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SOLVATE IONIC LIQUID ELECTROLYTE (SILE) WITH ADJUSTABLE STRUCTURE AND PREPARATION METHOD THEREOF, AND LITHIUM-SULFUR BATTERY.

(57)

The disclosure relates to a solvate ionic liquid electrolyte (SILE) with an adjustable structure and a preparation method thereof, a positive electrode of a lithium-sulfur battery, and a lithium-sulfur battery. The SILE is prepared from a solvent and the following raw materials in parts by weight: 10 to 35 parts of a compounding agent and 30 to 65 parts of a lithium salt, where the compounding agent is at least one selected from the group consisting of polyethylene glycol dimethyl ether, crown ether, and methoxy polyethylene glycol (MPEG); and the lithium salt is at least one selected from the group consisting of LiTFSI, LiTF, and LiBr. the SILE is designed using the unique structure of an ionic liquid and the special coordination competition of the ionic liquid with a high Gutmann-donor-number (DN) solvent; and an electrochemical deposition process of Li₂S promotes the formation of three-dimensional (3D) Li₂S.

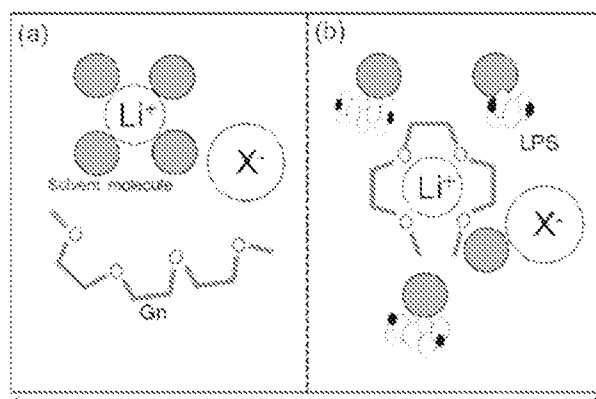


FIG. 1

**SOLVATE IONIC LIQUID ELECTROLYTE (SILE) WITH ADJUSTABLE
STRUCTURE AND PREPARATION METHOD THEREOF, AND LITHIUM-SULFUR
BATTERY**

TECHNICAL FIELD

The present disclosure relates to a solvate ionic liquid electrolyte (SILE) with an adjustable structure and a preparation method thereof, a positive electrode of a lithium-sulfur battery, and a lithium-sulfur battery, and belongs to the technical field of lithium-sulfur batteries.

BACKGROUND

Energy plays an irreplaceable role in the human society, and with the increasingly-prominent energy and environmental problems caused by the excessive consumption of fossil energy, the development of new renewable energy is of great significance. The energy storage technology plays an important bridging role in the adjustment of energy structure. With many advantages such as easy scale-up, convenient operation and maintenance, and low long-term operation cost, the flow battery energy storage technology is an ideal energy storage system matching with renewable energy power generation, and is a key technology to promote the transformation of main energy from fossil energy to renewable energy. However, the existing flow batteries have a low specific energy. In order to apply renewable energy such as wind energy and solar energy on a large scale, it is urgent to develop new flow batteries with high specific energy.

As a new type of flow batteries, lithium-sulfur flow batteries show outstanding advantages in terms of gravimetric and volumetric energy. Lithium-sulfur flow batteries also show prominent advantages in energy density, cost, and environmental protection, and will have promising application prospects in the field of large-scale energy storage. Lithium-sulfur flow batteries use liquid or semi-solid sulfur electrodes, which alleviates some of the problems of solid sulfur electrodes (such as electrode deformation) to some extent, is easy to scale, and is a new way to develop lithium-sulfur battery systems. However, slurry electrodes with high sulfur loads generally suffer from low sulfur utilization, resulting in a significant decrease in the energy density of lithium-sulfur flow batteries. The uncontrollable deposition of lithium sulfide during a cycling process leads to the formation of a passivation layer, which is the main reason for low sulfur utilization in a sulfur slurry electrode. The electrochemical reaction process of sulfur and the electrochemical performance of the discharge product Li_2S are quite different in different electrolytes. However, the high Gutmann donor number (DN), polarity, and viscosity of an

electrolyte solvent and the concentration of lithium phosphorus sulfide (LPS) in an electrolyte have a great influence on a deposition process and a structure of Li_2S . How to develop an electrolyte that can regulate a deposition process of Li_2S to improve a utilization rate of sulfur and a specific energy of a sulfur slurry electrode is an urgent problem to be solved in the research and development of lithium-sulfur flow batteries. LU501874

SUMMARY

The present disclosure provides an SILE with an adjustable structure and a preparation method thereof, a positive electrode of a lithium-sulfur battery, and a lithium-sulfur battery, such as to improve the specific energy of the lithium-sulfur battery.

In order to solve the above technical problem, the present disclosure adopts the following technical solutions:

An SILE with an adjustable structure is provided, which is prepared from a solvent and the following raw materials in parts by weight: 10 to 35 parts of a compounding agent and 30 to 65 parts of a lithium salt,

where the compounding agent is at least one selected from the group consisting of polyethylene glycol dimethyl ether, crown ether, and methoxy polyethylene glycol (MPEG); and

the lithium salt is at least one selected from the group consisting of LiTFSI, LiTF, and LiBr.

A molar ratio of the compounding agent to lithium ions in the lithium salt may be preferably (0.3-1.5):1 and more preferably 1:1.

The solvent may be at least one selected from the group consisting of *N,N*-dimethylformamide (DMF), dimethylsulfoxide (DMSO), and *N,N*-dimethylacetamide (DMA).

An amount-of-substance concentration of the lithium salt in the electrolyte may be 0.4 mol/L to 1.6 mol/L.

The polyethylene glycol dimethyl ether may be at least one selected from the group consisting of diethylene glycol dimethyl ether, triethylene glycol dimethyl ether, and tetraethylene glycol dimethyl ether. Preferably, the polyethylene glycol dimethyl ether may be composed of triethylene glycol dimethyl ether and tetraethylene glycol dimethyl ether in a molar ratio of 1:1.

A preparation method of the SILE with an adjustable structure is provided, including the following steps:

1) mixing the compounding agent and the lithium salt thoroughly to obtain an SIL with a structure of $[\text{Li}(\text{Gn})][\text{X}]$; and

2) adding the solvent to the SIL obtained in step 1), and thoroughly mixing to obtain the SILE with an adjustable structure.

In step 1), the compounding agent and the lithium salt may be thoroughly mixed by stirring at

35°C to 45°C for 5 min to 10 min.

In step 2), after the solvent is added, stirring may be conducted at 0°C to 15°C for 10 min to 15 min.

A positive electrode of a lithium-sulfur battery is provided, which is made of an ionic liquid electrolyte and a sulfur-carbon composite in a mass ratio of 100:(10-80), where the ionic liquid electrolyte is the SILE with an adjustable structure described above.

Preferably, a preparation method of the sulfur-carbon composite may include the following steps:

i) mixing Ketjenblack, polyvinylpyrrolidone (PVP), graphene oxide (GO), a sulfur source, hydrochloric acid, and a reducing agent to allow a reaction for 3 h to 15 h to obtain a precursor, where the Ketjenblack, the PVP, the GO, and the sulfur source are in a mass ratio of (0.5-3):(0.1-2):(1-5):(80-94);

the sulfur source is any one selected from the group consisting of sulfur and sodium thiosulfate; and

the reducing agent is any one selected from the group consisting of hydrazine hydrate, sodium citrate, and sodium borohydride; and

ii) keeping the precursor obtained in step i) in an inert atmosphere at 150°C to 160°C for 8 h to 10 h to obtain the sulfur-carbon composite.

In step i), the Ketjenblack, the PVP, the GO, the sulfur source, the hydrochloric acid, and the reducing agent may be thoroughly mixed as follows: the Ketjenblack and the PVP are thoroughly mixed in water to obtain a premixed solution; then the premixed solution is mixed with the sulfur source, the GO, and the concentrated hydrochloric acid, and a reaction is conducted at 70°C to 80°C for 2 h to 3 h to obtain a pre-reduced mixed solution; the pre-reduced mixed solution is thoroughly mixed with the reducing agent, a reaction is conducted at a pH of 10 to 11 for 1 h to 4 h, then a pH is adjusted to 2 to 3, and a reaction is further conducted for 1 h to 4 h; and a resulting mixture is subjected to solid-liquid separation (SLS), and a resulting solid is dried to obtain the precursor.

Thoroughly mixing the Ketjenblack and the PVP in water may refer to thoroughly mixing the Ketjenblack with a PVP aqueous solution with a concentration of 1 g/L.

Mixing the premixed solution with sodium thiosulfate, GO, and concentrated hydrochloric acid may refer to: adding sodium thiosulfate to the premixed solution, adding GO, heating to 70°C to 80°C, adding concentrated hydrochloric acid, and allowing a reaction for 2 h to 3 h.

5 mL of the reducing agent may be used per 100 mL of the PVP aqueous solution.

After the pre-reduced mixed solution and the reducing agent are thoroughly mixed, a pH may be adjusted to 10 to 11 with ammonia water. After the reaction is conducted at a pH of 10 to 11 for 1 h to 4 h, the pH may be adjusted to 2 to 3 with hydrochloric acid.

Preferably, the reaction may be further conducted for 1 h to 3 h.

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A lithium-sulfur battery is provided, including a positive electrode and a negative electrode, where the positive electrode is the positive electrode of a lithium-sulfur battery described above.

Beneficial effects:

In the present disclosure, the SILE with an adjustable structure is designed using the unique structure of an SIL and the special coordination competition of the SIL with a high DN solvent; and an electrochemical deposition process of Li_2S is regulated to promote the formation of three-dimensional (3D) Li_2S , inhibit electrode passivation, and improve a utilization rate of sulfur in a slurry electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a formation mechanism of the SILE with an adjustable structure according to the present disclosure (“(a)” shows an SILE structure, and “(b)” is a schematic diagram of a structural change of SILE during an electrochemical reaction process of sulfur);

FIG. 2 shows differential scanning calorimetry (DSG) curves of the SILEs with an adjustable structure in Example 5 and Example 6 of the present disclosure;

FIG. 3 shows charge-discharge curves of the lithium-sulfur batteries in Example 5 and Example 6 of the present disclosure; and

FIG. 4 shows cycling curves of the lithium-sulfur batteries in Example 5 and Example 6 of the present disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In order to make the technical problems, technical solutions, and beneficial effects of the present disclosure easy to understand, the present disclosure will be described in detail below with reference to specific embodiments.

The electrochemical deposition process and structure of Li_2S are directly associated with an electrolyte, and for the generation of 3D Li_2S , the electrolyte is mainly regulated from the following three aspects: (1) the concentration and state of an intermediate product LPS of charge-discharge, that is, the DN of an electrolyte solvent; (2) Li_2S solubility, that is, the dielectric constant (polarity) of an electrolyte solvent; and (3) Li^+ transmission speed, that is, the viscosity of an electrolyte.

As shown in FIG. 1, DMA, DMSO, and the like have high DN, dielectric constant, and sulfide solubility, which is favorable for the generation of 3D Li_2S . However, such solvents have severe side reactions with lithium. In SIL, there are both an interaction between ether oxygen bonds and Li^+ and an interaction between anions and cations to form a structure of $[\text{Li}(\text{Gn})][\text{X}]$. When SIL is mixed with a high-DN solvent, Gn undergoes coordination competition with solvent molecules to

form structural ions $[\text{Li}(\text{solvent})]^+$ or $[\text{Li}(\text{Gn})(\text{solvent})]^+$, and a part of Gn is dissociated into free solvent molecules. The polarity and viscosity of the electrolyte can be regulated through reasonable combination and ratio adjustment of the SIL and high-DN solvent, and the polar solvent can be prevented from directly contacting lithium to inhibit side reactions. Since LPS is dissolved in the electrolyte and interacts with the polar solvent, an electrolyte structure will change with the charge-discharge progress, and a change of the electrolyte structure will regulate the transformation between LPS and Li_2S . LU501874

The crown ether may be any one selected from the group consisting of 15-crown-5, 18-crown-6, and 21-crown-7. Preferably, the crown ether may preferably be 18-crown-6 or 21-crown-7. A molecular weight of MPEG may be any one selected from the group consisting of 350, 550, and 750. Among the preparation raw materials of the SILE with an adjustable structure of the present disclosure, the compounding agent can also be composed of tetraethylene glycol dimethyl ether and crown ether in a mass ratio of (8-9):(2-3).

Preferably, the solvent may be composed of DMF and DMSO in a mass ratio of (5-8):1.

Example 1

An SILE with an adjustable structure in this example was prepared from 200 mL of a solvent and the following raw materials in weight: 20 g of a compounding agent and 55 g of a lithium salt. The solvent was DMF ($\text{C}_3\text{H}_7\text{NO}$, molecular weight: 73.1), the compounding agent was diethylene glycol dimethyl ether ($\text{C}_6\text{H}_{14}\text{O}_3$, molecular weight: 134.2), and the lithium salt was LiTFSI (lithium bis(trifluoromethane)sulfonimide, $\text{C}_2\text{F}_6\text{LiNO}_4\text{S}_2$, molecular weight: 287.1).

A preparation method of the SILE with an adjustable structure in this example included the following steps:

- 1) the compounding agent was added to a three-neck flask, then the lithium salt was added, and a resulting mixture was stirred at 35°C for 10 min under the protection of an argon atmosphere to obtain an ionic liquid; and
- 2) the solvent was added to the three-neck flask with the ionic liquid prepared in step 1), and then a resulting mixture was further stirred for 10 min and allowed to stand for 30 min to obtain the SILE with an adjustable structure.

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:20. The sulfur-carbon composite was obtained by subjecting a mixture of elemental sulfur and Ketjenblack in a mass ratio of 55:45 to ball-milling for 8 h.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the

negative electrode was a lithium sheet.

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Example 2

An SILE with an adjustable structure in this example was prepared from 200 mL of a solvent and the following raw materials in weight: 20 g of a compounding agent and 60 g of a lithium salt. The solvent was DMF ($\text{C}_3\text{H}_7\text{NO}$, molecular weight: 73.1), the compounding agent was diethylene glycol dimethyl ether ($\text{C}_6\text{H}_{14}\text{O}_3$, molecular weight: 134.2), and the lithium salt was LiTFSI (lithium bis(trifluoromethane)sulfonimide, $\text{C}_2\text{F}_6\text{LiNO}_4\text{S}_2$, molecular weight: 287.1).

A preparation method of the SILE with an adjustable structure in this example included the following steps:

- 1) the compounding agent was added to a three-neck flask, then the lithium salt was added, and a resulting mixture was stirred at 40°C for 8 min under the protection of an argon atmosphere to obtain an ionic liquid; and
- 2) the solvent was added to the three-neck flask with the ionic liquid prepared in step 1), and then a resulting mixture was further stirred for 12 min and allowed to stand for 30 min to obtain the SILE with an adjustable structure.

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:30. The sulfur-carbon composite was obtained by subjecting a mixture of elemental sulfur and Ketjenblack in a mass ratio of 55:45 to ball-milling for 8 h.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the negative electrode was a lithium sheet.

Example 3

An SILE with an adjustable structure in this example was prepared from 200 mL of a solvent and the following raw materials in weight: 20 g of a compounding agent and 65 g of a lithium salt. The solvent was DMF ($\text{C}_3\text{H}_7\text{NO}$, molecular weight: 73.1), the compounding agent was diethylene glycol dimethyl ether ($\text{C}_6\text{H}_{14}\text{O}_3$, molecular weight: 134.2), and the lithium salt was LiTFSI (lithium bis(trifluoromethane)sulfonimide, $\text{C}_2\text{F}_6\text{LiNO}_4\text{S}_2$, molecular weight: 287.1).

A preparation method of the SILE with an adjustable structure in this example included the following steps:

- 1) the compounding agent was added to a three-neck flask, then the lithium salt was added, and a resulting mixture was stirred at 45°C for 5 min under the protection of an argon atmosphere to obtain an ionic liquid; and
- 2) the solvent was added to the three-neck flask with the ionic liquid prepared in step 1), and then

a resulting mixture was further stirred for 15 min and allowed to stand for 30 min to obtain the SILE with an adjustable structure. LU501874

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:40. The sulfur-carbon composite was obtained by subjecting a mixture of elemental sulfur and Ketjenblack in a mass ratio of 55:45 to ball-milling for 8 h.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the negative electrode was a lithium sheet.

Example 4

An SILE with an adjustable structure in this example was prepared from 200 mL of a solvent and the following raw materials in weight: 12 g of a compounding agent and 35 g of a lithium salt. The solvent was a mixture of DMF and DMSO in a mass ratio of 5:1, the compounding agent was triethylene glycol dimethyl ether ($C_8H_{18}O_4$, molecular weight: 178.2), and the lithium salt was LiTF (lithium trifluoromethanesulfonate, CF_3SO_3Li , molecular weight: 156.0).

A preparation method of the SILE with an adjustable structure in this example included the following steps:

- 1) the compounding agent was added to a three-neck flask, then the lithium salt was added, and a resulting mixture was stirred at 38°C for 7 min under the protection of an argon atmosphere to obtain an ionic liquid; and
- 2) the solvent was added to the three-neck flask with the ionic liquid prepared in step 1), and then a resulting mixture was cooled to 1°C, further stirred for 12 min, and allowed to stand for 30 min to obtain the SILE with an adjustable structure.

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:50. The sulfur-carbon composite was obtained by subjecting a mixture of elemental sulfur and Ketjenblack in a mass ratio of 75:25 to ball-milling for 8 h and incubating a product at 158°C for 10 h under a nitrogen atmosphere.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the negative electrode was a lithium sheet.

Example 5

An SILE with an adjustable structure in this example was prepared from 200 mL of a solvent and

the following raw materials in weight: 18 g of a compounding agent and 30 g of a lithium salt. The solvent was a mixture of DMA and DMSO in a mass ratio of 5:1, the compounding agent was tetraethylene glycol dimethyl ether ($C_8H_{18}O_4$, molecular weight: 222.3), and the lithium salt was LiTFSI (lithium bis(trifluoromethane)sulfonimide, $C_2F_6LiNO_4S_2$, molecular weight: 287.1).

A preparation method of the SILE with an adjustable structure in this example included the following steps:

- 1) the compounding agent was added to a three-neck flask, then the lithium salt was added, and a resulting mixture was stirred at 38°C for 7 min under the protection of an argon atmosphere to obtain an ionic liquid; and
- 2) the solvent was added to the three-neck flask with the ionic liquid prepared in step 1), and then a resulting mixture was cooled to 10°C, further stirred for 12 min, and allowed to stand for 30 min to obtain the SILE with an adjustable structure.

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:60. The sulfur-carbon composite was obtained by subjecting a mixture of elemental sulfur and Ketjenblack in a mass ratio of 75:25 to ball-milling for 8 h and incubating a product at 155°C for 10 h under a nitrogen atmosphere and then at 300°C for 2 h under a nitrogen atmosphere.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the negative electrode was a lithium sheet.

Example 6

An SILE with an adjustable structure in this example was prepared from 150 mL of a solvent and the following raw materials in weight: 15 g of a compounding agent and 50 g of a lithium salt. The solvent was a mixture of DMA and DMSO in a mass ratio of 5:1, the compounding agent was a mixture of triethylene glycol dimethyl ether ($C_8H_{18}O_4$, molecular weight: 178.2) and tetraethylene glycol dimethyl ether ($C_{10}H_{22}O_5$, molecular weight: 222.3) in a molar ratio of 1:1, and the lithium salt was LiTFSI (lithium bis(trifluoromethane)sulfonimide, $C_2F_6LiNO_4S_2$, molecular weight: 287.1).

A preparation method of the SILE with an adjustable structure in this example was the same as that in Example 5.

A positive electrode of a lithium-sulfur battery and a lithium-sulfur battery in this example adopted the above-mentioned SILE with an adjustable structure, and the remaining was the same as that in Example 5.

Example 7

An SILE with an adjustable structure in this example was prepared from 150 mL of a solvent and the following raw materials in weight: 13 g of a compounding agent and 45 g of a lithium salt. The solvent was a mixture of DMA and DMSO in a mass ratio of 5:1, the compounding agent was a mixture of triethylene glycol dimethyl ether ($C_8H_{18}O_4$, molecular weight: 178.2) and 21-crown-7 in a mass ratio of 8:3, and the lithium salt was LiBr (molecular weight: 86.9).

A positive electrode of a lithium-sulfur battery in this example was made by mixing the above-mentioned SILE with an adjustable structure and a sulfur-carbon composite. A mass ratio of the SILE with an adjustable structure to the sulfur-carbon composite was 100:70.

The sulfur-carbon composite was prepared by a method including the following steps:

1) 0.05 g of ketjenblack (KB) was added to 100 mL of a PVP aqueous solution with a concentration of 1 g/L, and a resulting mixture was stirred for 3 h to obtain a mixed system; then 3.1 g of $Na_2S_2O_3 \cdot 5H_2O$ was added to the mixed system, and a resulting system was rapidly stirred at room temperature for 8 h, during which 2.55 g of hydrochloric acid with a mass fraction of 36% was slowly added to the system; a resulting system was heated to 70°C, 0.05 g of GO was added to the system, and then 5 mL of hydrazine hydrate was added to the system; and a pH was adjusted to 10 to 11 using ammonia water with a mass fraction of 28%, a resulting mixed solution was stirred for 4 h, a pH of the mixed solution was adjusted to 2 with hydrochloric acid, and the mixed solution was further stirred for 4 h; and

2) a resulting mixture was subjected to SLS, a resulting solid was washed with deionized water and then dried in a vacuum drying oven at 55°C for 12 h, and a dried material was placed in a closed container and then heated at 155°C for 8 h under an argon atmosphere to obtain an S-KB-G@P composite.

A lithium-sulfur battery in this example included a positive electrode and a negative electrode, where the positive electrode was the above-mentioned lithium-sulfur positive electrode and the negative electrode was a lithium sheet.

Example 8

This example was different from Example 7 only in that the sulfur-carbon composite was prepared by a method including the following steps:

1) 0.1 g of KB was added to 100 mL of a PVP aqueous solution with a concentration of 1 g/L, and a resulting mixture was stirred for 3 h to obtain a mixed system; then 3.1 g of $Na_2S_2O_3 \cdot 5H_2O$ was added to the mixed system, and a resulting system was rapidly stirred at room temperature for 7 h, during which 2.55 g of hydrochloric acid with a mass fraction of 36% was slowly added to the system; a resulting system was heated to 80°C, 0.05 g of GO was added to the system, and then 5 mL of hydrazine hydrate was added to the system; and a pH was adjusted to 10 to 11 using ammonia water with a mass fraction of 28%, a resulting mixed solution was stirred for 4 h, a pH

of the mixed solution was adjusted to 2 with hydrochloric acid, and the mixed solution was further stirred for 4 h; and

2) a resulting mixture was subjected to SLS, a resulting solid was washed with deionized water and then dried in a vacuum drying oven at 55°C for 12 h, and a dried material was placed in a closed container and then heated at 160°C for 10 h under an argon atmosphere to obtain an S-KB-G@P composite.

All the other conditions were the same as those in Example 7.

Test Example

(1) The SILE with an adjustable structure in each of Examples 1 to 8 was tested for a lithium salt concentration, and test results are shown in the table below.

Table 1 Electrolyte performance test results of Examples 1 to 8

	Lithium salt concentration in electrolyte (mol/L)
Example 1	0.81-0.83
Example 2	0.88-0.91
Example 3	0.96-1.01
Example 4	1.02-1.05
Example 5	1.52-1.6
Example 6	0.90-0.85
Example 7	0.89-0.92

(2) The electrolytes in Examples 5 and 6 were each subjected to a DSC test, and the test results are shown in FIG. 2.

(3) The lithium-sulfur batteries in Examples 5 and 6 were each subjected to charge-discharge and cycling tests, and the test results are shown in FIG. 3 and FIG. 4.

It can be seen from the above table and FIG. 2 to FIG. 4, the SILE with an adjustable structure prepared by the present disclosure has prominent cycling performance at an appropriate concentration, and can be compounded with a sulfur-carbon composite to make the sulfur-carbon composite exert a higher specific capacity.

CLAIMS

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1. A solvate ionic liquid electrolyte (SILE) with an adjustable structure, prepared from a solvent and the following raw materials in parts by weight: 10 to 35 parts of a compounding agent and 30 to 65 parts of a lithium salt,

wherein the compounding agent is at least one selected from the group consisting of polyethylene glycol dimethyl ether, crown ether, and methoxy polyethylene glycol (MPEG); and the lithium salt is at least one selected from the group consisting of LiTFSI, LiTF, and LiBr.

2. The SILE with the adjustable structure according to claim 1, wherein the solvent is at least one selected from the group consisting of N, N-dimethylformamide (DMF), dimethylsulfoxide (DMSO), and N, N-dimethylacetamide (DMA).

3. The SILE with the adjustable structure according to claim 1 or 2, wherein an amount-of-substance concentration of the lithium salt in the electrolyte is 0.4 mol/L to 1.6 mol/L.

4. The SILE with the adjustable structure according to claim 1 or 2, wherein a molar ratio of the compounding agent to lithium ions in the lithium salt is (0.3-1.5):1.

5. The SILE with the adjustable structure according to claim 1 or 2, wherein the polyethylene glycol dimethyl ether is at least one selected from the group consisting of diethylene glycol dimethyl ether, triethylene glycol dimethyl ether, and tetraethylene glycol dimethyl ether.

6. A preparation method of the SILE with the adjustable structure according to claim 1, comprising the following steps:

1) mixing the compounding agent and the lithium salt thoroughly to obtain an SIL with a structure of $[\text{Li}(\text{Gn})][\text{X}]$; and

2) adding the solvent to the SIL obtained in step 1), and thoroughly mixing to obtain the SILE with the adjustable structure.

7. The preparation method of the SILE with the adjustable structure according to claim 6, wherein in step 1), the compounding agent and the lithium salt are thoroughly mixed by stirring at 35°C to 45°C for 5 min to 10 min.

8. The preparation method of the SILE with the adjustable structure according to claim 6, wherein in step 2), after the solvent is added, stirring is conducted at 0°C to 15°C for 10 min to 15 min.

9. A positive electrode of a lithium-sulfur battery, made of an ionic liquid electrolyte and a sulfur-carbon composite in a mass ratio of 100:(10-80), wherein the ionic liquid electrolyte is the SILE with the adjustable structure according to claim 1.

10. A lithium-sulfur battery, comprising a positive electrode and a negative electrode, wherein the positive electrode is the positive electrode of the lithium-sulfur battery according to claim 9.

1. Solvationenflüssigkeitselektrolyt (SILE) mit anpassbarer Struktur, der aus einem Lösungsmittel und den folgenden Ausgangsmaterialien in folgenden Gewichtsteilen hergestellt ist: 10 bis 35 Teile Compoundierungsmittel und 30 bis 65 Teile Lithiumsalz,

wobei das Compoundierungsmittel mindestens eins ausgewählt aus der Gruppe bestehend aus Polyethylenglycoldimethylether, Kronenether und Methoxypolyethylenglycol (MPEG) ist; und

das Lithiumsalz mindestens eins ausgewählt aus der Gruppe bestehend aus LiTFSI, LiTF und LiBr ist.

2. SILE mit anpassbarer Struktur nach Anspruch 1, wobei das Lösungsmittel mindestens eins ausgewählt aus der Gruppe bestehend aus *N,N*-Dimethylformamid (DMF), Dimethylsulfoxid (DMSO) und *N,N*-Dimethylacetamid (DMA) ist.

3. SILE mit anpassbarer Struktur nach Anspruch 1 oder 2, wobei eine Konzentrationsmenge des Lithiumsalzes in dem Elektrolyten 0,4 mol/l bis 1,6 mol/l beträgt.

4. SILE mit anpassbarer Struktur nach Anspruch 1 oder 2, wobei ein Molverhältnis des Compoundierungsmittels zu Lithiumionen in dem Lithiumsalz (0,3–1,5):1 beträgt.

5. SILE mit anpassbarer Struktur nach Anspruch 1 oder 2, wobei der Polyethylenglycoldimethylether mindestens eins ausgewählt aus der Gruppe bestehend aus Diethylenglycoldimethylether, Triethylenglycoldimethylether und Tetraethylenglycoldimethylether ist.

6. Verfahren zum Herstellen des SILE mit anpassbarer Struktur nach Anspruch 1, folgende Schritte umfassend:

1) gründliches Mischen des Compoundierungsmittels und des Lithiumsalzes zum Erlangen eines SIL der Struktur $[\text{Li}(\text{Gn})][\text{X}]$; und

2) Zusetzen des Lösungsmittels zu dem in Schritt 1) erlangten SIL und gründliches Mischen, um den SILE mit anpassbarer Struktur zu erlangen.

7. Verfahren zum Herstellen des SILE mit anpassbarer Struktur nach Anspruch 6, wobei in Schritt 1) das Compoundierungsmittel und das Lithiumsalz durch Rühren bei 35 °C bis 45 °C für 5 min bis 10 min gründlich gemischt werden.

8. Verfahren zum Herstellen des SILE mit anpassbarer Struktur nach Anspruch 6, wobei in Schritt 2) nach dem Zusetzen des Lösungsmittels bei 0 °C bis 15 °C für 10 min bis 15 min Rühren durchgeführt wird.

9. Positive Elektrode einer Lithium-Schwefel-Batterie, hergestellt aus einem Ionenflüssigkeitselektrolyten und einem Schwefel-Kohlenstoff-Verbundmaterial in einem Masseverhältnis von 100:(10–80), wobei der Ionenflüssigkeitselektrolyt der SILE mit

anpassbarer Struktur nach Anspruch 1 ist.

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10. Lithium-Schwefel-Batterie, umfassend eine positive Elektrode und eine negative Elektrode, wobei die positive Elektrode die positive Elektrode der Lithium-Schwefel-Batterie nach Anspruch 9 ist.

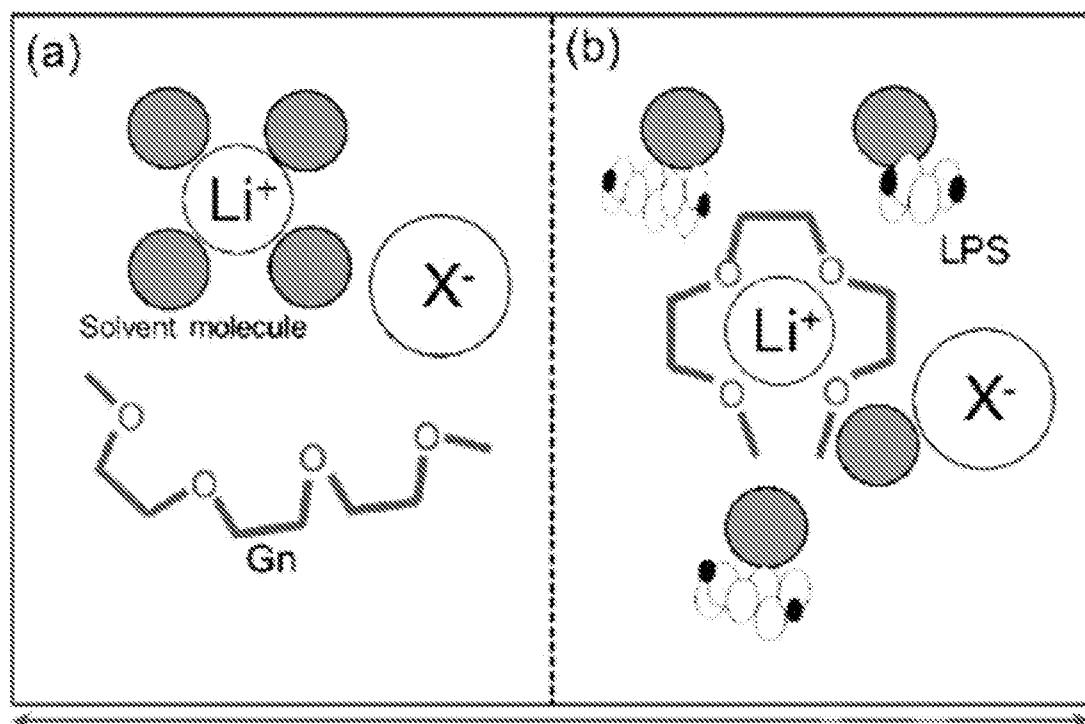


FIG. 1

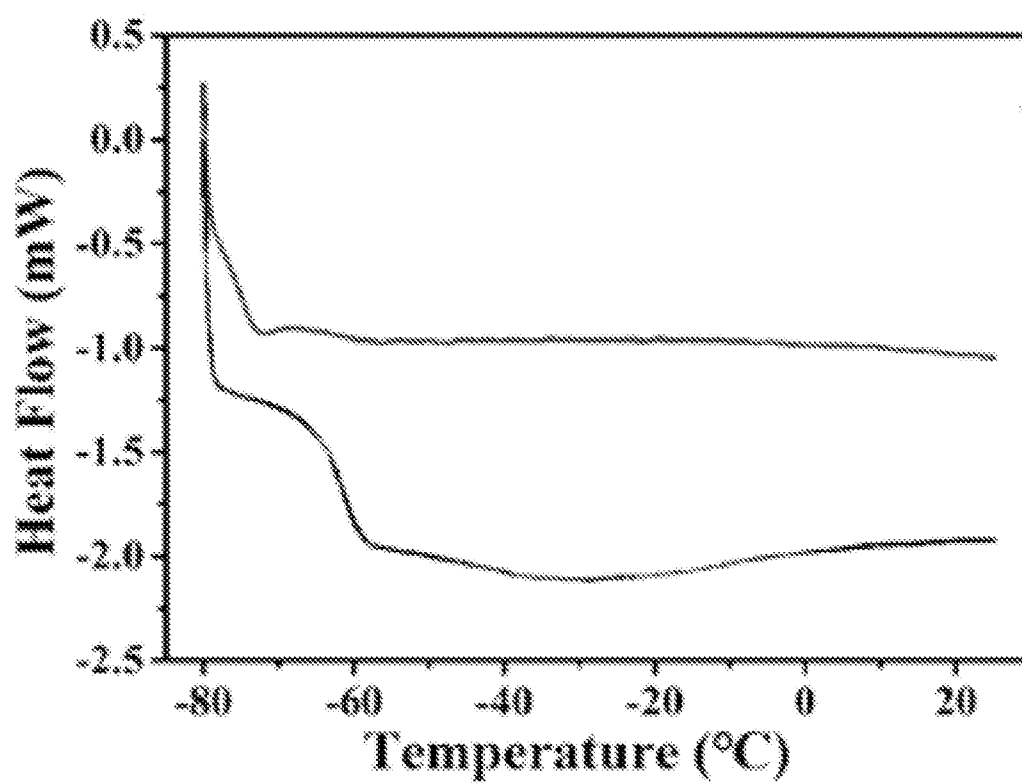


FIG. 2

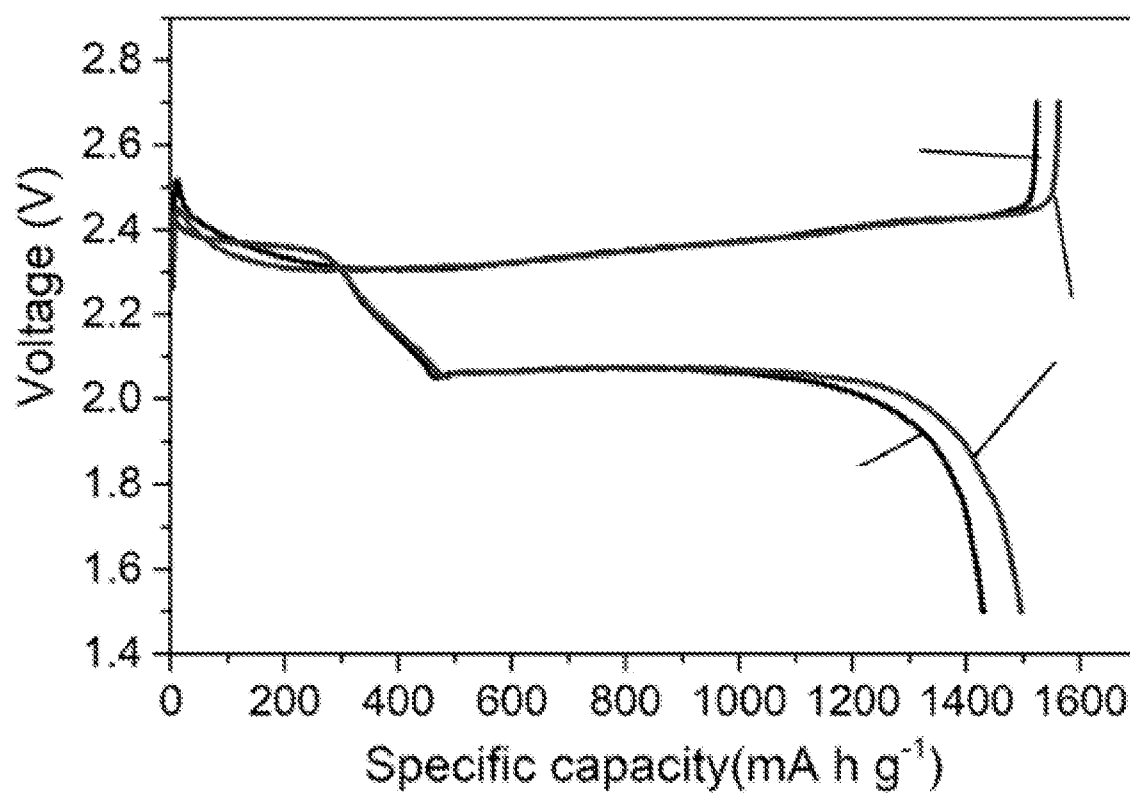


FIG. 3

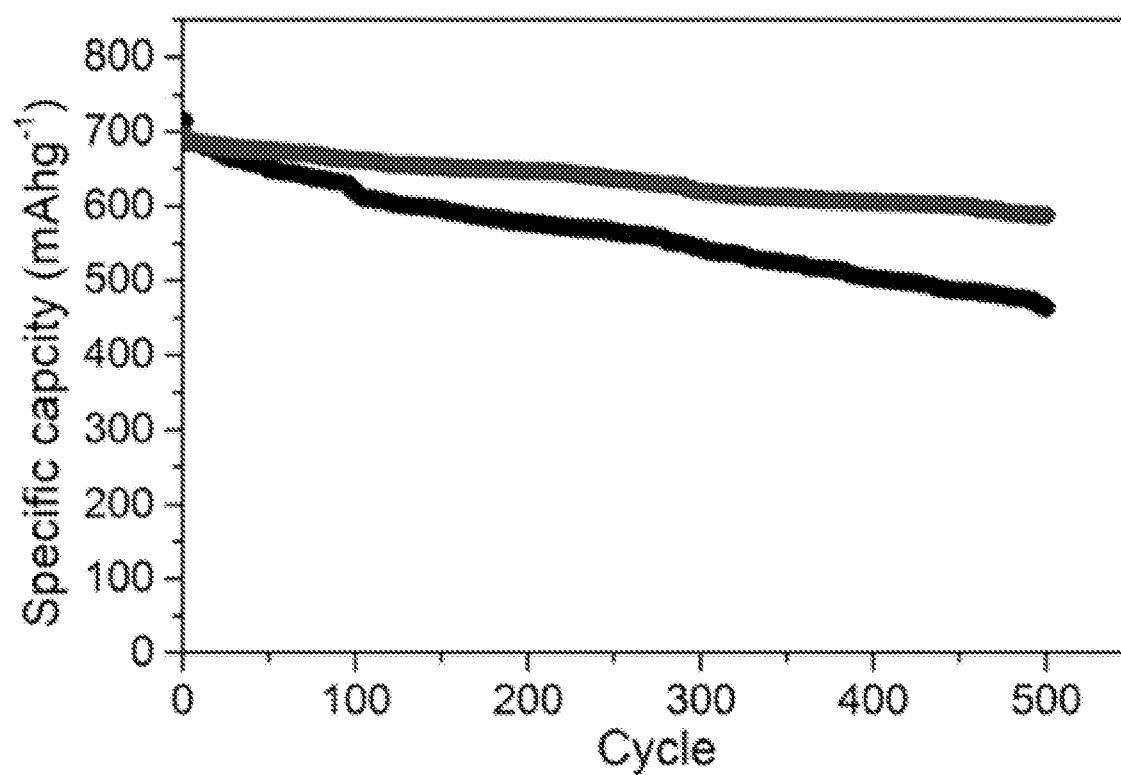


FIG. 4