Materials developments of ionic conductors and their application to all-solid-state batteries

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We synthesized materials that show great promise as solid electrolytes. All-solid-state batteries built using the solid electrolytes exhibit excellent properties, including high power and high energy densities, and could be used in long-distance electric vehicles.

High power batteries are desirable for numerous applications, including the electric vehicles of the future. These batteries must be rechargeable, remain safe to store and use at variable temperatures, and retain charge for a considerable length of time. We have successfully designed and trialled novel, high power all-solid-state batteries with promising results. Most traditional batteries rely on the flow of ions through a liquid electrolyte between two electrodes; lithium-ion batteries used in mobile phones would be one example of this type of battery. However, batteries incorporating a liquid electrolyte are prone to problems, including low charge retention and difficulties in operating at high and low temperature. Previous designs for solid electrolytes have shown promise, but have proven expensive and some have exhibited problems with electrochemical stability.

We found new lithium-based ‘high-ionic-conducting’ materials with extremely high ionic conductivity and a new crystal structure type; the high ionic conducting $Li_{10}GeP_2S_{12}$ (12 mScm^{-1} at room temperature) [1] and $Li_{9.54}Si_{1.74}P_{1.44}S_{11.7}Cl_{0.3}$(25 mS cm^{-1}) [2], $Li_{9.6}P_3S_{12}$ with wide electrochemical window[2], and $Li_{10+\delta}[Sn_ySi_{1-y}]_{1+\delta}P_{2-\delta}S_{12}$ with less expensive material[3].

High-ionic-conducting materials have crystal structures through which ions can ‘hop’ easily, essentially maintaining a flow of ions similar to that which occurs inside a liquid electrolyte (see Fig. 1[2]). They showed how the lithium ions move fast in the structure of their compounds even at room temperature. These LGPS-type materials showed extremely high ionic conductivity and high stability. We used their new solid electrolytes to create the all-solid-state batteries. The cell exhibited superior performance compared with lithium ion batteries, operating very well at temperatures between -30 and 100°C. The cells provided high power density, with ultrafast charging capabilities and a longer lifespan than existing battery types (See Fig. 2[2]).

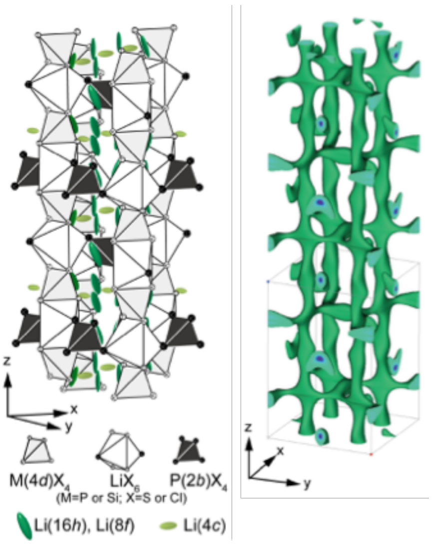

Fig. 1 Crystal structure and Li distribution of $Li_{9.54}Si_{1.74}P_{1.44}S_{11.7}Cl_{0.3}$.

Although the technology requires further development before it is commercially available, these promising results indicate that all-solid-state batteries may soon provide a much-needed boost to applications requiring stable, long-life energy storage.

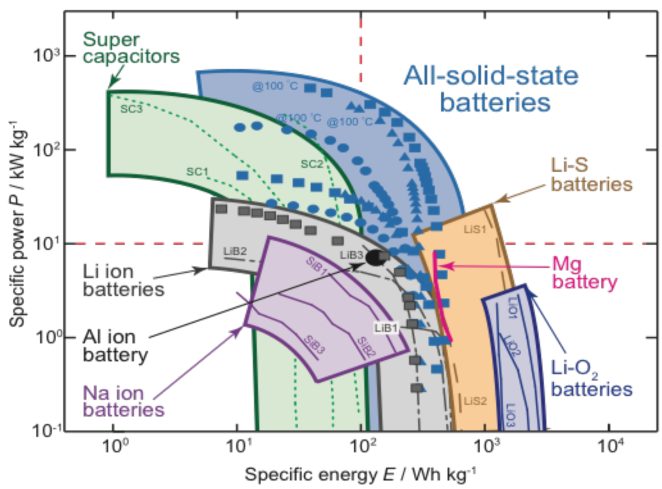

Fig. 2 Ragone plots for energy storage devices

Bibliography

[1] Kamaya, N. et al., *Nat. Mater.* **2011,** *10* (9), 682-686.

[2] Kato, Y., et al., *Nature Energy* **2016**,16030.

[3] Sun Y., et al., *Chemistry of Materials*, **2017**, 29(14)**,** 5858-5864.

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