An electrochromic composition is provided. The electrochromic composition includes 0.5–10 parts by weight of a first oxidizable polymer, 0.5–10 parts by weight of a reducible organic compound, 0.5–20 parts by weight of an electrolyte, and 60–98.5 parts by weight of a solvent. The first oxidizable polymer is a polymer of 1 molar part of diamine and 0.1–20 molar parts of dicarboxylic acid, diacyl chloride, or dianhydride, a mixture of the aforementioned polymers, or a copolymer of the aforementioned polymers. An electrochromic element including the aforementioned electrochromic composition is also provided.
FIG. 2
**FIG. 3A**

[Graph showing current density (mA/cm²) vs. potential (V) with markers for 1st and 2nd oxidation potentials.]

**FIG. 3B**

[Graph showing current density (mA/cm²) vs. potential (V) with markers for 1st and 2nd oxidation potentials.]
Comparative Example 2

1st oxidation potential (1.7V)

2nd oxidation potential (2.6V)

j (mA/cm²) vs. Potential (V)

Example 2

1st oxidation potential (1.1V)

2nd oxidation potential (1.7V)

j (mA/cm²) vs. Potential (V)

FIG. 4A

FIG. 4B
FIG. 5
Example 3

Example 4

FIG. 6A

FIG. 6B
Example 4

\[ \text{Transmittance} \% \]

Example 5

\[ \text{Transmittance} \% \]

Example 6

\[ \text{Transmittance} \% \]

FIG. 7

FIG. 8
FIG. 9

Example 6

--- 0.0V

--- 1.5V

Transmittance (%)

Wavelength (nm)
ELECTROCHROMIC COMPOSITION AND ELECTROCHROMIC ELEMENT

BACKGROUND

The present invention relates to an electrochromic composition and an electrochromic element.

Description of the Related Art

Electrochromic-related devices are attractive in green energy industries due to their low driving voltage (<3.0V) and bistability. The technique is deemed as an important industry in future decades, and electrochromic materials play an important role in the industry. Recently, the major part of electrochromic material is inorganic oxides for longer lifetime and endurance; however, films thereof are prepared by using expensive processes and equipment such as vacuum deposition, spray pyrolysis, or sputtering. Even ignoring the cost of processing, an inorganic oxide still has shortcomings such as a slow electrochromic rate, less color variation, and the like. In an organic system, electrochromic materials use conjugated polymer with more color variations and fast electrochromic rates. However, the conjugated compound has shortcomings such as expensive monomers, complicated synthesis, and formation by electro-polymerization. The electrochromic conjugated polymer has a deep color due to its conjugated length. Although the deep color can be lightened by applying a voltage, the conjugated polymer cannot be fully transparent. In other words, the conjugated polymer must be electrified to achieve a transparent state, thereby leading to the problem of high energy consumption.

Small molecules such as triarylamine and its derivatives have good electron hole conductive properties, and are mostly applied to the electron conductive layer of an organic light-emitting diode (OLED), and may also be applied in electrochromic applications. However, so far, the derivatives of triarylamine cannot appear as truly black in electrochromic applications.

To sum up the information above, a novel electrochromic organic material is currently needed to simultaneously achieve the goals of possessing high transparent property at usual time and possessing a high shielding effect after an electrochromic reaction.

BRIEF SUMMARY OF THE INVENTION

According to an embodiment, an electrochromic composition is provided. The electrochromic composition includes 0.5–10 parts by weight of a first oxidizable polymer, 0.5–10 parts by weight of a reducible organic compound, 0.5–20 parts by weight of an electrolyte, and 60–98.5 parts by weight of a solvent. The first oxidizable polymer is a polymer of 1 molar part of diamine and 0.1–20 molar parts of dicarboxylic acid, diacyl chloride, or diacyl anhydride, a mixture of the aforementioned polymers, or a copolymer of the aforementioned polymers. The diamine is Formula 1, Formula 2, or a combination thereof:
R is —H, —F, —Br, —Cl, —I, —CH₃, —C₂H₅, —C₃H₇, —n-C₆H₁₃, —s-C₆H₁₃, —t-C₆H₁₃, —OC₃H₇, —OC₆H₁₃, —OC₉H₂₁, or —OC₁₅H₃₁;

Ar² is Formula 9, Formula 10, Formula 11, or Formula 12:

Wherein the dicarboxylic acid is Formula 13, the diacyl chloride is Formula 14, and the dianhydride is Formula 15:

R¹ is selected from the group consisting of —(CH₂)ᵣ, Formula 9, Formula 16, Formula 17, Formula 18, Formula 19, Formula 20, Formula 21, Formula 22, Formula 23, and Formula 24, wherein r is between 1 and 12:

R² is cyclic aliphatic or organic aromatic.

According to another embodiment, an electrochromic element is provided. The electrochromic element includes a first transparent conductive layer, a second transparent conductive layer disposed opposite to the first trans-
parent conductive layer, an adhesive spacer, connected to the surfaces of the first transparent conductive layer and the second transparent conductive layer. The first transparent conductive layer, the second transparent conductive layer, and the adhesive spacer form a cell. Then, the aforementioned electrochromic composition is filled in the cell.

A detailed description is given in the following embodiments with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

FIG. 1A illustrates a schematic diagram of an electrochromic element in accordance with an embodiment of the present disclosure;

FIG. 1B illustrates a schematic diagram of an electrochromic element in accordance with another embodiment of the present disclosure;

FIG. 2 illustrates the overlapping absorption spectrum of each component of the electrochromic composition in accordance with an embodiment of the present disclosure;

FIG. 3A illustrates the cyclic voltammetry spectrum of the electrochromic composition in accordance with some examples of the present disclosure;

FIG. 3B illustrates the cyclic voltammetry spectrum of the electrochromic composition in accordance with some examples of the present disclosure;

FIG. 4A illustrates the cyclic voltammetry spectrum of the electrochromic composition in accordance with some other examples of the present disclosure;

FIG. 4B illustrates the cyclic voltammetry spectrum of the electrochromic composition in accordance with some other examples of the present disclosure;

FIG. 5 illustrates the cyclic voltammetry spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure;

FIG. 6A illustrates the transmission spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure;

FIG. 6B illustrates the transmission spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure;

FIG. 7 illustrates the transmission spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure;

FIG. 8 illustrates the transmission spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure; and

FIG. 9 illustrates the transmission spectrum of the electrochromic composition in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawing.

The present invention will be described with respect to particular embodiments and with reference to certain drawings, but the invention is not limited thereto and is only limited by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated for illustrative purposes and are not drawn to scale. The dimensions and the relative dimensions do not correspond to actual dimensions in the practice of the invention.

The present disclosure provides an electrochromic composition by using a bipolar design of an oxidizable organic polymer and a reducible organic small molecule. The neutral state of the electrochromic composition has a high transparency and can decrease the driving voltage and improve the electrochemical stability. In addition, the transmittance of the redox state of electrochromic composition may be reduced by the complementation of the colors produced by the oxidizable organic polymer and the reducible organic small molecule, making the electrochromic composition have a deeper color, or even truly black.

The first oxidizable polymer is a polymer of a molar part of diamine and 0.1–20 molar parts of dicarboxylic acid, diacyl chloride, or dihydride, a mixture of the aforementioned polymers, or a copolymer of the aforementioned polymers. An overly high ratio of dicarboxylic acid, diacyl chloride, or dihydride may lower the color change contrast of the electrochromic composition in an oxidation state. An overly low ratio of dicarboxylic acid, diacyl chloride, or dihydride may increase the electrochromic oxidation active sites, and coupling side reactions can easily occur. The diamine is Formula 1, Formula 2, or a combination thereof:

\[
\text{H}_2\text{N} \quad \text{N} \quad \text{Ar}^1 \quad \text{NH}_2
\]
In Formula 3, Formula 7, and Formula 8, R is —H, —F, —Br, —Cl, —I, —CH₃, —C₂H₅, —C₃H₇, —n-C₄H₉, —s-C₄H₉, —t-C₄H₉, —C₆H₁₁, —C₇H₁₅, —OCH₃, —OC₂H₅, —OC₃H₇, —n-OCC₄H₉, —s-OCC₄H₉, —t-OCC₄H₉, —OC₆H₁₁, —OC₇H₁₅, or —OC₇H₁₅.

In Formula 2, Ar² is Formula 9, Formula 10, Formula 11, or Formula 12. In Formula 12, the definition of Ar³ is the same as described above, and hence is not described again to avoid unnecessary repetition.

In Formula 1, Ar¹ is Formula 3, Formula 4, Formula 5, Formula 6, Formula 7, or Formula 8:

In Formula 13 and Formula 14, R¹ is selected from the group consisting of -(CH₂)ₙ-, Formula 9, Formula 16, Formula 17, Formula 18, Formula 19, Formula 20, Formula 21, Formula 22, Formula 23, and Formula 24, wherein n is between 1 and 12. If the number n is too large, the best resistance of the electrochromic material decreases. If the number n is too small, the solubility of the electrochromic material decreases.
raphenylbenzidine (TPB), may be obtained from the intermediate products of dinitro through a reduction reaction. Then, the dicarboxylic acid, dicarboxylic acid, or di-anhydride of various aromatics and aliphatics undergo a condensation reaction with dienamine monomers to obtain transparent oxidizable organic polymers. The aforementioned transparent oxidizable organic polymers may be applied not only to the electrochromic elements, but they may also be applicable as compounds with electron conductive properties used in the redox sensors, solar cells, organic electroluminescent devices, nonlinear materials, etc.

**[0041]** The transparent oxidizable organic polymers produced by the condensation reaction of the aforementioned dienamine, and the dicarboxylic acid, dicarboxylic acid, or di-anhydride of various aromatics and aliphatics may include polymers having a structure represented by Formula 25, Formula 26, Formula 27, or Formula 28, or a copolymer of the aforementioned polymers:

[0039] In Formula 15, R² is cyclic aliphatic or organic aromatic.

[0040] In an embodiment of the present disclosure, the intermediate products of dinitro may be manufactured in accordance with the synthetic methods described in J. Polym. Sci. Part A: Polym. Chem. 2006, 44, pp 4579-4592 and J. Mater. Chem. 2011, 21, 6230-6237. Then, the dienamine monomers, for example, monomers such as triphenylamine dienamine, triarylamine dienamine, pentaphenyl dienamine, hexaphenyl dienamine derived from triphenylamine (TPA), N,N,N', N'-tetraphenyl-p-phenylenediamine (TPPA), N, N,N',N'-tet-
In Formula 25, Formula 26, Formula 27, Formula 28, the definition of $\text{Ar}_1$, $\text{Ar}_2$, R, R$^1$, R$^2$ is the same as described above, wherein m is between 1 and 300. If m is too large, the viscosity is too large and it is inconvenient for the coating process. If m is too small, the molecular weight is not high enough which results in poor film-forming properties, causing poor heat resistance and lowering the range of applicable operative temperatures.

In an embodiment of the present disclosure, the aforementioned transparent oxidizable organic polymers may include a copolymer of the polymer having a structure represented by Formula 25, as shown by Formula 29:

In Formula 29, each of $\text{Ar}_3$ and $\text{Ar}_4$ may independently be Formula 3, Formula 4, Formula 5, Formula 6, Formula 7, or Formula 8, wherein $\text{Ar}_3$ and $\text{Ar}_4$ are different, and m is between 1 and 300. When forming the copolymer shown by Formula 29, the molar ratio of the polymer monomer including $\text{Ar}_3$ functional group to the polymer monomer including $\text{Ar}_4$ functional group may be between 99:1 and 1:99.

In an embodiment of the present disclosure, the aforementioned transparent oxidizable organic polymers may include a copolymer of polymers having a structure represented by Formula 26, as shown by Formula 30:
[0046] In Formula 30, each of $\text{Ar}^2$ and $\text{Ar}^6$ may independently be Formula 9, Formula 10, Formula 11, or Formula 12, wherein $\text{Ar}^2$ and $\text{Ar}^6$ are different, and $m$ is between 1 and 300. When forming the copolymer shown by Formula 30, the molar ratio of the polymer monomer including $\text{Ar}^2$ functional group to the polymer monomer including $\text{Ar}^6$ functional group may be between 99:1 and 1:99.

[0047] In an embodiment of the present disclosure, the aforementioned transparent oxidizable organic polymers may include a copolymer of polymers having a structure represented by Formula 27, as shown by Formula 31:

![Formula 31](image)

[0048] In Formula 31, each of $\text{Ar}^2$ and $\text{Ar}^6$ may independently be Formula 3, Formula 4, Formula 5, Formula 6, Formula 7, or Formula 8, wherein $\text{Ar}^2$ and $\text{Ar}^6$ are different, and $m$ is between 1 and 300. When forming the copolymer shown by Formula 31, the molar ratio of the polymer monomer including $\text{Ar}^2$ functional group to the polymer monomer including $\text{Ar}^6$ functional group may be between 99:1 and 1:99.

[0049] In an embodiment of the present disclosure, the aforementioned transparent oxidizable organic polymers may include a copolymer of polymers having a structure represented by Formula 28, as shown by Formula 32:

![Formula 32](image)

[0050] In Formula 32, each of $\text{Ar}^2$ and $\text{Ar}^6$ may independently be Formula 9, Formula 10, Formula 11, or Formula 12, wherein $\text{Ar}^2$ and $\text{Ar}^6$ are different, and $m$ is between 1 and 300. When forming the copolymer shown by Formula 32, the molar ratio of the polymer monomer including $\text{Ar}^2$ functional group to the polymer monomer including $\text{Ar}^6$ functional group may be between 99:1 and 1:99.

[0051] In an embodiment of the present disclosure, the aforementioned diamine is Formula 33, the aforementioned dicarboxylic acid is Formula 34, and the transparent oxidizable organic polymer formed through the polymerization thereof is represented by Formula 25, wherein $\text{Ar}^3$ has a structure represented by Formula 3, $R$ is $-\text{OCH}_3$, and $R'$ has a structure represented by Formula 18.
In an embodiment of the present disclosure, the aforementioned diamine is Formula 33, the aforementioned diacryl chloride is Formula 35, and the transparent oxidizable organic polymer formed through the polymerization thereof is represented by Formula 25, wherein Ar\(^1\) has a structure represented by Formula 3, R is —OCH\(_3\), and R\(^1\) is —(CH\(_2\))\(_4\) —.

In an embodiment of the present disclosure, the aforementioned diamine is Formula 36, the aforementioned diacryl chloride is Formula 35, and the transparent oxidizable organic polymer formed through the polymerization thereof is represented by Formula 26, wherein Ar\(^2\) has a structure represented by Formula 9, R is —OCH\(_3\), and R\(^1\) is —(CH\(_2\))\(_4\) —.

In an embodiment of the present disclosure, the aforementioned diamine is Formula 37, the aforementioned diacryl chloride is Formula 34, and the transparent oxidizable organic polymer formed through the polymerization thereof is represented by Formula 26, wherein Ar\(^2\) has a structure represented by Formula 10, R is —OCH\(_3\), and R\(^1\) has a structure represented by Formula 18.
In an embodiment of the present disclosure, the aforementioned diamine is Formula 37, the aforementioned diacetyl chloride is Formula 35, and the transparent oxidizable organic polymer formed through the polymerization thereof is represented by Formula 26, wherein Ar₂ has a structure represented by Formula 10, R is —OCH₃, and R¹ is —(CH₂)₄—.

In an embodiment of the present disclosure, the aforementioned reducible organic compound is Formula 38, Formula 39, Formula 40, derivatives thereof, or a combination thereof:

In Formula 40, R³ is H or C₁₁–C₁₂ alkyl. In an embodiment of the present disclosure, R² is C₆H₃–.

In an embodiment of the present disclosure, the transparent oxidizable polymer may be organic ammonium salts or inorganic ammonium salts. In one embodiment of the present disclosure, the electrolyte may contain at least one inert conducting salt. Examples of suitable inert conducting salts include lithium salts, sodium salts, and tetraalkylammonium salts. Suitable solvents include solvents which are redox-inert at the selected voltages and which cannot dissociate to form electrophiles or nucleophiles, or the solvents themselves cannot react as sufficiently strong electrophiles or nucleophiles, and thus could not react with the colored ionic free radicals. Examples of suitable solvents include propylene carbonate (PC), gamma-butyrolactone (GBL), N,N-dimethylacetamide, dimethylformamide, N-methylpyrrolidone, N-methylacetamide, toluene, or mixtures thereof. Preferable solvents are propylene carbonate (PC) and the mixture of propylene carbonate (PC) and N,N-dimethylacetamide. The concentration of the electrolyte may be between 0.01 M and 3.0 M.

In an embodiment of the present disclosure, the molar ratio of the transparent oxidizable polymer to the reducible organic polymer may be between about 1:50 and 50:1. By controlling the ratio of the transparent oxidizable polymer to the reducible organic polymer, an effect of changing colors may be accomplished. In one embodiment, the molar ratio of the transparent oxidizable polymer to the electrolyte may be between 1:1 and 1:300. In one embodiment, the molar ratio of the reducible organic compound to the electrolyte may be between 1:1 and 1:300. An overly low ratio of the electrolyte may slow down the rate of color-changing and color-fading.

In an embodiment of the present disclosure, the weight average molecular weight of the transparent oxidizable polymer may be between 1,000 and 200,000. If the weight average molecular weight of the transparent oxidizable polymer is too high, the viscosity is too high and it is inconvenient for the coating process. If the weight average...
molecular weight of the transparent oxidizable polymer is too low, the film-forming properties of the polymer are poor. [0062] In an embodiment of the present disclosure, the transparent oxidizable polymer may be a film layer, and the thickness of the film layer may be between 50 nm and 50 μm. If the thickness of the film layer is too thin, the contrast of the full band is lower. If the thickness of the film layer is too thick, it is difficult to appear as truly black after the electrochromic reaction through the interaction with the electrolytes.

[0063] The electrochromic composition is obtained after mixing 0.5–10 parts by weight of the transparent oxidizable polymers and 0.5–10 parts by weight of the reducible organic compounds with the electrolyte solution (including 0.5–20 parts by weight of the electrolyte and 60–98.5 parts by weight of the solvent). In an embodiment of the present disclosure, the transparent oxidizable polymer may be a film layer, which may form the electrochromic composition of the present disclosure with an electrolyte layer combination including the reducible organic compounds, the electrolyte, and the solvent.

[0064] In one embodiment, as shown in FIG. 1A, the electrochromic element 10 provided by the present disclosure includes a first transparent conductive layer 11, and a second transparent conductive layer 17 disposed opposite to the first transparent conductive layer 11. An adhesive spacer 12 is connected to the surfaces of the first transparent conductive layer 11 and the second transparent conductive layer 17, and forms a cell with the first transparent conductive layer 11 and the second transparent conductive layer 17. The electrochromic composition 13 is filled in the cell. The electrochromic composition 13 may be formed by mixing an oxidizable polymer 14 and a reducible organic compound 15, and then adding an electrolyte solution 16 including electrolyte and solvent. In other embodiments, the electrochromic composition 13 may further include a second oxidizable organic compound (not shown) other than the oxidizable polymer 14 and the reducible organic compound 15.

[0065] In another embodiment, as shown in FIG. 1B, the electrochromic element 20 provided by the present disclosure includes a first transparent conductive layer 21, and a second transparent conductive layer 27 disposed opposite to the first transparent conductive layer 21. The oxidizable polymer solution may be coated on the first transparent conductive layer 21 using a wet coating method. A film layer 22 is formed after baking. The adhesive spacer 23 connects with the surface of the film layer 22 and the surface of the second transparent conductive layer 28 facing the surface of the film layer 22. A cell is formed by the adhesive spacer 23, the film layer 22, and the second transparent conductive layer 27. The electrolyte is dissolved in a solvent to form an electrolyte solution 26. The electrolyte solution 26 which includes reducible organic compound 25 is used as an electrolyte layer 24 to fill the cell. In another embodiment, the electrolyte layer 24 is in a gel state, and may be coated on the film layer 22 using the same wet coating method. Then, the second transparent conductive layer 27 is attached. In this embodiment, the film layer 22 and the electrolyte layer 24 are together used as the electrochromic composition 27 of the present disclosure. In other embodiments, the electrolyte solution 26 may further include a second oxidizable organic compound (not shown) other than the reducible organic compound 25.

[0066] The transparent conductive layers 11, 17, 21, 28 may include transparent substrates and conductive layers. The transparent substrate may be made of glass or plastic, for example, polyethylene terephthalate, polyethylene naphthalate, polycarbonate, or high temperature resistant plastic. The conductive layer may include indium tin oxide (ITO), antimony- or fluorine-doped tin oxide (FTO), antimony- or aluminum-doped zinc oxide, or tin oxide. The adhesive spacers 12 and 23 may be formed by blending spacer elements with a thermosetting or photochemically curable adhesive agent. Spacer elements may be, for example, small spheres of plastic or glass or certain sand fractions. The thickness of the adhesive spacers 12 and 23 may be between 10 μm and 500 μm, for example, between 50 μm and 300 μm. The distance between the first transparent conductive layer and the second transparent conductive layer may be between 10 μm and 500 μm. If the distance between the transparent conductive layers is too small, current leakage and uneven color changing may occur. If the distance between the transparent conductive layers is too large, the reaction rate becomes slow.

[0067] When the electrochromic element is out of power, the original neutral state of the electrochromic composition is transparent. After applying a suitable voltage, the color becomes deeper, and the electrochromic composition changes from transparent to a specific color such as gray, dark green, dark blue black, or black because of the complementary effect of the colors produced by the oxidizable polymers and reducible organic compounds. Once the power is turned off, the electrochromic composition is restored to the original transparent state in a short period of time (less than 3 seconds). Compared to those using single oxidizable polymer as the electrochromic compound, the color-changing effect may be achieved by a lower driving voltage and in a shorter time. Also, the optical contrast is improved and makes the color-changing state appear truly black.

[0068] Below, exemplary embodiments will be described in detail with reference to the accompanying drawings so as to be easily realized by a person having ordinary knowledge in the art. The inventive concept may be embodied in various forms without being limited to the exemplary embodiments set forth herein. Descriptions of well-known parts are omitted for clarity, and like reference numerals refer to like elements throughout.

Preparation of Diamine Monomers


[0070] Diamine monomer (1): triphenylamine (TPA) containing methoxy group (the structure represented by Formula 1, wherein Ar1 is Formula 3, R is —OCH3);

[0071] Diamine monomer (2): N,N,N’,N’-tetrphenyl-p-phenylenediamine (TPPA) containing methoxy group (the structure represented by Formula 2, wherein Ar2 is Formula 9, R is —OCH3); and

[0072] Diamine monomer (3): N,N,N’,N’-tetrphenylbenzidine (TPB) containing methoxy group (the structure represented by Formula 2, wherein Ar2 is Formula 10, R is —OCH3).
Preparation of Viologen

[0073] 50 g of 4,4'-bipyridine was dissolved in 500 g of acetonitrile, and then 115 g of heptyl bromide was added. A heating reflux reaction was performed for 18 hours. Then, the golden precipitation was filtered, dried, and crystallized in ethanol to obtain HVBR$_2$. 10.00 g of HVBR$_2$ was dissolved in 100 mL of deionized water, mixed with 100 mL of saturated NaBH$_4$ aqueous solution to produce white solid precipitation of heptyl viologen tetrafluoroborate (HV(BF$_4$)$_2$). Then, after filtration, it was recrystallized in ethanol to white flake crystals.

Preparation Example A1 (Diamine Monomer (1)+Dicarboxylic Acid to Form Polyamine)

[0074] 305.37 mg (1.0 mmol) of diamine monomer (1), 258.23 mg (1.0 mmol) of 4,4'-oxydibenzoeic acid, and 100 mg of calcium chloride were added to 0.8 mL of triphenyl phosphate, 0.4 mL of pyridine, and 2.0 mL of N-methylpyrrolidone (NMP), heated at 105° C. and stirred for 3 hours. The resulting polymer solution was slowly poured into 300 mL of methanol, stirred and filtered to collect the tough fibrous precipitation. Then, it was fully washed with hot water and methanol and dried at 100° C. under vacuum. The polymer was dissolved by using dimethylacetamide (DMAc) and then precipitated in methanol. This step was repeated twice to finish the purification. The resulting product was called TPA-O for short.

Preparation Example A2 (Diamine Monomer (2)+Dicarboxylic Acid to Form Polyamine)

[0075] The same process as in Preparation Example A1 was repeated, except that diamine monomer (1) was replaced by diamine monomer (2): (N,N'-bis(4-aminophenyl)-N,N'-di(4-methoxyphenyl)-1,4-phenylenediamine). The resulting product was called TPA-O for short.

Preparation Example A3 (Diamine Monomer (2)+Dicarboxylic Acid to Form Polyamine)

[0076] The same process as in Preparation Example A1 was repeated, except that diamine monomer (1) was replaced by diamine monomer (3): (N,N'-bis(4-aminophenyl)-N,N'-di(4-methoxyphenyl)-4,4'-biphenyldiamine). The resulting product was called TBP-O for short.

Preparation Example A4 (Copolymer of Polyamine)

[0077] A similar process as in Preparation Example A1 was repeated, except that diamine monomer (2) and diamine monomer (3) were used in the same ratio (TPPA:TPB=1:1). 251.31 mg (0.5 mmol) of diamine monomer (2) and 289.35 mg (0.5 mmol) of diamine monomer (3), 258.23 mg (1.0 mmol) of 4,4'-oxydibenzoeic acid, and 100 mg of calcium chloride were added to 0.8 mL of triphenyl phosphate, 0.4 mL of pyridine, and 2.0 mL of N-methylpyrrolidone (NMP), heated at 105° C. and stirred for 3 hours. The resulting polymer solution was slowly poured into 300 mL of methanol, stirred and filtered to collect the tough fibrous precipitation. Then, it was fully washed with hot water and methanol and dried at 100° C. under vacuum. The polymer was dissolved by using dimethylacetamide (DMAc) and then precipitated in methanol. This step was repeated twice to finish the purification. The resulting product was called TPPA-TBP-O for short.

Preparation Example B1 (Diamine Monomer (1)+Diacyl Chloride to Form Polyamine)

[0078] 305.4 mg of diamine monomer (1): 4,4'-diamino-4'-methoxytriphenylamine was dissolved in 3.0 mL of DMAc, stirred and cooled to –20° C. in an ice-acetone bath. Then, 0.40 mL of propylene oxide was added to the mixture. 183.0 mg (1.0 mmol) of hexanediydichloride was added to the mixture. Then, the mixture was stirred at –10° C. for 1 hour, then stirred at room temperature for 2 hours. The resulting polymer solution was poured into 400 mL of methanol. The precipitated polymer was filtered, collected, and dried at 100° C. The polymer was dissolved by using DMAc and then precipitated in methanol. This step was repeated twice to finish the purification. The resulting product was called TPA-A for short.

Preparation Example B2 (Diamine Monomer (2)+Diacyl Chloride to Form Polyamine)

[0079] The same process as in Preparation Example B1 was repeated, except that diamine monomer (1) was replaced by diamine monomer (2): (N,N'-bis(4-aminophenyl)-N,N'-di(4-methoxyphenyl)-1,4-phenylenediamine). The resulting product was called TPPA-A for short.

Preparation Example B3 (Diamine Monomer (3)+Diacyl Chloride to Form Polyamine)

[0080] The same process as in Preparation Example B1 was repeated, except that diamine monomer (1) was replaced by diamine monomer (3): (N,N'-bis(4-aminophenyl)-N,N'-di(4-methoxyphenyl)-4,4'-biphenyldiamine). The resulting product was called TPB-A for short.

Preparation Example B4 (Copolymer of Polyamine)

[0081] A similar process as in Preparation Example B1 was repeated, except that diamine monomer (2) and diamine monomer (3) were used in the same ratio (TPPA:TPB=1:1). 251.31 mg (0.5 mmol) of diamine monomer (2) and 289.35 mg (0.5 mmol) of diamine monomer (3) were stirred and cooled to –20° C. in an ice-acetone bath. Then, 0.40 mL of propylene oxide was added to the mixture. 183.0 mg (1.0 mmol) of hexanediydichloride was added to the mixture. Then, the mixture was stirred at –10° C. for 1 hour, then stirred at room temperature for 2 hours. The resulting polymer solution was poured into 400 mL of methanol. The precipitated polymer was filtered, collected, and dried at 100° C. The polymer was dissolved by using DMAc and then precipitated in methanol. This step was repeated twice to finish the purification. The resulting product was called TPPA-TBP-A for short.

Preparation Example C1 (Diamine Monomer (1)+Dianhydride to Form Polyimide)

[0082] 577 mg of diamine monomer (1) and 424 mg of hydrogenated pyromellitic dihydride were mixed in a reaction bottle. 2.33 g of NMP was used as solvent and added into the reaction bottle. 20 mg of isoquinoline catalyst was added into the reaction bottle and mixed evenly. The mixture was heated to 210° C. and reacted for 4 hours to obtain a yellow viscous solution. The resulting polymer solution was poured into to 300 mL of methanol. The precipitated polymer was filtered, collected, and dried at 100° C. The polymer was dissolved by using DMAc and then
precipitated in methanol. This step was repeated twice to finish the purification. The resulting product was called TPA-I for short.

Preparation Example C2 (Copolymer of Polyimide)

[0083] 428 mg of diamine monomer (1), 246 mg of 2,2-bis (4-aminophenoxo)phenylpropane, and 496 mg of bicyclo
(2.2.2)oct-7-ene-2,3,5,6-tetraacrylic diianhydride were mixed in a reaction bottle. 2.73 g of NMP was used as
solvent and added into the reaction bottle. 20 mg of isooquin
noline catalyst was added into the reaction bottle and mixed
evenly. The mixture was heated to 210°C and reacted for
4 hours to obtain a yellow viscous solution. The resulting
polymer solution was poured in to 300 mL of methanol. The
precipitated polymer was filtered, collected, and dried at
100°C. The polymer was dissolved by using DMac and
then precipitated in methanol. This step was repeated twice
to finish the purification. The resulting product was called
TPA-C for short.

[0084] The products of the above Preparation Examples
A1–A4, Preparation Examples B1–B4, Preparation
Examples C1–C2 were coated on ITO glass substrates,
baked to form a thin film with a thickness of 1 μm. An
electrolyte gel with 0.1 M of tetrabutylammonium perchlo
rate (TBAP)/CH3CN was coated on the above thin film.
Viologen was independently dissolved in 0.1 M of tetrabu
tylammonium perchlorate (TBAP)/CH3CN. The electrolyte
gel mixed with viologen was coated on the ITO glass
substrate and baked to form a thin film with a thickness of
1 μm. Voltage was applied to each of the aforementioned
film layers and the optical absorption spectrum was mea
sured (not shown). The redox potentials obtained according
to the optical absorption spectrum are shown in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First oxidation</td>
<td>Second oxidation</td>
</tr>
<tr>
<td></td>
<td>potential (V)</td>
<td>potential (V)</td>
</tr>
<tr>
<td>Viologen</td>
<td>-0.42 (blue)</td>
<td>-0.84 (blue purple)</td>
</tr>
<tr>
<td>Preparation Example A1</td>
<td>0.95 (green)</td>
<td></td>
</tr>
<tr>
<td>Preparation Example A2</td>
<td>0.75 (green)</td>
<td>1.10 (blue)</td>
</tr>
<tr>
<td>Preparation Example A3</td>
<td>0.80 (red)</td>
<td>1.05 (blue)</td>
</tr>
<tr>
<td>Preparation Example A4</td>
<td>0.75 (green)</td>
<td>0.80 (brown black)</td>
</tr>
<tr>
<td>Preparation Example B1</td>
<td>0.95 (green)</td>
<td></td>
</tr>
<tr>
<td>Preparation Example B2</td>
<td>0.75 (green)</td>
<td>1.00 (blue)</td>
</tr>
<tr>
<td>Preparation Example B3</td>
<td>0.80 (red)</td>
<td>1.05 (blue)</td>
</tr>
<tr>
<td>Preparation Example B4</td>
<td>0.75 (red)</td>
<td>0.80 (brown black)</td>
</tr>
<tr>
<td>Preparation Example C1</td>
<td>1.25 (dark blue)</td>
<td></td>
</tr>
<tr>
<td>Preparation Example C2</td>
<td>1.25 (blue)</td>
<td></td>
</tr>
</tbody>
</table>

[0085] According to the experiments, it can be found that
viologen and all of the polyamide (Preparation Examples
A1–A4 and Preparation Examples B1–B4) were transparent
and colorless in the neutral state (0V). However, when in
the oxidation state (the applied voltage was increased),
the absorption significantly changed at a specific wavelength,
and revealed the specific spectral absorption characteristics
of each polyamide. When the first redox potential was
applied, viologen was at a reduced state and was blue.
Polyamides (Preparation Example A2 (TPPA-O) and Prepa
ration Example B2 (TPPA-A)) using TPPA units have a
stronger absorption peak at the wavelengths near the blue
light region 430 nm and red light region 600 nm of the
visible light region, making the thin film change to green at
the first redox potential. When the voltage was further
increased to the second oxidation potential, a new absorp
tion peak appeared at 835 nm, and the color of the thin film
changed from green to blue. Polyamides (Preparation
Example A3 (TPB-O) and Preparation Example B3 (TPB-
A)) revealed a strong absorption peak at 486 nm, making the
color of the thin film turn red. When the voltage was further
increased to the second oxidation potential, the color of the
thin film changed from red to blue. The main difference
between the two chromophores is mainly because of the
conjugation length. Compared to TPPA-polyamide, TPPB-
polyamides have one more benzene ring, resulting in a red
shift. Therefore, by using the significantly different absorp
tion range of these two polyamides (TPPA-PA and TPB-PA),
color control can be effectively performed in the visible light
region.

[0086] FIG. 2 illustrates the overlapping absorption spec
trum of each component of the electrochromic composition.
Referring to FIG. 2, it can be observed that the working
potentials and the characteristic absorption peaks of the
oxidized polyamide (Preparation Example B2 (TPPA-A)
and Preparation Example B3 (TPB-A), for example) and
reduced organic compound (viologen; HV) can be succes
sively matched and reveal an excellent complementary color
effect. When overlapping the absorption spectra of the
Preparation Example B2 (TPPA-A) (first oxidation state is
green), Preparation Example B3 (TPB-A) (first oxidation
state is red), and viologen (HV) (first reduced state is blue),
the absorption range can almost completely cover the
whole visible light region. There is a good shielding effect in
the visible light region.

[0087] Because the electrochemical behaviors of the poly
amides derived from aromatic and aliphatic dicarboxylic
acid are similar, the following Comparative Examples 1–2
and Examples 1–2 use aromatic polyamide (the product of
Preparation Example A2 (TPPA-O) and the product of
Preparation Example A3 (TPPA-O) as examples for ex
planation. At first, the aforementioned products were used
to manufacture electrochromic elements. Then, the cyclic vol
tammetry (CV) spectrum of the electrochromic composition
in the electrochromic element was measured.

Electrochromic Element

Comparative Example 1 (TPPA-O without Viologen)

[0088] The product of Preparation Example A2 (TPPA-O)
was prepared in DMAc to form a solution with a concen
tration of 10 (mg/mL). 300 mL of the solution was dropped
and coated on the effective area (25 mm×20 mm) of ITO
glass substrate (20 mm×30 mm×1 mm, 50C), and then
dried under vacuum to prepare a film with a thickness of 1
μm. The distance between two electrodes was defined by an
adhesive spacer frame with a thickness of 50 μm. 1.25 g of
polymethylmethacrylate (PMMA) (molar weight: 120, 000)
and 0.15 g of LiH2F4 were dissolved in 2.75 g of propylene
carbonate (PC) to form an electrolyte gel of 0.7 M.
The electrolyte gel was coated on one side of the
aforementioned film layer, and then clamped between the two
electrodes (the material of the electrode is ITO glass sub
strate), and sealed by PI tapes or quick-drying epoxy resins
to obtain the electrochromic element.

[0089] The cyclic voltammetry (CV) spectra of the ele
trochromic composition in the aforementioned electrochro
mic element are shown in FIG. 3A.
Example 1 (TPPA-O with Viologen)

[0090] The product of Preparation Example A2 (TPPA-O) was prepared in DMAc to form a solution with a concentration of 10 (mg/mL). 300 μL of the solution was dropped and coated on the effective area (25 mm x 20 mm) of ITO glass substrate (20 mm x 30 mm x 1 mm, 5Ω/□), and then dried under vacuum to prepare a film with a thickness of 1 μm. The distance between two electrodes was defined by an adhesive spacer frame with a thickness of 50 μm. 1.25 g of polymethylmethacrylate (PMMA) (molecular weight: 120,000) was dissolved in 2.75 g of propylene carbonate (PC), then 0.15 g of LiBF₄ and 0.06 g of viologen (HV(BF₄)₂) were mixed to form an electrolyte gel of 0.05 M. The electrolyte gel was coated on one side of the aforementioned film layer, and then clapsed between the two electrodes (the material of the electrode is ITO glass substrate), and sealed by PI tapes to obtain the electrochromic element.

[0091] The cyclic voltammetry (CV) spectra of the electrochromic composition in the aforementioned electrochromic element are shown in FIG. 3B.

Comparative Example 2 (TPB-O without Viologen)

[0092] The product of Preparation Example A3 (TPB-O) was prepared in DMAc to form a solution with a concentration of 10 (mg/mL). 300 μL of the solution was dropped and coated on the effective area (25 mm x 20 mm) of ITO glass substrate (20 mm x 30 mm x 1 mm, 5Ω/□), and then dried under vacuum to prepare a film with a thickness of 1 μm. The distance between two electrodes was defined by an adhesive spacer frame with a thickness of 50 μm. 1.25 g of polymethylmethacrylate (PMMA) (molecular weight: 120,000) and 0.15 g of LiBF₄ were dissolving in 2.75 g of propylene carbonate (PC) to form an electrolyte gel of 0.7 M. The electrolyte gel was coated on one side of the aforementioned film layer, and then clapsed between the two electrodes (the material of the electrode is ITO glass substrate), and sealed by PI tapes to obtain the electrochromic element.

[0093] The cyclic voltammetry (CV) spectra of the electrochromic composition in the aforementioned electrochromic element are shown in FIG. 4A.

Example 2 (TPB-O with Viologen)

[0094] The product of Preparation Example A3 (TPB-O) was prepared in DMAc to form a solution with a concentration of 10 (mg/mL). 300 μL of the solution was dropped and coated on the effective area (25 mm x 20 mm) of ITO glass substrate (20 mm x 30 mm x 1 mm, 5Ω/□), and then dried under vacuum to prepare a film with a thickness of 1 μm. The distance between two electrodes was defined by an adhesive spacer frame with a thickness of 50 μm. 1.25 g of polymethylmethacrylate (PMMA) (molecular weight: 120,000) was dissolved in 2.75 g of propylene carbonate (PC), then 0.15 g of LiBF₄ and 0.06 g of viologen (HV(BF₄)₂) were mixed to form an electrolyte gel of 0.05 M. The electrolyte gel was coated on one side of the aforementioned film layer, and then clapsed between the two electrodes (the material of the electrode is ITO glass substrate), and sealed by PI tapes to obtain the electrochromic element.

[0095] The cyclic voltammetry (CV) spectra of the electrochromic composition in the aforementioned electrochromic element are shown in FIG. 4B.

[0096] It can be found by comparing FIG. 3A and FIG. 3B that while 1.4 V of driving voltage was required in Comparative Example 1, the driving voltage required in Example 1 decreased to 0.9 V. It can be found by comparing FIG. 4A and FIG. 4B that while 1.7 V of driving voltage was required in Comparative Example 2, the driving voltage required in Example 2 decreased to 1.1 V. This reveals that the driving may be performed by using a lower oxidation potential because of the introduction of viologen (HV(BF₄)₂). The effect can be achieved because viologen can effectively capture electrons. Therefore, the working potential can be significantly reduced, and the overall performance of the electrochromic element is improved.

Example 3 (TPPA-TPB-O Copolymer with Viologen)

[0097] The product of Preparation Example A4 (TPPA-TPB-O) was prepared in DMAc to form a solution with a concentration of 10 (mg/mL). 300 μL of the solution was dropped and coated on the effective area (25 mm x 20 mm) of ITO glass substrate (20 mm x 30 mm x 1 mm, 5Ω/□), and then dried under vacuum to prepare a film with a thickness of 250 nm. The distance between two electrodes was defined by an adhesive spacer frame with a thickness of 50 μm. 1.25 g of polymethylmethacrylate (PMMA) (molecular weight: 120,000) was dissolved in 2.75 g of propylene carbonate (PC), then 0.15 g of LiBF₄ and 0.06 g of viologen (HV(BF₄)₂) were mixed to form an electrolyte gel of 0.05 M. The electrolyte gel was coated on one side of the aforementioned film layer, and then clapsed between the two electrodes (the material of the electrode is ITO glass substrate), and sealed by PI tapes to obtain the electrochromic element.

Example 4 (Mixture of TPPA-O and TPB-O with Viologen)

[0098] The product of Preparation Example A2 (TPPA-O) and the product of Preparation Example A3 (TPB-O) were prepared in DMAc to form a solution with a concentration of 10 (mg/mL). 300 μL of the solution was dropped and coated on the effective area (25 mm x 20 mm) of ITO glass substrate (20 mm x 30 mm x 1 mm, 5Ω/□), and then dried under vacuum to prepare a film with a thickness of 250 nm. The distance between two electrodes was defined by an adhesive spacer frame with a thickness of 50 μm. 1.25 g of polymethylmethacrylate (PMMA) (molecular weight: 120,000) was dissolved in 2.75 g of propylene carbonate (PC), then 0.15 g of LiBF₄ and 0.06 g of viologen (HV(BF₄)₂) were mixed to form an electrolyte gel of 0.05 M. The electrolyte gel was coated on one side of the aforementioned film layer, and then clapsed between the two electrodes (the material of the electrode is ITO glass substrate), and sealed by PI tapes to obtain the electrochromic element.

Example 5 (Mixture of TPPA-O and TPB-O with Viologen)

[0099] The same process as in Example 4 was repeated, except that the thickness of the film formed by the product of Preparation Example A2 (TPPA-O) and the product of Preparation Example A3 (TPB-O) was increased to 1000 nm.

Example 6 (Mixture of TPPA-A and TPB-A with Viologen)

[0100] The same process as in Example 4 was repeated, except that the product of Preparation Example A2 (TPPA-
O) and the product of Preparation Example A3 (TPB-O) were replaced by the mixed solution of the product of Preparation Example B2 (TPPA-A) and the product of Preparation Example B3 (TPPB-A). Also, the thickness of the film formed thereof was increased to 1000 nm.

[0101] FIG. 5 illustrates the cyclic voltammetry spectrum of the electrochromic compositions of Example 3 and Example 4. It can be observed from the CV curve shown in FIG. 5 that Example 3 and Example 4 have similar reversible redox behavior, the oxidation potential of Example 3 (TPPA-TPB-O copolymer) was 1.0 V and 1.1 V, the oxidation potential of Example 4 (a mixture of TPPA-O and TPB-O) was 1.0 V and 1.1 V, confirming the electroactive unit was successively included.

[0102] FIG. 6A illustrates the transmission spectrum of the electrochromic composition of Example 3. FIG. 6B illustrates the transmission spectrum of the electrochromic composition of Example 4. It can be observed by comparing FIG. 6A and FIG. 6B that the two electrochromic compositions in Example 3 and Example 4 were in a neutral state when no voltage was applied (0.0 V) and have high transmittance, the device was colorless and transparent with good transparency. When the voltage was increased to 1.1 V, it turned to be in an oxidation state (colored state) and to have low transmittance. The device appeared to be black, representing that the oxidizable polymers and reducible organic compounds in the electrochromic composition closely match each other under a redox potential (1.1 V). Therefore, the feature of color overlapping was obtained and a complementary effect of the colors was produced.

[0103] FIG. 7 illustrates the transmission spectrum of the electrochromic compositions of Example 4 and Example 5. It can be observed from FIG. 7 that Example 4 (film thickness was 250 nm) was in a neutral state when no voltage was applied (0.0 V), the device was colorless and transparent with good transparency. When the voltage was increased to 1.1 V, it turned to be in an oxidation state (colored state) and the transmittance in the absorption band of the whole visible light region and near infrared region (800—1100 nm) decreased. The device appeared to be dark green, but not yet a truly black. In comparison, Example 5 (film thickness was 1000 nm) was in a neutral state when no voltage was applied (0.0 V), the device was colorless and transparent with good transparency. When the voltage was increased to 1.9 V, it turned to be in an oxidation state (colored state) and the whole transmittance decreased significantly, the device appeared to be truly black. It can be learned that appropriately increasing the thickness of the film is beneficial to making the oxidation state (colored state) to appear as truly black.

[0104] FIG. 8 illustrates the transmission spectrum of the electrochromic compositions in Example 5 and Example 6. In can be observed from FIG. 8 that the overall transmittance of Example 5 and Example 6 was decreased significantly while in an oxidation state, and the device may appear as truly black. Also, when Example 6 was in a neutral state, the transmittance was enhanced to over 80%, further enhancing the transparency of the device.

[0105] FIG. 9 illustrates the transmission spectrum of the electrochromic composition of Example 6. The change of transmittance between the visible region and the near infrared region can be observed from FIG. 9. From a high transparency (T>85%) of the neutral state to a truly black (T<6%) of the oxidation state (colored state), it has a good optical contrast (ΔT). In addition, according to the data obtained from the colorimeter, when the electrochromic element of Example 6 was in a neutral state, the CIE 1976 chromaticity coordinates were L*: 96.8, a*: -2.0, b*: 5.3, and when the electrochromic element of Example 6 was in an oxidation state, the CIE 1976 chromaticity coordinates were L*: 8.6, a*: -4.0, b*: 5.0. The change of L* is greater than 79% (88.2 ΔL*), illustrating that the neutral state of the electrochromic element of Example 6 is transparent and the oxidation state (colored state) thereof is truly black.

[0106] The electrochromic composition provided by the present disclosure has a low driving voltage, electrochromic stability, and a high potential for application in transparent displays and related optical devices. In addition, the electrochromic composition provided by the present disclosure can have a high transparency in a neutral state, and the transmittance of the redox state can be decreased by the color complementarity produced by the oxidizable organic polymers and the reducible organic small molecules. Therefore, the electrochromic composition can have a deeper color, or even have a truly black color.

[0107] While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:
1. An electrochromic composition, comprising:
   0.5–10 parts by weight of a first oxidizable polymer;
   0.5–10 parts by weight of a reducible organic compound;
   0.5–20 parts by weight of an electrolyte; and
   60–98.5 parts by weight of a solvent,
   wherein the first oxidizable polymer is a polymer of 1 molar part of a diamine and 0.1–20 molar parts of dicarboxylic acid, diacetyl chloride, or dianhydride, a mixture of the polymers, or a copolymer of the polymers,
   wherein the diamine is Formula 1, Formula 2, or a combination thereof:

   (Formula 1)
Ar\(^1\) is Formula 3, Formula 4, Formula 5, Formula 6, Formula 7, or Formula 8:

\begin{align*}
\text{(Formula 3)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array} \\
\text{(Formula 4)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array} \\
\text{(Formula 5)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array} \\
\text{(Formula 6)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array} \\
\text{(Formula 7)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array} \\
\text{(Formula 8)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^1\) \\
\text{R}
\end{array}
\end{array}
\end{align*}

wherein the dicarboxylic acid is Formula 13, the diacyl chloride is Formula 14, the dianhydride is Formula 15:

\begin{align*}
\text{(Formula 13)} & \quad \begin{array}{c}
\begin{array}{c}
\text{O}
\end{array}
\end{array} \\
\text{(Formula 14)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Cl}
\end{array}
\end{array} \\
\text{(Formula 15)} & \quad \begin{array}{c}
\begin{array}{c}
\text{O}
\end{array}
\end{array}
\end{align*}

R\(^1\) is selected from the group of —(CH\(_2\))\(_n\)—, Formula 9, Formula 16, Formula 17, Formula 18, Formula 19, Formula 20, Formula 21, Formula 22, Formula 23, and Formula 24, wherein n is between 1 and 12:

\begin{align*}
\text{(Formula 9)} & \quad \begin{array}{c}
\begin{array}{c}
\text{R}
\end{array}
\end{array} \\
\text{(Formula 16)} & \quad \begin{array}{c}
\begin{array}{c}
\text{CH}_2
\end{array}
\end{array} \\
\text{(Formula 17)} & \quad \begin{array}{c}
\begin{array}{c}
\text{CH}_3
\end{array}
\end{array} \\
\text{(Formula 18)} & \quad \begin{array}{c}
\begin{array}{c}
\text{O}
\end{array}
\end{array}
\end{align*}

Ar\(^2\) is Formula 9, Formula 10, Formula 11, or Formula 12:

\begin{align*}
\text{(Formula 9)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^2\)
\end{array}
\end{array} \\
\text{(Formula 10)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^2\)
\end{array}
\end{array} \\
\text{(Formula 11)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^2\)
\end{array}
\end{array} \\
\text{(Formula 12)} & \quad \begin{array}{c}
\begin{array}{c}
\text{Ar}\(^2\)
\end{array}
\end{array}
\end{align*}
2. The electrochromic composition as claimed in claim 1, wherein the first oxidizable polymer comprises a polymer of Formula 25, Formula 26, Formula 27, or Formula 28, or a copolymer of the aforementioned polymers:

3. The electrochromic composition as claimed in claim 2, wherein the copolymer is a copolymer of the polymer of Formula 25, which is represented by Formula 29:
4. The electrochromic composition as claimed in claim 2, wherein the copolymer is a copolymer of the polymer of Formula 26, which is represented by Formula 30:

\[
\text{(Formula 30)}
\]

5. The electrochromic composition as claimed in claim 2, wherein the copolymer is a copolymer of the polymer of Formula 27, which is represented by Formula 31:

\[
\text{(Formula 31)}
\]

6. The electrochromic composition as claimed in claim 2, wherein the copolymer is a copolymer of the polymer of Formula 28, which is represented by Formula 32:

\[
\text{(Formula 32)}
\]
7. The electrochromic composition as claimed in claim 1, wherein the diamine is Formula 33, and the dicarboxylic acid is Formula 34 or Formula 35:

8. The electrochromic composition as claimed in claim 1, wherein the diamine is Formula 36, and the dicarboxylic acid is Formula 34 or Formula 35:

9. The electrochromic composition as claimed in claim 1, wherein the diamine is Formula 37, and the dicarboxylic acid is Formula 34 or Formula 35:

10. The electrochromic composition as claimed in claim 1, wherein the reducible organic compound is Formula 38, Formula 39, Formula 40, a derivative thereof, or a combination thereof:

11. The electrochromic composition as claimed in claim 1, further comprising a second oxidizable organic compound of Formula 41, Formula 42, Formula 43, Formula 44, Formula 45, or a combination thereof:
17. The electrochromic element as claimed in claim 16, wherein the electrochromic composition further comprises a second oxidizable organic compound of Formula 41, Formula 42, Formula 43, Formula 44, Formula 45, or a combination thereof:

wherein $R^3$ is $H$ or C$_1$-C$_{12}$ alkyl.

12. The electrochromic composition as claimed in claim 1, wherein the electrolyte is an organic ammonium salt or an inorganic lithium salt, and the concentration of the electrolyte is between 0.01 M and 3.0 M.

13. The electrochromic composition as claimed in claim 1, wherein the molar ratio of the first oxidizable polymer to the electrolyte is between 1:1 and 1:300, and the molar ratio of the reducible organic compound to the electrolyte is between 1:1 and 1:300.

14. The electrochromic composition as claimed in claim 1, wherein the weight average molecular weight of the first oxidizable polymer is between 1,000 and 300,000.

15. The electrochromic composition as claimed in claim 1, wherein the first oxidizable polymer is a film layer.

16. An electrochromic element, comprising:
   a first transparent conductive layer;
   a second transparent conductive layer disposed opposite to the first transparent conductive layer;
   an adhesive spacer, connected to the surfaces of the first transparent conductive layer and the second transparent conductive layer, the second transparent conductive layer, and the adhesive spacer form a cell; and
   an electrochromic composition as claimed in claim 1, filled in the cell.

wherein $R^3$ is $H$ or C$_1$-C$_{12}$ alkyl.

18. The electrochromic element as claimed in claim 16, wherein the distance between the first transparent conductive layer and the second transparent conductive layer is 10 μm–500 μm.

19. An electrochromic element, comprising:
   a first transparent conductive layer;
   a second transparent conductive layer disposed opposite to the first transparent conductive layer;
   a film layer disposed on the first transparent conductive layer and composed of a first oxidizable polymer, said first oxidizable polymer being a polymer of 1 molar part of a diamine and 0.1–20 molar parts of dicarboxylic acid, diacyl chloride, or dianhydride, a mixture of the polymers, or a copolymer of the polymers,
wherein the diamine is Formula 1, Formula 2, or a combination thereof:

\[
\begin{align*}
\text{(Formula 1)} & \quad \begin{array}{c}
\text{Ar}= \quad \begin{array}{c}
\text{N} \\
\text{Ar}_2 \\
\text{N}
\end{array}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 2)} & \quad \begin{array}{c}
\text{R} \\
\text{R}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{Ar}^1 \text{ is Formula 3, Formula 4, Formula 5, Formula 6, Formula 7, or Formula 8:}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 3)} & \quad \begin{array}{c}
\text{R}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 4)} & \quad \begin{array}{c}
\text{(Formula 5)}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 6)} & \quad \begin{array}{c}
\text{(Formula 7)}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{Ar}^2 \text{ is Formula 9, Formula 10, Formula 11, or Formula 12:}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 9)} & \quad \begin{array}{c}
\text{(Formula 10)}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 11)} & \quad \begin{array}{c}
\text{(Formula 12)}
\end{array}
\end{align*}
\]

wherein the dicarboxylic acid is Formula 13, the diacetyl chloride is Formula 14, the dianhydride is Formula 15:

\[
\begin{align*}
\text{(Formula 13)} & \quad \begin{array}{c}
\text{(Formula 14)}
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{(Formula 15)}
\end{align*}
\]

\[
\begin{align*}
\text{R}^1 \text{ is selected from the group of } -(\text{CH}_2)_n- \text{, Formula 9, Formula 16, Formula 17, Formula 18, Formula 19,}
\end{align*}
\]
Formula 20, Formula 21, Formula 22, Formula 23, and Formula 24, wherein n is between 1 and 12:

\[
\text{(Formula 9)}
\]

\[
\text{(Formula 16)}
\]

\[
\text{(Formula 17)}
\]

\[
\text{(Formula 18)}
\]

\[
\text{(Formula 19)}
\]

\[
\text{(Formula 20)}
\]

\[
\text{(Formula 21)}
\]

\[
\text{(Formula 22)}
\]

\[
\text{(Formula 23)}
\]

\[
\text{(Formula 24)}
\]

\[R^2 \text{ is cyclic aliphatic or organic aromatic; an adhesive spacer, connected to the surfaces between the film layer and the second transparent conductive layer, and the film layer, the second transparent conductive layer, and the adhesive spacer form a cell; and an electrolyte layer filled in the cell and composed of a reducible organic compound, an electrolyte, and a solvent.}
\]

20. The electrochromic element as claimed in claim 19, wherein the electrolyte layer further comprises a second oxidizable organic compound of Formula 41, Formula 42, Formula 43, Formula 44, Formula 45, or a combination thereof:

\[
\text{(Formula 41)}
\]

\[
\text{(Formula 42)}
\]

\[
\text{(Formula 43)}
\]

\[
\text{(Formula 44)}
\]

\[
\text{(Formula 445)}
\]

\[
\text{(Formula 45)}
\]

\[\text{wherein } R^3 \text{ is } H \text{ or } \text{C}_{11} \text{ alkyl.}
\]

21. The electrochromic element as claimed in claim 19, wherein the distance between the first transparent conductive layer and the second transparent conductive layer is 10 \(\mu\text{m}\)~500 \(\mu\text{m}\).