WHAT IS CLAIMED IS:

1. A recyclable sulfide composite solid electrolyte, comprising:

a polymer having dynamic reversible covalent bonds, wherein the polymer has the dynamic reversible covalent bonds integrated into a main chain or crosslinking branches; and

a sulfide solid electrolyte.

2. The recyclable sulfide composite solid electrolyte of claim 1, wherein the main chain of the polymer having the dynamic reversible covalent bonds is a flexible chain.

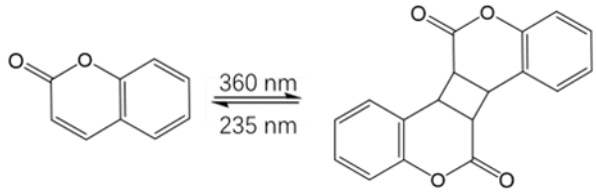
3. The recyclable sulfide composite solid electrolyte of claim 2, wherein the main chain of the polymer having the dynamic reversible covalent bonds is one or more selected from natural rubbers, synthetic rubbers, polyurethanes, polyacrylates, polyphosphazenes, polyethylene oxide, epoxy resins, polyolefins, polydimethylsilane, or polycarbonates.

4. The recyclable sulfide composite solid electrolyte of any one of claims 1 to 3, wherein the polymer comprises one or more functional groups capable of repeatedly bonding/debonding under light or heat induction.

5. The recyclable sulfide composite solid electrolyte of claim 4, wherein bonding and debonding reactions of the dynamic reversible covalent bonds comprise at least one of: bonding and debonding reactions between coumarin groups, bonding and debonding reactions between substituted or unsubstituted anthracene groups, bonding and debonding reactions between substituted or unsubstituted furans and substituted or unsubstituted maleimides, bonding and debonding reactions between aldehydes and amines, or bonding and debonding reactions between substituted or unsubstituted cinnamate groups.

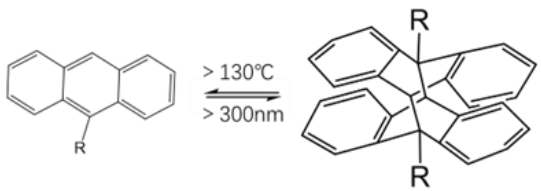
6. The recyclable sulfide composite solid electrolyte of claim 4, wherein bonding and debonding reactions of the dynamic reversible covalent bonds comprise at least one of:

i) bonding and debonding reactions between coumarin groups:



;

ii) bonding and debonding reactions between substituted or unsubstituted anthracene groups:



wherein R is selected from hydrogen; a halogen atom; an alkyl group having 1 to 18 carbon

atoms; or a haloalkyl group having 1 to 18 carbon atoms, wherein the haloalkyl group contains at least one halogen atom;

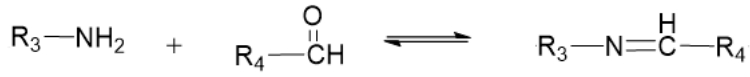
iii) bonding and debonding reactions between substituted or unsubstituted furans and substituted or unsubstituted maleimides:



wherein R_1 and R_2 are each independently selected from hydrogen; a halogen atom; an alkyl group having 1 to 18 carbon atoms; or a haloalkyl group having 1 to 18 carbon atoms, wherein the haloalkyl group contains at least one halogen atom;

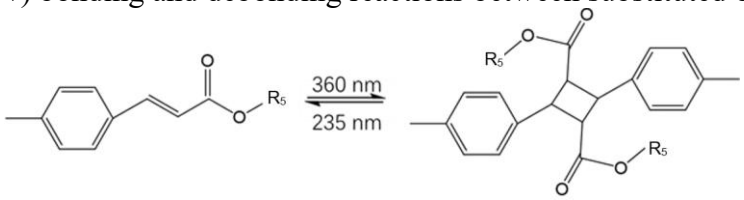
each of n and m is an integer greater than or equal to 1;

iv) bonding and debonding reactions between aldehydes and amines:



wherein R_3 and R_4 are each independently selected from hydrogen; a halogen atom; an alkyl group having 1 to 18 carbon atoms; a haloalkyl group having 1 to 18 carbon atoms, wherein the haloalkyl group contains at least one halogen atom; a cycloalkyl group; an aryl group; or a heteroaryl group;

v) bonding and debonding reactions between substituted or unsubstituted cinnamate groups:



wherein R_5 is selected from hydrogen; a halogen atom; an alkyl group having 1 to 18 carbon atoms; or a haloalkyl group having 1 to 18 carbon atoms, wherein the haloalkyl group contains at least one halogen atom.

7. The recyclable sulfide composite solid electrolyte of claim 6, wherein the halogen atom is selected from fluorine, chlorine, bromine, or iodine; R is selected from hydrogen, methyl, ethyl, n-propyl, or n-butyl; R_1 and R_2 are each independently selected from hydrogen, methyl, ethyl, n-propyl, or n-butyl; R_3 and R_4 are each independently selected from hydrogen, methyl, ethyl, n-propyl, or n-butyl; and R_5 is selected from hydrogen, methyl, ethyl, n-propyl, or n-butyl.

8. The recyclable sulfide composite solid electrolyte of any one of claims 1 to 3, wherein the sulfide solid electrolyte is one or more selected from Li_2S-P_2S_5, Li_2S-P_2S_5-MS_x, $Li_{3.4}Si_{0.4}P_{0.6}S_4$, $Li_{10}GeP_2S_{11.7}O_{0.3}$, $Li_{9.6}P_3S_{12}$, $Li_7P_3S_{11}$, $Li_9P_3S_9O_3$, $Li_{10.35}Si_{1.35}P_{1.65}S_{12}$, $Li_{9.81}Sn_{0.81}P_{2.19}S_{12}$, $Li_{10}GeP_2S_{12}$, Li_6PS_5X, $Li_7P_2S_8I$, $Li_{10.35}Ge_{1.35}P_{1.65}S_{12}$, $Li_{3.25}Ge_{0.25}P_{0.75}S_4$, $Li_{10}SnP_2S_{12}$, $Li_{10}SiP_2S_{12}$, or

$Li_{9.54}Si_{1.74}P_{1.44}S_{11.7}Cl_{0.3}$; wherein M comprises one or a combination of two or more selected from Si, Ge, or Sn; and X is one or more selected from Cl, Br, or I; where $0 \leq x \leq 2$.

9. The recyclable sulfide composite solid electrolyte of any one of claims 1 to 3, wherein the recyclable sulfide composite solid electrolyte further comprises a lithium salt; and

wherein a mass percentage of the polymer is 0.2% to 40%, a mass percentage of the sulfide solid electrolyte is 20% to 99.6%, and a mass percentage of the lithium salt is 0.2% to 40%, based on a total mass of the recyclable sulfide composite solid electrolyte.

10. The recyclable sulfide composite solid electrolyte of claim 9, wherein the lithium salt is one or more selected from lithium perchlorate ($LiClO_4$), lithium tetrafluoroborate ($LiBF_4$), lithium hexafluoroarsenate ($LiAsF_6$), lithium hexafluorophosphate ($LiPF_6$), lithium bis(oxalato)borate (LiBOB), lithium difluoro(oxalato)borate (LiDFOB), lithium bis(fluorosulfonyl)imide (LiFSI), or lithium bis(trifluoromethanesulfonyl)imide (LiTFSI).

11. A method for preparing a recyclable sulfide composite solid electrolyte according to any one of claims 1 to 10, comprising:

mixing a sulfide solid electrolyte and a polymer having dynamic reversible covalent bonds by a slurry process or a dry process to obtain a polymer/sulfide mixture; and

applying a light or heat induction condition to the polymer/sulfide mixture to obtain the recyclable sulfide composite solid electrolyte.

12. The method of claim 11, wherein the method further comprises:

adding a lithium salt, wherein the lithium salt is mixed with the polymer/sulfide mixture by at least one of screw extrusion, agitation, gas stirring, ball milling, internal mixing, or kneading.

13. The method of claim 11 or 12, wherein the light or heat induction condition comprises: irradiation with ultraviolet light at 360 nm, or lowering a temperature to below 60°C.

14. A recyclable sulfide composite solid electrolyte membrane, comprising a recyclable sulfide composite solid electrolyte according to any one of claims 1 to 10 or a recyclable sulfide composite solid electrolyte prepared by a method according to any one of claims 11 to 13.

15. A solid lithium-ion battery, comprising:

a positive electrode;

a negative electrode; and

a recyclable sulfide composite solid electrolyte membrane according to claim 14 disposed between the positive electrode and the negative electrode.