actuators, or artificial muscles, based on conducting polymers (CPs), constitute the base for the development of promising polymeric sensing motors, tools for surgeons, or zoomorphic and anthropomorphic soft robots. They are electrochemical devices; the CP oxidation/reduction drives the exchange of ions

and solvent with the electrolyte causing reversible volume variations and device actuation. Some electrochemical characterizations of these actuators have been already investigated. Moreover, some asymmetric bilayers constituted by two different conducting polymers, CP1/CP2, thus both reactive, have been described. In this study, three bilayer muscles (PPy-ClO4(Lithium perchlorate)/PPy-DBS (dodecyl benzyl sulphonate), PPy-ClO4/tape, and PPy-DBS/tape) are characterized during potential cycling in aqueous solutions. The dynamo-voltammetric (angle vs potential) and coulo-dynamic (charge vs potential) results give the reaction-driven ionic exchanges in each PPy film. Our aim in this work is to investigate the characterization of the three selected bilayer muscles, cooperative and antagonist dynamic effects.

1.3.12 Towards reduced order modeling of hydrogel-based microfluidic systems with flowchart descriptions

Philipp J. Mehner (1), Anthony Beck (1), Martin Elstner (1), Andreas Voigt (1), Uwe Marschner (1), Andreas Richter (1),

(1) Technische Universität Dresden, Institute Of Semiconductors And Microsystems, Chair Of Polymeric Microsystems

Presentation given by Mr. Philipp Mehner

Efficient, high-performance modeling of complex microfluidic systems for biomedical applications is a challenging endeavor because of the high number of interacting multi-field domains. In order to advance microfluidic systems, intrinsically triggered hydrogel-based transistors have been introduced. These transistors use a chemically-triggered hydrogel as a sensor-actuator system to open or close a flow path. For biomedical applications, for example cell preparation, the concentration level and velocity of the fluid effects the cell growth. To effectively develop such complex systems, advanced models are required to predict the behavior and to rapidly design demand-oriented microfluidic systems. To achieve efficiency in simulation, reduced order models are used. Based on experiments and finite element models we propose a reduced-order flowchart model to design microfluidic systems. A hydrogel based microvalve is implemented which automatically distinguishes between a stepped and ramped signal. The focus is laid on an implementation, which requires only the response period of the hydrogel for characterization. Other material parameters are not required to be changed in case of scaling the system.

Furthermore, an example circuit design of a two-valve oscillator will be demonstrated. The results show that the concept of using flowchart descriptions is feasible and will expand the microfluidic design toolboxes.

1.3.13 Soft platforms for objects transportation

Aurora De Acutis (1) (7), Luigi Calabrese (2) (3), Andrea Baù (2), Vinicio Tincani (7), Nicola Maria Pugno (3) (4) (5) (6), Antonio Bicchi (2) (7), Danilo De Rossi (1) (7),

(1) Department Of Information Engineering, University Of Pisa, Via Girolamo Caruso 16, 56122 Pisa, Italy
(2) Research Centre "E. Piaggio", University Of Pisa, Largo Lucio Lazzarino 2, 56122 Pisa, Italy.
(3) Department Of Civil, Environmental And Mechanical Engineering, University Of Trento, Via Mesiano 77, 38123 Trento, Italy.
(4) Laboratory Of Bio-Inspired And Graphene Nanomechanics, Department Of Engineering, University Of Trento, 38123 Trento, Italy
(5) School Of Engineering And Materials Science, Queen Mary University Of London, Mile End Road, E1 4NS London, United Kingdom.
(6) Italian Space Agency, Via Del Politecnico Snc, 00133 Rome, Italy.
(7) Department Of Advanced Robotics, Istituto Italiano Di Tecnologia, Via Morego 30, 16163, Genova, Italy

Presentation given by Mr. Luigi Calabrese

Handling of delicate objects on a horizontal table is a significant task of several productive activities and a challenge for both the robotic industry and research. In this work we present two devices specifically designed to handle round and flat objects respectively, based on the so called "Hydrostatically-Coupled" Dielectric Elastomer Actuators (HC-DEAs). The first device is a soft platform consisting of an array of 5 rectangular shaped actuators specially designed to trigger the rolling of round objects. The second one is a soft platform consisting of multiple bubble-like HC-DEAs to enable flat objects translation and rotation. Experiments were conducted to assess the actuation capability of both platforms. Results showed that round objects were translated with a speed up to 10 mm/s while flat objects were displaced in both translational and rotational directions with a speed respectively of 0.8 mm/s and 0.01 rad/s. Moreover, a preliminary study on the scalability of the presented devices allowed identifying the upper

dimensional limit for the fabrication of such devices.

1.3.14 Water droplet based sensing and vibrational energy harvesting

Graham Allegretto (1), Katelyn Dixon (2), Yuta Dobashi (1), John D.W. Madden (1),

(1) University Of British Columbia, Department Of Electrical And Computer Engineering, Vancouver, Canada
(2) McMaster University, Department Of Physics And Astronomy, Hamilton, Canada

Presentation given by Mr. Graham Allegretto

The emergence of a water-based vibrational energy harvester has recently garnered a lot of attention due to its simplicity and its ability to self-bias. Such a device can be as simple as sandwiching a droplet of water between two electrodes and allowing one electrode to vibrate with respect to the other. The theory of operation is very similar to that of electrostatic energy harvesters wherein mechanical energy is converted to electrical energy by pulling apart the plates of a charged capacitor. The droplet devices however vary capacitance by mechanically changing the interfacial surface area between an electrode and an electrolyte, eliciting a change in the interface's capacitance. They also do not require an external biasing source as charge is supplied via the electrical double layer. Although there has been work demonstrating its operation, there has been little investigation into frequency response. The model that has been developed and presented in literature is also a nonlinear differential equation which is difficult to interpret for optimization purposes. In our work, we demonstrate potentials as high as 500 mV peak-to-peak and show the frequency response of such a system from 0.1 Hz up to 100 Hz. We also present a linearized model that provides a more intuitive understanding of the system and that accurately predicts the point of maximum power transfer.

1.3.15 MnO_2 based micromotor: fabrication, characterization and potential application

Eswaran Murugasen (1), Christian E.Castro-Salazar (1), Jalal Ghilane (1), Hyacinthe Randriamahazaka (1),

(1) Surface-Ionicliquid-ELectrochemistry-Energy(SIELE) Group, ITODYS CNRS UMR -7086, University Paris Diderot, Sorbonne Paris Cite,Paris, France

Presentation given by Mr. Eswaran Murugasen

To fabricate wireless and functional miniature devices, chemically powered self-propelling micromotors are very crucial part. One of the mechanisms behind the self-propulsion is the conversion of chemical energy into mechanical energy which results in movement because of chemical gradient or bubble propulsion at the solid-liquid interface. The viscous forces and the Brownian motion are the main bottlenecks for the propulsion of micro objects in liquid medium. However, this problem can be overcome by careful fabrication and propulsion methods of micromotors. Herein, we report the fabrication of MnO_2 micromotor by electrodeposition over the flexible nickel substrate coated with PANI. The flexible nickel substrate was prepared by polymer assisted metal deposition of nickel on Nafion. PANI was coated upon the flexible nickel substrate by electropolymerization process. Thus prepared MnO_2 micromotors show wireless, autonomous self-propulsion in H_2O_2 containing solution due to the bubble propulsion mechanism. In this presentation, the detailed fabrication procedure of MnO_2 micromotor will be given and the different surface characterization will be discussed. The rate of movement of the micromotor can be tuned by varying the concentration of H_2O_2 fuel and the shape (circular, square and rectangular) of the micromotor. This kind of property will pave the way for the application towards chemotaxis.

1.3.16 Precise tip positioning of self-sensing polymeric actuators

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

(1) Arquimea Ingeniería, R&D Department, Leganes, Spain
(2) Technical University Of Cartagena, Laboratory Of Electrochemistry And Intelligent Materials, Cartagena, Spain

Presentation given by Ms. Johanna Schumacher

Bending self-sensing actuators based on electroactive polymers are driven by reversible redox reactions of the constitutive material. These actuators enable

silent bioinspired propulsion while sensing the available physical and chemical energy of their surroundings. The operation at low currents and potentials results in low energy consumption. The actuator's tip position during cyclic movements is controlled by the consumed charge during oxidation and reduction: faradaic control. A major drawback for a precise position control is the presence of dynamic hysteresis effects due to a delayed exchange of solvent molecules for osmotic balance exchange following the faradaic ionic exchanges. The dynamic hysteresis effects of polypyrrole-dodecylbenzenesulfonate (PPyDBS) actuators when submitted to square current waves were studied and analysed under ambient working conditions with the aim to develop an enhanced position control for future applications. A hysteresis model based on the experimental data was derived and experimentally verified.

1.3.17 Polypyrrole distributed actuators based on electrospun micro-ribbons

Alexandru Evanghelidis (1) (2), Mihaela Beregoi (1) (3), Victor Diculescu (1), Ionut Enculescu (1),

(1) National Institute Of Materials Physics, Multifunctional Materials And Structures Laboratory, Magurele, Romania
(2) University Of Bucharest, Bucharest, Romania
(3) Polytechnic University Of Bucharest, Faculty Of Applied Chemistry And Materials Science, Department Of Bioresources And Polymer Science, Advanced Polymer Materials Group, Bucharest, Romania

Presentation given by Mr. Alexandru Evanghelidis

Electroactive polymer (EAP) actuators are often presented as "artificial muscles", mainly due to their flexibility, but also because they have a similar mechanism of actuation, by contracting and swelling. A further step towards a true biomimetic actuator can be the use of a fibrillar scaffold for the EAP, thus simulating biological muscle. Electrospun nanofibers are great candidates for this role. Electrospinning is a simple, inexpensive method through which large quantities of polymeric fibers with submicronic diameters can be fabricated. With the deposition of a thin metallic layer, these can become conductive and usable as electrodes for the electrochemical deposition of an EAP. By manipulating process parameters, electrospinning can also be used to create flattened fibers, or ribbons, as well as to obtain varying degrees of anisotropy in

the resulting web. In this work, Nylon 6,6 micro-ribbons were electrospun into an aligned mesh, covered with a layer of gold and then polypyrrole was electrodeposited on them. This mesh can be thought of as a distributed actuator, with each individual ribbon behaving as a bilayer actuator. Actuation tests show excellent response times, probably thanks to the large aspect and surface-to-volume ratios of the ribbons, as well as complex, although sometimes unpredictable, movement patterns. Such distributed micro-actuators could prove useful in many fields, from biomedicine to micro-robotics.

1.3.18 Actuators based on polyaniline coated electrospun fibers nets

Mihaela Beregoi (1) (2), Alexandru Evanghelidis (1) (3), Elena Matei (1), Ionut Enculescu (1),

(1) National Institute Of Materials Physics, Functional Nanostructures Group, Magurele, Ilfov, Romania
(2) University Politehnica Of Bucharest, Faculty Of Applied Chemistry And Materials Science, Department Of Bioresources And Polymer Science, Advanced Polymer Materials Group, Bucharest, Romania
(3) University Of Bucharest, Faculty Of Physics, Magurele, Ilfov, Romania

Presentation given by Ms. Mihaela Beregoi

Conducting polymers used in manufacturing soft actuators present many benefits namely the facility of synthesize, great mechanical properties achieved by applying low voltages and fast response time. In the past years, some actuator configurations have been reported starting with bilayered/trilayered actuators using adhesive tapes, porous membranes which present improved actuation properties than classical films, but there are also several reports regarding the fabrication of actuators using fibers or tubes. Hence, the morphological aspects of the fabricated materials are very important because these characteristics will ascertain the final actuator properties. In this work, we propose a new strategy for obtaining electroactive materials with different morphologies by using one of the most investigated conducting polymers, polyaniline. Thus, by using electrospinning as preparation technique, poly(methyl methacrylate) fibers were reproducibly fabricated. Likewise, the poly(methyl methacrylate) fibers were employed as templates for obtaining well-shaped microtubes, by removing the poly(methyl methacrylate) fiber core with a commonly solvent. The free-standing electroactive fiber/tubes mats were morphological and electrochemical

characterized. The obtained configurations present fast response time by applying low voltages, using even biocompatible electrolytes like simulated gastric fluids.

1.3.19 All solid-state ionic actuators based on a polymeric ionic-liquid and electronic conducting polymers

Frederic B. Ribeiro (1), Cedric Plesse (1), Giao T.M. Nguyen (1), Sofia M. Morozova (2), Eric Drockenmuller (3), Alexander S. Shaplov (2) (4), Frederic Vidal (1),

(1) Université De Cergy-Pontoise, Laboratoire De Physico-chimie Des Polymères Et Des Interfaces (LPPI), Cergy, France
(2) A.N. Nesmeyanov Institute Of Organoelement Compounds Russian Academy Of Sciences (INEOS RAS), Moscow, Russia
(3) Université Lyon 1, Ingénierie Des Matériaux Polymères (IMP, UMR CNRS 5223), Lyon, France
(4) Luxembourg Institute Of Science And Technology (LIST), Esch-sur-Alzette, Luxembourg

Presentation given by Mr. Frédéric Ribeiro

Ionic-based actuators have interested numerous research groups all over the world since they represent promising active materials to elaborate biomimetic actuators and sensors. These actuators are usually built in a configuration where the internal layer is a solid polymer electrolyte (SPE) sandwiched between two electronic conducting polymer (ECP) layers. These electro-active polymers (EAP) are based on ECP volume change generated by the ions expulsion/insertion motion during the redox process. In 2011, IEMN and LPPI have produced very thin (10 µm) micro-actuators using microsystem process (photolithography, reactive ion etching). However, this method involves manipulation steps, in particular, the final one where an exogenous electrolyte is incorporated by swelling which becomes tricky at microscale. Here we propose to use a polymeric ionic-liquid (PIL) instead of an exogenous electrolyte. PILs are a new class of polyelectrolytes that has recently attracted considerable attention due to the combination of properties both from ionic liquids and polymers. In this work trilayer configuration actuators have been obtained with a PIL as internal SPE layer and a composite ECP/PIL as electrodes. Two ECP, PEDOT and PPy, have been investigated by vapor phase polymerization. The

thickness and the electronic conductivity of the electrodes were characterized regarding the synthesis conditions and the free strain of truly all-solid-state actuators was investigated and will be presented.

1.3.20 Motion control of a polymeric artificial muscle

Francisco García-Córdova (1), Toribio F. Otero (2), Antonio Guerrero-González (3) and Laura Valero (2,4)

(1) Universidad Politécnica de Cartagena, Department of Thermal and Fluid Engineering, 30203, Cartagena, Spain;
(2) Universidad Politécnica de Cartagena, Laboratory of Electrochemistry, Intelligent Materials and Devices, 30203, Cartagena, Spain; (3) Universidad Politécnica de Cartagena, Department of System Engineering and Automation, 30203, Cartagena, Spain; (4) Universidad Autónoma del Estado de México, Engineering School, Toluca 50000 México.

Interest in bio-inspired robotic applications of electroactive materials has expanded rapidly, received significant attention due to the development of novel materials and actuators which macroscopic and microscopic behaviour replicate those from natural muscles. Conjugated polymers have extraordinary electrochemomechanical properties such as simultaneous sensing and actuation replicating the characteristic bifunctionality from natural muscles. Unfortunatelly they present a low efficiency and compliance. Simultaneously they present some uncertain time dependent electro-chemo-mechanical dynamics, making accurate control of the actuator difficult. In this work, we present the sensing characteristics of bending pPy-DBS/tape/pPy-DBS trilayer artificial muscle as a function of electrolyte concentration, working temperature and driving current using lithium perchlorate (LiClO4) aqueous solution as electrolyte. A novel motion control for the bending trilayer artificial muscle was developed using a cortico-spinal network within constraints from neurophysiology and motor psychophysics. The neural-controller sends agonist and antagonist activation signals to each of the pPY-DBS layers of the artificial muscle for motion control. In addition, the reliability of the cortico-spinal controller is demonstrated by experimental results, where control system exhibits key kinematic properties of human movement, and dynamic compensation.

Session 1.4

EuroEAP Society Challenge Projects
(listed in the order of presentation)

N.	Project title	Last Name	First Name	Institution
1.	A 4x4 matrix of DEAs addressed with flexible high-voltage thin-film transistors	Marette	Alexis	École polytechnique fédérale de Lausanne (EPFL)
2.	DEAth-ray	Ghilardi	Michele	Queen Mary University of London
3.	Development of a vibratory conveyor	Hau	Steffen	Saarland University
4.	Smart body kinematics monitoring	Frediani	Gabriele	Queen Mary University of London
5.	Speedy BOT	Calabrese	Luigi	Università degli Studi di Trento (Unitn)
6.	Twisted and Coiled Polymer Muscles in action.	Van de Kamp	Cornelis	Delft University of Tehcnology (TUDelft)

Session 1.5

(abstracts are listed in the order of presentation)

1.5.1 Soft microorigami - self-folding stimuli-responsive polymer films and fibers

Leonid Ionov (1),

(1) College Of Engineering, College Of Family And Consumer Sciences, University Of Georgia, Athens, GA 30602, USA

Presentation given by Prof. Leonid Ionov

Nature offers an enormous arsenal of ideas for the design of novel materials with superior properties and interesting behaviors. In particular, self-assembly and self-organization, which are fundamental to structure formation in nature, attract significant interest as promising concepts for the design of intelligent materials. Self-folding stimuli-responsive polymers are exemplary biomimetic materials and can be viewed as model systems for bioinspired actuation. Such polymeric objects, on one hand, mimic movement mechanisms in certain plant organs and, on the other hand, are able to self-organize and form complex 3D structures. These self-folding objects consist of two polymers with different properties and one of these polymers, the active one, must change its volume more than the other one in response to changes in the external signals such as temperature, pH or light. Because of this non-equal expansion of polymers, bilayer films are able, for example, to form tubes, capsules or more complex structures. Similar to origami, the self-folding polymeric films provide unique possibilities for the straightforward fabrication of highly complex 3D micro-structures with patterned inner and outer walls that cannot be achieved using other currently available technologies. In this contribution, we demonstrate that the external shape of polymer bicomponent systems is able to direct their folding in a sophisticated manner leading to highly complex hierarchical folding.

1.5.2 Conducting polymer thin films: soft actuators/sensors in biorobotics and ultraconformable skin contact interfaces for bioelectronics

Francesco Greco (1) (2),

(1) Istituto Italiano Di Tecnologia, Center For Micro-BioRobotics, Pontedera, Italy
(2) Waseda University, School Of Advanced Science And Engineering, Tokyo, Japan

Presentation given by Dr. Francesco Greco

Conjugated polymers, with their unique combination of tunable functional properties, offer several possibilities for the development of novel smart and active materials with applications in micro and biorobotics, as well as in biomedicine. In particular, poly(3,4-ethylenedioxythiophene) : polystyrene sulfonate (PEDOT:PSS), due to its availability as a waterborne dispersion, is amenable to several deposition and fabrication processes onto various substrates. Thanks to these features, by combining PEDOT:PSS thin films with other passive or active polymer layers it is possible to investigate new paradigms for soft actuation/sensing as well as to develop new biointerfaces. In this presentation I review some recent researches of my groups on: I) Smart (electro)active materials for actuators/sensors; II) conducting polymer nanosheets / ultraconformable skin-contact electrodes and organic electronics. First, I report about bilayer actuators at different scales/thicknesses in which PEDOT:PSS was used in combination with other polymers and with several different fabrication and patterning techniques. Then, conducting polymer free-standing nanosheets prepared by spin-coating or R2R techniques and inkjet-printed temporary tattoo electrodes are introduced.

1.5.3 Polypyrrole and carbide-derived carbon actuators

Zane Zondaka (1) (2), Edwin W.H. Jager (2), Yong Zhong (2), Rudolf Kiefer (1), Tarmo Tamm (1), Alvo Aabloo (1),

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

Presentation given by Ms. Zane Zondaka

Conducting polymer-based actuators show good displacement and actuation. The most commonly used polymer in the field of actuation is polypyrrole (PPy). The addition of carbon-based materials (e.g. carbide-derived carbon(CDC)), thus creating composite materials, may improve the performance of PPy based actuators. Here we present our research on a composite material consisting of polypyrrole and embedded carbide-derived carbon particles. The PPy-CDC composite material was synthesized electrochemically with the addition of polyoxometalate. We have investigated the linear actuation properties: stress and strain of the composite material. Compared to doped PPy, the composite material has shown higher strain (12%) and stress (0.6MPa). To evaluate using these composite materials in microscale devices such as microactuators we have microfabricated and tested PPy-CDC composite material based devices at the microscale. We incorporated these novel composite materials in in-house developed microfabrication process based on photolithography enabling patterning of PPy-CDC. The composite material based microactuators show bending while actuated under 1V in an aqueous electrolyte solution. The PPy-CDC microactuators were compared to PPy microactuators and both actuators showed comparable actuation.

Session 1.6
(abstracts are listed in the order of presentation)

1.6.1 Dielectric elastomer loudspeaker driver

Petko Bakardjiev (1), Andreas Richter (1), Uwe Marschner (1), Ercan Altinsoy (2), Jan Troge (3),
(1) Technische Universität Dresden, Institute Of Semiconductors And Microsystems / Chair Of Polymeric Microsystems, Dresden, Germany
(2) Technische Universität Dresden, Institute Of Acoustics And Speechcommunications/ Chair
Of Acoustics And Haptics, Dresden, Germany
(3) Fraunhofer Institute For Machine Tools And Forming Technology, Acoustics And Structural
Dynamics, Dresden, Germany

Presentation given by Mr. Petko Bakardjiev

Dielectric Elastomers (DE) offer promising benefits for acoustic applications due to their large achievable strain, high energy density and small response time. Although the usage for loudspeakers is often mentioned, only few concepts have been developed and realized. Most prominent are speakers based on vibrating DE-diaphragms. However, these speakers are not competitive to conventional electrodynamic speakers so far. The main reason is their inability to produce significantly large sound pressure levels due to their low mechanical and acoustical impedance. We investigate and realize an alternative approach to loudspeakers based on DE. The driving unit of the speaker is a core-free rolled DE-actuator with improved electrical contacts for optimized frequency response and reliability. An electromechanical network model is designed to describe the actuator's dynamic behavior. The network parameters are determined by extensive measurements with different mechanical loads and bias voltages. The model is extended to the acoustical domain introducing a speaker cone and enclosure. Due to the gyratory behavior of the radiating surface the mechanical behavior can be transformed to maximize the sound power output. This approach allows the realization of DE-based speakers for a versatile range of applications with many benefits to conventional concepts.

1.6.2 Optimization of planar hydrogel-based micro-valves and -diodes for flow control

Anthony Beck (1), Philipp J. Mehner (1), Georgi Paschew (1), Martin Elstner (1), Andreas Richter (1),

(1) TU Dresden, Institute Of Semiconductors And Microsystems, Dresden, Germany

Presentation given by Mr. Anthony Beck

A successful miniaturization and commercialization of fully integrated microfluidic systems are still under development due to the lack of reliable microfluidic components. For example, feasible micro-valves concepts have been demonstrated and show a promising potential for high integration lab-on-chip applications. Due to the high range of synthesis procedures, design parameters and the underdevelopment of reproducible hydrogel based microfluidic components, the high integration of hydrogels still cannot accomplish the expectations which were made by many researches. We propose a reliable, systematic investigation of processing an electrothermal triggered, hydrogel-based micro-actuator to control on-chip flow by microfluidic components i.e. transistor-like microfluidic valves. Experimentally, the channel shapes, number and geometry of hydrogels have been evaluated to improve performance parameters. Furthermore, different MEMS compatible manufacturing techniques are assessed for next step miniaturisation. Additional modifications allow the development of one-directional micro structures with a diode-like behavior. Computer aided models describe physical design parameters which are implemented in the current concepts. The proposed designs improve the valve response time and break through pressures of up to 1 bar and formulate new design rules for next generation high integrable microfluidic components.

1.6.3 Functionalized silicones showing giant actuation strains

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

(1) Petru Poni Institute Of Macromolecular Chemitry

Presentation given by Mr. Adrian Bele

Among different strategies to improve the properties of silicones as Electroactive Polymers for artificial muscles, chemical modification seems to be the most promising one due to some advantages such as no compatibility issues, the possibility of limiting phase separation by properly managing the distribution of polar groups, or low stiffness. The main drawbacks regarding this strategy is the high dielectric loss and low breakdown strength which appear when polar entities are introduced. The main aim of this study is to improve the electromechanical behavior without inherently diminish properties of interest. Thus, two home-prepared hydroxyl ended poly(dimethyl-co-methylvinyl)siloxanes, having approximately the same molecular mass but different percentage of vinyl groups, were chemically modified via thiol-ene "click" reactions with 3-chloro-1-propanethiol. The resulted polar silicones were cross-linked by condensation reactions obtaining soft elastomers, which exhibited giant actuation strains, up to 80 % at 45 MV per metre.

1.6.4 Dielectric elastomer compression sensors for new operation elements

Holger Böse (1), Johannes Ehrlich (1),

(1) Fraunhofer-Institut Für Silicatforschung ISC, Center Smart Materials (CeSMa), Würzburg, Germany

Presentation given by Dr. Holger Böse

Dielectric elastomer sensors with high sensitivity for compression load were developed recently. The basic design of the sensors exhibits two profiled surfaces between which an elastomer film with an inner electrode layer is located. Depending on details of the sensor design, various effects contribute to the enhancement of the capacitance. The intermediate elastomer film is stretched and electrode layers on the elastomer profiles and in the intermediate elastomer film approach each other upon compression. Besides the detection of pressure in various environments, such dielectric elastomer compression sensors can also be used for operation elements in man-machine interfaces. This is demonstrated with three examples. First, a touch pad with six pressure-sensitive fields is presented. The corresponding sensors in the touch fields detect the forces exerted by the finger and display them in terms of the measured capacitances on a screen. Moreover, the brightness of LEDs is controlled by the strength of the

finger force. Second, the integration of sensor-based control fields on an automotive steering wheel is shown. Here, the sensor signals are capable to control sound, brightness, heating and ventilation. Third, the compression sensors can be used in fabrics to control electronic devices such as smartphone or MP3 player. These examples demonstrate the high performance of the dielectric elastomer compression sensor technology for novel operation elements.

1.6.5 Dielectric elastomer actuator-based wearable soft tactile displays with improved design

Hugh Boys (1) (2), Gabriele Frediani (2), Stefan Poslad (1), James Busfield (2), Federico Carpi (3),

(1) Queen Mary University Of London, School Of Electronic Engineering And Computer Science,
London, UK
(2) Queen Mary University Of London, School Of Engineering & Materials Science, London, UK
(3) University Of Florence, Department Of Industrial Engineering, Florence, Italy

Presentation given by Mr. Hugh Boys

Dielectric Elastomer Actuators (DEA's) are a promising actuation technology for wearable tactile haptic displays. In particular, Hydrostatically Coupled (HC)-DEA's offer a safe configuration in order to separate the user from the high voltage components of a DEA device. It achieves this by coupling a passive touchable membrane with an active high voltage membrane through an incompressible and electrically insulating gel. In effect, this configuration enables the safe application of electronically controlled tuneable forces, delivered through a soft deformable bubble-like interface. In this work, the role of different design parameters of HC-DEA's was investigated, for the sake of increasing the actuation stroke and force. The explored parameters were the thickness and base diameter of the dome-shaped constitutive membranes and the volume of the coupling gel. In addition, we present a multi-layer approach to obtain an improved active membrane allowing for significantly higher passive forces to be generated, i.e. a higher stiffness to be achieved, without increasing the driving voltages needed to obtain the same stroke.

1.6.6 High permittivity silicones with large actuation strains for dielectric elastomer actuators

Philip Caspari (1) (2), Simon Duenki (1) (2), Yauhen Sheima (1), Frank Nueesch (1) (2), Dorina M. Opris (1),

(1) Empa-Swiss Federal Laboratories For Materials Science And Technology, Duebendorf,
Switzerland
(2) École Polytechnique Fédérale De Lausanne (EPFL), Institute Of Materials, Lausanne,
Switzerland

Presentation given by Mr. Philip Caspari

The technology of dielectric elastomer actuators requires materials with excellent elastic properties and high dielectric permittivity. Commercially available silicone elastomers (e.g. PDMS) show excellent elastic and dielectric properties but suffer from a low permittivity. We synthesized high permittivity silicone based elastomers which are a promising alternative to PDMS. They are prepared via post-polymerization modification of a high molecular weight polymethylvinylsiloxane using thiol-ene click chemistry leading to thioether and cyano-functionalized polymers. Thin elastic films were prepared by either using a tin catalyzed condensation reaction or a thiol-ene click photoaddition reaction, respec-tively. Both approaches allowed preparation of silicones with well-balanced dielectric and mechanical properties. The thickness of the silicone films can be tuned from 100 microm to 20 microm using doc-tor blade techniques. Actuators show lateral actuation strains of more than 25% at an electric field of 24 V/microm and reached lifetimes of over 50.000 cycles (2Hz) with a constant actuation strain of 10%. The impact of thioether and cyano side groups on the elastic modulus and viscoelasticity, permittivity, conductivity, dielectric breakdown and actuation strain of the silicone films will be presented in detail

1.6.7 Polysiloxane-polyimide semi-interpenetrated networks with dual electromechanical response

Maria Cazacu (1), Codrin Tugui (1), Adrian Bele (1), Elena Hamciuc (1),

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

Presentation given by Dr. Maria Cazacu

As it is known, silicones are one of the promising classes of dielectric elastomers, which fulfil most of the performance criteria required for electromechanical applications (high deformability, energy density and coupling efficiency, low viscoelastic loss). In addition, they are able to operate in a wide range of temperature and humidity without significant alteration of their properties. However, silicones have low dielectric permittivity requiring relatively large voltages to be actuated and limiting the harvesting ability of the converters based on them. To improve this feature, different strategies are tried, most of which consist in chemical modification of silicones or in developing new formulations based on them. One approach is to build mixed networks of silicones with more polar polymers. Due to their excellent thermal, mechanical and dielectric properties, aromatic polyimides have so far generated, among others, a particular interest in the development of high temperature piezoelectric sensors and microelectromechanical devices. In the present study, the properties of polysiloxanes were combined with those of some polyimides within a highly sensitive material able to develop a large actuation strain and very good piezo-response. Polyimide derivatives functionalized with polar cyanide groups but also containing siloxane sequence along the chain to assure compatibility with silicone counterpart were used.

1.6.8 Tuneable Optical Transmission Devices Based on Dielectric Elastomer Actuators

Leihao Chen (1), Federico Carpi (2), James Busfield (1),

(1) Queen Mary University Of London, School Of Engineering And Materials Science, London, UK
(2) University Of Florence, Department Of Industrial Engineering, Florence, Italy

Presentation given by Mr. Leihao Chen

The applications of dielectric elastomer actuators (DEAs) for tuneable optics

have been under development with significant expected impact. Here, devices with variable optical transmission are fabricated based on planar DEAs made of transparent DE films and nearly transparent electrodes. They are capable of reversibly controlling light transmittance by electrically altering the surface roughness of DEAs. In particular, according to a principle of operation already described in the literature, light is scattered from actuator surfaces that are intentionally made crumpled, so that voltage-induced expansion flattens the active part and increases optical transmission. In this work, three types of transparent electrodes were tested for a validation of tuneable transmittance. It was found that polyacrylamide hydrogels containing LiCl were too hydrophobic to properly bond with acrylic films used as DEs and tended to shrink in open air. Silver nanowires (AgNW) on acrylic films were able to electrically tune the transmittance at 550 nm between 47% and 63%, although brownish AgNW scattered light even on the flat surfaces. In comparison, PMMA-embedded ionogels on silicone films offered relatively good transparency, with transmission tuning range between 83% and 92%. However, the ionogels were not durable as they gradually reacted with DE phase and impaired the actuation performance. Further studies are necessary to identify optimal electrode materials for tuneable optical transmission.

1.6.9 Heterogeneous bimodal condensation silicone networks as dielectric elastomers

Valeria Chiaula (1), Liyun Yu (1), Anne Ladegaard Skov (1),

(1) DTU Chemical Engineering – DPC

Presentation given by Ms. Valeria Chiaula

Ideal DEs are characterized by high extensibility, flexibility and good mechanical fatigue, as well as high electrical and mechanical breakdown strengths. Unimodal networks, where unimodal refers to that there is one polymer only in the system, make up the majority of model elastomers. Practically an end-linking process using a cross-linker with a certain functionality f and a linear polymer with functional groups in both ends is used to prepare aforementioned systems. As an alternative to unimodal networks, two polymers with significantly different molecular weights can be mixed together. The resulting networks are so-called bimodal networks. Bimodal networks can be created in one-step procedure by the random distribution of short polymer

chains within the long chains (homogeneous distribution), or as heavily cross-linked short chain domains joined the long-chain network in two-step procedures (heterogeneous bimodal networks). In this work, various heterogeneous bimodal condensation silicone elastomers were prepared by mixing long PDMS chains and short PDMS chains in different mass ratios, in order to formulate thin film networks characterized by regions with high cross-linking density. Such elastomers were evaluated by their rheology, dielectric properties, tensile strength, electrical breakdown and thermal stability. In addition, the curing conditions were optimized, taking into account the dependency of the dielectric and mechanical properties on the humidity level.

1.6.10 A bioreactor using a porous EAP actuator as a physiological-like interface for cell culture studies

Joana Costa (1) (2), Marta Feula (1), Daniele Cei (2), Arti Ahluwalia (1),

(1) Research Center "E.Piaggio" And Department Of Information Engineering, Pisa, Italy
(2) IVTech Srl, Pisa, Italy

Presentation given by Dr. Joana Costa

Physiological interfaces in the human body are characterized by dynamic conditions, exposing epithelial cell barriers to continuous mechanical stimuli. This study focuses on the development of a system for cell deformation using EAP (Electro Active Polymer) technology. Ultimately, the device will be used to develop a realistic in vitro model of different biological interfaces. Our proposal is a DEA (dielectric elastomer) composed of a VHB membrane cast on a rigid frame sandwiched between annular compliant electrodes, thus creating a central passive area dedicated for the cell culture. The area for the cell seeding should be porous to allow the creation of an interface across which substances can permeate. This work presents an approach to create pores on the actuator, rendering the system a two-compartment device. The method consists of using an array of microneedles obtained by chemical etching to physically puncture the VHB membrane set up on a micropositioner, creating micro pores. Imaging, permeability data and actuation results indicate that it is possible to create a functional porous actuator capable of being integrated in the bioreactor.

1.6.11 Powering electro active polymer generators with a constant voltage concept using passive components

Johannes Ehrlich (1), Alexander Görk (1), Dr. Bernhard Brunner (1),

(1) Fraunhofer Insitut Für Silicatforschung, Center Smart Materils, Würzburg, Germany

Presentation given by Mr. Johannes Ehrlich

This work investigates a passive concept powering electro active polymer generators with a constant voltage concept. The generator is powered with a fixed voltage and the energy flow direction is determined with passive standard diode arrays toward to a storage capacitor. Standard Si, Schotky and a new generation of SiC diodes are compared against each other their performance in the constant voltage system. For laboratory tests a standard electro active polymer generator made of silicon polymer with a capacity of 1.2 nF in a drum shaped geometry is used. During the cyclic operation of the electro active polymer generator, charge is pumped from the generator to the storage capacity. This results in a higher amount of charge in the storage capacity and an increased voltage, the energy content of the storage capacitor increases. The diode arrangement prevents a charge flow backwards from the storage capacitor to the generator. With this arrangement, the voltage of the storage capacitor increases from 2 kV to 3.5 kV after 1200 seconds of cyclic operation. To summarize the work, the harvested energy of the system, with two different types of diodes where compared regarding the surface stretch, and the initial voltage. A positive energy of about 16mJ per cycle after eliminating all losses and the initial energy of the system was observed. The use of a new generation of SIC diodes with high blocking voltages and very low reverse currents is recommended.

1.6.12 Influence of silicone oil content in electrodes on longevity of dielectric elastomer transducers (DET)

Bettina Fasolt (1), Stefan Seelecke (1) (2),

(1) Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Saarbrücken, Germany
(2) Department Of Systems Engineering, Department Of Material Science And

Engineering,
Saarland University, Saarbrücken, Germany

Presentation given by Ms. Bettina Fasolt

Longevity is an important factor for dielectric elastomer transducers (DET), especially where locations are remote and accessibility limited. One parameter which can influence the durability of the DE is the electrode. The electrode material used in the fabrication process for DETs is often composed of carbon grease (carbon black with silicone oil), carbon black in polydimethylsiloxan (PDMS), or a mixture of all three. During experiments with DE actuators it was observed that the electrical resistance increased over time not only in actuated samples but also in previously unused ones. This work investigates the influence of the silicone oil content on actuator and sensor performance of DETs over a period of 3 months. First, three silicone oils with different viscosities are applied to a silicone thin film and any effect on the film is recorded in photographs. Subsequently, DETs are manufactured with electrodes containing 0, 13, and 26 wt-% oil, using the oil with the lowest impact on the silicone film. The samples are tested 5 times over a period of 90 days, and the resistance is recorded in unstretched and stretched conditions. Additionally, voltage is applied under the same conditions and force is measured. After 90 days, the previously unused samples were measured in the same way to evaluate the aging of the sample due to repeated testing.

1.6.13 Electrochemical relaxation of aged poly(o-toluidine) films investigated by spectroelectrogravimetry

Amparo Ferrer (1), Alejandro Cuenca (1), Jerónimo Agrisuelas (1), Jose Juan García (1), Francisco Vicente (1),

(1) Universitat De València, Departament De Química Física, València, España

Presentation given by Ms. Amparo Ferrer Vilanova

Conducting polymers are being extensively studied due to its interesting applications in various technologically important devices such as batteries, smart windows, smart membranes, artificial muscles, nervous interfaces, or drug delivery systems. Structural changes such as conformational movements of polymeric chains during the electrochemical reactions take place with the

exchange of ions and solvent between the film and the solution. One of the most interesting features of conducting polymers occurs when these materials are electrochemically maintained for some time in the reduced state (ageing). In this work, the relaxation process induced by cyclic voltammetry of aged poly(o-toluidine) films (POT) was investigated by implemented electrochemical, gravimetric and Vis-NIR spectroscopic techniques. The information provided by these techniques allows the evolution of exchange of species and electrochromic centers induced by electrochemical relaxation to be studied. The exchange of protons and anions are associated to the formation of two different polaronic centers in POT films. Ageing time affect the electrochemical, electrochromic and electrogravimetric response of POT.

1.6.14 Electrically adjustable microcavity based on PDMS gel for tunable laser sources

Markus Franke (1), Irma Slowik (2), Philipp J. Mehner (1), Georgi Paschew (1), Andreas Voigt (1), Matthias Ploetner (1), Hartmut Froeb (2), Karl Leo (2), Andreas Richter (1),

(1) Institute Of Semiconductors And Microsystems (IHM), Technical University Of Dresden, Dresden, Germany
(2) Dresden Integrated Center For Applied Physics And Photonic Materials (IAPP) Institute For Applied Physics, Technical University Of Dresden, Dresden, Germany

Presentation given by Mr. Markus Franke

Tunable laser sources based on electrically tunable microcavities are essential elements for modern telecommunication and spectroscopy. Most realized device concepts consist of microelectromechanical systems that exhibit an air gap and suffer from extensive processing e.g. photolithography and etching. We demonstrate an easy fabricable, multi-half wavelength, Fabry-Pérot microcavity with an integrated dielectric elastomer actuator. The microcavity is able to tune electrically the cavity resonance by varying the physical cavity thickness through electrostriction of an ultra-soft PDMS gel. The device is realized by a multi-stack layer with PDMS gel as cavity layer sealed by a dielectric Bragg reflector as bottom mirror and a flexible silver layer on top acting as mirror and electrode. Additionally, we embed a pyrromethene dye into the PDMS gel matrix to show efficient gain medium integration. Hereby, we achieve a 40 nm

tuning range of the emission wavelength, which corresponds to a cavity thickness change of 1.3 microm. We further study the deformation behavior of the top silver mirror, which is highly depending on lateral structuring, by measurement and in-depth simulation with finite elements method. Finally, the dynamic actuation behavior of the microcavity is characterized by capacitance measurement and rheological model. Due to the simple, cost-efficient design and compact dye integration, our new laser concept offers a diverse application range for tunable laser sources.

1.6.15 Human body joint angle monitoring with a wearable dielectric elastomer stretch sensor

Gabriele Frediani (1), Maria Pasquini (2), Filippo Gerli (2), Laura Fabbri (2), Silvia Pancani (2), Vannetti Federica (2), Federico Carpi (3),

(1) School Of Engineering And Material Science, Queen Mary University Of London, London, UK
(2) Don Carlo Gnocchi Foundation, Firenze, Italy
(3) University Of Florence, Department Of Industrial Engineering, Florence, Italy

Presentation given by Dr. Gabriele Frediani

Analysing human body kinematics is of fundamental relevance in several biomedical disciplines.The measurement of kinematic variables of human movements is generally performed by employing accelerometers, electrogoniometers, electromagnetic sensors or cameras. These kinds of systems are usually bulky, can cause discomfort to the patient or require expensive devices. Here we present preliminary data on the study of dielectric elastomer (DE) capacitive stretch sensors as a competitive technology with respect to state-of-the-art systems. Their properties are considered particularly advantageous to enable wearable and cost-effective devices for continuous monitoring. With the aim of assessing the capabilities of such sensors for real-time monitoring of body joint angles, measurements performed using a commercial DE linear sensor mounted on the knee were compared with the knee angle detected by means of a conventional optoelectronic motion capture system routinely used in the clinical practice. Preliminary results show a good correlation between the knee angles assessed via the two systems, suggesting that wearable DE sensors can be as equally significant as marker-based external

optical tracking systems, at least for specific uses. Nevertheless, additional future tests are necessary to assess the full potential of this technology, especially in terms of repeatability of the measures, the response for different body conformations, and the effect of the sensor's positioning.

1.6.16 Double cone dielectric elastomer actuator-driven positioning system

Michele Ghilardi (1) (2), Hugh Boys (3), James Busfield (1) (2), Federico Carpi (4),

(1) School Of Engineering And Material Science, Queen Mary University Of London, UK
(2) Materials Research Institute, Queen Mary University Of London, UK
(3) School Of Electronic Engineering And Computer Science, Queen Mary University Of London, London, UK
(4) Department Of Industrial Engineering, University Of Florence, Italy

Presentation given by Mr. Michele Ghilardi

Dielectric Elastomer Actuators (DEAs) are emerging as a class of electromechanical transducers capable of undergoing large actuation strokes and performance not attainable with conventional transduction technologies. Several studies have been done on DEA-driven positioning systems. Here, we report on an investigation on a multiple degrees-of-freedom positioning system based on double cone DEAs coupled in an antagonist configuration without any strut. In this preliminary study we manufactured a first prototype of the proposed system and used it to control the pointing direction of a laser source attached to it. Future work will be dedicated to improving the system performance and embedding DEA-based active optical components to it.

1.6.17 Silicone based dielectric elastomer strip actuators coupled with non-linear biasing elements for large actuation strains

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

(1) Saarland University

Presentation given by Mr. Steffen Hau

Dielectric elastomers actuators (DEAs) technology enables the design of lightweight, energy efficient, and scalable actuators. There are two types of DEAs, which differ from the way in which the actuation is generated: stack DEAs, using the thickness compression, and membrane DEAs, which exploit the expansion in area. In this work we focus on a special type of membrane DEA, i.e., a silicon-based strip-in-plane (SIP) DEA with screen printed electrodes. Two opposite sides of the strip are constraint by screen printed solid frames used as mechanical terminations, while the other two sides are free to move. The performance of such actuators strongly depends on their geometry and the biasing system used. In literature, the biasing is normally based on elastomer pre-stretch or a dead load only, which results in fairly low actuation strain. This work aims at improving performance of SIP-DEAs via an optimal design of the biasing system. At first, these SIP-DEAs are characterized under electrical and mechanical load. Afterwards, two actuator systems are studied and compared in terms of actuation strain and speed. At a first design stage the SIP-DEA is coupled with a linear spring, while the second one uses for biasing a combination of linear and non-linear spring (working in a negative stiffness region). The influence of stacking several SIP-DEAs is studied, too. A maximum speed of 0.33 meter per second and an actuation strain of up to 44 % (11.1 millimeter) are measured

1.6.18 Iron oxide nanoparticles as fillers for silicone elastomers to improve their dielectric permittivity and induce piezoelectric effect

Mihail Iacob (1), Maria Cazacu (1), Tudor Vasiliu (1), Carmen Racles (1),

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

Presentation given by Dr. Mihail Iacob

Iron oxides are the oldest known and the most studied magnetic materials. Physical properties, biocompatibility and availability made iron oxide nanoparticles of high interest in magnetic hyperthermia, targeted drug delivery, magnetic refrigeration, electronics, catalysts, Li-ion batteries, pigments, gas sensors etc. As a new application, we used iron oxide nanoparticles as filler for silicone elastomers and studied their influence on dielectric and piezoelectric behavior. Iron oxide was prepared by alkaline precipitation method and the reaction time was finely tuned in order to obtain nanoparticles with various

structures and morphologies. The nanoparticles were mixed with hydroxyl ended polydimethylsiloxane (Mn=60000 g/mol) and the mixtures were processed as films and crosslinked by condensation with tetralkoxysilane at room temperature. It was found that using of iron oxide as filler lead to increasing of the dielectric constant (up to 135 %) keeping good mechanical properties (very low Young's modulus, high elongation, low viscoelastic loss) and dielectric strength. In addition, the crystalline nature of the nanoparticles induces a piezoelectric response emphasized by piezoelectric force microscopy. The improved properties of the composites make them suitable for applications in mechanical/electrical energy conversion and sensors.

1.6.19 Tensile stress impact on partial discharges in dielectric elastomer actuator

Alessandro Iannarelli (1), Mohamad Ghaffarian Niasar (1), Rob Ross (1),

(1) TU Delft

Presentation given by Mr. Alessandro Iannarelli

Dielectric elastomer actuators (DEA) are an example of alternative application of high voltage insulating systems. Unlike traditional cases where dielectrics are mostly rigid, in a DEA the insulator is intentionally made up of highly elastic material. This makes relatively large actuation possible under high electric stress. However, every material exposed to strong electric field eventually suffers of dielectric ageing and therefore the same and well known conventional diagnostic techniques can be applied to soft insulators. In this work, it is observed the behaviour of partial discharge (PD) mechanism in silicon elastomer by varying its intrinsic tensile stress. The stress is carried out by mean of initial static pre-stretching. Partial discharges are localized discharges that occur at defects or void of the insulation when the electric field strength exceeds the breakdown strength of that portion of the dielectric material. Over time, this activity may modify the morphology and local chemical composition of the insulator leading to electrical ageing of the material. Eventually it could lead to catastrophic failure of the DEA and therefore shorten its operational lifetime. The scope of this study is two-folded: first, by monitoring the PDs' magnitude and frequency over time, it is tried to assess the health of the actuator at different mechanical stress. Secondly, it is observed how the PD pattern is influence by low frequency rectangular waveform signal.

1.6.20 Second generation micromechanical stimulation chips to study mechanotransduction in the urinary tract

Ali Maziz (1), Na Guan (2), Nimish Sharma (2), Karl Svennersten (2), Edwin Jager (1),

(1) Linköping University
(2) Karolinska Institute

Presentation given by Prof. Edwin Jager

Cellular mechanotransduction is crucial for physiological function in the lower urinary tract. The bladder is highly dependent on the ability to sense and process mechanical inputs, illustrated by the regulated filling and voiding of the bladder. However, the mechanisms by which the bladder integrates mechanical inputs, such as intravesicular pressure, and controls the smooth muscles, remain unknown. To date no tools exist that satisfactorily mimic in vitro the dynamic micromechanical events initiated e.g. by an emerging inflammatory process or a growing tumour mass in the urinary tract. More specifically, there is a need for tools to study these events on a single cell level or in a small population of cells. This paper reports the development of the 2nd generation of micromechanical stimulation chips that can apply physiologically relevant mechanical stimuli to single cells to study mechanosensitive cells in the urinary tract. The chips comprise arrays of microactuators based on the electroactive polymer polypyrrole (PPy). The PPy microactuators can provide mechanical stimulation at different strains and/or strain rates to single cells or clusters of cells, including controls, all integrated on one single chip, without the need to pre-prepare the cells. We will present the mechanoresponse of urothelial cells using the chips, will show the urothelial cells viability and response with an expression of intra-cellular purinergic receptors to a micromechanical stimulation.

Wednesday, 7 June 2017

General programme of the day

Session 2.1 *Chair: Toribio Fernández Otero, Technical University of Cartagena, Spain*		
EAPlenary	9:00- 9:30	Invited talk **Gih-Keong Lau** Nanyang Technological University, Singapore
EAPodiums	9:30- 9:50	Invited talk **Anne Ladegaard** Technical University of Denmark, Denmark
	9:50- 10:10	Invited talk **Rocco Vertechy** University of Bologna, Italy
	10.10- 10:30	Invited talk **Espen Knoop** Disney Research, Switzerland
Break	10:30- 10:50	Coffee break
Session 2.2 *Chair: Gih-Keong Lau, Nanyang Technological University, Singapore*		
EAPromises	10:50- 11:10	Invited talk **Martin Kaltenbrunner** University of Linz, Austria
	11:10- 11:20	Invited Talk **Piotr Mazurek** Technical University of Denmark, Denmark
Session 2.3 *Chair: Martin Kaltenbrunner, University of Linz, Austria*		
EAPitches	11:20- 12:20	**Pitch oral presentations** 21 presentations of research activities, followed by presentations of prototypes/products (2 minutes each + 1 minute to change speaker)
Lunch	12:30-	Lunch

	13:40	
EAPosters **EAPrototypes** **EAProducts**	13:40- 15:00	**Posters & exhibitions** 21 posters, together with prototypes/products Coffee served during the session
Best poster award (sponsored by Springer)	15:00- 15:10	Announcement of the winner of the best poster award
EuroEAP Society Challenge award	15:10- 15:40	Announcement of the first three classified teams of the Society Challenge 2017 award and presentation of the descriptive videos
Closing ceremony	15.40- 15:50	Conference closure, handover to the next year's Chairperson and presentation of the next year's conference place
Social tour	16:00- 19:30	Guided tour of the Roman Museum and Theater (Cartagena) + free time for a city walk.
Social dinner	19:30	Social dinner at the Batel

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

2.1.1 Artificial Muscles for Soft Robots, Tunable Optics and Acoustics

Gih-Keong Lau (1),
(1) School Of Mechanical And Aerospace Engineering, Nanyang Technological University, Singapore 639798

Presentation given by Dr. Gih-Keong Lau

Dielectric elastomer actuators (DEAs) make artificial muscles, good for lightweight and distributed applications. Recent developments in my research group have seen DEAs successfully driving soft robots, tunable optics and even tunable acoustic absorbers (see Figure 1). Looking ahead, we also make use of dielectric gel passivation to improve the thermal stability of acrylic dielectric elastomer. This method is proven to greatly improve the dielectric strength of multilayer DEA by preventing localized electro-thermal breakdown. These fundamental understanding and methods are hopefully better DEAs as artificial muscles for future diverse applications.

2.1.2 Dielectric breakdown in silicone elastomers

Anne Ladegaard Skov (1), Liyun Yu (1), Ramona Matieu (2),

(1) Danish Polymer Centre, Department Of Chemical Engineering, DTU, Kgs Lyngby, Denmark
(2) Center For Electron Nanoscopy (CEN), DTU, Kgs Lyngby, Denmark

Presentation given by Prof. Anne Ladegaard Skov

Silicone-based dielectric elastomers are on the verge of a commercial breakthrough for applications where high electrical breakdown strengths are not required. However, to expand the product range for dielectric elastomers it is

crucial to understand how to develop high electrical breakdown strength elastomers without compromising the inherent softness of silicone elastomers. Recent studies have shown that by incorporation of e.g. dipolar moieties in minute amounts on the polymer backbone the electrical breakdown strength can be increased. Such studies include incorporation of aromatics and chloro propyl groups on the silicone backbone. In this study we focus on the chloro propyl functionalized silicone elastomers prepared in a recent work of ours and investigate the electrical breakdown patterns of two similar chloro propyl functionalized silicone elastomers which breakdown electrically in a rather different way as well as we compare them to a silicone based reference. Thermogravimetric analysis (TGA) and scanning electron microscopy (SEM) are used to evaluate the elastomers before and after electrical breakdown to reveal patterns in the breakdown processes.

2.1.3 Fatigue life characterization of dielectric elastomer transducers: preliminary results

Rocco Vertechy (1) (2), Marco Fontana (2) (3), Yi Chen (1), Lorenzo Agostini (2),

(1) University Of Bologna
(2) Scuola Superiore Sant"Anna
(3) University Of Trento

Presentation given by Prof. Rocco Vertechy

Dielectric elastomer transducers (DETs) are deformable capacitors, made by highly elastic dielectric layers coated with compliant electrodes, that make it possible to convert mechanical energy into direct current electricity and vice-versa. As such, they can be used to conceive solid-state electrostatic actuators, generators and sensors exhibiting the following properties: large energy and power densities; ease of manufacture and integration; good resistance to shocks and corrosion; silent operation; low cost. Recently, commercial rubber membranes made of silicone elastomers, natural rubber and styrenic rubber demonstrated excellent electromechanical properties for the development of high energy density DETs. In particular, in experimental applications as generators, inflatable DETs based on these materials made it possible to consistently convert pneumatic energy into electricity at an energy density per cycle greater than 400 J/kg. These experimented performances can however be

sustained for a limited number of cycles only, after which the DET will fail irreversibly. To date, very little information is available on the fatigue life performances of dielectric elastomer materials and of the transducers made thereof. Having identified the electrical breakdown as the most probable mode of DET failure, this presentation reports and discusses on a set of lifetime constant electric-stress tests conducted on frame stretched circular DET specimens made of a styrenic rubber.

2.1.4 Electroactive polymers for soft laterotactile displays

Espen Knoop (1) (2),

(1) Disney Research, Zurich, Switzerland
(2) University Of Bristol, Bristol, UK

Presentation given by Dr. Espen Knoop

Virtual Reality and smart wearable devices have seen a surge in recent years. While HD audio and video is readily available, the haptic feedback from such devices bears limited resemblance to real-world physical interactions. Ultimately, we wish to create haptic feedback which matches the cutaneous sense of touch both in spatial resolution and frequency content. Electroactive polymers could be a key enabling technology for creating large-scale high-spatial-resolution tactile displays that are flexible and stretchable. Laterotactile stimulation, where contactors move parallel to the skin surface to stretch and compress it locally, can produce tactile sensations which are perceived as moving into the skin (i.e. normal stimulation). Lateral stimulation means that no out-of-plane forces are required, making it particularly desirable for thin and flexible wearable devices. We have conducted psychophysical experiments characterising the sensitivity to laterotactile stimuli and comparing it to normal stimulation, laying the foundations for more effective laterotactile devices. We have built prototypes of laterotactile displays driven by Dielectric Elastomer Actuators, where the areal expansion of the actuator is coupled to stretching of the skin. The actuator compliance allows for small movements of the user during operation. Furthermore, by exploiting the self-sensing capabilities of DEAs we can achieve two-way tactile interactions, opening up for new interaction modalities.

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

2.2.1 Soft machines and electronics with tough hydrogels

Martin Kaltenbrunner (1),

(1) Linz Institute Of Technology (LIT), Johannes Kepler University Linz, Altenbergerstrasse 69, 4040 Linz, Austria

Presentation given by Dr. Martin Kaltenbrunner

Introducing methods for instant strong bonding between hydrogels and antagonistic materials from soft to hard - allows us to demonstrate elastic, yet tough biomimetic devices and machines with a high level of complexity. Tough hydrogels strongly attach, within seconds, to plastics, elastomers, leather, bone and metals reaching unprecedented interfacial toughness exceeding 2000 J/m2. Healing of severed ionic hydrogel conductors becomes feasible and restores function instantly. Soft, transparent multi-layered hybrids of elastomers and ionic hydrogels endure biaxial strain with more than 2000 % increase in area, facilitating soft transducers, generators and adaptive lenses. We demonstrate soft electronic devices, from stretchable batteries, self-powered compliant circuits and autonomous electronic skin for triggered drug delivery. Our approach is applicable in rapid prototyping and in delicate environments inaccessible for extended curing and cross-linking.

2.2.2 Novel high dielectric constant hybrid elastomers as candidates for dielectric elastomer actuators

Piotr Mazurek (1), Anne Ladegaard Skov (1),

(1) Technical University Of Denmark, Danish Polymer Centre, Kgs. Lyngby, Denmark

Presentation given by Mr. Piotr Mazurek

Presently, none of the reported elastomers meets the optimal requirements expected to produce a commercially attractive dielectric elastomer film. Therefore, bold approaches have to be undertaken in order to make significant improvements. The presented research deals with the simple idea of incorporating high-permittivity polar liquids in discrete compartments in silicone elastomer. The idea, though, has two very important advantages. Firstly, high-permittivity polar liquids are theoretically capable of enhancing the dielectric constant of a material in the same manner as classical ceramic fillers. Secondly, incorporating polar liquids into a non-polar polymer is envisioned to be realized via introducing discrete microdroplets of the liquid into the polymer, which will introduce zero-stress zones into the elastomer. Ultimately, the Young's modulus of such a material will decrease, and thereby theoretical DEA efficiency will be enhanced. Here various polar liquids and commercial silicones are investigated as potential candidates for creating high-performance DEA membranes.

Session 2.3
(abstracts are listed in the order of presentation)

2.3.1 Monolayer electrodes fabricated by Langmuir-Schaefer enable DEA actuation below 100 V

Xiaobin Ji (1), Alae El Haitami (2), Francesca Sorba (1), Samuel Rosset (1), Giao T.M. Nguyen (2), Cédric Plesse (2), Frédéric Vidal (2), Herbert Shea (1), Sophie Cantin (2),

(1) Microsystems For Space Technologies Laboratory (LMTS), Ecole Polytechnique Federale De Lausanne (EPFL), Neuchatel, Switzerland
(2) Laboratoire De Physicochimie Des Polymeres Et Des Interfaces (LPPI), Institut Des Materiaux, Universite De Cergy-Pontoise, Cergy-Pontoise, France

Presentation given by Mr. Xiaobin Ji

Dielectric elastomer actuators (DEAs) generally require kilovolts to operate. One challenge today is to decrease this voltage to below a few hundred volts. One path is to decrease the dielectric elastomer thickness to a few micron and the electrode thickness to tens of nanometers without stiffening the DEA. While conventional compliant electrode fabrication methods do not lead to very thin films, the Langmuir-Schaefer (LS) is a powerful molecule assembly technology leading to a one-molecule-thick layer. In this work, a Multiwall Carbon Nanotube/alkyl-polythiophene (MWCNT/PT) composite was assembled as DEAs electrodes using the LS method. These composites form stable monolayers at the air-water interface that can be then LS transferred onto a Polydimethylsiloxane (PDMS) substrate. Presenting an intrinsic stretchability, the monolayer electrode remains conductive up to over 20% uniaxial strain. Mechanical pull tests show a Young's modulus range between 3 to 50 MPa for the monolayer. For ultra-low voltage DEA fabrication, 1 µm pre-stretched PDMS is sandwiched between two patterned MWCNT/PT monolayer electrodes. A strain/Voltage square value of about 520 %/kV2 is obtained (5.2% linear strain under 100 V), which is 4 times higher than the highest reported value. This novel integration process combines LS technology with the

fabrication of DEAs, which opens a new area for decreasing the driven voltage of DEA.

2.3.2 Electric breakdown strength of new elastomer polymer sandwiched with compliant electrodes for soft electrostatic generators

Achraf Kachroudi (1), Olivier Lesaint (1), Sophie Iglesias (2), Claire Jean-Mistral (3), Sébastien Pruvost (2), Jinbo Bai (4), Emmanuel Taine (5), Alain Sylvestre (1),

(1) Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, F-38000 Grenoble, France.
(2) Université De Lyon, F-69003, Lyon, France; INSA Lyon, F-69621, Villeurbanne, France; CNRS,
UMR 5223, Ingénierie Des Matériaux Polymères, France
(3) University Of Lyon, CNRS, INSA-Lyon, LaMCoS, Lyon, France
(4) Lab. MSSMat, CNRS UMR 8579, Centrale-Supélec, Université Paris-Saclay, Châtenay-Malabry, 92290, France
(5) SBM OffShore, SBM France, 06510 Carros, France

Presentation given by Dr. Achraf Kachroudi

Electroactive polymers for Dielectric Elastomer Generators (DEGs) are generally represented by an elastic dielectric polymer film sandwiched between two compliant electrodes. The commonly met electrodes are constituted of carbon or silver conductive pastes. However, these conductive pastes have limitations in view of the achievement of a final prototype which can be set up. In this work, new families of electrodes based on a Sylgard 184 silicone polymer host matrix containing specific conductive carbon fillers ensure high conductivity. Various electrode formulations with different volume fractions of the conductive fillers were elaborated and deposited on each surface of an active silicone matrix (Wacker 3030). The dielectric strength of the obtained sandwich was investigated in a sphere-plane configuration. A statistical study based on the Weibull theory shows that the obtained stack presented an important dielectric strength but depending on the nature of electrodes with different formulations. Furthermore, first measurements obtained after stretching these devices in relation with their working use, confirm such good results.

2.3.3 Fabrication approaches of dielectric elastomer stack transducers for complex and large-scale production

Florian Klug (1), Susana Solano-Arana (1), Florentine Förster-Zügel (1), Helmut F. Schlaak (1), Georg Grötsch (2), Carsten Cornelißen (2), Almuth Streitenberger (2), Moritz Eulenburg (2),

(1) Technische Universität Darmstadt, Institute Of Electromechanical Design, Darmstadt, Germany
(2) InovisCoat GmbH, Monheim Am Rhein, Germany

Presentation given by Mr. Florian Klug

During the last years a lot of fabrication methods for dielectric elastomer stack transducers (DEST) have been developed. Existing methods are based on two-dimensional thin-film manufacturing technologies. Many applications with simple shaped DEST have been shown in the past but especially for prototyping three-dimensional structuring would allow individually suited modules for each application. Additionally, due to slow manufacturing and less quantities, available DEST are very expensive and that makes them futile for many applications at this time. In this work, two fabrication approaches are presented introducing three-dimensional structured DEST and an opportunity for large-scale production. First approach is based on a three-axis positioning system to deposit materials with a dual extruder on a heated build plate. By repetitive deposition of liquid electrode and elastomer materials printing of three-dimensional DEST with less than 50 µm layer thickness is feasible. Furthermore, it allows the integration of electrical connections, cavities, channels, sensors and other structural elements during the fabrication. In the second approach, an industrial slit die coater is used to deposit liquid materials onto a PET substrate. The setup is able to stack up to nine liquid layers consisting of different materials at the same time. Afterwards, all layers are dried and cross-linked in an oven. This allows large-scale production of DEST with up to four active layers.

2.3.4 Alternatives to external polarization source for dielectric elastomer generators: electrets versus piezoelectric materials

Clara Lagomarsini (1), Giulia Lombardi (2), Claire Jean-Mistral (3), Alain Sylvestre (1),

(1) Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, Grenoble, France
(2) Dept. Of Electrical, Electronic And Information Engineering, University Of Bologna, Italy
(3) Univ. Lyon, INSA-Lyon, CNRS UMR 5259, LaMCoS, Villeurbanne, France

Presentation given by Ms. Clara Lagomarsini

Among the different technologies for kinetic energy harvesting, dielectric elastomer generators (DEGs) may represent a promising solution for supplying power to wearable low power consumption sensors and devices. These electrostatic generators provide a low-cost and lightweight solution to harvest high electrical energy densities from the mechanical deformation of an elastomeric membrane. The main disadvantage of these structures is the need of an external high voltage polarization source to perform the energetic cycle. In order to overcome this limitation and have a completely autonomous energy scavenger, our research group has been working since 2012, on coupling dielectric elastomers with electret materials (i.e. insulator materials that can hold a permanent electric charge over a long period of time). In the present work, a new hybrid solution for wearable energy harvesters based on DEG will be presented. This new autonomous device is based on the combination of a DEG with a piezoelectric material, which is used as new polarization source for the DEG energetic cycle. The working principle and the first results obtained on this new prototype will be presented and a comparison between the two polarization solutions (electrets and piezoelectric materials) will be discussed.

2.3.5 Modelling buckled dielectric elastomers

Jacob Langham (1) (2), Hadrien Bense (3), Benoît Roman (3), José Bico (3), Dwight Barkley (2),

(1) University Of Bristol
(2) University Of Warwick
(3) Laboratoire De Physique Et Mécanique Des Milieux Hétérogènes (PMMH), CNRS, ESPCI
Paris

Presentation given by Dr. Jacob Langham

A dielectric elastomer whose edges are held fixed will eventually buckle, given sufficient applied voltage, resulting in an out-of-plane deformation. We model this situation numerically using a simple nonlinear elastic approach and obtain good agreement with experimental results. Interesting azimuthal wave patterns are observed in the case of an annular active region and these are well captured by the model. The importance of considering (and computing) multiple equilibrium configurations is also highlighted.

2.3.6 A flexible 4x4 array of 1 kV dielectric elastomer actuators driven by an integrated matrix of high-voltage thin-film transistors

Alexis Marette (1), Alexandre Poulin (1), Nadine Besse (1), Samuel Schlatter (1), Samuel Rosset

(1), Danick Briand (1), Herbert Shea (1),
(1) Ecole Polytechnique Federale De Lausanne (EPFL), LMTS, Neuchatel, SWITZERLAND

Presentation given by Mr. Alexis Marette

We report a flexible 4x4 matrix of dielectric elastomer actuators (DEAs) driven by high-voltage thin film transistors (HVTFTs). Each DEA is controlled by a HVTFT operating as a switch. The HVTFT breaks down over 1.1 kV drain-source voltage. The high-voltage operation is achieved thanks to (1) a gate dielectric bilayer composed of 100 nm alumina and 1 um Parylene-C and (2) a gate electrode offset from the drain electrode by 150 um out of a 500 um channel length. The DEA's active region is a 4 mm diameter circle defined by two parallel carbon-black electrodes on the top and on the bottom of a 17 um thick PDMS membrane. The DEA is suspended over a laser-cut circular hole in the HVTFT polyimide substrate. A flexible PCB interconnects the DEAs and the HVTFTs. The device is connected to a single high-voltage power supply and a microcontroller controls the HVTFTs gate-source voltage. A 30 V HVTFT gate voltage swing successfully controls 300 um DEA vertical deflection. The HVTFT on-current is 20 uA providing a DEA switching time response of 50 ms. The device operates normally when bent to a radius of curvature of 5 mm. Arraying DEAs with low-voltage controls paves the way towards compact, complex and compliant haptics and soft robotics.

2.3.7 Insight into the thermal degradation behaviour and degradation products of cross-linked polydimethylsiloxanes

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

(1) DPC, Department Of Chemical And Biochemical Engineering/DTU, Kgs.Lyngby, Denmark

Presentation given by Ms. Elisa Ogliani

Silicone elastomers are extensively used for electromechanical applications such as dielectric elastomers transducers, due to their unique features. In particular, thermal stability is fundamental with respect to the reliability and the performance of silicone-based devices. This remarkable resistance to high temperatures is due to the high bond dissociation energy of the siloxane bond and the pronounced flexibility of the chain backbone. Keeping in mind the vast majority of work done so far on the degradation of silicones, the goal of this study is to achieve a deeper insight into the thermal degradation mechanism of commercial silicone elastomers with the main aim of translating it into the complex, coupled thermal and electrical breakdown processes that dielectric elastomers undergo. A systematic analysis of the thermal behaviour was carried out using thermogravimetric analysis (TGA) performed in inert atmosphere (pure thermal degradation) on cross-linked PDMS networks. Extraction of the samples in heptane was exploited in order to remove the non-bonded PDMS chains and determine to which extent the thermal degradation is influenced compared to the pristine elastomers. This study is to be used in a design guide towards reliable and robust dielectric elastomers.

2.3.8 Modelling of thermal breakdown in dielectric elastomers

Line Riis Madsen (1), Anne Ladegaard Skov (1), Ole Hassager (1),

(1) DTU Chemical And Biochemical Engineering, DPC, Lyngby, Denmark

Presentation given by Ms. Line Riis Madsen

Several electrical aging mechanisms are known to occur during operation of dielectric elastomers; some cause fast breakdown while others cause slow degradation of the dielectric elastomer. One of the most significant fast aging

mechanisms is thermal breakdown. Thermal breakdown initiates when the heat produced within the elastomer, mainly joule heating, exceeds the heat loss to the surroundings. This may be either locally or macroscopically. We strive to enhance the understanding of thermal breakdown in dielectric elastomer by performing numerical simulation of the actuation of dielectric elastomer transducers in stacked configuration. Multiple simulations using experimental data for PDMS have been performed using COMSOL Multiphysics, from which the key parameters affecting thermal breakdown have been identified. In this presentation we will present the findings and identify the optimal operating conditions for a PDMS dielectric elastomer in order to minimize thermal breakdown.

2.3.9 Analytical and finite element modeling of a dielectric elastomer strip membrane undergoing inhomogeneous large deformations

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

(1) Saarland University, Department Of Systems Engineering, Department Of Material Science And Engineering, Saarbrücken, Germany
(2) Polytechnic University Of Bari, Department Of Electrical And Information Engineering, Bari, Italy

Presentation given by Dr. Gianluca Rizzello

Dielectric elastomer (DE) strip membranes allow to manufacture compact, large-strain, and low-energy consuming mechatronics transducers. In order to optimize the design of strip DE actuators by means of computer-aided tools, the development of mathematical models is of fundamental importance. The problem of modelling strip membranes with a nearly one-to-one aspect ratio (i.e., the ratio between the membrane length and width), however, is particularly challenging due to the inhomogeneous nature of the resulting deformation, which makes it not possible to use simplifying considerations based on pure-shear or uniaxial deformation. In this paper we develop and compare two modelling approaches for DE strip membranes. At first, a FE analysis of the inhomogeneous large deformations of the membrane is performed via COMSOL. A novel implementation, based on membrane elements, is also proposed in order to improve numerical efficiency. As a second step, an analytical, control-oriented model is developed for the same membrane. The model is based on a novel formulation, which exploits an anisotropic free-energy function. This

approach permits to describe pure-shear and uniaxial deformations, as well as cases in-between, by effectively representing the material inhomogeneous deformation in terms of average stretches. Comparison between analytical and FE models shows a remarkable agreement, proving the effectiveness of the novel approach. Finally, experimental validation is performed.

2.3.10 Self-sensing Dielectric Elastomer Generators

Plinio Rodrigues De Oliveira Zanini (1) (2), Gianluca Rizzello (3), Jonathan Rossiter (1) (2), Martin Homer (1), Stefan Seelecke (3),

(1) University Of Bristol, Department Of Engineering Mathematics, Bristol, United Kingdom
(2) Bristol Robotics Laboratory, Bristol, United Kingdom
(3) Universität Des Saarlandes, Department Of Systems Engineering And The Department Of Material Science & Engineering, Saarbrücken, Germany

Presentation given by Mr. Plinio Rodrigues De Oliveira Zanini

Dielectric elastomers generators (DEGs) emerge as a potential new possibility mechanical-to-electrical energy conversion, opening the possibilities of developing new lightweight, cheap and efficient devices for renewable energy harvesting. However, the cyclic nature of DEGs energy harvesting process, together with the need of a properly phased charging/discharging, raises an issue for real-world applications. To maximize its performance, the DEG needs to be charged and discharged in correspondence to the minimum and maximum membrane deformation, respectively. In many realistic scenarios, however, forcing over the material cannot be easily predicted (e.g.: buoy in the ocean, someone walking/running). Therefore, being able to sense the deformation profile becomes an important factor to manage the charging state of the material. In the present study, we aim at combining a self-sensing capacitive technique with a DEG cycle. The self-sensing permits to reconstruct the DEG capacitance via voltage and current. Real-time knowledge of DEG capacitance can then be used to optimally trigger the charging and discharging phases of the DEG. Despite self-sensing has been successfully applied to DE actuators, the variable topology of driving circuits for DEG make the implementation of the self-sensing to such a case non-trivial. The novel method is validated in simulation, in which non-ideal aspect such as DEG resistance and measurement noise are also accounted.

2.3.11 High cycle aging of electrodes for dielectric elastomer actuators

Christine Saint-Aubin (de) (1), Samuel Rosset (1), Samuel Schlatter (1), Herbert Shea (1),
(1) Ecole Polytechnique Federale De Lausanne (EPFL), LMTS, Neuchatel, Switzerland

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

To be implemented at the industrial scale, dielectric elastomer actuators (DEA) must demonstrate long term reliability. Therefore, we subjected DEAs to high cycle aging tests to characterize the lifetime and degradation of their electrodes. All our DEAs were made using the same silicone membrane but with different electrode materials: carbon grease, carbon black powder, inkjet- printed carbon black and a carbon black-elastomer composite. Our standardized test consists in monitoring simultaneously the in-plane strain and the change in electrode resistance of an expanding circle actuator (active area of approx. 10 mm^2) versus cycle number and drive voltage. This is done over a minimum of 1,000,000 cycles with a square input voltage at a 50 Hz frequency and of an amplitude chosen so as to remain far enough from the electrical breakdown. Our results show on one hand that classical carbon grease electrodes are to be avoided: they lead to DEAs with the shortest lifetime. On the other hand, DEAs made with carbon black electrodes -in powder form, inkjet-printed or combined with an elastomer- are far more reliable: their lifetime extends well beyond 1,000,000 cycles. Over aging, their performance shows however a slight reduction in actuation strain, correlated with an increase in resistance. We characterized the overall mechanical behavior of the DEAs over aging, and for the first time, we brought to light the influence of their electrode material on the lifetime of the device.

2.3.12 Inkjet printing of carbon-based electrodes for dielectric elastomer actuators

Samuel Schlatter (1), Samuel Rosset (1), Herbert Shea (1),

(1) Ecole Polytechnique Federale De Lausanne (EPFL), Neuchatel, Switzerland

Presentation given by Mr. Samuel Schlatter

We present a method to inkjet print carbon-based electrodes on silicone membranes to fabricate Dielectric Elastomer Actuators (DEA). DEA are transitioning from simple proof of concept devices to more complex integrated systems. These complex devices are beginning to find uses in the biomedical field, tuneable optics, and microfluidics due to their unique properties. However, these fields pose a new set of challenges. The electrodes for these devices must be smaller, have finer features, be reliable, and be manufacturable and reproducible. Today's fabrication techniques, which are often manual, are not well suited for such devices. We have thus chosen to use inkjet printing to pattern electrodes which can address these challenges. As there are no commercially available inks for DEA electrodes, we have developed a specially formulated electrode mixture. The electrode mixture is easy to prepare and consists of only three components: carbon black, a solvent, and a dispersant. The mixture was formulated so that no pre-treatment or heating of the silicone membrane is necessary. We show that the printed electrode performs excellently as a stretchable electrode. The electrode has resistances as low as 13k?/? and remains conductive at 150% strain. Cyclic tests show that the resistance increases by only 108% over 1500 stretch cycles, and the combination of electrode thickness and stiffness does not significantly impact the total stiffness (hence actuation) of a DEA.

2.3.13 A consistent hyper-viscoelastic lumped parameter model for dielectric elastomers

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

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

Presentation given by Mr. Tristan Schlögl

Theoretical models and numerical simulation tools provide a deeper understanding of the versatility of dielectric elastomers and contribute to the design and control of dielectric elastomer actuated systems. Whereas three-dimensional finite element approaches provide a very powerful tool to cover arbitrary actuator geometry and deformation, the computational cost is usually quite demanding. Therefore, so called lumped parameter models are often used

for complex tasks like solving optimisation problems. These models reduce the computational cost by assuming symmetry and uniform deformation, inevitably introducing an error to the simulation results. Quantifying this deviation is difficult as the lumped model is usually based on different modelling and time integration techniques compared to the three-dimensional counterpart, providing a different set of simulation parameters. In this work, a lumped parameter model is derived directly from the three-dimensional field theory within the framework of Lagrangian mechanics, including inertia terms and hyper-viscoelastic material behaviour. This allows for a consistent comparison between the lumped model and the corresponding three-dimensional finite element solution in terms of performance and accuracy, which is illustrated by various numerical examples.

2.3.14 Vibration analysis of a dielectric elastomer membrane actuator

Stefan Seelecke (1), Sophie Nalbach (1), Gianluca Rizzello (1),

(1) Saarland University

Presentation given by Prof. Stefan Seelecke

Other than for their large actuation strain, dielectric elastomers (DEs) are also well known for their relatively large bandwidth in the range of several kHz. While most of the current applications, e.g., pumps or valves, work within low frequency regimes (<100 Hz), the large bandwidth makes it possible to use the material in acoustic applications such as loudspeakers or noise cancellation devices. In order to exploit DEs in such applications, the high-frequency behaviour of DE membranes and in particular the modal shapes need to be properly investigated and understood. A large circular out-of-plane membrane actuator with a diameter of 220 mm is used for experimental investigation. The membrane material is silicone-based, the compliant electrodes (PDMS/carbon black) are applied by screen-printing techniques. A linear spring is also used to provide an out-of-plane pre-stress for the material. Vibrations are induced by means of high voltage, high frequency signals. The 3D motion of the vibrating membrane is measured by means of a Polytec PSV-500-3D Scanning Vibrometer and used to reconstruct the vibration states in the frequency range of up to 600 Hz. The frequency behaviour of the DE membrane is then characterized, and the principal resulting modes are identified. In addition, the influence of different parameters, such as geometry and pre-stress on the

resulting frequency spectrum and vibrational modes is studied.

2.3.15 Electroactive polymer generators for ocean wave energy harvesting

Nitin Kumar Singh (1),

(1) Institut National Des Sciences Appliquées De Lyon, France

Presentation given by Mr. Nitir Kumar Singh

Electroactive polymers (EAPs) are mainly known for its applications as an actuator, but these materials rapidly using as a generator also. Energy harvesting using Electroactive polymers is a process of electromechanical energy conversion in which electrical energy can be obtained by capturing ambient energy and then converted into electrical energy through Electroactive polymers. Ocean Wave generator utilizing Electroactive polymers, can directly drive Electroactive polymers by the up and down motions of ocean waves, the structure of the generator is simple and its size can be made small or big according to requirement. Because of its simplicity, efficiency, and size scalability, we believe that Electroactive polymers based ocean wave generators systems can be attractive not only for large wave applications but for many applications where the waves are much smaller.

2.3.16 A novel application of dielectric stack actuators: a micromixer

Susana Solano Arana (1), Florian Klug (1), Holger Mößinger (1), Florentine Förster-Zügel (1), Helmut F. Schlaak (1),

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

Presentation given by Ms. Susana Solano Arana

Lately, different fabrication methods for dielectric elastomer actuators (DEAs) have been exploited. The development of attractive applications, in which DEAs offer advantages over conventional technologies, is necessary for the advance of the technology. The fabrication of micromixers as a novel application of dielectric stack actuators is proposed in this work. The fabrication of DEA

micromixers is interesting for medical and pharmaceutical applications, due to: firstly, the biocompatibility of the used materials (PDMS and graphite); secondly, the actuation principle on which the micromixer is based; and thirdly, the low flow velocity in the micromixers required in many applications. The micromixer based on peristaltic movements, will not only mix, but also pump the fluids in and out the device. By changing the actuation frequency of the DEA, a different mixing ratio is provided. The developed micromixer is based on twelve actuators distributed in: two different pumping chambers consisting of four parallel actuators each; and a mixing chamber, made of four parallel actuators. The fabrication of the micromixer with varying film thicknesses is done automatically in a continuous process, which can be transferred to industrial production. The fabricated micromixer is able to mix two solutions with a flow rate of 21.5 microliter/min at the outlet, applying 1500 V at 10 Hz and actuating two actuators at a time.

2.3.17 A new wearable sensor in the shape of a braided cord (Kumihimo)

Yoshiro Tajitsu (1),

(1) Kansai University, School Of Science Engineering, Osaka, Japan

Presentation given by Prof. Yoshiro Tajitsu

A new piezoelectric sensor was developed in the shape of a Japanese traditional braided cord known as a "Kumihimo", by weaving piezoelectric poly-l-lactic acid (PLLA) fibers (piezoelectric PLLA braided cord). We then studied the decorative knots on a Kumihimo, which restricted the movement of the piezoelectric PLLA braided cord depending on its motion direction because of the constraint condition caused by the cord crossing itself at contact points. Therefore, we predicted that the desired piezoelectric signal could be detected selectively upon applying a complex stress by making preselected decorative knots. On the basis of the prediction, we developed a system for measuring pulse waves with a Wi-Fi communication system using a piezoelectric braiding cord with decorative knots. In fact, we realized that the piezoelectric braiding cord tied in various decorative knots, which can be worn as an accessory such as a choker or necklace, could detect pulse waves, swallowing, and coughing in a systematic order in one's daily life.

2.3.18 Comparative approaches to high performance stretchable electrodes

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

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

Presentation given by Mr. Codrin Tugui

Finding and developing new materials hold the key to new energy technologies that can replace the conventional energy resources. In this context, dielectric elastomers can play a significant role to harvesting energy from free environmental resources (oceans waves, body motion, etc.). The energy harvesting concept based on dielectric elastomer transducers (DEG) consist in converting the mechanical work straight into electrical energy using stretchable capacitors that are able to develop large strains. For high conversion efficiencies, the designed capacitors should meet certain properties such good mechanical properties, high breakdown voltage, while the compliant electrodes should resist until large deformation and over a large number of cycles without losing their conductivity. For this, two types of electrodes were achieved, a silver electrode deposited by Pulse Laser Deposition straight on the elastomer and a free standing PDMS-carbon black composite electrode. To tests the conversion efficiency, three types of capacitors having one, two and three active layers were successfully obtained using Elastosil as dielectric layer and PDMS-carbon black composites as electrodes. The fabricated capacitors were tested in a home-made energy harvesting setup. The obtained data point out that the rubber electrodes are working well after hundreds of cycles at large deformations.

2.3.19 Electrical breakdown phenomena of dielectric elastomers

Liyun Yu (1), Ramona Valentina Mateiu (2), Anne Ladegaard Skov (1),

(1) Danish Polymer Centre, Department Of Chemical And Biochemical Engineering, Technical University Of Denmark, Kgs. Lyngby, Denmark
(2) Center For Electron Nanoscopy, Technical University Of Denmark, Kgs. Lyngby, Denmark

Presentation given by Ms. Liyun Yu

Silicone elastomers have been heavily investigated as candidates for dielectric elastomers and are as such almost ideal candidates with their inherent softness and compliance but they suffer from low dielectric permittivity. Optimization with respect to the dielectric permittivity solely may lead to other problematic phenomena such as premature electrical breakdown. In this work, we focus on the chloropropyl functionalized silicone elastomers and investigate the electrical breakdown patterns of two similar chloropropyl functionalized silicone elastomers which break down electrically in a rather different way as well as we compare them to a silicone based reference. TGA and SEM are used to evaluate the elastomers before and after electrical breakdown. It was shown the chemically very similar silicone elastomers broke down electrically in very different ways. These observations emphasize that the modification of the silicone backbone may open up for completely new possibilities for stabilizing the silicone elastomer electrically. In order to tailor the elastomers, more knowledge is needed but these copolymers pave the first path towards a better understanding of the complex connection between electrical and thermal stability. Minor changes in the polymer backbone structure result in changes in electrical breakdown patterns and understanding why is crucial for enabling design for extraordinarily stable elastomers and thus ultimately reliable dielectric elastomer based products.

2.3.20 How do static pressures influence the cavity structure and the piezoelectricity of cellular and tubular-channel ferroelectrets?

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

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

Presentation given by Xunlin Qiu

Electro-mechanically active polymers (EAPs) include ferroelectrets that can exhibit large direct and inverse piezoelectric thickness coefficients and are therefore useful for sensor and actuator applications. Ferroelectrets are internally charged polymer foams or cavity-containing film systems that need to be carefully prepared in order to show high piezoelectricity. Due to their particular cavity structures, ferroelectrets are quite soft at least in the thickness direction. Consequently, the pressure dependence of the d33 coefficient is of particular importance for the applications of ferroelectrets. Here, we investigate the

dependence of the piezoelectric d33 coefficients of cellular-polypropylene and tubular-channel fluoroethylenepropylene-copolymer ferroelectrets on applied static pressures of up to 2000 kPa - a pressure range much broader than that reported in previous studies. It is found that appropriate static pressures may lead to optimal sample structures and to quite high d33 coefficients. Surprisingly, pressures up to 2000 kPa do not destroy the cellular PP ferroelectret films, but much higher d33 values than before are found after lowering the pressure again so that an additional pressure treatment of charged ferroelectrets may lead to applications-relevant improvements.

2.3.21 Energy harvesting from a backpack with an auxetic dielectric elastomer generator

Giulia Bassani (1), Claire Jean-Mistral (2), Emanuele Ruffaldi (1),

(1) Scuola Superiore Sant"Anna, PERCRO, Pisa, Italy
(2) INSA-Lyon, LaMCoS, Villeurbanne, France

The focus of this research is to develop a Dielectric Elastomer Generator (DEG) able to harvest energy from the stretch of the backpack straps without providing additional load as the present energy harvesting systems mostly do. After having proved that the mechanical energy available in the backpack straps is high enough to scavenge significant power (stretch 45% for 11Kg), different mechanical DEG configurations have been compared in term of energy output in order to evaluate which one allows to optimally exploit the stretch of the backpack straps during walking. Auxetic frames, converting the uniaxial stretch in a biaxial deformation of the DEG, have been proved to significantly increase the DEG performance (26.8uW at 1kV). A silicone based DEG with compliant electrodes has been fabricated and characterized. The use of the same matrix for all the DEG layers and rubber electrodes enables a great structural stability that allows the integration of such generators into real systems. The mechanical behaviour has been determined with stress-strain measurements performed on a uniaxial testing machine aided by a video extensometer inferring a maximal deformation of 73% and low viscous losses. The electrical behaviour has been evaluated performing dielectric spectroscopy over a frequency range of 10-1 to 105 Hz at 23°C. In the range typical of human motions (1-2Hz), the dielectric permittivity is slightly decreased and the loss tangent is halved comparing to the reference values.

List of participants

N.	Last name	First name	Organization	Country
1	Aabloo	Alvo	University of Tartu	Estonia
2	Allegretto	Graham	UBC	Canada
3	Bakardjiev	Petko	Tu-Dresden	Germany
4	Bassani	Giulia	Scuola Superiore Sant"Anna, Pisa	Italy
5	Beaumont	Samuel	Univ. Politécnica de Cartagena	Spain
6	Beck	Anthony	TU Dresden	Germany
7	Bele	Adrian	"Petru Poni" Institute Of Macromolecular Chemistry	Romania
8	Böse	Holger	Fraunhofer ISC	Germany
9	Boys	Hugh	Queen Mary University of London	United Kingdom
10	Calabrese	Luigi	University of Trento	Italy
11	Carpi	Federico	University of Florence	Italy
12	Caspari	Philip		Switzerland
13	Cattan	Eric	IEMN Université de Valenciennes et du Hainaut Cambrésis	France
14	Cazacu	Maria	"Petru Poni" Institute of Macromolecular Chemistry	Romania
15	Chen	Tian	Nanjing University Of Aeronautics And Astronautics (NUAA)	China
16	Chen	Leihao	Queen Mary University Of London	United Kingdom
17	Chiaula	Valeria	DTU	Denmark
18	Costa	Joana	IVTech	Italy
19	Dubbert	Janine	Evonik Creavis GmbH	Germany

20	Ehrlich	Johannes	Fraunhofer Society	Germany
21	Fasolt	Bettina	ZeMA Zentrum für Mechatronik und Automatisierungstechnik gGmbH	Germany
22	Ferrer Vilanova	Amparo	Universitat de València	Spain
23	Franke	Markus	TU Dresden	Germany
24	Frediani	Gabriele	Queen Mary University of London	United Kingdom
25	Gegg	Joachim	W.L. GORE & Associates GmbH	Germany
26	Ghilardi	Michele	Queen Mary University Of London	United Kingdom
27	Greco	Francesco	Istituto Italiano di Tecnologia	Italy
28	Hau	Steffen	Saarland University	Germany
29	Iacob	Mihail	"Petru Poni" Institute Of Macromolecular Chemistry	Romania
30	Iannarelli	Alessandro	TU Delft	Netherlands
31	Ionov	Leonid	University Of Georgia	United States
32	Jager	Edwin	Linköping University	Sweden
33	Ji	Xiaobin	École Polytechnique Fédérale de Lausanne (EPFL)	Switzerland
34	Kachroudi	Achraf	Grenoble Electrical Engineering Laboratory G2ELAB	France
35	Kaltenbrunner	Martin	Johannes Kepler University	Austria
36	Klug	Florian	TU Darmstadt	Germany
37	Knoop	Espen	Disney Research	Switzerland
38	Lagomarsini	Clara	Université Grenoble Alpes	France
39	Langham	Jacob	University Of Bristol	United Kingdom
40	Lau	Gih-Keong	Nanyang Technological University	Singapore

41	Madden	John	University of British Columbia	Canada
42	Mangelsen	Silke	Hivolt.de GmbH&Co. KG	Germany
43	Mansard	Vincent	CNRS	France
44	Martinez	Jose G.	Linköping University	Sweden
45	Mazurek	Piotr	Technical University Of Denmark	Denmark
46	Mazurek	Malgorzata	Technical University Of Denmark	Denmark
47	Mehner	Philipp	Technische Universität Dresden	Germany
48	Michalak	Barbara	Bürkert Werke GmbH & Co. KG	Germany
49	Minister	Frank	Evonik Resource Efficiency GmbH	Germany
50	Mossé	Aurélie	Ecole Nationale Supérieure Des Arts Décoratifs (ENSAD)	France
51	Mueller	Wulf	Hivolt.de GmbH&Co. KG	Germany
52	Murugasen	Eswaran	University Paris 7	France
53	Neuhaus	Raphael	Universität Stuttgart	Germany
54	Ogliani	Elisa	DTU	Denmark
55	Otero	Toribio F.	Univ. Politécnica de Cartagena	Spain
56	Pascual	Victor H	Univ. Politécnica de Cartagena	Spain
57	Poole	Alan	LEAP Technology	Denmark
58	Quintero Jaime	Andres Felipe	Universidad De Alicante	Spain
59	Ribeiro	Frédéric	University of Cergy - Pontoise	France
60	Riis Madsen	Line	Technical University Of Denmark	Denmark
61	Rizzello	Gianluca	Saarland University	Germany
62	Rodrigues De Oliveira Zanini	Plinio	University Of Bristol	United Kingdom
63	Rohtlaid	Kätlin	Université De Cergy-Pontoise	France
64	Saint-Aubin (de)	Christine	École Polytechnique Fédérale De Lausanne	Switzerland

65	Sarban	Rahimullah	LEAP Technology	Denmark
66	Schlaak	Helmut F.	TU Darmstadt	Germany
67	Scholz	Mario	Evonik Resource Efficiency GmbH	Germany
68	Schumacher	Johanna	Arquimea Ingeniería S.L.	Spain
69	Schupp	Michael	Bürkert Werke GmbH & Co KG	Germany
70	Seelecke	Stefan	Saarland University	Germany
71	Shanmugam	Sunjai Nakshatharan	University Of Tartu	Estonia
72	Singh	Nitin Kumar	Institut national des sciences appliquées de Lyon	France
73	Skov	Anne Ladegaard	DTU	Denmark
74	Solano Arana	Susana	Institut Für Elektromechanische Konstruktionen (EMK)/Technische Universität Darmstadt	Germany
75	Sugino	Takushi	National Institute of Advanced Industrial Science and Technology (AIST)	Japan
76	Sylvestre	Alain	G2Elab	France
77	Tajitsu	Yoshiro	Kansai University	Japan
78	Tauban	Mathieu	Solvay	France
79	Thomsen	Benjamin	LEAP Technology	Denmark
80	Trouillet-Fonti	Lise	Solvay	France
81	Tugui	Codrin	Institute Of Macromolecular Chemistry "Petru Poni" Iasi	Romania
82	Valero	Laura	University of Cartagena	Spain
83	Van Den Ende	Daan	Phlips Research	Netherlands
84	Vertechy	Rocco	University Of Bologna	Italy
85	Vidal	Frédéric	Université de Cergy-Pontoise	France
86	Wagner	Michael	Evonik Creavis GmbH	Germany

87	Yu	Liyun	Technical University Of Denmark (DTU)	Denmark
88	Zhong	Yong	Linköping University	Sweden
89	Zondaka	Zane	University Of Tartu	Estonia