Hybrid Fe-N-C oxygen reduction reaction electrocatalyst with high performance in anion exchange membrane fuel cells

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Designing low-cost precious metal-free efficient cathode catalysts in anion-exchange membrane fuel cells (AEMFCs) is of great interest. Metal-nitrogen-carbon (M−N−C) catalysts, containing transition metals such as Fe, Co, and Mn in the form of single metal atoms coordinated to nitrogen, have emerged as appealing substitutes to Pt/C due to their earth abundance and structural controllability.[1] While several transition metals have been utilized to create M−N−C catalysts, Fe-N-C materials have been of outstanding interest for several years as they have demonstrated the highest oxygen reduction reaction (ORR) activity.[2] However, the majority of these catalysts fail to deliver excellent electrocatalytic properties and stumble when used as cathode materials in fuel cells. The active sites for such electrocatalysts are essential to be well-dispersed across the suitable conducting carbon support in order to provide efficient electron transfer and gas flow channels that are essential for charge and mass transport, respectively. Herein, we developed a catalyst with partially transformed iron into Fe-N_x sites embedded in the carbonaceous matrix (Figure 1) and its excellent electrocatalytic performance is attributed to the hybrid Fe nanoparticles and built-in Fe-N-C structure. The optimized Fe@Fe-N-C catalyst was tested for ORR performance both ex-situ using the rotating (ring)-disk electrode technique and in an anion exchange membrane fuel cell (AEMFC). The Fe@Fe-N-C catalyst exhibited remarkable ORR activity in alkaline media with a half-wave potential of 0.822 V vs. RHE and showed the maximum power density (P_{max}) of 242 mW cm^{-2} in an AEMFC test, surpassing the peak power density obtained with the Pt/C cathode catalyst (P_{max} = 220 mW cm^{-2}) after pairing with PtRu/C anodes under H_2-O_2 conditions (see Figure 1). Therefore, the study provides a promising prospect for designing improved, cost effective, noble metal-free electrocatalysts for achieving high performance in AEMFCs.

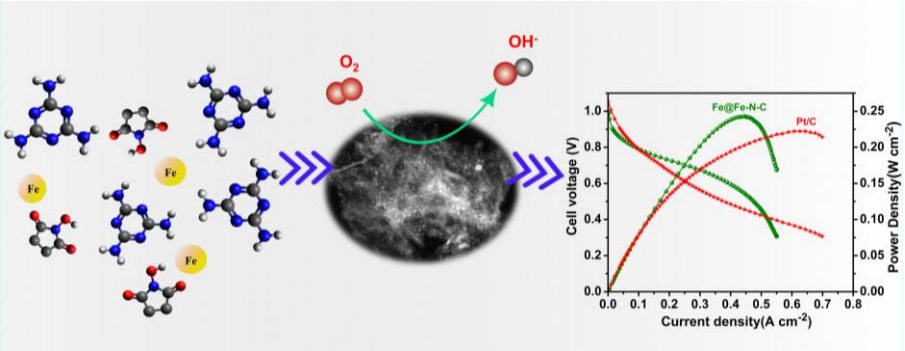

Figure 1: The schematic representation of the synthesis of Fe-N-C catalysts and the performance in H_2-O_2 AEMFC as a cathode.

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References
1. M.M. Hossen, M.S. Hasan, M.R. Islam Sardar, J. bin Haider, Mottakin, K. Tammeveski, P. Atanassov, State-of-the-art and developmental trends in platinum group metal-free cathode catalyst for anion exchange membrane fuel cell (AEMFC). Appl. Catal. B: Environ. 235 (2023) 121733.
2. K. Kisand, A. Sarapuu, J.C. Douglin, A. Kikas, A. Treshchalov, M. Käärik, H.-M. Piirsoo, P. Paiste, J. Aruväli, J. Leis, V. Kisand, A. Tamm, D.R. Dekel, K. Tammeveski, Templated nitrogen-, iron-, and cobalt-doped mesoporous nanocarbon derived from an alkylresorcinol mixture for anion-exchange membrane fuel cell application. ACS Catal. 12 (2022) 14050-14061.