

Nano materials in batteries engineering essay



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Abstract

Energy storage is necessary in this fast growing world in order to meet the demand and supply of users, various energy storage techniques has been found and many researches is being done in this field to increase the efficiency of the devices. In this essay we will discuss about use of nano materials in the batteries as they have huge energy density and high energy storage capacity. We will discuss the various advantages of using nano materials in battery instead of conventional batteries, some of the disadvantages and some probable solutions in order to overcome the disadvantages.

Introduction

Energy storage is the method in which a device or any other material is used to store the energy which can be used later for some useful purposes.

Storing of energy helps us to meet the supply and the demand for energy. Various energy storage method is been followed by us since the evolution of universe, sunlight is stored directly (heating)/indirectly (photosynthesis of plants). since then various new methods and technology has evolved in the field of Energy storage.

Energy storage system can be broadly classified into mechanical, electrical, chemical, biological and thermal. Various energy storage techniques have been found out under all these methods. Some of them are

Grid energy storage

Pumped water

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Compressed air

Thermal energy

Fly wheel

Battery

Fuel cell

Super conducting magnetic energy

Even in the above methods various researches is being done in order to increase the efficiency of the devices to store more energy without much losses.

Out of the above methods, energy storage using battery is one of the widely used devices for energy storage. Battery is electrochemical device which convert chemical energy into electrical energy. Energy can be stored in small scale as well as large scale in a battery. Various advancements have been made in batteries and the recent development is developing a battery using nano materials. There are many advantage of using this method for energy storage. Let us discuss the various advantage and disadvantage of using nano material in batteries

Battery

Before we discuss about nano material being used for a battery, let us have a basic idea about a simple battery. Battery is a electrochemical device which convert chemical energy stored in it to electrical energy. It consists of an anode and cathode connected by an electrolyte. The chemical in the

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anode and cathode reacts to produce a voltage potential which can be used for some useful applications.

The chemicals in the battery lead to accumulation of electron in anode which causes electron difference in the battery and the anode try to balance the electron difference by giving it to electron but electrolyte doesn't allow to do it directly; therefore when a battery circuit is closed the electron in the anode can go to cathode which produces energy. However this causes chemical changes in the battery which lead into decrease of the energy generated after each uses. This is one of the main concern of battery whose efficiency of energy storage is very less when compared to any other energy storage devices. The energy density is very less in battery therefore; we need large sized battery if we need to store more energy which becomes expensive and more bulky.

Advantage of Nano materials in a battery

1. Reduction of diffusion length.

Lithium ion battery is a type of battery which is very popular commercial due to its higher energy density and small size; however a new technology of battery with high energy and power density is required for more applications. In order to achieve this lithium ion should have excellent rate capability of electron. The time for intercalation of the lithium ion decreases with decrease in diffusion length. Therefore, if decrease the particle size, the lithium-ion diffusion length decreases and the rate capability of electrode materials increases. This can be provided by the nano materials. The effective specific capacity will depend on the volume ratio

$$\hat{i} = (1 - \text{Li}^+ / r) n$$

Where, r = the radius of the intercalation compound particle

n is determined from the dimension of the lithium-ion mobility.

Nano materials provide as less as 1-dimensional lithium ion diffusion ($n = 1$).

The required length of Lithium ion should be larger than r in order to obtain the maximum capacity which can be obtained using nano materials. The table below tells us the lithium ion diffusion co-efficient of different electrode materials.

Intercalation materials D_{Li}/cm² s⁻¹ Average voltage/V Theoretic capacity/mAh g⁻¹

LiMn₂O₄ 10⁻¹⁰ - 10⁻⁷ 4. 1 148

LiCoO₂ 10⁻¹¹-10⁻¹⁰ 3. 7 140

LiCo_{0.33}Mn_{0.33}Ni_{0.33}O₂ 10⁻¹⁰-10⁻⁹ 3. 8 200

LiFePO₄ 10⁻¹⁴-10⁻¹¹ 3. 5 170

LiV₃O₈ 10⁻⁹-10⁻⁸ 3. 0 280

LiTi₂(PO₄)₃ 10⁻⁷-10⁻⁵ 2. 5 138

Li₄Ti₅O₁₂ 10⁻¹⁷-10⁻¹⁴ 1. 5 175

Cu₆Sn₅ 10⁻¹⁰-10⁻¹² 0. 2 584

Graphite 10⁻¹¹-10⁻⁹ 0. 1 370

Beside this researchers (yongaang) were able to we can fabricate nano-materials like LiFePO_4 , $\text{Li}_{0.33}\text{MnO}_2$, $\text{Li}_{0.44}\text{MnO}_2$, LiCoO_2 , LiMn_2O_4 , $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$, $\text{Li}_4\text{Ti}_5\text{O}_{12}$ into the lithium ion battery using inexpensive, simple processes simple lithiation and post annealing processes.

2. Improving electron transport using nano-sized coating.

In a lithium battery many electrode active materials are semi-conductors or an insulator which causes a resistance arising from active materials which would limit the high power performance of the battery. This can be overcome by using nano materials which reduces the path length of the electron transfer. However there is still an electron resistance since only some nano-particle can have direct contact with the ions in the battery. This can be overcome by fully coating the nano materials with fully conductive electronic coating which further reduces the path length of electron transfer.

figure showing electron transport length in a nano material

Figure showing how the electron transport length is reduced after using electronic coating in nano material

3. Enhancement in Li storage capability.

One of the main advantages of using nano material for lithium ion battery is the increase in capability of Li storage which happens by initiating a new Li storage mechanism called ' Conversion' mechanism which refer to formation & decomposition of LiX (X = oxide or sulfide or fluoride or nitrate) accompanied reduction or oxidation of nano materials which give raise to highly reversible capacities ranging 400 to 1400 mAh g⁻¹

It promotes the electron activity when nano material is used which activates more Li storage material. It also increases surface/intersurface storage because of the short diffusion length and high contact area between active materials and electrolyte.

4. Fast electrode kinetics and high Li storage due to ordered mesoporous structure of nano material.

In a nano material the mesoporous material are arranged in an array which exists throughout the whole material. This property of nano material has various advantages like high porosity which result in large surface area and penetration. The meso size porous wets the non aqueous electrolyte which causes high flux of lithium across the interface. The ordered pore also helps in fast transport of electrolyte which is important for fast charge and discharge. The thin wall of few nano meters help in decrease of the transport length of lithium ion. It also helps against degradation of the material due to its rigid framework and the high porosity helps in accommodating the volume change upon lithium insertion/extraction which increases the cycle performance.

5. Increase in cycle stability

Besides having various advantages which has been discussed above the usage of nano material decreases the degrading of the active materials and thereby increasing the cycle stability of the material. The degrading is usually caused in a battery by large increase in decrease in the volume which can be absorbed by using a nano material which increases the cycle stability of the battery

Schematic representation of Li insertion and excertion method in a conventional battery and nano material battery

Disadvantages

Low density

Due to the large surface area and porous structure, the nano material has low density when compared to micro material; therefore the pack density of the nano material is lower than the micro material which reduces the volumetric energy density of the battery.

High surface reaction

As the surface area and surface energy is high in nano materials it leads to undesirable surface reaction when in contact with open air as some nano materials are unstable in open atmosphere. This limits the large scale application of the nano materials.

Complex synthesis method

Currently the most general method used for synthesis of nano material battery is by solid-state process which is an easy process and it can be easily extended to industrial processes, however there are lots of other complex methods like hard template method and hydro thermal synthesis which is very complex and cannot be extend to industrial processes.

Suggestion

Some of the suggestions to overcome the disadvantages of nano materials are

Using nano/nano or nano/micro mixed materials to increase the pack density and volumetric energy density of the battery.

Surface coating of the nano material can be done in order to avoid the unwanted side reaction of the material with atmosphere which can increase the durability of the material.

Conclusion

In this summary we have discussed about the basic introduction of energy storage and various development made in this field and we discussed about the various advantages and disadvantages of using nano materials in batteries and we have also analyzed some of the possible suggestion for the drawbacks of using nano material. In regards to the entire above summary we have to design a nano material with consideration of its advantages and its disadvantages and the place where we are going to use the material and the design and the cost of the material.