PREFACE

The growing global demand for clean and sustainable energy solutions has brought electrochemical energy conversion and storage technologies into sharp focus. Among the fundamental processes underpinning these technologies, the Oxygen Evolution Reaction (OER) holds a pivotal role. As a half-reaction in water electrolysis and a crucial step in the operation of fuel cells and metal–air batteries, the OER directly influences the overall efficiency and feasibility of green hydrogen production and other renewable energy systems. Despite its significance, the OER remains a major bottleneck in the development of efficient energy conversion systems due to its sluggish kinetics and high overpotentials, which stem from complex multi-electron transfer steps and the formation of reactive oxygen intermediates.

The Thesis presented the understanding of the OER mechanism and contribute to the ongoing search for efficient, stable, and cost-effective electrocatalysts that can overcome its inherent limitations. By bridging theoretical knowledge with experimental strategies, this work explores innovative catalyst materials and composite systems that aim to enhance the performance of the OER in practical applications.

The study begins with a comprehensive overview of the electrochemical water-splitting process, highlighting the critical role of OER in renewable hydrogen production and broader sustainable energy systems. The **Chapter 1** establishes the foundational principles, both kinetic and thermodynamic, that govern OER activity. It also presents a detailed literature survey to contextualize the current challenges and recent developments in catalyst design. The chapter concludes with the specific objectives and motivation guiding this research.

Chapter 2 is dedicated to the methodological framework used throughout this work. It outlines the principles and applications of the various characterization techniques employed to analyze the structural, morphological, elemental, and electrochemical properties of the synthesized catalysts.

In **Chapter 3**, the focus shifts to the synthesis and analysis of magnesium doped bismuth copper titanate catalysts (abbreviated as BCTO). Here, the impact of magnesium doping on the BCTO is systematically studied, with a special emphasis on how stoichiometric variations affect electrocatalytic performance. Various physical characterizations were performed for the confirmation of phase, structure, and elemental composition as well as electrochemical characterizations for understanding the role of prepared catalysts towards electrocatalytic OER.

Expanding upon the previous approach, **Chapter 4** explores the electrocatalytic performance of cobalt tungstate nanoparticles with varying stoichiometric ratios. This chapter examines how different proportions of cobalt (Co) and tungsten (W) influence the overall catalytic activity, highlighting the synergistic interactions between the two metal components. As in the preceding chapter, a comprehensive set of physical characterization techniques is employed to confirm the phase purity, crystal structure, and elemental composition of the synthesized materials. Additionally, detailed electrochemical analyses are conducted to evaluate the catalytic behavior of the prepared cobalt tungstate catalysts.

Chapter 5 introduces an innovative class of electrocatalyst materials, mixed metal oxides and their composites with conducting polymers, with a particular focus on cobalt tungstate ($CoWO_4$) and its composite with polypyrrole (ppy). This chapter aims to explore the synergistic enhancement in catalytic performance that arises from the combination of an inorganic metal oxide framework with a conductive polymer matrix. While cobalt tungstate provides the structural and catalytic framework for the OER, polypyrrole contributes enhanced electrical conductivity and facilitates efficient charge transfer at the electrode–electrolyte interface. The chapter delves deeply into the mechanistic aspects of how the conductive polymer matrix contributes to the overall catalytic behavior. The role of polypyrrole in facilitating faster electron transport, increasing active surface area, and improving the accessibility of catalytic sites is critically discussed.

Finally, **Chapter 6** includes the key findings from all experimental investigations, drawing conclusions on the design principles for high-performance OER catalysts. This chapter also outlines future research directions, emphasizing the need for integrated material systems and real-time analytical techniques to advance both the fundamental understanding and practical deployment of electrochemical water-splitting technologies.

The overall objective of the Thesis is to contribute meaningfully to the evolving field of electrocatalysis by not only identifying promising materials but also elucidating the underlying processes that govern their activity. By fostering a deeper connection between fundamental electrochemical science and materials innovation, this work aspires to support the broader vision of a sustainable, hydrogen-powered future.