

Interfacial Facets of Droplet Wetting, Metal Growth, and Gas Evolution on Structured Electrodes

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Abstract

Electrochemical systems, encompassing both energy storage and conversion devices, rely critically on the electrode–electrolyte interface, where surface architecture and wetting behavior govern transport processes. This thesis investigates how subtle variations in electrode structure and wettability dictate interfacial dynamics across different electrochemical environments. Initially, the spreading and imbibition dynamics of liquid droplets on rough metallic surfaces were examined to establish foundational wetting behavior. Building on this, structured electrodes with tunable morphology were fabricated via dynamic hydrogen bubble templating. These architected electrodes served as a unified experimental platform to investigate two interfacial phenomena: solid-phase metal electrodeposition and gas-phase electrolytic gas evolution. By employing real-time optical and high-speed imaging, the spatiotemporal evolution of metallic deposits and detached gas bubbles was quantified. Specifically, solid-phase analysis focused on the growth height and tortuosity of the metallic front, while gas-phase evaluations tracked current density, areal capacitance, bubble detachment size, and number density. By systematically correlating these interfacial dynamics with complex electrode geometries, such as structure width, spacing, and height, this work elucidates the role of substrate morphology in modulating electric field distributions and hence the evolution process. Ultimately, by combining multi-scale characterization and in situ observation, this research establishes a comprehensive framework and actionable design strategies to enhance the efficiency and scalability of structured electrodes.

Keywords: *Electrochemical Interface, DHBT Electrode, Droplet Spreading, Imbibition, Metal Growth Dynamics, Bubble Detachment, In-Situ Visualization.*