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Polar Media for Dimming Devices

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Certain electro-optic devices include liquid for changing optical properties of one or more components within such electro-optic devices. Conventional liquids used in the electro-optic devices may limit the switching speed of such electro-optic devices. In addition, such conventional liquids may break down, or degrade, over extended exposure to ultraviolet light (e.g., during outdoor use of the electro-optic devices), thereby reducing the performance of such electro-optic devices. Furthermore, conventional liquids may evaporate during operation of the electro-optic devices, causing bubbles, delamination, or other permanent defects in the electro-optic devices.

In accordance with some embodiments, an optical device includes a first set of one or more electrodes; a second set of one or more electrodes electrode distinct and separate from the first set of one or more electrodes; and medium including one or more ionic liquids. The medium is located between the first set of one or more electrodes and the second set of one or more electrodes. In some cases, the ionic liquids may increase the polarity of the medium, which increases the switching speed of the optical device. In addition, the ionic liquids have low vapor pressures, and thus are generally non-volatile. Furthermore, the ionic liquids have high electrochemical and thermal stabilities, and thus are stable for oxidation-reduction reactions. The ionic liquids may also have superior ionic conductivities. The ionic liquids can be nonflammable and highly viscous, which can also increase their use in portable electronic devices.

In some embodiments, the one or more ionic liquids include one or more deep eutectic solvents (DES). The deep eutectic solvents generally have many advantageous properties, such as low toxicity and neutral pH. In some embodiments, a deep eutectic solvent of the one or more deep eutectic solvents are based on one or more selected from: (i) a combination of quaternary ammonium salt and metal chloride, (ii) a combination of quaternary ammonium salt and metal chloride hydrate, (iii) a combination of quaternary ammonium salt and hydrogen bond donor, or (iv) a combination of metal chloride hydrate and a hydrogen bond donor. In some embodiments, the deep eutectic solvent is based on a mixture of AlCl3 and 1-Ethyl-3-methylimidazolium chloride. In some embodiments, the quaternary ammonium salt includes choline chloride. In some embodiments, the hydrogen bond donor includes urea, ethylene glycol, or a mixture of the two. In some embodiments, the one or more deep eutectic solvents include imidazolium chloroaluminates. In some embodiments, the one or more deep eutectic solvents are metal-free deep eutectic solvents.

In accordance with some embodiments, an optical device includes a first set of one or more electrodes; a second set of one or more electrodes, an electrode distinct and separate from the first set of one or more electrodes; and medium including one or more ionic gels, the medium located between the first set of one or more electrodes and the second set of one or more electrodes. In some embodiments, the one or more ionic gels include one or more deep eutectic solvent-based gels.

In some embodiments, the optical device further includes a first reflective layer coupled with the first set of one or more electrodes and a second reflective layer coupled with the second set of one or more electrodes, the first reflective layer and the second reflective layer defining a resonance structure.

Figure 1 illustrates an optical device in accordance with some embodiments. The optical device shown in Figure 1 includes a first set of one or more electrodes (e.g., a plurality of pixelated working electrodes) and a second set of one or more electrodes (e.g., a single counter electrode with a size corresponding to the plurality of pixelated working electrodes). In some embodiments, the optical device also includes liquid including metal halide (e.g., an optically transparent liquid containing one or more metal halides, such as silver halide) located between the first set of one or more electrodes (e.g., the working electrodes) and the second set of one or more electrodes (e.g., the counter electrode). In some configurations, the liquid including metal halide facilitates or allows reversible metal electrodeposition. In some embodiments, the optical device includes an electrolyte described herein, with or without one or more metal halides. For example, the optical device may change color or transparency primarily based on electrochromic material, instead of reversible metal electrodeposition. In some embodiments, the liquid includes the one or more ionic liquids described herein. In some embodiments, each working electrode of the plurality of pixelated working electrodes has a size of 1 mm × 1 mm, although the working electrode may have a different size or shape (e.g., the working electrode may be bigger or smaller, wider or narrower, taller or shorter, and may have a square shape, a non-square rectangular shape, or any other shape). In some embodiments, applying a first set of electrical inputs to the first set of one or more electrodes and the second set of one or more electrodes (e.g., between the working electrodes and the counter electrode) causes a layer of metal to be formed on, above, or adjacent to, the first set of one or more electrodes based on the first set of electrical inputs. This, in turn, modifies light transmitted through the optical device (e.g., by changing reflectivity and/or transmission of light). For example, the left side of Figure 1 shows the optical device without an electrical input (e.g., the optical device is transparent). The right side of Figure 1 shows the optical device with a particular electrical input (e.g., a 2 V, 0.01 A electrical input provided to one of the pixels). The electrical input causes deposition of approximately 20 nm of a metal layer (e.g., silver), which changes the optical property of the optical device (e.g., the metal layer increases reflectivity of a portion of the optical device corresponding to the pixel). In some embodiments, ceasing to provide the electrical input causes removal, or dissolution, of the metal layer. This returns the optical property of the optical device back to that of the optical device before formation of the metal layer (e.g., the optical device becomes transparent again). Thus, the plurality of pixelated working electrodes in the optical device illustrated in Figure 1 allows dimming in one or more portions, less than all, of a cross-section (perpendicular to the optical axis of the optical device) of the optical device (e.g., local dimming).

Figure 2 illustrates an optical device that is similar to the optical device illustrated in Figure 1, except that the optical device illustrated in Figure 2 includes a plurality of pixelated electrodes as the second set of one or more electrodes (e.g., both the first set of one or more electrodes and the second set of one or more electrodes include a plurality of pixelated electrodes). In addition, in some embodiments, the second set of one or more electrodes is coupled with a layer of electrochromic material. In some embodiments, the electrochromic material includes one or more metal oxides, such as WO_3, MoO_3, IrO_2, NiO, TiO_2, and V_2O_5, one or more organic or polymeric compounds, such as viologens or conjugated polymers, or any combination thereof. Similar to the optical device illustrated in Figure 1, the plurality of pixelated working electrodes in the optical device illustrated in Figure 2 allows dimming in one or more portions, less than all, of a cross-section of the optical device (e.g., local dimming).

Figure 3 illustrates an optical device that is similar to the optical device illustrated in Figure 2, except that the optical device illustrated in Figure 3 includes a single electrode as the first set of one or more electrodes (e.g., a single working electrode) and a single electrode as the second set of one or more electrodes (e.g., a single counter electrode). The use of the single working electrode allows (concurrent) dimming across the entire cross-section of the optical device (e.g., global dimming).

Figure 4 illustrates example configurations of electrodes in accordance with some embodiments. As shown in Figure 4, in some embodiments, one or more electrodes (e.g., the first set of one or more electrodes or the second set of one or more electrodes) are formed on, or over, a substrate. In some embodiments, one or more additional layers (e.g., a reflective layer or a layer for refractive index matching) are located between the substrate and the electrode. In some embodiments, the substrate is made of, or includes, an optically transparent material, such as glass or optically transparent plastic (e.g., polyethylene terephthalate (PET)).

In some embodiments, as shown on the left side of Figure 4, the working electrode (e.g., the first set of one or more electrodes) is made of, or includes, transparent conducting oxide (TCO), such as indium tin oxide (ITO), fluorine doped in oxide (FTO), or doped zinc oxide. In some embodiments, a (thin) layer of metal is preformed on, or over, the working electrode (e.g., a layer of platinum formed as, for example, a self-assembled monolayer). In some configurations, the presence of the preformed layer of metal facilitates subsequent formation of a layer of metal (e.g., silver) through reversible metal electrodeposition.

In some embodiments, as shown on the right side of Figure 4, the counter electrode (e.g., the second set of one or more electrodes) is made of, or includes, transparent conducting oxide (TCO), such as indium tin oxide (ITO), fluorine doped in oxide (FTO), or doped zinc oxide. In some embodiments, a counter material is placed on, or over the counter electrode (right-top side of Figure 4). In some embodiments, electrochromic material is placed on, or over the counter electrode (right-bottom side of Figure 4). In some embodiments, the counter electrode does not include transparent conducting oxide. For example, in some embodiments, the counter electrode includes, or consists of, a metal mesh (e.g., instead of the transparent conducting oxide).

What is claimed is:

1. An optical device, comprising:

a first set of one or more electrodes;

a second set of one or more electrodes electrode distinct and separate from the first set of one or more electrodes; and

medium including one or more ionic liquids, the medium located between the first set of one or more electrodes and the second set of one or more electrodes.

2. The optical device of claim 1, wherein the one or more ionic liquids include one or more deep eutectic solvents.

3. The optical device of claim 2, wherein a deep eutectic solvent of the one or more deep eutectic solvents are based on one or more selected from: (i) a combination of quaternary ammonium salt and metal chloride, (ii) a combination of quaternary ammonium salt and metal chloride hydrate, (iii) a combination of quaternary ammonium salt and hydrogen bond donor, or (iv) a combination of metal chloride hydrate and a hydrogen bond donor.

4. The optical device of claim 3, wherein the deep eutectic solvent is based on a mixture of $AlCl_3$ and 1-Ethyl-3-methylimidazolium chloride.

5. The optical device of claim 3, wherein the quaternary ammonium salt includes choline chloride.

6. The optical device of claim 3 or 5, wherein the hydrogen bond donor includes urea, ethylene glycol, or a mixture of the two.

7. The optical device of claim 2, wherein the one or more deep eutectic solvents include imidazolium chloroaluminates.

8. The optical device of claim 2, wherein the one or more deep eutectic solvents are metal-free deep eutectic solvents.

9. The optical device of any of claims 1-8, wherein the one or more ionic liquids are included in micelles.

10. An optical device, comprising:

a first set of one or more electrodes;

a second set of one or more electrodes electrode distinct and separate from the first set of one or more electrodes; and

medium including one or more ionic gels, the medium located between the first set of one or more electrodes and the second set of one or more electrodes.

11. The optical device of claim 10, wherein the one or more ionic gels include one or more deep eutectic solvent-based gels.

12. The optical device of any of claims 1-11, further comprising a first reflective layer coupled with the first set of one or more electrodes and a second reflective layer coupled with the second set of one or more electrodes, the first reflective layer and the second reflective layer defining a resonance structure.

13. The optical device of any of claims 1-12, wherein the medium also includes metal halide.

14. The optical device of claim 13, further comprising:

a first substrate on which the first set of one or more electrodes is located; and

a second substrate on which the second set of one or more electrodes is located, the second substrate being distinct and separate from the first substrate.

15. The optical device of claim 14, wherein:

the first set of one or more electrodes is positioned on the first substrate facing toward the second set of one or more electrodes; and

the second set of one or more electrodes is positioned on the second substrate facing toward the first set of one or more electrodes.

16. The optical device of any of claims 10-15, wherein:

the first set of one or more electrodes consists of a single electrode.

17. The optical device of any of claims 10-15, wherein:

the first set of one or more electrodes includes a plurality of pixelated electrodes.

18. The optical device of claim 16 or 17, wherein:

the second set of one or more electrodes consists of a single electrode.

19. The optical device of claim 16 or 17, wherein:
the second set of one or more electrodes includes a plurality of pixelated electrodes.

20. The optical device of any of claims 10-19, wherein:
the first set of one or more electrodes is coupled with a layer of electrochromic material.

21. The optical device of any of claims 10-20, wherein:
the second set of one or more electrodes is coupled with a layer of electrochromic material.

22. The optical device of any of claims 10-21, wherein:
one or more electronic controllers for providing a first set of electrical inputs to the first set of one or more electrodes and the second set of one or more electrodes at a first time and a second set of electrical inputs to the first set of one or more electrodes and the second set of one or more electrodes at a second time distinct from the first time so that the optical device has a first transmission pattern at the first time and a second transmission pattern distinct from the first transmission pattern at the second time.

23. A display device, comprising:
one or more display panels; and
the optical device of any of claims 1-22 positioned to receive light and conditionally provide at least a portion of the light to the one or more display panels.

24. A method, comprising:
providing a first set of electrical inputs to the first set of one or more electrodes and the second set of one or more electrodes of the optical device of any of claims 1-22 at a first time so that the optical device has a first transmission pattern; and
providing a second set of electrical inputs to the first set of one or more electrodes and the second set of one or more electrodes at a second time distinct from the first time so that the optical device has a second transmission pattern distinct from the first transmission pattern.

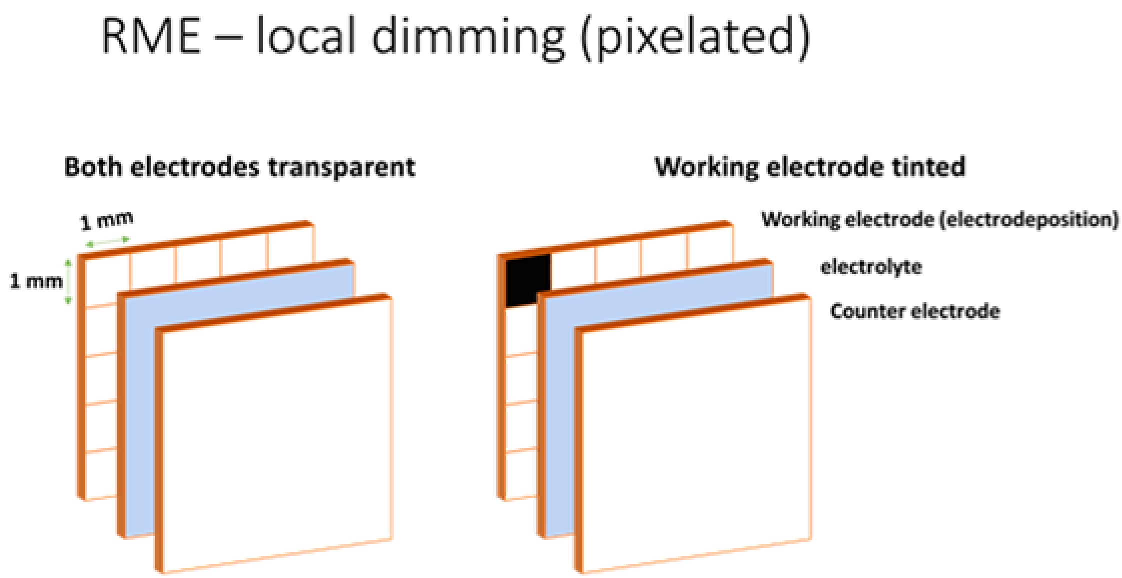

Figure 1

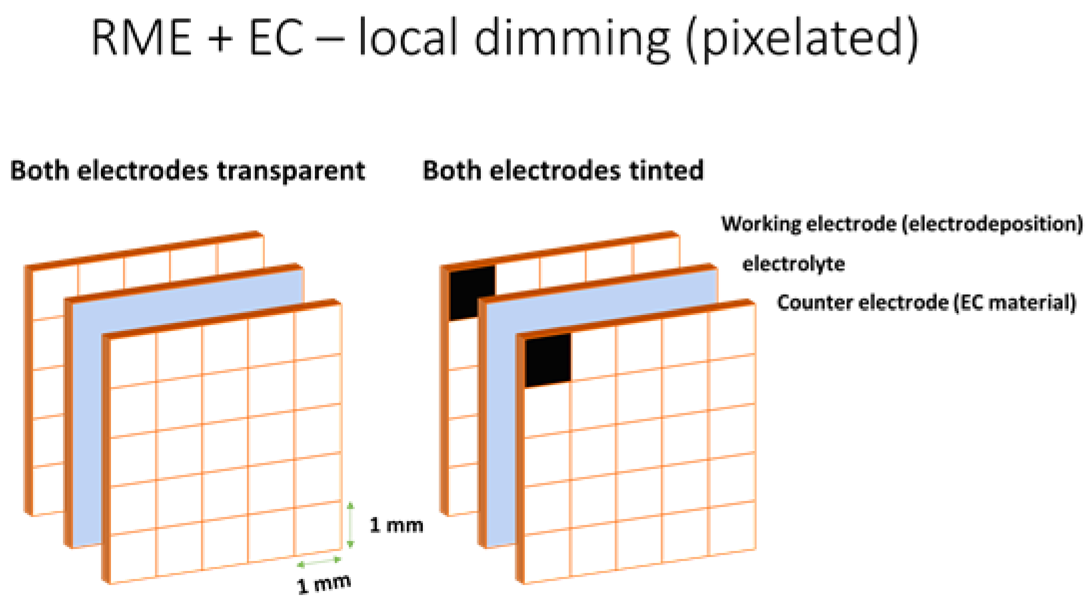

Figure 2

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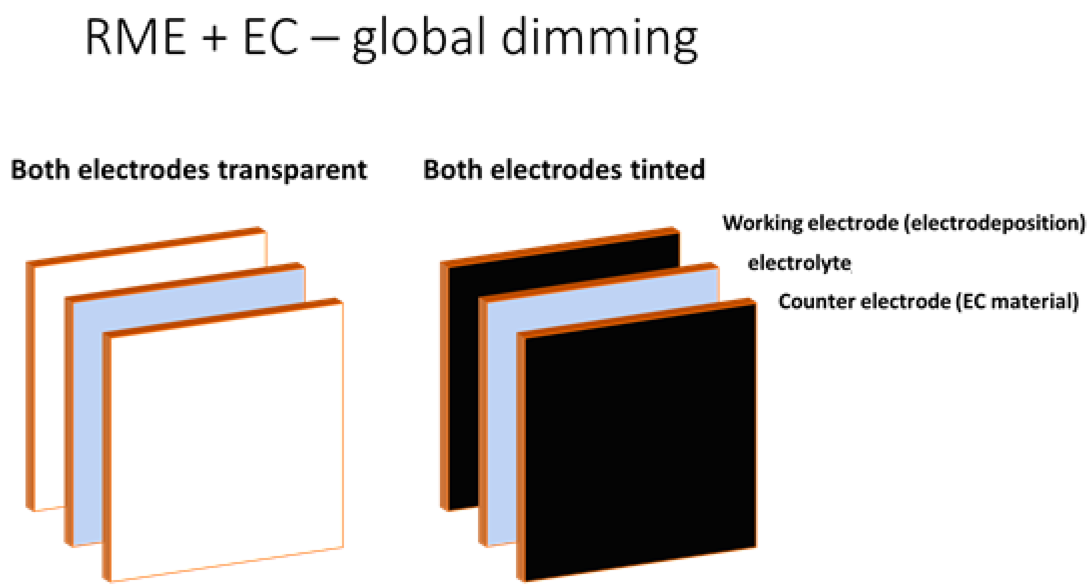

Figure 3

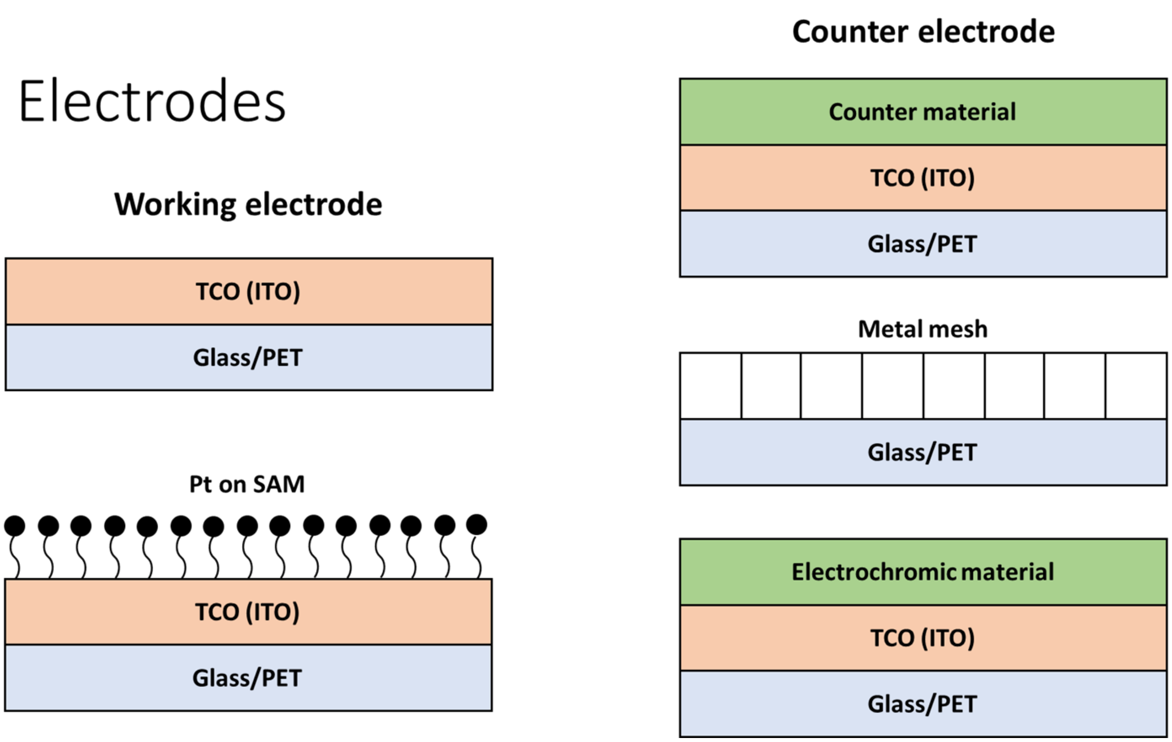

Figure 4

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