SYMPOSIUM EE

Electroactive Polymers and Their Applications as Actuators, Sensors, and Artificial Muscles

November 26 – 27, 2001

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*Invited paper
SESSION EE1: NOVEL ELECTROACTIVE POLYMER ACTUATOR MATERIALS
Chung-Ching Zhang and Sigfried Baier
Monday Morning, November 26, 2001
Fairfax (Sheraton)

8:30 AM EE1.1
CONDUCTING POLYMERS AND CARBON NANOTUBES AS ELECTROMECHANICAL ACTUATORS AND SENSOR MATERIALS.
Geoffrey M. Spinks, Gordon G. Wallace, Lu Liu, Deshi Zhou, University of Wollongong, Intelligent Polymer Research Institute, Wollongong, AUSTRALIA.

Electromechanical actuators are being investigated for a wide range of applications in medical, electronics and industrial areas. There is a wide range of electromechanical actuator materials but both conducting polymers and carbon nanotubes are attractive because of their low voltage operation. For practical applications, the strain generated by the actuator must be known under different applied loads. Unfortunately, there is very little information about the performance of polymer actuators at different loads: most studies report the strain generated as zero, or near zero, loads. We have measured the isotropic strain for both polypyrrole films and carbon nanotube sheets as increasing applied loads and found a linear decrease in strain with increasing stress. The rate of strain decrease with increasing stress was far greater for the polypyrrole actuator than for the carbon nanotube sheets. Analysis of the deformation induced during electrochemical charging and discharging of the materials shows that a decrease in strain with increasing load can be attributed to a change in the elastic modulus of the material during charging (doping). Thus, the polypyrrole modulus changes significantly between the oxidized (high modulus) and reduced (low modulus) states. The difference in modulus can be as much as 100% for these materials which correlates with the rapid decrease in actuator strain with increasing applied stress. Another aspect of the practical use of these materials is their stability in the off state. We have developed simple strain sensors based on conducting polymer - coated stretch fabrics. Calibration of these materials shows a wide linear range and high gauge factor (~2). Combining fabric strain gauges with polymer actuators in a common menu for providing feedback control to the actuating element.

9:00 AM EE1.2
EFFECT OF FABRICATION AND ACTUATION OF SINGLE WALL CARBON NANOTUBE/NANO COMPOSITES. Debjit Chattopadhyay, Ishara Galka, Botios Papadimitrioupolous, Nonmaterials Optoelectronics Laboratory, Department of Chemistry, Polymer Program, Institute of Materials Science, University of Connecticut, Storrs, CT, Ray Baughman, Honeywell Co., Morrisville, NV.

Recently ‘bucky’ papers fabricated from single wall carbon nanotubes (SWNTs) were shown to possess significant promise as non-faradic electrochemical actuators based on their high electrical conductivity and excellent mechanical properties. However, morphological and physical effects of the nanotube structure and the fabrication process have resulted in poor mechanical properties and low electrochemically generated strain.

Herein we demonstrate that processing SWNTs with polymeric electrolyte (Nafion 1) and alternative fabrication strategies significantly improve the performance of the annealed SWNTs/Nafion composite having higher densities (up to 0.75 g/cm3), larger surface areas (e.g., 500 m²/g), superior actuation strains (0.4%) and more uniform morphologies when compared to pure ‘bucky’ papers. Moreover, the X-ray diffraction along the edge of the SWNTs/Nafion annealed composite showed partial amorphity as opposed to totally isotropic pure bucky papers.

9:15 AM EE1.3
ELECTROMECHANICAL EFFECTS IN FERROELECTRIC LIQUID CRYSTALLINE ELASTOMERS. Friedrich Kremer, Walter Lehmann, University of Leipzig, Faculty of Physics and Geosciences, Leipzig, GERMANY; Elisabeth Gebhard, Rudolf Zentel, University of Mainz, Institute of Organic Chemistry, Mainz, GERMANY.

Michelson interferometry is employed to study electromechanical effects in self-supporting homotropically oriented layers of ferroelectric liquid crystalline elastomers (FLCE) [1, 2]. Applying electrical fields in the direction parallel to the smectic layers results in strong thickness charge perpendicular to the layers. The measured inverse electric response (response in the second harmonic) effects by two order of magnitude the data measured for conventional “smart” ceramics [3, 4]. The molecular origination of this giant electrostrictive response is based on the electroactive effect, which is well known for low molecular materials.


10:00 AM EE1.4
SOFT ACTUATORS BASED ON ELECTROCHEMICAL EXPANSION AND CONTRACTION IN CONDUCTING POLYMERS: POLY(3-ALKYTHIOPHENE) FILMS.
Mitsuru Fikizako, Osaka University, Graduate School of Life and Science Engineering, Osaka, JAPAN; Wataru Takashima, Keiichi Kimoto, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Fukuoka, JAPAN.

Upon oxidation, conducting polymers swell as well as increase in the conductivity. The change of dimension during electrochemical cycle is called electrochemical/electromechanical deformation (ECMD), which can be utilized as soft actuators. The mechanism of ECMD is based on anodic oxidation in conducting polymers like polyanioline (PANI), poly(pyrrole) (PPy) and their derivatives. The mechanisms of ECMD have been revealed to be due to (1) insertion and exclusion of bulky ions, (2) conformational change of structure by the delocalization of e-electrons and (3) electrostatic repulsion between like charges. It has been shown that actuators based on conducting polymers generate greater force than that of gel and ion exchange resins. However, the quantitative measurements for various conducting polymers have not been carried out sufficiently. In this report, quantitative studies of ECMD behaviors in head-to-tail poly(3-alkythiophene) (HT-PAT) with alkyl = hexyl (PAT6), alkyl = dodecyl (PAT12) and alkyl = tetradecyl (PAT14) are described. The ECMD of the PAT6 films was measured in nonaqueous electrolyte solution of tetrafluorohydrinum furanocarbonate with respect to the electrochemical expansion and contraction and their chemical and electrical stability. The results are discussed taking the morphology of film, comparing with ECMD behaviors of polyaniline (PANI), poly(α-methoxyxylene) (PMAn) and poly(pyrrole) (PPS) films. As a result, the expansion/contraction ratio of PAT6 films is ranging 2~3%, which is comparable to those of PANI and PAnm films. The expansion and contraction ratio is larger in PAT6 films compared with that of PAT12 films, because of the higher density of n-conjugation in PAT6 films. Large creeping effect was observed in PANI-PAT films, contrary to the case of HT-PAT films.

10:30 AM EE1.5
MONOLITHIC CONDUCTING POLYMER ACTUATORS BASED ON ASYMMETRICALLY CONFIGURED POLYANILINE MEMBRANES. Haing-Lin Wang, Bioscience Division, B-4, Los Alamos National Laboratory, Los Alamos, NM.

We report synthesis and characterization of polyaniline integrally skinned asymmetric membranes (PANI ISAmem), and the use of these membranes to fabricate polymer actuators. PANI ISA mem prepared from highly concentrated PANI solution comprised of a thin dense layer and a microporous structure, and have resulted in poor mechanical properties and low electrochemically generated strain.

Herein we demonstrate that processing SWNTs with polymeric electrolyte (Nafion 1) and alternative fabrication strategies significantly improve the performance of the annealed SWNTs/Nafion composite having higher densities (up to 0.75 g/cm3), larger surface areas (e.g., 500 m²/g), superior actuation strains (0.4%) and more uniform morphologies when compared to pure ‘bucky’ papers. Moreover, the X-ray diffraction along the edge of the SWNTs/Nafion annealed composite showed partial amorphity as opposed to totally isotropic pure bucky papers.

10:45 AM EE1.6
A NEW CONCEPT FOR ACTUATORS BASED ON CONDUCTING INTERPENETRATING POLYMER NETWORKS. Frederic Vial, Hervé Haufrasmanyahra, Claude Cerrot and Dominique Tapie, LPMF, University of Cergy-Pontoise, FRANCE.

Conducting polymers could provide actuator materials that work in a similar manner to natural muscles. Recent proposals increasingly report combinations of electronic conducting polymers arranged in a bilayer type geometry and sandwiching a solid electrolyte. One of the weak points in these bilayer type actuators is the interface and the adhesion between the conducting polymers and the solid electrolyte on the one hand and the long-term stability of the air-exposed conducting polymer on the other. In this work, a different approach is proposed in order to solve both problems. IPN type materials are synthesised between poly(3,4-dihexylthiophene) and a combination of an ionic conducting polymer network (poly(ethyleneoxide) based) and various thermoplastics. The synthetic pathway which will be presented ensures a gradual dispersion of the electronic conducting polymer through the thickness of the network. In consequence, the crystallinity decreases from the outside towards the center of the film. The system
is thus similar to a layered one with the advantage that the conducting polymer is protected from the environment and the intimate combination of the two polymers need no adhesive interface. The influence of the morphology and chemical composition of the matrix on the electrochemical characterization of the material has been studied. The best results are obtained for about 80% polyethyleneoxide in the mixture where the material remains elastomeric enough and still keeps good mechanical properties due to the polycarbonate partner. Moreover, the addition of plasticizing oligomers which increase the free volume improves the surface conductivity with a maximum 15 S/cm. A study of the influence of the nature of the electrolytes on the intensity of the current shows that KClO4 gives better results than LiClO4. Finally, we showed that this electrochemical actuator is capable of a 45° angle deflection under a 0.5 V potential difference.

11:00 AM EE1.7
PARALLEL ELECTROCHEMICAL METHODS TO ACCELERATE ELECTROACTIVE MATERIAL DISCOVERY AND OPTIMIZATION Peter G. Madden, John D. Madden, Inn W. Hunter, Massachusetts Institute of Technology, Cambridge, MA.

In the search for new electroactive polymer materials, determining which materials are most promising and finding optimal synthesis conditions are difficult and time consuming. There is a need for parallel synthesis and experimentation techniques that can accelerate the discovery process. We have developed an eight cell parallel electrochemical synthesis and testing platform. The system bandwidth of over 10 kHz is well above the minimum 1 kHz frequencies that are of interest for controlling current densities during the polymerization process. A peak current of 100 mA provided by each of the eight cell potentiostats is ample for the small working electrode sizes used (~180 mm²). Typical synthesis for polyacrylate film growth rates on the order of 10 cm/hr or current density around 0.1 to 1.0 A/cm² and can be done at temperatures down to -50°C. Initial results are presented that use linear system identification techniques to measure the electrochemical impulse and frequency response of polyacrylate synthesized under different conditions.

11:15 AM EE1.8
EAP BASED SKIN AND MUSCLES FOR MAN MACHINE INTERFACE. Dario De Rossi, Alberto Minzoni, Cemre ‘O’Plaggio’, Faculty of Engineering, University of Pisa, Pisa, ITALY.

Biomimetic EAP sensors and actuators are being developed in forms that can be used as skin-like and pseudomuscular systems. Conducting electroactive and piezoelectric polymers in form of fibers, threads and fabrics have been made and their mechanoelectric transduction properties quantified. Wearable haptic interface in form of a sensory-motor glove has been designed under solid biomechanical arguments and then built. It is intended to be used in the virtual reality and rehabilitation fields. An android face has also been constructed, endowed with stereotypical expressivity. Facial movements are governed by biomimetic actuators and controlled by learning algorithm and a limited set of actor face expression. Animatronics is its intended field of use. This talk will mostly address crucial material issues to be identified and solved to realize truly effective interfaces.

SESSION EE2: ELECTROACTIVE POLYMER DEVICE APPLICATIONS (INCLUDING THIN FILMS)
Chair: Siegfried Bauer and Qiming Zhang
Monday Afternoon, November 26, 2001
Fairfax (Sheraton)

1:30 PM EE2.1
THE ELECTROACTIVE POLYMERS INFRASTRUCTURE. Yoav Shabtai, JPL, Pasadena, CA.

In the last ten years, new EAP materials have emerged that exhibit large displacement in response to electrical stimuli enabling great potential for the field. To develop efficient EAP that are robust for practical applications there is a need to establish an adequate EAP infrastructure. This requires developing adequate understanding of EAP materials, as well as effective processing and characterization techniques. Enhancement of the actuation force requires understanding the basic principles using computational chemistry models, comprehensive material science, electro-mechanics numerical techniques and advanced measurement techniques. Efforts are needed to gain better understanding of the parameters that control the EAP actuation force and deformation. The processes of synthesizing, fabricating, testing, and handling need to be refined to maximize the EAP materials actuation capability and robustness. Methods of reliably characterizing the response of these materials are required to establish database with documented material properties in order to support design engineers considering use of these materials and towards making EAP as actuators of choice. Various configurations of EAP actuators and sensors need to be modeled to produce innovative and effective smart EAP driven system. The development of the infrastructure is a multidisciplinary task involving materials science, chemistry, electro-mechanics, computers, electronics, and others. This paper will be a review of the status of the EAP infrastructure and the challenges to practical application of EAP materials as actuators.

1:45 PM EE2.2
SOUND REFLECTION AND ABSORPTION BY PIEZOELECTRIC POLYMER FILMS. Hideki Koshida, Munehiro Date, Eiichi Fukada, Keio University, Institute of Physical Research and Rion Co., Ltd., Dept. of Research and Development, Tokyo, JAPAN; Tomosei Okubo, Keio University, Institute of Physical Research, Tokyo, JAPAN.

It has been found that the elastic properties of piezoelectric materials are controlled by connecting negative capacitance circuits. The stress induced by charge is amplified by the circuit and the feedback voltage is applied on the materials. The direct and inverse piezoelectric effects are thus superposed. By matching the capacity and resistance of the circuits to those of piezoelectric materials, the apparent elastic constants of the materials are arbitrarily increased or decreased depending on the kind of the circuit. The present paper describes experiments on sound reflection and absorption using this principle. About 10 μm thick films of PVDF or PVDF/TFE were installed in the center of an acoustic tube with a 43 mm diameter and about 1 m length. Glass wool or urethane foam was placed behind the film to keep this under tension. Using a standard two-microphone method for the absorption coefficient and transmission loss of the film were determined as a function of frequency. With the circuit increasing the elastic constant, 10-20 dB increase of transmission loss (increase of reflection) was observed at arbitrary tuned frequencies. With the circuit decreasing the elastic constant, the increase of the absorption coefficient was observed at tuned frequencies. By choosing appropriate circuit components, 10 dB sound isolation over a frequency range from 200-1000 Hz was achieved. A piezoelectric ceramic PZT plate was fixed between a shaker and a mass and connected to a negative capacitance circuit. The transmissibility of vibration through the PZT plate was determined as a function of frequency. When the circuit components were adjusted to match with the impedance of PZT plate, the sharp decrease of transmissibility by 60 dB was observed at 3kHz. Owing to the high piezoelectric activity in PZT, the complete isolation of vibration was achieved. New applications of piezoelectric polymers and ceramics in noise control and vibration suppression are proposed.

2:15 PM EE2.3
Ferroelectric POLYMERS FOR HIGH PRESSURE AND SHOCK COMPRESSION SENSORS. Francois Baeur, Institute Franco-allemand de Recherches de Saint-Lois, TSL, Saint-Lois, FRANCE.

Ferroelectric polymers (PVDF) with well-defined and precisely known electrical properties are now routinely available from commercial sources. Electrical processing with the Bauer poling method can produce individual films with well-defined remnant polarization up to 50 μC/cm². These polymers provide an unusual opportunity to study the structure and physical properties of materials subjected to shock loading. The behavior of PVDF has been studied over a wide range of pressures using high-pressure shock loading and has yielded well-behaved, reproducible data up to 26 GPa in inert materials. Application of PVDF gauges for recording shock waves induced in polar materials like polymers or in reactive materials is hampered by observations of nonlinear responses due to shock-induced polarization. A solution using an appropriate electrical shielding has been identified and applied to PVDF for shock measurements of polymer (Kevlar), and for Hugoniot measurements of High Explosives (HE). Furthermore, shock pressure profiles obtained with in situ PVDF gauges in porous H.E. in a detonation regime have been achieved. Typical results of shock pressure profile versus time show a fast pressure of a few nanoseconds followed by a pressure release down to a plateau level and then by a pressure increase. Observations have raised the question of the leading path dependence of the piezoelectric response of PVDF at high shock pressure levels. Consequently, studies of the piezoelectric behavior of PVDF gauges under impact loading using a two-stage light gas gun have been conducted. Results show that the PVDF response appears independent of the leading path up to 30 GPa. P(VDF-TrFE) copolymers exhibit unique piezoelectric properties over a wide range of temperatures depending on their composition and phase transition are being investigated. These copolymers are also strong candidates for electroactive applications. Emphasis of the presentation will be on key results and implications.

2:45 PM EE2.4
DEVICE FABRICATION AND PERFORMANCE OF
4:30 PM **EE2.7**

**FINITE SIZE EFFECT IN FERROELECTRIC POLYMER THIN AND ULTRATHIN SPIN CAST FILMS.** Feng Xin, H. S. Xu, B. Ruzin, Z.-Y. Cheng, and Q. M. Zhang, Penn State University, Materials Research Laboratory, University Park, PA.

Ferroelectric polymer thin films have gained a lot of attention due to their emerging applications in MEMS, memory devices, and pyroelectric sensors. Thin ferroelectric polymer films also provide unique system to investigate the finite size, dimensional, and interface effects in the ferroelectric behavior. Recently, we examined the structures, morphology, and ferroelectric switching behavior in spin cast (P(VDF-TrFE)) thin and ultrathin films (from 40 nm to 1 mm) on electrode silicon wafer. It was observed that the ferroelectric behavior in these films does not change with thickness and the observed changes in various properties are caused by interface effects and also by the change of the crystallinity. However, the activation energy increases as the film thickness is reduced, this phenomenon is caused by the interface effect, likely due to the charge injection process across metal-polymer film interface barrier. Furthermore, for films below 100 nm, there is an additional large increase of the activation energy with reduced film thickness, which is caused by the precipitous drop of the film crystallinity (as verified by the X-ray and AFM data) at this thickness. The result indicates that for the spin cast (P(VDF-TrFE)) thin films, there exists a critical thickness, below which the crystallization process is strongly hindered. Detailed X-ray study on films annealed under different conditions suggests that this critical thickness in the crystallization process of polymer thin films is determined by the crystalline lamella width along the film thickness direction.

4:45 PM **EE2.8**

**MORPHOLOGY, MELTING, AND CRYSTALLIZATION OF FERROELECTRIC LANGMUIR-BLATTNER FILMS.** P. Bal, M. Pestemer, A. V. Sorokin, Stephen Durham, Department of Physics and Astronomy and Center for Materials Research and Analysis, University of Nebraska, Lincoln, NE. V. M. Fokin, Institute of Crystallography, Russian Academy of Sciences, Moscow, RUSSIA.

We report the investigation of the morphology of films of vinylidene fluoride (70/30 mol%) and trifluoroethylene (30/70 mol%) copolymer made by Langmuir-Blodgett (LB) deposition on Si (100) deposition on Si (100) substrates, followed by thermal annealing at 120°C. X-ray diffraction and infrared ellipsometry measurements show that the films are highly planar with the ferroelectric (002) phase structure having [110] orientation, where the polymer chains are parallel to the film and the CO2-CH2 dipoles are tilted from the normal. Melting the film at 150°C and then slow cooling it results in destruction of the [110] crystals and growth of needle-like structures with dimensions of 10 μm long by 0.3 μm wide, resembling lamellae lying on the substrate, as observed by scanning electron microscopy. The melted films have polymer chains segments tilted out of the film plane, as confirmed by infrared ellipsometry.

This work is supported by National Science Foundation and by the Nebraska Research Initiative.

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**SESSION EE3: POSTER SESSION**

**NOVEL ELECTROACTIVE POLYMERS I**

Chair: Qingmin Zhang

Monday, November 26, 2001
8:00 PM
Exhibition Hall D (Hyatt)

EE3.1

**CHARACTERIZATION OF ORDERED MESOPOROUS CONDUCTING POLYMER FILMS.** Yun-Ju Lee, Katharine A. Penning, Stephanie A. Pruzinsky, Paul V. Braun, UIUC, Dept. of Mat Science and Eng, Urbana, IL.

It has been demonstrated that colloidal crystals formed by self-assembly from colloidal suspensions can template the synthesis of various materials, leading to mesoporous solids with translationally ordered pores following the removal of the colloidal crystal template. Here, we demonstrate the electrochemical synthesis of thin films of mesoporous poly(pyrrole) on glassy carbon, showing complete filling of interstitial voids by the conducting polymer and successful removal of the contiguous colloidal crystal template. Such mesoporous conducting polymer films are promising due to the close contact between the film and the supporting electrode, which may speed up or alter the relatively slow counter ion mass transport kinetics that in many cases represent the rate-limiting factor in charging and discharging of conducting polymers. We present the results of electrochemical characterization of mesoporous poly(pyrrole) films. Cyclic voltammetry and chronoamperometry indicate that mesoporous...
conducting polymer films operate under different kinetics compared with bulk films. It is hypothesized that such difference originates in part from the presence of a large number of small nanoparticles and electrolytes present in the interconnected pores. Understanding the kinetics may enable the fabrication of devices such as supercapacitors and fast-response actuators from conducting polymers.

E3.2 SENSING MECHANISM OF CONDUCTING POLYMER SENSOR FOR VOLATILE ORGANIC COMPOUNDS. Jeong-soo Hah, Ha-Hyung Hong, Jeong Hwang, Duk Dong Lee, Environmental Gas Monitoring Lab, Kyungpook National University, Daegu, KOREA; Jeong-Ok Lim, Medical Research Institute, Kyungpook National University, KOREA.

The importance of environment gas sensing is well understood and much research has focused on the development of suitable gas sensitive materials. Among many different types of gas sensors, metal oxide and conducting polymer type sensors are most popular. There has recently been interest in the use of conducting polymers such as poly(pyrrole) (PPy) and polyaniline (PANI) as sensors for volatile organic compounds (VOC). PPy and PANI detect VOCs at room temperature and their synthesis is simple. Sensing principle associated with conducting polymers is in progress. However, as explained, the mechanism of conducting polymer sensing on gas molecules, especially VOCs, in this study, we fabricated chemically polymerized PPy and PANI films with different selectivity by controlling doping time. The sensing properties and mechanism of VOCs adsorption to conducting polymers were investigated with contact angle measurements, scanning probe microscopy and UV–vis spectroscopy. Upon gas adsorption, PPy–based sensor exhibited positive sensitivity while poly(aniline) had negative sensitivity. PPy film showed hydrophilic property and PANI film showed hydrophobic property. After gas adsorption, the sensitivity increased as function of polarity of adsorbed gas. We found that conducting polymer sensor is very sensitive to the difference in polarity of gas molecules.

E3.3 THIQ-WRISTNEITHER INCORPORATED METHACRYLATE POLYMERS FOR MICROSENSOR FOR MERCURY IONS IN SOLUTION. Jagannathan Arockiam, Thomas Johnson, Valiyaveettil Suresh, Lee Han Kee, National University of Singapore, SINGAPORE.

Due to the high demand for smart sensors in environmental monitoring and biomedical applications, major studies are underway towards the development of sophisticated sensors with real-time applications. The major roadblock in developing a chemical sensor lies in the modification of the functional layer. We have explored the possibility of developing metal ion sensors using crownether as a sensing moiety. We incorporated the thia-crownether by covalent bond to a methacrylate polymer backbone. From the extraction studies, the polymer is found to be an excellent candidate for the mercury sensor applications. This paper will focus on the synthesis, metal extraction studies, and the fabrication of the sensor.

E3.4 AN ENHANCED REDOX PROCESS OF CYTOCHROME C DISULFIDE AT POLYANILINE FILM ELECTRODE. Yuanyun Zhou, Bin Yu, Kalle Leven, Dept. of Chemistry and Chemical Engineering, Brooklyn, NY.

Conducting polymer, polyaniline was used as a probe to analyze the role of cytochrome c disulfide in the redox transition of cytochrome c. Peak potential separation of 1.22 mV between the cathodic and anodic peak with a formal potential of 0.38 V (vs. NHE) of disulfide presenting in cytochrome c became 70 mV on a polyaniline electrode. This enhancing effect can be attributed to the formation of redox adducts between the disulfide group and the N sites in the polyaniline moieties. As a result, the presence of disulfides in cytochrome c was responsible for the lack of the electrochemical responses of the conducting polymer film on the electrodes, such as gold, platinum electrode, which have high affinities towards adsorption of sulfur-containing protein. The mechanism for the effect was using electrochemistry and IRRAS spectroscopy.

E3.5 SURFACE MODIFICATION OF NEURAL RECORDING MICROELECTRODES BY CONDUCTING POLYMER SENSORS. Miyao Yang, Ed C. Martin, University of Michigan, Macromolecular Science and Engineering Center, Ann Arbor, MI.

Micromachined multichannel neural probe consists of silicon chips that have gold or iridium microelectrode sites on their surface. They have been successfully used in acute neural recording from central nervous system, but their recording capability degrades after a few weeks of implantation. Clearly, improvement of the electrode-tissue interface needs to be done to enhance signal transport and chronic stability. Conducting polymer poly(pyrrole) and poly(3,4-ethylenedioxythiophene) (PEDOT) have been deposited on the electrode sites electrochemically. The deposition of conducting polymer film provides an interface with much higher surface area and lower impedance than the metal electrode sites. CDPGyigSR is a fragment of hemin and has been proved to be able to promote neuron attachment. Deproteinization CDPGyigSR was synthesized with poly(pyrrole) and co-deposited with PEDOT on the neural electrodes. In cell culture test, conducting polymer/polymer coated electrode attracted local attachment of neurons, which demonstrated the biocompatibility of the peptide in the polymer films. The peptide in the conducting polymer film proved to be stable by micro-focusing infrared spectroscopy after 3 months of soak testing in de-ionized water. The electrochemical property of the conducting polymer was examined by cyclic voltammetry. PEDOT was a more robust material than the poly(pyrrole) under electrochemical cycling. Chronic implantation of poly(pyrrole)/peptide coated probes was performed and followed by neural recording. After 2 weeks, the probe was explanted and examined for neuron attachment. It was found that neurons preferentially attached onto the peptide coated electrode sites and stable single unit of neural activity was recorded through those sites.

E3.6 FERROELECTRIC PROPERTIES OF VINYLIDENE FLUORIDE Oligomer. Kenji Ishida 1,2, Kei Noda 1, Atsushi Kubono 3, Toshihiko Morita 1, Hirofumi Yamada 1 and Kazumi Matsushita 1.

Kyoto Univ., Dept. of Electronic Science and Engineering, Kyoto, JAPAN. "PREST-JST. Kyoto Institute of Technology, Dept. of Polymer Science and Engineering, Kyoto, JAPAN.

Ferroelectric polymers are attractive for various application fields, such as sensor, actuator and molecular ferroelectric devices. However, it is difficult to clearly discuss the polarization mechanism in molecular scale on the polymers due to the wide distribution of molecular weight and thickness of amorphous regions. Therefore, we selected a newly synthesized vinylidene fluoride (VDF) oligomer, CF 2(CH 2CF 2) 4I, with low molecular weight and its narrow distribution, and studied on structure and local piezoelectric behavior of VDF oligomer thin films. Here, we report their ferroelectric properties investigated by polarization response. VDF oligomer thin films of 5–10 nm were prepared by vacuum evaporation without pyrolysis. The structures of VDF oligomer thin films strongly depend on the kinds of substrate and heat treatment temperature and after film preparation. In particular, the VDF films with ferroelectric crystal phase could be prepared on metal substrate at low substrate temperature. Then, the top electrode was evaporated on the film for the electric measurement. The polarization hysteresis loops and I/V characteristics were evaluated by direct charge/current measurement system using high S/N op-amp. The difference of ferroelectric properties between polymer and oligomer films as well as their dependency on their crystal phases will be discussed.

E3.7 FERROELECTRIC POLARIZATION REVERSAL OF POLYMERS UNDER HIGH HYDROSTATIC PRESSURE. Susumu Kodama, Toshio Yuki, Takanori Nogisi, Hidetoshi Suzuki, Tomonori Koda, Yamanagta Univ., Dept. of Polymer Science and Engineering, Yonezawa, JAPAN.

Polymers which exhibit ferroelectric properties are classified into three stages. Some fluoro-polymers give clear polarization reversal phenomena and sharp ferroelectric-paraelectric phase transitions. Some polymers including urethane and urea groups have the possibility of ferroelectricity but the polarization reversal phenomena characteristic of ferroelectric materials have not been confirmed so far. On the other hand, odd-numbered oxalates including odd carbon in a monomer exhibit clear polarization reversal process although they do not give any phase transition below the melting temperature. In this paper, we report on their ferroelectric polarization reversal under high hydrostatic pressures. Specifically, we compared the ferroelectric polarization reversal of nylon 11 with those of copolymers of vinylidene fluoride (VDF) and trifluoroethylene (TFE). The hydrostatic pressure affects directly to the materials. Since the polarization reversal occurs due to the rotation of a molecular chain around the chain axis in both cases of nylon 11 and VDF–TFE copolymers, the effect of the hydrostatic pressure upon the polarization reversal phenomena reflects the nature of the intramolecular interaction controlling the ferroelectric properties of these polymers, We thus discuss the physical nature of the polarization reversal phenomena of these ferroelectric polymers.

E3.8 HIGH FREQUENCY DIELECTRIC RELAXATION IN POLYMERS FILLED WITH FERROELECTRIC CERAMICS. Noriko Noda and Jun OISHI, National Institute of Standards and Technology, Gaithersburg, MD.
We have investigated high frequency relaxations in polymer composite films filled with ferroelectric ceramics. Such materials can be used in the construction of compacted digital devices in microwave circuits and fast digital electronics. In order to extend the dielectric measurements to the microwave range, we developed an accurate measuring technique that utilizes a thin film capacitance determining microbridge. The complex permittivity measured at frequencies of 100 Hz to 10 GHz for several films 50 mm to 100 mm thick, having the dielectric constant of 2 to 30, was fitted to a dielectric model as a superposition of Havriliak-Negami functions. An intrinsic high dielectric loss peak has been identified in the polymers filled with ferroelectric ceramics. It was found that the position of the loss peak depends on the relaxation of the polymer matrix, while its magnitude is amplified by the permittivity of the ferroelectric material. Thus, both of the dielectric constants as well as the position and magnitudes of the loss peak can be controlled by modifying the composition of the dielectric material at the molecular level.

SESSION EE4: NOVEL ELECTROACTIVE

Chairs: Yosegh Bar-Cohen and Eishi Fukuda
Tuesday Morning, November 27, 2001
Fairfax (Sheraton)

8:30 AM *EE4.1
TOWARD MOLECULAR MUSCLES: DESIGN OF SINGLE MOLECULE ELECTRO-MECHANICAL ACTUATORS BASED ON POLYTETRATHIENYLENE (TETRA[2,3-THIENYLENE])
S. Michael J. Marujo, University of California, Department of Chemistry, Riverside, CA.

Electrically conducting polymers (CPs) have the ability to function as bulk electromechanical actuators (EMAs), and have been utilized in the fabrication of microactuators. The interest in further shrinking devices to the molecular level has intensified in recent years, including the concept of a molecular actuator (molecular muscle). In the case of traditional bulk CP-EMAs, actuation results from volume changes occurring in the bulk material via redox-induced counterion intercalation (expansion) and expulsion (contraction). In contrast, poly(tetra[2,3-thielenyl]) has been specifically designed to function as a single molecule EMA. In this system, the tetra[2,3-thielenyl] repeat unit serves as a masked [8]helicene, and expansion and contraction of the polymer chain results from a redox-induced conformational change that occurs at each tetra[2,3-thielenyl] repeat unit. Specifically, the conformational change that allows single molecule EMA to be analogous to the tubo-to-plane interconversion that is observed in the reversible reduction of cytochrome c. The evidence for single molecule EMA in poly(tetra[2,3-thielenyl]) has been elusive, as analysis is complicated by the fact that traditional methods of determining EMA in bulk systems do not apply to analysis at the single molecule level. These issues, as well as progress to date in the functional "molecular muscle" will be reported.

9:00 AM *EE4.2
GIANT ROTARY POWER AND LIGHT MODULATION BY POLYLACTIC ACID FILM: Yoshiro Tachibana, Yamagata Univ, Dept of Polymer Sci & Eng, Yonezawa, Yamagata, JAPAN

Aliphatic polyester is an example of such polymers; in particular, expectations for polyactic acid (PLA) in which molecules containing asymmetric carbon atoms have a helical orientation have been expected, for a long time, to exhibit optical activity with significantly higher optical rotary power in their solid state, compared with inorganic low-molecular-weight crystals. We examined the optical rotation and light modulation properties of poly-l-lactic acid (PLLA) and poly-d-lactic acid (PDLA) films in which the helical-structure is controlled by heating. The findings from this study are summarized as follows:

1) Existence of significant rotary power in the fiber axis direction of PLLA and PDLA films.
2) PLLA and PDLA films possess levorotatory power and dextrorotatory power, respectively. The rotary optical power of a PLLA film is 3200 degrees/mm and approximately 100 times greater than that of quartz. The required thickness of a component is 10 mm for a PLLA film, while it is 1 mm for quartz.
3) The demonstration of light modulation by PLLA films.

We confirmed light modulation up to 10 Mhz. Since the PLLA film provides a fast response, we believe that a light modulation speed in the GHz range using a more modified PLLA sample is possible.

Acknowledgments:
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We would like to thank Dr. Y. Shikimori of Takiron Co., Ltd. for providing us with PLLA samples.

9:30 AM EE4.3
FORCE, TIME RESPONSE AND EFFICIENCY OF IONIC METAL POLYMER COMPOSITES. Anthony Kuczeruk, Department of Chemistry, Imperial College of Science, Technology and Medicine, London, UNITED KINGDOM.

Ionic polymer metal composites (IPMCs) are a class of materials composed of two high surface area metal electrodes deposited on either side of an ion exchange membrane. A range of these materials have been produced through the use of a metal powder mixed with a Nafion membrane and or the deposition of an ink of a particulate powder mixed with Nafion solution. The best results are obtained when the electrodes are composed of gold, although good results are also obtained when platinum is used. Electrodes composed of lead or cadmium show reasonably good results, although suffer from long term stability problems. Electrodes composed of carbon work, although suffer from large residual drops in their extreme layers. All of these materials show good met Nafion interfacial contact areas, equal to thickness factors of several hundred. The IPMCs flex in both air and water when a potential of 3-4 V is applied across the two sides. In this paper we produce a range of IPMCs of different thicknesses and examine the force developed by these materials, the time constant of the flexing response and efficiency for converting electrical energy into work. The force developed by these materials at constant applied potential increases linearly with the thickness of the material over the range 70-440 m. Efficiency of electrical to mechanical work is less than 1%, although this appears to be dominated by irreversibility in the electrochemical reactions occurring on the electrodes and resistive losses in the electrode layer. This work was in part supported by Dr. Alan Hooper of QinetiQ plc [formally the UK Defence Research and Evaluation Agency] and funded through the UK MoD TP04 Materials and Structures Corporate Research Programme.

9:45 AM EE4.4
CHARACTERIZATION OF THE ELECTRO-MECHANICAL PROPERTIES OF IPMC. Yosegh Bar-Cohen, JPL, Pasadena, CA; Kushik Bhattacharya, Caltech, Pasadena, CA; Xingqiu Bao, JPL, Pasadena, CA; Shyli-Shih Li, JPL, Pasadena, CA; and Xiao Yu, Caltech, Pasadena, CA.

Ionic Polymer-Metal Composite (IPMC) as electroactive polymer (EAP) was the subject of research and development since 1992. IPMC’s low required activation voltage and the large bending led to the considerations of various potential applications. However, before the benefits of IPMC can be effectively exploited for practical use, the electro-mechanical behavior must be properly quantified. An experimental setup was developed for data acquisition from IPMC strips subjected to various tip mass levels and in parallel an analytical model was developed to predict the material response. Using the analytical model and an inversion algorithm the modulus, and relaxation time were determined. The programmable setup was used to acquire the displacement and curvature of IPMC as a function of the electrical signal characteristics. Sample strips were immersed in water to minimize the effect of moisture content and were tested with and without tip mass. In order to avoid hydrolysis the samples were subjected to 3 V square wave with either positive or negative polarity. A multiscale model was developed that showed satisfactory results for tetra-n-butylammonium cations/Filmic IPMC, which responds slowly and monotonically without reduction. This model starts at the mesoscale level with three fully coupled partial differential equations in concert concentration, electric potential and elasticity. Solution in the strip geometry leads to a macroscopic ordinary differential equation whose solution fits the observed behavior very well. Deviation from the model was observed when the material shows relaxation, in the case of Li cations/Nafion. This type of IPMC has history dependence and responds with a quick bending in front of a second starts relaxing and address this deviation would require further studies.

10:00 AM EE4.5
SHAPING MEMORY BEHAVIOR OF MODIFIED POLYCYCLOOCITENE. Changdeng Liu, Seung-Bum Chun, Patrick T. Mather, University of Connecticut, Polymer Program and Chemical Engineering Dept., Storrs, CT; E. Bryan Coughlin, University of Massachusetts, Polymer Science and Engineering, Amherst, MA.

Shape memory materials are those that, after deformation to a different shape at certain conditions and fixing, can recover the original shape (memory) by heating to a certain temperature. While the most common shape memory material is nisal, a shape memory alloy (SMA), recent years have led to the discovery and investigation of shape memory polymers (SMP). Such materials attract significant attention due to low cost, large strain to several hundred percent, and a broad range of transition temperatures compared with SMAs.
Examples of SMPs include polynorbornene, polystyrene-b-butadiene,
bistrene, and trans-polyisoprene. In this presentation, we report on
electromechanical characterization of a shape memory polymer we have recently
developed—a modified polycrylooctene—
that acts as a shape memory rubber (SMR). Quantitative assessment of
strain recovery reveals a fast shape memory effect of the new
materials which is controlled by the material’s microstructure.
We present results of SMR characterization by differential scanning
thermal analysis (DSC), dynamic mechanical analysis (DMA),
and wide-angle x-ray scattering (WAXD) and the mechanism of the shape
memory is discussed in detail.

10:45 AM EE4.6
FACTORS AFFECTING ACTUATION RATE IN PARTIALLY
NEUTRALIZED POLYACRYLATE GELS. Ingrid A. Ressman,
Kimberly G. Ozkan and Patrick T. Mather, Polymer Program
Chemical Engineering Department, University of Connecticut, Storrs, CT.

Polyelectrolyte networks composed of poly(acrylic acid) (PAAc)
cross-linked with poly(ethylene glycol dimethacrylate) are sensitive to
electrical stimuli, allowing potential use as soft actuators. In our
studies, PAAc was prepared via radical polymerization using UV
irradiation from pregel solutions that allow independent control of the
crosslinking density, the extent of neutralization, as well as the water
content after polymerization. The networks thus formed underwent a
swelling process that consists of, first, a soaking in deionized water to
allow for the removal of the uncrosslinked species, followed by several
soakings in deionized water to reach swelling and pH equilibrium in
the swelling bath. The swelling behavior of these swollen PAAc
gels was studied under the influence of a DC electric field when
applied either in deionized water, in the swelling medium or at
equilibrium, or in solutions of various pH. We find that the curvature
observed for these hydrogels depends strongly on all of the chosen
variables and that a compromise of low hydrogel neutralization and
high pH of the suspending medium yields the fastest electrical
response. However, an unexpected phenomenon is also observed: the
swelling behavior seems to be composed of three stages that are active
counter-diffusion processes. The earliest stage consists of a
swelling of the network, and is followed by an intermediate stage
that reverses the bending direction to be toward the cathode. Finally,
the last stage features hydrogel rod shrinkage in all the directions.

Depending on the conditions of our electromechanical analyses, the
earlier and intermediate stages are more or less improved in terms of
fast response and/or higher curvature attained. In order to evaluate the
potential of these gels for eventual further applications, clarity as
well as rheological measurements have been performed. Furthermore,
the field-sensitive response of the gel was considered for both
microporous and thin film-reinforced hydrogels.

11:00 AM EE4.7
MECHANICAL PROPERTIES CHARACTERIZATION AND
MODELING OF ACTIVE POLYMER GELS. Steven P. Mets K.T.
Hamesh, Andrew S. Douglass, The Johns Hopkins University,
Department of Mechanical Engineering, Baltimore, MD.

Active polymer gels expand and contract in response to certain
environmental stimuli, such as the application of an electric field or a
drastic change in the surrounding medium. The ability to achieve
large, reversible deformations with no external mechanical loading has
generated much interest in the use of these biomimetic gels as
actuators and "artificial muscles." A thermodynamically consistent
finite-strain constitutive model was developed to describe the
mechanical and actuation behaviors of active polymer gels. The
mechanical properties are characterized by a free-energy function, and
the model utilizes an evolving internal variable to describe the
actuation state. Poly(vinyl alcohol)/poly(acrylic acid) (PVA-PAA) gel
was chosen as the model material for this work because it is relatively
simple and safe to both fabricate and operate. These gels expand when
moved from acidic to basic solutions, and contract when moved from
basic to acidic solutions. The form and parameters of the free-energy
function for fully contracted and fully expanded PVA-PAA gels were
determined from uniaxial tests, and the evolution law for the internal
variable was determined from free actuation experiments. The full
constitutive model is used to predict the response of the PVA-PAA
gel to isotonic and isometric loading and actuation. The model is
shown to give relatively good agreement with experimental results.

11:15 AM EE4.8
MULTIFUNCTIONAL ELECTROELASTOMER ROLLS. Qibing Pei,
Ron Pellegrino, Scott Stanford, Roy Kornbluh, Marcus Rosenblad,
Kenneth Mejers*, Robert Full*, SRI International, Menlo Park, CA,*
Department of Integrative Biology, University of California, Berkeley, CA.

We will present multifunctional electroelastomer rolls (MER’s) exhibiting high force, stroke, and strain sensor functions. The MER’s are
useful in a variety of applications where compact and high-stroke
actuation is required. Simulation results of a wheeled robot using the
MER’s as the robot’s one-degree-of-freedom legs are described. The
simulations show that MER’s produce a “synthetic leg” that can run and clear obstacles.

11:30 AM EE4.9
OPTIMAL DESIGN OF ELECTRORESTRICTIVE COMPOSITES.
Jingyu Li, Department of Engineering Mechanics, University of
Nebraska, Lincoln, NE.

Electrostrictive response is inherent in any material, but usually is
too small for practical applications. Recently several polymer systems
with high electrostrictive strain have been demonstrated. One
approach to significantly enhance the electrostrictive strain is to
incorporate the dielectric constant of polymer, which could be achieved
using composite technology by adding a high-permittivity second
phase. Care must be taken, however, to keep a balance between the
increase of dielectric constant which tends to increase the
electrostrictive strain, and increase of elastic constant which tends to
decrease the electrostrictive strain. We propose a micromechanical
approach for optimal design of electrostrictive composites, where
the connection between macroscopic properties of composites and their
microstructural details will be established. The optimal volume
fraction and morphology of the second phase will then be identified,
depending on whether the maximum electrostrictive strain or
maximum strain energy is desired.

11:45 AM EE4.10
PHASE BEHAVIORS OF PARTIALLY IONIZED HYDROGEL
PARTICLES IN AQUEOUS SALT SOLUTIONS: APPLICABILITY
OF MODIFIED DOUBLE LATTICE THEORY. Young Poo Hong,
Young Chae Bae, Hyeong Univ, Division of Chemical Engineering,
Seoul, KOREA.

Temperature and pH sensitive hydrogels play an important role in
the application of biotechnology, pharmacy and medicine. But for
successful applications, responses to some stimuli need to be quick
and uniform. Thermodynamically, the swelling equilibrium of gels
formed at different concentrations is governed by the osmotic pressure of mixing, elasticity and difference of concentration of mobile ions between gels and
surroundings. Recently, Hu et al. reported the double lattice model to
predict phase behaviors for polymer solution systems. In their model,
ordinary polymer solutions are described by the primary lattice while
the secondary lattice is introduced as a perturbation to account for the
specific interaction. To predict successfully phase behaviors of
poly-electrolyte hydrogels, we combined modified double lattice model
(MDL), Florý and Erman’s theory of elasticity and ideal domain theory.
Florý and Erman considered the elastic contribution to the change of
the free energy due to isotropic swelling or shrinking as a rubber
elasticity theory, which takes account of the nonaffine displacements of
network junctions under strain. In this study, we modify Hu et al.’s double-lattice model by introducing new universal
constants and simplifying the expression of the Helmholtz energy of
mixing. Interaction parameters obtained from LLC data of the linear
PNIPAAm/Water system are directly used to predict the swelling
equilibria for the NIPA gel/Water systems and for cationic NIPA
gel/water systems. Swelling behaviors are examined by using photon
correlation spectroscopy (PCS) technique.

SESSION EE5—NOVEL ELECTROACTIVE POLYMERS III
Chairs: Eiichi Fukuda and Joseph Bar-Cohen
Tuesday Afternoon, November 27, 2001
Fairfax (Sheraton)

1:30 PM *EE5.1
UNDERSTANDING THE ROLE OF CURING HISTORY ON THE
POLING AND PIEZOELECTRIC RESPONSE OF AMORPHOUS
POLY(METHYL METHACRYLATE) FILMS. Krystofor E. Wise, NRC/NASA-LARC, Hampton, VA; Chiao Park, TCAE/NASA-LARC, Hampton, VA.

Maximizing the piezoelectric response of amorphous polymer
materials depends critically on the extent of polarization achieved
during the poling procedure and on its retention after the field is
removed. High temperature polyamide polymers are characterized by
relative low rotational mobility along the backbone. This has the
desirable effect of increasing their operational temperature and the
undesirable effect of making them much more difficult to polarize. Using
a combination of theory and experiment, we have investigated a
procedure in which partially cured polymers are polarized prior to the
final poling reaction. Films produced in this manner exhibit increased
piezoelectric properties and high thermal stability.

2:00 PM EE5.2
HETEROGENEOUS SPACE CHARGE ELECTRET: MATERIALS

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WITH LARGE AND BROADBAND PIEZOELECTRICITY. Seyfried Bauer, Simon Bauer-Gogonea, Mario Durandmiller, Reinhard Schmidberger, Applied Physics, Johannes Kepler University, Linz, AUSTRIA.

Piezoelectricity is an electromechanical effect describing the coupling between mechanical and electrical fields. Near-zero piezoelectricity is at the heart of a large number of applications, requiring sensitive and low-cost piezoelectric materials. Strong piezoelectric responses have been found in ferroelectric crystals, ceramics, and polymers. The piezoelectric properties of ferroelectric polymer films can only be found in comparison to crystals and ceramics. Since several applications require low-density piezoelectric materials, with an acoustic impedance matched to air or water, the development of new piezoelectric polymers is of high urgency. It is shown that piezoelectricity is possible in space-charge electrets with quasi-permanent excess charges and heterogeneous material properties. A major breakthrough in the field has been independently reported most recently by several groups.

The finding that irradiation of copolymer films serve to break up the large crystalline regions in polar microregions resulting in a high-strain electroactive material has prompted an investigation to identify alternative routes to electrostriction. To determine whether these changes could be reproduced without the need for electron-irradiation, computations on PVDF-BFe terpolymer chains containing small levels of third monomer incorporating chlorine have provided a theoretical framework to support the hypothesis that the introduction of chlorine in the polymer chain can producing structural defects that result in the poling of the small-monomers in smaller regions. This calculation also demonstrates that poling can be created since introduction of bulky chlorine atoms into the polymer chains creates conformational defects that provide an alternative to break the long-range crystalline regions. The defects of polar regions can be regarded as distorted defect structures that give rise to random fields and electrostriction. Theoretical predictions as well as experimental support will be presented that show that certain chlorine-containing terpolymers such as CTF-Chs are indeed quite capable of converting P(VDF-TrFE) films into high-strain electroactive films.

3:00 PM EES.5

MOLECULAR MODELING STUDIES ON HIGH-STRAIN ELECTROACTIVE TERPOLYMERS. George Kwarsn, University of Rhode Island, Department of Chemistry, Kingston, RI; Thomas Ramotowski, Richard Hughes, Naval Undersea Warfare Center, Newport, RI; Qiming Zheng, Dana Olson, The Pennsylvania State University, Materials Research Laboratory, University Park, PA.

The finding that irradiation of copolymer films serves to break up the large crystalline regions in polar microregions resulting in a high-strain electroactive material has prompted an investigation to identify alternative routes to electrostriction. To determine whether these changes could be reproduced without the need for electron-irradiation, computations on PVDF-BFe terpolymer chains containing small levels of third monomer incorporating chlorine have provided a theoretical framework to support the hypothesis that the introduction of chlorine in the polymer chain can producing structural defects that result in the poling of the small-monomers in smaller regions. This calculation also demonstrates that poling can be created since introduction of bulky chlorine atoms into the polymer chains creates conformational defects that provide an alternative to break the long-range crystalline regions. The defects of polar regions can be regarded as distorted defect structures that give rise to random fields and electrostriction. Theoretical predictions as well as experimental support will be presented that show that certain chlorine-containing terpolymers such as CTF-Chs are indeed quite capable of converting P(VDF-TrFE) films into high-strain electroactive films.

3:45 PM EES.6

CHEMICAL AND PHYSICAL CHANGES ASSOCIATED WITH HIGH-STRAIN ELECTROSTRICTION IN BETA-IRRADIATED PVDF-BFe COPOLEMS. Thomas Ramotowski, O. Richard Hughes, Naval Undersea Warfare Center, Newport, RI; George Kwarsn, University of Rhode Island, Kingston, RI; Karen Olson, Massachusetts Institute of Technology, Cambridge, MA; Qiming Zheng, Pennsylvania State University, University Park, PA; Robert Ting, University of Central Florida, Orlando, FL.

In 1998, Zhang et al. demonstrated that large doses of high-energy beta radiation could transform certain vinylidene fluoride-trifluorooethylene (PVDF-TrFE) copolymers into high-strain electroactive materials. Since then, the research group of the U.S. Navy researchers and their colleagues have been analyzing irradiated PVDF-BFe copolymers to determine what physical and chemical changes were associated with the materials’ desirable high-strain electroactive properties. The model, obvious radicants-induced structural change in the introduction of chain scission and repair of backbone towards the polymer’s Curie temperature. TGA, TGA-M, TAF-NMR, FTIR, and DTA data documenting the existence of these beta-radiation-induced chemical changes have been collected and will be presented. This research has importance from the material perspective. Materials scientists can be interested in improving the existing materials and/or creating new, high-strain electroactive polymers with or without the use of beta radiation.

4:00 PM EES.7

NEW FERROELECTRIC FLUOROELECTRIC TERPOLYMERS BASED ON VINYLIDENE AND BULKY TERMOPLASTIC HIGH-DIELECTRIC-CONSTANT AND LARGE ELECTRIC RESPONSE AT ROOM TEMPERATURE. T.C. Mike Chung, A. Petuchowski, The Pennsylvania State University, Materials Research Laboratory, University Park, PA.
This paper discusses a new family of ferroelectric polymers with high
dielectric constant (> 50 at 1 kHz) and large electrostrictive
response (> 5%) at ambient temperature. These polymers are high
molecular weight semicrystalline terpolymers comprising vinylidene
difluoride (VDF), trifluoroethylene (TrFE), and a bulky third
monomer, such as chlorotrifluoroethylene (CTFE). They were
prepared by a living free radical initiator, based on the in situ
oxidation adduct of trialkylborane/oxygen, and bulk polymerization
process at low reaction temperature. The combination of living
polymerization mechanism and monomer feeding control to maintain
constant monomer feed ratio affords the terpolymers with the designed
polymer molecular weight and relatively narrow molecular weight and
composition distributions. The incorporated bulky third monomer
units homogeneously distributed along the polymer chain seem to
reduce the thickness of ferroelectric crystalline domains without
destroying the overall crystallinity. This nanoscale semicrystalline
morphology results in the reduction of ferroelectric-paraelectric (P-P)
phase transition to near ambient temperature with a very small
energy barrier. Some terpolymers exhibited common ferroelectric
relaxor behaviors with a broad dielectric peak that shifted toward
higher temperatures as the frequency increased, and a slim
polarization hysteresis loop at near the dielectric peak (around
ambient temperature) that gradually evolved into a normal
ferroelectric polarization hysteresis loop with reduced temperature.

4:15 P.M. EE5.8
MODEL DEVELOPMENT FOR HIGH-PERFORMANCE
PIEZOELECTRIC POLYMERS. Zoheida Ounni, ICASE, M/S
132C, NASA Langley Research Center, Hampton, VA; Ralph Smith,
Department of Mathematics, North Carolina State University,
Raleigh, NC.

Piezoelectric polymers have been incorporated as sensors and
actuators in devices employed in applications ranging from biomedical
imaging to flap design for flow control. An important emerging
application area for electroactive polymers is in the biomedical field
where polymers are being explored as potential artificial muscle
actuators, actuator implants to stimulate tissue and bone growth, and
sensors to monitor vascular grafts and to prevent blockages. Such
applications are ideal for polymers since they have excellent
conformability and impedance matching to body fluids and human
tissue and they can be designed to be biocompatible. Polymers
typically possess a high dielectric breakdown and high operating field
strength, which means that they can withstand much higher driving
fields than ceramics. Due to inherent properties, their behavior
exhibits nonlinear and hysteretic effects which must be characterized
to fully realize the potential of these materials in high performance
applications. This work focuses on the characterization of fundamental
properties of piezoelectric materials (e.g., PVDF), including molecular
structure effects and constitutive nonlinearities, through a symbiotic
combination of experimental and analytic techniques. Aspects of the
model will be validated through comparison with experimental data.

4:30 P.M. EE5.9
Transferred to EE5.1