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EDITORIAL

Direction for Development of Next-Generation Lithium-Ion Batteries

The electric vehicle (EV) is considered as one of the solutions to reduce the problem of severe pollution. Many automobile companies around the world are focusing on the development of EVs, and it is expected that they will invest a lot of money for the development of EVs in the next several years. Despite these efforts, however, it is true that the performance of today's EVs is inferior to that of conventional automobiles operated on gasoline. The most important part of the problem is the battery. Lithium-ion batteries (LIBs) are used in most EVs today, but they are inadequate to meet user needs. LIBs significantly deviate from users' expectations under most conditions such as driving distance, charging speed, and battery life. It is believed that the energy density of a battery, which determines the moving distance of an EV, can be increased only by replacing the present LIBs by a new battery system. To overcome this problem, a great deal of research has already been conducted to develop next-generation LIBs since more than a decade ago. Among them, lithium−air batteries and lithium−sulfur batteries, which have a very high theoretical energy density, and sodium-ion batteries (SIBs), which use cheaper and more abundant materials than lithium, are attracting much attention as the next-generation system. However, the use of these batteries to replace LIBs still suffers from many problems. In order to achieve these goals, we present here the areas that next-generation batteries should be focused on in the future (Figure 1).

Lithium−air batteries, which have the greatest theoretical energy density among the next-generation LIBs, have been in the spotlight for about 20 years since they were first developed. However, due to numerous problems, there are many pessimistic opinions about their commercialization. Problems such as their low energy efficiency, irreversibility of the reaction, and poor rate characteristics have not yet been solved, and even their high theoretical energy density characteristics, which are an advantage, have not been exhibited in practice. In the early stage of the development of lithium−air batteries, control of capacity and limitation of the loading level for cathode materials were adapted to improve their cycle characteristics. As a result, most of the lithium−air batteries that have been reported so far have practical energy densities lower than 1/10th of that of LIBs. In addition, it is necessary to replace or stabilize the lithium metal anode of both lithium−air and lithium−sulfur batteries in order to commercialize them. Currently, various attempts have been made to use the lithium metal as an anode in other systems as well as in lithium−air batteries. Therefore, the lithium metal anode should be explored further. In order to increase the commercialization possibility of lithium−air batteries, research for increasing their energy density should be carried out.

Similar to lithium−air batteries, lithium−sulfur batteries also suffer from many problems such as low electronic conductivity of sulfur and lithium sulfide, solubility of reaction intermediates in the electrolyte, and degradation of the lithium metal anode. In order to solve these problems, various studies have been conducted on topics such as formation of a complex for enhancing the conductivity, adsorption of reaction intermediates, and stabilization of the lithium metal. However, the formation of a composite may reduce the energy density by decreasing the absolute amount of active material present in the electrode. In addition, the use of many electrolytes is an obstacle to the development of lithium−sulfur batteries with high energy densities. Many studies are being conducted to increase the energy density while reducing the amount of electrolytes or increasing the amount of active materials. As a result, the present lithium−sulfur batteries exhibit higher specific energy density than that of current LIBs. Lithium−sulfur batteries can be a good alternative to LIBs; however, the former still suffer from a limitation. Lithium−sulfur batteries have a very high specific energy density, but their volumetric energy density is still lower than that of LIBs, which is insufficient for applications in EVs where a large number of cells must be loaded in a limited space. In addition, it is very important that the lithium−sulfur batteries should be stable because the lithium metal is used as the anode, similar to the lithium−air batteries. Because lithium−sulfur batteries have low operating voltages, the use of the lithium metal is the best in terms of electrochemical performance as the energy density can be significantly reduced if the lithium metal is replaced by an alternative anode. Therefore, lithium−sulfur batteries should be investigated in order to confirm whether their energy density, especially volumetric energy density, can be increased. Research on lithium metal stabilization should be also carried out.

SIBs have been considered as one of the best candidates for next-generation battery systems because sodium is widely available and SIBs exhibit similar chemistry to that of LIBs. Even though the study of SIBs began at around the same time as that of LIBs, the former were largely abandoned later because of their low operating potentials (approximately 0.3 V versus Li). Since 2010, owing to the increasing concerns on the sustainability of lithium sources, researchers have revisited and accelerated the development of SIBs in order to develop batteries that can replace LIBs. However, the larger ionic radius of Na^+ (1.02 A) than that of Li^+ (0.76 A) induces a simultaneous structural change during the Na^+ insertion and extraction process, leading to a rapid capacity decline and poor rate capability. To overcome these shortcomings, scientific and industrial societies have focused on investigating the sodiation/desodiation mechanism and improving the electrochemical performance. In addition, with rapid progress in the field of materials chemistry and nanotechnology, SIBs are being extensively explored. Up to now, the use of an O_3-type cathode

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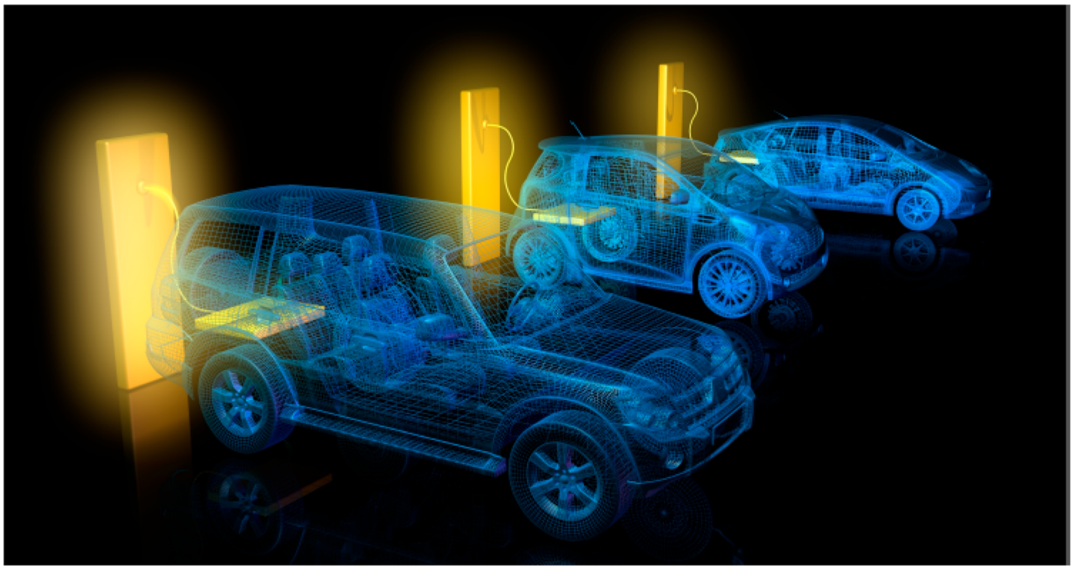

Figure 1. Designing next-generation batteries for automobiles (Source: Shutterstock).

and hard carbon anode assembly for successful full cell configuration is one of the best choices for fabricating practical SIBs. In addition, the development of a suitable electrolyte and binders is equally important to obtain electrode materials for making operational SIBs. The energy density of SIBs as full cells operable at room temperature is competitive compared to that of the state-of-the-art LIBs with graphite and layered oxides. However, most of the current research concentrated on small-sized half-cells (employing Na metal) with low electrode density, which severely hindered the development of practical sodium ion full cells. To successfully fabricate practical SIBs, from now on, we should start evaluating various electrode materials in a scale-up full cell design to investigate the stability of the electrode and Na storage performance for application in practical cells.

Replacing LIBs, which are already being used extensively in energy storage devices, with another system requires a great deal of effort and time. Development of new battery systems is essential to keep pace with the fast-moving automotive market. In order to rapidly develop next-generation LIBs and replace conventional LIBs with the next-generation LIBs, it is necessary to carry out extensive research by combining the efforts of many researchers.

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Notes

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