Abstract

The global transition from fossil fuels to sustainable energy alternatives demands a major leap in energy storage solutions. The importance of safe and inexpensive batteries cannot be overstated in this context. Over the past decade, interest in post-lithium battery technologies, including multivalent batteries, has grown significantly. By combining energy-dense metal anodes (such as Ca and Mg) with environmentally friendly and structurally diverse organic cathodes, the full potential of multivalent technology could be realized. Despite intensive research efforts, multivalent metal-organic batteries still lag behind their monovalent counterparts, especially in terms of cathode utilization.

This thesis analyzes the main factors contributing to this performance gap and explores strategies to overcome this challenge. The research is divided into two parts that combine chemical synthesis with advanced electrochemical characterization to gain a deeper understanding of the parameters governing the charge transfer reactions in organic materials.

In the first part, we aim to identify a reliable electrochemical setup that enables detailed kinetic studies of redox-active organic compounds. We use electrochemical impedance spectroscopy measurements within this setup, combined with microscopy techniques. This method allows us to visualize the distribution of multivalent ions and evaluate ionic resistances. We also propose a method to determine the electronic conductivity in the reduced state and its impact on the observed electrochemical performance.

The second part of the work focuses on chemical synthesis, including mini-emulsion polymerization to obtain nano-sized polymers. We synthesize organic polymers with different electronic and ionic conductive fillers, polymers with varying degrees of porosity, and polymers with different lengths of aromatic cores and linkers. These efforts are aimed at evaluating the influence of structural and morphological factors on electrochemical performance in conjunction with Mg and Ca charge carriers.

Keywords: redox-active organics, magnesium batteries, calcium batteries, electrochemical impedance spectroscopy, electron microscopy, multivalent ion transport