The Progress and Future Prospects of Lithium Iron Phosphate Cathode Materials

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Abstract. Generally, the lithium iron phosphate (LFP) has been regarded as a potential substitution for $LiCoO_2$ as the cathode material for its properties of low cost, small toxicity, high security and long life. However, it still has many disadvantages like poor electrical conductivity and low ion mobility. This article will focus on the preparation of lithium iron phosphate cathode materials successfully at the present stage, introduce its development status, and predict the future development direction of such materials. Analysis shows that with significant modification and process, both performance and cost of this material will be significantly improved. These results show some potential ways for the further wide application of LFP positive electrode.

Keywords: Lithium iron phosphate, cathode material, preparation method, performance evaluation, existing situation.

1. Introduction

Contemporarily, the energy crisis is becoming a much more severe problem throughout the world [1]. Thus, the discovery of new devices storing energy and replacing the traditional fossil energy has been greatly developed with more and more sources invested. Rechargeable metal ion battery like lithium battery, is a typical representative of such devices. Benefited from the explosion of rechargeable battery, as a necessary part of it, the cathode material has become a research focus.

Compared with traditional cathode material (Lithium cobalt oxide, lithium magnesium manganese, nickel cobalt oxide), LFP has obvious advantages: low cost, high security, good stability, environmentally friendly. As a result, it has been widely applied to electric vehicles, energy saving and other fields. However, it still has drawbacks such as low lithium-ion transmission rate (10^{11} cm^2/s) and low conductivity (10^9 s/cm) [2]. These disadvantages limit its charging and discharging efficiency at high rate, thus reduce its electrochemical performance. Based on three recent research results, this article will introduce the development status of LFP-based cathode materials, including the main preparation methods of lithium-ion cathode, test the properties of the prepared materials, and predict the development direction of external materials.

For the synthesis method, the synthesis of LFP is divided into two main categories at present: the preparation of under solid state and liquid preparation [3]. Relatively speaking, the solid-phase synthesis method has been used for a long time and the technology is relatively mature, thus more researchers will adopt the solid-phase synthesis method to prepare LFP powder, while the liquid-phase synthesis method has been gradually favored by researchers as the technology continues to mature due to its short operation process and lower energy consumption [4].

At present, there are many methods to test the performance of materials. For phase test, mainly through DSC, XRD, FTIR, SEM, TEM analysis, in order to test whether the composition of the

structure meets the expectation, in addition, for whether it meets the standard of preparing the cathode material, currently mainly through electrochemical test and its conductivity test conclusions.

2. Synthesis Method

The synthesis ways of LFP powder have two main categories: solid phase and liquid phase. The solids phase seeks high temperature, while liquid phase tends to have chemical reaction in synthetic solution.

2.1. Synthesis of LFP powder under solid phase.

In general, high temperature solid phase approach, carbon thermal reduction process microwave heating method are the common methods to prepare LFP powder under solid solution. The advantage of these methods is to produce ordered crystal structure under high temperature in a simple way.

2.1.1 High Temperature Solids Phase Method

As a traditional method to produce LFP powder, the main mechanism is to generate chemical structure at higher temperature (400℃-800℃). In general, the lithium is obtained from lithium salt and the ferrous compound will be chosen as iron sources. Phosphorus nitrogen compound is preferred to be provide phosphorus since the N will be easily released as NH_3 at high temperature. The normal process of high temperature solid phase method is to mix the precursor made by ball milling or other technical means in certain proportion, then further calcination of heat treatment. The prepared precursor mixture typically undergoes a two-step heat treatment process. The temperature of the first step is low (between 250℃ and 350℃ [2]), useless gas (e.g., NH_3) will be released to prevent that they won't interfere with later reaction during this process. The powder will be calcined below. Temperature will have a significant effect on the performance of powder: particle growth, structure and discharge capacity, e.g., 650℃-700℃ is the common temperature for this process. Based on high temperature solid phase method, Ref. [2] produced a new kind of lithium battery. During the process, the carbon sources are polyethylene glycol (PEG) grafted carbon nanotubes (CNTs). The preparation process of their LFP is schematically shown in Fig. 1 [2]. In addition to the traditional high-temperature solid-phase synthesis, an improved high-temperature solid-phase method is also applied to synthesize LFP powder. Other scholars' fabricated $LiFePO_4$ by heating Fe_2O_3, $NH_4H_2PO_4$ and LiOH in deionized water for three hours in a carbon-covered crucible without inert gas flow at 700℃ [5]. This method is also used to produce large quantities of certain chemical compounds because of its mature industrialization. Nevertheless, the disadvantage is that the product produced by this method has non-uniform amorphous particles and it takes a long time to synthesize the product. Meanwhile, the long and complex process and the continuous grinding and calcination of the product lead to larger particles and lower electrochemical performance.

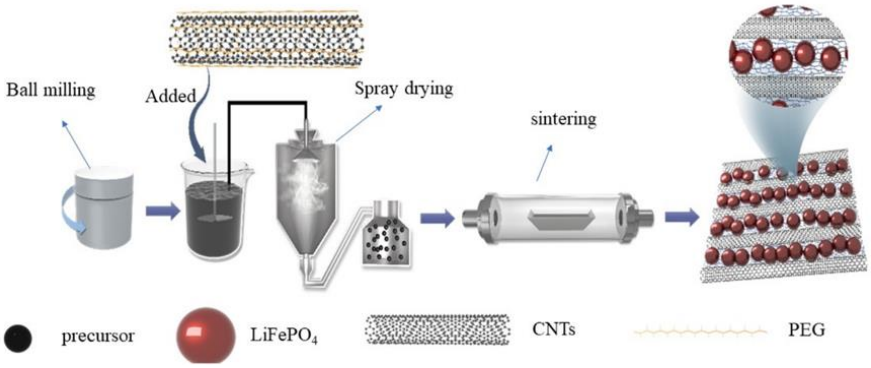

Figure 1. LFP/PEG/CNTs synthesis process [2]

2.1.2 Carbon Thermal Reduction

Different from the approach mentioned above, this process chooses iron compounds rather than ferrous compound to be the iron source. The obvious advantage of the replacement is to prevent the

instability of Fe^{2+} and omit the measures of preventing its oxidation. Additionally, the cost of iron compounds is much lower. As a reduction process at high temperature, the carbon thermal reduction will use carbon source to reduce the Fe^{3+} and get the LFP powder. In general, carbon black, graphite and thermally degraded organic compounds are traditional reductants. Besides, the operation procedure for this method is varied, the main procedure includes two steps [6]. First step is to mix the precursor in certain proportion and ball milling for 2-4 hours. Then, one needs to calcinate at 550℃-850℃ for 8-10 hours. Under normal conditions, the previous calcination is not required since the reductant (solid carbon powder) is contacted with the reactants very well. Calcination is required to undergo in an inert gas environment (N_2 or Ar). The two main reactions of reduction of Fe^{3+} in carbothermic reduction are [3]: $C+O_2 \rightarrow CO_2$(T＜650℃) and $2C+O_2 \rightarrow 2CO$ (T>650℃). Moreover, the reaction mechanism and rate are not only, they are highly connected with many items: the kind of reductant, the density of impurity, particle size of precursor and the condition when mixing the reductant and precursor. In addition, the LFP powder can be coated with residual carbon and the particle shape can be effectively controlled under the carbon thermal reduction.

2.1.3 Microwave heating method

The heating method is the best process separating microwave heating method from other solid-phase methods. Its heating process is at the molecular level, movement of electronic will cause polarization inside the material, which will produce heat. Since the microwave heating device is used in the heating process, the main advantage of this method is good control, uniform heating, short processing time (2 to 20 minutes) [7], which will significantly reduce the cost. In addition, this method has high repeatability, and there is no need for reducing gas. The carbon with low cost and fast heat production will be chosen as the microwave absorbent to ensure the heat production be effective enough. It can also form reducing gas to protect ferrous ions, as well as eliminate the iron ions. Figure 2 presents a planar display of microwave heating [8].

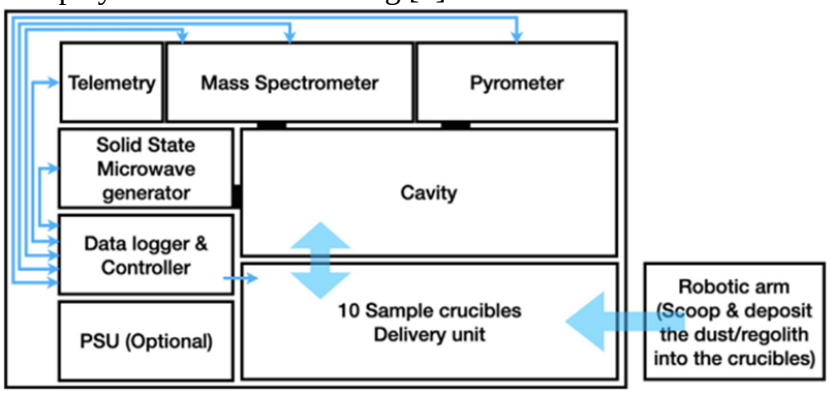

Figure 2. Plane diagram of microwave heating [8]

2.2. *Synthesis of LFP powder under liquid phase.*

Spray pyrolysis, co-precipitation method and hydrothermal synthesis method are common method to synthesize LFP powder under liquid phase. The liquid phase methods tend to have purer product compared with solid ones, which will ensure the consistency of carbon coating. In addition, compared with solid methods, liquid product will have smaller morphologies and better consistency.

2.2.1Spray Pyrolysis

Spray Pyrolysis is a kind of chemical synthesis method. The main process is mixing the precursor in the water while heating the whole above the boiling water, which will avoid calcination. Instead, pure LFP powder can be obtained directly from heated aqueous solution. The usual process for this method is divided into 3 steps:

(1) Mix the precursor in the water with certain proportion according to the demand of product.

(2) Put the mixture into the autoclave and treat at 120-220℃ for 5-10 hours.

(3) The slurry was dried and LFP powder was obtained.

Considering the request for the product, if additional carbon coating is required, additional heat treatment (generally calcination) in inert gas between 400℃ and 750℃ will be provided. As the method is processed in autoclave, the enclosed environment, compared with other methods, there are fewer environmental problems, i.e., it is a relatively simple, clean and cost saving way to synthesize LFP powder. Based on hydrothermal synthesis (HS), other researchers proposed supercritical hydrothermal synthesis (SCHS) [9, 10]. According to the investigation in Ref. [11], the temperature and pressure rise to the critical value, the vapor pressure and the number of products rise, the fluid density, viscosity and surface tension decrease.

2.2.2 Co-precipitation Method

Co-precipitation method method is a kind of way to synthesize LFP powder based on solution, by controlling pH of solution, Li and phosphate compound will co-precipitate in the precursor solution. Then the slurry after common precipitation is washed and dried in an inert gas atmosphere. After drying, amorphous LFP powder will form, then crystalline LFP powder can be produced in N2 or Ar atmosphere [12], calcination at 500-800℃ for about 12 hours. More reliable structure and properties can be achieved on products by combining co-precipitation with other methods.

2.2.3 Spray pyrolysis

Spray pyrolysis, also known as ultrasonic spray pyrolysis, is a method of preparing ceramic particles with high purity and rapid crystallization speed, which is widely used in the production of thin films. The process of the metal salt as required for the preparation of compound powder stoichiometric match into the precursor solution, after atomizer atomized by the carrier gas into high temperature (400℃-600℃) reactor [13], instantaneous solvent evaporation in the reactor, the solute precipitation formation of solid particles, dry particles, particles thermal decomposition, sintering molding and a series of physical and chemical process, Finally, a superfine powder is formed. The solution can be atomized into micron or even nano-level uniformly with the application of ultrasonic atomization technology. Then, it will be transferred into high-temperature reaction furnace for further cracking reaction by carrier gas [13]. Ultrasonic spray pyrolysis method can prepare more uniform and fine powder particles than the conventional pyrolysis method. In addition, LFP powder with smaller particle size can be obtained by adding raw materials in spray pyrolysis.

3. Research method

3.1 Analyse method

3.1.1 XRD

XRD is a method to analyze the phase composition, crystal structure and lattice parameters of materials by using the diffraction phenomenon of X-ray in crystals. The position of the X-ray diffraction peak depends on the crystal plane spacing of each crystal plane, so each phase has a unique diffraction pattern. Combined with the standard card, the composition of the material can be obtained [14].

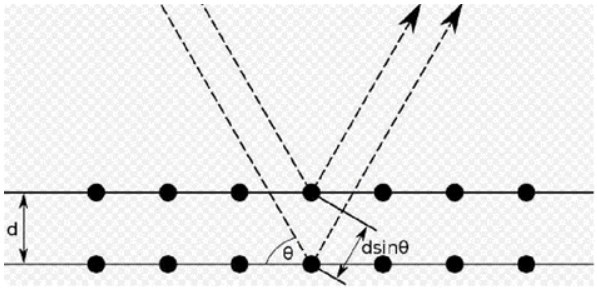

Figure 3. A sketch of XRD mechanisms

3.1.2 SEM

Scanning electron microscope is used to observe and analyze the geometric morphology and particle morphology of the sample surface. It through the secondary electrons and scattered electrons generated by the interaction between the scanning focused electron beam and the sample within the depth range of about 10 nm [14].

3.1.3 Infrared Spectroscopy

Infrared Spectroscopy is a widely implemented tool of material structure analysis and characterization, which can also be used as a method to characterize and identify chemical species. Prism and grating spectrometer and Fourier transform infrared spectrometer are two common instruments.

3.1.4 Single particle electrochemistry

The electrical analysis measurement on the composite electrode is generally considered as a traditional experimental device and certain precision dynamic parameters. The polydispersity of the active material, the powder, the porosity and the non-uniformity of the composite material, and the existence of electrodes and adhesives will lead to large errors even when measured on a thin electrode. When single particles of electrode materials are detected, it is possible to characterize the charge transmitted by ions with high accuracy [15].

3.2 Performance evaluation method

3.2.1 Self discharge loss evaluation

After the battery is placed for a period of time, its usable capacity will decline most. This phenomenon is called self-discharge. The reason for the self-discharge phenomenon of the battery is: when the battery normally forms the external circuit, the electrons from the negative electrode of the battery arrive at the positive electrode of the battery through the external circuit, and the electrochemical reaction occurs. The reaction is fast, and the battery capacity changes most obviously. Specifically, when the battery is empty, the electrons diffuse from the positive electrode of the battery via the electrolyte to the cathode of the battery. This is a fast reaction, meanwhile the change of battery capacity is not obvious. According to the data, the self-discharge rate of early nickel cadmium batteries and nickel hydrogen batteries can reach 30% in one month due to chemical composition and manufacturing process. For LFP power battery, due to the advantages of chemical structure and manufacturing process, the self-discharge rate in a month is generally only 2% - 5%.

The steps of measuring self-discharge current under laboratory conditions are as follows:

(1). Place the battery in the incubator, set the temperature to 20℃, charge it with 0.3C current until the charging is finish, and the upper voltage limit is 3.6V.

(2). After standing for 1 hour, discharge with 0.3C current to the lower limit of discharge cut-off voltage of 2.5V, and record the discharge capacity C1.

(3). After standing for 1 hour, charge with 0.3C current to the upper limit of charging cut-off voltage of 3.6V.

(4). Let the battery stand for 30 days and keep it constant for 20℃.

(5). Discharge at 0.3C current to 2.5V lower limit of discharge cut-off voltage, and record discharge capacity C2, then the battery Self discharge loss capacity: $\delta C=C1-C2$ [16].

3.2.2 Low temperature loss assessment

Battery capacity is a key factor affecting the estimation accuracy of battery state of charge (SOC). As for practical use, temperature has a great influence on battery capacity. Therefore, in order to improve the SOC estimation, it is necessary to test the charge and discharge capacity of the battery at different temperatures and investigate the impact of low temperature on the temperature capacity characteristics of the battery [17]. The energy barrier of electron migration in the battery increases and the electrochemical reaction speed is slow, which is reflected in the obvious decline of the available capacity of the battery at the macro level.

(1). Discharge the battery at room temperature (20℃) to the lower limit of discharge cut-off voltage of 2.5V.

(2). Place the battery in the incubator, set the target low temperature and let it stand for 24 hours.

(3). Charge with 0.3C current to the cut-off voltage of 3.65v in low temperature environment (slightly higher than normal temperature charging cut off voltage (upper limit), standing for 1 hour.

(4). Discharge at 0.3C current to 2.5V lower limit of discharge cut-off voltage under low temperature environment, and stand for 1 hour,

Record the battery discharge.

(5). Repeat 3 times, and take the average capacity of 3 times as the actual usable capacity of the battery at this temperature[16].

3.2.3 Cyclic attenuation assessment

The self-discharge and low-temperature capacity loss of the battery belong to reversible capacity loss. However, during the normal cycle use of the power battery, the lithium ion in the positive electrode of the battery will undergo redox reaction with electron migration, resulting in the gradual reduction of active lithium ion. At the same time, there are also a lot of side reactions in the battery, such as electrolyte decomposition, active material dissolution, metal lithium deposition and so on, which will cause the irreversible attenuation of the available capacity of the battery [15].

3.2.4 Cyclic voltammetry evaluation

Cyclic voltammetry is to make the electrode potential within a certain range and scan back and forth repeatedly with triangular waveform once or many times over time. The electrode will alternately undergo reduction and oxidation reactions within the potential range, record the corresponding changes of current and draw the corresponding map. This method can provide rich information for the study of electrode reactions, such as the redox potential of substances, the cyclic reversibility of electrochemical reactions, and the electrochemical activity of electrode active substances [14].

Table 1. Summary diagram of input parameter values of battery unit [19]

cathode			anode		
foil	material	aluminum	foil	material	copper
	thickness	15μm		thickness	8μm
Active material	material	NCM/LFP/LMO	Active material	material	graphite
	density	4.8/3.6/4.28g/cm^3		density	2.24g/cm^3
Conductive agent	material	carbon	Conductive agent	material	carbon
	Weight percentage	3%		Weight percentage	3%
binder	material	PVdF	binder	material	PVdF
	Weight percentage	3%		Weight percentage	3%

3.2.5 Modelling evaluation

The core of energy storage modeling is a continuity differential equation, which tracks the battery power. Generally speaking, it is e*=PB, where e* is the battery power and PB is the battery power input. The former cannot take a negative value, while the latter is positive when the battery is charged and negative when discharged. Battery power input PB indicates the amount of power in and out of the battery. Due to the power loss in the actual battery, the power input PB of the battery power supply is different from that at terminal P, Pt - the power in and out of the grid. In the simplest expression, the ratio of PB to PT is considered to be constant, corresponding to constant battery efficiency [18].

4 Frontier research on lithium iron phosphate cathode

Contemporarily, olivine shape LFP is commonly regarded as the most promising alternatives to commercialized $LiCoO_2$. However, because the lattice of LFP is an octahedral network of discontinuous FeO_6, the electronic conductivity and Li^+ diffusion rate of LFP are low. It has no advantage over other normal cathode materials. Therefore, the improvement of LFP cathode material has become the focus of current researchers.

4.1 Fluorine doped carbon coating

Fluorinated carbon (FC) is synthesized by using polyvinylidene fluoride as fluoride source (seen from Fig. 4). FC can adhere closely to the positive electrode surface of lithium iron phosphate to form a three-dimensional conductive network structure with good conductivity. By means of this structure, the diffusion distance of Li^+ is greatly reduced and the charging and discharging speed is increased. In addition, the C-F covalent bond in the structure can effectively promote the electron and ion transport, and the electrolyte can be more easily penetrated. The experimental results show that the composite with 2.8wt% FC coating on LFP has excellent electrical conductivity, cycling performance and high capacity close to the theoretical value. Its cycle stability is more than 1000 times and its good efficient conductivity of 100.2mA·h·g^{-1} is maintained at 20°C. According to its excellent performance, it is proved that the performance of LFP can be greatly improved by coating it with FC. It is able to sever as a kind of high-performance cathode material worthy of commercial usage [21].

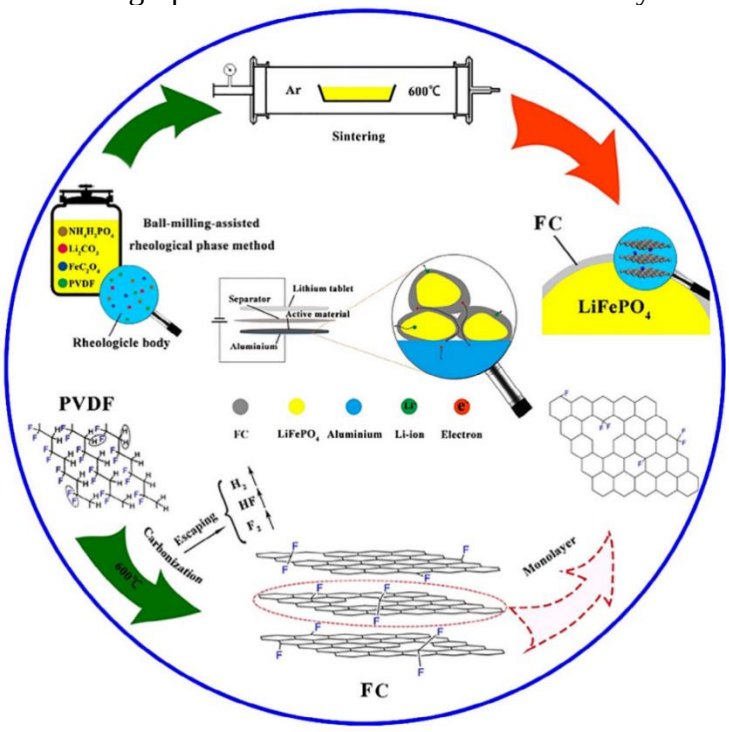

Figure 4. A sketch of the synthesis for the LFP&FC nanocomposites and FC [21]

4.2 carbon nanofibers composite

In view of the excellent conductivity and strong directivity, carbon nanofibers (CNFs) are conductive auxiliary material. Based on the SEM results (as illustrated in Fig. 5), the existence of CNFs makes the long-distance conductive network between the positive electrode materials and reduces the porosity curvature in the composite electrode. CNF not only facilitates electronic connectivity, but also improves ion connectivity. After 400 cycles at 5C and 10C, it is found that the discharge capacity of the composite cathode is always higher than that of the original LFP cathode, it shows that adding CNFs makes LFP/CNF structure more stable. In particular, the specific discharge capacity of the composite can reach 150 mA·h·g^{-1}at 0.1 C, and the excellent conductivity can be obtained at more than 5C, and the capacity retention can reach 98.4% at 5C [22].

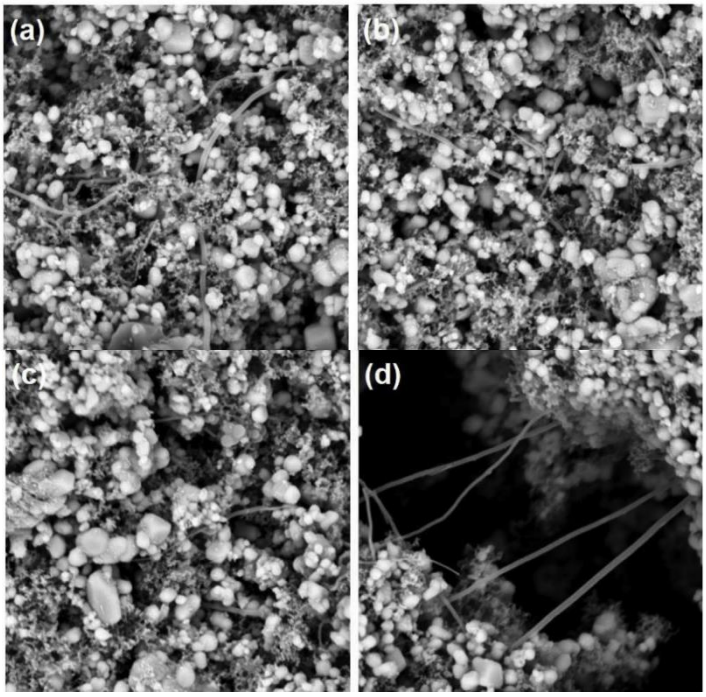

Figure 5. The SEM results of LFP/CNF composite [22]

4.3 Ho-substituted C/$LiFePO_4$

Ho/$LiFePO_4$ powders are prepared by solid state synthesis technique. The XRD analysis shows that the LFP has an amorphous structure due to the presence of carbon, and the measured peaks are matched with olivine LFP. The lattice volume of Ho substituted $LiFePO_4$ decreased with the increase of Ho content. In the $LiFe_{1-x}Ho_xPO_4$, Ho ion directly affects the formation mechanism. When x = 0.01, the grain size decreases, the specific surface area increases, and the grains begin to grow at a larger size. The bond of Fe, P and Li ions can be observed in the FTIR (as depicted in Fig. 6), but the Ho-O bond is lower than the measurement that the FTIR system could detect in this study. The magnetic study points out that the material has Fe^{2+} with HS configuration and Ho substitution, which causes the increase of the magnetic moment. According to the CV results, Ho has no redox mechanism in the composite due to the absence of additional peak substitutions. This suggests that these similar lanthanides do not react with lithium ions but that they can increase lattice stability in the battery cycle and lead to defect-induced lithium vacancy formation. In addition, lanthanides can optimize the crystal structure, reduce the cell's particle size and charge transfer resistance, improve the cell's conductivity and Li^+ diffusion rate. Compared with the undoped $LiFePO_4$, the Ho-substituted $LiFePO_4$ has a better rate dependence [23].

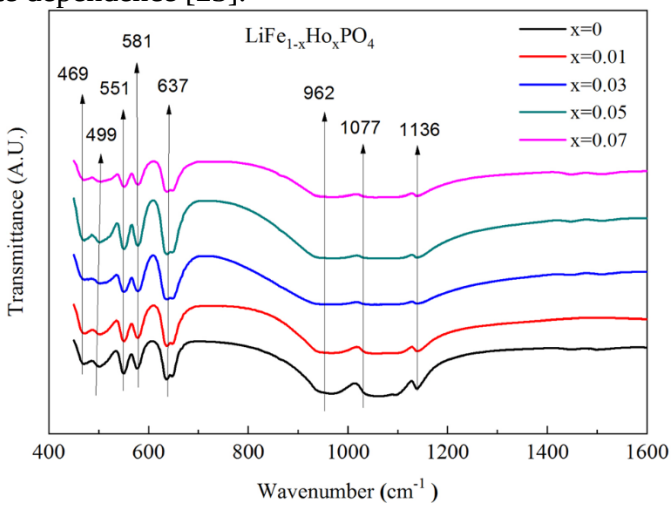

Figure 6. Infrared spectrum analysis of Ho replacing LiFePO4 [23]

4.4 PAni-coated $LiFePO_4$

For the sake of improving the electrochemical properties of $LiFePO_4$/polyaniline, $LiFePO_4$/polyaniline composites are prepared by chemical synthesis. $LiFePO_4$ with high crystallinity and no secondary phase is prepared by low temperature solvothermal method. The composition ratio of $LiFePO_4$/PAni composite is 44% to oxide and 56% to polyaniline. The orthogonal crystal structure of $LiFePO_4$ is characterized by X-ray diffraction (XRD). $LiFePO_4$ has a high degree of order and its surface interacts with the structural conjugate of Conductive polymer. Polyaniline can adjust the difference of polarity between the cathode and electrolyte, promote electrolyte penetration on the surface of active particles, serve as a conductive network connecting $LiFePO_4$ particles, and reduce the resistance between them. The results show that the redox process of the composite is more reversible than that of $LiFePO_4$, and ΔEp (ΔEp=0.20V) is significantly lower than that of $LiFePO_4$(ΔEp=0.41V), and the redox process of the composite is more reversible than that of $LiFePO_4$(ΔEp=0.20V), the lower value of the charge transfer resistance is beneficial to the rate of electron transfer. Therefore, polyaniline has a significant contribution to the electrical conductivity of the composite. The redox reversibility of $LiFePO_4$ can be significantly improved by using other conductive agents such as carbon and graphene. In addition, the coating improves the electron transfer kinetics, and the polymer chains of polyaniline form conductive network inter connection [24].

4.5 $LiFePO_4/Ti_nO_{2n-1}$/reduced graphene oxide cathode

The researchers prepare the $LiFePO_4/Ti_nO_{2n-1}$ composited through a hydrothermal method, and then prepared the flexible composite membrane by a simple vacuum filtration process. In XRD, the position and offsets of the main peak of LFP/Ti_nO_{2n-1}/rGO composite are small, which shows that the addition of Ti_nO_{2n-1} and rGO does not change the crystal structure. SEM results show that $LiFePO_4$ particles are dispersed in the layered structure, which is favorable for electron transfer. However, it can be seen that because of the large size and surface area of the graphene sheet materials, most of the graphene sheet materials are bent and folded, unable to cover all the $LiFePO_4$ particles, forming a conductive bridge, provide more efficient electronic conductive network. The good conductivity of Ti_nO_{2n-1} particles dispersed among $LiFePO_4$ particles can effectively compensate the defect. At the same time, graphene can effectively enhance the mechanical strength and flexibility of the material, but will lower the proportion of active materials. As a cathode material of lithium-ion battery, the composite film has a high capacity of 151.2-155.5mA·h·g^{-1} at 0.2C. The capacity of the composite after 100 cycles is 131.2 mA·h·g^{-1}, and the capacity loss per cycle is 0.13%. According to the charge-discharge curve, the voltage gap between LFP/Ti_nO_{2n-1}/rGO decreases obviously, which states that high conductivity Ti_nO_{2n-1} and graphene can effectively increase discharge specific capacity and decrease polarization. Therefore, this flexible composite membrane is a promising lithium-ion battery cathode [25].

5 Defect

5.1 Structural limitations

Because of the crystal cell structure of $LiFePO_4$, lithium ions have to pass through the structure channel and angle, and the diffusion speed of lithium ions is slow, which makes LFP have congenital deficiency compared with other cathode materials. For example, $LiFePO_4$, has low charge-discharge efficiency and specific capacity at high rates compared with other battery systems, so scientists have developed a variety of technologies, where the core of these state-of-art scenarios is to reduce particle size and increase conductivity with the coating of carbon particles. Moreover, Lithium iron phosphate also has a number of performance defects.

5.2 Danger

In addition, during the process of preparing lithium iron phosphate, iron oxide can be reduced to iron in reducing environment at a high temperature. Iron is able to lead to battery micro-short circuit, which can be regarded as the most dangerous material in the battery.

5.3 Manufacturing costs

The preparation cost of materials and the manufacturing cost of batteries are higher and the rate of finished products of batteries is inferior. Although the processes of nano crystallization and carbon coating for lithium iron phosphate have improved the electrochemical properties of the material, it also brings some problems, such as the reduction of the energy density, the improvement of synthesis cost, and harsh environmental requirements, which make its commercialization more difficult.

5.4 Poor consistency

Individual lithium iron phosphate batteries currently have more than 2,000 times life, but battery pack life will be significantly reduced, possibly 500 times. Besides, the voltage platform of lithium iron phosphate is narrow, which makes the battery more difficult to observe.

6 Future expectations

As a candidate for batteries, lithium iron phosphate has outstanding safety performance, Long Life and stable discharge platform. Because the material is also environmentally friendly, low-cost advantages, in the future development of new energy has a strong commercial value and status, is now in good development, one of the most widely used positive materials for batteries. At present, the improvement of LFP mainly involves the incorporation of Ho, graphene, carbon nanofibers and other composite materials, as well as the coating of auxiliary materials on the electrode materials to improve its original structural defects and increase conductivity. According to the results, the improved materials can maintain high capacity at high rate and cycle times, and exhibit excellent electrochemical properties. At the same time, the development of advanced characterization technology is an important direction to study the properties and structure of materials. Finally, the way to convert the laboratory products into the same performance industrialization is crucial to the future development of new energy.

7 Conclusion

In summary, this paper discusses Lithium iron phosphate battery that have high energy density and long service life. They are widely used in consumer electronics, portable devices, electric vehicles and other fields. LFP battery has good capacity ratio, safety and balanced performance. Due to the different preparation route and processing technology. Their service life, low temperature performance and charge-discharge performance are different. LFP has the defects of self-cell mechanism (e.g., low conductivity and poor consistency). It is necessary to improve the performance by doping and coating with composite materials or auxiliary materials. In addition, it is necessary to detect the structure and composition of the battery by XRD, SEM, IS and other technologies. A method to accurately estimate the State-of-Charge for $LiFePO_4$ batteries is urgently required. To sum up, LFP battery has broad development prospects and serves as a key in the field of new energy vehicles and portable batteries. Overall, these results offer a guideline for increased use of LFP batteries.

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