Therefore, there is a need to provide a coral-like composite material, a coating material and methods of preparing the same that overcome or ameliorate one or more of the disadvantages mentioned above.

Summary

The present disclosure relates to a coral-like composite material comprising highly dispersed conductive metal nitride, metal carbide or metal carbonitride nanoparticles on mesoporous carbon nanosheets.

In one aspect, the present disclosure relates to a coral-like composite material comprising highly dispersed conductive metal nitride, metal carbide or metal carbonitride nanoparticles on mesoporous carbon nanosheets, wherein the metal carbide, metal nitride or metal carbonitride nanoparticles further comprises surface metal oxides.

Advantageously, the coral-like composite material may be used in a modified separator for a lithium-sulfur battery to address the issue of polysulfide shutting effect due to its strong polysulfide adsorption capability and therefore to achieve high areal capacity at a sulfur loading more than 6 mg cm^{-2}. The particular structure and morphology of the coral-like composite material may result in high surface area of the modified separator and high activity of the lithium-sulfur battery due to the small size of the nanoparticles.

The present disclosure relates to a method for preparing a coral-like composite material comprising the steps of

a) mixing a mixture of a precursor of metal nitride, metal carbide or metal carbonitride material and a graphitic carbon nitride material; and
b) drying the mixture and heating solids obtained from dried mixture at a first elevated temperature for a first time period and at a second elevated temperature for a second time period in an inert atmosphere.

In another aspect, the present disclosure relates to a method for preparing a coral-like composite material comprising the steps of

a) mixing a mixture of a precursor of metal nitride, metal carbide or metal carbonitride material and a graphitic carbon nitride material;
b) drying the mixture and heating solids obtained from dried mixture at a first elevated temperature for a first time period and at a second elevated temperature for a second time period in an inert atmosphere; and
c) introducing nitrogen followed by introducing air after the furnace is cooled to room temperature,

wherein the coral-like composite material comprises highly dispersed conductive metal nitride, metal carbide or metal carbonitride nanoparticles on mesoporous carbon nanosheets, and wherein the metal carbide, metal nitride or metal carbonitride nanoparticles further comprises surface metal oxides.

Advantageously, the method may produce a high surface area, porous coral-like composite material with highly dispersed conductive metal carbide, metal nitride or metal carbonitride nanoparticles as an effective polysulfide barrier with high polysulfide adsorption capabilities.

In another aspect, the present disclosure relates to a coral-like composite material prepared by the method as described herein.

In another aspect, the present disclosure relates to a coating material for a modified separator of a lithium-sulfur battery comprising the coral-like composite material as described herein, a conducting carbon material and a binder.

In another aspect, the present disclosure relates to a method for preparing a modified separator for lithium-sulfur battery comprising the steps of

a) mixing a mixture of the coral-like composite material as described herein, a conducting carbon material and a binder; and
b) coating the mixture on a porous and non-electrically-conductive membrane.

In another aspect, the present disclosure relates to a lithium-sulfur battery comprising the coating material as described herein.

Advantageously, the lithium-sulfur battery comprising the modified separator as described herein may have a reduced charge transfer resistance R_{CT} as characterized by electrochemical impedance spectroscopy (EIS) as compared to a lithum-sulfur battery with a unmodifed separator. The reduced R_{CT} values after separator modification could be due to the high electrical conductivity of the metal carbide, metal nitride or metal carbonitride, which could enhance the surface charge transfer reactions for better electrochemical performance.

Definitions

The following words and terms used herein shall have the meaning indicated:

Claims

1. A coral-like composite material comprising highly dispersed conductive metal nitride, metal carbide or metal carbonitride nanoparticles on mesoporous carbon nanosheets, wherein the metal carbide, metal nitride or metal carbonitride nanoparticles further comprises surface metal oxides.

2. The coral-like composite material of claim 1, wherein the size of the metal nitride, metal carbide or metal carbonitride nanoparticles is in the range of 2 nm to 20 nm.

3. The coral-like composite material of claim 1 or 2, wherein the metal element from the metal nitride, metal carbide or metal carbonitride nanoparticles is scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, yttrium, zirconium, niobium, molybdenum, technetium, ruthenium, rhodium, palladium, silver, cadmium, hafnium, tantalum, tungsten, rhenium, osmium, iridium, platinum, or their combinations thereof.

4. The coral-like composite material of any one of the preceding claims, wherein the metal carbide is niobium carbide, titanium carbide, tungsten carbide, molybdenum carbide, vanadium carbide, hafnium carbide, niobium titanium carbide, niobium tungsten carbide, niobium molybdenum carbide, niobium vanadium carbide, niobium hafnium carbide, titanium tungsten carbide, titanium molybdenum carbide, titanium vanadium carbide, titanium hafnium carbide, tungsten molybdenum carbide, tungsten vanadium carbide, tungsten hafnium carbide, molybdenum vanadium carbide, molybdenum hafnium carbide, vanadium hafnium carbide or their mixtures thereof.

5. The coral-like composite material of any one of the preceding claims, wherein the metal nitride is titanium nitride, tungsten nitride, molybdenum nitride, vanadium nitride, niobium nitride, zirconium nitride, hafnium nitride, titanium tungsten nitride, titanium molybdenum nitride, titanium vanadium nitride, titanium niobium nitride, titanium zirconium nitride, titanium hafnium nitride, tungsten molybdenum nitride, tungsten vanadium nitride, tungsten niobium nitride, tungsten zirconium nitride, tungsten hafnium nitride, molybdenum vanadium nitride, molybdenum niobium nitride, molybdenum zirconium nitride, molybdenum hafnium nitride, vanadium niobium nitride, vanadium zirconium nitride, vanadium hafnium nitride, niobium zirconium nitride, niobium hafnium nitride, zirconium hafnium nitride or their mixtures thereof.

6. The coral-like composite material of any one of the preceding claims, wherein the metal carbonitride is vanadium carbonitride, titanium carbonitride, tungsten carbonitride, molybdenum carbonitride, niobium carbonitride, zirconium carbonitride, vanadium titanium carbonitride, vanadium tungsten carbonitride, vanadium molybdenum carbonitride, vanadium niobium carbonitride, vanadium zirconium carbonitride, titanium tungsten carbonitride, titanium molybdenum carbonitride, titanium niobium carbonitride, titanium zirconium carbonitride, tungsten molybdenum carbonitride, tungsten niobium carbonitride, tungsten zirconium carbonitride, molybdenum niobium carbonitride, molybdenum zirconium carbonitride, niobium zirconium carbonitride or their mixtures thereof.

7. The coral-like composite material of any one of the preceding claims, wherein the coral-like composite material has a surface area larger than 100 m^2/g.

8. The coral-like composite material of any one of the preceding claims, wherein the coral-like composite material has a pore volume in the range of 0.5 cm^3/g to 2 cm^3/g.

9. The coral-like composite material of any one of the preceding claims, wherein the coral-like composite material has a pore size in the range of 2 nm to 50 nm.

10. A method for preparing a coral-like composite material comprising the steps of

a) mixing a mixture of a precursor of metal nitride, metal carbide or metal carbonitride material and a graphitic carbon nitride material;

b) drying the mixture and heating solids obtained from dried mixture at a first elevated temperature for a first time period and at a second elevated temperature for a second time period in an inert atmosphere; and
c) introducing nitrogen followed by introducing air after the furnace is cooled to room temperature,

wherein the coral-like composite material comprises highly dispersed conductive metal nitride, metal carbide or metal carbonitride nanoparticles on mesoporous carbon nanosheets, and wherein the metal carbide, metal nitride or metal carbonitride nanoparticles further comprises surface metal oxides.

11. The method of claim 10, wherein the precursor of the metal nitride metal carbide or metal carbonitride material is metal alkoxide.

12. The method of claim 10 or 11, wherein the first elevated temperature of step b) is in the range of 400°C to 700°C and the first time period of step b) is more than 3 hours.

13. The method of any one of claims 10 to 12, wherein the second elevated temperature of step b) is in the range of 750°C to 1000°C and the second time period of step b) is more than 2 hours.

14. A coating material for a modified separator of a lithium-sulfur battery comprising the coral-like composite material of any one of claims 1 to 9, a conducting carbon material and a binder.

15. The coating material of claim 14, wherein the conducting carbon material is selected from the group consisting of reduced graphene oxide, graphene, graphite, carbon nanotube, carbon fiber, acetylene black, and ketjenblack.

16. The coating material of claim 14 or 15, wherein the conducting carbon material has a diameter in the range of 0.1 nm to 100 μm.

17. The coating material of any one of claims 14 to 16, wherein the coating material has a thickness in the range of 5 μm to 70 μm.

18. The coating material of any one of claims 14 to 17, wherein the coating material has a mass density in the range of 0.5 mg cm^{-2} to 3 mg cm^{-2}.

19. A method for preparing a modified separator for lithium-sulfur battery comprising the steps of
a) mixing a mixture of the coral-like composite material of any one of claims 1 to 9, a conducting carbon material and a binder; and
b) coating the mixture on a porous and non-electrically-conductive membrane.

20. The method of claim 19, wherein the conducting carbon material is selected from the group consisting of reduced graphene oxide, graphene, graphite, carbon nanotube, carbon fiber, acetylene black, and ketjenblack.

21. The method of claim 19 or 20, wherein the porous and non-electrically-conductive membrane is a glass fiber membrane, a polypropylene and/or a polyethylene electrolytic membrane.

22. A lithium-sulfur battery comprising the coating material of any one of claims 14 to 18.