Pulsed Laser Deposited-Ruthenium Dioxide Thin Films with Enhanced Electrocatalytic Performance for Energy Conversion Applications

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ABSTRACT

Ruthenium dioxide (RuO_2) is a promising material for advancing renewable energy solutions; however, its practical applications remain limited due to stability challenges and performance variations depending on the fabrication method. In this study, high-quality RuO_2 thin films were synthesized on crystalline sapphire substrates via the pulsed laser deposition (PLD) method. The orientation and crystallinity of the RuO_2 thin films were precisely controlled by adjusting the PLD growth temperature, and its impact on electrocatalytic performance was systematically investigated as the first part of this study. The structural and morphological properties of the films were characterized using high-resolution X-ray diffraction, X-ray reflectivity, X-ray photoelectron spectroscopy, scanning electron microscopy, and transmission electron microscopy, confirming epitaxial growth and high crystallinity. The second part of the study is focused on examining the effect of film thickness on the electrocatalytic activity and charge transfer behavior at the electrical double layer, enabling a comprehensive comparative analysis. Electrochemical characterization revealed a wide potential window with highly reversible redox reactions, indicating robust electrochemical activity. Furthermore, electrochemical impedance spectroscopy was conducted under varying applied potentials and different potassium hydroxide electrolyte concentrations to evaluate charge transfer dynamics. A comparative analysis of films with different thicknesses, controlled by varying the pulse number (4800 and 2100), demonstrated that thicker films with a higher pulse number exhibited superior electrocatalytic performance and enhanced stability. Notably, RuO_2 films grown at a pulse number of 4800 at 600 °C outperformed those fabricated at 2100, underscoring the significance of optimized deposition conditions. These findings highlight the potential of RuO_2 thin films as efficient and stable electrocatalysts, offering valuable insights for the advancement of energy conversion and storage technologies.

Keywords: Ruthenium dioxide; pulsed laser deposition; thin film; energy application