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Editorial

Novel Photo(electro)catalysts for Energy and Environmental Applications

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Photo(electro)catalysis is regarded as one of the most promising approaches to addressing energy and environmental issues and thus achieving the sustainable development of human society; as such, various catalytic materials have been developed in recent decades [1,2]. These catalysts have been widely applied in fields associated with energy and the environment, such as organic matter degradation, hydrogen production, and biofuel production [3–5]. Currently, developing novel photo(electro)catalysts plays a critical role in this specific research field and is becoming a vital area of research.

This Special Issue includes eleven articles in total, of which ten are research articles and one is a review paper. The contributions to this Special Issue are summarized below:

In their study, Gu et al. [6] synthesize Fe-doped perovskite-type $PbBi_2Nb_2O_9$ (PBNO) via a simple solid-state reaction for methylene blue (MB) photodegradation under visible light irradiation. The introduced Fe dopants act as an intermediate band, resulting in a redshift in the absorption edge compared to pure PBNO. On the other hand, the optimum ratio of Fe dopants also serves as a trap for the photoinduced electron and hole pairs to enhance the separation of charge carriers, while excessive Fe dopants result in too many defects, leading to the severe recombination of charge carriers. Consequently, Fe-doped PBNO with a 0.2 molar ratio exhibits the highest MB degradation efficiency, with 94.1% efficiency.

Rani et al. [7] fabricate a series of $NiSe_2/Ag_3PO_4$ composites via a simple hydrothermal method, and apply them to the photodegradation of Rhodamine B (RhB) and bisphenol A (BPA), in which a 20% $NiSe_2/Ag_3PO_4$ composite shows the greatest photocatalytic efficiency for both RhB (10 ppm in 20 min) and BPA degradation (20 ppm in 30 min). A possible mechanism of the Z-scheme electron transfer process, with electrons transferring from the Ag_3PO_4 conduction band (CB) to the $NiSe_2$ valence band (VB), is proposed based on their band structures, and holes are further elucidated to be the crucial factor in the photodegradation process according to active species capture experiments. In addition, the impact of other factors, such as the initial concentration of dye, the catalyst amount, pH, and reaction time, on the photodegradation performance are also investigated and pseudo-first-order kinetic models with rate constants of 0.1266 min^{-1} and 0.2275 min^{-1} are analyzed for RhB and BPA photodegradation, respectively.

Carbon-based materials, with high stability, good conductivity, and nontoxicity, are also widely employed in the formation of a heterojunction with semiconductors. In their study, Jiang et al. [8] synthesize a granular Fe_2O_3/C heterojunction-based rape pollen via a simple hydrothermal method, effectively inhibiting the photo-induced recombination of electron–hole pairs. For Fe_2O_3/C composites, Fe_2O_3 nanoparticles were found to be uniformly distributed on the surface and inside the pore of the treated rape pollen (TRP), which guarantees sufficient contact between the photocatalyst and solution. In addition,

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TPR also exhibits absorption intensity in the infrared region (IR), thereby boosting its photocatalytic performance via the photothermal effect. Consequently, the composites with a 50% mass ratio of Fe_2O_3 exhibited the best photo degradation capacity for Methylene Blue (MB) and *Escherichia coli* (*E. coli*) disinfection in water under visible and infrared light irradiation.

Apart from water pollutants, photocatalysts are also applied in the purification of volatile organic compounds (VOCs). In their study, Samangsri et al. [9] fabricate a nitrogen-doped TiO_2@SiO_2 core/shell photocatalyst (N-TiO_2@SiO_2) as an additive in photocatalytic paint and apply it to the photocatalytic degradation of gaseous acetaldehyde. The well-designed SiO_2 shell could increase the specific surface area, reduce aggregation, and prevent charge recombination in photocatalytic reactions. Accordingly, the paint containing the N-TiO_2@SiO_2 core/shell photocatalyst was found to possess stronger alkali resistance and a better capacity for adhesion than commercial paint.

Despite photocatalytic technologies, photoelectrocatalysis (PEC) has also garnered extensive attention for its efficient ability to remove organic pollutants without producing any harmful by-products. However, traditional PEC systems require high electrical energy input to drive the PEC process. To address this problem, in their contribution, Hu et al. [10] develop a self-driven dual-photoelectrode PEC system (TiO_2 NNs-Co_3O_4) composed of a TiO_2 nanoneedle array (TiO_2 NNs) photoanode and Co_3O_4 photocathode. The self-driven TiO_2 NNs-Co_3O_4 PEC system could efficiently degrade sulfamethazine (99.62%, 0.042 min^{-1}) under LED light irradiation; this was approximately 6 and 10.5 times as high as that of the TiO_2 NNs-Pt (0.007 min^{-1}) and Pt-Co_3O_4 (0.004 min^{-1}) system, respectively. Moreover, quenching experiments indicated that h^+, •OH, and $•O^{2-}$ were the predominant ROS during the decomposition process of SMT.

Hydrogen, with the merits of being carbon-free and possessing a high energy density, is considered to be an ideal energy carrier [11]. It can be obtained from water via various approaches, such as photocatalysis, photoelectrocatalysis, electrolysis, and biophotolysis [12–15]. Among them, photocatalytic water splitting is one of the most promising approaches to converting solar energy into chemical energy, which is of great significance for the realization of a carbon-neutral economy. In their study, Guo et al. [16] prepare WSe_2/TiO_2 nanocomposites via a facile mechanical grinding method for photocatalytic water splitting. The introduction of WSe_2 nanosheets not only facilitates the efficient electron transfer of TiO_2 to WSe_2, but also supplies abundant active sites for hydrogen evolution. Consequently, the prepared WSe_2/TiO_2 nanocomposites display the highest hydrogen evolution rate of 2.28 mmol h^{-1} g^{-1}, corresponding to an apparent quantum yield of 43.8% at 365 nm.

It is worth noting that WSe_2 in the WSe_2/TiO_2 nanocomposites functions more like an "cocatalyst", and thus plays a vital role in photocatalytic water splitting. To promote research on the design of efficient cocatalysts in photocatalytic overall water splitting (POWS), Tian et al. [17] introduce various cocatalyst loading methods, clarify the roles of various cocatalysts in the POWS process, and define the key challenges and potential research directions associated with cocatalyst loading in the POWS system.

Electrocatalytic water splitting driven by renewable energy such as solar, wind, and tide is another attractive approach to producing hydrogen energy. However, for efficient water electrolysis, the oxygen evolution reaction (OER) process is more challenging due to its sluggish surface reaction kinetics and the multiple steps of the proton-coupled electron-transfer process. In their contribution, Wan et al. [18] develop a series of $Ni_xCo_{1-x}O$ and $Ni_xCo_{1-x}N$ catalysts on nickel foams for application as efficient OER-electrocatalysts. By adjusting the ratio of the Ni/Co and calcination atmospheres, the composition and morphology of the catalysts can be rationally modulated. It is found that $Ni_xCo_{1-x}N$ catalysts exhibit far superior activities than $Ni_xCo_{1-x}O$, due to their metallic electronic structures. Specifically, the $Ni_{0.3}Co_{0.7}N$ catalyst, with a unique nanostructure of nanosheets embedded in nanocorals, exhibited a small overpotential of 268 mV at 20 mA cm^{-2}, and a Tafel slope of 66 mV dec^{-1}.

Similarly, in their study, Chen et al. [19] synthesize a series of Ce-doped $CoMn_2O_4$ (CMO) spinel as bifunctional catalysts for ORR and OER processes. The surface electronic structure of Ce-CMO varies with the content of Ce, and Ce-CMO-18% exhibits the optimum ORR/OER performance due to its large surface area, high ratio of Co^{3+}/Co^{2+}, Mn^{4+}/Mn^{3+}, and O_V/O_L, and suppressed Jahn–Teller effect. Moreover, Ce-CMO-18% was found to be a hybrid with multiple walled carbon nanotubes (MWCNTs), with the as-prepared Ce-CMO/MWCNTs possessing an ORR onset potentials of 0.93 V and 0.84 V at a density of 3 mA cm^{-2} (at 1600 rpm), which is comparable to commercial Pt/C.

Stainless steel mesh (SSM), with the merits of low cost, high conductivity, and excellent stability in mild acidic solutions, has been extensively employed as an anode material for water electrolysis. However, it suffers heavily from severe corrosion in the presence of acidic fluids or chloride solution. To improve the corrosion resistance of SSM, in their contribution, An et al. [20] incorporate cobalt-doped iron phosphate on SSM through a simple one-step hydrothermal method. Compared with bare SSM, the as-prepared OER catalyst (0.84-CoFePi) exhibits a dramatic improvement in corrosion resistance. Specifically, the electrolysis current density of 0.84-CoFePi showed a negligible decrease after 12 h in 0.0441 wt% H_2SO_4 (pH ≈ 3) containing 0.1 M NaCl solution.

In recent decades, biodiesel production has received significant attention for its potential utilization as a renewable energy resource. In their study, Zahid et al. [21] prepare a Mn-doped ZnO (Mn-ZnO) nanocatalyst via a sonochemical method and apply it to the conversion of castor oil to biodiesel. The optimum temperature, catalyst amount, and oil-to-methanol ratio were systemically investigated and identified as 55 °C, 1.2 g, and 1:12, respectively, with the maximum biodiesel yield (90.3%). The as-prepared Mn-ZnO catalyst demonstrated excellent potential for commercialization due to its optimal efficiency in the manufacturing of biodiesel.

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