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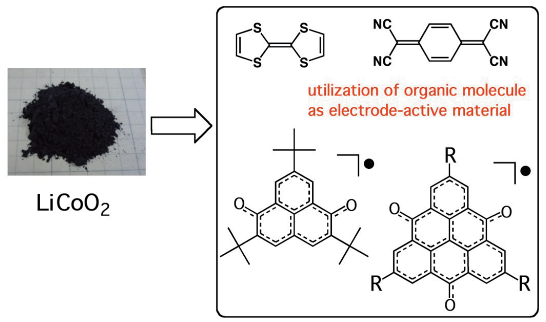
SCIENCE

Organic Batteries, Better Batteries

Ames Pomeroy reports on a breakthrough development in next-generation battery research.

Osaka University and Osaka City University researchers, along with researchers at Murata Manufacturing and JEOL, have been able to use organic "tailor-made" battery materials based upon stable open-shell molecules with degenerate frontier orbitals to produce new "molecular spin batteries"; the researchers focused on said batteries as they can be rare metal-free (i.e., cobalt [Co]-free) rechargeable batteries. Since such secondary batteries using organic electrode-active materials promise to surpass Lithium (Li)-ion batteries now available from safety and resource price standpoints, new products are seen being born in the wake of this effort. Li-ion batteries having $LiCoO_2$ as the cathode-active material are known for being batteries attaining the highest performance level, widely used for electronic devices such as mobile phones and laptop personal computers. Said batteries, however, are plagued with serious problems in terms of safety and price, as they contain cobalt as the most crucial element inside the rechargeable battery cells.

Also since the academic researchers, led by Associate Professor Morita Yasushi of the Graduate School of Science at Osaka University were organic chemists who could create materials that play a central role in these batteries, this use of organic molecules for cathode-active materials allows a high voltage and cycle performance to be achieved, and facilitated design and preparation of these batteries. Independent of the issues of cobalt use in Li-ion batteries, other economic and political concerns led the chemists to expand new possibilities for organic materials, especially open-shell organic molecules like trioxotriangulene (TOT) having a singly occupied molecular orbital (SOMO) and two degenerate molecular orbitals (LUMOs). "Synthetic organic spin chemistry" can be applied for producing structurally well-defined "open-shell graphene fragments" for example.



The results this time enable new products to be brought forth, the high-performance batteries based on organic materials opening up a path away from dependence upon the use of cobalt. Since cobalt is a rare metal which is produced in a limited number of countries, its price fluctuates significantly. A stable supply of high-performance yet low-cost batteries will reduce fossil fuel dependency while contributing to a reduction in greenhouse gas emission. The new science and technology can be applied to the design and production of compact, lightweight batteries that have a high capacity. If the researchers are lucky, the batteries may also be applied for use in electric vehicles in the near future.

Osaka University Graduate School of Science
Associate Professor Morita Yasushi

High Capacity, Low Price

The new batteries feature two extraordinary characteristics, both merits. First is the price since the cost of the resource required is low; the other is the high capacity level surpassing those of other high-performance Li-ion batteries. It is a widely accepted fact that an increase in capacity of rechargeable batteries based upon inorganic materials having a relatively high durability cannot be easily realized, in spite of very active R&D efforts taking place around the globe. On the other hand, the new Kansai-spawned batteries do have a disadvantage in that the output voltage is low, around 2.5V, quite lower than those produced by conventional Li-ion batteries. In addition, these items have a durability level which is not yet sufficient enough to warrant mass production.

Nevertheless it is believed that the organic approach promises to bring forth superbatteries with energy densities perhaps thrice those of conventional batteries. To increase the energy density of organic tailored batteries, understanding the electron transport phenomena is vital, in addition to electrochemical reactions inside batteries on a microscopic scale; this is where the industry researchers, who excel in observing actual microscopic level activities, have been of immense help.

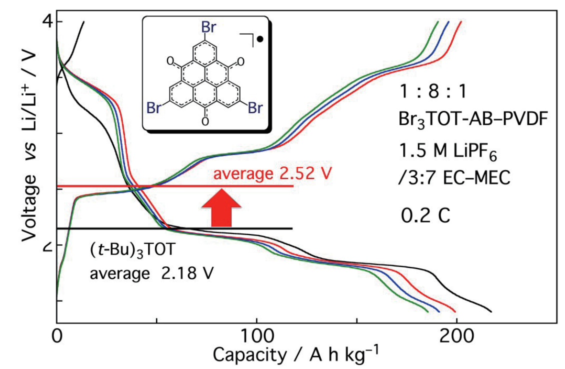
The current research endeavor has thus been investigating electrochemical and electrically detected electron spin resonance in *in situ* studies of the cathode during the charge-discharge processes while carrying out advanced quantum chemical calculations for redox potentials, in light of the fact that recently, organic radical batteries using nitroxide radical polymers as cathode-active materials have been able to realize output voltages as high as 3.6V while maintaining a high cycle performance compared with capacity being limited to 2/3 for conventional Li-ion batteries.

There are many obstacles foreseen for further development but Professor Morita notes that the most important thing which needs to be realized is an increase in capacity and the output voltage along with an improvement in durability against charge-discharge cycles. The joint R&D team took a tailor-made approach to design the organic materials, having already obtained a clue as to the solution of the aforementioned problems in terms of organic chemistry. In the near future, they hope to develop more high-performance batteries, having an output voltage of 3V and a durability level against 500 cycles of charge-discharge that will replace the Li-ion batteries currently available.

As for costs, in comparison to using cobalt these are difficult to fathom at the present time, with the estimate of the cost of manufacturing being the most difficult. However, Professor Morita thinks that the production cost can be reduced in comparison to those for the conventional Li-ion batteries if mass production becomes possible, because the organic materials the Japanese researchers can prepare are derived from inexpensive chemicals that are obtained from petroleum at a high yield through short synthetic steps. Furthermore, a stable supply of high-performance organic batteries will result in lowered total cost over the medium to long term.

In terms of safety, because the current study is still in the initial stages, the researchers have yet to evaluate the potential risks entailed for human health and the environment in realizing high-performance batteries based upon organic materials. Nevertheless, they can say that at least the risks involved upon use of cobalt oxide can be reduced. Professor Morita believes that the new batteries can be put into practical use within the next ten years. For this, researchers have to establish the best composition required in fully utilizing the potential of the original organic materials together with the conduct of further studies on the fabrication method of the battery structure, a "single battery" being a precise system comprising a cathode, an anode, electrolyte solution and so on. They have already started honing the design criteria for the organic materials and the search for the best composition, through collaboration with companies that have in-depth knowledge and experience related to rechargeable batteries.

Charge-Discharge Properties of Br_3TOT



Toward Organic-Battery Chemistry

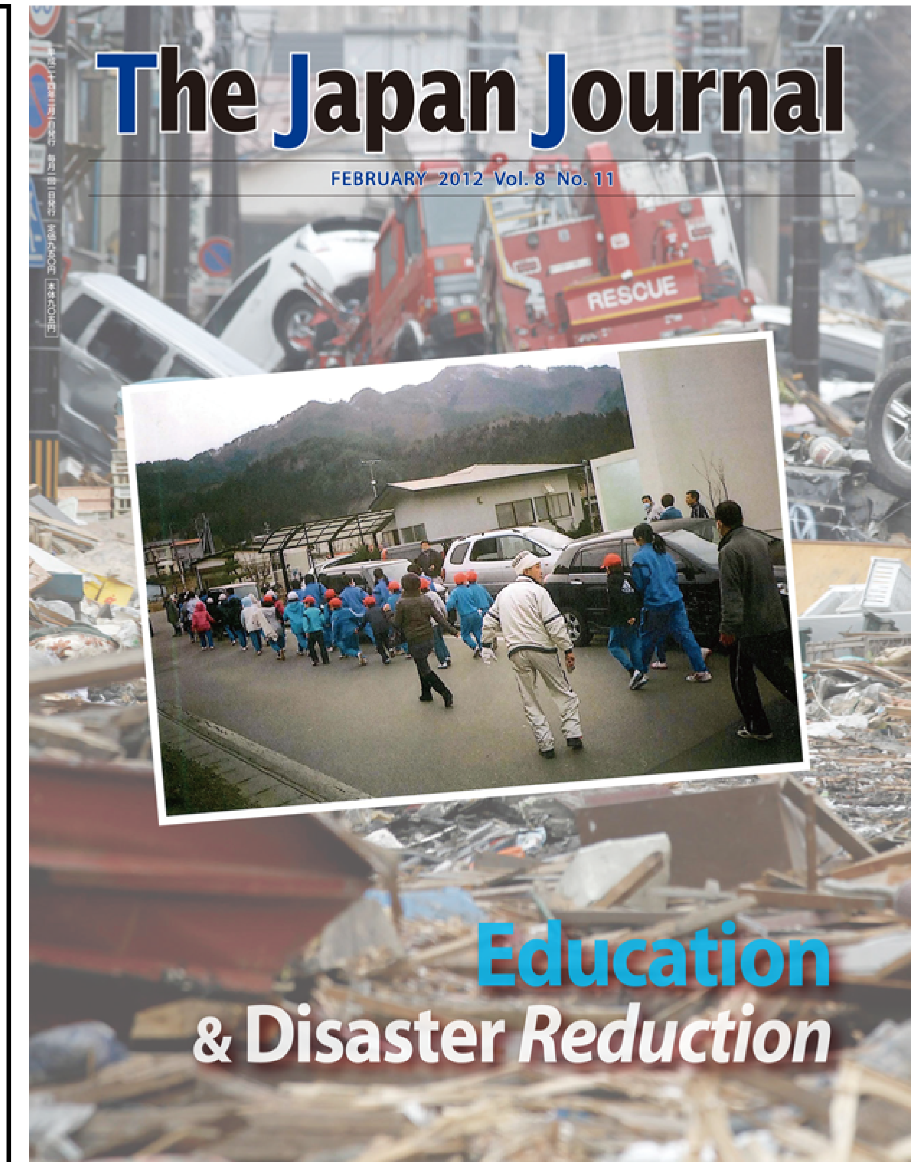
The new batteries were designed on the basis of original Japanese concepts and make use of proprietary materials produced. Professor Morita thinks this is very important as these batteries can be realized only through use of Japanese technology. The Osaka-area researchers have much experience designing and preparing organic materials with a degenerate molecular orbital. As such, at this time they have no other research group competing with it directly on a global basis. But there are concerns that there could be competitors arising over the next several years because the procedure used in synthesizing organic materials has been disclosed in published papers. Of course they have already applied for patents to cover the most important portions of the research work and also hope to protect the results with patents.

Nevertheless, along with working diligently in an academic setting, engaged in research and education revolving around fundamental science, Professor Morita and his academic colleagues would like to pave the way for development of chemistry covering organic electrode-active materials. Along with their industrial researcher counterparts, they wish to open up a new interdisciplinary field of science, tentatively called "organic-battery chemistry" for now, this being their biggest goal. Should the Goddess of Fortune smile upon the researchers, the challenges of developing long-lasting, lightweight batteries for mobile phones, laptops and electric vehicles in the near future may be met. As a result, organic-based battery production could grow into a competitive industry for Japan.

The conductive polymer Br_3TOT used in the new, cobalt-free lithium-ion battery was obtained from organic derivatives of petroleum.

PHOTOS COURTESY OF DR MORITA YASUSHI

Ames Pomeroy, *The Japan Journal*



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