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Nanotechnology Using Electroactive Polymers as Artificial Muscles

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INTRODUCTION

During the last ten years, new polymers have emerged that respond to electrical stimulation with a significantly shape or size change. This capability of the new electroactive polymers (EAP) attracted the attention of engineers and scientists from many different disciplines. Since these materials behave similar to biological muscles, they have acquired the moniker “artificial muscles” [Bar-Cohen, 2001]. Practitioners in bio-mimetics, a field where robotic mechanisms are developed based on biologically inspired models, are particularly excited about these materials since they can be applied to mimic the movements of animals and insects. The emergence of micro- nano- and molecular size EAP is allowing to consider such scale mechanisms that were unimaginable in past years. The current limitations of EAP materials that include low actuation force, mechanical energy density and robustness are limiting the scope of their practical application.

In recognition of the need for international cooperation among the developers, and users, the author organized the first EAP Conference on March 1-2, 1999, though SPIE International as part of the Smart Structures and Materials Symposium. This conference was held in Newport Beach, California, USA and was the largest ever on this subject, marking an important milestone and turning the spotlight onto these emerging materials and their potential. The SPIE conferences are now organized annually and have been steadily growing in number of presentations and attendees. Currently, there is a website that archives related information and links to homepages of EAP research and development facilities worldwide, and a semi-annual Newsletter is issued electronically [http://ndeaa.jpl.nasa.gov/]. In June 2002, for the first time the Conf. ACTUATOR will include an EAP session.

The increased resources, the growing number of investigators conducting research related to EAP, and the improved developers/user collaboration are expected to lead to rapid progress in the coming years. In 1999, the author posted a challenge to the worldwide community of EAP experts to develop a robotic arm that is actuated by artificial muscles to win an arm wrestling match with a human opponent (Figure 1). Progress towards this goal will lead to great benefits, particularly in the medical area, including effective prosthetics. Decades from now, EAP may be used to replace damaged human muscles, potentially leading to a "bionic human."

FIGURE 1: Grand challenge for the development of EAP actuated robotics

THE EVOLUTION OF EAP

Electrical excitation is only one of the stimulators that can induce elastic deformation in polymers. Other activation mechanisms include chemical, thermal, pneumatic, optical, and magnetic. The convenience and practicality of electrical stimulation, and technology progress led to a growing interest in EAP materials. The beginning of the EAP field can be traced back to an 1880 experiment that was conducted by Roentgen using a rubber-band that was charged and discharged with cantilever having a fixed end and a mass attached to the free end. The following milestone was recorded only in 1925 with the discovery of a piezoelectric polymer called electret. Following the 1969 observation of a substantial piezoelectric activity in PVF2, investigators started examining other polymer systems, and a series of effective materials have emerged. The largest progress in EAPs development occurred in the last ten years where effective materials have emerged that can induce strains that exceed 300%.

ELECTROACTIVE POLYMERS (EAP)

Polymers that exhibit shape change in response to electrical stimulation can be divided into two distinct groups: electronic (driven by electric field or Coulomb forces) and ionic (involves mobility or diffusion of ions). The electronic polymers can be made to hold the induced displacement under activation of a DC voltage, allowing them to be considered for robotic applications. Also, these materials have a greater mechanical energy density and they can be operated in air with no major constraints. However, they require a high activation fields (>150-V/μm) close to the breakdown level. In contrast, ionic EAP materials require drive voltages as low as 1-10 Volts. However, there is a need to maintain their wetness, and except for conductive polymers it is difficult to sustain DC-induced displacements. The materials in each group include:

ELECTRIC EAP

- Dielectric EAP
- Electrostrictive Graft Elastomers
- Electrostrictive Paper
- Electro-Viscoelastic Elastomers
- Ferroelectric Polymers
- Liquid Crystal Elastomer (LCE) Materials

IONIC EAP

- Carbon Nanotubes (CNT)
- Conductive Polymers (CP)
- ElectroRheological Fluids (ERF)
- Ionic Polymer Gels (IPG)
- Ionomeric Polymer-Metal Composites (IPMC)

The induced displacement of both EAP groups can be designed to bend, stretch or contract. Making them to bend with a significant curving response offers an appealing easy to see reaction. However, due to the low force or torque that can be induced, bending actuators have relatively limited applications.

EAP TECHNOLOGY INFRASTRUCTURE

As polymers, EAPs can be easily formed in various shapes, their properties can be engineered and potentially they can be integrated with MEMS sensors to produce smart actuators. Their most attractive feature is their ability to emulate biological muscles having high fracture toughness, large actuation strain and inherent vibration damping. Unfortunately, current EAPs exhibit low force, operate far below their efficiency limits, are not robust, and there is no standard commercial material available. In order to take these materials from the development phase to actuators of choice there is a need for an established infrastructure [Bar-Cohen, 2001]. The development of the EAP infrastructure is a multidisciplinary task and it requires international collaboration. This requires understanding their basic principles using computational chemistry models, comprehensive material science, electro-mechanical analytic tools and improved material processing techniques. The processes of synthesizing, fabricating, electroding, shaping and handling will need to be refined to maximize the EAP materials actuation capability and robustness. Methods of reliably characterizing the response of these materials are needed to establish database with documented material properties.

NANOTECHNOLOGY POTENTIALS

EAP materials may be scalable to support such fields as MEMS and nanotechnologies and their ability to operate as actuation and sensors are important characteristics. Naturally, Carbon Nano-tubes are the closest to be applicable to these scales. The carbon-carbon bond of nanotubes (NT) suspended in an electrolyte changes length as a result of charge injection that affects the ionic charge balance between the NT and the electrolyte. Novel designs of conductive polymers (CP) also show such a potential. Researchers at the University of California, Riverside, USA, suggested that since CPs as EAP is an intrinsic property of the individual molecules they are capable of functioning at all size regimes, from macro- thru nano-scale down to the single-molecule level. Potential applications of such materials can range from shutters of micro-optics to steering micro-mirrors to a variety of other nano-actuators. Also, this technology may be considered as actuators for making robotic explorers at the level of micron or nanometers. Potentially, small robots can be developed to travel through the human body and treat such diseases as cancer.

CONCLUSIONS

EAPs have emerged with great potential and are enabling the development of unique devices that are inspired by biological systems. As actuators and sensors these materials are offering an important arsenal of building blocks for MEMS and nanotechnologies. Having an effective infrastructure is critical to the commercial availability of robust EAP actuators for practical applications. The challenges are enormous, but the recent trend of international cooperation, the greater visibility of the field and the surge in funding of related research are offering great hope for the future of these exciting new materials. The author's arm-wrestling challenge having a match between EAP-actuated robots and a human opponent highlights the potential of EAP. Progress towards this goal will lead to great benefits to mankind particularly in the area of medical prosthetics.

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REFERENCE

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