

Investigation on Performance-Degradation Mechanism of Lithium-ion Cells Simulated Low-Earth-Orbit Satellite Operation by Using Instrument Analysis

Xianming Wang, Chisa Yamada, Hitoshi Naito, and Saburo Kuwajima

Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency (JAXA), Tsukuba Space Center, Sengen 2-1-1, Ibaraki 305-8505, Japan

To develop lithium-ion batteries for space application, lithium-ion cells with capacities ranging from 0.6 Ah to 100 Ah are being assessed in real-time by simulating low-Earth-orbit (LEO) or geosynchronous-Earth-orbit (GEO) satellite operation at JAXA. In this work, we investigated the performance-degradation mechanism of commercial laminated lithium-ion cells (0.65 Ah) with LiCoO₂ cathode and graphite anode simulated LEO satellite operation by instrument analysis on electrode materials (FTIR-ATR, XPS, NMR, XRD).

One aged cell was taken apart and the anode and cathode were used for instrument analysis. This aged cell experienced 4,350-cycle cycle-life testing (DOD: 40%) simulating LEO satellite operation and exhibited severe performance degradation, as shown in Figure 1. As a reference, another fresh cell with the same specification was also tested for instrument analysis.

Compared with the fresh cell, a new surface hydroxide metal compound was detected on anode surface of the aged cell by FTIR-ATR analysis. The organic component thickness of electrode surface film was calculated from the permittivity of surface film by simulating the FTIR spectrum (Figure 2). The calculation result was summarized in Table 1. While the organic component thickness of cathode surface film of the aged cell was almost identical with that of the fresh cell, the aged cell had a thinner organic surface film at anode than that of the fresh cell. This is a very interesting finding.

XPS results were summarized in Table 2. Compared with organic components, inorganic component amount increased with cycling at the anode surface. Peak separation disclosed that LiF was a main factor to the inorganic component increase on anode surface film of the aged cell. Co metal and Co²⁺ ion were detected at the anode surface film of the aged cell, different from the sole Co²⁺ ion for the fresh cell.

NMR analysis detected a new lithium compound in anode particle of the aged cell. XRD results disclose that lattice size of the electrode material for the aged cell was smaller than that of the fresh cell. The distance between the cathode layers of cathode became small due to cycle-life testing.

The following cell behavior may be considered as the primary cause of cell performance degradation. With cycling, the lithium salt as solute was decomposed and LiF deposited at anode surface. This caused the cell impedance increase since LiF was well known as a high-impedance component. Additionally, this may suppress the original organic surface film of the anode. Due to the increasing surface-film impedance, a part of lithium-ion was trapped in the anode lattice and could not take part in the charge and discharge cycle again. The layer distance of cathode increased since the lithium-ion left in cathode material became fewer and fewer. As a result, lithium-ion cell subjected to the performance degradation due to the loss of lithium-ion.

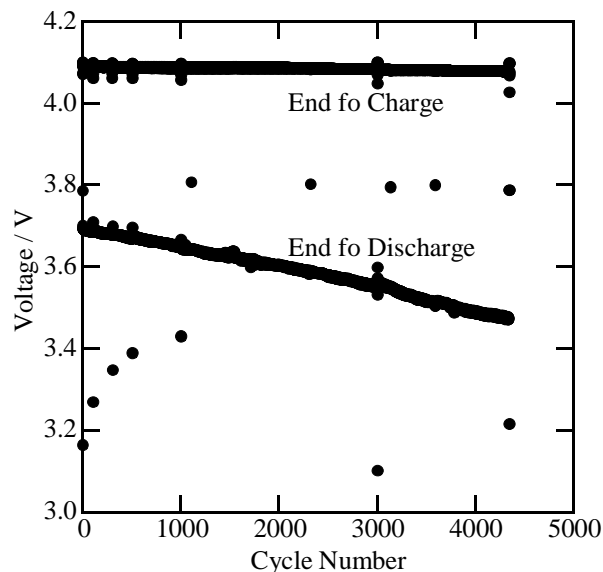


Figure 1. Voltage trend of aged cell simulated LEO satellite operation. Charge: CC-CV, 0.5 C, 4.1 V, 60 minutes; discharge: CC, 0.8 C, 30 minutes.

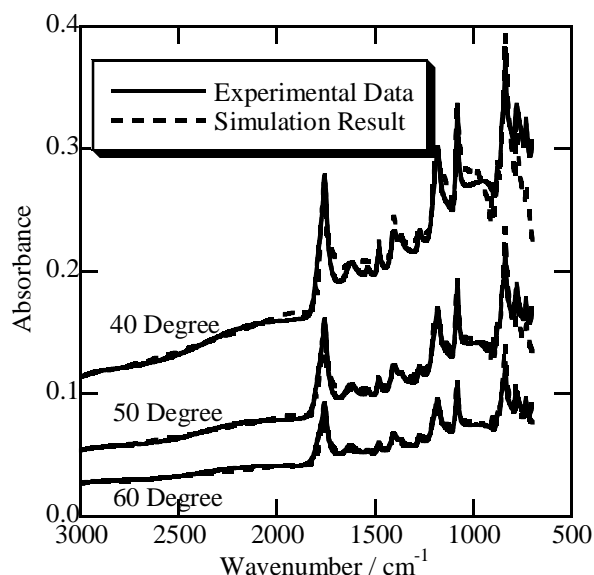


Figure 2. Simulation on FTIR-ATR spectra of aged cell cathode. Good agreement was obtained between the simulation result and experimental data.

Table 1. Surface film thickness of electrode material

Sample	Aged		Fresh	
	Cathode	Anode	Cathode	Anode
Thickness, nm	45.5	65.3	48.9	91.0

Table 2. Element composition (%) obtained from XPS

Sample		C	F	O	Li	P	Co
Anode	Aged	20.3	31.6	16.2	29.0	2.5	0.4
	Fresh	29.7	27.5	18.7	20.8	2.9	0.4
Cathode	Aged	39.3	29.2	15.4	13.4	1.2	1.5
	Fresh	41.1	28.1	15.2	12.4	0.9	2.3