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## Low temperature effect of lithium diffusion in 18650-type MNC battery

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Investigations of the phenomena in atomic scale are essential for fully understandings of the activities in battery operation. The battery is known to be operated in a broad temperature range below and above the ambient temperature. Temperature change could affect the performance, and might even raise safety issue. Li-plating, where metallic Li-ions accumulate onto the graphite anode, is a recently realized atomic phenomenon that severely degrades the performance of the battery. These including capacity loss, impedance raise, activity slowing down and aging speeding up.

It is now known that intercalation into the graphite and plating onto the graphite surface can both occur when Li-ions return to the graphite anode upon charging. Li-plating will partially block the insertion of Li-ions onto the graphite electrode in some extent, which reduces the migration of Li-ions during discharging and charging. Clearly, local environment, such as temperature or electric field, could affect the insertion rate, but experimental study or theoretical modeling concerning these effects are still limited.

Here, we report on the results of studies made, using cold neutron triple-axis spectrometer – SIKA's elastic mode, on the Li<sup>+</sup> diffusion rate of an 18650-type Li-ion battery in discharging-charging operations, carried out at and below the ambient temperature. Sizable in-situ neutron diffraction intensities for the {001} reflection of LiC<sub>6</sub>, for the {002} reflection of LiC<sub>12</sub>, as well as for the {004} reflection of LiC<sub>54</sub> were clearly detected in very 5 minute interval during a discharging-charging operation, which were then used to extract the Li<sup>+</sup> diffusion rate during operation.

Interestingly, operation with a C/5 discharging rate performed at -20 °C causes a dramatically 25% reduction in the Li<sup>+</sup> diffusion rate and even more surprisingly the discharge transfers only 35% of the Li out of the graphite anode since the diffusion essentially stop in the early stage (~1/3) of the discharge period. The reduction and stopping of Li<sup>+</sup> diffusion can effectively be corrected by employing a lower discharging rate in the operation.

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