Electric Potential Mapping of an All-solid-state Lithium Ion Battery by In situ Electron Holography

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Lithium-ion batteries, which provide the largest energy storage densities among several battery technologies, can serve as storage devices for renewable energy. Therefore, they are considered an essential technology for environmentally friendly and sustainable societies [1]. However, the electrochemical reactions in the batteries that control their performance are not yet fully understood. Consequently, important clues to develop more efficient batteries are hard to find. One effective way to understand electrochemical reactions in the batteries is to visualize electric potential distributions inside them, in particular, near the interface between an electrode and an electrolyte during charge-discharge cycling.

Electron holography is an electron microscopy technique to observe electric or magnetic fields in micrometer to nanometer scale that is now available to map electric potential distributions in batteries [2]. We prepared a TEM sample from a working model battery using the Focused Ion Beam method and loaded the TEM sample into the microscope with a holder equipped with two electrodes for applying voltage. The potential distributions in the battery were observed during charging and discharging cycles by in situ electron holography.

Figure 1 schematically shows the model battery sample used for this experiment. Figure 2 shows an example of our in situ electron holography experiment. Charging voltage of 1.2V was applied to the sample, and soon after that, electric potential distributions were observed. Figure 1(a), (b), and (c) show a transmission electron micrograph, electric potential distribution, and its profile, respectively, near the interface between the positive electrode and the electrolyte. Figure 1(d), (e), and (f) show those at the interface at the negative electrode side. They clearly show that a large potential drop is seen at the negative electrode side, while a small potential drop is recognized at the positive electrode side. This implies that the ion diffusion resistance is mainly at the negative electrode side. This talk will present the insights gained by measuring the electric potential distribution profiles near both interfaces.

In conclusion, we successfully observed electric potential distributions in an all-solid-state Li-ion battery. We believe that this technique will be helpful in understanding electrochemical reactions in batteries and contribute to developing superior batteries in the future.

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References

[1] M. Armand and J.-M. Tarascon, Nature 451, 652-657 (2008).
[2] K. Yamamoto, et al., Angew. Chem. Int. Ed. 49, 4414-4417 (2010).

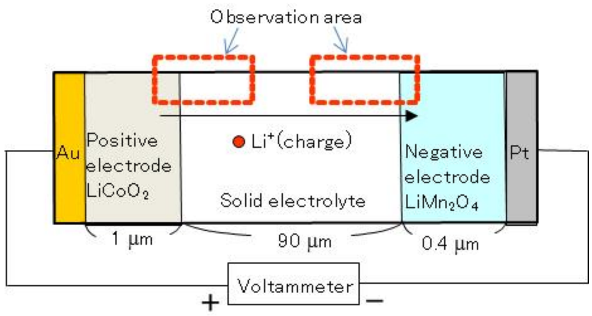

FIG. 1. Schematic of the model battery sample used for this experiment

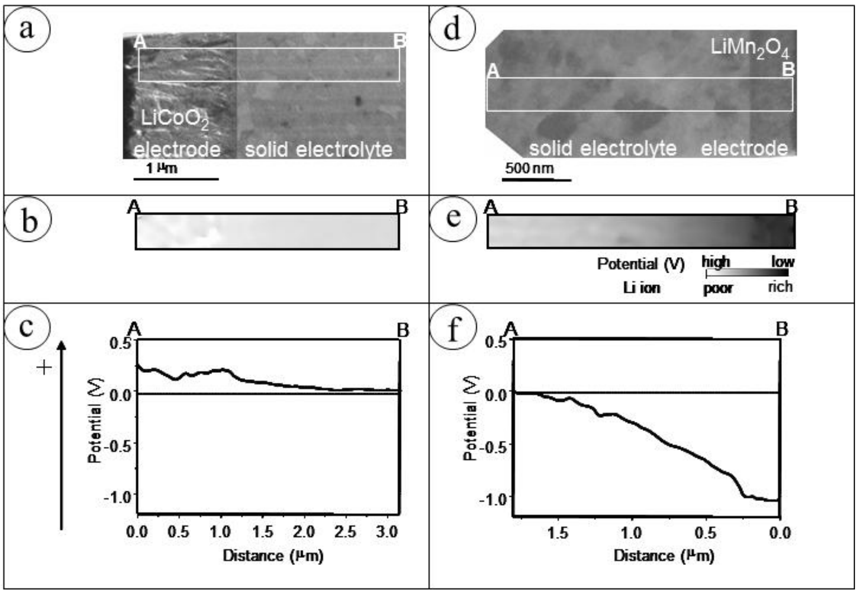

FIG.2. Results obtained by in situ electron holography experiment. Charging voltage of 1.2V was applied to the sample battery, and electric potential distributions were observed. (a) transmission electron micrograph, (b) electric potential distribution, and (c) potential profile in the vicinity of the interface between the positive electrode and the electrolyte. (d), (e), (f) those at the interface at the negative electrode side. Note that a large potential drop is at the negative electrode side, while a small potential drop is seen at the positive electrode side. This implies the large resistance for the charging is at the interface between the negative electrode and the electrolyte.