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(54) Title: SOLUTION BASED ENHANCEMENTS OF FUEL CELL COMPONENTS AND OTHER ELECTROCHEMICAL SYSTEMS AND DEVICES

(57) Abstract: This invention relates in general to components of electrochemical devices, and to methods of preparing the components. The components and methods include the use of a composition comprising an ionically conductive polymer and at least one solvent, where the polymer and the solvent are selected based on the thermodynamics of the combination. In one embodiment, the invention relates to a component for an electrochemical device which is prepared from a composition comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected such that $(\delta_{\text{solvent}} - \delta_{\text{solute}}) < 1$, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and where δ_{solute} is the Hildebrand solubility parameter of the polymer. In another embodiment, the invention relates to a method of improving at least one property of a component for an electrochemical device or at least one property of the electrochemical device, the method comprising preparing the component from a composition comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected such that $(\delta_{\text{solvent}} - \delta_{\text{solute}}) < 1$, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and where δ_{solute} is the Hildebrand solubility parameter of the polymer.

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AMENDED CLAIMS**[Received by the International Bureau on 23 January 2007 (23.01.2007)]**

What is claimed is:

1. A component for a fuel cell which is prepared from a composition comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer.
2. The component defined in claim 1 where $|\delta_{\text{solvent}} - \delta_{\text{solute}}| < 1$.
3. The component defined in claim 1 which is an electrode for a fuel cell, wherein the composition further comprises a catalyst.
4. The component defined in claim 1 which is a membrane for a fuel cell.
5. The component defined in claim 1 which is a membrane electrode assembly for a fuel cell comprising a polymer electrolyte membrane having electrodes on both sides, at least one of the membrane and the electrodes prepared from the composition.
6. The component defined in claim 1 wherein the ionically conductive polymer comprises a perfluorosulfonic acid polymer.
7. The component defined in claim 1 which is an electrode for a fuel cell, wherein the composition further comprises a salt, an oxide or a metal alloy.

8. A polymer binder solution comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer, the polymer in the solution functioning as a binder when combined with a catalyst.

9. A catalyst ink comprising a catalyst and a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer.

10. An electrode for an electrochemical device which is prepared from a composition including an ionically conductive polymer, the electrode having a morphology that includes domains of the polymer, at least about 80% of the polymer domains being smaller than about $0.63 \mu\text{m}$ in any one direction.

11. The electrode defined in claim 10 wherein the composition is a catalyst ink including the polymer and further including at least one solvent and a catalyst.

12. The electrode defined in claim 10 wherein the composition comprises a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer.

13. The electrode defined in claim 10 wherein substantially all of the polymer domains are smaller than about $0.63 \mu\text{m}$ in any one direction.

14. The electrode defined in claim 10 wherein the morphology includes the polymer domains throughout the electrode.

15. A membrane electrode assembly for an electrochemical device comprising a polymer electrolyte membrane and a pair of electrodes on opposing sides of the membrane, wherein at least one of the electrodes is prepared from a composition including an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce a true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer, the membrane electrode assembly having improved durability as measured by an open circuit voltage (OCV) holding time of at least about 100 hours.

16. The membrane electrode assembly defined in claim 15 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.

17. The membrane electrode assembly defined in claim 15 wherein the membrane has an OCV holding time of at least about 300 hours.

18. The membrane electrode assembly defined in claim 15 wherein the electrochemical device is a fuel cell.

19. A membrane electrode assembly for an electrochemical device including an electrode which is prepared from a composition including an ionically conductive polymer, the membrane electrode assembly having improved performance as measured by a current density of at least about 0.6 A/cm^2 at a cell potential of 0.7 V with a high frequency resistance less than $0.08 \Omega \cdot \text{cm}^2$.

20. The membrane electrode assembly defined in claim 19 wherein the membrane electrode assembly has improved performance over time as measured by a current density of at least about 0.6 A/cm^2 at a cell potential of 0.7 V with a high frequency resistance less than $0.08 \Omega \cdot \text{cm}^2$, and a current density of at least about 0.04 A/cm^2 at a cell potential of 0.85 V with a high frequency resistance less than $0.08 \Omega \cdot \text{cm}^2$.

21. The membrane electrode assembly defined in claim 19 wherein the electrochemical device is a fuel cell.

22. An electrode for an electrochemical device which is prepared from a composition including a polymer and a catalyst, the electrode having a low catalyst utilization as measured by an electrochemical area of less than about 40 square meters of catalyst per gram of catalyst, and the electrode having improved performance as measured by a current density of at least about 0.6 A/cm^2 at a cell potential of 0.7 V with a high frequency resistance less than $0.08 \Omega \cdot \text{cm}^2$.

23. The electrode defined in claim 22 wherein the electrode has an electrochemical area of less than about 35 square meters of catalyst per gram of catalyst.

24. The electrode defined in claim 22 wherein the electrochemical device is a fuel cell.

25. A component for an electrochemical device which includes a fiber formed from an ionically conductive polymer, the fiber having a diameter of not greater than about 1,000 nm and an aspect ratio within a range of from about 100:1 to about 1000:1 length:diameter, the fiber being processed from a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer.

26. The component defined in claim 25 where $|\delta_{\text{solvent}} - \delta_{\text{solute}}| < 1$.

27. The component defined in claim 25 wherein the component is a membrane electrode assembly for a fuel cell.

28. The component defined in claim 27 wherein the membrane electrode assembly comprises a polymer electrolyte membrane, electrodes on opposing sides of the membrane, and the fiber reinforcing at least one of the electrodes.

29. The component defined in claim 25 wherein the component is an electrode.

30. The component defined in claim 28 wherein the fiber is positioned between the membrane and at least one of the electrodes.

31. The component defined in claim 28 wherein the fiber is positioned within at least one of the electrodes.

32. The component defined in any of claims 25-31 wherein the fiber is formed by electrospinning.

33. The component defined in any of claims 25-31 wherein the fiber has a diameter between about 100 nm and about 500 nm.

34. A composite component for an electrochemical device which includes a fiber formed from an ionically conductive polymer and having a diameter of not greater than about 1,000 nm, and which further includes a component prepared from a composition comprising a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer.

35. The component defined in claim 34 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.

36. The composite component defined in claim 34 wherein the component is a polymer electrolyte membrane.

37. A composite electrode for an electrochemical device comprising an electrode prepared from a catalyst ink comprising a catalyst and a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer, the composite electrode further comprising a fiber formed from the polymer and having a diameter of not greater than about 1,000 nm, the polymer reinforcing the electrode.

38. The composite electrode defined in claim 37 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.

39. The composite electrode defined in claim 37 wherein the fiber is processed from a true solution of the polymer and the at least one solvent.

40. The composite electrode defined in claim 39 wherein the fiber is formed by electrospinning.

41. The composite electrode defined in claim 39 wherein the fiber has a diameter between about 100 nm and about 500 nm.

42. A membrane electrode assembly for a fuel cell comprising a polymer electrolyte membrane, electrodes on opposing sides of the membrane, and fibers reinforcing at least one of the electrodes, the fibers formed from an ionically conductive polymer and having a diameter of not greater than about 1,000 nm, the fibers being processed from a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer.

43. The membrane electrode assembly defined in claim 42 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.

44. The membrane electrode assembly defined in claim 42 wherein the fibers are positioned between the membrane and at least one of the electrodes.

45. The membrane electrode assembly defined in claim 42 wherein at least one of the electrodes is prepared from a catalyst ink comprising a catalyst and a true solution of the polymer and the solvent.

46. The membrane electrode assembly defined in claim 42 wherein the membrane is prepared from a composition comprising a true solution of the polymer and the solvent.

47. The membrane electrode assembly defined in claim 42 wherein the fibers are formed by electrospinning.

48. The membrane electrode assembly defined in claim 42 wherein the fibers have a diameter between about 100 nm and about 500 nm.

49. A composite electrode for an electrochemical device comprising an electrode which is reinforced with a fiber formed from an ionically conductive polymer.

50. The composite electrode defined in claim 49 wherein the electrode includes a binder comprising the ionically conductive polymer.

51. A method of forming a membrane electrode assembly for a fuel cell comprising the steps of:

providing a polymer electrolyte membrane;

applying a fiber onto one side of the membrane, the fiber being formed from an ionically conductive polymer and having a diameter of not greater than about 1,000 nm, the fiber being processed from a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer; and

applying a catalyst ink onto the fiber and onto the side of the membrane to form an electrode, the catalyst ink comprising a catalyst, the polymer and the at least one solvent.

52. The method defined in claim 51 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.
53. The method defined in claim 51 wherein the fiber is formed by electrospinning.
54. The method defined in claim 51 wherein the fiber is a first fiber applied to a first side of the membrane, and the method further comprising applying a second fiber onto a second side of the membrane, the second fiber being formed from the true solution of the polymer and the at least one solvent.
55. The method defined in claim 51 wherein the polymer electrolyte membrane is formed from a composition comprising a true solution of the polymer and at least one solvent.
56. The method defined in claim 51 wherein the polymer and the solvent used to make the catalyst ink are in the form of a true solution.
57. A method of forming a membrane electrode assembly for a fuel cell comprising the steps of:
- forming a reinforced first electrode by applying a fiber and a catalyst ink, the fiber being formed from an ionically conductive polymer and having a diameter of not greater than about 1,000 nm, the fiber being processed from a true solution of the polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce the true solution, where $\delta \text{ solvent}$ is the Hildebrand solubility parameter of the at least one solvent and $\delta \text{ solute}$ is the Hildebrand solubility parameter of the polymer, and the catalyst ink comprising a catalyst, the polymer and the at least one solvent;
 - forming a polymer electrolyte membrane by applying the fiber onto the first electrode; and
 - forming a reinforced second electrode by applying the fiber and the catalyst ink onto the membrane opposite the cathode.

58. The method defined in claim 57 which is a continuous process.

59. The method defined in claim 57 wherein the steps are repeated to form a continuous stack of membrane electrode assemblies.

60. The method defined in claim 57 wherein the polymer and the solvent used to make the catalyst ink are in the form of a true solution.

61. A composition for preparing a component for an electrochemical device, the composition comprising an ionically conductive polymer, a solvent and a co-solvent, wherein the polymer when mixed with the solvent forms a dispersion or a suspension, and wherein the polymer when mixed with both the solvent and the co-solvent forms a true solution, wherein the polymer, the solvent and the co-solvent are selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the average Hildebrand solubility parameter of the solvent and the co-solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer.

62. An electrode for an electrochemical device which is prepared from a composition including an ionically conductive polymer, the electrode having improved performance as measured by a current density of at least about 0.5 A/cm^2 at a cell potential of 0.65 V with a high frequency resistance less than $10 \text{ } \Omega \cdot \text{cm}^2$.

63. A method of improving at least one property of a component for a fuel cell or at least one property of the fuel cell, the method comprising preparing the component from a composition comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer.

64. The method defined in claim 63 where $|\delta_{\text{solvent}} - \delta_{\text{solute}}| < 1$.
65. The method defined in claim 63 wherein the component is an electrode.
66. The method defined in claim 63 wherein the component is a polymer electrolyte membrane.
67. The method defined in claim 63 wherein the component is a membrane electrode assembly.
68. The method defined in claim 63 wherein the component is a stack of membrane electrode assemblies.
69. The method defined in claim 63 wherein the component is a gas diffusion layer.
70. A method of improving the durability of a first component for a fuel cell, the method comprising preparing the first component or a related second component from a composition comprising a true solution of an ionically conductive polymer and at least one solvent, the polymer and the at least one solvent being selected based on the relationship $|\delta_{\text{solvent}} - \delta_{\text{solute}}|$ in order to produce the true solution, where δ_{solvent} is the Hildebrand solubility parameter of the at least one solvent and δ_{solute} is the Hildebrand solubility parameter of the polymer.
71. The method defined in claim 70 where $|\delta_{\text{solvent}} - \delta_{\text{solute}}| < 1$.
72. The method defined in claim 70 wherein the durability of the first component is improved by preparing the second component from the composition.

73. The method defined in claim 70 wherein the first component is a polymer electrolyte membrane and the second component is an electrode, and wherein the durability of the membrane is improved by preparing the electrode from the composition.

74. A method of selecting at least one solvent of a composition useful for preparing a component for a fuel cell, the composition including an ionically conductive polymer and the at least one solvent, the method comprising selecting the polymer and the at least one solvent based on the relationship $|\delta \text{ solvent} - \delta \text{ solute}|$ in order to produce a true solution, where δ solvent is the Hildebrand solubility parameter of the at least one solvent and δ solute is the Hildebrand solubility parameter of the polymer.

75. The method defined in claim 74 where $|\delta \text{ solvent} - \delta \text{ solute}| < 1$.

76. The method defined in claim 74 wherein the component is a membrane electrode assembly.

77. The method defined in claim 74 wherein the component is a polymer electrolyte membrane.

78. The method defined in claim 74 wherein the component is an electrode, and wherein the composition is a catalyst ink further comprising a catalyst.

79. An electrode for an electrochemical device which is prepared from a composition including a polymer and a catalyst, the electrode having a low catalyst utilization as measured by an electrochemical area of less than about 100 square meters of catalyst per gram of catalyst, and the electrode having improved performance as measured by a current density of at least about 0.6 A/cm² at a cell potential of 0.7 V with a high frequency resistance less than 0.08 $\Omega \cdot \text{cm}^2$.