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Mini Review

A Mini Review on Progress of Nanostructured Anode Materials for Sodium Ion Battery

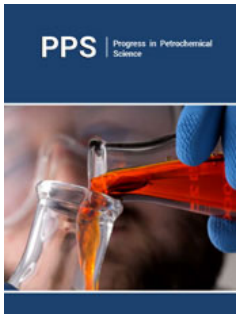
Laraib Kirana[1], Muhammad Imran Shahzad[3], Muhammad Kamran Khan[2], Uzair Naeem[3] and Syed Sakhawat Shah[1]*

[1]Chemistry Department, Quaid-i-Azam University, Islamabad 45320, Pakistan

[2]Physics Department, Quaid-i-Azam University, Islamabad 45320, Pakistan

[3]Nanosciences and Technology Department (NS&TD), National Centre for Physics (NCP), Islamabad 44000, Pakistan

ISSN: 2637-8035



***Corresponding author:** Syed Sakhawat Shah, Chemistry Department, Quaid-i-Azam University, Islamabad 45320, Pakistan

Submission: October 27, 2023
Published: November 20, 2023

Volume 5 - Issue 5

How to cite this article: Laraib Kirana, Muhammad Imran Shahzad, Muhammad Kamran Khan, Uzair Naeem and Syed Sakhawat Shah*. A Mini Review on Progress of Nanostructured Anode Materials for Sodium Ion Battery. Progress Petrochem Sci. 5(5). PPS. 000625. 2023. DOI: 10.31031/PPS.2023.05.000625

Abstract

The powerful and rapid growth of Lithium-ion batteries in the field of secondary batteries has resulted in a shortage of lithium resources, which has led to an increase in the price of batteries. As a result of these factors, sodium-ion batteries, also known as NIBs, have developed into one of the most appropriate options for large-scale energy storage devices. These batteries have a low cost, limitless sodium reserves and a working principle that is similar to that of LIBs. Na-ion batteries, also known as NIBs, have gained a lot of attention as a potential excellent candidate for grid-scale energy storage systems due to the abundance and accessibility of Na as well as its electrochemistry that is very similar to that of the well-established LIBs technology. This review article provides a concise assessment of the most recent developments in the field of electrode materials for NIBs, including the discovery of new electrode materials and the Na storage mechanisms possessed by those materials.

Introduction

Because of rising energy demands and an expanding population, the consumption of fossil fuels has expanded around the world. The high levels of CO_2 emissions that result from this trend are expected to contribute to a number of environmental issues, such as the spread of desertification and rising temperatures [1]. Even though the price of oil has been going down since 2010, energy harvesting from renewable energy resources, including wind, tidal, solar, hydro and geothermal energies, has become a key worry in recent years. This is the case despite the fact that solar, wind, hydro, and tidal energies are among the most cost-effective forms of renewable energy. In order to store and make use of these energy resources in the most effective manner possible, there has been an increase in the development of large-scale energy storage systems, also known as ESSs. Grid-scale Energy Storage Systems (ESSs) have been evaluated using a variety of technologies, including pumped hydropower storage, compressed-air energy storage, capacitors, and flywheels and batteries, among others [2,3]. As a direct result of this, technology for nickel cadmium, nickel-metal hydride, lead acid, lithium-ion batteries and other types of batteries have been created. Since its first commercial launch by Sony, rechargeable Lithium-Ion Batteries (LIB) with high charge/discharge current rates have been found to have a great deal of promise for their application in a variety of portable electronic devices.

As a result, researchers are attempting to build energy storage technologies that are not only economical but also ecofriendly and kind to the environment [4]. One such technology is the Lithium Ion Battery (LIB). Because of its long cycle life, high energy, extended service, power densities, cycling performance, light weight, low self-discharge, strong storage capacity [5,6] and small memory effect [7]. These benefits have contributed to the widespread use of LIBs. It finds widespread application across a variety of industries, including grid-scale batteries, electric vehicles, power devices and energy storage equipment's [8]. On the other hand, LIBs are confronted with a number of substantial problems when it comes to their deployment in grid-scale ESSs. The expense of not only the processing and manufacture,

but also raw materials, is currently one of the most significant challenges that has been faced to this day. Even for applications of a medium scale, like Electric Vehicles (EVs), significantly lowering the cost of LIBs is not yet a simple thing to solve. In addition, there is a rising concern regarding the viability of the traditional LIB technology. It is predicted that the global Li resources only amount to 30-40Mt, which is not enough to meet the growing demands placed on energy storage by LIB technology [9,10].

Despite the fact that recent assessments have projected that the supply of lithium resources should be able to partially fulfill the demand for lithium for Electric Vehicles (EVs) based on scenarios from the International Energy Agency (IEA), the demand for lithium continues to grow. Since there is a large supply of Na and it is not difficult to get, researchers have focused a lot of their attention on developing rechargeable battery systems that use Na as a guest ion in the hopes of creating more affordable and long-lasting ESSs [11]. The crust of the Earth contains approximately 2.6% sodium, making it the sixth most plentiful element overall. Seawater provides a source of almost endless sodium supplies. An early emphasis in the field was placed on high-temperature Na rechargeable battery systems, such as $Na/NiCl_2$ and Na-S batteries [11,12]. These batteries are presently commercialized as grid-scale ESSs; nonetheless, the significant corrosion difficulties and high operating temperature (about 300 degrees Celsius) must be addressed. Since Na intercalation compounds were first investigated in the 1980s, room-temperature NIBs have also received attention for large-scale ESSs [11]. This is because room temperature NIBs are more stable than their low-temperature counterparts. Despite this, only a small number of studies were carried out up until the year 2010, despite the success of LIBs in the field of energy storage applications for small and medium-sized applications. When compared with those of Li (0.76 and 3.04 V vs Li^+/Li, respectively), the large ionic size of Na (1.02) and its low standard electrochemical potential (2.71 V vs Na^+/Na) resulted in low power and energy densities, which held back further advances of NIBs [2]. Since the demand for batteries as well as their sizes has expanded, there has been a recent resurgence in interest in NIBs, particularly for grid-scale ESSs.

Anode Materials for NIBS

In recent years, there has been a great interest in the study of metal chalcogenides with both layered and nonlayered structures as conversion-type anodes for Sodium-Ion Batteries (SIBs). This is mostly due to their diverse range of material species, which has made them a focal point of research in this field. Metal sulfides and Metal Selenides (MSex) have remarkable electrochemical properties, offering several advantages such as abundant reserves, low cost, consistent performance and high theoretical capacity. In contrast to metal oxides, the M-X (M = Mo, W, Co V, Bi, Zn, Fe Sn, Sb, Ti, Ni, Cu, Mn, et al. X=S, Se) exhibit weaker bonding compared to M-O, hence promoting the conversion reaction. In addition, in the case of MSex with a layered structure, the metal atom layer and the adjacent two selenide layers form covalent bonds to construct a Sandwich-Like Arrangement (Se-M-Se). The layers of Se-M-Se are further interconnected through weak van der Waals forces. The alkali ions exhibit enhanced migration capabilities due to the wider interlayer distance and weaker contact, resulting in a reduced diffusion energy barrier. This facilitates a more efficient intercalation reaction. In addition to the inherent ability of structure intrinsic features to enhance diffusion kinetics, the electrode's improved sodium ion storage properties are also positively influenced by its favorable conductivity [13]. Furthermore, the variation between metal sulfides and metal selenides cannot be ignored. Evidently, the selenium atoms possess a larger atomic radius and stronger metallicity than sulfur atoms, resulting in metal selenides with larger layer spacing and high conductivity. The lowest band gap was observed in case of metal selenides and sulfides.

As a result, these characteristics will ensure that the metal selenides exhibit excellent performances in numerous aspects than metal sulfides [14]. Lee SY et al. [15] developed composites of tin oxide and reduced Graphene Oxide (SnO/rGO) to address the issues pertaining to limited discharge capacity and inadequate cycling stability. The nanocomposite electrode composed of SnO and rGO demonstrates enhanced specific capacity, enhanced stability, and exceptional rate performance. It achieves a discharge capacity of 391.9mAh/g at a current density of 100mA/g after 120 cycles, with a capacity retention of 96.2%. Additionally, it achieves a discharge capacity of 338.7mAh/g at a current density of 500mA/g after 500 cycles, with a capacity retention of 92.2% [15]. Cui L et al. [16] prepared the composite material consisting of SnS/Fe7S8/NS-CNs exhibits remarkable performance as an anode for Sodium-Ion Batteries (SIBs). It demonstrates exceptional cycling and rate capabilities, with an initial discharge/charge capacity of 873/559.2mAhg^{-1} at a rate of 0.2Ag^{-1}. Furthermore, it maintains a high capacity of 305.2mAhg^{-1} even after undergoing an extensive cycling process of over 2000 cycles at a rate of 1.0Ag^{-1}. The exceptional electrochemical features of the SnS/Fe_7S_8/NS-CNs electrode can be attributed to the utilization of a bimetallic sulfide heterostructure. This heterostructure enhances the kinetics of electron/Na^+ transfer and prevents the breaking of SnS/Fe_7S_8 particles by employing a 3D carbon matrix consisting of dense carbon nanosheets.

Consequently, the electrode exhibits remarkable performance. Furthermore, the electrochemical conductivity was enhanced through the utilization of a 3D carbon nanosheet matrix co-doped with N and S. Therefore, it can be inferred that the SnS/Fe_7S_8/NS-CNs composite exhibits promising characteristics as an anode material for high-performance sodium-ion batteries [16]. Wang J et al. [17] and colleagues In this study, we have effectively developed and produced a Three-Dimensional (3D) heterojunction for use as anode material in Sodium-Ion Batteries (SIBs). This heterojunction consists of interlayer-expanded $MoSe_2$ nanosheets that are vertically attached to nitrogen-doped branching TiO_2-C nanofibers, resulting in the formation of $MoSe_2$-NBT-CNFs. The branching TiO_2-C nanofibers not only mitigate the pronounced self-aggregation of $MoSe_2$ nanosheets but also serve as a buffer for the volumetric expansion that occurs during cycling process. In addition, the increased interlamellar spacing of $MoSe_2$ nanosheets enhances the rate of sodium ion diffusion. Furthermore, the robust chemical contacts between $MoSe_2$ nanosheets and carbon nanofibers facilitate the improvement of charge-transfer kinetics and enhance

structural durability. As anticipated, the anode composed of $MoSe_2$-NBT-CNFs demonstrates exceptional cycling performance characterized by a high level of reversibility, as evidenced by a capacity of 315.2mAhg^{-1} after undergoing 800 cycles at a current density of 2Ag^{-1}. Additionally, this anode exhibits outstanding rate capability, achieving a capacity of 194.2mAhg^{-1} when subjected to a high current density of 30mAg^{-1}. The utilization of the rational design technique has the potential to provide valuable assistance in the development of electrode materials for Sodium-Ion Batteries (SIBs) that are based on metal chalcogenides [17]. He Y et al. [18] developed heterostructure materials that exhibit both long-term cycle stability and high-rate capacity as anodes for Sodium-Ion Batteries (SIBs) continue to pose significant difficulties. In this study, a novel Three-Dimensional (3D) heterostructure.

Consisting of micro-flowerlike MoS_2 -modified Co_9S_8(Co_9S_8/MoS_2) was successfully synthesized using a solvothermal method and subsequent solid sulfidation treatment. The Co_9S_8/MoS_2-based electrode, denoted as CM55-S, demonstrates the highest sodium storage performance among anode materials for Sodium-Ion Batteries (SIBs). It exhibits enhanced capacity, excellent reversibility (424.5mAhg^{-1} at 2Ag^{-1} after 1600 cycles, 401.1mAhg^{-1} at 5Ag^{-1} after 800 cycles), and superior rate capacity (210.1mAhg^{-1} at 20Ag^{-1}). The utilization of Density Functional Theory (DFT) computations provides confirmation that the heterostructure formed by the combination of Co_9S_8 and MoS_2 exhibits a reduced energy barrier (0.30eV) compared to the pure Co_9S_8 (0.53eV). This heterostructure material holds promise as a potential contender for the anode material in sodium-ion batteries [18]. Jin Q et al. [19] conducted a study in which they synthesized many spheroidal hard carbons using various carbonization conditions. The objective of their research was to evaluate the impact of microstructure on the behavior of Na^+ storage [19]. Liu and colleagues conducted a study in which they synthesized a variety of hard carbons that resemble permeable channels, using a method that involved controlled phase-transition. This approach resulted in enhanced ionic diffusion, as well as improved electrode and electrolyte interface and affinity [20].

The findings of the experiments indicate that the capacity of porous hard carbon materials with crosslinked mesoporous structure can be increased, which is useful for storing sodium ions. When compared to other initial hard carbon materials that had a lesser pore concentration, the ICE of the synthesized porous hard carbon anode increased from 51.5% to 68.3%. It had a high capacity of 332.7mAhg^{-1} when operated at 50mAhg^{-1}, and its capacity retention rate improved from 46.5% to 67.4% when operated at 2Ag^{-1}. After 90 cycles, the capacity retention rate was increased from 86.4% to 95%, and the anode capacity, cycle stability, and rate performance were all significantly improved. The micropores included within the hard carbon that Yang et al. worked with were transformed into ultrafine pores by using melt diffusion carbonization. The capacity of the anode was able to be increased thanks to the ultrafine pores, which were proven to provide extra sodium-ion storage sites by in situ XRD. The ICE of hard carbon grew up to 80.6%, with a capacity of 346mAhg^{-1} at 0.03Ag^{-1}; more than 90% of the capacity was given by regions with a voltage of less than 1V. Under a high load of 19mgcm^2, the surface capacity was 5.32 and 6.14mAhcm^2 when the temperature was 20 and 25 degrees Celsius, respectively. In order to increase the cycle stability and rate performance of sodium-ion batteries, it is possible to produce porous hard carbon with a three-dimensional structure by the use of morphological and structural regulation [21].

Challenges

Sodium-Ion Batteries (NIBs) have garnered significant interest within the energy storage field due to the abundant availability of sodium supplies and their comparable electrochemical properties to widely used Lithium-Ion Batteries (LIBs). These characteristics make NIBs highly advantageous for large-scale applications. Despite the fact that Sodium (Na) has a relatively high atomic weight and ionic radius, these characteristics result in a lower energy density for Sodium-Ion Batteries (NIBs) compared to Lithium-Ion Batteries (LIBs). Additionally, NIBs necessitate the use of open framework electrodes. Several recent investigations have contributed to the advancement of layered-type cathodes that exhibit high specific capabilities while utilizing low-cost transition metals. The primary challenges associated with the insertion and extraction of Na in high-capacity layered-type anodes are the fundamental issues.

Conclusion

The development of technologies that utilize clean and renewable energy sources is a pressing necessity in light of the rising demand for energy and the diminishing availability of fossil fuels. In order to accomplish this goal, suitable storage technologies that are economical and kind to the environment need to be created. LIBs are currently considered as the most promising energy storage devices; however, owing to low Li reserves and high cost, the interest has been shifted towards the NIBs. This is because NIBs are considered to be cost-effective substitutes for the development of large-scale energy storage applications. Investigations have been carried out on numerous components of SIBs in order to produce optimum battery systems.

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