Journal of Energy Chemistry 27 (2018) 513–527

Contents lists available at ScienceDirect

Journal of Energy Chemistry

journal homepage: www.elsevier.com/locate/jechem

http://www.journals.elsevier.com/journal-of-energy-chemistry/

Review

Recent progresses in the suppression method based on the growth mechanism of lithium dendrite

Xiaolong Xu[a], Suijun Wang[b], Hao Wang[a,*], Chen Hu[b], Yi Jin[b], Jingbing Liu[a], Hui Yan[a]

[a] The College of Materials Science and Engineering, Beijing University of Technology, Beijing 100124, China
[b] State Key Laboratory of Operation and Control of Renewable Energy & Storage Systems, China Electric Power Research Institute, Beijing 100192, China

ARTICLE INFO

Article history:
Received 15 October 2017
Revised 14 November 2017
Accepted 15 November 2017
Available online 22 November 2017

Keywords:
Lithium dendrite
Growth mechanism
Suppression method
Lithium secondary battery

ABSTRACT

Lithium secondary batteries (LSBs) with high energy densities need to be further developed for future applications in portable electronic devices, electric vehicles, hybrid electric vehicles and smart grids. Lithium metal is the most promising electrode for next-generation rechargeable batteries. However, the formation of lithium dendrite on the anode surface leads to serious safety concerns and low coulombic efficiency. Recently, researchers have made great efforts and significant progresses to solve these problems. Here we review the growth mechanism and suppression method of lithium dendrite for LSBs' anode protection. We also establish the relationship between the growth mechanism and suppression method. The research direction for building better LSBs is given by comparing the advantages and disadvantages of these methods based on the growth mechanism.

Xiaolong Xu received his bachelor and master degree from the Qilu University of Technology in 2014 and 2016, respectively. Now he is a Ph.D. student in the Beijing University of Technology. He is major in advanced materials for electrochemical energy storage materials, mainly including metal organic frameworks, battery material and carbon material.

Suijun Wang received his master degree from the Beijing University of Technology in 2009. In 2010, he joined the China Electric Power Research Institute. His interests are in new materials of lithium ion battery. He has 10 years of experience in lithium ion battery materials research and development. He is the leader of over 5 State Grid Corporation of China's R&D projects. Till now, he is the author of around 10 publications and holding 3 patents.

Hao Wang is the professor in the College of Materials Science and Engineering, Beijing University of Technology, China. Prof. Wang received his Ph.D. in applied chemistry in 1997 from the Beijing Institute of Technology, China. Then he worked as a postdoctoral fellow in the Tokyo Institute of Technology, Japan. His current research interests are focused on advanced materials for electrochemical energy storage, and electrochromic materials and devices.

Chen Hu obtained her Ph.D. in 2007 in the Department of Chemical Engineering, Wuhan University of Technology. His research interests focus on electrochemistry and energy materials, including lithium-ion batteries, lead-carbon batteries, and nano-carbon materials.

---

* Corresponding author.
E-mail address: haowang@bjut.edu.cn (H. Wang).

https://doi.org/10.1016/j.jechem.2017.11.010

Yi Jin received his bachelor and Ph.D. degree from the University of Science and Technology of China (USTC) in 2003 and 2008, respectively. In 2008, he joined the LiTeng Energy Technology Company (LTET) as a co-founder and CTO in China. After leaving LTET at 2011, he joined the China Electric Power Research Institute. Now he is a senior engineer and director of the Energy Storage Battery Materials Research group. His interests are in energy materials, includes sodium-ion battery electrode materials, modified electrolyte and inorganic separator. Dr. Jin is in charge of over 3 "863" and "major research plan project", he is also the leader of over 10 State Grid Corporation of China's R&D projects. Till now, he is the author of around 30 publications in the field of advanced energy materials, 1 book chapters, and holding 5 patents.

Jingbing Liu is the associate professor in the College of Materials Science and Engineering, Beijing University of Technology. Prof. Liu received her Ph.D. degree in materials science from the Beijing University of Technology, and visited the Leeds University for 4 months in doctoral period. Her research activities are mainly focused on advanced functional materials synthesis and applications, including energy materials.

Hui Yan is the professor in the College of Materials Science and Engineering, Beijing University of Technology. Prof. Yan received his Ph.D. in the Department of Electronic Engineering in 1993 from Kanazawa University, Japan.

1. Introduction

In the early 1960s, the concept of lithium second battery (LSB) was initialized [1,2]. LSBs have been widely used in portable electronic devices (PEDs) in the past decades [3,4]. Recently, it is still the object of intense research with the aim at further improving electrochemical performance for the requirements of electric vehicles (EVs), hybrid electric vehicles (HEVs) and smart grids (SGs) [5–10]. However, these performance requirements with high energy and high power may accelerate the growth of lithium dendrite on the anode surface; it leads to safety concern and low coulombic efficiency [11–13]. Therefore, the investigation of lithium dendrite has become the focus on energy storage of LSBs [14,15].

In the early 1990s, rechargeable lithium ion battery (LIB) with graphite anode was announced to significantly overcome the dendrite problem because graphite anode involves intercalation/de-intercalation of lithium ion in graphite lattice during cycles [16]. Regrettably, the energy density of graphite anode is approximate 380 Wh kg^{-1} in LIB with a $LiCoO_2$ cathode [17], which could not meet the requirement for the development of next generation energy storage equipment [18,19]. Aimed at an energy density beyond the practical 500 Wh kg^{-1}, lithium sulfur battery and lithium air battery with lithium metal anode are intensively investigated [20–24]. In addition, lithium dendrite also forms on the surface of the recycled graphite anode [25,26]. Therefore, metallic lithium is becoming the most promising anode candidate again. Finding the effective way to suppress the growth of dendrite becomes more and more important for the better application of lithium metal anode [27–30].

Over the past 20 years, various attempts were made to solve the problems of safety concerns and low coulombic efficiency [31,32]. In 1997, Takehara [33] reviewed the suppression methods of lithium dendrite formations during the charging process. In 1999, Song et al. [34] reported the gel-type polymer electrolytes for LIBs. In addition, they pointed out that these electrolytes could suppress the growths of lithium dendrites. In 2012, Wen et al. [35] summarized the mechanisms of lithium dendrites in the review about LIBs safety issues. In 2014, Li et al. [36] reviewed the deposition criteria and models, and stated that the morphology control might be the key to suppress the initiation and propagation of lithium dendrites in LSBs.

Particularly in 2017, Guo et al. [37] reviewed the behavior of lithium ions upon deposition/dissolution and the failure mechanisms of lithium-metal anodes, as well as the protection method of lithium anode including, tailoring the anode structures, optimizing the electrolytes, building artificial anode electrolyte interfaces, and functionalizing the protective interlayers. Yang et al. [38] outlined the approaches to protect lithium metal anodes from liquid batteries to solid-state batteries and discussed to facilitate the practical application of lithium metal batteries. Zhang et al. [39] reviewed some typical micro/nanostructured lithium metal anodes and presented the suppression of lithium dendrite growth. It illustrated the principles and current situations of micro/nanostructured lithium metal anodes. Cheng et al. [40] presented an overview of the lithium metal anode and its dendritic lithium growth and endeavor to realize the practical applications of lithium metal batteries.

Although lithium dendrite growth received attention, it is quite difficult to completely eliminate dendrites. It is necessary to establish a link between the growth mechanism and the suppression method of dendrite for searching a better way to suppress its growth. Here we reviewed the growth mechanism and suppression method of lithium dendrite. The growth mechanism includes growth model and experimental research. Based on the growth mechanism, the suppression method is divided into two categories: interface modification and manufacturing three dimensions (3D) pore structure. In addition, the link between the growth mechanism and the suppression method is established.

2. Growth mechanism

Lithium dendrite is a kind of dendritic crystal, which forms in the condition of deviation from balance. As shown in Fig. 1, this was the typical dendritic morphology, which was reported by Tatsuma et al. [41]. Various researches prove that the current density and the working temperature have great influences on the growth of lithium dendrite [42–44]. In general, both the high current density and the low working temperature can increase the mass transport resistance on the lithium ion and reduce surface reaction resistance offered by a thinner solid electrolyte interphase (SEI) layer, therefore, which causes and accelerates the growth of lithium dendrite [45,46].

2.1. Model of dendrite growth

In the theoretical research, a series of models are proposed to describe the thermodynamics and dynamics behaviors of dendrite formation. Yamaki et al. [47] proposed the classical theoretical model in 1998, it was the deposition/dissolution model (Fig. 2). This model was described below: (a) Lithium metal was deposited under the SEI film. (b) Supplied with an external power, lithium ions in the electrolyte transported to lithium metal surface through the protective SEI film. The deposition sites on the protective film exhibited higher lithium ion conductivity, thus crystal defects and grain boundaries in the SEI initiated the continuous deposition of lithium. (c) The mechanical stress within the lithium anode induced an asymmetrical deposition of lithium, resulting in the formation of lithium dendrites.