



- (51) International Patent Classification:
G02F 1/167 (2006.01)
- (21) International Application Number:
PCT/US2016/056356
- (22) International Filing Date:
11 October 2016 (11.10.2016)
- (25) Filing Language:
English
- (26) Publication Language:
English
- (30) Priority Data:
62/240,407 12 October 2015 (12.10.2015) US
- (71) Applicant: E INK CALIFORNIA, LLC [US/US]; 47485
Seabridge Drive, Fremont, California 94538 (US).
- (72) Inventors: LIN, Craig; Suite 301, 200 2nd Street, Oak-
land, California 94607 (US). CHAN, Bryan Hans; Apart-
ment No. 705, 235 Berry Street, San Francisco, California
94158 (US). DU, Hui; 730 Clouser Drive, Milpitas, Cali-
fornia 95035 (US).
- (74) Agent: COLE, David J.; E Ink Corporation, 1000 Tech-
nology Park Drive, Billerica, Massachusetts 01821-4165
(US).
- (81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

— with international search report (Art. 21(3))

(54) Title: ELECTROPHORETIC DISPLAY DEVICE

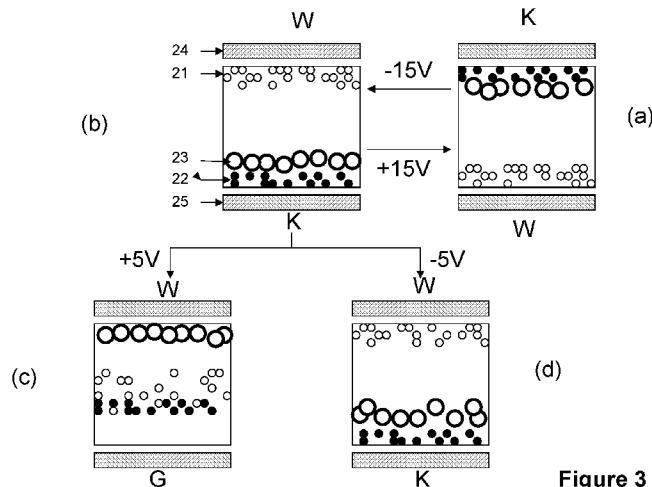


Figure 3

(57) Abstract: An electrophoretic display is provided suitable for passive matrix driving. The electrophoretic display comprises three types of particles, with the first (11; 21; 41) and second (12; 22; 42) types of charged particles carrying charges of opposite polarities and having contrasting colors. The third type of particles (13; 23; 43) has the same color as the first or the second type of particles.



ELECTROPHORETIC DISPLAY DEVICE

[Para 1] This application is related to:

(a) U.S. Patents Nos. 8,717,664; 8,964,282; and 9,360,733; and U.S. Patent Publication No. 2016/0260372;

(b) U.S. Patent Publication No. 2015/0103394;

(c) U.S. Patent Publication No. 2015/0097877; and

(d) U.S. Patent Publication No. 2016/0293111

[Para 2] The entire contents of these patents and copending applications, and of all other U.S. patents and published and copending applications mentioned below, are herein incorporated by reference.

[Para 3] This invention relates to electrophoretic displays, methods for driving such displays and electrophoretic media for use in such displays.

[Para 4] The electrophoretic display (EPD) is a non-emissive device based on the electrophoresis phenomenon of charged pigment particles dispersed in a solvent. The display typically comprises two plates with electrodes placed opposing each other. One of the electrodes is usually transparent. An electrophoretic medium composed of a colored fluid with charged pigment particles dispersed therein is enclosed between the two plates. When a voltage difference is imposed between the two electrodes, the pigment particles migrate to one side or the other causing either the color of the pigment particles or the color of the fluid being seen from the viewing side.

[Para 5] Alternatively, an electrophoretic medium may comprise two (or more) types of charged pigment particles of contrasting colors and carrying opposite charges, and the two types of the charged pigment particles are dispersed in a clear fluid. In this case, when a voltage difference is imposed between the two electrode plates, the two types of the charged pigment particles would move to opposite sides. Thus one of the colors of the two types of the charged pigment particles would be seen at the viewing side.

[Para 6] The aforementioned patents and published applications describe an electrophoretic medium containing three types of particles, typically all having differing optical characteristics. (Although the optical characteristic is typically color perceptible to the human eye, it may be another optical property, such as optical transmission, reflectance, luminescence or, in the case of displays intended for machine reading, pseudo-color in the sense of a change in reflectance of electromagnetic wavelengths outside the visible range.) The first and second types of particles carry charges of opposite polarities. The third type of particles carries a charge of the

same polarity as the second type of particles but has a lower zeta potential and/or electrophoretic mobility than the first or second types of particles. By careful control of the magnitude and sequencing of the electric fields applied to such an electrophoretic medium, the optical characteristics of the three types of particles can be displayed at a viewing surface of a display. As illustrated for example in Figure 2 of the aforementioned United States Patent No. 8,717,664, the optical characteristics of the first and second types of particles are displayed by applying high electric fields of the appropriate polarity to the electrophoretic medium in essentially the same way as in the two particle media discussed in the preceding paragraph. To display the optical characteristic of the third type of particles, one first drives the medium to display the optical characteristic of the first type of particles (i.e., the particles bearing a charge of the opposite polarity to the third type of particles) and then applies a *low* electric field of a polarity which tends to drive the third type of particles towards the viewing surface. This low electric field causes the first type of particles to move away from the viewing surface and the second and third type of particles to move towards the viewing surface. However, it appears (although the present invention is in no way limited by this belief) that the highly charged first and second types of particles aggregate with each other, so that only the third type of particles are driven adjacent the viewing surface, so that the optical characteristic of the third type of particles is displayed.

[Para 7] One problem with conventional electrophoretic media is that they cannot be driven using passive matrix driving methods (in which an electric field is applied by means of a first set of elongate electrodes disposed on one side of the electrophoretic medium and a second set of elongate electrodes are disposed on the opposed side of the electrophoretic medium, the first and second sets of elongate electrodes being arranged with their long axes at an angle to each other so that a plurality of pixels are formed, each pixel being defined by the overlap of one electrode of the first set with one electrode of the second set). Passive matrix driving methods require that the electrophoretic medium have a substantial threshold voltage (i.e., a voltage which can be applied across the medium for a prolonged period without causing any change in the optical state displayed) and most conventional electrophoretic media have no threshold voltage or only a minimal one. It has now been discovered that a subset of the three particle electrophoretic media described in the aforementioned patents and published applications can be driven by passive matrix driving methods, and the present invention relates to such media, electrophoretic displays incorporating such media, and driving methods for use in such electrophoretic displays.

[Para 8] Accordingly, in one aspect this invention provides an electrophoretic display having a viewing surface and comprising an electrophoretic medium and means for applying an electric field to the electrophoretic medium, the electrophoretic medium comprising a fluid and first, second and third types of particles dispersed in the fluid, wherein:

- (i) the first and second types of particles bear charges of opposite polarities and have first and second optical characteristics differing from each other;
- (ii) the third type of particles has substantially the first optical characteristic and bears a charge of the same polarity as the second type of particles but have a lower zeta potential or electrophoretic mobility than the second type of particles; and
- (iii) when the first optical characteristic is displayed at the viewing surface, application for a time T of an electric field E of a polarity which drives the second type of particles towards the viewing surface will cause the second optical characteristic to be displayed at the viewing surface, but application for a time T of an electric field $E/3$ of the same polarity will cause the first optical characteristic to remain displayed at the viewing surface.

[Para 9] In this electrophoretic display of the present invention, the first and second optical characteristics may be differing colors, such as white and black colors. In a first embodiment of the electrophoretic display, the first type of particles is white and negatively charged, the second type of particles is black and positively charged, and the third type of particles is white and positively charged. In a second embodiment, the first type of particles is black and positively charged, the second type of particles is white and negatively charged, the third type of particles is black and negatively charged. In a third embodiment, the first type of particles is white and positively charged, the second type of particles is black and negatively charged, and the third type of particles is white and negatively charged. In a fourth embodiment, the first type of particles is black and negatively charged, the second type of particles is white and positively charged, and the third type of particles is black and positively charged.

[Para 10] In the electrophoretic display of the present invention, the third type of particles may have a larger average size than the first and second types of particles; for example, the third type of particles may be about 2 to about 50 times the size of the first or second types of particles. The means for applying an electric field may comprise a first set of elongate electrodes disposed adjacent the viewing surface and a second set of elongate electrodes disposed on the opposed side of the electrophoretic medium from the viewing surface, the first and second sets of elongate electrodes being arranged with their long axes at an angle to each

other so that a plurality of pixels are formed, each pixel being defined by the overlap of one electrode of the first set with one electrode of the second set, thereby forming a passive matrix driving system.

[Para 11] In another aspect, this invention provides a (first or “via first”) method for driving a display of the present invention, the display having a plurality of pixels, each capable of displaying either the first or the second optical characteristic at the viewing surface, from a first image to a second image. This method comprises:

- (i) driving all pixels of the display to display the first optical characteristic; and
- (ii) driving the pixels which display the second optical characteristic in the second image from the first optical characteristic to the second optical characteristic.

[Para 12] In this first method of the invention, the display may be a passive matrix display (as defined above) and step (b) may be effected on a line-by-line basis. In such a passive matrix method, step (b) may be effected by applying to the electrodes of one set 0 or $\pm (2V/3)$ and to the electrodes of the other set $\pm (V/3)$, where V is the voltage difference necessary to drive a pixel from displaying the first optical characteristic to displaying the second optical characteristic.

[Para 13] In another aspect, this invention provides a (second or “balanced two step”) method. A method for driving a display of the present invention having a plurality of pixels, each capable of displaying either the first or the second optical characteristic at the viewing surface, from a first image to a second image. This method comprises:

- (i) driving pixels having the first optical characteristic in the first image and the second optical characteristic in the second image to display the second optical characteristic; and
- (ii) driving pixels having the second optical characteristic in the first image and the first optical characteristic in the second image to display the first optical characteristic.

[Para 14] In this second method of the invention, the display may be a passive matrix display (as defined above) and steps (a) and (b) may both be effected on a line-by-line basis. In such a passive matrix method, steps (a) and (b) may each be effected by applying to the electrodes of one set 0 or $\pm (2V/3)$ and to the electrodes of the other set $\pm (V/3)$, where V is the voltage difference necessary to drive a pixel from displaying the first optical characteristic to displaying the second optical characteristic or *vice versa*.

[Para 15] In another aspect, this invention provides an electrophoretic medium comprising a fluid and first, second and third types of particles dispersed in the fluid, wherein:

- (i) the first and second types of particles bear charges of opposite polarities and have first and second optical characteristics differing from each other; and
- (ii) the third type of particles has substantially the first optical characteristic and bears a charge of the same polarity as the second type of particles but have a lower zeta potential or electrophoretic mobility than the second type of particles.

[Para 16] In such an electrophoretic medium, the first and second optical characteristics may be differing colors, such as white and black colors. The third type of particles may have a larger average size than the first and second types of particles; for example, the third type of particles may be about 2 to about 50 times the size of the first or second types of particles.

[Para 17] Figure 1 is a schematic cross-section through an electrophoretic display of the present invention.

[Para 18] Figure 2 is a schematic cross-section, similar to that of Figure 1 but illustrating changes in particle positions effected during various steps of driving methods of the present invention.

[Para 19] Figure 3 is a schematic cross-section similar to that of Figure 2 but illustrating the effects of applying various electric fields to various states illustrated in Figure 2.

[Para 20] Figure 4 is a schematic cross-section similar to that of Figure 3 but illustrating an alternative electrophoretic display in which the colors of the various particles are reversed compared to the display of Figure 3.

[Para 21] Figure 5A illustrate the arrangement of electrodes in a passive matrix driving system.

[Para 22] Figure 5B illustrates a transition from a first image to a second image in the passive matrix driving system of Figure 5A.

[Para 23] Figures 6A-6D illustrate the individual steps needed to effect the overall transition shown in Figure 5B using the first method of the present invention and the potentials applied to the various electrodes shown in Figure 5A during these steps.

[Para 24] Figures 7A-7E illustrate the individual steps needed to effect the overall transition shown in Figure 5B using the second method of the present invention and the potentials applied to the various electrodes shown in Figure 5A during these steps.

[Para 25] As indicated above, the present invention provides electrophoretic media, electrophoretic displays incorporating such media, and driving methods for use in such electrophoretic displays. The electrophoretic media of the present invention are especially useful for use in passive matrix displays.

[Para 26] Figure 1 is a schematic cross-section through an electrophoretic display of the present invention, this display comprising an electrophoretic medium (generally designated 10) disposed between two electrode layers 14 and 15. The display may be an active matrix display, in which case electrode layer 14 is a common, light-transmissive electrode (formed for example of indium tin oxide, ITO), extending across one entire surface of the display and the other electrode layer 15 is a layer of pixel electrodes (e.g., a thin-film-transistor (TFT) backplane). Alternatively, the display may be a passive matrix display, in which case one of the electrode layers comprises a set of elongate row electrodes and the other electrode layer comprises a set of column electrodes, with the row and column electrodes (typically) being perpendicular to each other. As already noted, the electrophoretic media of the present invention are particularly suitable for passive matrix driving.

[Para 27] For ease of comprehension, it will be assumed hereinafter that the upper surface of each display (as illustrated in the drawings) is the viewing surface through which a user views the display. It will be appreciated that optical characteristics may also be displayed on the lower (as illustrated) non-viewing surface and that such optical characteristics may be visible depending upon whether the electrode layer 15 is or is not light-transmissive.

[Para 28] The dotted lines in Figure 1 indicate individual pixels of the display. If the display is an active matrix display, each pixel has a corresponding pixel electrode. If the display is a passive matrix display, a pixel is defined by the overlap between one row electrode and one column electrode. Other types of electrode addressing may be used provided the electrodes provide the necessary electric field across the electrophoretic medium.

[Para 29] The electrophoretic medium 10 comprises three types of charged particles dispersed in a fluid, typically a dielectric solvent or solvent mixture, the three types of particles will be referred to as a first type of particles 11, a second type of particles 12 and a third type of particles 13. The first and second types of particles have differing optical characteristics (typically contrasting colors) and carry charges of opposite polarities. The first type of particles may be white particles and the second type of particles may be black particles, as shown in Figure 1, with one type being positively charged and the other type negatively charged.

[Para 30] The third type of particles 13 has substantially the same optical characteristic as the first type of particles, but carries a charge having the same polarity as that of the second type of particles, but at a lower intensity. The second type of particles may be regarded as having a threshold voltage in the sense that, as explained below, the second particles will not move adjacent the viewing electrode is the voltage between the electrodes falls below a certain value.

[Para 31] The term “threshold voltage” is defined for present purposes as the maximum voltage between the electrodes that may be applied for a period of time (typically not longer than 30 seconds, preferably not longer than 15 seconds), to particles, without causing them to appear at the viewing surface of a pixel, when the pixel is driven from a color state different from the color state of the particles. The threshold voltage may be either an inherent characteristic of the charged pigment particles or an additive-induced property. In the former case, the threshold is generated by certain attraction force between particles or between particles and certain substrate surfaces. A threshold may also be generated via interaction of two types of oppositely charged particles. In the latter case, to achieve a threshold voltage a threshold agent which induces or enhances the threshold characteristics of an electrophoretic medium may be added. The threshold agent may be any material which is soluble or dispersible in the solvent or solvent mixture of the electrophoretic fluid and carries or induces a charge opposite to that of the charged pigment particles. The threshold agent may be sensitive or insensitive to the change of applied voltage. The term “threshold agent” may broadly include dyes or pigments, electrolytes or polyelectrolytes, polymers, oligomers, surfactants, charge controlling agents and the like. Additional information relating to the threshold agent may be found in US Patent No. 8,115,729, the content of which is incorporated herein by reference in its entirety.

[Para 32] In order to facilitate passive matrix driving, the threshold voltage is at least one third of the voltage required to drive from the color state of the first type of particles to the color state of the second type of particles. More details are given below.

[Para 33] The third type of particles has a low level of charge intensity than the second type of particles although the two types of particles bear charges of the same polarity. The charge carried by the third type of particles may be less than about 50%, preferably about 5% to about 30%, of the charge carried by the second type of particles. The term “charge intensity”, in the context of the present application, may be used interchangeably with “zeta potential” or with electrophoretic mobility. The charge polarities and levels of charge potential of the particles may be varied by the method described in U.S. Patent Application Publication No. 2014/0011913 and/or may be measured in terms of zeta potential. In one embodiment, the zeta potential is determined by Colloidal Dynamics AcoustoSizer IIM with a CSPU-100 signal processing unit, ESA EN# Attn flow through cell (K:127). The instrument constants, such as density of the solvent used in the sample, dielectric constant of the solvent, speed of sound in the solvent, viscosity of the solvent, all of which at the testing temperature (25°C) are entered

before testing. Pigment samples are dispersed in the solvent (which is usually a hydrocarbon fluid having less than 12 carbon atoms), and diluted to be 5-10% by weight. The sample also contains a charge control agent (Solsperse 17000, available from Lubrizol Corporation, a Berkshire Hathaway company; "Solsperse" is a Registered Trade Mark), with a weight ratio of 1:10 of the charge control agent to the particles. The mass of the diluted sample is determined and the sample is then loaded into the flow through cell for determination of the zeta potential. Methods and apparatus for the measurement of electrophoretic mobility are well known to those skilled in the technology of electrophoretic displays.

[Para 34] While the specific displays illustrated in the drawings use black and white particles as the first and second types of particles, it should be understood that the scope of the invention broadly encompasses two types of particles of any colors as long as they are visually contrasting.

[Para 35] White particles may be formed from an inorganic pigment, such as TiO₂, ZrO₂, ZnO, Al₂O₃, Sb₂O₃, BaSO₄, PbSO₄ or the like. Black particles may be formed from CI pigment black 26 or 28 or the like (e.g., manganese ferrite black spinel or copper chromite black spinel) or carbon black. Particles which are non-white and non-black may be red, green, blue, magenta, cyan, yellow or any other desired colored, and may be formed from, for example, CI pigment PR 254, PR122, PR149, PG36, PG58, PG7, PB28, PB15:3, PY83, PY138, PY150, PY155 or PY20. Those are commonly used organic pigments described in color index handbooks, "New Pigment Application Technology" (CMC Publishing Co, Ltd, 1986) and "Printing Ink Technology" (CMC Publishing Co, Ltd, 1984). Specific examples include Clariant Hostaperm Red D3G 70-EDS, Hostaperm Pink E-EDS, PV fast red D3G, Hostaperm red D3G 70, Hostaperm Blue B2G-EDS, Hostaperm Yellow H4G-EDS, Novoperm Yellow HR-70-EDS, Hostaperm Green GNX, BASF Irgazine red L 3630, Cinquasia Red L 4100 HD, and Irgazin Red L 3660 HD; Sun Chemical phthalocyanine blue, phthalocyanine green, diarylide yellow or diarylide AAOT yellow. The colored particles may also be inorganic pigments, such as red, green, blue and yellow. Examples may include, but are not limited to, CI pigment blue 28, CI pigment green 50 and CI pigment yellow 227.

[Para 36] The particles used may be primary particles without a polymer shell. Alternatively, each particle may comprise an insoluble core with a polymer shell. The core could be either an organic or inorganic pigment, and it may be a single core particle or an aggregate of multiple core particles. The particles may also be hollow particles.

[Para 37] The fluid in which the particles are dispersed may be clear and colorless. It preferably has a low viscosity and a dielectric constant in the range of about 2 to about 30, preferably about 2 to about 15 for high particle mobility. Examples of suitable dielectric solvent include hydrocarbons such as isoparaffin, decahydronaphthalene (DECALIN), 5-ethylidene-2-norbornene, fatty oils, paraffin oil, silicon fluids, aromatic hydrocarbons such as toluene, xylene, phenylxylylene, dodecylbenzene or alkyl naphthalene, halogenated solvents such as perfluorodecalin, perfluorotoluene, perfluoroxylene, dichlorobenzotrifluoride, 3,4,5-trichlorobenzotrifluoride, chloropentafluorobenzene, dichlorononane or pentachlorobenzene, and perfluorinated solvents such as FC-43, FC-70 or FC-5060 from 3M Company, St. Paul MN, low molecular weight halogen containing polymers such as poly(perfluoropropylene oxide) from TCI America, Portland, Oregon, poly(chlorotrifluoroethylene) such as Halocarbon Oils from Halocarbon Product Corp., River Edge, NJ, perfluoropolyalkylether such as Galden from Ausimont or Krytox Oils and Greases K-Fluid Series from DuPont, Delaware, polydimethylsiloxane based silicone oil from Dow-corning (DC -200).

[Para 38] The electrophoretic fluid in an electrophoretic display may be filled in display cells. The display cells may be microcells as described in US Patent No. 6,930,818, the content of which is incorporated herein by reference in its entirety. The display cells may also be other types of micro-containers, such as microcapsules, microchannels or equivalents, regardless of their shapes or sizes. All of these are within the scope of the present invention.

[Para 39] The three types of particles may have varying sizes; for example, one of the three types of particles may be larger than the other two types. Among the three types of particles, the third type having the lower charge intensity preferably has the larger size. For example, both the first and second types of particles may be relatively small and their sizes (tested through dynamic light scattering) may range from about 50 nm to about 800 nm, and more preferably from about 200 nm to about 700 nm, and in this example, the third type of particles which carries a lower charge intensity, preferably is about 2 to about 50 times, and more preferably about 2 to about 10 times, the sizes of the first and second types of particles.

[Para 40] The electrophoretic medium may contain additional additives to enhance performance of the display, such as additives to improve switching speed, bistability and reliability.

[Para 41] Figure 2 is a schematic cross-section illustrating changes in particle positions effected during various steps of driving methods of the present invention. In the electrophoretic medium shown in Figure 2, the first type of particles 21 is white and negatively charged and

the second type of particles 22 is black and positively charged. The third type of particles 23 is white and carries a positive charge, but at a lower intensity than that of the second type of particles. As a result, the black particles 22 move faster than the third type of particles 23 when high electric fields are applied because of the stronger charges the black particles carry. In Figure 2, the “top” or “front” electrode” 24 lying adjacent the viewing surface is a common electrode and the “bottom electrode” 25 is a pixel electrode, in the case of active matrix driving. Alternatively, the “top electrode” associated with a pixel may be a row electrode and the bottom electrode may be a column electrode, or *vice versa*, in passive matrix driving.

[Para 42] In state (a) in Figure 2, the pixel electrode 25 is set at +15V relative to the front electrode 24 (hereinafter, it will be assumed that the front electrode will be maintained at 0V, so in this case the common electrode is strongly negative relative to the pixel electrode) so the first type of particles 21 move adjacent the pixel electrode 25, while the black particles 22 and the third type of particles 23 move adjacent the front electrode 24. Because of their lower charge, the third type of particles 23 move towards the front electrode 24 more slowly than do the black particles 22, so that the black particles 22 lie immediately adjacent the front electrode 24 and mask the third type of particles 23, so that a black color is displayed at the viewing surface.

[Para 43] In state (b) in Figure 2, the pixel electrode 25 is set at -15V relative to the front electrode 24 so the first type of particles 21 move adjacent the front electrode 24, while the black particles 22 and the third type of particles 23 move adjacent the pixel electrode 25, so that a white color is displayed at the viewing surface.

[Para 44] State (c) in Figure 2 illustrates the manner in which the color of the third type of particles 23 is displayed at the viewing surface. The process starts from the white state (b). A low positive voltage (e.g., +5V) is applied to the pixel electrode 25 for a time period of sufficient length to cause the first type of particles 21 to move towards the pixel electrode 25 while the black particles 22 and the third type of particles 23 move towards the front electrode 24. However, when the first and second types of particles 21 and 22 meet intermediate the pixel and front electrodes as shown in state (c) in Figure 2, they remain at the intermediate position because the electric field generated by the low driving voltage is not strong enough to overcome the attractive forces between them. As shown, the first and second types of particles stay intermediate the pixel and front electrodes in a mixed state. Accordingly, the color of the third type of particles (white) is visible at the viewing surface. Adjacent the non-viewing surface,

the first and second types of particles are mixed, resulting in an intermediate color (gray) being displayed, assuming the pixel electrode 25 is light-transmissive.

[Para 45] The upper part of Figure 3 repeats states (a) and (b) from Figure 2 and illustrates the transitions between them using driving voltages of $\pm 15\text{V}$. Figure 3 also shows that application of a $+ 5\text{V}$ driving voltage to a pixel in state (b) transforms it to state (c), in which the color of the third particles 23 is displayed at the viewing surface. However, since the optical characteristic (color) of the third particles 23 is essentially the same as that of the first particles 21, the transition from state (b) to state (c) causes no visible change in the appearance of the pixel.

[Para 46] Finally, Figure 3 shows that when a driving voltage of $- 5\text{V}$ is applied to the pixel in state (b), none of the particles move, since the effect of the $- 5\text{V}$ driving voltage is to drive the first particles 21 adjacent the front electrode 24 and the first and third particles adjacent the pixel electrodes 25. Thus, Figure 3 shows that once the pixel has been driven by means of a $- 15\text{V}$ driving voltage from black state (a) to white state (b), no further visible change is brought about by later application of either a $+ 5\text{V}$ or a $- 5\text{V}$ driving voltage. It is this characteristic of the electrophoretic of the present invention which renders them especially suitable for passive matrix driving.

[Para 47] Figure 4 is exactly analogous to Figure 3 but illustrates an electrophoretic display in which the first type of particles 41 is black and positively charged and the second type of particles 42 is white and negatively charged. The third type of particles 43 is black and negatively charged. The white particles (i.e., the second type) have a threshold voltage, which is one third of the voltage required to drive from the black state to the white state.

[Para 48] It is believed that the transitions shown in Figure 4 will readily be apparent to those skilled in electrophoretic displays in view of the preceding explanation of the transitions shown in Figure 3, and thus the transitions shown in Figure 4 may be summarized as follows. When to a pixel in state (a) shown in Figure 4 (this is of course the white state of the pixel) a driving voltage of $+ 15\text{V}$ is applied, the first type of (black) particles 41 move adjacent the front electrode 44 and the white particles 42 move adjacent the pixel electrode 45, so that a black color is displayed at the viewing side. The third type of particles 43 move with the white particles 42, but more slowly than the white particles. Applying a driving voltage of $- 15\text{V}$ to the pixel in state (b) reverses these particle movements and restores the white state (a).

[Para 49] Figure 4 also illustrates the effect of applying $\pm 5\text{V}$ driving voltages to the pixel in state (b). As shown in Figure 4, and as should readily be apparent from the foregoing

explanation of Figure 3, application of a -5V driving voltage to the pixel in state (b) results in state (c), in which the third type of particles 43 lie adjacent the front electrode 44 and an aggregated mixture of the first and second types of particles 41 and 42 lie intermediate the front and pixel electrodes 44 and 45. Since the third type of particles are black, a black color is displayed at the viewing surface, while a gray color is visible at the non-viewing surface if the pixel electrode 45 is light-transmissive. Similarly, application of a $+5\text{V}$ driving voltage to the pixel in state (b) produces essentially no particle movement and the pixel remains in the same state as shown at (d) in Figure 4. Thus, from Figure 4 it can be concluded that once the pixel has been driven from the white state (a) to the black state (b) using a $+15\text{V}$ driving voltage, subsequent application of $\pm 5\text{V}$ driving voltages to the pixel produces no further visible change in the appearance of the pixel.

[Para 50] More generally, the foregoing consideration of Figures 3 and 4 shows that, in the electrophoretic media of the present invention, once a pixel has been driven from the state in which the optical characteristic of the second type of particles is displayed (state (a)) to the state in which the optical characteristic of the first type of particles is displayed (state (b)) using a driving voltage E ($\pm 15\text{V}$ in Figures 3 and 4), subsequent application to the pixel of driving voltages of $\pm (E/3)$ ($\pm 5\text{V}$ in Figures 3 and 4) will produce no further visible change in the appearance of the pixel (states (c) and (d)). It is this immunity of the pixel displaying the optical characteristic of the first type of particles which renders the electrophoretic media of the present invention especially suitable for passive matrix driving, although active matrix or other driving techniques may be used if desired.

[Para 51] Figure 5A depicts schematically the configuration of electrodes in a typical passive matrix display. As shown, a set of column electrodes (C1-C3) are perpendicular to a set of row electrodes (R1-R3); in practice, there would normally be a much larger number of both column and row electrodes and the numbers of electrodes in each set need not be equal, since, for example, a display with an aspect ratio of 4:3 might have 600 row electrodes and 800 column electrodes. As illustrated in Figure 5A, the column electrodes underlie the row electrodes. Each pixel of the display is defined by the overlap between one row electrode and one column electrode, and therefore for each pixel as illustrated, the row electrode would be the front electrode and the column electrode would be the bottom electrode. The nine pixels shown are designated (a)-(i) for illustrative purposes. Pixels (a)-(c) are on line 1; pixels (d)-(f) on line 2; and pixels (g)-(i) on line 3.

[Para 52] Figure 5B illustrates two sample images used in the discussion of the methods of the present invention below. In a first image, pixels (a)-(i) are W (white), K (black), W, K, W, K, W, W and W, respectively. In a second image, pixels (a)-(i) are K, W, W, W, K, K, W, K and K, respectively. Methods of the present invention for driving the first image to the second image are described below.

[Para 53] Figures 6A-6D illustrate the steps needed to drive the electrophoretic display of Figure 3 from the first image to the second image shown in Figure 5B using the first, via first method of the present invention. In Step 1, illustrated in Figure 6A, all pixels are driven to display the color of the first type of particles (white) regardless of their state in the first image. To accomplish this, all column electrodes C1-C3 are set to -10V and all row electrodes R1-R3 are set to +5V. As a result, all pixels experience a driving voltage of -15V and therefore switch to the state in which the color of the first type of particles is displayed (state (b) in Figure 3).

[Para 54] In Step 2 (Figure 6B), only line 1 is driven to switch to black any pixels required to be black in the second image. As illustrated, pixel (a) is the only pixel that needs to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to +10V, 0V and 0V, respectively, and row electrodes R1-R3 are set to -5V, +5V and +5V, respectively. As a result, pixel (a) experiences a driving voltage of +15V, and therefore switches to the black state (see Figure 3, transition from state (b) to state (a)). The remaining pixels experience driving voltages of +5V or -5V and thus remain white (see Figures 3, transitions from state (b) to states (c) and (d) respectively).

[Para 55] In Step 3 (Figure 6C), only line 2 is driven to switch to black any pixels required to be black in the second image. In this example, pixels (e) and (f) are the only pixels that need to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to 0V, +10V and +10V, respectively and row electrodes R1-R3 are set to +5V, -5V and +5V, respectively. As a result, both pixels (e) and (f) experience a driving voltage of +15V and therefore switch from white to black and the remaining pixels experience a driving voltage of either +5V or -5V and thus remain white (cf. description of Step 2 in the preceding paragraph).

[Para 56] In the final Step 4 (Figure 6D), only line 3 is driven to switch to black any pixels required to be black in the second image. In this example, pixels (h) and (i) are the only pixels that need to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to 0V, +10V and +10V, respectively and row electrodes R1-R3 are set to +5V,

+ 5V and - 5V, respectively. As a result, both pixels (h) and (i) experience a driving voltage of + 15V and therefore switch from white to black and the remaining pixels experience a driving voltage of either + 5V or - 5V and therefore remain white (cf. description of Steps 2 and 3 in the two preceding paragraphs).

[Para 57] Thus, the first driving method of the present invention, as shown in Figures 6A-6D comprises an initial step of driving all pixels to the color of the first type of particles, and thereafter driving, line by line, until all lines have been driven, the pixels required to be in a different color states in the second image. While black and white color states have been used to exemplify the method, it will be understood that the present method can be applied to any two color states as long as the two color states are visually distinguishable.

[Para 58] Figures 7A-7E illustrate the steps of the second driving method of the present invention. In this second method, the pixels are driven line by line, and in the illustrated system, black pixels are driven to white (i.e., pixels displaying the color of the second type of particles are driven to the color of the first type of particles) before white pixels are driven to black.

[Para 59] In Step 1, illustrated in Figure 7A, only line 1 is driven to switch any black pixels to white if the pixels are required to be white in the second image. As illustrated, pixel (b) in line 1 is the only pixel that needs to be driven from black to white (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to 0V, - 10V and 0V, respectively and row electrodes R1-R3 are set to + 5V, - 5V and - 5V, respectively. As a result, pixel (b) experiences a driving voltage of - 15V, and therefore switches to the white state (see Figure 3A, transition from state (b) to state (a)). The remaining pixels experience driving voltages of + 5V or - 5V and thus remain unchanged.

[Para 60] In Step 2 (Figure 7B), only line 2 is driven to switch any black pixels which are required to be white in the second image. In this example, pixel (d) is the only pixel that needs to be driven from black to white (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to - 10V, 0V and 0V, respectively and row electrodes R1-R3 are set to - 5V, + 5V and - 5V, respectively. Pixel (d) experiences a driving voltage of - 15V and switches from black to white, while the remaining pixels experience driving voltages of either + 5V or - 5V and remain unchanged.

[Para 61] There are no pixels at line 3 that need to be driven from black to white (see Figure 5B). Hence, this step can be omitted in the method as illustrated, although it should be noted that the second method will typically require 2N steps where N is in the number of row electrodes in the passive matrix.

[Para 62] In the next step, illustrated in Figure 7C, only line 1 is driven to switch any white pixels to black if the pixels are required to be black in the second image. In this example, pixel (a) is the only pixel that needs to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to + 10V, 0V and 0V, respectively and row electrodes R1-R3 are set to - 5V, + 5V and + 5V, respectively. Pixel (a) experiences a driving voltage of + 15V and therefore switches from white to black, while the remaining pixels experience driving voltages of either + 5V or - 5V and therefore remain unchanged.

[Para 63] In the next step, illustrated in Figure 7D, only line 2 is driven to switch any white pixels to black if the pixels are required to be black in the second image. In this example, pixel (e) is the only pixel that needs to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to 0V, + 10V and 0V, respectively and row electrodes R1-R3 are set to + 5V, - 5V and + 5V, respectively. Pixel (e) experiences a driving voltage of +15V and therefore switches from white to black, while the remaining pixels experience driving voltages of either + 5V or - 5V and remain unchanged.

[Para 64] In the final step, as illustrated in Figure 7E, only line 3 is driven to switch any white pixels to black if the pixels are required to be black in the second image. In this example, pixels (h) and (i) are the only pixels that need to be driven to the black state (see Figure 5B). To accomplish this, column electrodes C1-C3 are set to 0V, + 10V and + 10V, respectively and row electrodes R1-R3 are set to + 5V, + 5V and - 5V, respectively. Pixels (h) and (i) experience a driving voltage of + 15V and therefore switch from white to black and the remaining pixels experience a driving voltage of either + 5V or - 5V and remain unchanged.

[Para 65] Thus, in the second method of the present invention, driving, as shown, is carried out line by line until the last line of the second pass when all pixels have been driven to the colors needed in the second image.

[Para 66] From the foregoing, it will be seen that the present invention can provide a electrophoretic medium, electrophoretic display and driving methods which are well adapted for use with passive matrix drive schemes.

CLAIMS

1. An electrophoretic display having a viewing surface and comprising an electrophoretic medium (10) and means (24, 25; 44, 45) for applying an electric field to the electrophoretic medium (10), the electrophoretic medium comprising a fluid and first (11; 21; 41), second (12; 22; 42) and third (13; 23; 43) types of particles dispersed in the fluid, wherein:

(i) the first (11; 21; 41) and second (12; 22; 42) types of particles bear charges of opposite polarities and have first and second optical characteristics differing from each other, the display being characterized in that:

(ii) the third type (13; 23; 43) of particles has substantially the first optical characteristic and bears a charge of the same polarity as the second type (12; 22; 42) of particles but have a lower zeta potential or electrophoretic mobility than the second type (12; 22; 42) of particles; and

(iii) when the first optical characteristic is displayed at the viewing surface, application for a time T of an electric field E of a polarity which drives the second type (12; 22; 42) of particles towards the viewing surface will cause the second optical characteristic to be displayed at the viewing surface, but application for a time T of an electric field $E/3$ of the same polarity will cause the first optical characteristic to remain displayed at the viewing surface.

2. An electrophoretic display according to claim 1 wherein the first and second optical characteristics are differing colors.

3. An electrophoretic display according to claim 2 wherein the first and second optical characteristics are white and black colors.

4. An electrophoretic display according to claim 3 wherein the first type of particles (21) is white and negatively charged, the second type of particles (22) is black and positively charged, and the third type of particles (23) is white and positively charged.

5. An electrophoretic display according to claim 3 wherein the first type of particles (41) is black and positively charged, the second type of particles (42) is white and negatively charged, and the third type of particles (43) is black and negatively charged.

6. An electrophoretic display according to claim 3 wherein the first type of particles is white and positively charged, the second type of particles is black and negatively charged, and the third type of particles is white and negatively charged.

7. An electrophoretic display according to claim 3 wherein the first type of particles is black and negatively charged, the second type of particles is white and positively charged, and the third type of particles is black and positively charged.

8. An electrophoretic display according to claim 1 wherein the third type of particles (13; 23; 43) has a larger average size than the first and second types of particles.

9. An electrophoretic display according to claim 8 wherein the third type of particles (13; 23; 43) are about 2 to about 50 times the size of the first or second types of particles.

10. An electrophoretic display according to claim 1 wherein the means for applying an electric field comprises a first set of elongate electrodes (R1-R3) disposed adjacent the viewing surface and a second set of elongate electrodes (C1-C3) disposed on the opposed side of the electrophoretic medium from the viewing surface, the first and second sets (R1-R3, C1-C3) of elongate electrodes being arranged with their long axes at an angle to each other so that a plurality of pixels (a-i) are formed, each pixel (a-i) being defined by the overlap of one electrode of the first set (R1-R3) with one electrode of the second set (C1-C3), thereby forming a passive matrix driving system.

11. A method for driving a display according to claim 1 having a plurality of pixels, each capable of displaying either the first or the second optical characteristic at the viewing surface, from a first image to a second image, which method comprises:

- (a) driving all pixels of the display to display the first optical characteristic; and
- (b) driving the pixels which display the second optical characteristic in the second image from the first optical characteristic to the second optical characteristic.

12. A method according to claim 11 wherein the display is a passive matrix display according to claim 10 and step (b) is effected on a line-by-line basis.

13. A method for driving a display according to claim 1 having a plurality of pixels, each capable of displaying either the first or the second optical characteristic at the viewing surface, from a first image to a second image, which method comprises:

- (a) driving pixels having the first optical characteristic in the first image and the second optical characteristic in the second image to display the second optical characteristic; and
- (b) driving pixels having the second optical characteristic in the first image and the first optical characteristic in the second image to display the first optical characteristic.

14. A method according to claim 13 wherein the display is a passive matrix display according to claim 10 and steps (a) and (b) are both effected on a line-by-line basis.

15. An electrophoretic medium comprising a fluid and first, second and third types of particles dispersed in the fluid, wherein:

- (i) the first and second types of particles bear charges of opposite polarities and have first and second optical characteristics differing from each other; and
- (ii) the third type of particles has substantially the first optical characteristic and bears a charge of the same polarity as the second type of particles but have a lower zeta potential or electrophoretic mobility than the second type of particles.

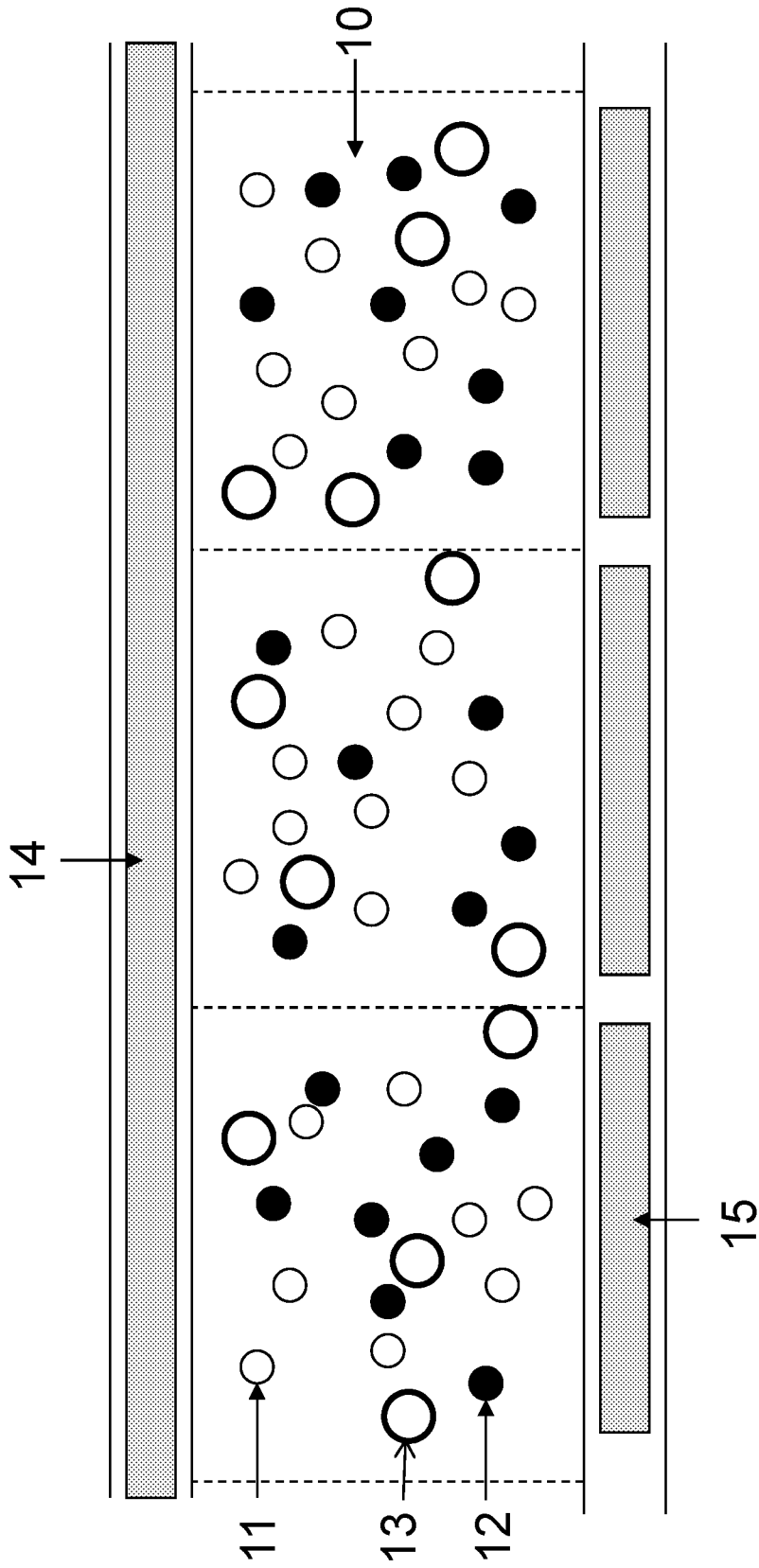


Figure 1

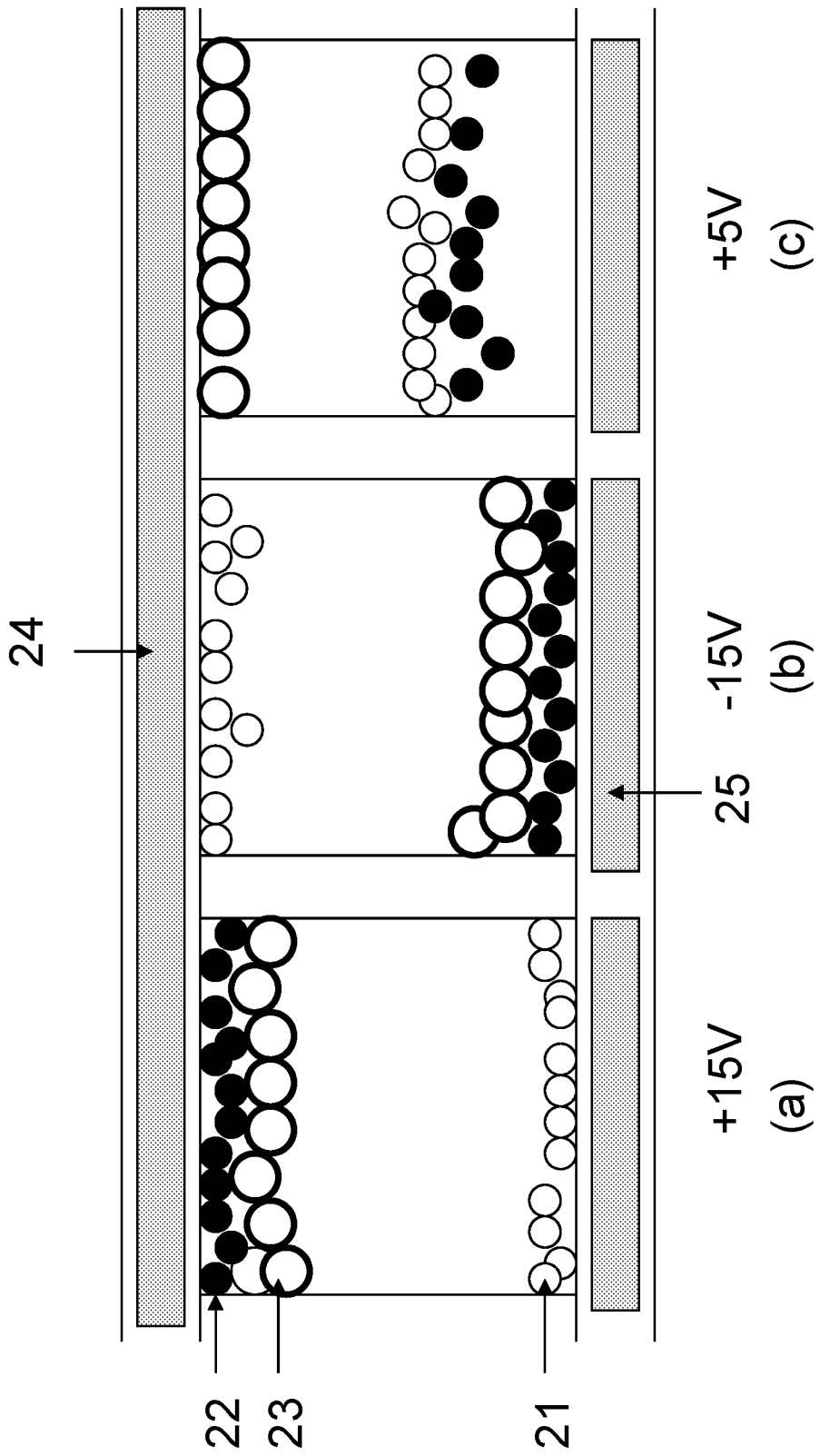


Figure 2

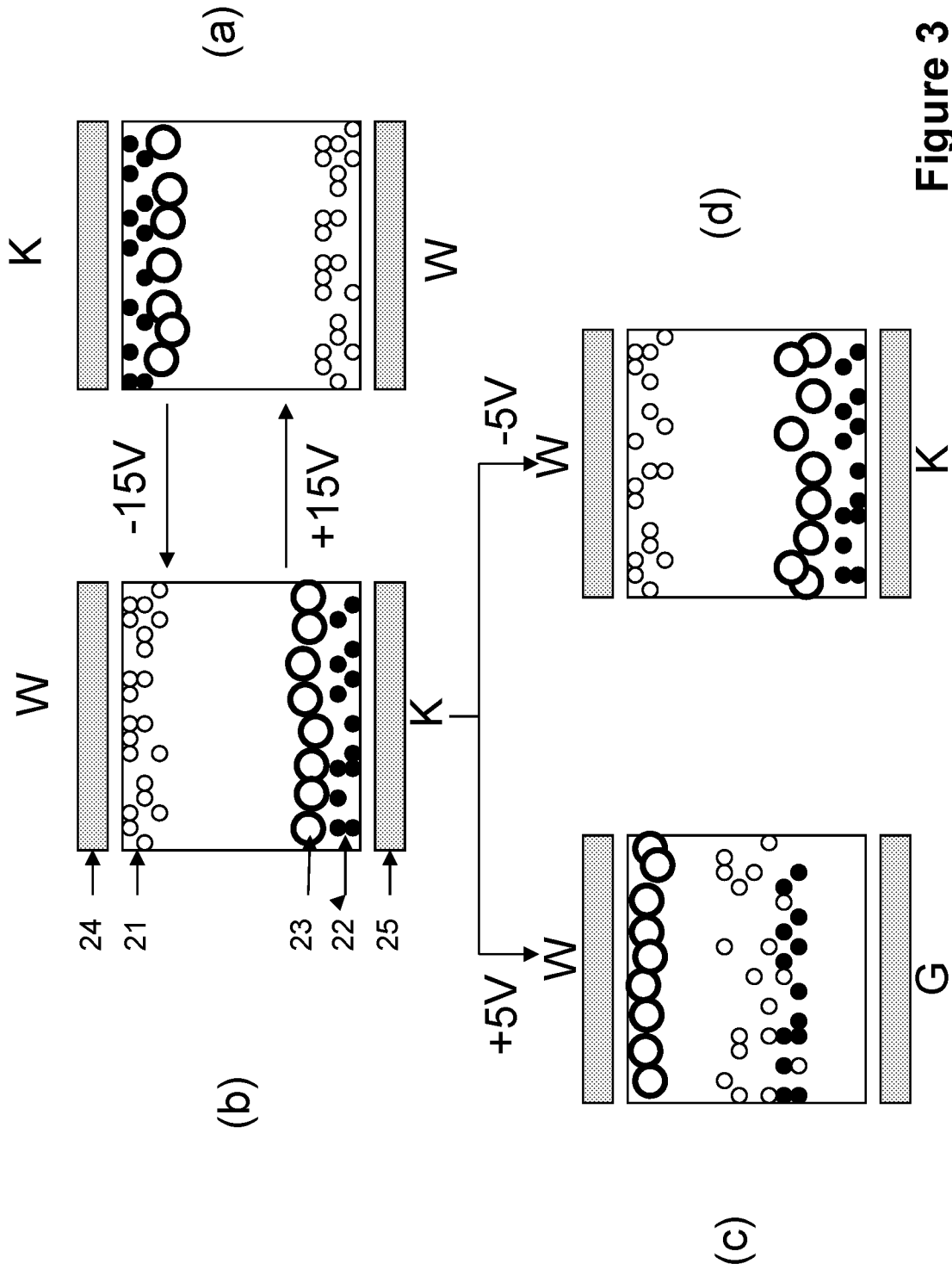


Figure 3

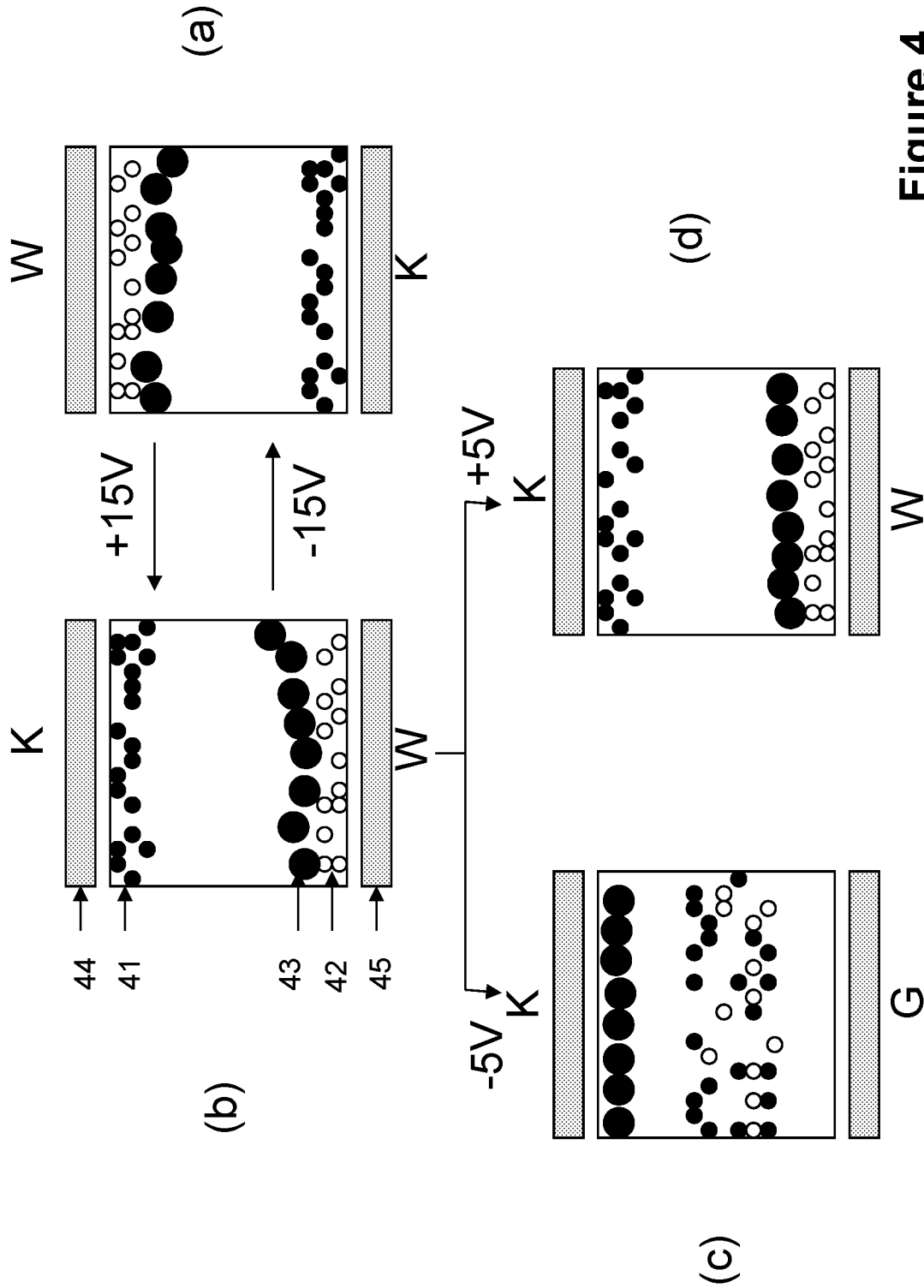


Figure 4

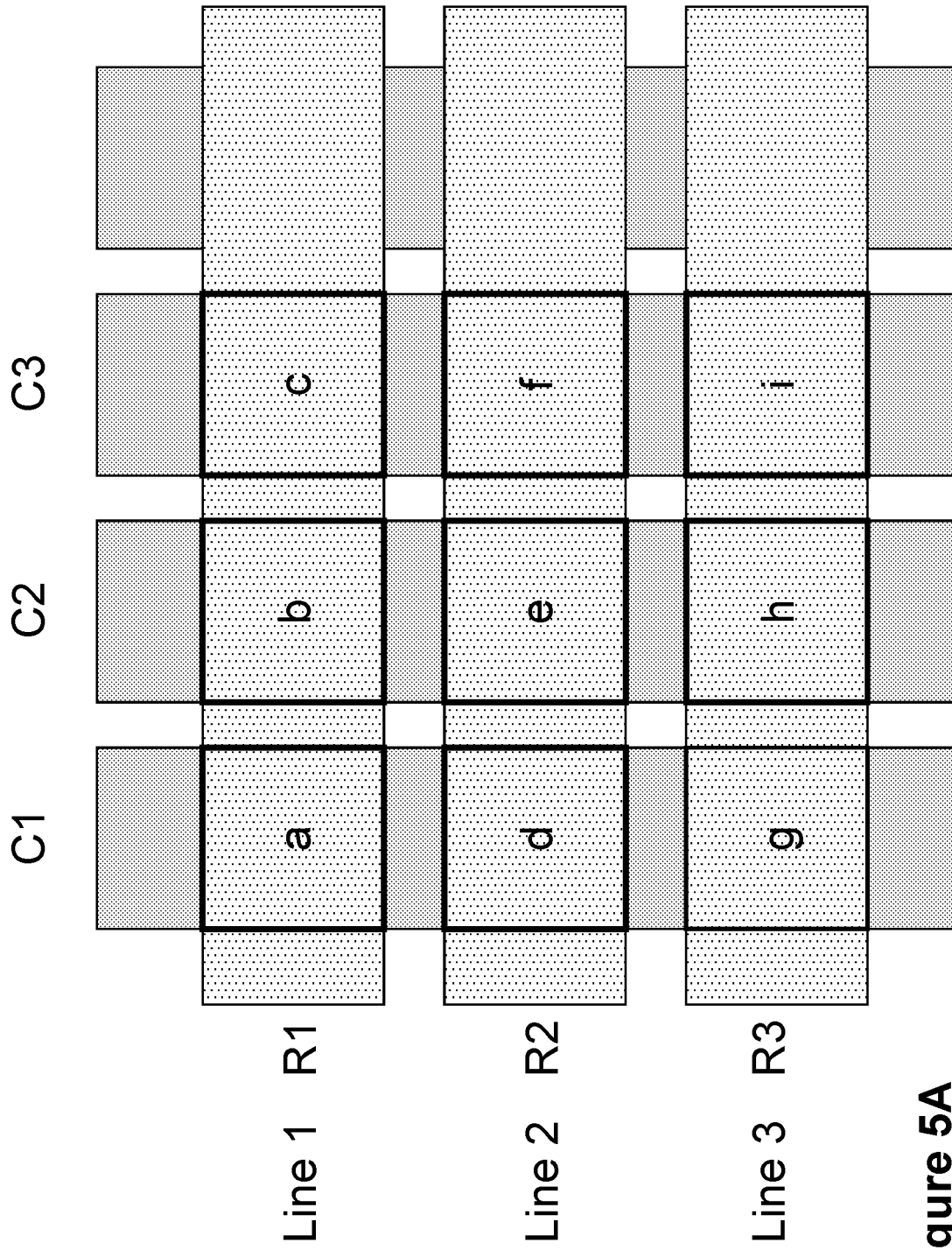


Figure 5A

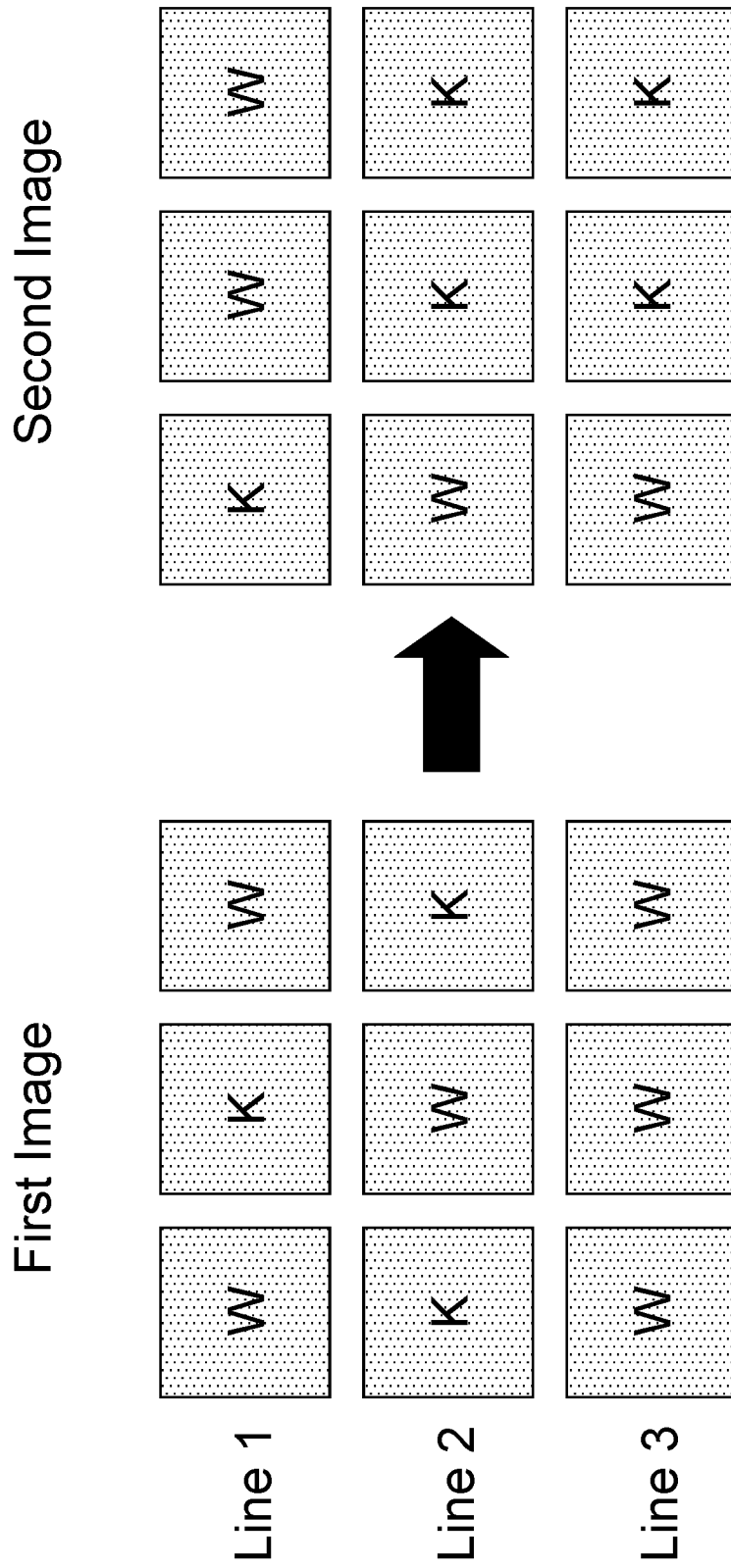


Figure 5B

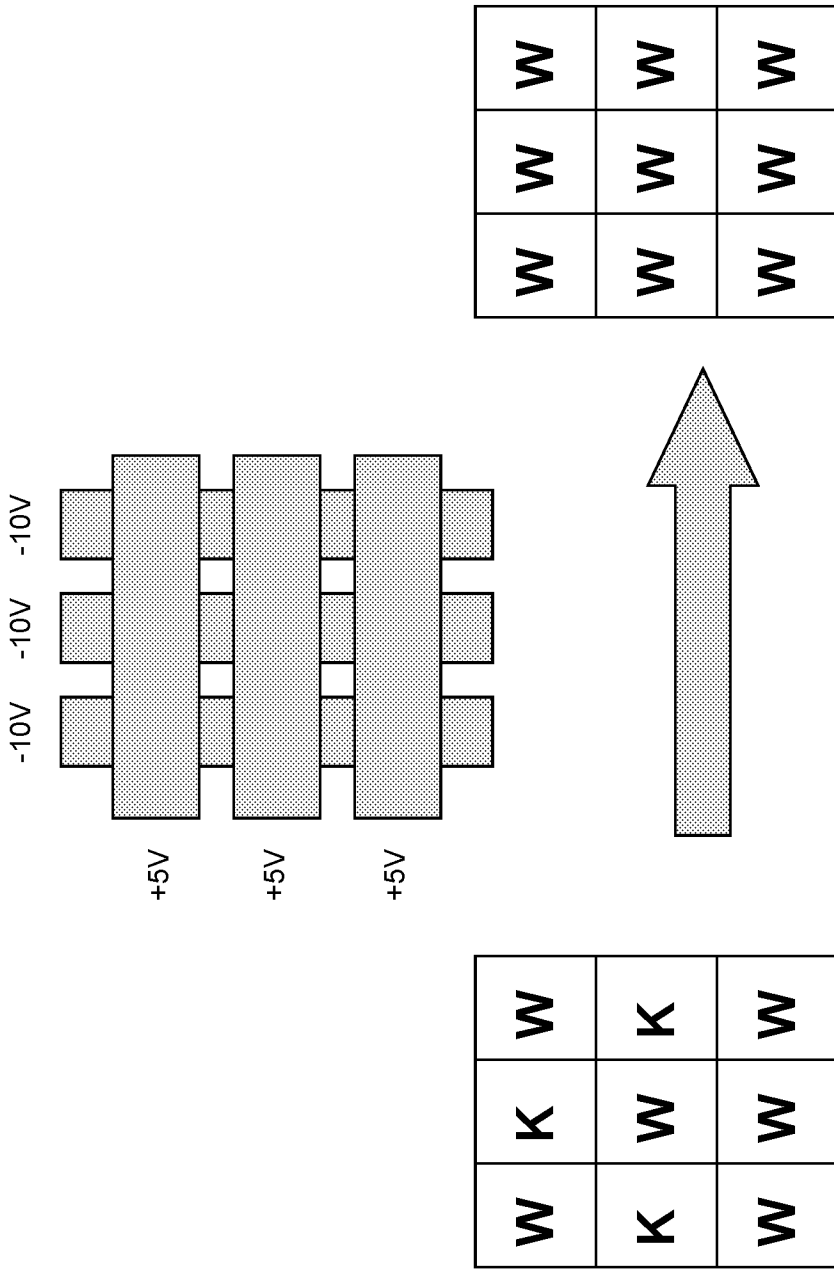


Figure 6A (Step 1)

(First image)

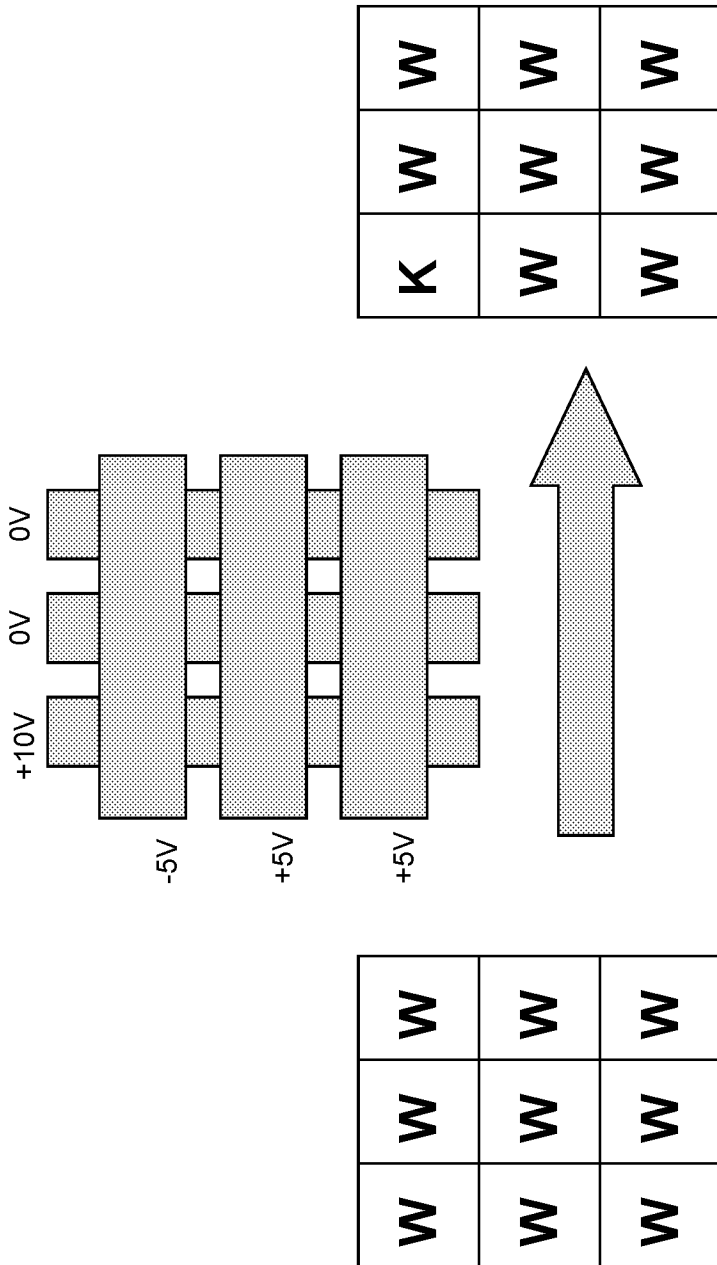


Figure 6B (Step 2)

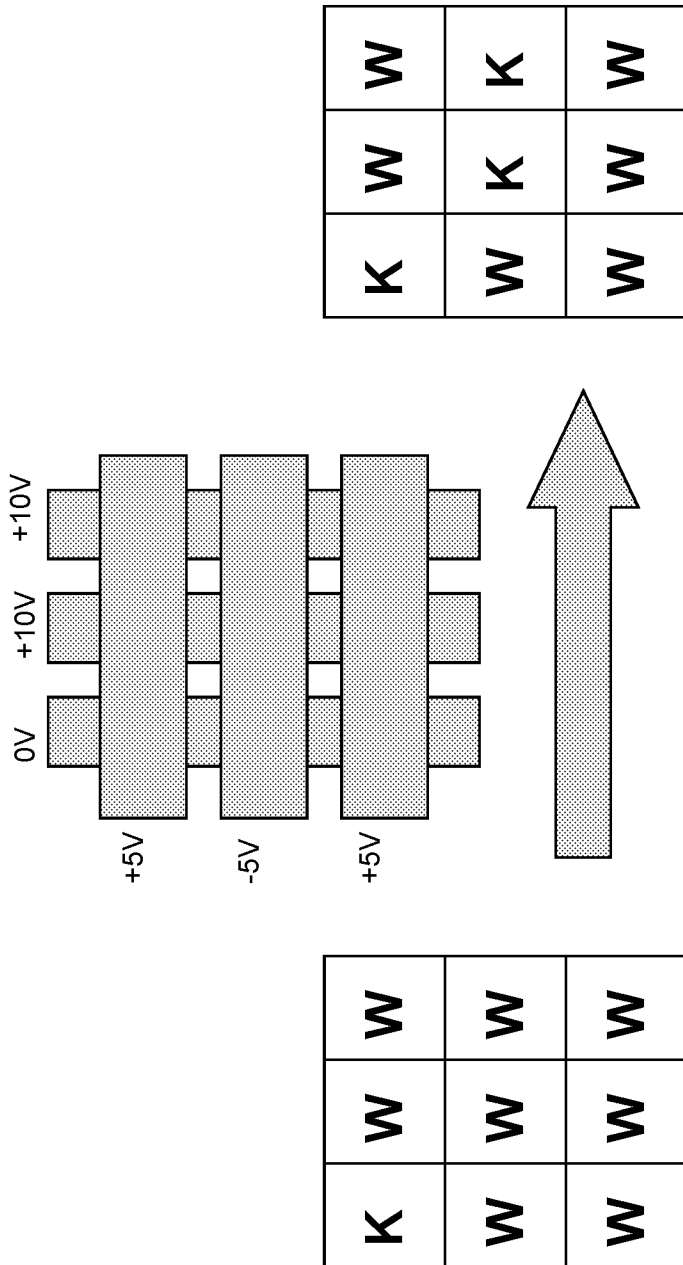


Figure 6C (Step 3)

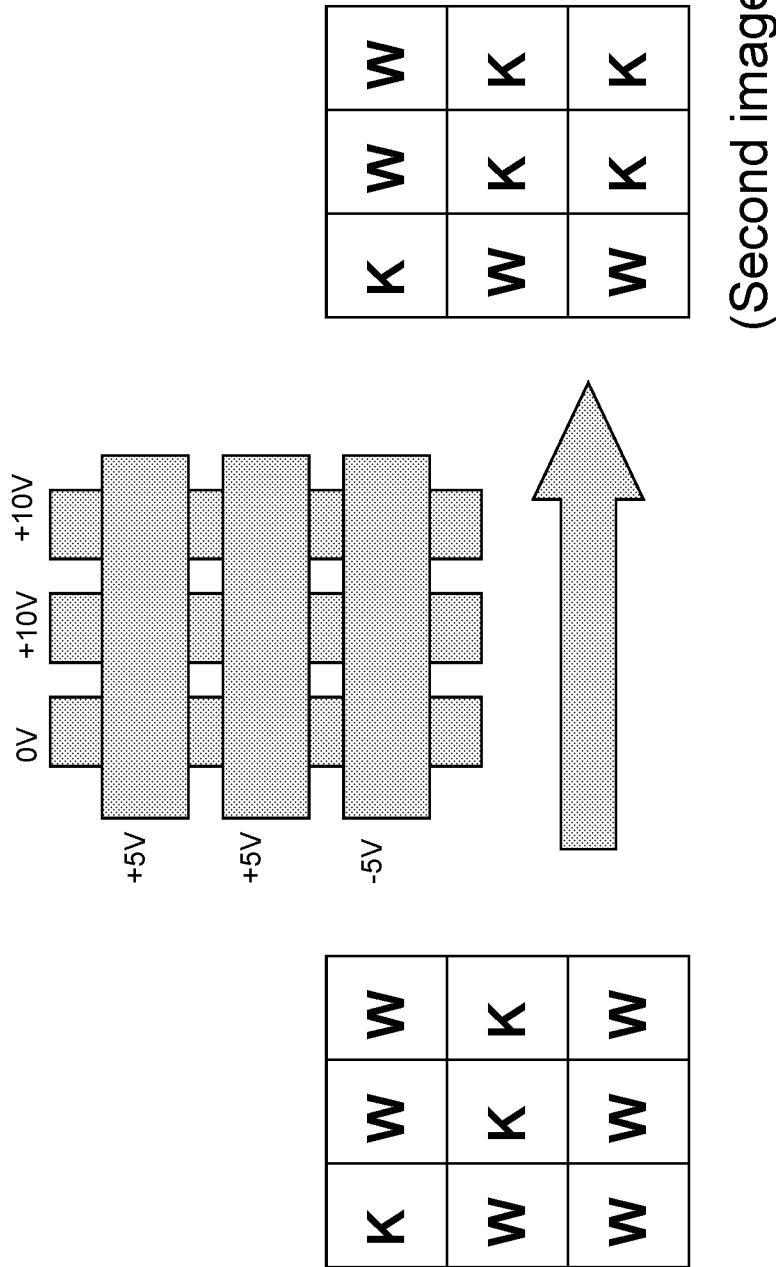
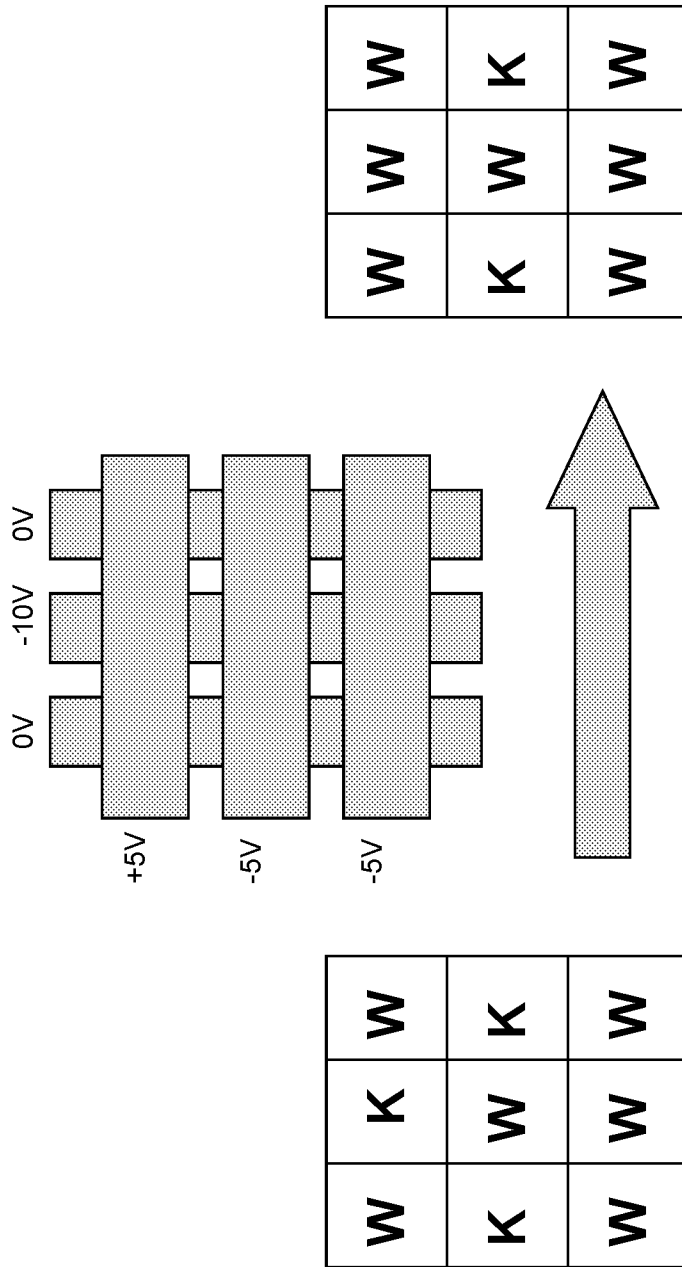


Figure 6D (Step 4)



(First image)

Figure 7A (Step 1)

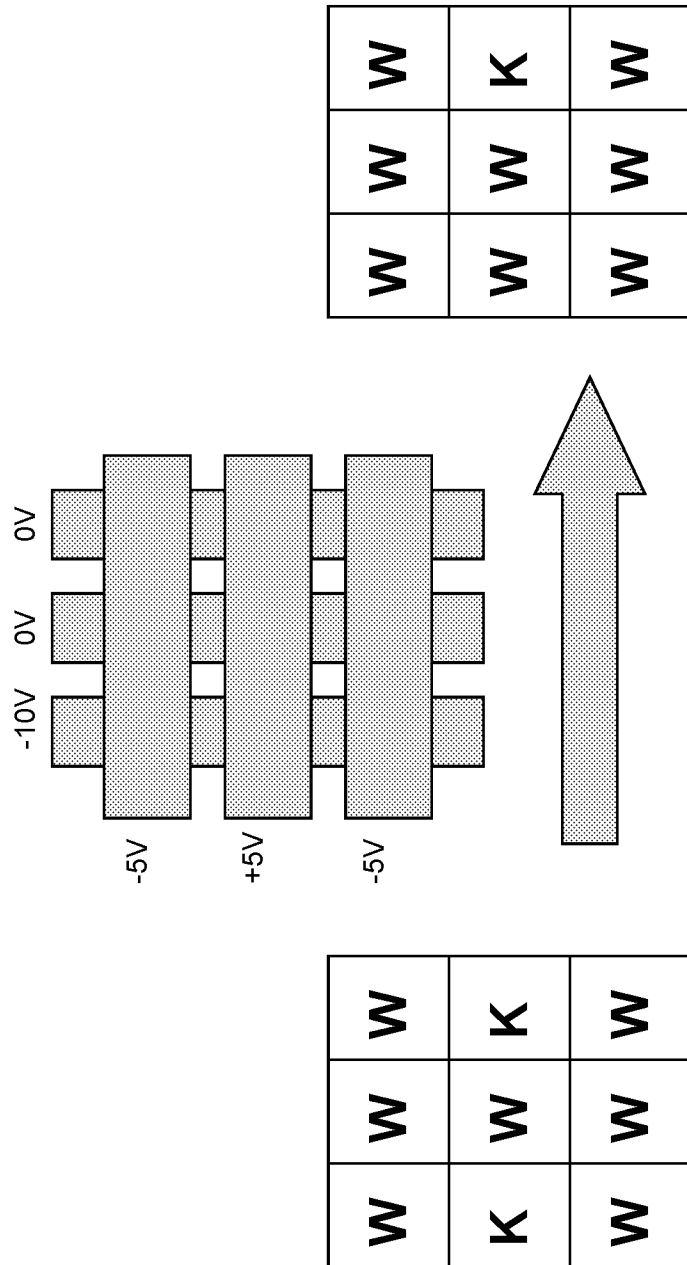


Figure 7B (Step 2)

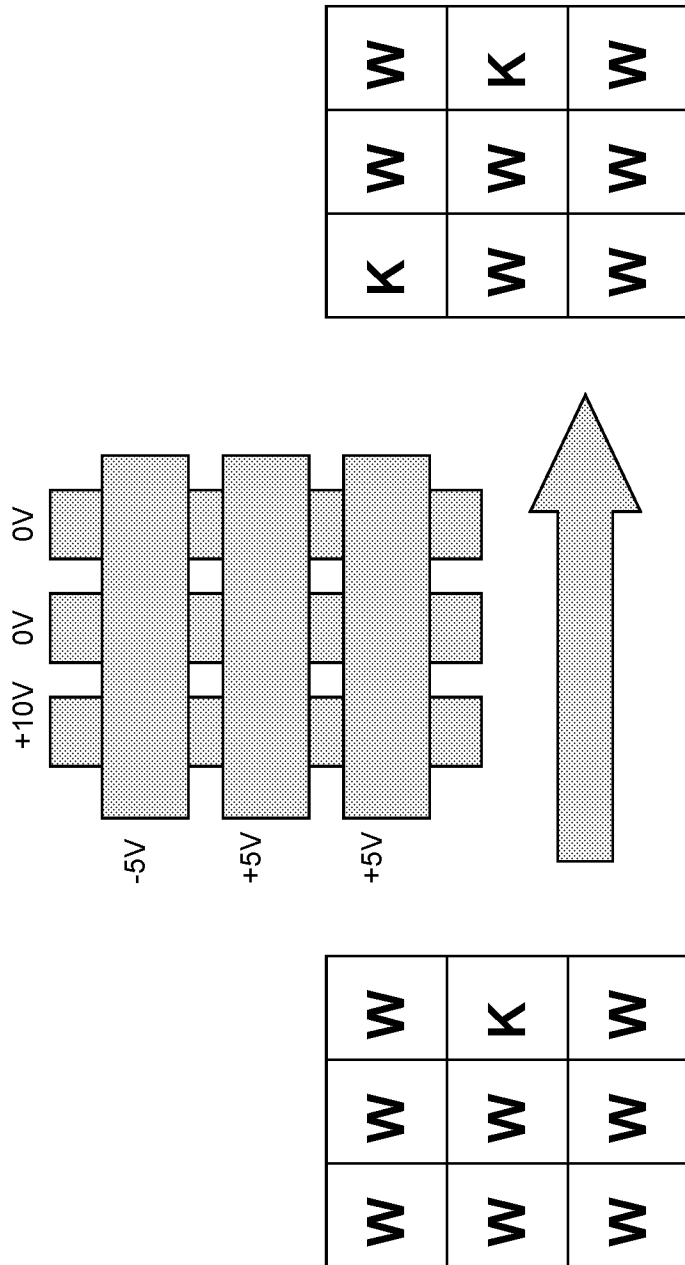


Figure 7C (Step 3)

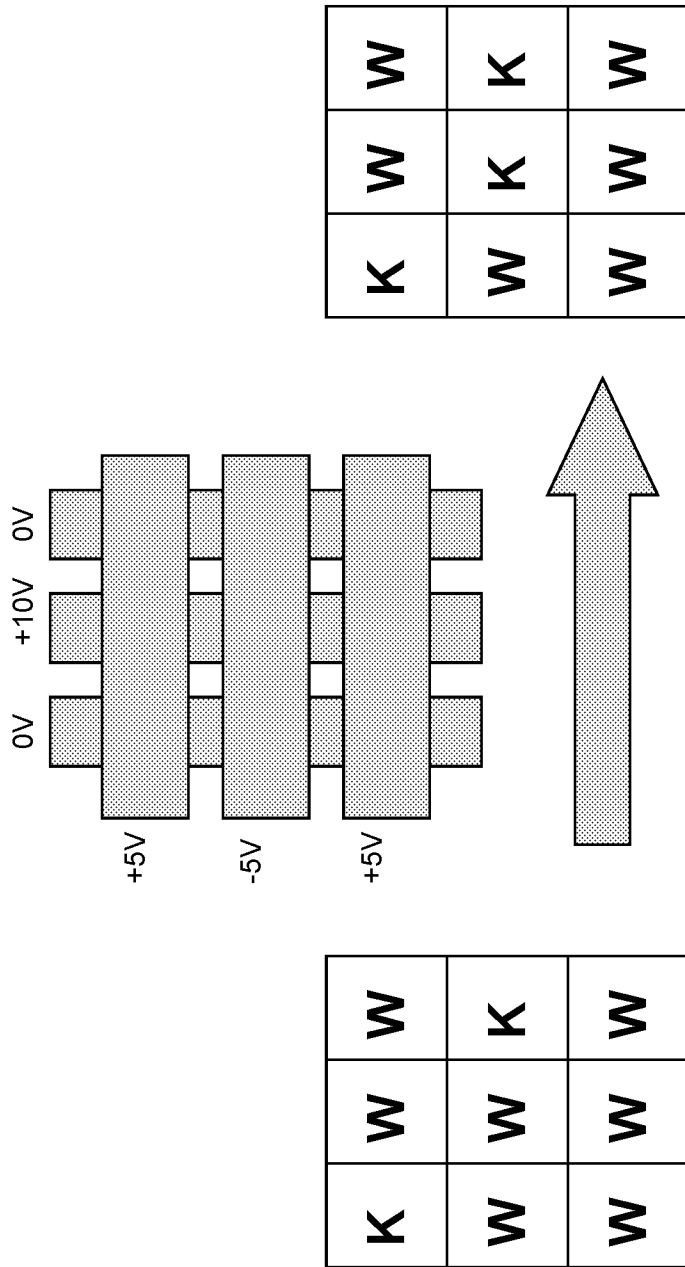
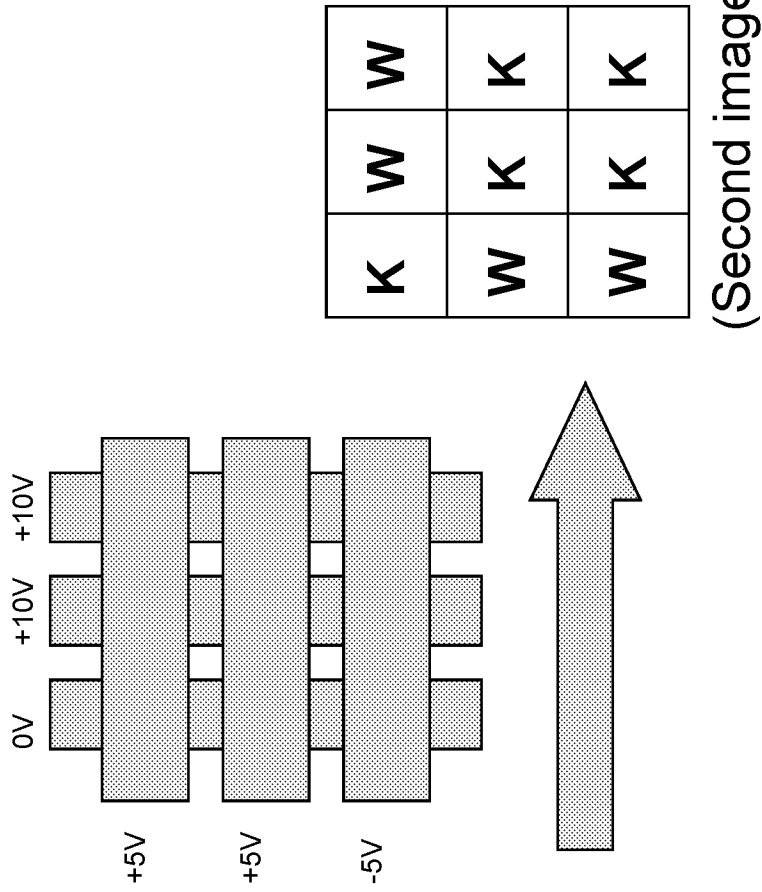


Figure 7D (Step 4)



K	W	W
W	K	W
W	K	W

Figure 7E (Step 5)

A. CLASSIFICATION OF SUBJECT MATTER**G02F 1/167(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
G02F 1/167; G09F 9/00; G09F 9/30; H01B 1/12; G09G 3/34; G02F 1/00Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: electrophoretic, third particle, polarity, color characteristic, mobility**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0293398 A1 (SIPIX IMAGING, INC.) 02 October 2014 See paragraphs [0027], [0042], [0060]-[0082]; claims 1-4, 7-14; and figures 1, 3(3a)-7d.	1-15
Y	WO 2014-055551 A1 (SIPIX IMAGING, INC.) 10 April 2014 See page 9, line 9 - page 11, line 28; and claim 1.	1-15
A	JP 2009-116041 A (SEIKO EPSON CORP.) 28 May 2009 See paragraphs [0016]-[0030]; claim 1; and figure 1.	1-15
A	US 2013-0077155 A1 (MING WANG et al.) 28 March 2013 See paragraphs [0019]-[0024], [0041]-[0042]; claims 1, 3-4; and figure 1.	1-15
A	KR 10-2007-0082680 A (LG.PHILIPS LCD CO., LTD.) 22 August 2007 See paragraphs [0052]-[0059]; figures 5-6.	1-15

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 January 2017 (23.01.2017)

Date of mailing of the international search report

23 January 2017 (23.01.2017)

Name and mailing address of the ISA/KR

International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

LEE, Dong Yun

Telephone No. +82-42-481-8734



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/056356

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0293398 A1	02/10/2014	None	
WO 2014-055551 A1	10/04/2014	CA 02885843 A1 CN 104813385 A EP 2904602 A1 EP 2904602 A4 JP 2015-532461 A KR 10-2015-0063552 A TW 201418862 A US 2014-0092465 A1 US 2014-0092466 A1 US 8717664 B2 US 8964282 B2	10/04/2014 29/07/2015 12/08/2015 01/06/2016 09/11/2015 09/06/2015 16/05/2014 03/04/2014 03/04/2014 06/05/2014 24/02/2015
JP 2009-116041 A	28/05/2009	JP 5320724 B2	23/10/2013
US 2013-0077155 A1	28/03/2013	CN 103018995 A TW 201324015 A TW I485503 B US 8902491 B2	03/04/2013 16/06/2013 21/05/2015 02/12/2014
KR 10-2007-0082680 A	22/08/2007	KR 10-1232146 B1	12/02/2013