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(54) **Title**: MULTI-COLOR ELECTROPHORETIC DISPLAYS

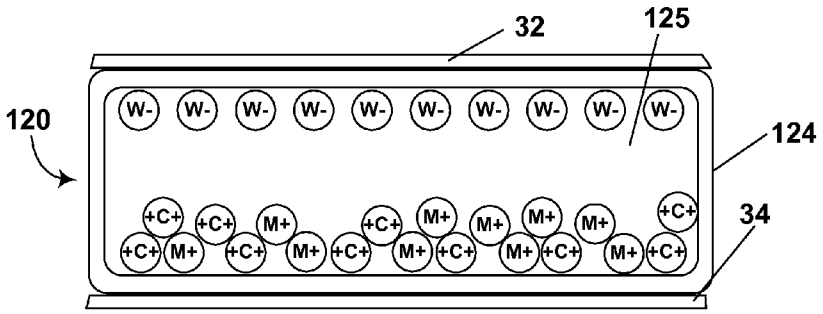

Fig. 1A

(57) **Abstract**: A multi-color electrophoretic medium contains first, second and third species of particles, the particles having substantially non-overlapping electrophoretic mobilities and bring of three different colors, one of which is white. The particles are dispersed in a fluid having a fourth color. A method for driving such a display is also described.

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MULTI-COLOR ELECTROPHORETIC DISPLAYS

[Para 1] This application is related to U. S. Patents Nos. 7,791,789; 7,352,353; and 6,710,540; and to U.S. Patent Application Publication No. 2008/0150888, to which the reader is referred for general background information regarding the technology of electrophoretic displays.

[Para 2] The present invention relates to multi-color electrophoretic media and to displays incorporating such media.

[Para 3] The terms "bistable" and "bistability" are used herein in their conventional meaning in the art to refer to displays comprising display elements having first and second display states differing in at least one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element. It is shown in U.S. Patent No. 7,170,670 that some particle-based electrophoretic displays capable of gray scale are stable not only in their extreme black and white states but also in their intermediate gray states, and the same is true of some other types of electro-optic displays. This type of display is properly called "multi-stable" rather than bistable, although for convenience the term "bistable" may be used herein to cover both bistable and multi-stable displays.

[Para 4] Nevertheless, problems with the long-term image quality of non-encapsulated electrophoretic displays have prevented their widespread usage. For example, particles that make up electrophoretic displays tend to settle, resulting in inadequate service-life for these displays.

[Para 5] Numerous patents and applications assigned to or in the names of the Massachusetts Institute of Technology (MIT) and E Ink Corporation describe various technologies used in encapsulated electrophoretic and other electro-optic media. Such encapsulated media comprise numerous small capsules, each of which itself comprises an internal phase containing electrophoretically-mobile particles in a fluid medium, and a capsule wall surrounding the internal phase. Typically, the capsules are themselves held within a polymeric binder to form a coherent layer positioned between two electrodes. The technologies described in the these patents and applications include:

(a) Electrophoretic particles, fluids and fluid additives; see for example U.S. Patent No. 7,002,728; and U.S. Patent Application Publication No. 2007/0146310;

(b) Capsules, binders and encapsulation processes; see for example U.S. Patents Nos. 6,922,276 and; 7,411,719;

(c) Films and sub-assemblies containing electro-optic materials; see for example U.S. Patent No. 6,982,178; and U.S. Patent Application Publication No. 2007/0109219;

(d) Backplanes, adhesive layers and other auxiliary layers and methods used in displays; see for example U.S. Patent No. 7,116,318; and U.S. Patent Application Publication No. 2007/0035808;

(e) Color formation and color adjustment; see for example U.S. Patents Nos. 6,017,584; 6,664,944; 6,864,875; 7,075,502; and 7,167,155; and U.S. Patent Applications Publication Nos. 2004/0190114; 2004/0263947; 2007/0109219; 2007/0223079; 2008/0023332; 2008/0043318; and 2008/0048970;

(f) Methods for driving displays; see for example U.S. Patent No. 7,012,600; and U.S. Patent Application Publication No. 2006/0262060;

(g) Applications of displays; see for example U.S. Patent No. 7,312,784; and U.S. Patent Application Publication No. 2006/0279527; and

(h) Non-electrophoretic displays, as described in U.S. Patents Nos. 6,241,921; 6,950,220; and 7,420,549.

[Para 6] Many of the aforementioned patents and applications recognize that the walls surrounding the discrete microcapsules in an encapsulated electrophoretic medium could be replaced by a continuous phase, thus producing a so-called polymer-dispersed electrophoretic display, in which the electrophoretic medium comprises a plurality of discrete droplets of an electrophoretic fluid and a continuous phase of a polymeric material, and that the discrete droplets of electrophoretic fluid within such a polymer-dispersed electrophoretic display may be regarded as capsules or microcapsules even though no discrete capsule membrane is associated with each individual droplet; see for example, U.S. Patent No. 6,866,760. Accordingly, for purposes of the present application, such polymer-dispersed electrophoretic media are regarded as sub-species of encapsulated electrophoretic media.

[Para 7] A related type of electrophoretic display is a so-called "microcell electrophoretic display". In a microcell electrophoretic display, the charged particles and the fluid are not encapsulated within microcapsules but instead are retained within a plurality of cavities

formed within a carrier medium, typically a polymeric film. See, for example, U.S. Patents Nos. 6,672,921 and 6,788,449, both assigned to Sipix Imaging, Inc.

[Para 8] Although electrophoretic media are often opaque (since, for example, in many electrophoretic media, the particles substantially block transmission of visible light through the display) and operate in a reflective mode, many electrophoretic displays can be made to operate in a so-called "shutter mode" in which one display state is substantially opaque and one is light-transmissive. See, for example, U.S. Patents Nos. 5,872,552; 6,130,774; 6,144,361; 6,172,798; 6,271,823; 6,225,971; and 6,184,856. Dielectrophoretic displays, which are similar to electrophoretic displays but rely upon variations in electric field strength, can operate in a similar mode; see U.S. Patent No. 4,418,346. Electrophoretic media operating in shutter mode may be useful in multi-layer structures for full color displays; in such structures, at least one layer adjacent the viewing surface of the display operates in shutter mode to expose or conceal a second layer more distant from the viewing surface.

[Para 9] As already indicated, an encapsulated or microcell electrophoretic display typically does not suffer from the clustering and settling failure mode of traditional electrophoretic devices and provides further advantages, such as the ability to print or coat the display on a wide variety of flexible and rigid substrates. (Use of the word "printing" is intended to include all forms of printing and coating, including, but without limitation: pre-metered coatings such as patch die coating, slot or extrusion coating, slide or cascade coating, curtain coating; roll coating such as knife over roll coating, forward and reverse roll coating; gravure coating; dip coating; spray coating; meniscus coating; spin coating; brush coating; air knife coating; silk screen printing processes; electrostatic printing processes; thermal printing processes; ink jet printing processes; electrophoretic deposition (See U.S. Patent No. 7,339,715); and other similar techniques.) Thus, the resulting display can be flexible. Further, because the display medium can be printed (using a variety of methods), the display itself can be made inexpensively.

[Para 10] Throughout the specification, reference will be made to printing or printed. As used throughout the specification, printing is intended to include all forms of printing and coating, including: premetered coatings such as patch die coating, slot or extrusion coating, slide or cascade coating, and curtain coating; roll coating such as knife over roll coating, forward and reverse roll coating; gravure coating; dip coating; spray coating; meniscus coating; spin coating; brush coating; air knife coating; silk screen printing processes;

electrostatic printing processes; thermal printing processes; and other similar techniques. A "printed element" refers to an element formed using any one of the above techniques.

[Para 11] Most prior art electrophoretic media essentially display only two colors. Such electrophoretic media either use a single type of electrophoretic particle having a first color in a colored fluid having a second, different color (in which case, the first color is displayed when the particles lie adjacent the viewing surface of the display and the second color is displayed when the particles are spaced from the viewing surface), or first and second types of electrophoretic particles having differing first and second colors in an uncolored fluid (in which case, the first color is displayed when the first type of particles lie adjacent the viewing surface of the display and the second color is displayed when the second type of particles lie adjacent the viewing surface). Typically the two colors are black and white. If a full color display is desired, a color filter array may be disposed over the viewing surface of the monochrome (black and white) display. Such a color filter array is typically of three the red/green/blue ("RGB") or red/green/blue/ white ("RGBW") type. Displays with color filters rely upon an area sharing approach with (in the case of RGB displays) or four (in the case of RGBW displays) sub-pixels together functioning as a single full color pixel. Unfortunately, each color can only be displayed by part of the display area. For example, in an RGBW display, each of red, green and blue can only be displayed by ¼ of the display area (one sub-pixel out of four) and white can effectively be displayed by ½ of the display area (one complete sub-pixel out of four, plus each colored sub-pixel acts as 1/3 white, so the three colored sub-pixels together provide another one complete white sub-pixel). This area sharing approach result in colors less bright than is desirable.

[Para 12] Alternatively full color displays can be constructed using multiple color-changing layers, with at least one front (i.e., adjacent the viewing surface) color-changing layer operating in shutter mode. Apart from being complicated and potentially expensive, such a multi-layer display requires precise alignment of the various layers, and highly light transmissive electrodes (and transistors, in the case of an active matrix display).

[Para 13] The aforementioned U. S. Patent No. 6,017,584 describes an electrophoretic medium having three different types of particles having three different colors in a fluid, and a method of driving the particles so as to enable each of the three different colors to be displayed.

[Para 14] There is still, however, a need for electrophoretic media capable of displaying more colors at each pixel in order that, for example, such media can reproduce the

appearance of high quality color printing. Such high quality printing is typically effected using at least four inks, cyan/magenta/yellow/black ("CMYK"). It is often not appreciated that a so-called "four-color" CMYK printing system is in reality a five-color system, the fifth color being the white background provided by the paper (or similar) surface when no ink is applied thereto. Since there is no comparable background color in an essentially opaque electrophoretic medium unless it is being used in shutter mode, a non-shutter mode electrophoretic medium should be capable of displaying five colors (black, white and three primary colors, the three primary colors typically being cyan, magenta and yellow). It has now been realized that by this aim can be achieved by using the electrophoretic medium from the aforementioned U. S. Patent No. 6,017,584 having three different types of particles in a colored fluid and choosing the colors of both the particles and the fluid carefully.

[Para 15] In yet another aspect, this invention provides a multi-color electrophoretic medium containing at least first, second and third species of particles, the particles having substantially non-overlapping electrophoretic mobilities and first, second and third colors respectively, the first, second and third colors differing from each other, the particles being dispersed in a fluid having a fourth color different from the first, second and third colors, wherein one of the first, second and third types of particles has a white color.

[Para 16] In such a multi-color medium, the first, second, third and fourth colors may be cyan, magenta, yellow and white, in any order. As already noted, the first, second and third types of particles must having differing (and non-zero) electrophoretic mobilities. Although in principle all three types of particles could bear charges of the same polarity but differing magnitudes to provide the differing electrophoretic mobilities, it is generally more convenient to have two types of particles bearing charges of one polarity, with the other type of particles bear charges of the opposite polarity. It is preferred that the white particle bear charges of one polarity and that the other two types of particles (conveniently cyan and magenta) bear charges of the opposite polarity.

[Para 17] The electrophoretic medium of the invention has three types of particles colored white and two other colors. Both transmissive and reflective colored particles can be used in the present invention. White particles operate by scattering light and hence are essentially reflective; a "transmissive" white particle would be essentially transparent and hence not useful in the present invention. However, as illustrated in the drawings and described below, both transmissive and reflective particles having colors other than white can be used, although the positioning of the various particles, and especially the positioning of the white

particles, needed to produce various colors varies depending upon whether transmissive or reflective non-white particles are used.

[Para 18] The electrophoretic medium of the present invention may be of the encapsulated type and comprise a capsule wall within which the fluid and the electrically charged particles are retained. Such an encapsulated medium may comprise a plurality of capsules each comprising a capsule wall, with the fluid and electrically charged particle retained therein, the medium further comprising a polymeric binder surrounding the capsules. Alternatively, the medium may be of the microcell or polymer-dispersed types discussed above.

[Para 19] This invention extends to an electrophoretic display comprising an electrophoretic medium of the present invention and at least one electrode disposed adjacent the electrophoretic medium for applying an electric field to the medium. The displays of the present invention may be used in any application in which prior art electro-optic displays have been used. Thus, for example, the present displays may be used in electronic book readers, portable computers, tablet computers, cellular telephones, smart cards, signs, watches, shelf labels and flash drives.

[Para 20] In another aspect, this invention provides a method of driving a multi-color electrophoretic display containing at least first, second and third species of particles, the particles having substantially non-overlapping electrophoretic mobilities and first, second and third colors respectively, the first, second and third colors differing from each other, wherein one of the first, second and third types of particles has a white color, the particles being dispersed in a fluid having a fourth color different from the first, second and third colors, the display further comprising a first electrode forming a viewing surface of the display and a second electrode on the opposed side of the fluid from the first electrode, the method comprising:

bringing all three species of particles adjacent one of the first and second electrodes;

applying an electric field between the first and second electrodes to cause at least one species of particles to move away from said one electrode, thereby placing a desired one of the three species of particles adjacent the viewing surface; and

applying an electric field between the first and second electrodes to cause all three species of particles to move away from the first electrode, whereby the fourth color of the fluid is displayed at the viewing surface.

[Para 21] The advantages of the invention described above, together with further advantages, may be best understood by referring to the following description taken in conjunction with the accompanying drawings. In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

[Para 22] Figures 1A-1H depict a color display element having white, cyan and magenta particles of different electrophoretic mobilities in a yellow colored fluid, the cyan and magenta particles being reflective, and illustrate respectively, the white, cyan, magenta, yellow, red, green, blue and black optical states of the display.

[Para 23] Figures 2A-2H depict a color display element similar to that shown in Figures 1A-1H but in which the cyan and magenta particles are transmissive, with Figures 2A-2H illustrating the same optical states as Figures 1A-1H respectively.

[Para 24] The following description assumes familiarity with the disclosure of the aforementioned U. S. Patent No. 7,791,789, to which the reader should refer for background information regarding this invention.

[Para 25] Figures 1A-1H illustrate a capsule 120 having a capsule wall 124 and containing three different species of particles differing in color and electrophoretic mobility and dispersed in a colored fluid 125. The capsule 120 is provided with light transmissive front and rear electrodes 32 and 34 respectively on opposed sides thereof, with the front electrode 32 providing the viewing surface of the capsule. More specifically, the capsule 120 comprises negatively charged white particles (denoted W-), and positively charged cyan and magenta particles, with the cyan particles (denoted +C+) having a higher electrophoretic mobility than the magenta particles (denoted M+). The fluid 125 is colored with a yellow dye. The concentration of yellow dye should be chosen such that the yellow optical state of the display (described below with reference to Figure 1D) provides a sufficiently saturated yellow color, but the yellow does not substantially contaminate other colors when electrophoretic particles lie adjacent the front electrode 32. The white W-, cyan +C+ and magenta M+ particles are all reflective. The yellow color of the dyed fluid is apparent only when there are no electrophoretic particles adjacent the front electrode 32. For example, if the white particles W- are driven adjacent the front electrode 32, the yellow color of the fluid 125 is not visible because the path of light (which enters through the front electrode 32, is reflected from the white particles W- and passes back through the front electrode 32) through the colored fluid is

very short. If, however, the white particles W- are spaced from the front electrode 32 by a sufficient display (perhaps ¼ of the thickness of the fluid layer) the yellow color of the dyed fluid 125 will become visible as the path of reflected light through the fluid becomes substantial. The effect is similar to that in prior art single particle/dyed fluid electrophoretic displays.

[Para 26] As already noted, the cyan +C+ and magenta M+ particles are both positively charged but have differing electrophoretic mobilities; the present description will assume that the cyan particles have the higher mobility but obviously the reverse could be the case.

[Para 27] The capsule 120 is capable of displaying white, cyan, magenta, yellow, red, green, blue and black colors at its viewing surface (the front electrode 32), as illustrated in Figures 1A-1G respectively. To display a white color, the rear electrode 34 is simply made negative relative to the front electrode 32 for an extended period (all references hereinafter to making the rear electrode 34 negative or positive refer to making this rear electrode negative or positive relative to the front electrode 32, since typically in practice the front electrode 32 will be a common front electrode extending across the whole display, while the rear electrode 34 will be one of a multitude of individually controllable pixel electrodes), so that the white particles W- lie adjacent the front electrode 32 and the cyan +C+ and magenta M+ particles lie adjacent the rear electrode 34. In this situation, the white particles W- mask the cyan +C+ and magenta M+ particles and the yellow color of the fluid 125 (as previously noted, the pass length of light through the fluid 125 is too short for any appreciable contamination of the white color of the white particles W- by the yellow color of the fluid), so that a white color is displayed at the viewing surface of the display.

[Para 28] To produce a cyan color, as illustrated in Figure 1B, one first applies a negative pulse to rear electrode 34 (which brings about substantially the same situation as in Figure 1A, with the white particles W- adjacent the front electrode 32 and the cyan +C+ and magenta M+ particles adjacent the rear electrode 34), followed by a positive pulse shorter than the negative pulse. The positive pulse causes the white particles W- to approach the rear electrode 34 and both the cyan +C+ and magenta M+ particles to approach the front electrode 32. However, because of the greater mobility of the cyan +C+ particles, they approach the front electrode 32 more rapidly and the length of the positive pulse is chosen so that the cyan +C+ particles reach the front electrode 32 but the magenta particles M+ do not; in colloquial terms, the cyan particles "outrace" the magenta particles. In the situation shown in Figure 1B, the cyan particles +C+ mask the magenta M+ and white W- particles and the yellow color of

the fluid 125 (as previously noted, the pass length of light through the fluid 125 is too short for any appreciable contamination of the cyan color of the cyan particles +C+ by the yellow color of the fluid), so that a cyan color is displayed at the viewing surface of the display.

[Para 29] To produce a magenta color, as illustrated in Figure 1C, one first applies a long positive pulse, which brings both the cyan particles +C+ and the magenta particles M+ adjacent the front electrode 32 and the white particles adjacent the rear electrode 34. There is then applied a very short negative pulse, which causes both the cyan particles +C+ and the magenta particles M+ to move away from the front electrode 32. However, because of the greater mobility of the cyan particles +C+, they move away from the front electrode 32 more rapidly than the magenta particles M+ , leaving the magenta particles visible through the front electrode 32 and screening the cyan particles C+, the white particles W- and the yellow color of the fluid 125. The duration of the short negative pulse is chosen such that the pass length of light through the fluid 125 is too short for any appreciable contamination of the magenta color of the magenta particles M+ by the yellow color of the fluid. The short negative pulse also, of course, causes the white particles W- to move away from the rear electrode 34 but this has no effect on the color displayed.

[Para 30] To produce a yellow color, as illustrated in Figure 1D, one first applies a negative pulse, which brings about substantially the same situation as in Figure 1A, with the white particles W- adjacent the front electrode 32 and the cyan +C+ and magenta M+ particles adjacent the rear electrode 34. One then applies a positive pulse, shorter than the negative pulse, to cause the white particles W- to move away from the front electrode 32 and the cyan +C+ and magenta particles to move away from the rear electrode 34. The length of the positive pulse is controlled so that the white particles W- remain closer to the front electrode 32 than the cyan +C+ and magenta particles but such that there is a substantial distance between the white particles W- and the front electrode 32. Thus, as illustrated in Figure 1D, the white particles W- mask the cyan particles +C+ and the magenta particles M+. However, unlike the situation in Figure 1A, in Figure 1D the white particles are spaced a substantial distance from the front electrode 32 and act as a diffuse reflector causing light entering through the front electrode 32 and passing through the yellow fluid 125 to be reflected back through the yellow fluid 125 and the front electrode 32. Since this light has a substantial pass length through the yellow fluid 125, a yellow color is displayed.

[Para 31] To display a red state, as illustrated in Figure 1E, one first applies a relatively long positive pulse which, like the long positive pulse used in Figure 1C, brings the cyan +C+ and

magenta M+ particles adjacent the front electrode 32 and the white particles W- adjacent the rear electrode 34. Next, a negative pulse shorter than the initial positive pulse but longer than the negative pulse applied in Figure 1C, is applied, and, for the same reasons as in Figure 1C, causes the magenta particles M+ to be closest to the front electrode 32 and to mask the cyan particles +C+ and the white particles W-. However, the final negative pulse still leaves the magenta particles M+ substantially spaced from the front electrode 32, so that, for reasons similar to those discussed above in relation to Figure 1D, the appearance of the display is affected by the yellow dye through which light reflected from the magenta particles M+ passes, and thus the appearance of the display is a combination of yellow dye absorption and magenta reflection, giving a red appearance.

[Para 32] To display a green state, as illustrated in Figure 1F, one first applies a relatively long negative pulse which, like the long negative pulse used in Figure 1A, brings the white particles W- particles adjacent the front electrode 32 and the cyan +C+ and magenta M+ adjacent the rear electrode 34. Next, a very short positive pulse is applied. This positive pulse causes the cyan particles +C+ to move forwardly until they lie forward of the white particles W-, which of course move backwardly from the front electrode 32. The positive pulse also causes the magenta particles M+ to move forwardly, but at a slower rate than the cyan particles +C+. The final situation is similar to that shown in Figure 1B, in as much as the cyan particles +C+ lie closest to the front electrode 32 and mask the white particles W- and the magenta particles M+. However, in the situation shown in Figure 1F, the cyan particles are spaced from the front electrode 32 by a distance sufficient to cause substantial absorption by the yellow dye present in the fluid 125. Hence, for reasons similar to those already discussed with reference to Figure 1E, the appearance of the display in Figure 1F is a combination of yellow dye absorption and cyan reflection, giving a green appearance.

[Para 33] To display a blue state, as illustrated in Figure 1G, one applies a long positive pulse which, like the long positive pulse used in Figure 1C and the first pulse used in Figure 1E, brings the cyan +C+ and magenta M+ particles adjacent the front electrode 32 and the white particles W- adjacent the rear electrode 34. Note that in the situation shown in Figure 1G two different reflection mechanisms are at work. If light is reflected only from a single particle, the mixtures of reflections from cyan and magenta particles will appear to the eye as a light blue. If, however, light is reflected by at least one cyan particle and one magenta particle, the light will appear a deeper blue. Since it can be shown that much of the light

scattering from electrophoretic media involves multiple reflections, the situation shown in Figure 1G will provide a well saturated blue.

[Para 34] Finally, to display a black state, as illustrated in Figure 1H, one applies a long positive pulse, which produces the situation shown in Figure 1G, and then applies a short negative pulse. The short negative pulse moves the cyan +C+ and magenta M+ particles away from the front electrode 32 thus (for reasons similar to those already discussed with reference to Figures 1D, 1E and 1F) admixing the yellow color of the fluid 125 with the blue reflection shown in Figure 1G and producing a process black appearance.

[Para 35] Figures 2A-2H illustrate a display generally similar to that illustrated in Figures 1A-1H but in which the cyan particles +C+ and the magenta particles M+ are transmissive rather than reflective. The use of transmissive rather than reflective particles requires some modifications of the necessary positions of the particles in certain optical states because a transmissive colored particle does not screen out the colors of particles "further back" (i.e., closer to the rear electrode 34) and hence in some optical states it is necessary to control carefully the positions of the white particles W- in order to ensure that such screening does occur.

[Para 36] Figure 2A shows the white state of the display. This white state is identical to that shown in Figure 1A and is reached in exactly the same manner; since the white particles W- hide both the cyan particles +C+ and the magenta particles M+ in this state of the display, the use of transmissive cyan and magenta particles rather than reflective particles makes no difference to the appearance of this state of the display.

[Para 37] Figure 2B shows the cyan state of the display. This state of the display differs from that shown in Figure 1B in that the white particles W- need to be disposed immediately behind the cyan particles +C+ in order that the white particles can screen the magenta particles M+. Light entering the display through the front electrode 32 passes through the transmissive cyan particles, is reflected from the white particles, and then passes back through the cyan particles and back out of the display through the front electrode. To avoid contaminating the cyan color thus produced with yellow (and thus shifting the displayed color towards green), it is important that the white particles be close behind the cyan particles, so that the light travelling the aforesaid path does not have to travel a significant distance through the yellow fluid 125.

[Para 38] Provided that the electrophoretic mobility of the cyan particles +C+ is much greater than that of the magenta particles M+, and the absolute values of the electrophoretic

mobilities of the magenta and white particles are comparable, the display state shown in Figure 2B can be produced by first driving the display to the state shown in Figure 2A and then applying to the rear electrode 34 a positive pulse just sufficient to drive the cyan particles to the front electrode 32 and the white particles a short distance away from this front electrode.

[Para 39] Figure 2C shows the magenta optical state of the display. This is generally similar to the cyan optical state shown in Figure 2B, but with the magenta particles adjacent the front electrode 32 and the cyan particles adjacent the rear electrode 34. The magenta optical state functions in a manner exactly parallel to the cyan optical state; light entering the display through the front electrode 32 passes through the transmissive magenta particles, is reflected from the white particles, and then passes back through the magenta particles and back out of the display through the front electrode. Again, to avoid contaminating the magenta color thus produced with yellow (and thus shifting the displayed color towards red), it is important that the white particles be close behind the magenta particles, so that the light travelling the aforesaid path does not have to travel a significant distance through the yellow fluid 125.

[Para 40] Figure 2D shows the yellow optical state of the display. This is identical to the yellow state shown in Figure 1D, can be produced using the same drive pulses, and the yellow color is produced in the same manner; light entering the display through the front electrode 32 passes through the yellow fluid 125, is reflected from the white particles, passes back through the yellow fluid 125 and back through the front electrode 32.

[Para 41] Figure 2E shows the red optical state of the display. The positions of the particles in this red optical state are identical to those of the similar red state shown in Figure 1E, and the red state can be brought about using the same drive pulses as in Figure 1E. However, the actual manner in which the red color is produced in Figure 2E differs slightly from that described with reference to Figure 1E. In Figure 2E, light entering the display through the front electrode 32 passes through the yellow fluid 125 and the transmissive magenta particles, is reflected from the white particles, passes back through the magenta particles and the yellow fluid 125 and back through the front electrode 32 to produce a red appearance to the display.

[Para 42] Figure 2F shows the green optical state of the display. The positions of the particles in this green optical state are identical to those of the similar green state shown in Figure 1F, and the green state can be brought about using the same drive pulses as in Figure 1F. However, as with the red optical state shown in Figure 2E, the actual manner in which the

green color is produced in Figure 2F differs slightly from that described with reference to Figure 1F. In Figure 2F, light entering the display through the front electrode 32 passes through the yellow fluid 125 and the transmissive cyan particles, is reflected from the white particles, passes back through the cyan particles and the yellow fluid 125 and back through the front electrode 32 to produce a green appearance to the display.

[Para 43] Figure 2G shows the blue optical state of the display, which differs from the corresponding blue state shown in Figure 1G in that the white particles are located relatively close to the front electrode, immediately behind the mixed layer of cyan and magenta particles. In Figure 2G, light entering the display through the front electrode 32 passes through the transmissive magenta and cyan particles, is reflected from the white particles, passes back through the magenta and cyan particles and back through the front electrode 32 to produce a blue appearance to the display.

[Para 44] Finally, Figure 2H shows one possible black state of the display, this black state being identical, as to particle position to that shown in Figure 1H. However, the way in which the black state is produced is slightly different from that described above with regard to Figure 1H. In Figure 2H, light entering the display through the front electrode 32 passes through the transmissive magenta and cyan particles and the yellow fluid 125, so that essentially all light is absorbed before it can reach the white particles adjacent the rear electrode 34. Any light which does reach the white particles will be reflected back and again pass through the transmissive magenta and cyan particles and the yellow fluid 125, so that essentially no light will re-emerge from the front electrode 32, and a black optical state will be displayed. It should be noted that in this black optical state, there is considerable freedom as regards the disposition of the magenta and cyan particles, provided both types of particles lie closer to the front electrode than the white particles; since the yellow fluid 125 and the magenta and cyan particles are all transmissive, the exact order in which incoming light encounters the fluid and the two types of particles is essentially irrelevant, and hence the positions of the magenta and cyan particles can be varied provided both lie closer to the front electrode than the white particles. For example, in the display shown in Figures 2A-2H, the particle positions shown in Figure 1G would provide a black optical state.

[Para 45] It will be seen from the foregoing that the displays illustrated in Figures 1A-1H and 2A-2H are capable of displaying white, black, cyan, magenta, yellow, red, green and blue colors over their entire display areas. As previously noted, displays using RGB color filter arrays are capable of displaying red, green and blue colors over only one third of their display

area, black over the whole display area and a process white equivalent to white over one third of the display area. Similarly, displays using RGBW color filter arrays are capable of displaying red, green and blue colors over only one fourth of their display area, black over the whole display area and a process white equivalent to white over one half of the display area. The white states of the displays illustrated in Figures 1A-1H and 2A-2H should thus be dramatically better than that of any display based upon color filters, and the red, green and blue states should also be improved. Furthermore, the white states of the displays illustrated in Figures 1A-1H and 2A-2H should be dramatically better than that of the multi-particle display illustrated in Figures 6-9 of the aforementioned U. S. Patent No. 7,791,789, which relies upon a process white state equivalent to white over one third of the display area.

[Para 46] In certain cases, it may be difficult to procure colored particles having the desired colors and relative electrophoretic mobilities needed to enable each of the optical states shown in Figures 1A-1H or 2A-2H to be achieved using simple sets of drive pulses. In such cases, it may be appropriate to use at least one type of particle which has an electrophoretic mobility which varies with applied voltage, so that the relative electrophoretic mobilities of two types of particles can be varied by adjusting the driving voltage used, as described in U.S. Patent Application Publication No. 2006/0202949. Since the particles used in the displays of the present invention may have voltage-dependent mobilities, references herein the particles having differing electrophoretic mobilities should be understood as including particles having differing electrophoretic mobilities at at least one driving voltage used in the display containing the particles.

CLAIMS

1. A multi-color electrophoretic medium comprising first, second and third species of particles, the particles having substantially non-overlapping electrophoretic mobilities and first, second and third colors respectively, the first, second and third colors differing from each other, the particles being dispersed in a fluid having a fourth color different from the first, second and third colors, wherein one of the first, second and third types of particles has a white color.

2. An electrophoretic medium according to claim 1 wherein the first, second, third and fourth colors are cyan, magenta, yellow and white, in any order.

3. An electrophoretic medium according to claim 1 wherein the two types of non-white particles are transmissive.

4. An electrophoretic medium according to claim 1 wherein the two types of non-white particles are reflective.

5. An electrophoretic medium according to claim 1 wherein one of the first, second and third types of particles bears a charge of one polarity and the other two types of particles bear charges of the opposite polarity.

6. An electrophoretic medium according to claim 5 wherein the one type of particle which bears a charge of one polarity is white in color.

7. An electrophoretic medium according to claim 1 wherein the fourth color is yellow.

8. An electrophoretic medium according to claim 1 wherein the first type of particles are white in color and bear a charge of one polarity, the second type of particles are cyan in color and bear a charge of polarity opposite to that of the white particles, the third type of particles are magenta in color and bear a charge of polarity opposite to that of the white particles, and the fluid is yellow in color.

9. An electrophoretic medium according to claim 1 further comprising a capsule wall within which the fluid and the particles are retained.

10. An electrophoretic medium according to claim 10 comprising a plurality of the capsules within which the fluid and the particles are retained, and a polymeric binder surrounding the capsules.

11. An electrophoretic medium according to claim 1 wherein the fluid and the particles are present as a plurality of discrete droplets dispersed in a continuous phase of a polymeric material.

12. An electrophoretic medium according to claim 1 wherein the fluid and the particles are retained within a plurality of cavities formed in a carrier medium.

13. An electrophoretic display comprising an electrophoretic medium according to claim 1 and at least one electrode disposed adjacent the electrophoretic medium and arranged to apply an electric field to the medium.

14. An electronic book reader, portable computer, tablet computer, cellular telephone, smart card, sign, watch, shelf label or flash drive incorporating a display according to claim 14.

15. A method of driving a multi-color electrophoretic display containing at least first, second and third species of particles, the particles having substantially non-overlapping electrophoretic mobilities and first, second and third colors respectively, the first, second and third colors differing from each other, wherein one of the first, second and third types of particles has a white color, the particles being dispersed in a fluid having a fourth color different from the first, second and third colors, the display further comprising a first electrode forming a viewing surface of the display and a second electrode on the opposed side of the fluid from the first electrode, the method comprising:

bringing all three species of particles adjacent one of the first and second electrodes;

applying an electric field between the first and second electrodes to cause at least one species of particles to move away from said one electrode, thereby placing a desired one of the three species of particles adjacent the viewing surface; and

applying an electric field between the first and second electrodes to cause all three species of particles to move away from the first electrode, whereby the fourth color of the fluid is displayed at the viewing surface.

16. A method according to claim 15 wherein the first, second, third and fourth colors may be cyan, magenta, yellow and white, in any order.

17. A method according to claim 15 wherein one of the first, second and third types of particles bears a charge of one polarity and the other two types of particles bear charges of the opposite polarity.

18. A method according to claim 15 wherein the one type of particle which bears a charge of one polarity is white in color.

19. A method according to claim 15 wherein the fourth color is yellow.

20. A method according to claim 15 wherein the first type of particles are white in color and bear a charge of one polarity, the second type of particles are cyan in color and bear a charge of polarity opposite to that of the white particles, the third type of particles are magenta in color and bear a charge of polarity opposite to that of the white particles, and the fluid is yellow in color.

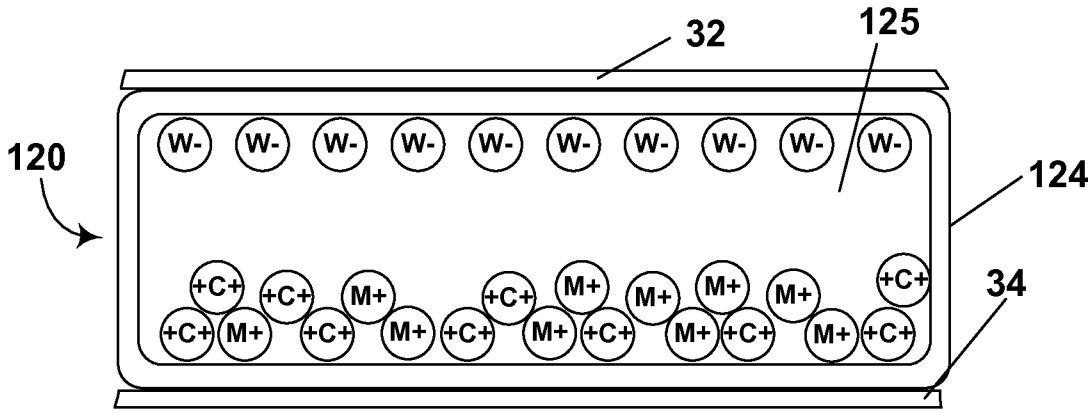

Fig. 1A

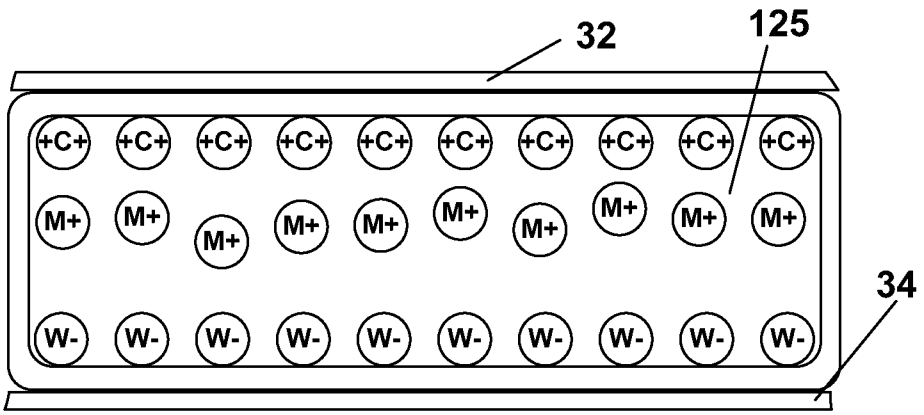

Fig. 1B

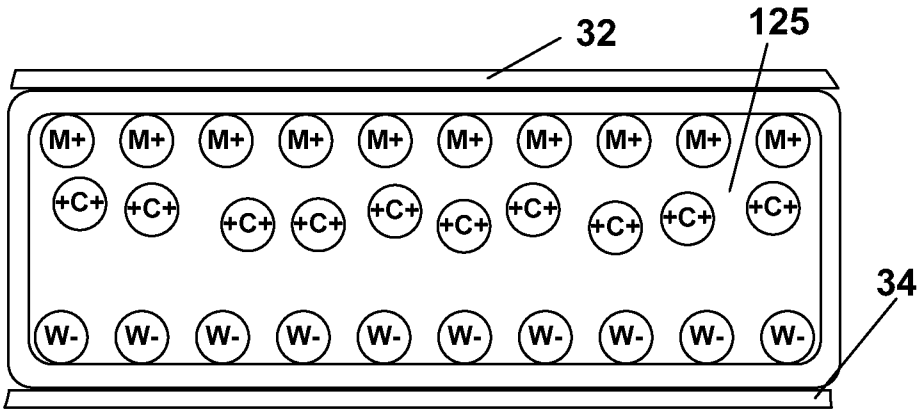

Fig. 1C

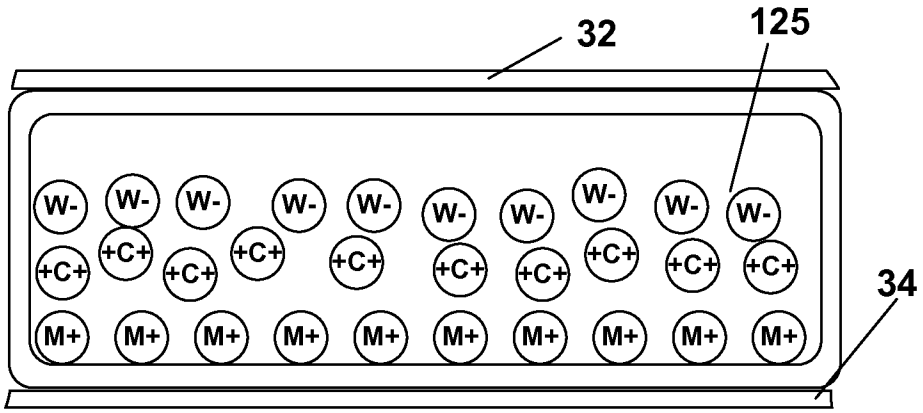

Fig. 1D

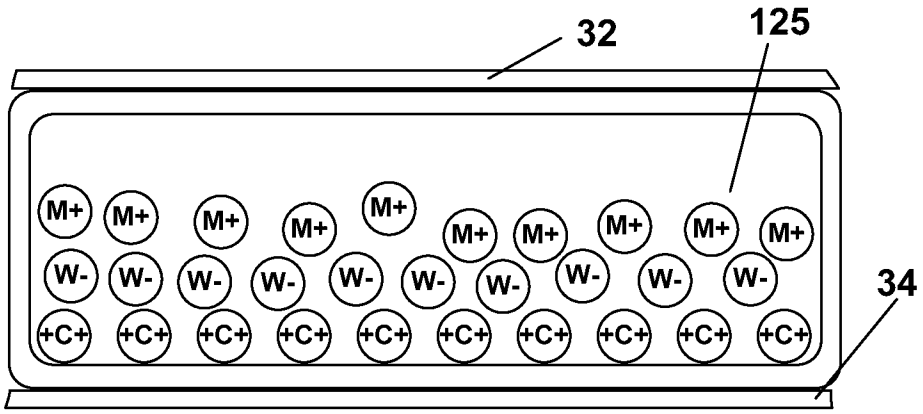

Fig. 1E

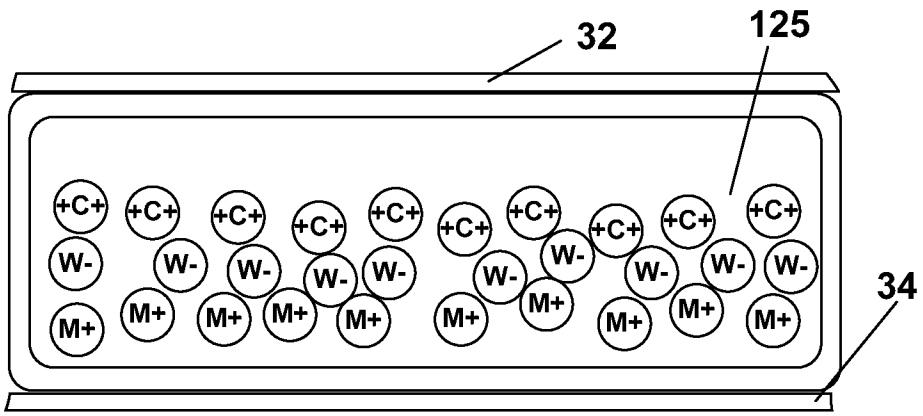

Fig. 1F

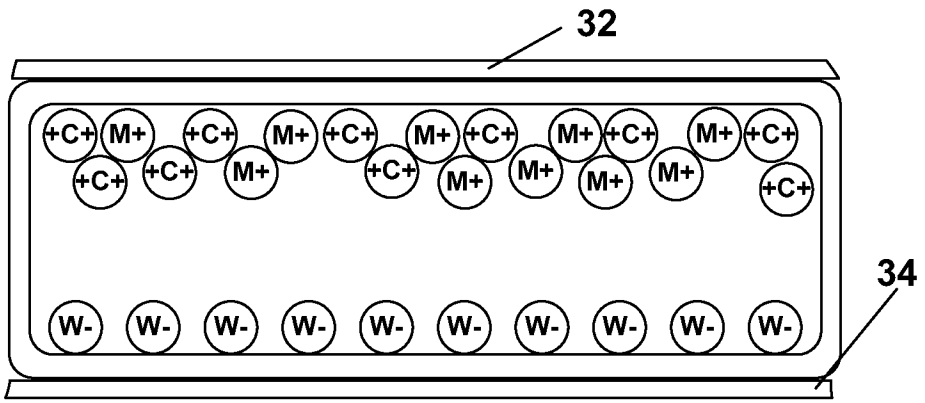

Fig. 1G

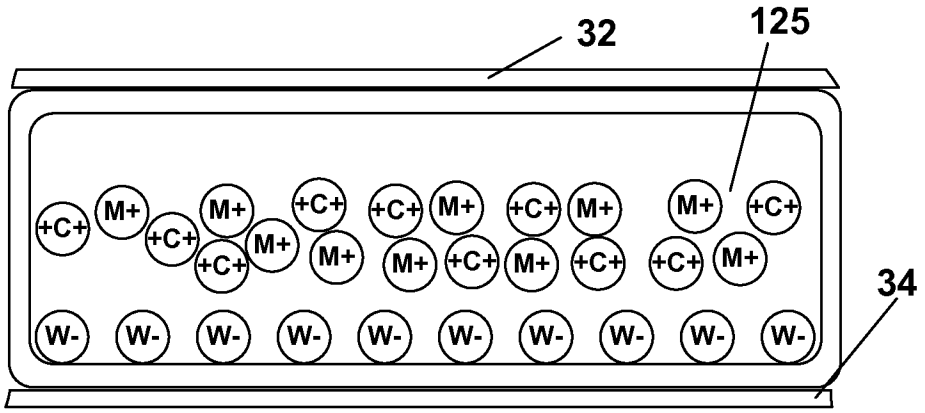

Fig. 1H

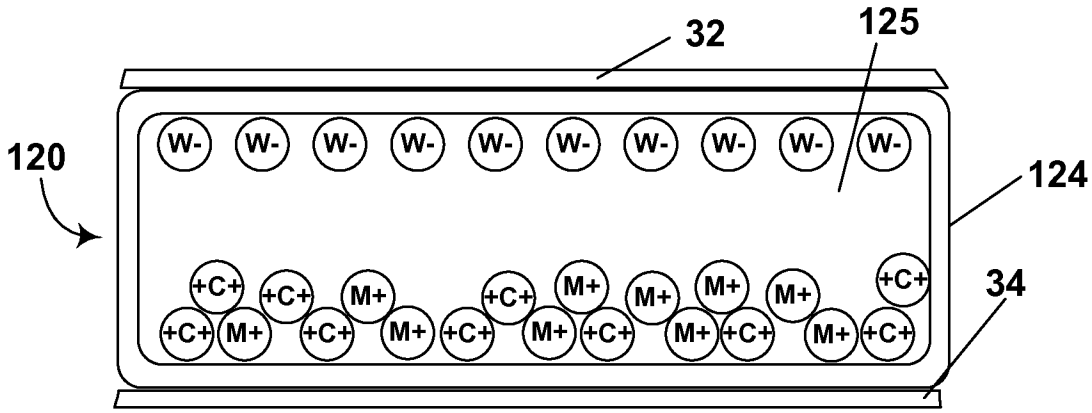

Fig. 2A

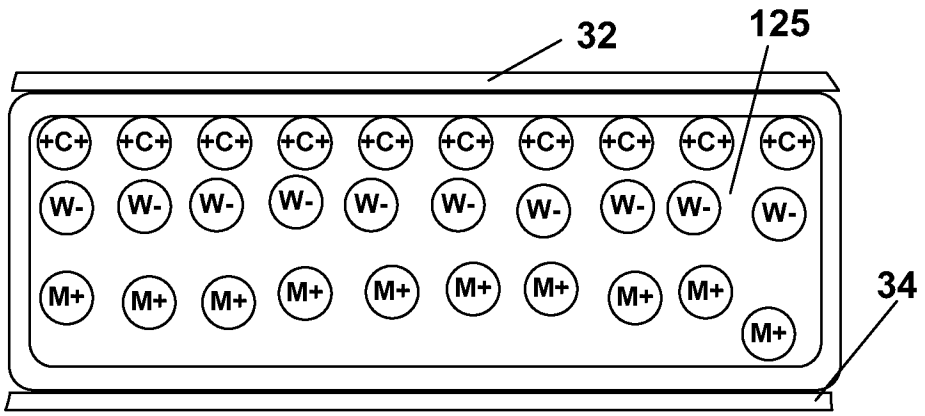

Fig. 2B

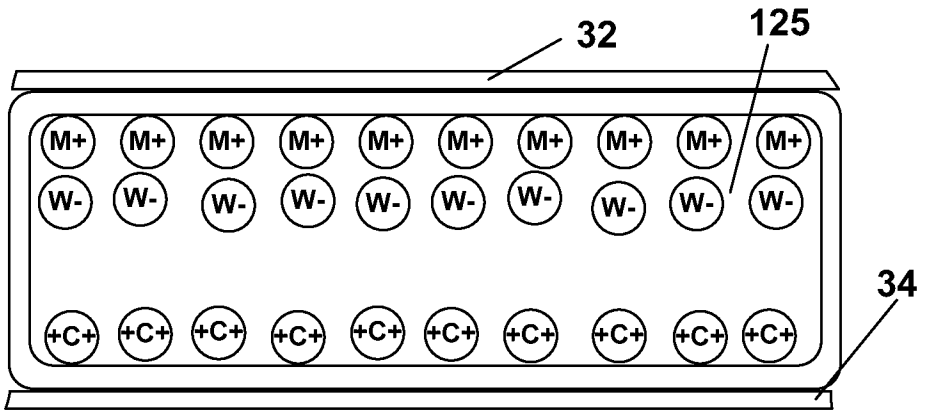

Fig. 2C

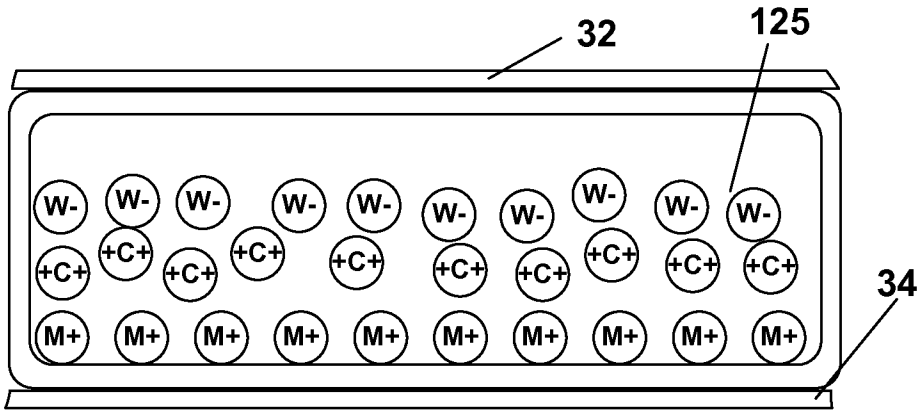

Fig. 2D

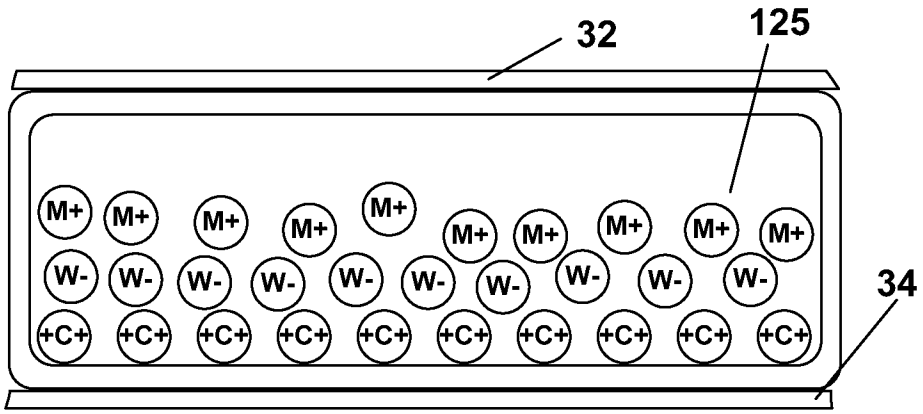

Fig. 2E

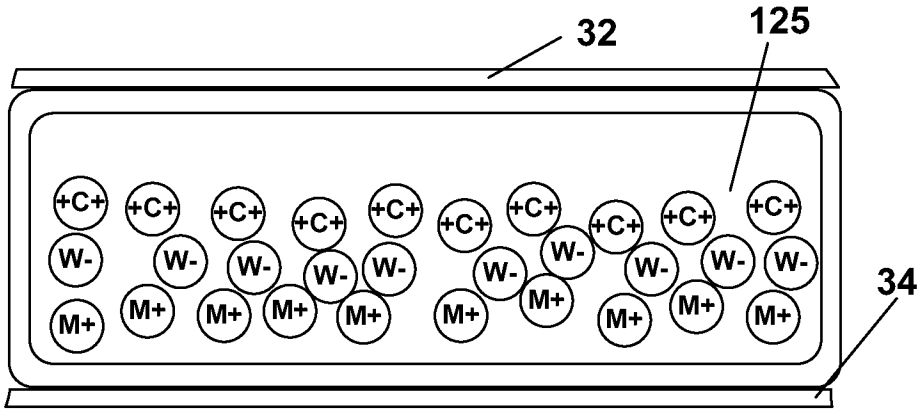

Fig. 2F

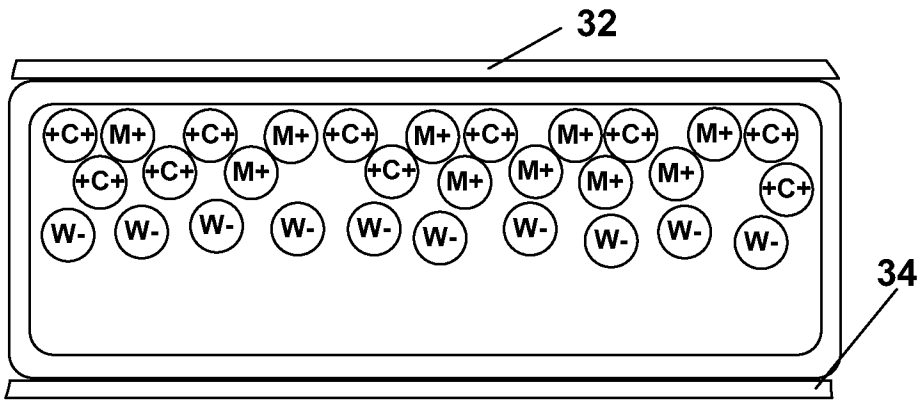

Fig. 2G

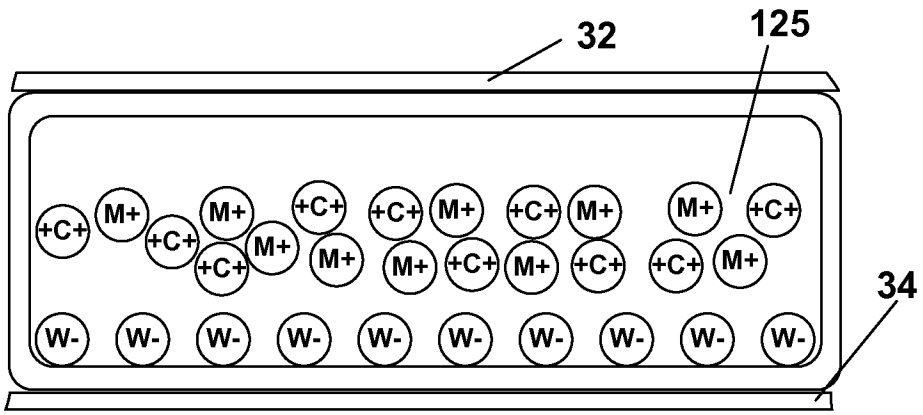

Fig. 2H