Design and Development of Advanced Materials for Energy Storage and Conversion

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It is now a common realization that our society is moving towards renewable and sustainable energy sources. In witness we are observing an increase in renewable energy production from sun and wind. Due to their intermittent availability however, energy storage and energy conversion techniques are starting to play a more and more important part in our lives.

My research focuses on the understandings of fundamental principles that govern the materials performance using well-defined model systems and first-principles-based calculations, based on which the rational design of high-performance materials for energy storage and conversion applications was carried out. For example, my recent work on the development of supercapacitor electrodes demonstrates my research philosophy: three key parameters that control the behavior of supercapacitor electrodes were identified through a series of mechanistic investigations on model systems[1]. Based on the gained fundamental insights, a novel nanotechnology was developed to simultaneously optimize those parameters and to achieve practical supercapacitor electrodes with both high-energy and power densities[2]. In addition, every fabrication procedure employed in this technology was designed to be cost-effective and industrially scalable. As a result, this technique has been adapted for commercialization in a startup company for grid-scale electricity storage.

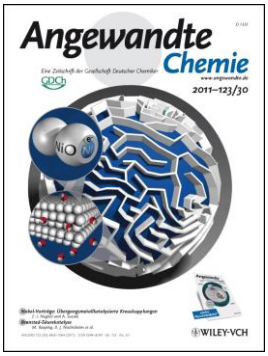


Figure 1. A supercapacitor electrode with interconnected metal core and active outer layer.

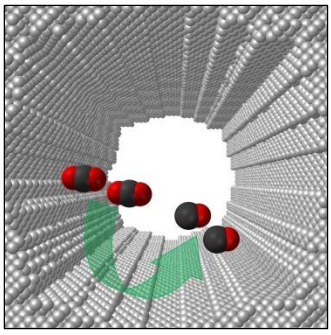


Figure 2. A nanoporous Ag catalyst that converts CO_2 to CO with high-selectivity and efficiency.[3]

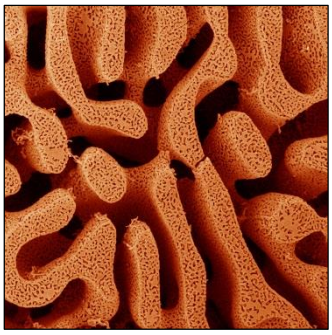


Figure 3. A Bimodal porous CuTi catalyst exhibits a Pt-like surface reaction sites for H_2 evolution reaction.[4]

In two of my most recent works, I developed highly active, non-precious metal-based catalysts for the electrochemical conversion of CO_2 and H_2O to CO and H_2, respectively. The design of this catalyst was investigated using density function theory-based calculations. Dealloy-based techniques were developed afterwards to synthesize practical catalysts with high surface area and density of active sites. The structure of the catalysts was further tailored to maximize the material utilization and electrode conductivity, achieving catalytic materials with optimal over-all performance for CO_2 conversion[3] and H_2 evolution reaction[4].

My future research will focus on the following aspects: 1) battery-capacitor hybrid electrochemical energy storage for solar- and wind- power grid applications; and 2) CO_2 and CH_4 conversion to value-added fuels and chemicals. The overarching goal of my research program is to provide the society advanced materials for future energy usage, which will be pursued via a combination of computational and experimental techniques.

References:

1. Lu Q. *et al.* "Nanostructured Electrodes for High-performance Pseudocapacitors" ***Angew. Chem. Int. Ed.***, 2013, 52 (7): 1882–1889

2. Lu Q. *et al.* "Supercapacitor Electrodes with High-Energy and Power Densities Prepared from Monolithic NiO/Ni Nanocomposites" ***Angew. Chem. Int. Ed.***, 2011, 50 (30): 6847–6850 (Covered by MaterialsViews, ChemistryViews, PhysOrg, *etc*.)

3. Lu Q. et al. "A Selective and Efficient Electrocatalyst for Carbon Dioxide Reduction" ***Nat. Commun.*** 2013, 5:3242 (Covered by Science Daily, R&D, Science World Report, etc.)

4. Lu Q. et al. unpublished results