Battery cycling capability based on different nanomaterials

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Abstract. In nowadays society, as the increase requirement of energy power supply, lifetime cycling of battery have become more and more necessary to the whole world. Based on the operation theory of battery, the expansion of electrode cannot be prevented. Different strategies have been developed and used to address this drawback. Introducing nanomaterials into batteries has become a simple and effective method. To this end, this research will analyze the performance of different types of nanomaterials in battery cycling. Nanotube structure has played a huge role in providing empty space and restricting too much expansion of electrode. In addition, differences and common thing are going to be concluded and find out their disadvantages and advantages in this research. Based on the current disadvantages of all these solutions, future plan expectation has been shown out in this research as well. Furthermore, there are various variables like working temperature which affects cycling lifetime of battery which can also add in future observation plan.

Keywords: Nanotechnology; Battery; Cycling lifetime.

1. Introduction

With the growing demand of energy, battery has increased dramatically into all aspects of life. Battery can be used in different situation, like daily electric device or small scale of electric motor. It can also be used in power supply of transportation or act as the storage of green energy. In the same situation, there are various batteries can be chosen. All these facts point out batteries have significant influence on every aspect in daily life. Lithium-ion battery has one of the best performances in all situations due to its extremely high specific capacity which is equal to 1672 $mAh\cdot g^{-1}$ [1]. As the requirement of battery rises rapidly, experts paid more attention on battery recycling. Most of the research are mainly focus on changing inside battery. In lithium-ion battery, graphene is normally act as cathode which act as negative electrode.

The nanotube structure is the key to the lithium-ion battery. The nanostructure of graphene has lots of holes which let ions easily passing through. However, a pure graphene electrode has few more weaknesses. For instance, a pure graphene electrode doesn't have a balance voltage during recycling and the capacity of electrode decays quickly as the number of cycling times increases [2]. All these weaknesses of pure graphene let the traditional lithium-ion battery has lower times of cycling. There are some other materials such as transition metal oxide which has higher theoretical specific value than graphene tried to use inside lithium battery. However, the real performance of these transition metal oxide doesn't reach the expectation. During the battery recycling, the structure of anode is going to be expanded and its structure is easily to be destroyed when the number of cycling times increases [3].

All these improvements will largely increase the using life of battery which bring raw material to build up batteries. Increasing times of life cycling will largely reduce the waste of batteries. Due to advanced technique in lithium-ion batteries, there are more and more combination electrode inside the batteries which highly upgrade the cost and deal with these waste batteries. The main objective of this research is to figure out some current improvement in battery recycling. For each nowadays solutions, every solution should analyze their weaknesses or advantages compared to different ways of improving battery recycling. At the end, conclusion should be made and tried to figure out future development of the battery cycling.

2. Applying different nanomaterials to change the cycling ability of batteries

2.1. Hallow nanomaterials

The technique of hallow nanomaterial is aim to use transition metal as anode for lithium-ion battery. As the cycling times of battery getting higher, the transition metal electrode is going to expand which will lose its initial function and let the whole battery defunctionalized. To fix this problem, it mentioned some technique which fix this problem. The first is to change transition metal into transition metal oxide. Even though transition metal oxide material has the same issue as transition metal, its special nanostructure hallow nanotube dramatically fixed this problem out. Due to the hallow nanotube structure, there are larger surface area which allow lithium ions passing through. When the recycling times increases, the whole material tried to expand which will slowly occupy the empty space inside the tube. The restriction of expansion will large slow down the anode defunctionalized. There are some other examples of material such as sulfide or multi-metal oxide which has the same nanostructure as transition metal oxide. The main principle of this technique is to use the hallow nanotube structure which slow down the expansion during recycling and keep the ability of anode is nearly the same [3].

2.2. Electrode nanoparticles and adhesives

The fundamental components inside a lithium battery are two electrodes and adhesive with electrolyte. The main research is focus on calculation of the expansion of lithium ions during cycling due to adhesive inside battery. The size of lithium ions is going to expand during cycling. If adhesive covering around anode, it will slowly restrict the expansion of lithium electrode. In the whole model, there are few components to be considered inside the calculation. These are lithium-ion concentration and lithium expansion constant. These two variables will affect the whole volume of the anode during different times of recycling. When adhesive attach to the surface of the anode which forms a passive film outside, the lithium ion has lower concentration attach to the silicon electrode which decrease the rate of expansion. The number of recycling times will also affect the performance of electrode. In the first-time recycling, the whole electrode is under irreversible reaction force which increases its volume. Even though adding adhesive is able to slow down the expansion of electrode, if the number of recycling times increases, it will defunctionalized as well. The whole calculation and performance testing graph show the thickness will also affect the electrode corrosion. The thicker adhesive it has, the longer time required to corrode the electrode [4].

2.3. Antimony-based nanomaterials

Potassium-ion battery has the similar problem as lithium-ion battery which is the expansion of electrode during cycling time increases. This scenario slightly being restrict due to the size change from bulk into nanoscale. The nanoscale electrode inside which improve the diffusion rate of electrons and reduce the mechanical stress. Even though the nanoscale electrode upgrades the performance of potassium-ion battery, when the recycling of battery up to 20 times, the Sb nanoparticles capacity drops rapidly. This is because there is little empty space for electrode expansion. The key is to use conductive matrix which stabilized the whole electrode. The manufacture of Pb-graphene electrode is different to traditional electrode. The main technique is 24-hour high energy ball hot-milling which largely increases its mechanical stress and more empty space for expansion. The hot-milling electrode has larger empty space in nanoscale structure which allows electrode to expand. The advanced electrode will not change its original ability up to 100 times of recycling (Fig. 1). When the whole battery cycling is more than 100 times, the whole electrode maintains 60% of initial function of the battery. If the number of times getting larger, the function of whole battery reduces as slowly as possible to maintain it is functionalized. This research is to use specific technique to make the whole structure to overcome higher mechanical stress and leave more empty space for the electrode expansion [5].

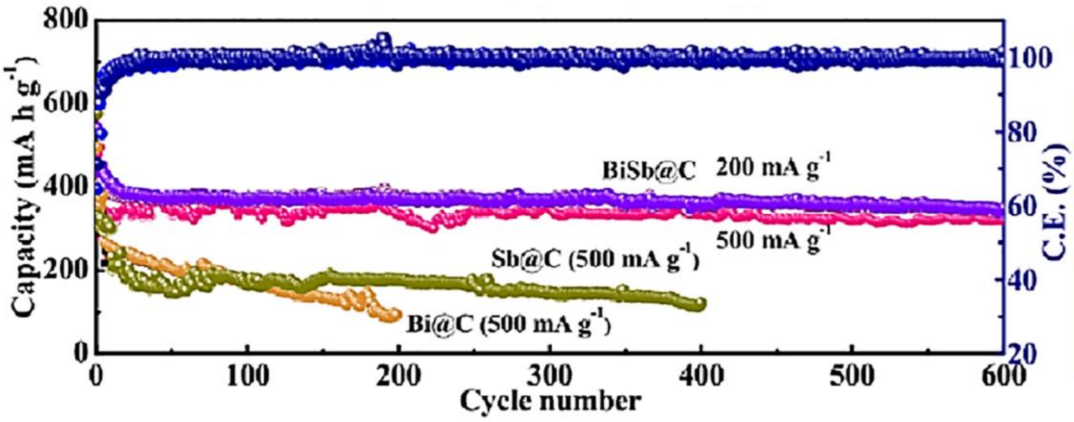

Fig. 1 Capacity change with different times cycling [5].

2.4. Sn-based nanomaterials

The key restriction of battery cycling is the expansion of electrode which let the whole battery defunctionalized. The key observation is based on different compound of Sn compound. One example is SnO_2-based electrode in battery. Even though during expansion issue can be solved by adding in carbon matrix, cracks still occur on SnO_2 electrode which let ions detach to the electrode. The nanotube vacancy shows the oxygen-containing percentage inside the tube. The presence of oxygen inside the nanotube will largely decrease the energy barrier of reaction. As the combination of carbon and SnO_2, the whole electrode exhibits extraordinary reversibility from Sn to SnO_2. This largely increase the battery cycling. Another electrode combination SnO_2+P_2O_5 has the similar ability as SnO_2+carbon electrode both of them exhibit fantastic cycling reversibility. SnO_2-based electrode also enhances flexible chemical bonds which let the ion has highly ion diffusion rate. The nanoscale electrode has extraordinary energy storage inside the electrode which let the battery has greater performance in different cycling. SnO_2 nanotube structure largely improves the cycling and its specific reversibility performance let the whole battery keeping stable performance during cycling [6].

2.5. Nano-silicon materials

The effect of shape or size of silicon electrode on the battery is discussed [7]. At the beginning of cycling, the inversely capacity of electrode increase linearly with an increase in specific area. Si electrode has zero effect on inversely capacity. However, the size of electrode has strongly affected to electrochemical performance as number of cycling above 40 times. This is due to when the cycling times between 2 to 40 times, the lithium electrode fades it distribution to the electrochemical sintering. As a result, polarization, electrochemical sintering both leads to less effect to the electrode during cycling. In the other case study, different Si-based electrodes have different effect to the battery cycling life. This is due to the nano 3D structure which keeps all the particles apart compares to other Si-based electrode. Even though 3D structure affects the specific capacity for different electrode, as the size of electrode is smaller, particles are close with each other which has less effect to its capacity. The size of electrode influences the particle arrangement inside the nanotube which influence its capacity during cycling [7].

2.6. Carbon nanotube-based nanomaterials

The material selection for cathode has huge influence in battery cycling performance. Different kinds of material have been developed in the past few decades. All these materials exhibit great performance in storing sodium ions when combine with carbon nanotubes. Even though these materials are beneficial to battery cycling, its poor electronic conductivity restrict the battery performance. Phosphate is regard as the best cathode of sodium-ion battery due to its extraordinary operating voltage and greater conductivity. Phosphate is manufactured under nanoscale which improves its electronic conductivity. The whole nanotubes have a 3D electron conductive network which reduce the diffusion path inside sodium-ion battery. Fluorophosphates has the similar property as phosphate. However, fluorophosphates improves its crystallinity which ultimately increases the cycling ability of sodium-ion battery. All particles forming a three-phase structure which each layer embedded with each other. What's more, all these layers twist with each other which forms carbon nanotube network. All these features inside fluorophosphates have proved the specific capacity of whole electrode. It will remain 90% of initial performance until 2000 times cycling (Fig. 2). The key feature of these two materials has nanotube structure which creates ion transfer network leads to a greater performance in long times cycle [8].

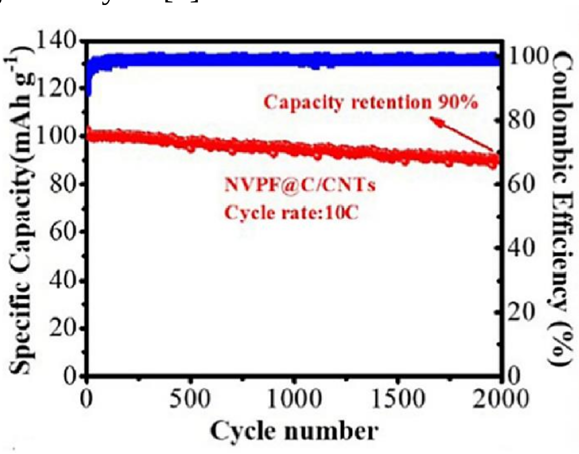

Fig. 2 Specific capacity change with changing cycle number [8].

2.7. Transition metal oxide-based nanomaterials

Coating is acting an ultimate role in energy storing system. The coating outside the nanostructure which provides more diffusion pathway for lithium-ions. This result in a quicker charge and discharge rate. Coating also prevent the dendrite formation outside the electrode which let the whole battery operate normally. The coating technique will also improve the mechanical strength of grain boundaries. Even though grain boundaries are responsible for phase transformation which forms nuclei during charging, nanoscale material coating outside of grain boundary can block the diffusion of metal ions from electrode. Due to the nanoscale coating materials, metal ions are not able to nucleate to form large particles and block the triangle phase at the surface of grain boundary. Additionally, the nanocoating largely increase the surface area of storing lithium-ion. Increasing in surface area let the whole battery has higher charge and storage lithium capacity. As shown in Fig. 3, nanoscale coating attaches to the grain boundaries which provide higher charge and prevent the nucleation occurs at electrode [9]. The coating outside the nanostructure which provides more diffusion pathway for lithium-ions and this can result in a quicker charge and discharge rate.

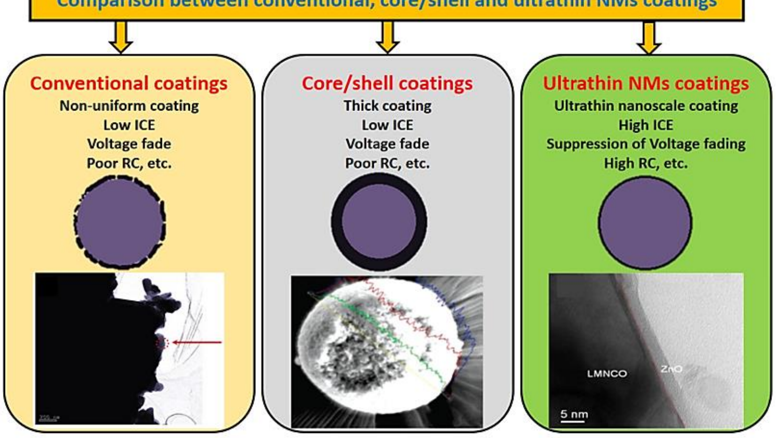

Fig. 3 Effect of different coating outside gran boundary [9].

3. Analysis of strategies for improving battery cycling capability based on nanomaterials

It's clearly to find out that all of these solutions are all trying slow down the rate of expansion as soon as possible which keeps the whole electrode functionalized. The other problem is how to change the material combination which keeps less electrode functionalized as possible. The fundamental theory of ion battery is going to be explained. The whole battery can be divided into three parts, these are cathode, anode and electrolyte which is in the middle of the battery. If lithium-ion battery as an example, in a single cycle, lithium-ions come from cathode and passing through electrolyte pathway to anode. At the side of anode, tons of lithium ions recombine with free electrons and carbon to form Li_nC. $LiCoO_2$ at cathode turns into $LiCoO_2$ and release lithium ions and electrons to anode [7]. The formation of Li_nC at the surface of electrode which directly lead to expansion of anode. When the times of cycling increase, the volume of electrode is going to increases until the whole electrode break. The fundamental theory points out it's impossible to prevent electrode expansion, the key issue is how to slow down the corrosion rate of electrode. Nanotechnology perform perfectly in prevent expansion of electrode.

The nanotube structure has holes along the surface of material, and these empty spaces are used for expansion of electrode and its structure also restrict too much expansion of electrode in order to make sure the electrode work normally. There are other solutions like change the material of electrode into multi-material electrode like SnO_2+P_2O_5 which has fantastic reversibility during ion transfer reaction. Some other materials like fluorophosphates or metal oxide are having the same ability as these metal electrodes. These materials have stable reversibility during cycling which decreases the rate of corrosion [8]. Coating outside of grain boundary also improves the ability to overcome electrode expansion. The outside coating keeps metal ions away from each other which directly prevent nucleation around electrode [9]. However, whatever which technique have been used, they are all under nanoscale like nanotube structure.

Nanotube structure not only improves the battery for longer cycling life, but also upgrade the charge capability of the battery. When phosphate layers attach to each other and forms 3D network which let electrons have more pathway during transfer [8]. The 3D ion transfer network largely decreases the time required for battery getting charge or recharge. Coating outside grain boundary has the same effect as phosphate material. Due to lots of diffusion pathway inside the structure, ion battery has better charge capability. There are other influences which leads to better charge capability for each electrode. Different charge ability will affect battery has better performance during charging or recharging. Even though these solutions have developed longer cycling lifetime battery, sometimes the battery cycle lifetime performance cannot predict accurately. It points out the size of electrode will affect the performance of ion battery [7]. Although the cycling times of battery up to 40 times, there's a chance that battery doesn't reach to the expectation of battery performance. The unpredictable battery performance may create troubles during testing. Other disadvantages like if phosphate acting as electrode, its lower electric conductivity influence the charge efficiency of battery [8]. These disadvantages result to objective for future researching of unique selection of electrode materials. There are other variables like temperature, these can't be simply fixed as changing material. As the larger requirement of longer cycling lifetime battery have increased due to limited resource of electrode. Among all these factors, these could be regard as observation target in the future researching.

4. Conclusion

The whole research mainly focusses on review current technique in powering cycle lifetime of battery. All these changes are based on the fundamental theory of battery operation which is expansion of electrode. The mainly solution are related on three aspects which are material of electrode, coating and size of electrode. All these variables have various degree of effect on cycling performance. Nanotechnology have become Indispensable technique in cycling performance. The nanotube structure is widely used in advanced battery due to its large empty space around the wall. These empty spaces allow and restrict expansion of electrode which prevent break of electrode. Even though these solutions have changed cycle lifetime longer, there are still some other disadvantages like less electrode conductivity, longer charge and recharge. There are other variables like operation temperature affect cycling life time as well. All these factors can be regards as one of observed objective to breakthrough in the future.

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