Sheila Goodman's PhD defense

Tuesday May 18th, 2021 @ 9:30 am PST - *https://washington.zoom.us/j/94325388408*

Committee: Anthony Dichiara, UW Bioresource Science & Engineering (chair)
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Title: Sustainable Cellulose Composite Membranes for Multifunctional Sensing Applications

Abstract: With growing environmental conscientiousness and climate effects being more readily seen around the world, the next generation of wearable electronics will not only be characterized by their portability, flexibility, and drop-in implementation, but also their low cost and environmental impact. A variety of natural polymers have been considered as potential substrates to meet this increasing demand, but none possess the sustainability or commercializability of cellulose. As the most abundant natural polymer, cellulose can be extracted from a number of biological sources, including lignocellulosic biomass, algae, and bacterial sources. Cellulose microfibers, extracted from lignocellulosic sources, have been used by societies for thousands of years, and are still the major feedstock of the pulp and paper industries. Recent advances in biopolymer extraction and manipulation have allowed for the isolation of cellulose in its nano form (i.e. cellulose nanofibrils), derived from its naturally occurring hierarchical structure. In this work, membranes comprised of cellulose microfibers and nanofibrils are prepared for multifunctional sensing and energy storage applications. When fabricated using traditional papermaking techniques, cellulose microfibers form a porous entangled structure. Through the incorporation of carbon nanotubes (CNTs), an electrically conductive cellulose-CNT composite matrix is formed whose electrical resistance changes in response to environmental stimuli. Specifically, the hygroscopic nature of cellulose causes the discrete fibers to swell when immersed in water, driving the matrix below a conductivity percolation threshold, and significantly increasing the electrical resistance. By attaching an inexpensive microcontroller, this 'smart' paper can function as a stand-alone remote leak detection device. By leveraging mature web-forming techniques, the adaptation of composite 'smart' papers from the batch to the pilot-scale was facilitated which allowed for continuous production with minimal nanoparticle loss, demonstrating commercial viability for the rapid and reliable quantification of small volumes of water over large areas. In addition to the investigation of cellulose-CNT composites, cellulose nanofibrils (CNFs) were examined for suitability as the main component in flexible dielectric films, with applications in advanced energy storage and piezoelectric sensing technologies. The dielectric performance and energy storage capabilities of the material were tuned through the optimization of the CNF fabrication process, as well as through the incorporation of poly(vinylidene fluoride) (PVDF) nanoparticles. Optimized performance was further extended through the development of a layer-by-layer fabrication process in which bi- and tri-layer films of varying composition were evaluated, significantly improving breakdown strength and permittivity. In this work, cellulose-based composites were successfully adapted to multifunctional sensing and energy storage applications, and this exercise offers insight into the possibility of the large-scale integration of biopolymers in the field of flexible electronics.