The Current Situation and Prospect of Lithium Batteries for New Energy Vehicles

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Abstract. Under the current international situation, the use of newer clean energy has become a necessary condition for human life. The use of new energy vehicles is undoubtedly closely related to most people's lives. As the core and power source of new energy vehicles, the role of batteries is the most critical. This paper analyzes the application and problems of lithium-ion batteries in the current stage. By comparing lithium-iron phosphate batteries with ternary lithium-ion batteries, the medium and long-term development directions of lithium-ion batteries are put forward. And the research products of different development directions and the current progress are illustrated with examples.

1. Introduction
Under the Paris Agreement, people need to be carbon neutral, meaning zero net emissions. In this international situation, the use of new clean energy sources, such as wind, solar, and electricity, is necessary. At present, the only clean energy that people can use on a large scale is electric energy, which is reflected in more and more new energy automobile industry. New energy vehicles include four types: hybrid electric vehicle (HEV), pure electric vehicle (BEV, including solar cars), fuel cell electric vehicle (FCEV) and other new energy sources including mechanical energy. By far the most popular type of vehicle is pure electric.

As the core and power source of new energy vehicles, the role of batteries is the most critical. The battery types for pure electric vehicles mainly include lead-acid(LAB), nickel-hydrogen(NHB) and lithium-ion battery(LIB). For the on-board batteries that are mainly used by human beings at this stage, LIBs have many advantages over other batteries, such as higher operating voltages and the ability to charge continuously.

In this context, lithium batteries play an extremely important role. At present, there are some defects in the large-scale industrialization of two kinds of power LIBs, among which the most important problem is that the energy supplied by LIBs for BEV cannot reach the same range as the traditional fossil energy powered vehicles. Based on this background, this paper analyzes and studies the advantages and problems of LIBs at present, and puts forward some views on the future development of dynamic LIBs.

2. The working principle and advantages of lithium battery
The chemical equation of lithium batteries’ working mechanism is as follows: LiX+6xC==Li(1-x)X+LixC6. LIBs have the following characteristics: (1) the single battery has a high working voltage; (2) the service life of electric vehicles is longer; (3) the weight is light and the specific energy is large;
(4) the volume is smaller under the same capacity, and the application range is greatly increased; (5) the cycle life is long (more than 1,000 times); (6) the operating temperature range is wide.[1]

![Figure 1. The superiority of lithium metal anode. (a) Specific capacities, standard reaction potentials (vs. SHE.), value, and cation radii for lithium metal and others. (b) Gravimetric energy densities of lithium metal coin cell and others.][2]

Compared with other metal materials, lithium as the positive electrode of the battery has a lower elemental mass and a higher Gibbs free energy. Figure 1 shows these characteristics more intuitively.[2]

3. Current applications of lithium batteries

3.1. Materials of LIB

The main materials of power lithium battery include cathode and negative active materials, diaphragm and electrolyte.

The cathode material of lithium-ion battery should meet the following criteria: high potential relative to lithium; corresponding high electrochemical specific capacity; high thermal stability; the highest possible electronic conductivity; insoluble in electrolyte[1]. Currently, the two most commonly employed materials are lithium iron phosphate and lithium ternary.

Negative electrode active materials include carbon and non-carbon. At present, the most mature technology is graphite, which is characterized by large specific capacity and low price. The disadvantage
is that the irreversible capacity is slightly larger. Therefore, the improvement of graphite performance is the main research direction. [1]

Table 1. Coupling Experiment Results and Errors [6]

| Serial Number | Capacity Decay Rate% | Serial Number | Capacity Decay Rate% | Serial Number | Capacity Decay Rate% | Coupling Error% |
|---------------|----------------------|---------------|----------------------|---------------|----------------------|-----------------|
| 3.2.1         | 0.00576              | 3.2.2         | 0.01425              | 3.3.1         | 0.02025              | -1.19           |
| 3.2.1         | 0.00576              | 3.2.3         | 0.00543              | 3.3.2         | 0.00527              | 112.33          |
| 3.2.1         | 0.00576              | 3.2.4         | 0.00474              | 3.3.3         | 0.00798              | 31.58           |
| 3.2.1         | 0.00576              | 3.2.5         | 0.00481              | 3.3.4         | 0.00535              | 97.57           |
| 3.2.2         | 0.01425              | 3.2.3         | 0.00543              | 3.3.5         | 0.02221              | -11.39          |
| 3.2.2         | 0.01425              | 3.2.4         | 0.00474              | 3.3.6         | 0.02065              | -8.04           |
| 3.2.2         | 0.01425              | 3.2.5         | 0.00481              | 3.3.7         | 0.01783              | 6.9             |
| 3.2.3         | 0.00543              | 3.2.4         | 0.00474              | 3.3.8         | 0.00824              | 23.42           |
| 3.2.3         | 0.00543              | 3.2.5         | 0.00481              | 3.3.9         | 0.00826              | 23.97           |
| 3.2.4         | 0.00474              | 3.2.5         | 0.00481              | 3.3.10        | 0.00705              | 35.46           |

The diaphragm of ordinary lithium battery requires that the closed hole can be melted at high temperature to ensure that the positive and negative terminals of the battery will not fuse. On this basis, on-board lithium ion battery has higher requirements for high temperature shrinkage resistance. Ultrahigh molecular weight polyethylene (PE) is considered to be a new generation of diaphragm material that can improve battery safety by significantly reducing the high temperature thermal shrinkage of the membrane and improving the melting integrity of the membrane. It is currently the dominant diaphragm type used in on-board lithium-ion batteries. [3]

Electrolyte is very important to the specific capacity, operating temperature range, circulation efficiency and safety performance of the battery. The requirements of lithium ion batteries for electrolytic materials are: there should be high conductivity, especially for the negative electrode to have a high amount of embedding and phase capacitance; The decomposition voltage of organic solvent should be higher to reduce the self-discharge and gas pressure inside the battery; Use safe and pollution-free, and have low price. So far the most suitable material is lithium LiPF6. [4]

3.2. The most used battery and recycling technology

3.2.1. LiFePO4 Vs. Ternary Material (LiNi<sub>x</sub>CoyMn1-x-yO2 or LiNi<sub>x</sub>CoyAl1-x-yO2). At present, the two most widely used types of batteries, lithium-iron phosphate and ternary lithium-iron, have obvious advantages and disadvantages. The two batteries will be summarized separately in the following.

The first one is lithium iron phosphate batteries. Its single-section operating voltage is 2.8 to 4.0V, and the specific energy of the unit is 120 to 180Wh/Kg. It is characterized by stable P-O bond in the crystal, which is difficult to decompose. It is resistant to high temperature, and has good safety performance; It can be recharged cyclically and has long service life; The electric heat peak is 350 to 500 degrees Celsius, so its high temperature performance is good. But its disadvantages are equally obvious. For example, due to some technical reasons, lithium iron phosphate has a low vibrational and compaction density, resulting in its low energy density; Secondly, although it has strong performance at high temperature, it has poor performance at low temperature. Thirdly, it is bigger than other types of batteries under the condition of equal capacity. As a result of the above reasons, it is utilized more in large vehicles. [1,5]
As one of the most important battery properties, the battery capacity decay rate can be an indicator of battery durability. According to the above figure, by means of coupling experiments, and by the calculating of sensitivity:

\[ \frac{d}{d \Delta T} = \frac{d}{d \Delta \delta} = \frac{d}{d \delta} = \frac{d}{d \Delta I} = \frac{d}{d \Delta \delta} = 0.0015, \]

it can be concluded that the capacity attenuation rate of lithium iron phosphate battery increases by 0.0015 and its life is shortened by 5% for every 10 degrees Celsius increase in temperature [6].

Ternary lithium battery, namely NCM or NCA. It has a charging voltage of 4.5V and specific monomer energy of 80 to 140Wh/Kg. Its characteristic is that the basic properties change with the proportion of the three used metals. In general, the increase of cobalt content can effectively increase the rate and circulation performance of this material. Its advantage is its high energy density for the same volume, but its disadvantages are equally obvious. First, cobalt's high price makes it too expensive. Another is the poor safety performance and short cycle life, especially the short cycle life highlights the shortcomings of the adoption of high prices of materials [1,8].

**Figure 2.** Results of Contrast Experiment[7]

The capacity attenuation trend chart of the above ternary lithium battery is obtained through comparative experiments. The internal resistance of the battery in Figure 2 cycles 1 is less than that in cycles 2, and the difference of the internal resistance of the battery increases with the increase of discharge [7].
3.2.2. Recycling of waste lithium batteries at present stage. Recycling of used batteries is also a major factor restricting the development of on-board LIBs at the present stage. Waste LIBs can cause other contamination if they are not properly disposed of. The most mature and widely used method of recovering waste lithium in history is fire recovery. However, it is characterized by high energy requirements, relatively low metal recovery rates, and adverse environmental impacts. At the present stage, people will use the recycled waste LIBs in stages, and then dismantle it after the maximum capacity of the battery is less than 30% of the original capacity. However, it is still not possible to reuse the precious metals, such as cobalt or lithium, which will undoubtedly be a problem to be solved in the future.[9]

4. Improvements of the technology

4.1. Improvements to the current technology

The development of battery technology mainly depends on the progress of the materials used, among which the most critical enhancement of the specific energy of the battery is mainly based on the improvement and upgrading of the electrode materials. For the positive electrode, under the existing conditions, it is necessary to study how to increase the expansion coefficient of lithium ions so as to make them more active and to increase the specific capacity of the battery. At the same time, it is necessary to ensure that the free energy of electrode reaction does not change much so as to make the charge and discharge voltage of the battery stable. These are also negative side’s standard.[1] In order to ensure the safety of the battery, the thermal stability of the interaction between the positive and negative electrodes and the organic electrolyte is the primary factor, which is also related to the battery life. With the development of new solid-state batteries, the demand for electrolyte is also increasing. For example, it is necessary to improve the conductivity of solid electrolyte and the contact and stability of the contact surface; for example, how to deal with the pulverization and dendrite growth of lithium metal surface; or how to improve the circularity and safety of electrolyte are all the following development directions.[1] In terms of battery separator, how to use or improve the new polymer material is the key. The current polypropylene (PP) and polyethylene (PE) still have the disadvantages of high thermal shrinkage and low film breaking temperature. In the future, new inorganic nanoparticles may be selected to coat the membrane surface. This involves the application of new nano-materials, which will not be discussed here.[1]

4.2. Batteries will be industrialized in medium term

Based on mentioned above, two new types of lithium-ion batteries are likely to appear in the medium term.

4.2.1 Manganese acid lithium(LiMn2O4)/Silicon Carbon. It has been developed for a long time, but has long been dismissed because of erratic experimental results and questions about its safety. But now, based on the application of a new material, the negative material of the battery is changed to silicon carbon, and the experiment of lithium manganate battery has performed well. The experimental results show that it has good safety performance and low temperature performance. The nominal voltage is 3.7V. The theoretical monomer specific energy is up to 280-400Wh/Kg. And the material cost is low. However, the material is unstable and easy to decompose to produce gas, which leads to a short cycle life.[1,10]

4.2.2 Solid state lithium battery. Different from the current LIBs, the positive and negative electrodes of the solid-state lithium battery are both solid. Its theoretical nominal voltage is 3V, and the theoretical specific energy is about 300Wh/Kg. However, the electrolyte material is limited. At present, due to technical reasons, solid electrolyte can not be well compatible with solid anode and negative electrode, and experiments have proved that the conductivity of current solid electrolyte materials is not better than
that of liquid electrolyte. But this kind of batteries offers four advantages: its high energy density, which means it can store the same amount of power as other batteries at a lighter mass; Second, it does not need to use a diaphragm, which reduces the cost and volume at the same time; Third, it can become soft while being light and thin, so that it can withstand impact but not damage; Finally, due to the use of solid materials, there is no lithium dendrite, or oxidation and explosion at high temperature and the safety is further improved.[1,11]

5. Future development

5.1. Future development direction of LIB technology
At present, the utilization rate of lithium ion battery is less than 50%, so its research and development prospects are very bright, and now many related enterprises are turning their attention to the development of lithium ion battery research. However, no matter the current lithium iron phosphate battery or ternary lithium battery, or the lithium manganese acid battery and solid lithium battery that will seize a new round of market, their specific energy is relatively low, and unable to support the long-distance running of vehicles like fossil energy. Therefore, there are two research directions for lithium ion in the future. One is to reduce the volume of lithium ion, and the other is to increase the specific energy. Therefore, it is necessary to conduct innovative research on battery materials, especially anode and cathode materials of batteries.[1,12]

5.2. The ideal battery: Li2O2 Vs. Li2S
Lithium-sulfur battery is a research hotspot in the world. The reaction equation is: 2Li + S == Li2S. The theoretical specific capacity calculated with elemental sulfur as active substance is 1675mAh/g and the theoretical specific energy paired with lithium is up to 2600Wh/Kg. This kind of battery has the advantages of high theoretical energy density, abundant raw material sources, low cost and ecological friendliness, and is considered to be an ideal choice for the next generation of lithium batteries. However, there are still some problems in the process of experiment, such as the uncontrollable polysulfide shuttle and lithium dendrite growth, which result in its short cycle life, low safety, poor performance of large current discharge, and difficulty in industrialization in the short term[1,13]. Lithium Oxide battery, or lithium-air batteries, the reaction is 2Li + O2 == Li2O2. The battery is characterized by a very high theoretical specific energy of up to 3505Wh/Kg. Because it uses oxygen in the air as the active substance, and the capacity of the positive electrode is theoretically infinite, so it can achieve a large capacity. Compared with other batteries, the advantages of lithium-air batteries are high specific energy, abundant raw materials, low cost, strong rechargeable and dischargeable, and environmentally friendly and completely pollution-free. At present, the air electrode and the supporting electrolyte catalyst have been studied in the world, but the discharge performance and energy efficiency are still problems. According to the discharge test of lithium-air battery in recent years, the experimental results show that: first, the discharge performance of lithium-air battery is proportional to the oxygen concentration of negative electrode. The battery's resistance is very high at room temperature. This demonstrates the current lack of a strong interfacial contact between the solid electrolyte, the negative and the positive electrodes of the air. It's related to the materials used.[1,14]

6. Conclusion
Generally, how to expand the specific capacity while reducing the volume and mass of LIBs is the main task that people need to complete. The use of new materials proposed in this paper and future developments in superconducting technology may create better and more durable lithium batteries. At the same time, the introduction of some new concepts, such as the development of solid state positive electrode, will make LIBs easier to recycle used batteries in the future. Of course, there is not much experiment data here, and it needs to be further strengthened in the future.

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Acknowledgement
This paper was written under the guidance of Professor Jeffrey Kantor from the University of Notre Dame. Professor Kantor is a rigorous scholar with profound knowledge. Hereby, I would like to express my heartfelt thanks to Professor Kantor for his help. At the same time, thanks also go to Ms. Han Min of the project team and Mr. Ma Jianyu of the teaching assistant for their help in writing this paper. Finally, I would also like to express my gratitude to students who have given me help and support in this project.