Summary

~~In one aspect, there~~There is provided a method of synthesizing a porous carbon-sulfur composite, comprising the steps of: (a) carbonizing a carbon material having a metal-organic framework at a temperature in the range of 800 °C to 1000 °C to produce a porous carbon; (b) mixing and heating the porous carbon with sulfur to infuse the sulfur into the pores of the porous carbon; and (c) removing excess sulfur not infused into the pores or present on the surface of the porous carbon.

In one aspect, there is provided a method of synthesizing a porous carbon-sulfur composite, comprising the steps of: (a) carbonizing a carbon material having a metal-organic framework at a temperature in the range of at least 900 °C to less than 1000 °C to produce a porous carbon; (b) mixing and heating the porous carbon with sulfur to infuse the sulfur into the pores of the porous carbon; and (c) removing excess sulfur not infused into the pores or present on the surface of the porous carbon.

Advantageously, the carbonizing step (a) may be performed at a temperature less than 1000 °C, which saves energy and results in high battery performance.

Further advantageously, the removing step (c) may fully remove sulfur on the surface of the porous carbon, which leads to enhanced cycling stability in sodium-sulfur batteries.

In another aspect, there is provided a porous carbon-sulfur composite synthesized by the method as described herein.

In another aspect, there is provided a cathode comprising the porous carbon-sulfur composite as described herein.

In another aspect, there is provided a method of preparing the cathode as described herein, comprising: (a) mechanically treating a mixture comprising the porous carbon-sulfur composite as described herein, a conductive carbon, and a polymer binder; (b) adding an organic solvent into the mixture to yield a slurry; and (c) coating the slurry onto a carbon-coated aluminium foil.

In another aspect, there is provided an electrochemical cell comprising: (a) the cathode as described herein; (b) an anode; and (c) an electrolyte in fluid communication with both said cathode and said anode.

Advantageously, the electrochemical cell may have high battery performance and cycling stability due to the low temperature used to prepare the porous carbon and the complete removal of sulfur on the surface of the porous carbon.

Definitions

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

The term “porous” as used herein when applied to a material is to be interpreted broadly as referring to a material that has pores with a mean effective pore diameter in the range of about 0.1 nm to about 50 nm, and total surface area in the range of about 10 m^2/g to about 1500 m^2/g as determined by the Brunauer-Emmett-Teller (BET) method.

The term “carbonizing” as used herein refers to a method of heating an organic material at a temperature of at least 800 °C to reduce the content of non-carbon elements.

Claims

1. A method of synthesizing a porous carbon-sulfur composite, comprising the steps of:

(a) carbonizing a carbon material having a metal-organic framework at a temperature in the range of at least 900 °C to less than 1000 °C~~800 °C to 1000 °C~~ to produce a porous carbon;

(b) mixing and heating the porous carbon with sulfur to infuse said sulfur into the pores of said porous carbon; and

(c) removing excess sulfur not infused into the pores or present on the surface of said porous carbon.

~~2. The method of claim 1, wherein the temperature for the carbonizing step (a) is at least 900 °C to less than 1000 °C.~~

~~3~~2. The method of claim 1~~ or 2~~, wherein the metal-organic framework of the carbon material is selected from the group consisting of zeolite-type metal-organic frameworks, micro-porous metal-organic framework (MMOFs), porous coordination networks (PCNs) and porous coordination polymers (PCPs).

~~4~~3. The method of claim ~~3~~2, wherein the zeolite-type metal-organic framework is selected from the group consisting of zeolitic imidazolate framework-3 (ZIF-3), zeolitic imidazolate framework-6 (ZIF-6), zeolitic imidazolate framework-8 (ZIF-8), zeolitic imidazolate framework-11 (ZIF-11), zeolitic imidazolate framework-14 (ZIF-14), zeolitic imidazolate framework-20 (ZIF-20), zeolitic imidazolate framework-60 (ZIF-60), zeolitic imidazolate framework-68 (ZIF-68) and zeolitic imidazolate framework-95 (ZIF-95).

~~5~~4. The method of any one of claims 1 to ~~4~~3, wherein the method does not comprise a washing step after the carbonizing step (a).

~~6~~5. The method of any one of claims 1 to ~~5~~4, wherein the sulfur infused into the pores of said porous carbon in step (b) is short-chain sulfur allotropes S_2, S_3 or S_4 and the excess sulfur not infused into the pores or present on the surface of said porous carbon in step (c) is elemental sulfur S_8.

~~7~~6. The method of any one of claims 1 to ~~6~~5, wherein in the mixing and heating step (b), the sulfur and porous carbon are provided in a weight ratio in the range of 5:1 to 1:1.

~~8~~7. The method of any one of claims 1 to ~~7~~6, wherein the removing step (c) comprises evaporating the excess sulfur under an inert gas flow in an open system.

~~9~~8. A porous carbon-sulfur composite synthesized by the method of claim 1.

~~10~~9. The porous carbon-sulfur composite of claim ~~9~~8, wherein the composite has a weight percentage of sulfur in the range of 30 weight % to 40 weight % based on the porous carbon-sulfur composite.

~~11~~10. The porous carbon-sulfur composite of claim ~~9 or 10~~8 or 9, wherein the composite has a weight ratio of carbon and nitrogen in the range of 20:1 to 3:1.

~~12~~11. The porous carbon-sulfur composite of any one of claims ~~9 to 11~~8 to 10, wherein the composite has a sulfur content consisting essentially of S_2, S_3, S_4 and combinations thereof.

~~13~~12. A cathode comprising the porous carbon-sulfur composite of any one of claims ~~9 to 12~~8 to 11.

~~14~~13. A method of preparing the cathode of claim ~~13~~12, comprising the steps of:
(a) mechanically treating a mixture comprising the porous carbon-sulfur composite of any one of claims ~~9 to 12~~8 to 11, a conductive carbon, and a polymer binder;
(b) adding an organic solvent into the mixture to yield a slurry; and
(c) coating the slurry onto a carbon-coated aluminium foil.

~~15~~14. The method of claim ~~14~~13, wherein the mechanically treating step (a) comprises mixing the porous carbon-sulfur composite, the conductive carbon and the polymer binder at a weight ratio of about 7:2:1.

~~16~~15. The method of claim ~~14~~ 13 or ~~15~~14, wherein the adding step (b) further comprises stirring the slurry overnight.

~~17~~16. The method of any one of claims ~~14 to 16~~13 to 15, further comprising a drying step after the coating step (c); wherein the drying step is performed under a temperature in the range of 40 ^{o}C to 80 ^{o}C.

~~18~~17. An electrochemical cell comprising:
(a) the cathode of claim ~~13~~12;
(b) an anode; and
(c) an electrolyte in fluid communication with both said cathode and said anode.

~~19~~18. The electrochemical cell of claim ~~18~~17, further comprising a separator.

~~20~~19. The electrochemical cell of claim ~~18 or 19~~17 or 18, wherein the anode is a sodium anode or a lithium anode.

~~21~~20. The electrochemical cell of any one of claims ~~18 to 20~~17 to 19, wherein the electrolyte is $NaClO_4$ in tetraglyme, $NaCF_3SO_3$ in tetraglyme or a combination thereof.

~~22~~21. The electrochemical cell of any one of claims ~~18 to 21~~17 to 20, wherein the electrolyte has a concentration in the range of 0.1 M to 2 M.