

Chapter 15

Nanostructured Materials for the Realization of Electrochemical Energy Storage and Conversion Devices: Status and Prospects

Imran Shakir

*Sungkyunkwan University, Korea & King Saud
University, Saudi Arabia*

Zahid Ali

Sungkyunkwan University, Korea

Usman Ali Rana

King Saud University, Saudi Arabia

Ayman Nafady

King Saud University, Saudi Arabia

Mansoor Sarfraz

King Saud University, Saudi Arabia

InasMuen Al-Nashef

King Saud University, Saudi Arabia

Rafaqat Hussain

Universiti Teknologi Malaysia, Malaysia

DaeJoon Kang

Sungkyunkwan University, Korea

ABSTRACT

One of the greatest challenges for the modern world is the ever-increasing demand of energy, which may soon outstrip the amount of natural resources that can be obtained using currently known energy conversion and energy storage technologies such as solar cells, fuel cells, lithium ion batteries, and supercapacitors. It appears that the maximum output efficiencies of these devices have already reached the intrinsic limits of almost all electrocatalyst materials. Hence, it is a high time to think about new material architectures by controlling size, shape, and geometry, as well as composition that can potentially make a significant improvement in the performance of these electrochemical devices. Among several known electrocatalyst materials are nanomaterials and their composites due to their unique electrical, mechanical, physical, chemical, and structural characteristics. These materials have opened a whole new territory of possibilities in designing high performance energy storage and conversion devices. In

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this chapter, the authors review the recent progress in energy storage and conversion devices that utilize various nanomaterials and their composite materials and identify future directions in which the field is likely to develop.

1. INTRODUCTION

A rapidly growing global population, diminishing natural resources, emission of greenhouse gases that contribute to global warming and sufficient energy supply to meet the growing energy demand are some of the most important challenges mankind is currently facing and the intensity of these issues is expected to become uncontrollable in the next few decades (Fröhlich, 1968; Dell & Rand, 2001). An estimate suggests that the current global energy demand of 15 TW for a population of ~ 7 billion people will double to 30 TW for a population of 9 billion in 2050. The current level of CO₂ in the atmosphere is around ~ 394 ppm and approximately 2 ppm of CO₂ is added each year to this value. These CO₂ emissions cause global warming and according to the International Panel on Climate Change (IPCC), a CO₂ level ~ 450 ppm will cause a temperature rise of ~ 2 °C. A 2 °C rise in temperature will have severe environmental impacts. Hence, sufficient supply of energy with low environmental impact is one of the biggest challenges facing mankind in the 21st century. One possible solution which has great potential to fulfill our growing energy demand is to transform the energy from one form to another and storage of a particular form of energy by using the state-of-the-art technology is indispensable for sustainable future (Woodcock *et al.*, Hasnain, 1998; Walker & Dracoulis, 1999; Sun *et al.*, 2006; Kaygusuz, 2007; Sarı & Karaipekli, 2007; Vera & Langlois, 2007; Rae & Bradley, 2012). There has always been an incredible source of unlimited, free and clean power right above our heads *i.e* the Sun but for most of us, it was still out of reach until now. In order to exploit such an abundant but intermittent resource to extract energy in future there is a great need to develop highly efficient

energy conversion and storage devices (Licht, 2001; Aricò *et al.*, 2005; Lewis, 2007; Guo *et al.*, 2008; Liu *et al.*, 2008; Cavaliere *et al.*, 2011; Dai *et al.*, 2012; Jose *et al.*, 2012; Sahoo *et al.*, 2012). Currently a vast variety of devices exist that can be used for energy conversion and storage purposes. Some of them are supercapacitors, lithium ion batteries, photoelectrochemical water splitting, fuel and solar cells, which are the most promising candidates for the generation and storage of energy from renewable resources. Unfortunately, we have a limited choice of materials available which are capable of converting or storing energy. Moreover, bulk materials have already reached their inherent limits in performance, which makes the situation much more challenging for future development (Tarascon & Armand, 2001; Liu *et al.*, 2005a, 2005b; Gwon *et al.*, 2011; Nyholm *et al.*, 2011; Zhao *et al.*, 2011a). During the last decade, various approaches such as the downsizing of materials, development of composite structures and the exploitation of vertical arrays of nanowires or nanotubes for improving the surface area, reactivity, conductivity and stability of materials have been investigated to maximize the performance of materials. Among these approaches downsizing materials to nanoscale has attracted the greatest interest due to the unusual mechanical, electrical and optical properties of nanomaterials. It has been found that the performance of electrochemical energy conversion and storage devices is dramatically enhanced by using nanomaterials. In this chapter, we will attempt to review recent progress concerning the development of energy storage devices such as lithium ion batteries and energy conversion devices such as dye sensitized solar cells, photoelectrochemical cells for solar hydrogen production and fuel cells.

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