Multidimensional and multifunctional carbon nanomaterials for energy conversion and storage

Liming Dai
Center of Advanced Science and Engineering for Carbon (Case4Carbon)
Departments of Macromolecular Science and Engineering,
Case Western Reserve University, Cleveland, Ohio, 44106, USA

With the rapid development in nanoscience and nanotechnology, graphitic carbon nanomaterials (e.g., 0D C-dots, 1D CNTs, 2D graphene, 3D carbon architectures) have been playing a more and more important role in the development of energy conversion and storage devices, including fuel cells, supercapacitors, batteries, and water-splitting systems. Although green and renewable energy technologies hold great promise to solve current energy and environmental challenges, noble metal catalysts (e.g., Pt, Pd, RuO_2, IrO_2) are generally needed to promote the hydrogen evolution reaction (HER) for hydrogen fuel generation from photo-electrochemical water-splitting, oxygen reduction reaction (ORR) in fuel cells for energy conversion, and oxygen evolution reaction (OER) in metal-air batteries for energy storage. The high cost of precious metal-based catalysts and their limited reserve have precluded these renewable energy technologies from large-scale applications.

Along with the recent intensive research efforts in reducing/replacing noble metal based catalysts (i.e., Pt) for ORR in fuel cells, we have previously demonstrated that vertically aligned nitrogen-doped carbon nanotubes (VA-NCNTs) could actively catalyze ORR via a four-electron process free from the methanol crossover and CO poisoning effects with a 3-time higher electrocatalytic activity and better long-term durability than that of commercial Pt/C catalysts. The improved catalytic performance was attributed to the doping-induced charge transfer from carbon atoms adjacent to the nitrogen atoms to change the chemisorption mode of O_2 and to readily attract electrons from the anode for facilitating the ORR. Subsequently, it was demonstrated that various carbon nanomaterials, doped with heteroatoms of electronegativities different from that of carbon atom, physically adsorbed with certain polyelectrolytes, and even without any apparent dopant or physically adsorbed polyelectrolyte, could also exhibit good ORR performance. Recent studies have further demonstrated that certain heteroatom-doped carbon nanomaterials could act as metal-free bifunctional catalysts for ORR/OER in metal-air batteries for energy storage, and even ORR/OER/HER trifunctional catalysts for self-powered water-splitting to generate hydrogen fuel and oxygen gas from water for integrated energy systems. More recently, certain 3D graphitic carbon architectures (e.g., CNT-graphene pillared networks, graphene foams) have been demonstrated to show additional advantages for efficient energy conversion and storage in fuel cells, batteries, and supercapacitors.

In this talk, I will present some of our rational concepts for the design and development of multidimensional and multifunctional carbon nanomaterials for various energy-related applications, including fuel cells and metal-air batteries with carbon nanomaterials as multifunctional metal-free catalysts, and energy storage devices with nanotube/graphene hybrid electrodes. A brief overview of this exciting field, along with some challenges and opportunities, will also be presented

Email: lxd115@case.edu