

Pulse Charging Model to Rapidly Charge Lithium Ion Battery

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Lithium ion batteries using graphite/carbon as an intercalation electrode have a high voltage (0.2–0.4 V Vs. Li/Li⁺) and excellent capacity (~ 372 Ah/Kg of graphite mass) with high energy density (~ 150 Wh/Kg). Because of the high energy density of lithium ion batteries and the ease of minimizing battery size, they are ideal for portable equipments and hand held devices.

Conventional lithium ion battery charging is carried in a DC mode in two stages. The battery is charged first at a constant current until the cell voltage reaches the upper voltage limit of 4.2 volts. This is followed by a second, constant potential charging stage until the current drops to about 3% of its rated value. The charge time for stage 1 (constant current) is typically 1 hr, during which, about 88 % of the battery is charged. The 2nd stage (constant voltage) takes about 2 hrs, extending significantly the battery charging time [1].

Pulse charging of the lithium ion batteries [1-3] with short relaxation periods and short discharge pulses has been shown to enable faster charging. However, no adequate explanation was provided.

In this study, lithium diffusion into the graphite intercalant layer is modeled under both DC and current pulsing. During charging, lithium ions diffuse through the electrolyte and are reduced at the graphite/SEI interface. The lithium formed, diffuses into the graphite and intercalates (Fig. 1). However, if the current density is too high; the lithium formation at the interface exceeds the rate at which it can intercalate and metallic lithium will start accumulating at the interface, limiting the maximum rate at which the battery can be charged. Fig. 2 shows the time to saturate lithium as a function of the current density.

We present a model based on a macro-homogenous analysis of lithium diffusion into the intercalant for both DC and pulse charging. It is shown by proper selection of the current pulsing parameters; the current density range over which lithium does not saturate at the interface can be extended, thereby significantly enhancing the charging rate. Pulse sequences such as current pulsing with constant current density amplitude but with *increasing relaxation times* (Fig. 3), current pulsing with constant pulse widths but with *decreasing current density amplitudes* and *linearly decreasing current density amplitude* were modeled and shown to be effective. The total charging time is about 1 h in comparison to 3 h charging by conventional method (Fig. 4). The strategy is to apply large current densities at initial times and small current densities later.

References:

1. J. Li, E. Murphy, J. Winnick, and P. A. Kohl, J. Power Sources, 102, 302 (2001).
2. B. N. Popov, A. Durairajan, Y. Podrazhansky, and R. C. Cope, Annual Battery Conference on Applications and Advances, 15th, Long Beach, Calif., Jan. 11-14, p. 185, (2000).

3. Y. Podrazhansky, US Patent No. 5,504,415, (1996).

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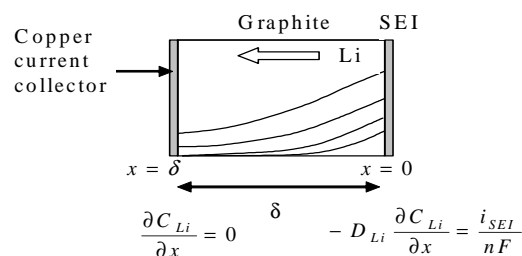


Fig. 1: Schematic representation of lithium diffusion from the SEI into the graphite.

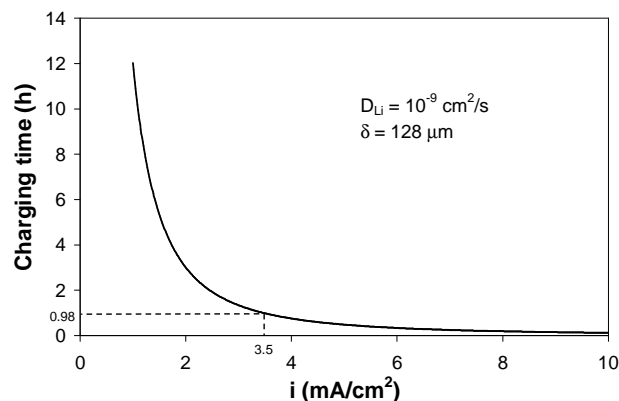


Fig. 2: Maximal constant current charging time before metallic lithium is formed at the graphite/SEI interface as a function of current density. A diffusion coefficient of $10^{-9} \text{ cm}^2/\text{s}$ and graphite layer thickness of $128 \text{ }\mu\text{m}$ are assumed.

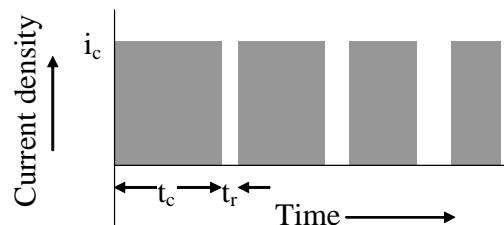


Fig. 3: Schematic of pulsed current interspersed with rest periods. The charging pulse width decreases and the rest pulse width increases with time.

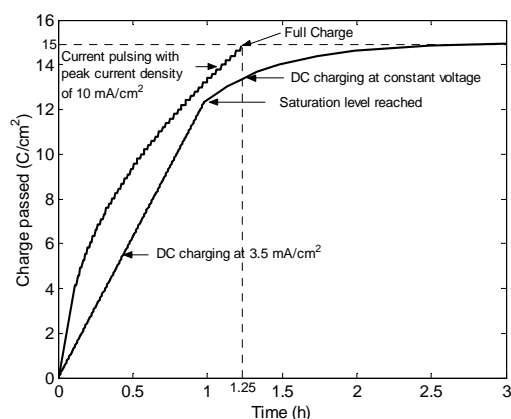


Fig. 4: Comparison of current pulse charging with varying charge and rest periods to DC charging. Saturation at the interface is reached after 1 h. The subsequent constant voltage charging (dotted line) is approximated based on experimental data. Current pulse charging is about 2.4 times faster than DC charging.