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Review

Prospects of non-noble metal single atoms embedded in two-dimensional (2D) carbon and non-carbon-based structures in electrocatalytic applications

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ABSTRACT

The idea of single-atom catalysts (SACs) has gained attention in electrocatalysis owing to its high efficiencies in energy conversion reactions. Supported single-atoms (SAs) exhibit major advantages, such as high atom utilization, strong interfacial interaction, and well-defined active centers, compared with nanoparticles. From a practical point of view, SACs comprising non-noble metals seem to be an attractive alternative to expensive noble-metal catalytic systems. As the intrinsic activity and the electronic structure of SACs are governed by the support material and coordination environment of the metal species. Two-dimensional (2D) materials could be a promising candidates for supporting SAs owing to their high chemical stabilities and layered structures. This review provides an overview of recent developments in 2D materials-supported non-noble metal SACs for electrochemical energy conversion applications. The relevance of performing the comprehensive characterization of the 2D supported catalysts to elucidate their catalytic activities under different reaction conditions were highlighted. In light of recent findings in the field, we discussed the existing challenges and future opportunities regarding the correlation between the 2D structures and activities of SACs toward electrochemical energy conversion reactions.

Contents

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; AA, ascorbic acid; ALD, atomic layer deposition; BM, boron monolayer; BMOF, bimetallic metal–organic framework; BN, boron nitride; CC, carbon cloth; CD, carbon dot; $Co(Cp)_2$, bis(cyclopentadienyl)cobalt; CO_2RR, carbon dioxide reduction reaction; COF, covalent organic framework; DA, dopamine; DFT, density-functional theory; DPV, differential pulse voltammetry; DRIFTS, diffuse reflectance infrared Fourier-transform spectroscopy; ECSA, electrochemical active surface area; EELS, electron energy-loss spectroscopy; EXAFS, extended X-ray absorption fine structure; Fe–Pc, Fe–phthalocyanine; FE-SEM, field emission scanning emission microscopy; FC, fuel cell; FDMNES, finite difference method near edge structure; G, defective graphene; g-C_3N_4, graphitic carbon nitride; GD, graphdyine; GO, graphene oxide; HAADF-STEM, high-angle annular dark-field scanning transmission electron microscopy differential phase-contrast (DPC); HER, hydrogen evolution reaction; hG, holy graphene; HR-TEM, high-resolution transmission microscopy; ICP-AES, inductively coupled plasma atomic emission spectroscopy; FTIR, Fourier-transform infrared spectroscopy; SECM, scanning electrochemical microscopy; LSV, linear sweep voltammetry; MOF, metal–organic framework; MoS_2, molybdenum disulfide; MW, microwave; MWCNT, multiwalled carbon nanotube; MXene, 2D carbides and nitrides; NG, N-graphene; NEXAFS, near edge X-ray absorption fine structure; NR, nanorod; NRR, nitrogen reduction reaction; NS, nanosheet; OCP, open-circuit potential; OER, oxygen evolution reaction; ORR, oxygen reduction reaction; PEMFC, proton exchange membrane fuel cell; R_{ct}, charge-transfer resistance; RRDE, rotating ring-disk electrode; SAs, single-atoms; SACs, single-atom catalyst; SAsCo@NG, Co single-atoms on N-doped graphene sheet; SCoNC, Co SAs on N-doped graphene-like carbon; SEI, solid–electrolyte interphase; SEM, scanning electron microscopy; SGGT, solution-gated graphene transistor; STEM, scanning transmission electron microscopy; TEM, transmission electron microscopy; UA, uric acid; WT, wavelet transform; XANES, X-ray absorption near edge structure; XPS, X-ray photoelectron spectroscopy; Z, atomic number.

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