



Editorial: Carbon-Based Bifunctional Oxygen Electrocatalysts

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Editorial on the Research Topic

Carbon-Based Bifunctional Oxygen Electrocatalysts

With the ever-increasing environmental pollution and energy crisis, the demand for sustainable and environmentally friendly energy conversion and storage technologies has been on the rise. Recently, metal-air batteries have been extensively investigated because of their high theoretical energy density, low cost, environmental benignity, and satisfactory safety and are, thus, considered as promising energy devices (Wang et al., 2014; Fu et al., 2018). However, the sluggish kinetics of oxygen-related reactions, including the oxygen reduction reaction (ORR) and the oxygen evolution reaction (OER), hinders the large-scale practical applications of metal-air batteries (Pan et al., 2018; Wang et al., 2018). Therefore, it is necessary to exploit efficient electrocatalysts that exhibit high ORR and OER activities.

Until now, Pt- and Ir/Ru-based materials exhibit the best electrocatalytic performances for the ORR and OER, respectively. Nevertheless, their scarcity and high cost limit their large-scale employment in metal-air batteries. Therefore, it is important to exploit low-cost and earth-abundant electrocatalysts as alternatives to noble metals for the ORR and OER. Among the studied non-precious electrocatalysts, carbon-based nanomaterials have been widely investigated for oxygen electrode reactions because of their numerous advantages such as wide availability, low cost, remarkable electroconductivity, and environmental benignity. However, the electrocatalytic activities of carbon-based nanomaterials are lower than those of noble metals. Recently, various strategies have been adopted to improve the electrocatalytic performance, such as heteroatom (e.g., N, P, S, B, and F) doping and nanostructure design (including the porous structure and multi-dimensional morphology). Heteroatom doping facilitates electronic redistribution and electroconductivity improvement, which, in turn, enhances the electrocatalytic performance (Chen et al., 2019; Zheng et al., 2019). The presence of a porous structure with multi-dimensional morphology is beneficial for promoting catalytic activity by accelerating the diffusion of the electrolyte and the release of the generated gas (Zhang et al., 2017; Hu et al., 2019). Furthermore, in addition to their application as an electrocatalyst for oxygen-related reactions, carbon-based nanomaterials are considered as ideal matrices to support metal compounds, which can prevent the aggregation of metal nanoparticles and reduce the electrical resistance. Herein, we collected six valuable contributions focusing on the preparation, structure control, and application of various carbon-based electrocatalysts. The outstanding ORR performance of nitrogen-doped porous carbon, designed and developed by (Liu et al., 2019) via the direct pyrolysis of natural cattail fibers, is discussed. The preparation methods proposed by (Wang M. et al., 2020) for various biomass-derived

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catalysts and their catalytic performance for the ORR in alkaline, neutral, and acidic media are summarized. Furthermore, the carbon-based materials serving as matrices to support Fe-Ni₂P, (Xiao et al., 2019) Co₃O₄, (Cheng et al., 2019) Fe_{1-x}S, (Wang H. et al., 2019), and Fe/N (Rauf et al., 2020) are also discussed in this Research Topic; all the prepared electrocatalysts were found to exhibit excellent electrocatalytic activities for oxygen electrode reactions. As guest editors, we would like to thank all the authors for their valuable contributions to this Research Topic and all the reviewers for their important and thoughtful

comments and insights. We hope that this Research Topic will provide useful insights for the development of carbon-based bifunctional catalysts and furnish a background for the research related to advanced carbon chemistry in redox reactions.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

- Chen, J., Fan, C., Hu, X., Wang, C., Huang, Z., Fu, G., et al. (2019). Hierarchically porous Co/CoxMy (M = P, N) as an efficient Mott-Schottky electrocatalyst for oxygen evolution in rechargeable Zn-Air batteries. *Small* 15:1901518. doi: 10.1002/sml.201901518
- Cheng, G., Liu, G., Liu, P., Chen, L., Han, S., Han, J., et al. (2019). Nitrogen-doped ketjenblack carbon supported Co₃O₄ nanoparticles as a synergistic electrocatalyst for oxygen reduction reaction. *Front. Chem.* 7:766. doi: 10.3389/fchem.2019.00766
- Fu, G., Tang, Y., and Lee, J.-M. (2018). Recent advances in carbon-based bifunctional oxygen electrocatalysts for Zn-air batteries. *ChemElectroChem* 5, 1424–1434. doi: 10.1002/celec.201800373
- Hu, X., Chen, Y., Zhang, M., Fu, G., Sun, D., Lee, J.-M., et al. (2019). Alveolate porous carbon aerogels supported Co₉S₈ derived from a novel hybrid hydrogel for bifunctional oxygen electrocatalysis. *Carbon* 144, 557–566. doi: 10.1016/j.carbon.2018.12.099
- Liu, Y., Hu, M., Xu, W., Wu, X., and Jiang, J. (2019). Catalytically active carbon from cattail fibers for electrochemical reduction reaction. *Front. Chem.* 7:786. doi: 10.3389/fchem.2019.00786
- Pan, J., Xu, Y., Yang, H., Dong, Z., Liu, H., and Xia, B. (2018). Advanced architectures and relatives of air electrodes in Zn-Air batteries. *Adv. Sci.* 5:1700691. doi: 10.1002/advs.201700691
- Rauf, M., Wang, J., Iqbal, W., Abbas, M., Khan, S. A., Khan, Q. U., et al. (2020). Novel heteroatom-doped Fe/N/C electrocatalysts with superior activities for oxygen reduction reaction in both acid and alkaline solutions. *Front. Chem.* 8:78. doi: 10.3389/fchem.2020.00078
- Wang, H., Qiu, X., Wang, W., Jiang, L., and Liu, H. (2019). Iron sulfide nanoparticles embedded into nitrogen and sulfur co-doped carbon sphere as a highly active oxygen reduction electrocatalyst. *Front. Chem.* 7:855. doi: 10.3389/fchem.2019.00855
- Wang, H.-F., Tang, C., and Zhang, Q. (2018). A review of precious-metal-free bifunctional oxygen electrocatalysts: rational design and applications in Zn-Air batteries. *Adv. Funct. Mater.* 28:1803329. doi: 10.1002/adfm.201803329
- Wang, M., Wang, S., Yang, H., Ku, W., Yang, S., Liu, Z., et al. (2020). Carbon-based electrocatalysts derived from biomass for oxygen reduction reaction: a minireview. *Front. Chem.* 8:116. doi: 10.3389/fchem.2020.00116
- Wang, Z.-L., Xu, D., Xu, J.-J., and Zhang, X.-B. (2014). Oxygen electrocatalysts in metal-air batteries: from aqueous to nonaqueous electrolytes. *Chem. Soc. Rev.* 43, 7746–7786. doi: 10.1039/C3CS60248F
- Xiao, Y., Deng, S., Li, M., Zhou, Q., Xu, L., Zhang, H., et al. (2019). Immobilization of Fe-doped Ni₂P particles within biomass agarose-derived porous N, P-carbon nanosheets for efficient bifunctional oxygen electrocatalysis. *Front. Chem.* 7:523. doi: 10.3389/fchem.2019.00523
- Zhang, W., Xu, X., Zhang, C., Yu, Z., Zhou, Y., Tang, Y., et al. (2017). 3D space-confined pyrolysis of double-network aerogels containing In-Fe cyanogel and polyaniline: a new approach to hierarchically porous carbon with exclusive Fe-Nx active sites for oxygen reduction catalysis. *Small Methods* 1:1700167. doi: 10.1002/smt.201700167
- Zheng, X., Wu, J., Cao, X., Abbott, J., Jin, C., Wang, H., et al. (2019). N-, P-, and S-doped graphene-like carbon catalysts derived from onium salts with enhanced oxygen chemisorption for Zn-air battery cathodes. *Appl. Catal. B. Environ.* 241, 442–451. doi: 10.1016/j.apcatb.2018.09.054

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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