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Multiscale Integration of Two-Dimensional Transition Metal Carbides (MXenes) into Textile-Based Devices

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Significant breakthroughs have been made in the development of wearable technologies by integrating functional nanomaterials into fiber-, yarn-, and fabric-devices. Developing electrically conductive dispersions is the first step for the development of functional devices across a diverse range of commercial printing and manufacturing applications. However, current conductive dispersions use either organic solvents or additives such as surfactants, co-solvents, or binders to meet the rheological requirements for printing and coating processes. This increased chemical complexity introduces higher costs and technical challenges. The ability to formulate conductive dispersions with on-demand rheological properties is a step forward toward the development of industrial-scale, reliable printing and coating processes. However, meeting the rheological requirements for various solution processing techniques for additive-free and aqueous dispersions has been a major challenge. Due to their versatile chemistry and facile processability, two-dimensional (2D) transition metal carbides, *i.e.* MXenes, are promising candidates for achieving seamless integration in wearable devices due to their facile processability, tunable chemistry and biocompatibility. Despite its potential, optimizing the rheological parameters of MXene dispersions for various solution processing techniques such as wet-spinning, dip coating, and thermal inkjet printing remains to be one of the least explored areas.

This dissertation aims to develop additive-free, aqueous MXene dispersions with controlled rheological properties by adjusting flake size and concentration to produce conductive liquid crystals, dyes and inks. As a result, pure MXene-based fibers, MXene-coated yarns/fabrics, as well as printed patterns on fabrics can be produced with tunable properties for various applications. At the fiber level, discovery of self-assembled LC phases in aqueous and organic solvent based MXene dispersions without using LC additives, binders, or stabilizing agents is studied. The discovery of LC phases in dispersions of 2D materials has enabled the development of free-standing, highly conductive $Ti_3C_2T_x$ fibers produced *via* wet spinning. Additionally, development of MXene dispersions towards optimal yarn and fabric coating is explored. Successful demonstration of the first washable and knittable MXene-coated yarns with tunable electrical and electrochemical properties for touch sensor and energy storage applications is introduced. While developing conductive yarns provides better design flexibility, many of these conductive fibers/yarns do not yet have sufficient strength for industrial textile manufacturing. Therefore, $Ti_3C_2T_x$-coated fabrics are fabricated with high electromagnetic interference shielding performance by simple and scalable dip-coating method. Lastly, development of the additive-free, jettable and conductive aqueous MXene ink formulation for wearable printed electronics is demonstrated for the first time. This dissertation provides insights to bridge the gap between 2D nanomaterials research, ink development, and textile manufacturing, which will enable better performing wearable devices for an ever-growing smart textile industry.