Automotive Lithium-ion Batteries

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OVERVIEW: A new generation of high-power lithium-ion battery for the hybrid electric vehicles are under development aiming the improvement of fuel efficiency and reduction of exhaust gas emissions in response to the worsening of global environmental problems. For Hitachi, this corresponds to its fourth generation of lithium-ion batteries and the group is currently investigating the prismatic shape. An output density of 4,500 W/kg (approximately 1.5 times that of the third generation) has been achieved through the development that includes use of a new manganese-based anode material, thinner electrodes, a low-resistance collector structure, and other new structural features. Prismatic batteries have numerous advantages including superior heat dissipation and Hitachi plans to evaluate the potential of these new-generation batteries for mass production by developing manufacturing processes while also verifying their long-term reliability.

INTRODUCTION

GLOBAL environmental problems including the depletion of fossil energy reserves and global warming caused by a build-up of CO_2 are widely recognized and people are looking for ways both to solve the problems of energy use and achieve sustainable economic development.

For automobiles that have been a major contributor to those problems, improvement of their fuel efficiency and reduction of exhaust gas emissions have become major issues. One specific measure for the solution of environmental problems is the ongoing commercialization of HEVs (hybrid electric vehicles) and EVs (electric vehicles) that use rechargeable (secondary) batteries. Although most such vehicles currently use Ni-MH (nickel-metal hydride) rechargeable batteries, it is anticipated that lithium-ion rechargeable batteries with their higher output and greater capacity will enter widespread use.

This article describes the outlook for these automotive lithium-ion batteries and what Hitachi is doing to improve their performance.

OVERVIEW OF LITHIUM-ION BATTERIES

Lithium-ion battery is a kind of the rechargeable batteries that differs from the primary lithium metal battery. The materials that are capable of absorbing and releasing lithium are used for the lithium-ion battery such as a composite metal oxide containing lithium for the positive electrode and a carbon material for the negative electrode, and an electrolyte is impregnated consisting of a dissociable lithium salt and an organic solvent in which the salt dissolves. These structures provide the battery systems with a high cell voltage, a high energy efficiency and a long life. Lithium-ion battery shows the highest performance in commercialized rechargeable batteries in the energy density (energy per battery weight) as a measure of ability to store energy.

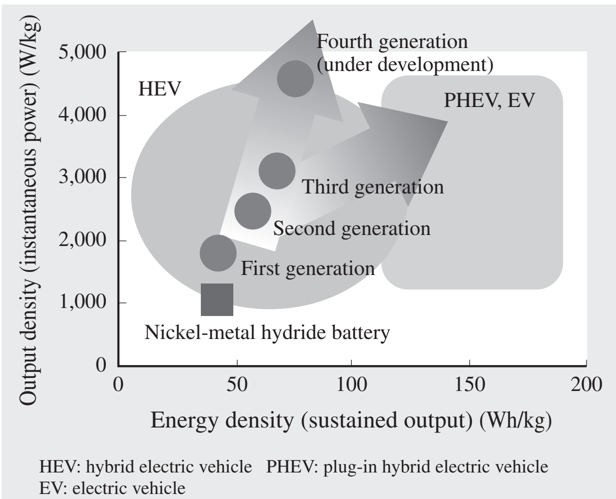

Fig. 1—Performance of Different Lithium-ion Batteries. Improvements are being made in output and energy density using proprietary materials based on cost-competitive manganese compounds. Hitachi also seeks to achieve a high level of safety in both materials and structural design.

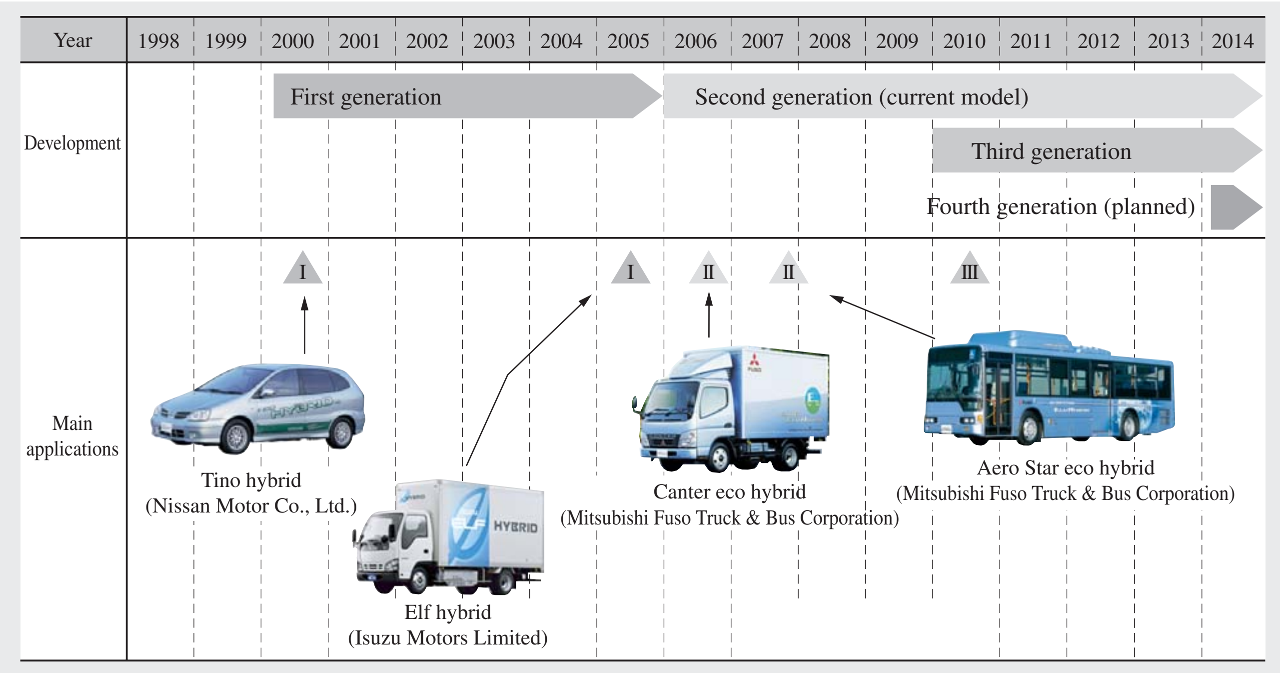

Fig. 2—Vehicles that Use Lithium-ion Batteries.
Starting with the 2000 Tino hybrid prototype made by Nissan Motor Co., Ltd., the first and now the second generation of Hitachi batteries have been used in production-model vehicles, primarily commercial vehicles. The new third-generation batteries are to be released in 2010 for use in passenger cars.

Despite having a relatively short history from the launching in 1992 for consumer use, the lithium-ion battery now has the largest market share in Japan and holds a dominant position after the lead-acid battery in the World.

PAST DEVELOPMENTS

Hitachi has been researching and developing large lithium-ion batteries since the early 1990s. In 2004, it established Hitachi Vehicle Energy, Ltd. to develop and manufacture automotive lithium-ion batteries and has taken a lead in producing and bringing to market batteries with high performance and long life based on vertically integrated technical and manufacturing capabilities that extend from materials through to battery control systems. Lithium-ion batteries have high reaction efficiency and energy density, and Hitachi is also putting particularly significant human resources into the development of both battery designs and production technologies in order to improve their safety.

Fig. 1 shows the performance of different generations of battery.

Energy density and output power density are two important characteristics of a battery and although it is difficult to satisfy these two requirements, ongoing improvements in both materials and structural design of the battery have delivered steady improvements to each new generation battery.

First and second generation batteries are already used in some commercially available vehicles (see Fig. 2). These are the HEVs with lithium-ion batteries that can be seen on the road, although the total number of such vehicles is still low.

Table 1 lists the lineup of automotive lithium-ion batteries.

Key features of Hitachi batteries are the use of an cathode material based on a manganese (Mn) compound and an amorphous carbon anode. The manganese-based material is more cost-competitive than conventional cobalt (Co) compounds and the amorphous carbon provides a high degree of safety.

The batteries currently in full-scale production are second-generation batteries (see Fig. 3). With an output power density of 2,600 W/kg, these batteries represent the top end of what is available in mass-produced models. They are used in hybrid trucks and are currently in high demand. Total accumulated sales to date have reached 700,000 cells.

Improvement has been made to the structural design of second-generation batteries to make them more suitable for mass production, and development of third generation batteries and the battery packs with them have already been completed. The output density of

TABLE 1. Key Specifications and Current Status of Each Battery Generation

The second-generation batteries currently in full-scale production are used in hybrid trucks and other vehicles, with total sales over five years reaching 700,000 cells. The development of third-generation batteries has already been completed and are in the final stages of preparation for full-scale production. Development is now underway on fourth-generation batteries with world class performance with much improvement of output power density.

	Second generation	Third generation	Fourth generation
Cathode material	Mn-based	Mn-based	Newly developed Mn-based
Anode material	Amorphous carbon	Amorphous carbon	Amorphous carbon
Capacity (Ah)	5.5	4.4	4.8
Weight (kg)	0.30	0.26	0.24
Cell shape	Cylindrical	Cylindrical	Rectangular
Output density (W/kg)	2,600	3,000	4,500
Status	In production	Readying for production	Under development

these batteries has been improved to 3,000 W/kg (see Fig. 4).

The batteries are intended for use in hybrid vehicles and full-scale production will start in 2010 with a production capacity of 300,000 cells per month.

DEVELOPMENT OF FOURTH-GENERATION BATTERY

It is forecasted that the real market growth for vehicles with the use of lithium-ion batteries will be realized after 2014, but that once started, the market size will be very large. Hitachi is now developing its fourth generation of new batteries with the aim of being ready to enter the market at this timing.

Development Stance

The factors that influence the relationship between energy density and output density mentioned above include the choice of materials and how the electrode layers are formed. Fine tuning of these is important to meet the required battery characteristics.

For example, whereas energy capacity is relatively more important for EVs in order to obtain a reasonable driving mileage, the important requirement for HEVs is the instantaneous power (battery output) used to provide immediate assistance to the vehicle engine when driving conditions demand it. Although both the capacity and output power can be increased by increasing the quantity and surface area of the electrode

Fig. 3—Second-generation Battery.
Positioned as the model with one of the highest output of any mass-produced automotive battery, the battery is currently in high demand.

Fig. 4—Third-generation Battery.
The 3,000 W/kg output performance is the best in the world for a mass-produced battery. Full-scale production is planned to start from 2010.

material, this is detrimental to the product as a whole because it increases the volume of the battery, and the battery weight, and cost. Because HEVs and EVs are aiming to be promoted as low fuel consumption and low cost vehicles, and as each vehicle may contain several dozen of these batteries, there are strict limits on factors such as their weight and cost.

In this way, the basic approach to the battery development process is firstly to have a clear definition of the type of battery to be developed, and then to satisfy the overall value by achieving the required performance levels for the targeted characteristics through material innovation and the introduction of new technology.

As fourth-generation batteries are targeted at HEVs, the objective is to achieve rigorously defined as high output levels. While past lithium-ion battery products have been produced using a cylindrical design, development has started on a prismatic battery shape which represents a new innovation for the fourth generation. The reasons for this include: (1) superiority in heat radiation, (2) compliance with the needs of vehicle manufacturers, (3) ability to increase output power using a simple design.

Responding to Issues

Ultimately, the quest for higher output is about reducing the battery's internal resistance. To achieve this, Hitachi decided on resistance tolerances for each material and package component, and then set out to satisfy these specifications.

In terms of materials, Hitachi aimed to reduce the cathode resistance by adopting a new material based on a manganese compound which had been designed to have optimum grain structures through techniques such as crystallization processes. As this technology is suitable for all lithium-ion batteries, it can also be used to improve the output power of cylindrical batteries. In terms of the structural design, the targets for the rectangular battery development were achieved by using an FEM (finite element method) analysis of current flow to optimize the current collection method and the shape of the connections between the electrode and external terminals.

Other measures aimed at ensuring a reasonable energy capacity as well as high output power were the thinner electrode with larger surface area.

Testing

Fig. 5 shows the battery used for performance testing.

The external dimensions are 120 × 90 × 18 (mm) and the weight is 240 g. The output density is 4,500 W/kg and the energy density is 75 Wh/kg.

Fig. 6 shows a graph of the temperature on the surface of the prismatic battery versus its charging and discharging current to give an example of its heat radiation characteristics.

The battery used for these tests had a temperature increase of approximately 23°C for a current flow of 11 C (where 1 C is the current required to discharge the battery in 1 hour) under natural convection cooling, and the temperature range inside the battery was approximately 2°C. In addition to the rectangular battery characteristics of large surface area (heat radiation area) and short distance from the center of the battery to its surface, the reduced internal resistance is considered to result in less heat generation.

A high output power means the battery can provide good assistance to the engine to achieve responsiveness in the HEV. These benefits can also be utilized to reduce cost, improve fuel economy, and reduce the overall weight of the vehicle through the use of fewer batteries. Good heat radiation characteristics should also allow for simpler cooling systems and longer battery life by providing a more uniform temperature distribution with the inside the battery.

Fig. 5—Fourth-generation Battery.
The new cathode material, thinner electrodes, and lower current-path resistance achieve an output power density of 4,500 W/kg.

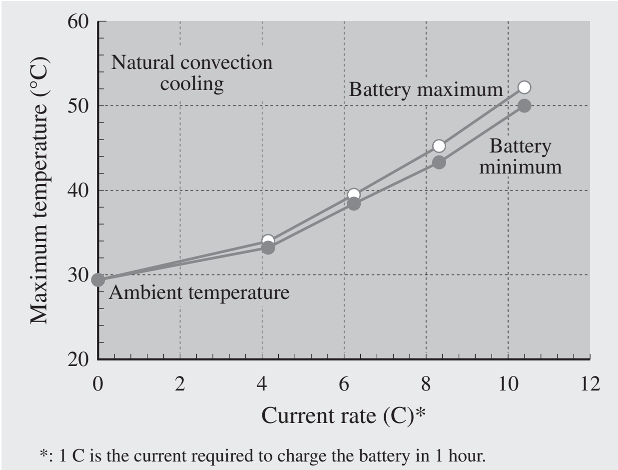

Fig. 6—Temperature Increase in Fourth-generation Battery during Use.
By reducing temperature variation in the battery, the rectangular design can be expected to help extend the battery life and allow simpler cooling systems to be used.

Hitachi plans to make a decision about putting the prismatic battery into commercial production following study of full-scale production processes together with testing of its long-term reliability, safety, and similar characteristics. Hitachi also intends to investigate incorporating the electrode technology obtained from this development into its proven cylindrical batteries.

CONCLUSIONS

This article has described the outlook for automotive lithium-ion batteries and what Hitachi is doing to improve their performance.

Hitachi intends to strengthen its social innovation businesses while also contributing to the future of the global environment by expanding its lithium-ion battery business and other system businesses that use storage batteries under the group's "Environmental Vision 2025" long-term plan for reducing global warming.

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