



Highlight

Practical fuel cells enabled by unprecedented oxygen reduction reaction on 3D nanostructured electrocatalysts

Hong Yuan^a, Qiang Zhang^{b,*}

^aAdvanced Research Institute of Multidisciplinary Science, Beijing Institute of Technology, Beijing 100081, China

^bBeijing Key Laboratory of Green Chemical Reaction Engineering and Technology, Department of Chemical Engineering, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:

Received 1 January 2020

Accepted 2 January 2020

Available online 9 January 2020

Keywords:

Oxygen reduction reaction

Fuel cells

Precious metal electrocatalyst

3D nanostructured materials

Electrocatalysis

Oxygen reduction reaction (ORR) is of significance for energy conversion technologies such as fuel cells and metal-air batteries [1,2]. Currently, the electrocatalysts still need to employ expensive precious metal platinum (Pt) as the main active component to overcome the sluggish kinetics of ORR [3,4]. The exploration of low-cost, highly active and highly stable ORR catalysts is then the key to the development and promotion of these new energy technologies [5]. In the last decades, great breakthroughs have been made in the activity of noble metal-based catalysts, while the investigations on the stability, especially their service and failure of membrane electrode assemble (MEA) are still limited [6,7]. However, measuring and evaluating the performance of nanostructured catalysts on the MEA level is the key to the catalyst's practical applications.

Recently, Xia, Lou, and co-workers firstly synthesized chains of platinum–nickel (Pt–Ni) alloy nanocages connected by necking regions derived from Pt–Ni alloy nanospheres by selectively removed Ni species under acidic conditions (Fig. 1). The synthesized one-dimensional bunched Pt–Ni alloy nanocages with a Pt-skin structure for the ORR display high mass activity ($3.52 \text{ A mg}_{\text{Pt}}^{-1}$) and specific activity (5.16 mA cm^{-2}), or nearly 17 and 14 times higher than that of commercial platinum carbon (Pt/C) catalyst. More importantly, the catalyst exhibits high stability with negligible activity decay after 50,000 cycles, and the single H_2 – O_2 fuel cell assembled by these catalysts can be operated for at least 180 h [8].

In situ X-ray absorption fine structure revealed that the strongly bonded oxygenated species on the Pt atoms were greatly inhibited from 0.54 to 0.9 V (vs. RHE) on the novel catalysts, benefiting the ORR activity. In addition, the density functional theory calculations also demonstrated that the atomic O adsorption energy (ΔE_{O^*}) of Pt_4Ni skin was 0.17 eV weaker than on Pt(111), which are near the optimal ΔE_{O^*} value (0.2 eV). Furthermore, it is found that the required activation energy for the spillover of surface Pt atoms is substantial, indicating that dissolution of surface Pt atoms of PtNi-BNCs is kinetically prohibited for Pt-skin structures, even in the presence of oxygen adsorbates, verifying the high stability of the catalysts. Both the high ORR activity and durability endowed the catalysts a high performance on the fuel cell test, and the fuel cell assembled by this catalyst delivered a current density of 1.5 A cm^{-2} (0.6 V) and could be operated steadily for at least 180 h.

The successful combination of high Pt utilization efficiency (porous nanostructures), a favorable nanoscale chemical environment (chemical alloying), and stability derived from the one-dimensional structure provides the final product an exciting ORR performance. This leading work provides an effective strategy for the rational design of Pt alloy nanostructures and will help guide the future development of catalysts for their practical applications in energy conversion technologies and beyond. The applications of 3D nanostructures are a practical strategy to full render the effective energy chemical process for vast practical applications in rechargeable batteries, supercapacitors, fuel cells, and other heterogeneous catalysis process [9,10].

* Corresponding author.

E-mail address: zhang-qiang@mails.tsinghua.edu.cn (Q. Zhang).

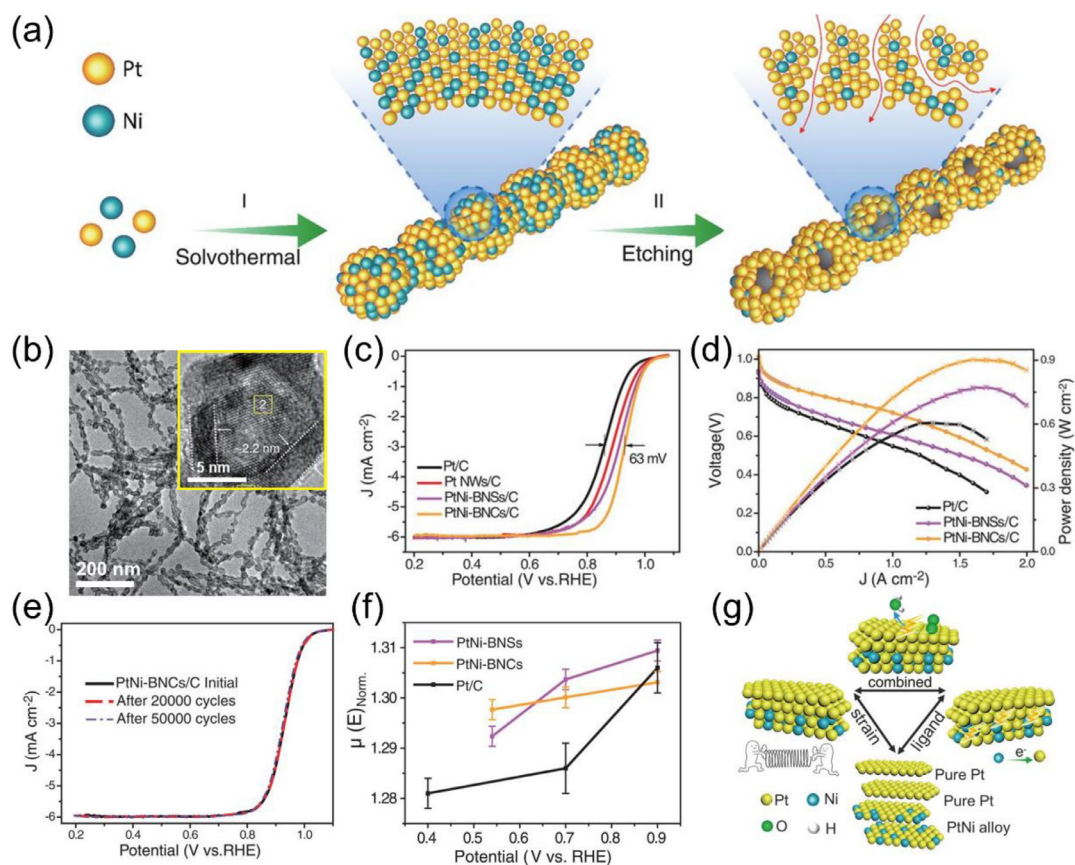


Fig. 1. (a) Schematic illustration of the preparation of PtNi-BNCs; (b) TEM images of PtNi-BNCs, and the inset is the enlarged TEM image of a nanocage; (c) LSVs of Pt/C, Pt NWs/C, PtNi-BNSs/C, and PtNi-BNCs/C at 0.9 V (vs. RHE); (d) H_2 -air fuel cell polarization plots; (e) LSVs of PtNi-BNCs/C before and after the durability test for various potential-scanning cycles; (f) In situ potential-dependent normalized white-line peak intensities and (g) illustration of the synergistic effects derived from both the lattice strain and ligand effects in the catalysts [8].

Declaration of Competing Interest

The authors declare no competing financial interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (21825501 and 21808124), and China Postdoctoral Science Foundation (2017M620049 and 2019T120098).

References

[1] A. Kulkarni, S. Siahrostami, A. Patel, J.K. Nørskov, *Chem. Rev.* 118 (2018) 2302–2312.

- [2] A.A. Gewirth, J.A. Varnell, A.M. DiAscro, *Chem. Rev.* 118 (2018) 2313–2339.
- [3] M. Kiani, J. Zhang, Y. Luo, C. Jiang, J. Fan, G. Wang, J. Chen, R. Wang, *J. Energy Chem.* 27 (2018) 1124–1139.
- [4] L. Bu, Q. Shao, Y. Pi, J. Yao, M. Luo, J. Lang, S. Hwang, H. Xin, B. Huang, J. Guo, D. Su, S. Guo, X. Huang, *Chem* 4 (2018) 359–371.
- [5] Z.W. Seh, J. Kibsgaard, C.F. Dickens, I.B. Chorkendorff, J.K. Nørskov, T.F. Jaramillo, *Science* 355 (2017) eaad4998.
- [6] X.L. Tian, Y.Y. Xu, W. Zhang, T. Wu, B.Y. Xia, X. Wang, *ACS Energy Lett.* 2 (2017) 2035–2043.
- [7] L. Wang, X. Wan, S. Liu, L. Xu, J. Shui, *J. Energy Chem.* 39 (2019) 77–87.
- [8] X. Tian, X. Zhao, Y.-Q. Su, L. Wang, H. Wang, D. Dang, B. Chi, H. Liu, E.J.M. Hensen, X.W.D. Lou, B.Y. Xia, *Science* 366 (2019) 850–856.
- [9] X. Zhang, X. Cheng, Q. Zhang, *J. Energy Chem.* 25 (2016) 967–984.
- [10] C. Tang, M.-M. Titirici, Q. Zhang, *J. Energy Chem.* 26 (2017) 1077–1093.