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Innovations in Nanomaterials for Proton Exchange Membrane Fuel Cells

Robin Sandström

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Fakultetsopponent: Prof. Licheng Sun,
Department of Chemistry, KTH Royal Institute of Technology,
Stockholm, Sweden.

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Author
Robin Sandström

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Abstract

Hydrogen technologies are rapidly receiving increased attention as it offers a renewable energy alternative to the current petroleum-based fuel infrastructure, considering that continued large-scale use of such fossil fuels will lead to disastrous impacts on our environment. The proton exchange membrane fuel cell should play a significant role in a hydrogen economy since it enables convenient and direct conversion of hydrogen into electricity, thus allowing the use of hydrogen in applications particularly suited for the transportation industry. To fully realize this, multiple engineering challenges as well as development of advanced nanomaterials must however be addressed.

In this thesis, we present discoveries of new innovative nanomaterials for proton exchange membrane fuel cells by targeting the entire membrane electrode assembly. Conceptually, we first propose new fabrication techniques of gas diffusion electrodes based on helical carbon nanofibers, where an enhanced three-phase boundary was noted in particular for hierarchical structures. The cathode catalyst, responsible for facilitating the sluggish oxygen reduction reaction, was further improved by the synthesis of platinum-based nanoparticles with an incorporated secondary metal (iron, yttrium and cobalt). Here, both solvothermal and high-temperature microwave syntheses were employed. Catalytic activities were improved compared to pure platinum and could be attributed to favorably shifted oxygen adsorption energies as a result of successful incorporation of the non-precious metal. As best exemplified by platinum-iron nanoparticles, the oxygen reduction reaction was highly sensitive to both metal composition and the type of crystal structure. Finally, a proton exchange membrane based on fluorine and sulfonic acid functionalized graphene oxide was prepared and tested in hydrogen fuel cell conditions, showing improvements such as lowered hydrogen permeation and better structural stability. Consequently, we have demonstrated that there is room for improvement of multiple components, suggesting that more powerful fuel cells can likely be anticipated in the future.

Keywords
Fuel Cells, Membrane Electrode Assembly, Oxygen Reduction Reaction, Platinum alloy catalyst, Nanoparticles, Gas Diffusion Electrode, Proton Exchange Membrane

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