Electroactive polymers for healthcare and biomedical applications

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ABSTRACT

Electroactivity was noticed early in biological substances, including proteins, polynucleotides and enzymes, even piezo- and pyroelectricity were found in wool, hair, wood, bone and tendon. Recently, ferroelectricity has been identified in a surprisingly large number of biologically relevant materials, including hydroxyapatite, aortic walls and elastin. Inspired by the variety of natural electroactive materials, a wealth of new elastomers and polymers were designed recently, including an all organic elastomer electret and self-healing dielectric elastomers. Let's further draw inspiration from nature and widen the utilization of electroactive polymers towards (mobile) healthcare and biomedical applications. Ferroelectrets, internally charged polymer foams with a strong piezoelectric thickness coefficient are employed in biomedical sensing, for example as blood pressure and pulse sensor, as vital signs monitor or for the detection of tonic-clonic seizures. Piezo- and pyroelectric polymers are booming in printed electronics research. They provide electronic skin the ability to "feel" pressure and temperature changes, or to generate electrical energy from vibrations and motions, even from contractile and relaxation motions of the heart and lung. Dielectric elastomers are pioneered by StretchSense as wearable motion capture sensors, monitoring pressure, stretch, bend and shear, quantifying comfort in sports and healthcare. On the cellular level, electroactive polymer arrays are used to study mechanotransduction of individual cells. Ionic electroactive polymers show potential to be used in implantable electroactive biomedical devices. Already with the currently available science and technology, we are at the verge of witnessing the demonstration of truly complex bionic systems.
Keywords: biological ferroelectricity, ferroelectrets, piezoelectric polymers, conjugated polymers, dielectric elastomers, biomedical device

1. INTRODUCTION

Electro-active polymers became indispensable for a wide range of applications, perhaps best documented by the most successful EAPAD conference series, with the true highlight of each year's conference – the electro-active polymers in action session. Many application areas are very well represented in this activity, paving the way to commercial applications of electro-active polymers, including applications in electronic skin, soft robots and energy harvesting [1]. Many new developments in materials development and design, as well as in device demonstrators were noticed recently that even may widen the application areas of electro-active polymers to healthcare and biomedical applications. Starting from the surprisingly large variety of electro-active phenomena in natural materials [2], this brief review will summarize recent developments in stretchable piezoelectrics [3] and self-healing elastomers [4], followed by a discussion of established applications of electro-active polymers in sonic-tonic seizure detection [5], and sensors for well-being and healthcare [6]. Soft implantable neuroprostheses are engineered systems that are designed to restore or substitute function for individuals with neurological deficits or disabilities [7]. In this emerging research megatrend conjugated electro-active polymer actuators may become indispensable [8], potentially enabling integration of actuators for implants in the human body. Cell stimulation [9,10] and surgical simulators [11] provide further avenues for employing electro-active polymers in sports, well-being, healthcare and biomedical applications. The author of this brief review hopes, that in the years to come, exciting demonstrations of such applications will be displayed in the electro-active polymer in action sessions at the EAPAD meetings.

2. FERROELECTRICITY AND ELECTRO-ACTIVE PHENOMENA IN NATURAL MATERIALS

Ferroelectric materials are in the focus of materials science, stemming from their wide variety of applications in sensors, actuators, memories etc. [12]. Erwin Schrödinger theoretically predicted ferroelectricity in his habilitation thesis [13], years before experimental confirmation in the early 1920s [2]. In the 1950s electroactive phenomena were found in

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many natural systems, often being relatively weak these findings did not lead to practical applications [14]. Already in 1957, a significant piezoelectric response was observed in bone [15], attributed to the polar collagen components of bone. However, recently hydroxyapatite was identified to show a strong piezoelectric response [16]. Widely used in artificial form in reconstructive orthopedic and dental surgery, hydroxyapatite thin films may thus prove useful for piezoelectric applications. Besides piezoelectricity, also strong hints on ferroelectricity were found by piezoelectric force microscopy in thin film hydroxyapatites [17]. But piezoelectricity and ferroelectricity is not limited to hydroxyapatites, it was recently also confirmed in a wide range of biological materials, ranging from aortic walls [18] to elastin [19,20]. The physiological significance of these findings is still under debate, but the electro-active polymer community may take inspiration from these observations for the development of new materials, being highly stretchable and self-healing. **s**

3. STRETCHABLE PIEZOELECTRICS AND SELF-HEALING DIELECTRIC ELASTOMERS

Electro-active polymers became mature; we currently have excellent materials available, ranging from cellular piezoelectrics [21] to piezoelectric polymers from the PVDF family [22], as well as from conjugating polymers [23] to dielectric elastomers [24]. They are widely employed in electronic skin and printed electronics [25,26], for example in human machine interaction, soft robotic skin and prostheses. However, demands in applications drives research to find new forms of electro-active polymers, mimicking natural materials. Two very recent developments include a stretchable form of a piezoelectric elastomer [3,27] and dielectric elastomers displaying self-healing [4]. Such unusual materials are highly promising for applications of electrp-active polymers in healthcare and biomedical applications. In piezoelectric elastomers, electro-active effects are achieved by incorporating polar molecules that are noncentrosymmetrically ordered by electric field poling. In self-healing dielectric elastomers, iron-ligang bonds that can readily break and re-form were introduced to provide self-healing capacities even at low temperatures down to -20°C. While it is currently not clear if such materials will play a prominent role in future electro-active polymer systems, they provide playing grounds in materials synthesis and design, potentially enabling truly complex bionic systems.

4. COMMERCIAL APPLICATIONS OF ELECTRO-ACTIVE POLYMERS IN WELL-BEING AND HEALTHCARE

Being already mature in materials development, electro-active polymers have found their way to the market. It is not the aim of this brief review to provide an in-depth analysis of commercial applications of electro-active polymers, rather two applications were chosen to describe the potential of these materials. Charged cellular polymers, pioneered in Finland and commercialized by the company EMFIT display large piezoelectric responses, they are easily prepared at low-cost in large area forms [5]. Not surprisingly, they were early on used in large area electronic skins, directly integrated with field effect transistors for signal conditioning [25]. Being available in large area sheets they are also very the material of choice for bed sensors, monitoring quality of sleep and detecting sonic tonic seizures [5]. It is interesting to note that the company delivers complete sensor solutions and not only the electro-active polymer sheet device. Dielectric elastomers are not only interesting for actuators; they also provide ample means of use in sensor systems. StretchSense is pioneering the commercialization of self-powered soft sensing systems, developing into a leading supplier of smart stretch sensors [6]. It is highly encouraging to see successful industrial applications of electro-active polymers in sports, well-being and healthcare, illustrating the huge potential of our materials in these booming areas.

5. NEURAL IMPLANTS, CELL STIMULATION AND SURGICAL SIMULATORS

Applications of electro-active polymers may not only span on skin devices, they may also be implanted in the future. One exciting research direction being neural implants. Here, conjugated electro-active polymers proved to work under cerebral physiological conditions [28], having the potential to be used in implantables for modulating the position of electrode sites within the brain tissue. So far, work has reached the proof of concept stage, so lot of room for further research remains until electro-active polymers will find their way into the human body. On the cellular level, electro-active polymers also display large potential for applications. The quantitative characterization of contractile stress of cardiac and smooth muscle cells requires novel methodologies and experimental approaches. Electrically stimulating a mechanical response of cells grown on electro-active polymer scaffolds is highly promising in this respect. Both dielectric elastomer transducers [29] as well as conjugated polymers seem attractive to perform such tasks [30], and very nice proof of concept devices were recently published. Dielectric elastomers were shown to not only enable electromechanically induced deformation of cells, they are also effective in quantitatively recording the strain by capacitive self-sensing, enabling scaling up to high-throughput measurements. Finally, the author sees huge potential for applications of electro-active polymers in surgical simulators as well, potentially changing the way we train medical doctors, not immediately on patients but with smart simulators.

6. CONCLUSION

Electro-active polymers remain fascinating; research is active in materials design and development, as well as in identifying novel application fields, besides robotics and prosthethics. Being already successful on the market, mobile health, body implants, and surgical simulators may benefit from electro-active polymer research, significantly helping to improve the quality of our lives. The author strongly believes that we are currently seeing the verge of the soft matter age, and electro-active polymers will be an indispensable part.

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