SUMMARY

According to an aspect of the present invention, there is provided a method comprising:

forming an electrically conductive layer comprising a dendrite seeding material in an electrolyte solution disposed between a metal-containing electrode and an electrolyte permeable separator membrane;

growing metal dendrites from the dendrite seeding material toward the metal-containing electrode; and

contacting metal dendrites extending from the metal-containing electrode with metal dendrites extending from the dendrite seeding material;

wherein the electrolyte solution contains metal ions.

According to another aspect of the present invention, there is provided a method comprising:

forming an electrically conductive layer comprising a dendrite seeding material on an electrolyte permeable separator membrane in an electrolyte solution containing a metal-containing electrode, the electrolyte solution containing metal ions.

CLAIMS

1. A method comprising:

forming an electrically conductive layer comprising a dendrite seeding material in an electrolyte solution disposed between a metal-containing electrode and an electrolyte permeable separator membrane;

growing metal dendrites from the dendrite seeding material toward the metal-containing electrode; and

contacting metal dendrites extending from the metal-containing electrode with metal dendrites extending from the dendrite seeding material;

wherein the electrolyte solution contains metal ions.

2. The method of claim 1, wherein contact between metal dendrites extending from the metal-containing electrode with metal dendrites extending from the dendrite seeding material substantially stops growth of the contacting metal dendrites along a major axis.

3. The method of claim 1, further comprising:

intertangling metal dendrites extending from the metal-containing electrode with metal dendrites extending from the dendrite seeding material; and

forming a lithium layer from intertangled metal dendrites.

4. The method of claim 1, further comprising producing the dendrite seeding material, wherein the producing the dendrite seeding material comprises:

functionalizing a carbon separator surface with a chemically-bound anion to produce a functionalized carbon separator surface;

introducing a neutral metal salt to the functionalized carbon separator surface;

reacting the neutral metal salt to yield a metal cation and an anion; and

attracting the metal cation to the chemically-bound anion.

5. The method of claim 4, wherein metal cation comprises lithium, calcium, magnesium, sodium, potassium, or a combination containing lithium, calcium, magnesium, sodium, or potassium.

6. The method of claim 5, wherein the metal cation is a functionalized metal substrate containing a functional group comprising sulfonate, carboxylate, tertiary amine, diazonium salt, or combinations thereof.

7. The method of claim 1, further comprising:

determining a desired porosimetry value for the electrolyte permeable separator membrane;

wherein the electrolyte permeable separator membrane has a porosimetry configured for growing dendrites from the electrolyte permeable separator membrane; and

wherein the growing comprises:

introducing a metal cation gradient for moving metal cations from the metal-containing electrode to the electrolyte permeable separator membrane;

immobilizing a portion of the metal cations on an electrode-facing surface of the electrolyte permeable separator membrane; and

promoting directional growth of the metal dendrites from a membrane-facing side of the metal-containing electrode and from the electrode-facing surface of the electrolyte permeable separator membrane containing the dendrite seeding material.

8. The method of claim 7, further comprising, preventing dendrite growth in a through-plane direction of the electrolyte permeable separator membrane when the metal dendrites extending from the metal-containing electrode contact with metal dendrites extending from the dendrite seeding material.

9. The method of claim 1, wherein the electrolyte permeable separator membrane is selectively permeable.

10. The method of claim 9, wherein the electrolyte permeable separator membrane includes a layer of functionalized nanocarbon particles.

11. The method of claim 1, further comprising producing the electrolyte permeable separator membrane, wherein producing the electrolyte permeable separator membrane comprises:

mixing a particulate carbon source with a plurality of solvents to form a suspension;

identifying a binding element to affect adhesion of suspended carbon particles to a permeable membrane;

applying the binding element to the permeable membrane to define an adhesive membrane;

applying the suspension to the adhesive membrane; and

forming an interface between the suspension and the permeable membrane.

12. The method of claim 11, wherein the suspension comprises plurality of functionalized nanocarbon particles.

13. The method of claim 11, wherein the particulate carbon source comprises carbon black, graphene, graphite, nanographite, or a combination containing carbon black, graphene, graphite, or nanographite.

14. The method of claim 11, wherein the binding element and the electrolyte permeable separator membrane have a substantially similar chemical composition.

15. The method of claim 11, wherein applying the suspension is accomplished by hot pressing, spraying, machine blade coating, brush painting, or a combination of processes that includes hot pressing, spraying, machine blade coating, or brush painting.

16. The method of claim 13, wherein the suspension is uniformly dispersed.

17. The method of claim 13, further comprising maintaining adhesion of the suspension by the binding element.

18. The method of claim 1, further comprising:

coating the electrolyte permeable separator membrane with a non-reactive metal coating;

functionalizing the non-reactive metal coating to yield a functionalized non-reactive metal coating; and

positioning the electrolyte solution between the metal-containing electrode and the functionalized non-reactive metal coating;

wherein the growing comprises:

introducing a metal cation gradient from a metal electrode through the electrolyte permeable separator membrane;

immobilizing a portion of the metal cations on the functionalized non-reactive metal coating; and

promoting the growing of the metal dendrites through the electrolyte solution from the metal-containing electrode and from the electrolyte permeable separator membrane containing the dendrite seeding material.

19. A method comprising

forming an electrically conductive layer comprising a dendrite seeding material on an electrolyte permeable separator membrane in an electrolyte solution containing a metal-containing electrode, the electrolyte solution containing metal ions.

20. The method of claim 19, further comprising causing metal dendrites to grow from the dendrite seeding material toward the metal-containing electrode, and from the metal-containing electrode toward the electrolyte permeable separator membrane, wherein dendrite growth continues at least until dendrites from dendrite seeding material contact dendrites from the metal-containing electrode.