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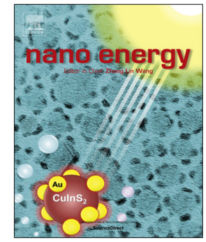

REVIEW

Graphene-based nano-materials for lithium-sulfur battery and sodium-ion battery

Songping Wu*, **Rongyun Ge, Mingjia Lu, Rui Xu, Zhen Zhang**

School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510641, China

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Abstract
Graphene-based nano-materials have provided an opportunity for next-generation energy storage device, particularly for lithium-sulfur battery and sodium-ion battery (SIB), due to their unique properties. This review comprehensively summarizes the present achievements and the latest progress of inorganic nano-materials/graphene composites as the electrode materials for Li-S battery and SIBs. Electrochemical principles, performances and key obstructions of graphene-based materials in the actual application are considered. This review gathers and classifies updated knowledge about Li-S battery and SIB nanomaterials related to graphene, with the aim of offering a wide view of those systems. It is concluded that cost-effective SIBs and Li-S battery are promising next-generation battery candidates in the near future, but require further investigation and improvement to deal with some critical scientific issues.

Contents

*Corresponding author. Tel./fax: +86 20 87112897.
E-mail address: chwsp@scut.edu.cn (S. Wu).

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Introduction

Sustainable development has been becoming a globally competitive new industry due to the urgent reality on unsustainable energy consumption, environmental degradation, and especially, the increasing appeal for the improvement of the living quality. As the hottest fields of investment, solar energy, geothermal energy, wind energy, tidal power and rechargeable chemical power source et al. have attracted great attention and funding. Among them, rechargeable lithium-ion batteries have established themselves as a dominant role for portable electronic devices as agile and universal power sources, and moreover, are widespread utilized in the small electronic equipment. In fact, three, based on lithium, are receiving extensive interest at the present time: rechargeable LIBs, Li-air (Li-O_2 as O_2 is the fuel) and Li-S batteries (Figure 1).

Of particular note is that the electrical vehicles are now being commercialized. As important components of the electrical vehicles, power battery pack is the core of electric vehicles, and directly related to the cost and crucial technologies such as life and safety of electric vehicles, therefore, is the key of the industrial chain. Despite the great achievements, lithium ion battery, a widely used power in the present stage, still faces two long-term, fundamental challenges, those are: a low energy density, limited resources and high cost. (1) Lithium-ion batteries unfortunately remain the low energy density of 120 Wh kg^{-1}, [1,2] thus largely limits the overall improvement of battery life, weakens the competitiveness of the electric vehicle and reduces the purchase desire of consumers. Therefore, large energy battery become highly desirable due to the extremely urgent requirement in high-power applications; (2) with the coming of the era of electric vehicles and smart grids, global lithium resources will not be able to effectively meet the huge demand of power LIBs.

In 2012, JCESR (US Joint Center for Energy Storage Research) stated an "impossible" and "very aggressive" goal. That is that cell, when scaled up to the sort of commercial battery packs used in electric vehicles, would reach a target of 400 W-hours (Wh kg^{-1}) per kilogram as of 2017 [3]. As a result, several new-concept batteries have been emerging for achieving the grand prospect, for example, flow battery [4] that packs a high energy density with no need for the expensive metals found in other models, vanadium flow batteries [5], Li-S and sodium-ion batteries (as will be discussed in the article), Li-O batteries [6,7], thermal batteries, [8] sodium-sulfur batteries [9], sodium breathing batteries (Na_2O batteries) [10], magnesium ion batteries [11], calcium-ion batteries (CIBs) [12], and high-energy supercapacitor [13] and so on. Among them, Li-S and sodium ion batteries are being commercialized, and establishing themselves as the most promising next-generation storage device due to high energy density, good versatility, reliability and cost advantages. Based on above opinion, we concentrated our interest on the LiS battery and sodium-ion battery in this review.

As a two-dimensional sheet of sp^2-hybridized carbon material [14], rather than carbon [15], graphene has been confirmed as excellent matrix to support oxides nanoparticles for LiBs [16-20]. Of late years, the enormous achievements in synthesis of defectless graphene make them easier to be commercialized [21,22] inevitably producing a profound impact on the development of the next generation battery. In addition, a recent review summed up six different structure models of graphene and inorganic nanoparticles composites (Figure 2), and showed the channels for Li insertion/de-insertion, as a consequence, provided an important reference for future work [23].

Of special note is that, when the nanomaterials are employed in both of Li-S battery materials or SIBs materials,

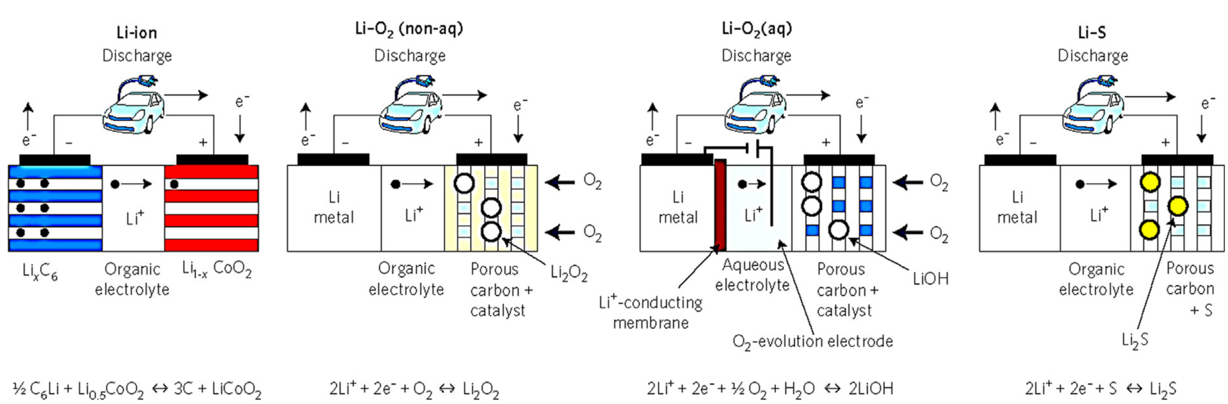

Figure 1 Schematic representations of Li-ion, non-aqueous and aqueous Li-O_2 and Li-S cells. Reproduced with permission from Ref. [31]. Copyright 2012 Nature.