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Electrochemical and kinetic studies of chemical vapor deposition (CVD)-processed carbon-doped nickel for hydrogen evolution reaction (HER)

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ABSTRACT

In this study, carbon-doped nickel (C–Ni) was synthesized via CVD at different synthesis temperatures (700 °C, 800 °C, and 900 °C) to investigate the effect of temperature on material structure and HER performance in acidic media. At 700 °C, the C–Ni surface featured amorphous carbon layers, while higher temperatures promoted increased graphitization, with crystalline carbon observed at 900 °C. Electrochemical testing in 0.5 M H_2SO_4 revealed overpotentials of −268 mV, −279 mV, and −295 mV at 10 mA/cm^2 for C–Ni synthesized at 700 °C, 800 °C, and 900 °C, respectively. Tafel slope analysis demonstrated improved HER kinetics at lower synthesis temperatures. C–Ni@700 °C achieved the lowest slope of −85 mV·dec^{-1} at low current densities. FEM simulations supported the experimental findings, illustrating enhanced charge distribution (V–H–T mechanism) and current density uniformity. These results confirm that lower synthesis temperatures favour the formation of carbon structures enhancing catalytic activity. This work provides insights into temperature-controlled synthesis of C–Ni catalysts for hydrogen generation.

1. Introduction

Hydrogen is increasingly recognized as a promising chemical fuel for sustainable energy applications, as it is a vital source of clean and renewable energy [1]. This has been driven by extensive research into hydrogen energy utilization and the rapid advancement of water splitting technology [2,3]. Water-splitting has garnered considerable attention as an efficient and environmentally benign approach for hydrogen production [4,5], wherein the hydrogen evolution reaction (HER) [6] plays a fundamental step in the overall process.

Currently, the HER predominantly employs traditional noble metal-based catalysts, that exhibit excellent electrocatalytic performance such as Ru [7], Rh [8], Pd [9], Pt [10]and Au [11]. Platinum (Pt) remains as the benchmark electrocatalyst, yet its limited availability and high cost significantly restrict large-scale applications in HER [12,13]. Consequently, the development of cost-effective electrocatalysts with performance comparable to Pt has become crucial [12,14]. Recent research has presented the potential of non-precious transition metal as HER electrocatalysts, including Ni [15], Co [13], Fe [16], Mo [17] and W [4,15].

In the emerging field of non-precious electrocatalysts, amorphous materials have consistently demonstrated superior performance in both HER and OER across various media [18]. Amorphous catalysts possess inherent flexibility, enabling them to adapt dynamically to electrocatalytic conditions [19]. This flexibility facilitates both surface and volume-confined catalysis and allows the material to transition into

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