Impact of Electrode Surface/Volume Ratio on Li-ion Battery Performance

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Abstract

Introduction: Micro- and nano-structured electrodes are known to enable the improvement of Li+ battery performance by increasing the surface area of electrodes and enhancing the chemical reaction rate. But this improvement saturates at a certain level of electrode surface/volume ratio (ESVR). Performance of Li+ battery and heat dissipation strongly depend on the structure of the current collector, which is theoretically and numerically studied as the functions of ESVR.

Use of COMSOL Multiphysics® software: Numerical simulation of Li+ battery is carried out using COMSOL 2-D Lithium-Ion Battery interface and Joule Heating interface to investigate the discharge time and heat distribution. Copper and aluminum are used as negative and positive current collectors; Carbon and LiMn2O4 are used as electrode materials, and 1:2 EC:DMC (with LiPF6 salt) is used as the electrolyte. Properties of those materials are taken from COMSOL Material Library. The battery is initially fully charged and then a constant current is set for discharging.

Results: The simplest structure of battery consists of two electrodes extended from the opposite current collectors, with electrolyte filled between them. The simulation proceeds by keeping constant volumes of electrodes and electrolyte, while increasing the number of electrodes, so that the electrode surface area increases accordingly. In general, with the increase of ESVR, the discharge time becomes longer as shown in Figure 1. This discharge time increase is equivalent to an energy capacity increase, which is attributed to the improved penetration of Li+ into the electrode and thus more efficient use of the electrode volume in the chemical reaction. However, this energy capacity increase eventually saturates when the ESVR is large enough so that the electrode becomes thinner than the diffusion length of Li+.

If the number of electrode increases by a factor of n, both ESVR and electrode surface area will increase by the same factor, while for a fixed total discharge current, the power consumed by each current collector will be reduced by n times [1]. The increased surface area facilitates heat dissipation, and therefore the temperature of current collector is reduced accordingly. This is verified by using COMSOL Joule Heating interface. Figure 2 shows examples of simulated temperature distribution across negative current collectors in batteries with two and five negative electrodes, which indicate that the average temperature is reduced in the battery with larger

number of electrodes.

Conclusion: Results of COMSOL Multyphysics® simulation indicates that, with the increase of electrode surface/volume ratio in a Li+ battery, the battery energy capacity can be increased up to a certain level, and the heat dissipation can also be improved because of the increase of electrode surface area.

Reference

[1] P. Taheri ,A. Mansouri et al. "Electrical Constriction Resistance in Current Collectors of Large-Scale Lithium-Ion Batteries" Journal of The Electrochemical Society, Vol.160 (10), pp. A1731-A1740 (2013).

Figures used in the abstract

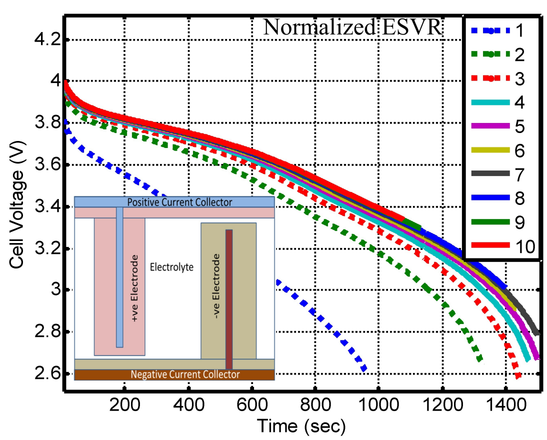

Figure 1: Discharge Graph for different normalized ESVRs.

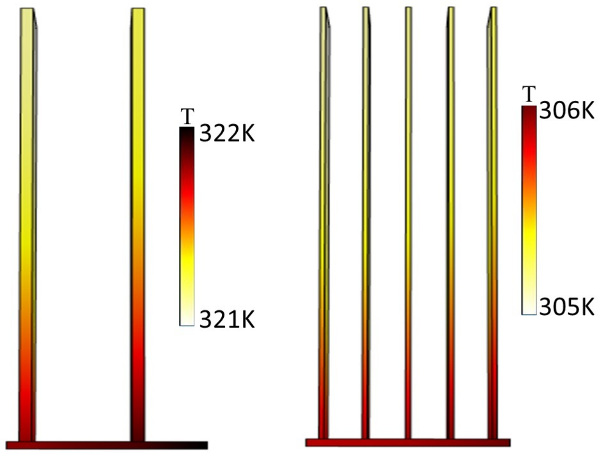

Figure 2: Temperature distribution of V- current collectors in batteries with two and five V-electrodes.