Piezoelectric Biopolymer–Polymer Composite Films and Microfibers

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For decades, polymer-based piezoelectric materials have served as a novel alternative to ceramics for sensor/transducer applications where flexibility is preferred in addition to high piezoelectricity. Although flexibility is enabled in polymer-based systems, an ideal "piezo"

is one where the piezoactivity and mechanical properties can be altered individually so that the mechanical stiffness of the material can be controlled for particular applications or tuned to match that of the surroundings (e.g., air or water) for increased transduction sensitivity.

Here, we present a new piezoelectric material based on a helical biopolymer with an inherently large electric dipole that allows production of thin films and fibers (submicrometer to millimeter) directly from polymer solution. Furthermore, we show fabrication and piezoelectric properties of the films and fibers composed of poly(α-benzyl γ,L-glutamate) (PBLG) (Fig. 1).

FABRICATION TECHNIQUES

To form a polar PBLG–poly(methylmethacrylate) (PMMA) composite film of high piezoelectricity, we explored the concept of corona charging (Fig. 2), which is commonly used to cause polymers to become piezoelectric. Corona was the preferred method for poling the PBLG rods because it allows us to expose the system to extremely high voltages without making direct contact with the sample. Higher potentials are required to ensure that the PBLG rods are oriented perpendicular to the film surface, and the noncontact method is preferred because we start with a mixture solution.

The process begins by dissolving PBLG in a liquid monomer (methylmethacrylate) and applying the PBLG–methylmethacrylate mixture solution to a Teflon plate. The Teflon plate is anchored to a metal support and contains cavities that aid in the formation of the composite film in various uniform shapes and sizes. After the mixture solution is applied to the fixture, the fixture is placed on the grounded electrode and charged under corona. The corona tip is ~4 inches away from the sample during the charging process, with an exposure potential of –15 kV. The composite film is formed within 30 min, allowed to dry, and then peeled off of

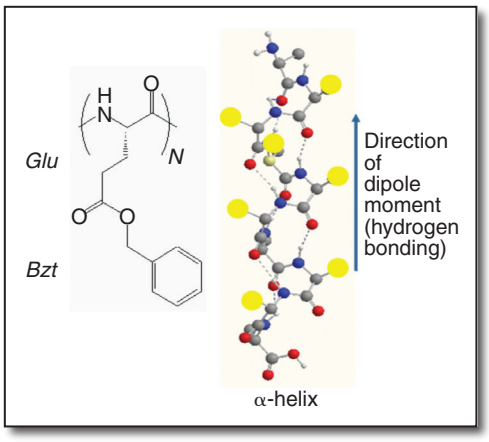

Figure 1. The helical polypeptide PBLG. PBLG is a polar and stable rod-like structure with a large dipole moment.

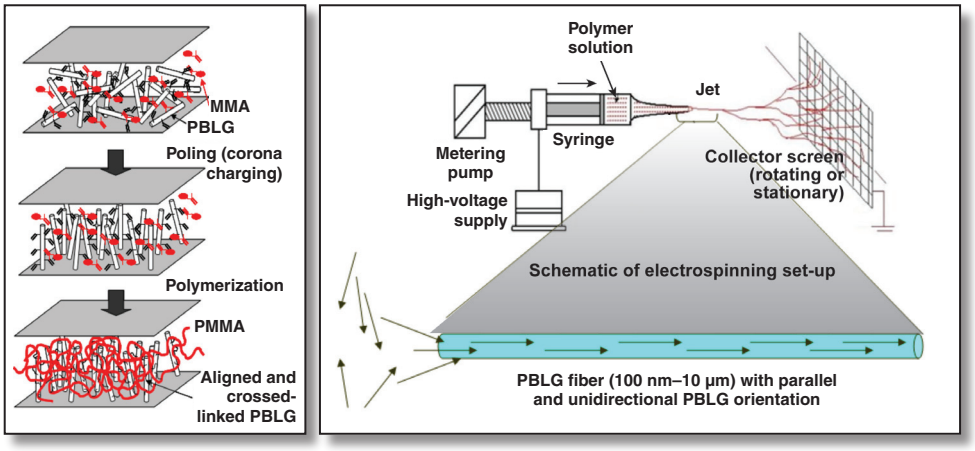

Figure 2. Schematic of fabrication techniques used for development of poled PBLG–PMMA composite film and electrospun PBLG microfibers.

the fixture. The microstructural characterization of the composite film, as well as its piezoelectric and mechanical properties, is then evaluated. Piezoelectric performance results of the composite film revealed a d_{33} piezo coefficient of 20 pC/N (with only 20% orientation of the electrical dipoles).

Exploring alternative processing techniques led to electrospinning of PBLG solutions. Using electrospinning to take advantage of the known PBLG properties led to the advent of the PBLG microfibers. Although work in this area is ongoing, x-ray diffraction results indicate that such fibers achieve nearly 100% alignment of the electrical dipoles within the PBLG structure (Fig. 3). Therefore, embedding the fibers into a matrix similar to that used with the composite film would allow for enhanced piezoelectric characteristics obtained from the composite film and would also offer a platform for investigation of alternative stand-alone piezo characteristics (i.e., d_{31}).

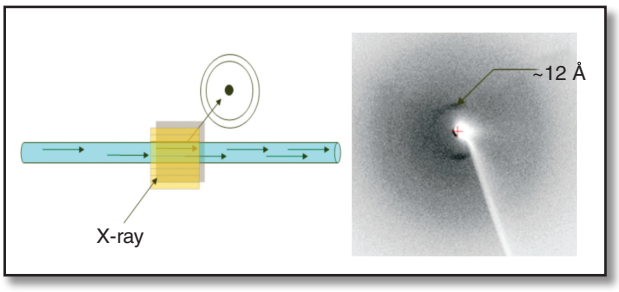

Figure 3. X-ray diffraction pattern. PBLGs are oriented parallel to the long fiber axis.

CONCLUSIONS

Use of the discussed piezoelectric systems could potentially pave the way for many new and innovative applications. Although the existing composite film properties are comparable to other polymer-based piezo systems, we are actively pursuing ways to further optimize the results. The systems described herein are fabricated from solution, making them inexpensive, easy-to-fabricate alternatives to existing piezoelectric materials. In addition, the flexibility in processing allows for the creation of various shapes/sizes (e.g., contoured and/or sheet-like piezo materials) (Fig. 4), which has proven to be advantageous when comparing similar processing for other piezo materials. One could potentially realize the benefit of such materials as sensors, as alternate energy sources in low-power applications, as microphones/hydrophones, and as directional arrays for acoustic applications.

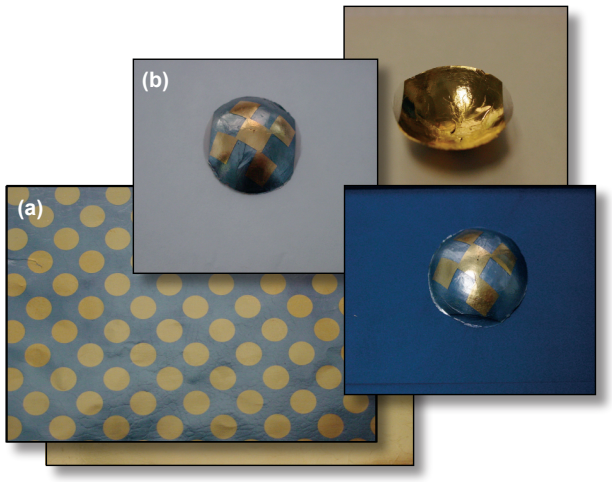

Figure 4. Top- and bottom-side images of patterned piezoelectric composite film as a polymer sheet (a) and contoured/dome-shaped (b) sample.

For further information on the work reported here, see the references below or contact dawnielle.farrar@jhuapl.edu.

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[2]Nakiri, T., Imoto, K., Ishizuka, M., Okamoto, S., Date, M., Uematsu, Y., Fukada, E., and Tajitsu, Y., "Piezoelectric Characteristics of Polymer Film Oriented Under a Strong Magnetic Field," *Jpn. J. Appl. Phys.* 43(9B), 6769–6774 (2004).