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Nanocrystals from Oriented-Attachment for Energy Applications

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Preface

The ultimate goal of this book is to provide an integrated view of the basic theory, materials science, and engineering of oriented-attachment (OA) nanocrystals (NCs) in energy conversion devices. Further, this book will provide an invaluable, contemporary reference for the development of fundamental theory and experiment, advanced materials assembly techniques, and industrial applications of OA NCs in energy conversion devices.

Oriented attachment has evolved to be a fundamental growth mechanism for nanocrystals. In OA growth, nanoparticles (NPs) in a colloidal dispersion collide and attach together along a specific crystalline orientation. OA growth has exhibited great versatility and governed the synthesis of various functional materials and structures. Compared to the traditional Ostwald ripening (OR) mechanism, OA exhibits unprecedented advantage in synthesizing efficiently anisotropic NRs of various materials. In particular, nanocrystals with various shapes and various materials have been synthesized *via* OA growth. Previous studies have indicated that oriented attachment growth is effective for morphological transformations, which allows for the synthesis of crystals ranging from zero-dimension (0D, nanoparticles) to one-dimension (1D, nanowires, nanorods, or nanotubes), two-dimension (2D, nanosheets, or nanoribbons), and three-dimension (3D) structures. In particular, large-area 3D nanostructured materials *via* oriented attachment growth are considered to be promising candidates for next generation energy conversion devices.

OA growth involves collision and coalescence of the adjacent nanoparticles to eliminate crystalline boundaries. The driving force of OA growth is the reduction of the free energies of the surface and grain boundary. During the reaction, the OA growth rate is dependent on the initial particles, both on the size and the concentration. In the first chapter of this book, we mainly emphasize the OA growth mechanism, OA growth kinetics, and colloidal state impact in the synthesis of NCs with different dimensionalities. In this chapter, we will also present an overview on OR growth mechanism and the fundamental differences between OA and OR growth mechanisms.

With the rapid development in information communication, the human society has entered an era advancing with an ever-fast pace, noted largely with the speedy innovation in electronics typically depicted with or beyond the Moore's Law. The fundamental drive for such civilization advancement is high-performance energy resources with high-capacity, durability, and cost-effectiveness. Among applications requiring further improvement in current energy resources, electrical vehicles and portable electronic devices have drawn particular research attention stimulated by the world-wide customer and industry demands. Three types of energy conversion devices including lithium-ion batteries, fuel cells, and metal-air batteries are frequently proposed as the most promising devices for large-scale energy supplies. All types of current lithium-ion batteries have exhibited specific disadvantages regarding energy capacity, operation stability, and cost. For instance, all of them are instable as operation temperatures are varied substantially from room temperature, their cost-effectiveness remains at a relatively low level and the mechanical strength and flexibility at the electrode/electrolyte interfaces is still questionable for meeting the requirement of flexible electronics applications. The most-extensively researched fuel cells are solid oxide fuel cells and proton membrane exchange fuel cells. Both fuel cell systems allow for the efficient production of high-capacity electricity, but require high-temperature operation or costly and durable electrolyte membranes. The energy capacity of lithium-air batteries is comparable with the energy capacity of current commercially-available gasoline, but the relatively-low rate capacity and cathode instability have prevented their implantation in real-life applications. To address fundamentally the issues associated with the aforementioned energy conversion devices, progress in energy materials has been frequently achieved in research activities, including overcoming the performance limit of current battery/fuel cell materials and developing novel efficient battery/fuel cell materials and systems. In the middle chapters of this book, we look into the advances in employing OA NCs in energy conversion devices including fuel cells, batteries, and supercapacitors.

In general, the photoelectric conversion efficiencies of solar cells are determined by the photoanode materials and counter electrodes. During the past decades, scientists have been dedicated to developing efficient photoanode materials. Broad-band (Eg > 3eV) semiconductors such as TiO_2, ZnO, SnO_2, NiO, BiOI, CuS, and Fe_2O_3 have been widely studied in construction of solar cells owing to their efficient electron-hole separation and electric functionalities. Since the electrical and optical properties of nanoparticles are size- and shape-dependent, it is of great significance to control materials morphology to improve the performance of solar cells. In addition, the properties and application potentials of OA NCs for photo water splitting have also gained increased research interests. In the middle chapters, we also overview the advantages of employing OA growth mechanism for the synthesis and solar cell and photocatalysis applications of various NCs.

Finally, an outlook on research and development of large-scale and low-cost OA NCs in energy conversion devices will be presented.

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