taken in conjunction with the accompanying figures and this background of the disclosure.

Summary

According to the present disclosure, there is provided a composite material comprising:

an ionic liquid A; and

a polymer matrix comprising a network of crosslinked poly(ionic liquid B).

According to a first aspect of the present disclosure, there is provided an electrochromic device comprising an electrolyte sandwiched between two electrodes, the electrolyte comprising a composite material comprising:

an ionic liquid A, wherein the ionic liquid A is 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIMTFSI); and

a polymer matrix comprising a network of crosslinked poly(ionic liquid B), wherein the polymer matrix is formed by reaction of an ionic liquid B with a crosslinking agent, wherein the ionic liquid B is 1-butyl-3-vinylimidazolium bis(trifluoromethanesulfonyl) imide (BVIMTFSI), and the crosslinking agent is poly(ethylene glycol) diacrylate (PEGDA).

Advantageously, the composite materials are in a solid state or immobilized, and are thus non-volatile (i.e., do not evaporate) and do not leak and/or seep. Furthermore, the composite materials are flexible and/or deformable with low glass transition temperature (T_g) and modulus. The composite materials are advantageously stable with long lifetime, durable and do not pose any safety concerns.

Also advantageously, the composite materials are highly transparent in visible and part of near-infrared region (i.e., 380 nm to 1250 nm). This allows the composite material to be used for various applications such as electrochromic devices.

Advantageously, the polymer matrix may comprise chemicals with similar structures as well as compatibilized polarity and solubility. This advantageously results in a homogenized polymer matrix where the chemicals in the polymer matrix are miscible with one another and form a single phase. Furthermore, the chemicals in the polymer matrix may advantageously remain miscible with one another during temperature changes such that there is no phase separation occurring in the polymer matrix when temperature changes. This temperature independence means that the composite materials of the present invention do not undergo phase changes with temperature variations. The composite materials may remain stable and do not experience phase separation or aggregation. This advantage can be attributed to the presence of electrostatic interactions between the ionic liquid and the polymer matrix. These interactions

in solid state. As a result, the composite materials possess excellent physicochemical stability, including thermal stability (from -20 °C to 100 °C), electrochemical stability, and air stability, allowing them to perform in various conditions and applications.

Even more advantageously, the composite materials exhibit high ionic conductivity in the region of mS/cm, allowing good electrochemical and electrochromic performance (in terms of optical modulation, response time, stability) with either organic or inorganic electrochromic materials. Hence, the composite materials may be utilized as solid-state composite materials for electrochromic applications due to its high ionic conductivity with promising thermal and electrochemical stability.

According to the present disclosure, there is provided a method of preparing a composite material as disclosed herein, comprising the steps of:

(i) preparing a mixture of ionic liquid A, ionic liquid B, crosslinking agent, and a photoinitiator;

(ii) curing the mixture with light irradiation,

wherein the crosslinking agent reacts with ionic liquid B to form a polymer matrix comprising a network of crosslinked poly(ionic liquid B).

Advantageously, the disclosed method enables the preparing of composite materials in less than a minute under ambient conditions. The disclosed method is fast, simple and easy to perform. Furthermore, the materials required for the method are inexpensive and easy to obtain.

According to the present disclosure, there is provided an electrochromic device comprising an electrolyte sandwiched between two electrodes, wherein the electrolyte comprises the composite material as disclosed herein.

Furthermore, this ensures better interface quality and reduces the likelihood of defects of the electrolytes in the electrochromic devices. In addition, it may be easy to apply and handle a low viscosity electrolyte and thus the electrolyte is able to be applied directly on the electrode for in-situ polymerization of electrolyte in the electrochromic device. The in-situ method may be an effective approach to improve the processability and enhance electrolyte contact, while maintaining the dimension of the composite materials in the electrochromic devices, which in turn give excellent electrochromic performance.

Further advantageously, the polymer matrix may be formed by reaction of alkene with reactive groups which allows the polymer matrix to be formed via in-situ polymerization. This greatly enhances its processability and facilitates its translation into industrial settings, offering controllability over the manufacturing process.

According to another aspect of the present disclosure, there is provided a use of a composite material as an electrolyte sandwiched between two electrodes in an electrochromic device, the composite material comprising:

an ionic liquid A, wherein the ionic liquid A is 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIMTFSI); and

a polymer matrix comprising a network of crosslinked poly(ionic liquid B), wherein the polymer matrix is formed by reaction of an ionic liquid B with a crosslinking agent, wherein the ionic liquid B is 1-butyl-3-vinylimidazolium bis(trifluoromethanesulfonyl) imide (BVIMTFSI), and the crosslinking agent is poly(ethylene glycol) diacrylate (PEGDA)

Claims

1. An electrochromic device comprising an electrolyte sandwiched between two electrodes, the electrolyte comprising a composite material comprising:

   an ionic liquid A, wherein the ionic liquid A is 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIMTFSI); and

   a polymer matrix comprising a network of crosslinked poly(ionic liquid B), wherein the polymer matrix is formed by reaction of an ionic liquid B with a crosslinking agent, wherein the ionic liquid B is 1-butyl-3-vinylimidazolium bis(trifluoromethanesulfonyl) imide (BVIMTFSI), and the crosslinking agent is poly(ethylene glycol) diacrylate (PEGDA).

2. The electrochromic device of claim 1, wherein the polymer matrix is formed by reaction of an alkene of ionic liquid B with an acrylate of the crosslinking agent.

3. The electrochromic device of claim 1 or 2, further comprising a metal borate complex.

4. The electrochromic device of claim 3, wherein

   the metal borate complex is lithium methacrylate trifluoroborate complex in propylene carbonate.

5. The electrochromic device of any one of claims 1 to 4, wherein the composite material is an ionogel.

6. The electrochromic device of any one of claims 1 to 5, wherein the composite material has a transmittance of about 90% to about 98% at 1 mm thickness.

7. The electrochromic device of any one of claims 1 to 6, where the composite material has a crosslink density of about 0.02 mol/g to about 0.05 mol/g, or 0.035 mol/cm^3 to about 0.06 mol/cm^3.

8. A method of forming an electrochromic device comprising:

   (i) applying a mixture of ionic liquid A, ionic liquid B, crosslinking agent, a photoinitiator, and optionally a metal borate complex between two electrodes; and

   (ii) curing the mixture with light irradiation,

   wherein the crosslinking agent reacts with ionic liquid B to form a polymer matrix comprising a network of crosslinked poly(ionic liquid B); and

   wherein the ionic liquid A is 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIMTFSI), the ionic liquid B is 1-butyl-3-vinylimidazolium bis(trifluoromethanesulfonyl) imide (BVIMTFSI), and the crosslinking agent is poly(ethylene glycol) diacrylate (PEGDA).

9. The method of claim 8, wherein step (ii) is performed for a duration of about 30 seconds to about 90 seconds.

10. The method of claim 8 or 9 , wherein the photoinitiator is selected from the group consisting of diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide (TPO), benzophenone, phenyl bis (2,4,6-trimethylbenzoyl)phosphine oxide, 2-hydroxy-2-methyl-1-phenyl-propan-1-one, 2-hydroxy-4'-(2-hydroxyethoxy)-2-methylpropiophenone, 2,2'-azobis[2-methyl-n-(2-hydroxyethyl)propionamide], 2,2-dimethoxy-2-phenylacetophenone, lithium phenyl(2,4,6-trimethylbenzoyl)phosphinate), and ethyl (2,4,6-trimethylbenzoyl) phenylphosphinate.

11. Use of a composite material as an electrolyte sandwiched between two electrodes in an electrochromic device, the composite material comprising:

    an ionic liquid A, wherein the ionic liquid A is 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide (EMIMTFSI); and

    a polymer matrix comprising a network of crosslinked poly(ionic liquid B), wherein the polymer matrix is formed by reaction of an ionic liquid B with a crosslinking agent, wherein the ionic liquid B is 1-butyl-3-vinylimidazolium bis(trifluoromethanesulfonyl) imide (BVIMTFSI), and the crosslinking agent is poly(ethylene glycol) diacrylate (PEGDA).

12. The use of claim 11, wherein the polymer matrix is formed by reaction of an alkene of ionic liquid B with an acrylate of the crosslinking agent.

13. The use of claim 11 or 12, further comprising a metal borate complex.

14. The use of claim 13, wherein the metal borate complex is lithium methacrylate trifluoroborate complex in propylene carbonate.

15. The use of any one of claims 11 to 14, wherein the composite material is an ionogel.

16. The use of any one of claims 11 to 15, wherein the composite material has a transmittance of about 90% to about 98% at 1 mm thickness.

17. The use of any one of claims 11 to 16, where the composite material has a crosslink density of about 0.02 mol/g to about 0.05 mol/g, or 0.035 mol/cm^3 to about 0.06 mol/cm^3.