Analysis on Effects of Metal Ion Implantation on NCM811 Cathode Materials

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1. Introduction

NCM, with the chemical formula $Li(Ni_xCo_yMn_z)O_2$ ($x + y + z = 1$), is a lithium-transition metal oxide that has recently been developed as a cathode active material due to its higher theoretical capacity compared to conventional materials such as $LiCoO_2$ (LCO) and $LiFePO_4$ (LFP). However, because its capacity is still relatively lower than that of anode materials, a high proportion of NCM is required in the cathode to maintain capacity balance, which necessitates a thicker cathode layer.

While a high NCM content or thicker cathode increases the overall capacity, it also leads to a significant reduction in electrode lifespan due to structural instability under repeated charge–discharge cycles. This is a critical drawback of high-capacity cathode materials, and improving the cycle life is essential for efficient utilization of their high capacity. In addition, to meet the growing energy demands of modern society, much higher energy density must be achieved. To improve the energy density of cathode materials, increasing the discharge voltage along with capacity is a viable approach. Moreover, the low output performance of NCM, caused by its lower conductivity compared to LCO and LFP, must also be addressed.

It is generally known that increasing the Ni content in NCM can enhance both capacity and discharge voltage.[1] However, a high Ni ratio leads to various stability issues, such as severe structural changes during lithium extraction, side reactions with the electrolyte, and the formation of inactive NiO.[2] Additionally, while the addition of Al to NCM to produce NCMA or NCA can improve output performance, it also induces significant structural deformation, resulting in cracking and markedly reduced stability.[3] Therefore, new techniques are required to effectively improve the energy density, cycle life, and output performance of NCM materials.

In our previous studies, we investigated the effects of gas ion irradiation on the cycling performance of NCM cathodes. However, it was difficult to obtain meaningful improvements through gas ion irradiation alone. In this study, we aim to evaluate the cycling performance of NCM cathodes through the implantation of transition metal ions.

2. Method

2.1 Fabrication of Cathode

The fabrication process of the NCM cathode is as follows. Commercial NCM811 powder was used as the active material and mixed with carbon black (conductive agent) and PVDF binder in NMP solvent. The resulting slurry was coated onto an aluminum foil (thickness: 15 µm) at a loading level of 1.0 mg cm^{-2}. The coated electrode was roll-pressed to approximately 30% compression at 75 °C, then dried under vacuum at 120 °C for 20 h..

2.2 Electron Beam Irradiation

Metal ion implantation was performed using a 150 kV metal ion beam facility at the Korea Multi-purpose Accelerator Complex (KOMAC) of the Korea Atomic Energy Research Institute (KAERI). Cobalt (Co^+) and copper (Cu^+) ions were used as the metal ion species, and the ion was accelerated to an energy of 140 keV. Ion implantation was carried out at fluences of 10^{12}, 10^{13}, and 10^{14}cm^{-2}, and all experiments were conducted at room temperature.

2.3 Electrochemical measurements

After ion implantation, the cathodes were assembled into 2032-type coin cells using lithium foil and a polyethylene (PE) separator with a lithium salt-based electrolyte. The assembled cells were rested for 12 h, followed by charge-discharge cycling in the voltage range of 3.0-4.2 V (vs. Li/Li^+) at a current density of 0.5 C (1 C = 200 mA g^{-1}). For the first cycle, a lower current density of 0.1 C was applied to activate the electrode. All cycling tests were conducted at room temperature.

3. Result and Discussion

Figure 1 shows the charge-discharge cycling performance of the NCM cathode after Co^+ ion implantation. As the ion fluence increased, a decreasing trend in capacity was observed, with similar capacity levels exhibited at higher fluences. This is attributed to the implanted Co^+ ions disrupting the NCM structure, thereby hindering its ability to retain sufficient lithium ions.

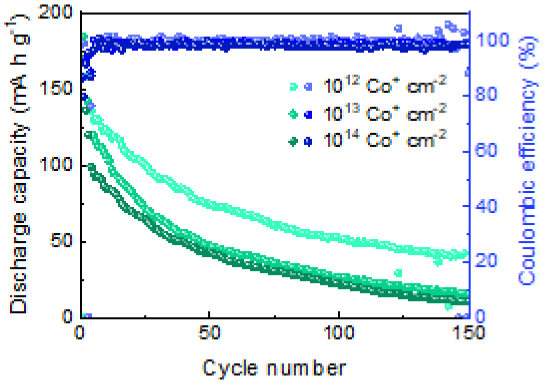

Figure 1. Cycle performance of NCM cathode after Co+ ion implantation.

Next, Figure 2 presents the cycling performance of the NCM cathode following Cu^{+} ion implantation. Similar to the results with Co^{+}, higher fluence levels led to reduced capacity. The implanted Cu^{+} ions also compromised the structural stability of the NCM, interfering with its ability to host lithium ions.

Therefore, to improve the performance of NCM cathodes, it is essential to carefully select the appropriate ion species and to optimize the fluence and energy conditions. Continued research and development will be necessary to achieve this.

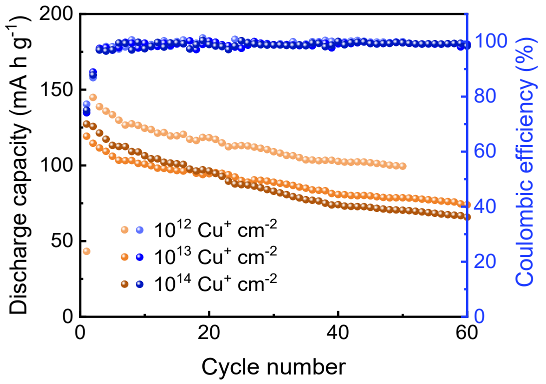

Figure 2. Cycle performance of NCM cathode after Cu+ ion implantation.

4. Conclusion

T The effects of Co^{+} and Cu^{+} ion implantation on the charge-discharge cycling performance of NCM cathodes for lithium-ion batteries were analyzed. Regardless of the ion species, an increase in ion fluence led to a decrease in cathode capacity. Further studies are needed to evaluate the performance changes of NCM cathodes following implantation with other metal ion species.

REFERENCES

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [1]. It is recommended that the number of references does not exceed five.

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