

## Ferroelectric display device

### Field of the invention

- 5 The present invention relates to a flat display device which displays image information. In particular, the present invention relates to a display device which employs ferroelectric elements.

### Background of the invention

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- Flat panel displays are gradually taking the place of cathode ray tubes (CRT). Especially for mobile devices, flat panel displays such as liquid crystal displays are suitable in terms of thickness. One of the commercial applications of mobile display devices is as electronic books, which display letters and pictorial images on their flat display panel as if they were pages of a printed book. Liquid crystal display (LCD) panels and another kind of display panel, which is called "an electronic ink display", are currently utilized for that purpose.
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- The outline of an electronic ink display is as follows. The principal components of the electronic ink are millions of tiny microcapsules and a binder material. Each microcapsule contains positively charged white particles and negatively charged black particles suspended in a clear fluid. The microcapsules are dispersed in a binder material and supported by it. The binder contains millions of microcapsules, and is formed like a sheet. Transparent top electrodes and bottom electrodes are attached to the sheet in arrays on the sheet's respective surfaces. When a negative voltage is applied to one of the top electrodes and a positive voltage is applied to the corresponding bottom electrode, the white particles move to the top of the microcapsules where they become visible to the user. This makes the surface appear white at that spot. At the same time, the electric field pulls the black particles to the bottom of the microcapsules where they are hidden. By reversing the applied voltage, the black particles move to the top of the capsule, which now makes the surface appear dark at that spot.
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Both LCD display devices and electronic ink display devices require electric power to maintain the displayed image. Since for certain applications, such as electric books, the frequency of turning pages (i.e. updates of the displayed image) is quite low, most of power seems to be wasted. If a display device which required no power to maintain an image were available, the power consumption of such mobile devices could be reduced dramatically.

### Summary of the Invention

The present invention aims to provide a new and useful display device.

In general terms, the present invention proposes that the elements of the display device comprise ferroelectric capacitors and a display element having a colour which depends on the polarisation of the ferroelectric capacitor. Since a ferroelectric capacitor can maintain its state of polarisation in the absence of an applied electric field, embodiments of the invention may be able to maintain a displayed image with little or no consumption of electricity.

More specifically, the present invention proposes a display device having:

an array of display elements, each display element comprising:

(i) an element of fluid; and

(ii) charged particles suspended in the fluid and having different visual characteristics from said fluid;

each of said display elements being proximate a respective ferroelectric capacitor comprising an element of ferroelectric material and electrodes for generating an electric field in the element of ferroelectric material to polarize the element of ferroelectric material;

wherein polarisation of the element of ferroelectric material produces an electric field in the corresponding element of fluid, which displaces the charged particles within the fluid and thereby changes the appearance of the display element.

An alternative expression of the invention is a method of displaying information on display device having:

an array of display elements, each display element comprising:

5 (i) an element of fluid; and

(ii) charged particles suspended in the fluid and having different visual characteristics from said fluid;

the method including applying a voltage to an element of ferroelectric material proximate the element of fluid to polarize the element of ferroelectric material, the polarisation of the element of ferroelectric material producing an  
10 electric field in the corresponding element of fluid, which displaces the charged particles within the fluid and thereby changes the appearance of the display element.

15 The array of display elements is preferably two-dimensional, with the respective ferroelectric capacitors on a first side of the array of display elements. The display preferably includes a transparent solid layer, on the other, opposite side of the array of display elements.

20 The electrodes may be provided as a separate pair of electrodes for each ferroelectric capacitor. Alternatively, one or both, of the electrodes may be shared between more than one of the ferroelectric capacitors. For example, a first electrode may be arranged to provide a first voltage (e.g. ground) to a first side of a plurality of the ferroelectric elements, and the ferroelectric elements  
25 may be provided with a respective second electrode on their opposite side, so that the polarization states of the plurality of ferroelectric elements can be controlled by controlling the respective potentials of the respective second electrodes, and optionally without changing the potential of the first electrode.

30 Optionally, the charged particles may all be of the same colour, such as a first colour. In this case, the fluid is typically of a second, different colour.

Alternatively, there may comprise uncharged particles having a second colour, different from the first colour, and the fluid itself may be of any colour, e.g. clear.

Alternatively, the charged particles may be of different colours from each other.

5 For example, the charged particles may comprise, or consist of, positively charged particles having a first colour, and negatively charged particles having a second colour. In this case the fluid may be transparent and without colour, i.e. be clear.

10 The fluid element of a given display element may be separated from the fluid elements of other display elements. Alternatively, the fluid elements of different display elements may be in fluid communication with each other. In some embodiments, for example, the fluid elements may be different portions of a sheet-shaped fluid body, and the charged particles may be able to move  
15 between different fluid elements.

A further possibility is for the fluid elements to be microcapsules, which are themselves dispersed and supported in a binder material.

20 Optionally, a given display element may contain multiple fluid elements, each containing charged particles, and all within the electric field of the ferrocapacitor.

The invention is particularly useful in the case that the display device is a part of  
25 a mobile device (such as a hand-held item of consumer electronics), since using the present display device helps the mobile devices prolong its battery life. The present display device is also suitable for use as a public display device, e.g. for displaying an advertisement such as electric poster which does not require frequent updating of the image.

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Brief description of the drawings

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

Fig. 1 is a schematic view of a display element of a device which is an embodiment of the invention;

Fig. 2(a) illustrates a polarization process of the ferroelectric layer of the display element of Fig. 1;

Fig. 2(b) illustrates how the display element of Fig. 1 displays a black pixel;

Figure 2(c) illustrates how the display element of Fig. 1 displays a white pixel;

Figure 3 shows the relationship between the applied electric field, the polarization state of the display element of Fig. 1, and the optical density of the display element of Fig. 1; and

Figure 4 shows typical polarization properties of ferroelectric materials.

#### Detailed Description of Preferred Embodiments

Referring firstly to Fig. 1, a cross-sectional schematic view is shown of a portion of a ferroelectric display device which is an embodiment of the present invention. Specifically, the display device includes a two dimensional rectilinear array of display elements (pixels), and the cross-sectional view is in a plane perpendicular to the surface of the display device and including one line of the pixels. In Fig. 1, the  $n$ -th pixel is shown. The  $n$ -th pixel is located between the  $(n-1)$ -th pixel and the  $(n+1)$ -th pixel. It comprises an arrangement of a ferroelectric layer 1, and two electrodes 2, 3 attached on both surfaces of said ferroelectric layer 1. A layer 4 of a clear fluid extends over a plurality of the display elements and includes positively charged white particles 5 and negatively charged black particles 6. One suitable material for the ferroelectric

layer 1 is a copolymer of vinylidene fluoride and trifluoroethylene (P(VDF/TrFE)). Alternative possibilities would be  $\text{PbZrTiO}_3$  (PZT) or  $\text{SrBi}_2\text{Ta}_2\text{O}_9$  (SBT). The bottom electrode 3 is shared between multiple pixels. Indeed, the upper electrode 2 also may be formed as a line extending in the direction into the page, and extending through multiple pixels.

Fig. 2, which is composed of Figs. 2(a) to 2(c), illustrates how the display element of Fig. 1 is able to display information. Fig. 3 shows the profile of the potentials applied to the electrode 2, 3 during this process.

During the period of length  $T_d$  shown as 10 in Fig. 3, a positive voltage pulse is applied to the top electrode 2 which faces the fluid 4, and a negative voltage is applied to the bottom electrode 3. The generated electric field between the electrodes is higher than the coercive field  $E_c$  of the ferroelectric material 1, so the ferroelectric layer 1 is polarized so that the polarization points upward (i.e. the direction from the bottom surface to the top surface. See Fig. 2(a)).

In the subsequent period shown as 20 in Fig. 3, when the voltage pulse is over, the polarization remains in the ferroelectric layer 1 even though the applied electric field is turned off. The remnant polarization  $P_r$  induces surface charges on the top and the bottom electrodes. As a negative charge appears on the top electrode and a positive charge appears on the bottom electrode, the positively charged white particles 5 are attracted to the top electrode and the negatively charged black particles 6 are repelled toward the top panel of the cell 7. Thus, the cell displays a black pixel (when viewed from the top of Fig. 2(b)). After the ferroelectric layer is polarized, the polarization is maintained even no electric field is applied between the electrodes 2, 3. Therefore, the displayed image is maintained without the electric power.

Subsequently, an opposite voltage pulse can be applied to the electrodes 2,3, reversing the polarization. This produces the state shown in Fig. 2(c) in the period 30 on Fig. 3. In this state, the pixel appears white.

Naturally, in a variant of this embodiment the white particles could be negatively charged, and the black particles positively charged. A generalized explanation of this embodiment is there are particles of two different colours, and that these  
 5 have opposite respective charge signs.

Note that it may not be necessary for all the particles of a given charge sign to have exactly the same colour. Instead, it may just be true that the average colour of the positive particles should be different from the average colour of the  
 10 negative particles. See below where further possibilities are discussed.

Note that by making the duration of the applied field ( $T_d$ ) sufficiently shorter than the mean travelling time ( $T_m$ ) of the charged particles (e.g.  $T_d$  may be at most half of  $T_m$ , or at most a quarter of  $T_m$ ), the ferroelectric layer 1 is polarized  
 15 before most of charged particles are attracted or repelled to the electrodes by the applied field. The mean travelling time ( $T_m$ ) is defined by the following formula:

$$T_m = (1/n) \sum_{i=0}^n (T_i)$$

where  $n$  is the number of charged particles,  $T_i$  is travelling time of  $i$ th particle to  
 20 traverse the fluid element to arrive at one of electrodes.

Although only a single embodiment of the invention has been described in detail above, many variations are possible within the scope of the invention as will be clear to a skilled reader. For example, instead of the above-mentioned  
 25 arrangement of a clear fluid, charged white particles and charged black particles, the display device may use a combination of a white fluid and charged black particles. When the black particles are attracted to the top electrode 2, the white fluid would be visible through the transparent layer 7 and the display element would be white. Otherwise, when the black particles are repelled from  
 30 the top electrode 2, they would be visible, and the display element would appear black. A further alternative is to utilize a mixture of a clear fluid and uncharged white particles instead of a white fluid.

Furthermore, although the two colours have been described above as “white” and “black”, any other pair of colours could be used, preferably a combination is used which gives good contrast, such as yellow and purple.

Claims:

1. A display device having:  
an array of display elements, each display element comprising:  
(i) an element of fluid; and  
5 (ii) charged particles suspended in the fluid and having different visual characteristics from said fluid;  
each of said display elements being proximate a respective ferroelectric capacitor comprising an element of ferroelectric material and electrodes for generating an electric field in the element of ferroelectric material to polarize the  
10 element of ferroelectric material;  
wherein polarisation of the element of ferroelectric material produces an electric field in the corresponding element of fluid, which displaces the charged particles within the fluid and thereby changes the appearance of the display element.  
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2. A display device according to claim 1 in which the electrodes and respective elements of ferroelectric material are arranged on a first side of the array of display elements, and the display device further includes a transparent solid layer on the other, opposite side of the array of display elements.  
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3. A display device according to claim 1 or claim 2 in which the charged particles have a first colour, and the fluid has a second, different colour.
4. A display device according to claim 1 or claim 2 in which the charged  
25 particles have a first colour, and the fluid elements contain uncharged particles having a second, different colour.
5. A display device according to claim 1 or claim 2 in which the charged particles comprise positively charged particles having a first colour, and  
30 negatively charged particles having a second, different colour.
6. A display device according to claim 4 or claim 5 in which the fluid is clear.

7. A display device according to any preceding claim further including voltage supply means to supply voltage pulses to the electrodes to effect polarization of the elements of ferroelectric material, the pulse having a duration  
5 shorter than the average time for charged particles to traverse the fluid element.

8. A display device according to any preceding claim which is a hand-held consumer electronics product.

10 9. A display device according to any preceding claim which is a public display device in which the display have a maximum dimension of at least 50cm.

10. A method of displaying information on display device having an array of display elements, each display element comprising:

15 (i) an element of fluid; and  
(ii) charged particles suspended in the fluid and having different visual characteristics from said fluid;

the method including applying a selected voltage to a respective element of ferroelectric material proximate each element of fluid to polarize the element  
20 of ferroelectric material, the polarisation of the element of ferroelectric material producing an electric field in the corresponding element of fluid, which displaces the charged particles within the fluid and thereby changes the appearance of the display element.

25 11. A method according to claim 10 in which said selected voltage is applied as a pulse having a selected polarization and a duration shorter than the average time for charged particles to traverse the fluid element.