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PhD Dissertation Defense

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Manufacturing of MXene-Based Fibers, Yarns, and Knitted Electrochemical Capacitors

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Textile-based energy storage devices are a flexible, safe, and lightweight solution to powering wearable electronic devices. While they have benefited from the discovery of new conductive materials and innovations in device design, the limited energy density of textile devices has restricted their use in practical applications. To improve the electrochemical performance of such devices requires new electrode materials that have higher electronic conductivity and theoretical capacitance than present materials. $Ti_3C_2T_x$, the most studied member in the MXene family, is known for its metallic conductivity and high volumetric capacitance in acidic electrolytes due to its pseudocapacitive behavior. These properties, along with its processability, make MXene an attractive material for the development of electrodes, current collectors, and interconnects for textile-based energy storage devices. The first demonstrations of MXene-based fibers and yarns showed their potential to enable energy storage in textiles. However, achieving high loadings of MXene while simultaneously demonstrating flexibility presents a critical challenge, preventing the integration of these fibers/yarns into textiles using industrial manufacturing equipment. In order to improve the properties of MXene-based fibers and yarns, a systematic study is needed to understand how flake size, concentration, polymer type, and fiber architecture influence fiber/yarn properties and device performance.

This dissertation aims to design and develop MXene-based fiber and yarn electrodes with high electrical conductivity and electrochemical performance for the manufacture of knitted energy storage textiles. Various methods are explored to capture and infiltrate MXene into fibers and yarns, including electrospinning and coating. By producing MXene-based fibers and yarns with different architectures (coated and composite), MXene flake size, concentration, and polymer host, the effects of fundamental material and fabrication parameters on fiber and yarn properties (mechanical, electrical, and electrochemical) are investigated. The fabrication of meters of conductive and electrochemically active fiber/yarn electrodes enabled the development of the first prototypes of knitted energy storage devices using industrial machines. The relationship between knit structure and electrochemical performance is explored to provide insights into the design of knitted energy storage devices to maximize capacitance, energy density, and power density. This dissertation represents a major step towards the mass production of knittable yarn electrodes and textile energy storage devices and their use in practical applications.