



Strategies for the viability of rechargeable lithium-sulfur batteries

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ABSTRACT

Purpose: Lithium-sulfur (Li-S) batteries are considered as one of the most promising next-generation rechargeable batteries for electrical energy storage because of their high theoretical specific energy of $\sim 2500 \text{ Wh kg}^{-1}$, low production cost, and high abundance of sulfur. However, the high charge-storage capacity of sulfur cannot be effectively utilized due to the insulating nature of the active material and the easy migration of polysulfide intermediates from the cathode to the anode. In this research article, we describe a concise summary of two successful methods for solving the scientific problems and improving the Li-S cell performances.

Design/methodology/approach: Successful strategies in addressing the scientific and engineering issues of Li-S cells can be divided into two major categories: (i) sulfur-based nanocomposites that improve the Li-S cell performance based on the cathode active material and (ii) cell configuration modifications that enhance the Li-S cell performance by adopting the materials nature of sulfur.

Findings: Current technologies including nanocomposite development and cell configuration design have greatly ameliorated the overall electrochemical performance of Li-S batteries by improving the electrochemical utilization of sulfur and the retention rate of polysulfides.

Research limitations/implications: To overcome the challenges of Li-S batteries, a fair balance has to be taken between (i) sulfur loading/content and cell performances, (ii) amount of active material and porosity of the matrix, and (iii) added weight from the modified cell components and energy density of the custom Li-S cells.

Practical implications: The next step for the reality of commercial Li-S batteries might be (i) development of high-loading sulfur cathodes, (ii) anode configuration modification, and (iii) design of electrochemically stable electrolytes.

Originality/value: A concise introduction of the development of the sulfur core in Li-S cells is provided.

Keywords: Multifunctional materials; Nanomaterials; Lithium-sulfur batteries; Cell configuration; Rechargeable batteries

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MATERIALS

1. Introduction

High capacity, high energy-density power sources are urgently needed to meet the ever-growing demand for powering electronic devices and electric vehicles. Lithium-sulfur (Li-S) batteries are considered as one of the most promising next-generation rechargeable batteries for electrical energy storage because of their high theoretical specific energy of $\sim 2500 \text{ Wh kg}^{-1}$, high abundance of sulfur, and low production cost.

The attraction to the Li-S technology stems from the high-capacity sulfur. Sulfur cathode has a high theoretical charge-storage capacity of 1675 mA h g^{-1} , which is one order of magnitude higher than that of the conventional transition-metal oxide cathodes [1-5]. In addition, sulfur is one of the most abundant elements in the earth's crust, so sulfur is inexpensive ($\sim \$150$ per ton) as compared to the currently used transition-metal oxide cathodes, such as lithium cobalt oxide (LiCoO_2) ($\sim \$10,000$ per ton) [5-8]. The electrochemical advantages and engineering merits of sulfur cathode have attracted lot of interest in making the Li-S batteries a reality.

However, the high charge-storage capacity of sulfur is attributed to the reversible redox conversion reaction between active sulfur and its end discharge product Li_2S . This two-electron electrochemical conversion reaction involves a dynamic, complex $\text{solid}_{(\text{sulfur})}$ - $\text{liquid}_{(\text{polysulfides})}$ - $\text{solid}_{(\text{sulfide})}$ phase transition [2,3,9]. Hence, the Li-S cells employing a conventional sulfur cathode configuration that contains pure sulfur, carbon black, and binder fail to exhibit the key benefits of Li-S cells.

2. Scientific and engineering challenges

The electrochemical instability and irreversibility of Li-S cells result from many inherent properties of sulfur: (i) insulating nature of sulfur core, (ii) severe diffusion issues of polysulfide intermediates, and (iii) the redeposition of insoluble $\text{Li}_2\text{S}_2/\text{Li}_2\text{S}$ on the electrodes during electrochemical cycling. The resulting low electrochemical utilization of sulfur and rapid loss of the active material hamper the commercialization efforts of Li-S battery technology [10-13].

First, the insulating nature of sulfur (conductivity = $\sim 10^{-30} \text{ S cm}^{-2}$) and its end discharge product Li_2S (conductivity = $\sim 10^{-14} \text{ S cm}^{-2}$) limits the efficient utilization of the active material. The poor electrochemical utilization of sulfur leads to low discharge capacity with Li-S cells

that employ the conventional sulfur cathode configuration [2,4].

Second, during electrochemical cycling, sulfur converts to polysulfide intermediates (Li_2S_x , with $x = 4-8$) that are highly soluble in the organic electrolyte currently used in Li-S cells [2,4]. These dissolved polysulfides are prone to diffuse out from the conventional sulfur cathode and then freely migrate from the cathode side to the anode side of the cell through the separator. The irreversible polysulfide migration is derived from the difference in the chemical potential and concentration between the two electrodes, which causes both the cathode and anode degrade. In the cathode side, the active-material loss and the insoluble $\text{Li}_2\text{S}_2/\text{Li}_2\text{S}$ deposits block electron and ion transfer. This exacerbates fast capacity fade and causes short cycle life. In the anode side, the migrated polysulfides react with Li-metal anode and the anode deterioration starts the shuttle effect. The polysulfide shuttle is the origin of the low Coulombic efficiency of Li-S batteries [11,12].

During the continuous discharge and charge processes, a huge volume change of 80% between sulfur (density = 2.07 g/cm^3) and lithium sulfide (density = 1.66 g/cm^3) along with the solid-liquid state phase transition leads to cathode structure degradation [2-4].

The abovementioned three scientific challenges lead to poor electrochemical utilization, low charge-discharge efficiency, and short operation life of Li-S cells. In order to address these scientific and engineering issues, many chemical/physical methods have been innovated to improve the electrochemical performance of Li-S batteries, especially the discharge capacity (the electrochemical utilization of sulfur) and cycle stability (the retention rate of polysulfides). Successful strategies can be divided into two major categories: (i) sulfur-based nanocomposites that improve the Li-S cell performance from the cathode active material [3-5,7,13-25] and (ii) cell configuration modifications that enhance the Li-S cell technology by adopting the materials nature of sulfur [3-5,10,26-38]. In this research article, we describe a concise summary of these two approaches.

3. Sulfur-based nanocomposites

Figure 1 depicts the various sulfur-based nano-composites that have been designed to enhance the electrochemical properties of Li-S cells, such as (i) sulfur-carbon nanocomposites [3-5,7,13-25,39-47], (ii) sulfur-polymer nanocomposites [3-5,42,48-61] and (iii) sulfur-metal oxide nanocomposites [3-5,62-69].

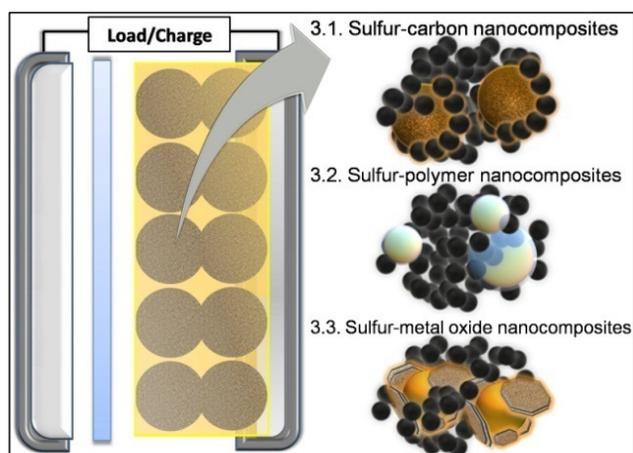


Fig. 1. Schematic configuration of a sulfur cathode with various sulfur-based nanocomposites

3.1. Sulfur-carbon nanocomposites

The development of sulfur-carbon nanocomposites mainly depends on the design of the carbon matrix and the nanocomposite synthesis process. Various porous carbon materials have been fabricated to serve as the conductive matrix for enhancing the cathode conductivity and as active-material containers for restricting the polysulfide dissolution/migration [2-5,13,18].

The most important achievement in the sulfur-carbon nanocomposite design was reported first by Nazar group in 2009 [14]. For the first time, Li-S cells employing 84% sulfur-mesoporous carbon nanocomposites in the composite cathode exhibited a high discharge capacity of 1320 mA h g^{-1} and stable cyclability and electrochemical reversibility. The corresponding electrochemical utilization of sulfur was as high as 79%. The key factor in this study is to impregnate sulfur into a highly ordered mesoporous CMK-3 carbon host at 155°C . The CMK-3 matrix possesses a conductive framework and nanoporous spaces so that the impregnated sulfur easily reaches the electrical pathways and ionic channels. This facilitates fast electron transfer and redox reaction. The encapsulation of sulfur within a porous carbon host further reduces the polysulfide migration. This study became a key index in developing high-performance sulfur cathodes. A close interaction among the active material, electrolyte, and conductive matrix results in high sulfur utilization and stable cyclability [3,14,42].

The application of porous carbon substrates as the active-material container and polysulfide trap has attracted a lot of research groups in the modification of various

porous carbon matrices, such as mesoporous carbon [20,42,70], microporous carbon [19,40,42] hierarchically porous carbon [23,24,39-42,71], and hollow carbon sphere [3-5,18,47].

A systematic investigation of the effect of the tunable pore sizes in the mesoporous carbon indicates that the mesoporous carbon with a large pore volume of $4.8 \text{ cm}^3 \text{ g}^{-1}$ and with a mesopore size of 22 nm can reduce polysulfide dissolution and diffusion via partial sulfur filling and surface functionalization [20,42]. On the other hand, the pore size and volume seem to have minor influence toward the battery chemistry under a full sulfur filling situation [20]. In addition to the utilization of mesoporous carbon, the utilization of microporous carbon in sulfur-porous carbon nanocomposites also shows promising cyclability because the narrow micropores ($<2 \text{ nm}$) can effectively trap and isolate the active material within the microporous carbon host [19,41,42].

The progress on the porous carbon engineering and template design promotes the development of hierarchical porous carbon. The synthesized hierarchical porous carbon combines the advantages of mesoporous carbon and microporous carbon and, therefore, has adjustable nanopore sizes for optimizing the cell performance of sulfur-carbon nanocomposites [23-25,41-43,71]. Specifically, the micropores aim at accommodating the active material and confining the polysulfide intermediates. The macropore and mesopore channels can facilitate the charge transport and ensure proper electrolyte penetration. Thus, the use of hierarchical porous carbon in the sulfur-carbon nanocomposite maximizes the sulfur utilization and also suppress the severe capacity fade, resulting in the excellent cycling performance [3-5,41-43].

For instance, by the way of infiltrating sulfur into the inner meso- and macro- hybrid porous structure while the outer micropores remained empty, the composite cathode utilizing hierarchical porous carbon delivers a high discharge capacity of 1412 mA h g^{-1} , translating to a 84% electrochemical utilization rate, with an outstanding capacity retention rate of 77% after 500 cycles [71]. On the other hand, the hollow carbon sphere possesses an interior void space for storing the active sulfur, which differs from the hierarchical porous carbon that consists of various nanoporous spaces and channels. The hollow carbon sphere restricts the active material within the core and has a porous shell for the continuous supply of lithium ions and electrolyte [3-5,18,42]. Jayaprakash et al. pioneered the study of utilizing porous hollow carbon in sulfur-carbon nanocomposites for Li-S batteries. The resulting Li-S cells employing porous hollow carbon@sulfur composites exhibit a high capacity retention of 91% after 100 cycles [47].

3.2. Sulfur-polymer nanocomposites

In addition to carbon, various polymer networks have also been used in synthesizing the sulfur-polymer nanocomposite, such as polyacrylonitrile (PAN) [48-51] polyaniline (PANi) [57-60], polypyrrole (PPy) [52-56] polythiophene (PTh) [61], and poly(3,4-(ethylene-dioxy)thiophene) (PEDOT) [72]. The advantages of using polymers is associated with their functional groups that have strong interaction with the polysulfide species, resulting in promising cycling performance of Li-S batteries.

In 2002, the first sulfur-polymer nanocomposite, sulfurized polyacrylonitrile (SPAN), was reported by Wang et al. who heated S/PAN mixtures at 300°C for 6 h [48]. In this process, -CN functional groups formed heterocycles, rendering the backbone to form a conjugated π -system like the conductive polymer, polyacetylene [48,49]. Therefore, the active sulfur could be intercalated and confined within the polymer main chain. The resulting molecular-level SPAN nanocomposites exhibited a high reversible capacity of 600 mA h g⁻¹ after 50 cycles with a gel electrolyte [48].

Afterward, a lot of follow-up studies focused into the investigation of various sulfur-polymer nanocomposites. Among these polymers, the intrinsically conductive polymers (ICPs), such as PANi, PPy, and PEDOT, are widely used in sulfur-polymer nanocomposites [48,49,53,55-62,72]. The advantages of using ICPs are their facile processing ability, mixed ionic/electronic conductivity, and strong affinity toward polysulfides. As a result, ICPs promote the overall cell performance and simplify the complex nanocomposite synthesis processes.

A novel conductive S-PPy composite material prepared by the chemical polymerization method was first presented by Wang et al. in 2006 [52]. The initial discharge capacity and cyclability of S-PPy nanocomposites were greatly improved. The main reasons for the improved electrochemical properties are the use of conductive PPy coating on the sulfur particles. The PPy coating functions as a conductive binder, ensuring the close connection among particles and enhancing the cathode conductivity. Also, the PPy coating could function as an absorption layer for reducing the dissolution of polysulfides into the electrolyte [42,52]. In addition to PPy, PANi is another popular ICP host in sulfur-polymer nanocomposites. Self-assembled PANi nanotubes were utilized to encapsulate the active sulfur as a soft approach for battery chemistry improvements [60]. The resultant materials form a 3D, cross-linked, structurally stable S-PANi nanocomposite, in which the main chains of PANi are interconnected with inter- and/or intra-chain disulfide bonds, resulting in a confinement of polysulfides. The structural design of

nanocomposites provides the Li-S batteries with enhanced cycle stability and rate capability. The reversible discharge capacity retained 432 mA h g⁻¹ after 500 cycles. Further progress is a S-PANi nanocomposite with a yolk-shell structure [57]. The internal void space that was produced from the partial vulcanization with PANi to form a cross-linked structure can accommodate the active material and the volumetric expansion of sulfur during the continuous discharge and charge processes. The outer layer of conducting polymer improves the ionic/electronic conductivity, ensuring an excellent active material utilization. The yolk-shell structure also functions as a polysulfide container for avoiding the irreversible loss of the active material. Therefore, the yolk-shell structure of S-PANi nanocomposites effectively preserves the structural integrity and greatly improves the cycling performance.

3.3. Sulfur-metal oxide nanocomposites

Recently, metal oxides have been employed as absorbents, coatings, and catalyzers to retard the migration of polysulfides and retain them within the sulfur-metal oxide nanocomposites. The investigated metal oxides include Mg_{0.6}Ni_{0.4}O [63], La₂O₃ [73], TiO₂ [66,74,75], MnO₂ [67], Al₂O₃ [76,77], and SiO₂ [64].

The application of nanosized Mg_{0.6}Ni_{0.4}O particles in sulfur cathodes has evidenced that both the discharge capacity and cycling stability can be improved [63]. The added Mg_{0.6}Ni_{0.4}O nanoparticles increase the porosity of the resulting sulfur cathodes for absorbing polysulfides. In addition, Mg_{0.6}Ni_{0.4}O has catalytic effect for promoting the redox reaction during cell cycling [5,63]. Nazar group also reported sulfur-manganese dioxide nanosheets (S/MnO₂) as sulfur-metal oxide nanocomposites that exhibit extremely long cyclability over 2000 cycles with very low fading rate of 0.036% per cycle [67]. This excellent cyclability is attributed to the unique mechanism. An active polythionate complex serves as an anchor and a transfer mediator to, respectively, curtail the dissolution of polysulfides and control the deposition of Li₂S₂/Li₂S [67]. However, the sulfur loading is only 0.75-0.9 mg cm⁻², which should provide certain contribution to the amazing cycle stability. Similar issue could be found in the sulfur-metal oxide nanocomposite with a yolk-shell structure following the idea of the hollow carbon@sulfur composites and the yolk-shell structure S-PANi nanocomposites [47,57]. The sulfur-TiO₂ yolk-shell nanocomposites exhibit desirable cyclability (>1000 cycles) [66]. However, the sulfur loading is as low as 0.4-0.6 mg cm⁻², failing to meet the standard for practical applications.

3.4. Summary

Overall, various sulfur-based nanocomposites have been obtained with different routes to increase the electrochemical utilization of sulfur and to stabilize the polysulfide within the framework of the nanocomposites. Further challenges for the progress of sulfur-based nanocomposites are possible to take a fair balance between (i) the sulfur loading/content and the cell performance and (ii) the amount of active material and the porosity of the porous matrix.

4. Cell Configurations

In consideration of the unique battery chemistry of the Li-S cells, the conventional cathode configuration has evidenced that it might not make the best use of sulfur [2-5,42]. Therefore, the custom cathode configuration aims at utilizing the materials chemistry of sulfur rather than restrict it in the nanocomposite, which enlightens a new research direction, as shown in Fig. 2. A concerted effort has focused into stabilizing the active material in a porous current collector [4,5,10,26,36-38,40] and a sandwiched cathode [4,5,26-28,32,33,35-37] as well as holding the active-material diffusion within the cathode region by various polysulfide-trapping means, such as an interlayer [3-5,26,37] and a functional separator [3-6,29-31,34].

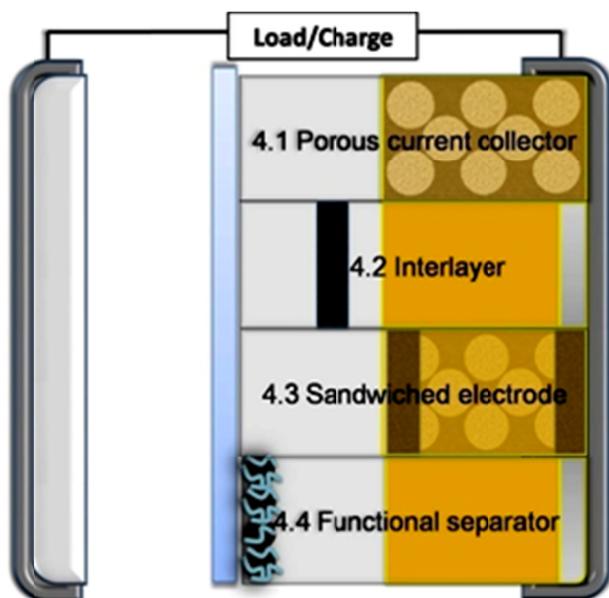


Fig. 2. Schematic configuration of a Li-S cell employing various cell configurations

4.1. Porous current collectors

The commonly used current collector in Li-ion battery is an aluminum (Al) foil. Although this two-dimensional (2D) non-porous substrate is inexpensive and electrochemically stable, its morphology cannot hold the active material with the sulfur cathode. As a result, a new concept is to hold the active material within the cathode region by employing a 3D porous current collector as a porous cathode configuration. The possible porous current collectors could be metallic foams [78,79], porous carbon substrates [26,36-38,79-82], and anodic aluminum oxide (AAO) templates [40].

Specifically, the porous current collector functions as the active-material container to store the active material and retain polysulfides within its conductive framework [78,79]. Therefore, the intimate contact between the active material and the conductive framework decrease significantly the internal resistance [41,45,77-79]. The application of a porous nickel (Ni) foam current collector exhibits a reversible discharge capacity of 810 mA h g^{-1} after 50 cycles and retains 85% of the initial capacity after two-month storage, which exhibits both dynamical and static electrochemical stability [79]. The outstanding cyclability and low self-discharge are attributed to the embedment of the active material into the conductive skeleton of Ni foam and the stabilization of the dissolved polysulfides within the porous cathode region [78,79].

In order to decrease the weight of the porous current collector, our research group subsequently employed porous carbon current collectors in Li-S cells [36,80-83]. The use of porous carbon current collector allows a high-loading sulfur cathode (sulfur loading: 2.3 mg cm^{-2}) to achieve high discharge capacity and better cyclability [81]. Additionally, by using hierarchically porous carbon as the current collector, the micro-meso-macro-porous architectures provide the resulting Li-S cell with a high discharge capacity of 1314 mA h g^{-1} with a good capacity retention rate of 84% after 50 cycles [80]. The improvement in performance can be attributed to the better contact between the active material and the conductive framework as well as the superior polysulfide absorption capability of the porous current collector [5,36,78].

The progress in the porous current collector is now entering the integration with polysulfide catholytes and the development of high-loading sulfur cathode [4,5,33,81]. These two progresses mainly depend on using an ideal porous substrate to hold a high amount of catholyte or active-material fillings. Therefore, a well-designed porous current collector could be their suitable cornerstone.

4.2. Bifunctional interlayers

The polymeric separator with a high porosity is utilized in Li-ion battery to avoid the internal short circuit and to allow fast lithium-ion transport. Nonetheless, in the case of Li-S cell, this porous membrane cannot stop the severe polysulfide migration from the cathode side to the anode side of the cell. Thus, the severe polysulfide migration would result in an irreversible loss of active material and the polysulfide shuttle during electrochemical cycling [28,32,33,35,82-87].

Our research group proposed a new concept that a bifunctional interlayer inserted between the polymeric separator and sulfur cathode could limit the free penetration of polysulfide species [35]. In addition, the bifunctional interlayer provides extra electron pathways. This upper current collector significantly diminishes the internal resistance of the sulfur cathode and improves sulfur utilization. During electrochemical cycling, the bifunctional interlayer aims at first trapping the migrating polysulfides and then transferring electrons and electrolyte to continuously utilize the trapped active material. As a result, the active material is well stabilized within the cathode region of the cell and could be continuously utilized during cell cycling [3,4,35,36]. Therefore, the pure sulfur cathode assembled in the Li-S cells using the bifunctional separator shows superior active material utilization, cyclability, and rate performance.

This novel cathode design has promoted the development of various interlayer configuration with different materials, such as (i) porous carbon substrates [32,87-89], (ii) carbon nanofiber/carbon nanotube framework [26,27,36,83,86], (iii) conducting polymers [6,90,91], (iv) carbon/metal oxide hybrid materials [92], (v) porous metal foam [85], and (vi) carbonized free-standing substrates [28,82,84].

Recently, Balach et al. developed a mesoporous carbon interlayer and investigated its electrochemical performance by tuning the pore volume and surface area [89]. The research findings indicate that the pore volume of the mesoporous carbon exerts a significant influence on the electrochemical properties of the interlayer-type sulfur cathode. The cell employing the mesoporous carbon interlayer with a large pore volume of $3.23 \text{ cm}^3 \text{ g}^{-1}$ and a high surface area of $900 \text{ m}^2 \text{ g}^{-1}$ shows initial discharge capacities of 1364, 1060, and 966 mA h g^{-1} and retains high reversible capacities of 1015, 746, and 650 mA h g^{-1} after 200 cycles at, respectively, 0.2, 0.5 and 0.1°C rates. This indicates that the strong tortuosity and conductive network

of the bifunctional interlayers is able to, respectively, suppress the severe polysulfide migration and enhance the capacity retention.

The improved electrochemical stability and reversibility of the interlayer-type Li-S cells lead to good cycling performance of Li-S batteries. In spite of the great progress with the interlayer, the bifunctional interlayer inserted in cell eventually is an additional cell component. Thus, the weight of the interlayer should be kept as low as possible while preserving a high polysulfide-trapping capability.

4.3. Sandwiched cathodes

The development and application of porous current collectors (2011-2013) [4,5,10,26,36-38,40,78-83] and interlayers (2012-2014) [3-5,26,37,83-91] have inspired the development of a sandwiched cathode configuration since 2013. Our group, therefore, designed the sandwiched cathode that integrates the functions of a bifunctional interlayer and a porous current collector into one sulfur cathode [82,83].

The basic configuration of a sandwiched cathode could have a self-weaving MWCNT paper as the porous current collector that can work as a polysulfide locker. Another layer of MWCNT paper, on the other hand, is the interlayer that functions as a barrier to intercept the migrating polysulfides [83]. The active material Li_2S is localized in between the two self-weaving MWCNT papers. With the sophisticated configuration, the Li-S battery displays promising sulfur utilization and superior cyclability. Carbonized natural materials employed as sandwiched cell configurations have also received much attention. The free-standing carbonized eggshell membranes were used as the polysulfide reservoir with dissolved polysulfides as the active material [82]. In other words, the carbonized eggshell membranes stabilize polysulfides within two sandwiched electrodes. Consequently, the Li-S cell even with high loadings (sulfur loading = $3+\text{mg cm}^{-2}$) accomplishes excellent electrochemical performance by using the sandwiched cell structure.

Again, a successful cell configuration could lead to a series of new studies. Various sandwiched cathodes with various active material, such as Li_2S , pure sulfur, and polysulfide catholyte, have been applied in Li-S cells and have shown promising electrochemical performances [26,82,83,93-96].

4.4. Functional separators

Very recently, our group has pioneered the investigation of carbon-coated separators, which exponentially improve the performance of Li-S batteries [6,29-31,34]. The prototypical functional separator has the a layer of the commonly used carbon Super P firmly attached onto one side of a commercial separator while the other side remained clean and insulating [30]. The resulting carbon-coated separator (C - coated separator) has its carbon-coated side facing the pure sulfur cathode for suppressing the severe polysulfide diffusion. Therefore, the active material could be stabilized within the cathode region. Moreover, the C - coated separator that adopts the mechanical strength of the commercial separator is mechanically flexible and robust. Most importantly, the ultralight-weight characteristics eliminates the weight concern encountered by other novel or modified cell components, which makes us one step closer to the reality of Li-S batteries.

The Li-S cells employing the C-coated separator and pure sulfur cathodes are able to approach a high initial discharge capacity of 1389 mA h g^{-1} and a reversible capacity of 828 mA h g^{-1} after 200 cycles [30]. Additionally, the C-coated separators also inhibit the self-discharge behaviors of Li-S batteries. The outstanding performance results from the C-coated separator that acts as (i) a barrier to intercept and trap the migrating polysulfides and (ii) an upper current collector to reutilize the trapped active materials. Thus the C - coated separator improves the dynamic and static stability of Li-S batteries that uses a pure sulfur cathode [4,5,30].

The C coating attached onto the flexible separator could also suppress the severe polysulfide migration. Thus, the application of the C - coated separator also allows the use of pure sulfur cathode in Li-S cells [5,6,29-32,34, 89,94]. The successes of the C - coated separators open the door for functional separators. Different custom functional separators have been investigated extensively by utilizing different coating materials, including (i) porous carbon [29] (ii) graphene (oxide), [98,100] (iii) MWCNT, [34] (iv) polymer, [99] and (vi) carbon/polymer mixtures [6,29,97] The development of functional separator paves the way for developing high-performance Li-S batteries at an affordable cost.

4.5. Summary

Overall, various cathode configuration modifications and designs have evidenced their capability to utilize the

materials nature of sulfur for improving the electrochemical performance of Li-S cells. The custom cathode configuration allows polysulfides to migrate within the cathode region of the cell, stabilizing the active material at the most electrochemically favorable sites in the cathode region of the cell and thereby facilitating the electrochemical redox reaction.

5. Conclusions

The inexpensive Li-S batteries with a high specific capacity and energy density have triggered the revolution in rechargeable batteries. However, persistent drawbacks are slowing down their commercialization. Current technologies including nanocomposite development and cell configuration design have greatly ameliorated the overall electrochemical performance of Li-S batteries. The next step for the reality of commercial Li-S batteries is (i) the development of high-loading sulfur cathode, (ii) the anode configuration modification, and (iii) the design of electrochemically stable electrolytes. In order to realize these goals, a good wedding of academic research and industrial research is needed.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME'2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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