Advanced Electrolyte System Design of Battery Towards Expanded Applications on Energy Storage

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PhD Thesis Defense Presentation

November 16, 2020

10:00 - 12:00 p.m. EDT

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Abstract

The battery technology is approaching a larger share portion of the energy storage demands nowadays. These sustainable electrochemical-based methods are gradually replacing the traditional fossil resource to power the world with its carry-on capability and eco-friendly nature. Many applications such as, military power supplies, civil transportation, and stationary storage need higher energy density of the rechargeable battery as the development of society. For example, the goal of commercializing next-generation electric vehicles which can satisfy a longer traveling distance is hard to achieve since the lack of lower cost, higher energy density and longer cycling life rechargeable batteries as next-generation energy storage devices. Both lithium sulfur (Li-S) battery and lithium ion battery (LIB) with silicon anode have potential to be the of the next-generation storage batteries. Because sulfur and silicon are both stored largely on earth, exploited easily and low cost. Therefore, a variety of deep dive and large-scale research have been started about Li-S battery and Si anode applied in LIB. Over the last few years, Argonne National Laboratory team has developed various idea and methods to optimize Li-S battery and Si anode used in LIB, such as, introducing appropriate co-solvents and additives, replacing traditional electrolyte with ionic liquid and polymer electrolyte and enhancing Si anode by surface modification. For a comprehensive study, here we discuss four design schemes based on two major problems and one main barrier of Li-S battery and Si anode, respectively. In terms of Li-S battery, first problem is the rapid capacity fading during cycling process and second problem is the lithium polysulfide shuttling issue.

The main barrier of Si anode applied in LIB is the strength and stability of solid electrolyte interphase (SEI) layer formed on the surface of Si anode. The first part of this paper is to determine the relationship between various electrochemical properties of Li-S battery and a series of lithium salt concentrations. According to the experimental results, choosing an appropriate salt concentration by balancing different properties in an ideal way for each electrolyte is more reasonable than using a certain salt concentration as a standard for all electrolytes and this is also an effective way to constrain the rapid capacity fading during cycling process. In the second part, we report for the first time such an additive hexafluorobenzene (HFB) to tackle the issue of rapid capacity fading during cycling process. When used as an electrolyte additive for Li-S cell, HFB preferably chelates with low-order lithium sulfides Li_2S and Li_2S_2 and subsequently reacts and converts both into active aromatic sulfides: bis(pentafluorophenyl) disulfides and bis(pentafluorophenyl) polysulfides in-situ, thus facilitating the utilization of the electronically insulating Li_2S and Li_2S_2 and improving the cycling stability of Li-S cell. In the third part, the impact of the electrolyte solvation structure on the performance of Li-S battery was investigated using an electrolyte system containing various solvent ratios of DOL and a nonafluorinated ether: 1,1,2,2-tetrafluoroethyl-2,2,3,3,3-pentafluoropropyl ether (TPE).

The cell testing results indicate that increasing the ratio of TPE led to both a higher discharge capacity and a higher Coulombic efficiency, because lithium polysulfide shuttling issue is constrained when increasing the ratio of TPE in the electrolyte. In the fourth part, we introduce for the first time such a solvent 2,2,2-Trifluoroethyl methyl carbonate (FEMC) to optimize the Si anode. Based on the performance of LIBs, FEMC has potential to be an effective electrolyte co-solvent to protect Si anode due to the rich fluorine groups in its structure. When used as an co-solvent of all-fluorinated electrolyte, FEMC preferably passivates Si anode, helps the formation of a robust and resilient SEI layer and alleviate the continuous reactions between Si and electrolyte and the delamination of electrode caused by the large volume change of Si during charging and discharging process. Therefore, FEMC co-solvent improves the electrochemical properties of LIB applying Si as anode.