The reproducibility of coin cell data for NMC111, LFP and Sa1520

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Abstract

Nowadays lithium-ion batteries play essential roles in almost any aspect of our lives. Most electronic gadgets run on these batteries and a deep understanding of them would allow engineers to optimize the technology and improve all of the gadgets at once. A few important metrics that every battery has include capacity, resistance, optimal voltage, and gravimetric energy density of the materials Reproducibility of such metrics is an extremely important question for our study since objective comparison of results for different materials is only possible if all other factors were held constant. Numerous researches are conducted all around the globe. Questions include the difference between coin cells, and pouch cells, characterization of newly formed batteries, the impact of the formation protocol on the lifetime and capacity of the cell, the increase of battery's performance, protocols for lithium-ion cells production, and characteristics that matter the most. More research is done with different non-lithium materials and some teams focus on the variety of protocols that help conduct more knowledge about the cells.

Introduction

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In our research we want to investigate each material separately, but a battery needs both a cathode and an anode. In order to separate different materials, we created special coin cell batteries. Coin cells were produced using NMC111, LFP, or graphite as a working electrode and lithium metal as a counter electrode. These special coin cells would allow us to separate cathode and anode characteristics and have two sets of values for each part of the battery.

The usage of pure lithium in coin cells has some disadvantages. Firstly, lithium has a relatively low Coulombic efficiency. Secondly, lithium metal is expected to have dendritic growth. The growth would expose some of the pure lithium without SEI on the surface. Moreover it is possible for dendrites to break which would simply make electrochemically isolated. Lastly, pure lithium contracts and expands as lithium ions enter and leave the material. This exposes new pure lithium surface area where the formation of SEI would start immediately.

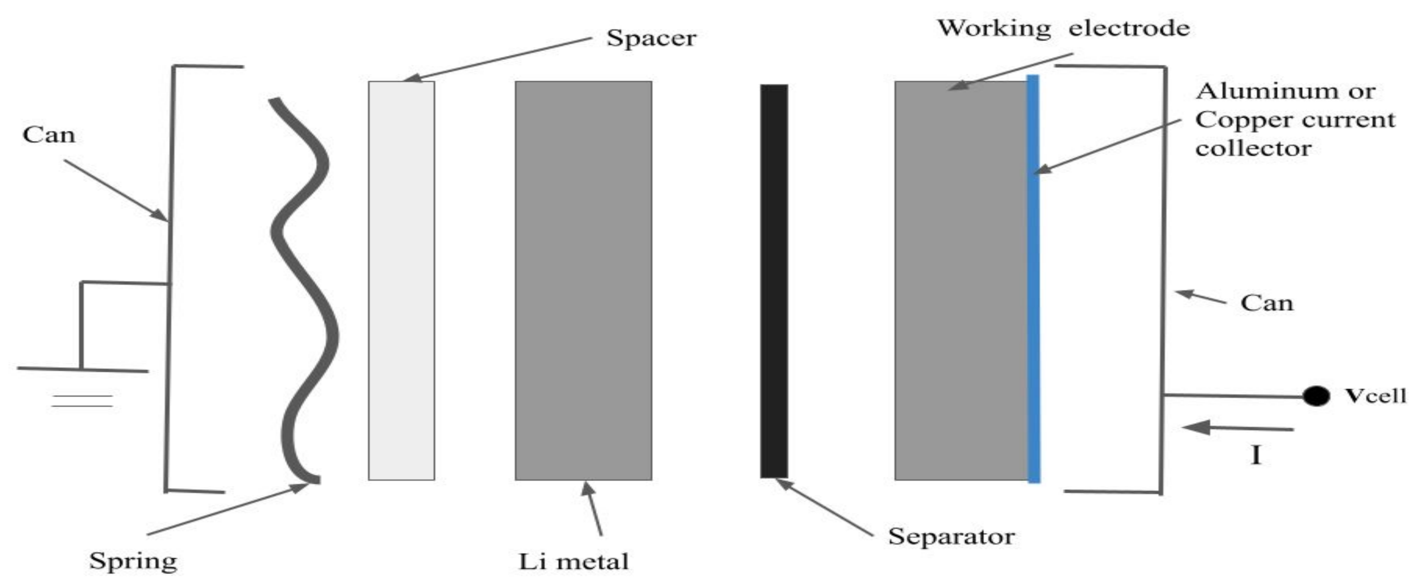

Figure 1. The structure of Lithium-ion coin cell

Table 1. The log of all the protocols that were run on 9 coin cells

Cell #	Material in Cell	Voltage (V)	Capacity (mAh)	Type of Holder	Channel	PreCondition	HPPC	C-50	C-150
1	NMC111	1.784	1.94		2	2	1		
2	NMC111	2.078	1.99	A	2	2(4)	3	1	
3	NMC111	2.010	2.02	B	4	2(3)			
4	LFP	3.029	2.93	A	4	1(2)			
5	LFP	2.871	2.96		4	2(3)			
6	LFP	3.029	2.77		4	2	2	3	
7	Sa1520	2.820	4.66	A	7	3(6)	2	3	1
8	Sa1520	2.980	4.49		8	2	1	2	
9	Sa1520	2.984	4.59		8	1			

Methods and Materials

The coin cells were built and characterized at the University of Michigan battery lab. The cell consists of a stainless steel top with a donut-like spring between it and an aluminum spacer. Then the counter electrode which is a shim of lithium metal is coated on the piece of copper. It is about 16mm in diameter and 750 micrometres thick. Then comes the polymeric separator with the ability to let lithium ions pass, but not the electrons. It is 19mm in diameter and is soaked in electrolyte on both sides. Then the working electrode is placed: either NMC111, LFP, or graphite. The active material is about 14mm in diameter, 60 micrometres thick and is coated on the aluminum foil. Both aluminum and copper current collectors collect electrons from the working and counter electrodes. Calculated theoretical capacities for the NMC111, LFP, and graphite cells were 2.0, 2.9, and 4.6 mAh, respectively.

Using Biologic potentiostat, we were running two different tests on these batteries: The first test was a preconditioning protocol. It consisted of the 3 cycles in which the battery is being charged and discharged at the C/5 rate. That test helped us measure the capacities of each coin cell. The second protocol is Hybrid Pulse Power Characterization (HPPC). In this program, we charge the battery and then gradually discharge it. What is interesting about it is that there are current drops to C/5 discharge for 10 seconds. It leads to the voltage dropping down faster in a parabolic shape. As the current drop ends voltage curve comes back to the smoother discharge curve. During such a drop we are able to measure the resistance of the cell by dividing the difference in voltage at the first and the last moments of the drop by the current applied

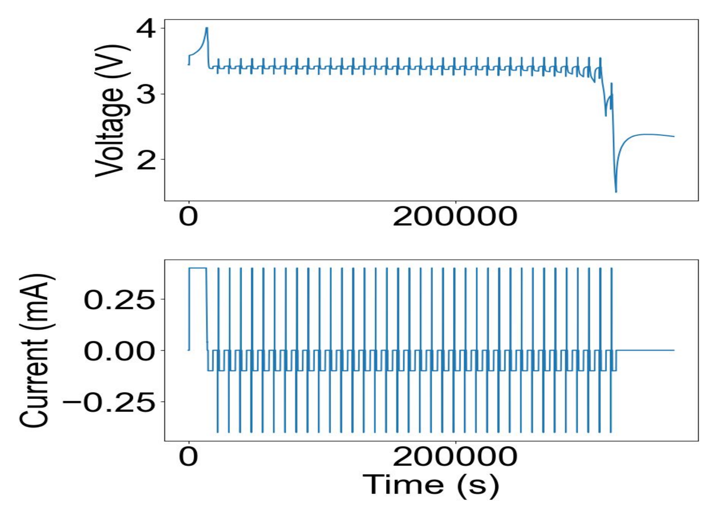

Figure 2. The Voltage and Current vs time graph of HPPC protocol

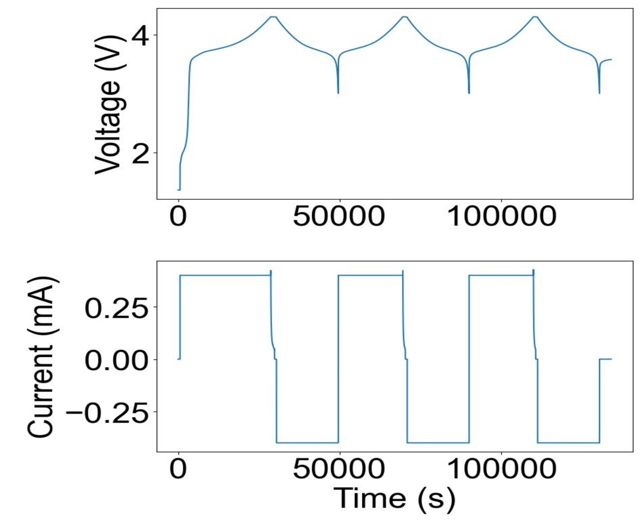

Figure 3. The progress of the same LFP cell through multiple protocols

Results

From the Figures 1,2 and 3, we can see that the capacities of the coin cells with graphite are way greater compared to the capacities of NMC111 and LFP. It is the case due to the higher theoretic capacity of the material:372 mAh/g compared to 160 mAh/g for NMC111 and 170mAh/g for LFP. Graphite has an exceptional energy density due to its structure: it can place a lot of Lithium-ion between its layers.

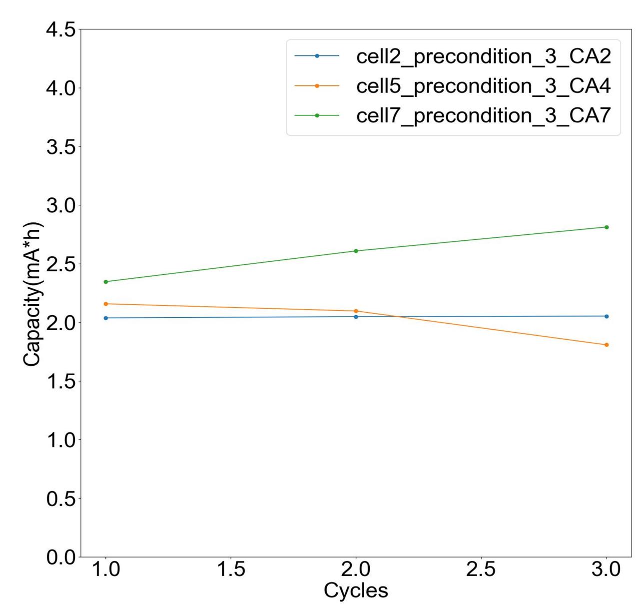

Figure 8. The comparison of capacities of the three materials

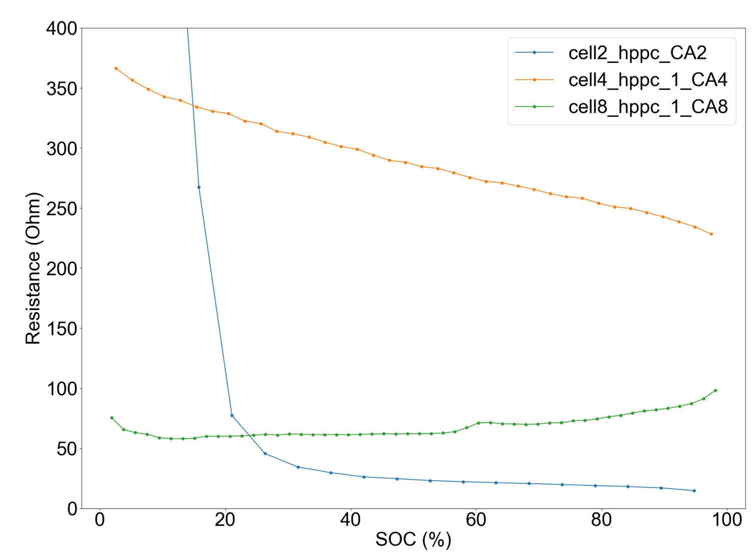

Figure 9. The comparison of resistances of the three materials

Discussion

There are multiple reasons for both increases and decreases in capacity. Firstly, graphite is an extremely porous material that has a lot of layers. Considering the fact that during the charging and discharging process materials expand and contract, it seems reasonable to assume that liquid electrolyte gets a chance to enter deeper and deeper inside the working electrode increasing the surface area and therefore the capacity of the coin cell. Secondly, for all cells the counter electrode was lithium, and lithium is known to expand and contract greater than other materials therefore it is one of the reasons for all three types of cells to demonstrate the increase in the capacity as more and more protocols were run.

Overall, a quite big variation of capacities can be observed from the same types of cells. Another possible reason for that can be the slight misalignment between working and counter electrodes. Our cells are created by humans which increases the chance of misalignment between the cathode and anode. Even a slight deviation in the electrode's position can decrease the surface area between the counter electrode and working electrode and lead to the lack of electrolyte on a part of the electrode shim and therefore create that part electrochemically isolated.

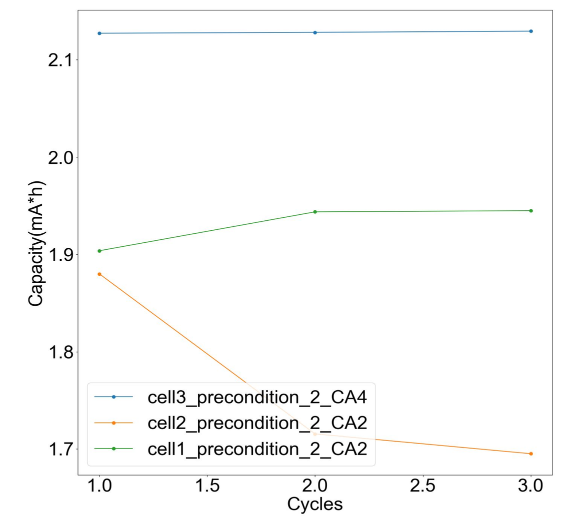

Figure 4. The comparison of NMC111 preconditioning cells

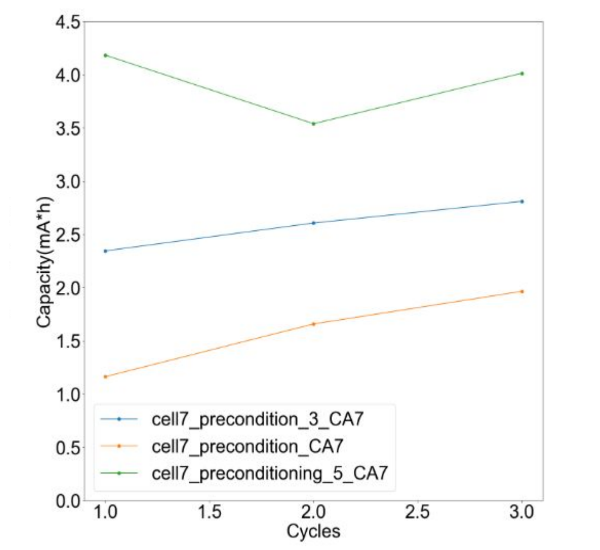

Figure 5. The progress of the same Graphite cell through multiple protocols

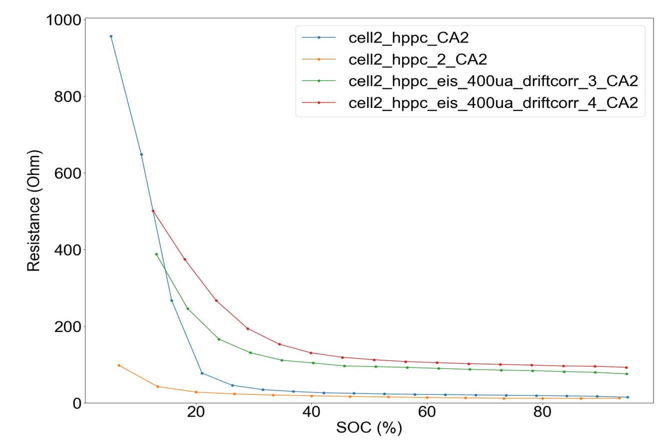

Figure 6. The progress of the same LFP cell through multiple HPPC protocols

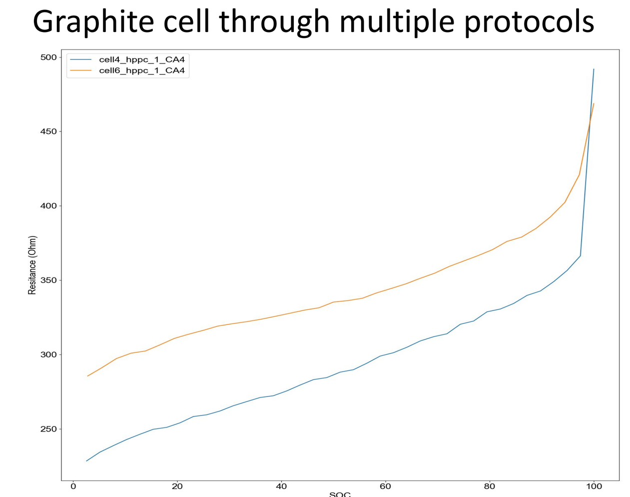

Figure 7. The progress of the same LFP cell through multiple HPPC protocols

Conclusions

- Certainly, it is clear that careful management is necessary while working with coin cells: the data can be reasonably compared only if exactly the same sequence of protocols was run on the cell and if researchers keep track of the time. Due to the usage of the more unstable lithium, the cells are more unstable and the data can variate greatly.
- Also our data indicates that graphite anode has a much greater overall capacity and less resistance. It can be interfered that in a full battery we expect to use less mass of graphite and more working electrode
- In the future, our team plans to implement electrochemical impedance spectroscopy to dive deeper in the processes of the coin cells. That way we would be able to point out specific processes that affect our batteries and possibly change the way we assemble them, in order to get more stable results.

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