Plasma nanotechnology: Novel tool for high performance electrode materials for energy storage and conversion

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The focus of m Plenary Talk will be on energy storage (batteries)[1-4] and conversion (electrolysis)[5,6] devices using plasma nanotechnology which is a cost-, time- and energy-efficient method for high performance energy materials. Among many energy storage approaches, lithium/sodium ion batteries and supercapacitors, are attractive due to high capacity energy storage, power density, large number of charging-discharging cycles and ease of transport of energy in portable devices. Similarly, the economic conversion of water by electrolysis into chemical fuels, such as hydrogen, is one of the most important challenges of 21st century. The electrode materials are the keystone and bottleneck of the ever-expanding market for energy conversion and storage devices. The exploitation of new materials and modification of existing materials at the atomic level are two prime strategies to increase the performance of these devices. The innovation in synthesis and processing of new materials with desired structural, morphological, physical and chemical properties is urgently required to achieve improved performance. Recently, plasma-based strategy is emerging to serve as a promising tool in the preparation of advanced nanoassemblies for energy storage and conversion materials.

In this talk I will present our work on using low temperature nitrogen and carbon plasma in RF-PECVD system to process, dope and synthesize energy storage[1-4] and conversion[5,6] materials. The detailed physical characterization, and performance evaluation of these plasma processed/synthesized nanostructured materials show superior energy storage and conversion performances will be discussed in detail in my talk. Due to limited time for talk, for the energy storage material electrodes I will focus on our most recent work on novel tunable void structure of SnO_2-void-hierarchically vertical graphene (SnO_2□hVG) nanoarray designing via facile C-plasma technique[1]. This method allowed us to achieve simultaneous encapsulation of protective vertical graphene and moderate void formation in the electrode. This tunable void and interconnected highly conductive graphene shells and backbones resulted in excellent structural integrity and superior Li^+ storage performance with excellent capacity of 650 mA h g^{-1} at 2 A g^{-1} with negligible capability degradation after 1000 cycles.

We used nitrogen plasma processing based conversion of cobalt oxide nanostructures in cobalt nitride porous 3-D nano-assembly to develop efficient, durable, low-cost, and earth-abundant electrocatalysts electrode for the oxygen evolution reaction (OER)[5]. Nitrogen plasma based conversion was achieved in significantly shorter reaction times (about 1 min) at room temperature compared to conventional high-temperature NH_3 annealing which requires a few hours. The plasma treatment significantly enhanced the OER activity, as evidenced by a low overpotential of 290 mV to reach a current density of 10 mA cm^{-2}, a small Tafel slope, and long-term durability in an alkaline electrolyte. This electrode was coupled with nickel–molybdenum bimetallic nitride dendritic 3D nanostructure synthesized using N_2-plasma-activation with outstanding catalytic activity for the hydrogen-evolution reaction (HER) in an alkaline electrolyte[6]; thus achieving the full cell[5].

References

1. B. Ouyang, D. L. Chao, G. C. Jia, Z. Zhang, E. Kan, H. J. Fan and R. S. Rawat*, *C-Plasma Derived Precise Volumetric Buffering for High-Rate and Stable Alloying-Type Energy Storage*, Nano Energy 80, 105557 (2021).
2. B. Ouyang, D. L. Chao, G. C. Jia, Z. Zhang, H. J. Fan and R. S. Rawat*, *Hierarchical vertical graphene nanotube arrays via universal carbon plasma processing strategy: A platform for high-rate performance battery electrodes*, Energy Storage Materials 18, 462-469 (2019).
3. Dongliang Chao, Bo Ouyang, Pei Liang, Tran Thi Thu Huong, Guichong Jia, Hui Huang, Xinhui Xia, Rajdeep Singh Rawat,* and Hong Jin Fan*, *C-Plasma of Hierarchical Graphene Survives SnS Bundles for Ultra-Stable and High Volumetric Na-Ion Storage*, Advanced Materials 1804833 (2018).
4. M.V. Jacob, R.S. Rawat, Bo Ouyang, K. Bazaka, D. Sakthi Kumar, Dai Taguchi, Mitsumasa Iwamoto, Ram Neupane, and Oomman K. Varghese, *Catalyst-Free Plasma Enhanced Growth of Graphene from Sustainable Sources*, Nano Letters *15* (9), 5702–5708 (2015). IF: 13.592 – 100 citations
5. Y. Zhang, Bo Ouyang, J. Xu, G. Jian, S. Chen, R. S. Rawat and Hong Jin Fan*, *Rapid synthesis of cobalt nitride nanowire: Highly efficient and low-cost Catalysts for oxygen evolution*, Andewandte Chemie Int. Ed. 55(30), 8670-8674 (2016).
6. Y. Zhang, Bo Ouyang, J. Xu, S. Chen, R. S. Rawat* and Hong Jin Fan*, *3D Porous Hierarchical Nickel-Molybdenum Nitrides Synthesized by RF Plasma as Highly Active and Stable Hydrogen Evolution Reaction Electrocatalysts*, Advanced Energy Materials 6, 1600221 (2016).