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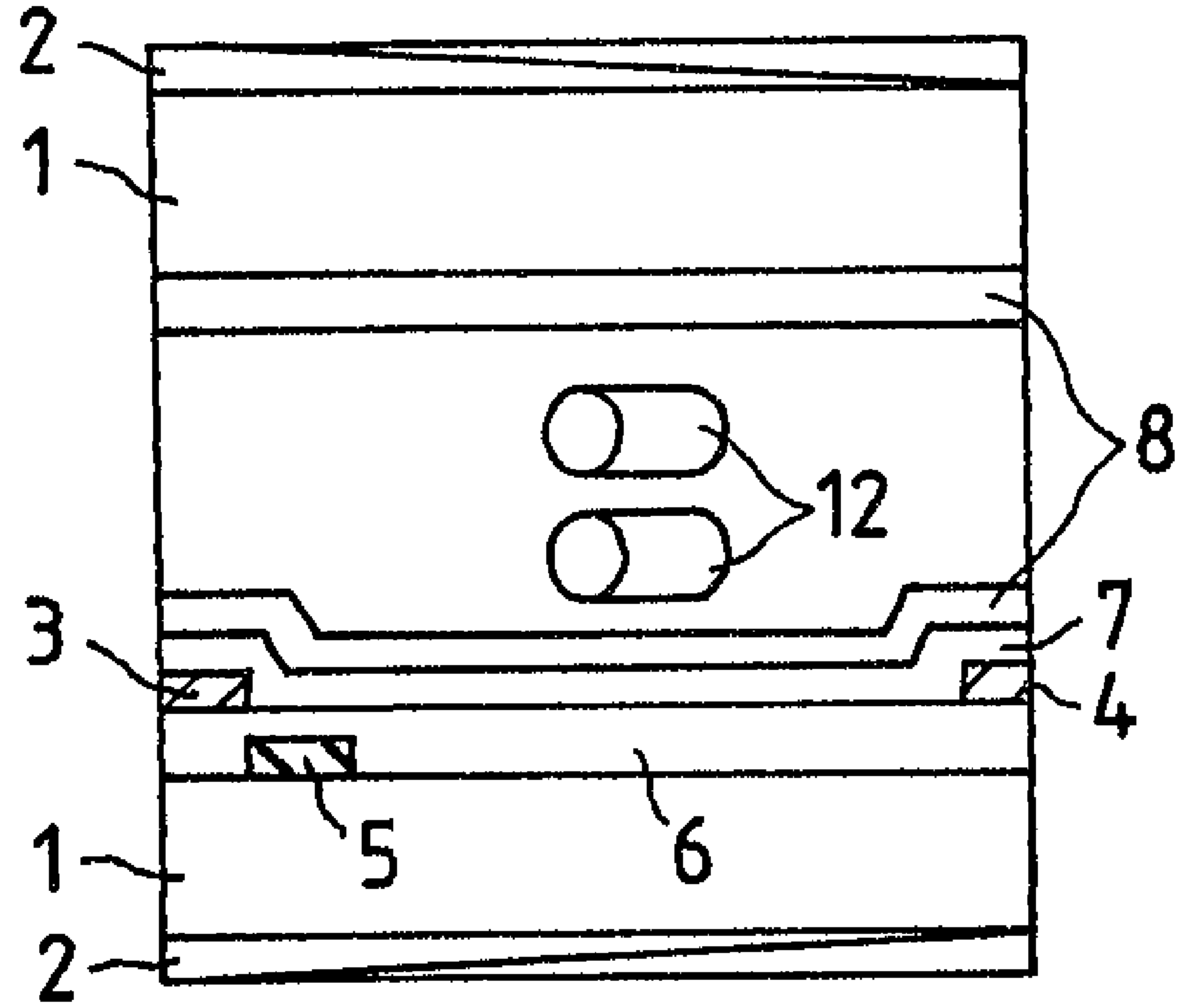
(54) **DISPOSITIF D'AFFICHAGE A CRISTAUX LIQUIDES**
(54) **LIQUID CRYSTAL DISPLAY DEVICE**



(57) A liquid crystal display device having electrodes that form a picture element matrix and generate an electric field substantially parallel to a substrate that has a brightness recovery time no greater than five minutes. The brightness recovery time is the time until the brightness of the displayed portion that has been displayed for 30 minutes and is turned off returns to the background brightness.

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Abstract

A liquid crystal display device having electrodes that form a picture element matrix and generate an electric field substantially parallel to a substrate that has a brightness recovery time no greater than five minutes. The brightness recovery time is the time until the brightness of the displayed portion that has been displayed for 30 minutes and is turned off returns to the background brightness.

LIQUID CRYSTAL DISPLAY DEVICE

The present invention relates to a liquid crystal display device of high picture quality with substantially eliminated residual image.

In a prior art liquid crystal display device, two facing transparent electrodes formed respectively on each of two substrates were used as the electrodes for driving the liquid crystal layer. A display method represented by a twisted nematic display method has been adopted, wherein the crystal display operates by being supplied with an electric field having approximately a vertical direction to the substrate boundary planes. On the other hand, for a method wherein the electric field has approximately a parallel direction to the substrates, methods utilizing a pair of comb-like electrodes are disclosed, for examples, in JP-B-63-21907 and WO91/10936. In these cases, the electrodes are not necessarily transparent. Opaque metallic electrodes having high conductivity can be used. However, the above prior art does not teach a liquid crystal material, oriented film, and an insulating film, which are necessary for obtaining high picture quality when driving a display system wherein the electric field is supplied to the liquid crystal in an approximately parallel direction to the substrate plane (hereinafter called an in-plane switching system), with an active matrix driving method or a simple matrix driving method.

When a character or a drawing is displayed in a display plane, the image of the character or the drawing remains for a while in the display plane even after erasing, and sometimes it causes an uneven display called an afterimage. The afterimage is a common problem that deteriorates image quality for both the display methods, i.e. where the electric field is supplied in a perpendicular direction, or in the in-plane switching system. Especially in the case of the in-plane switching system, the afterimage is generated more easily than in the case wherein the electric field is generated perpendicularly to the substrate plane.

The object of the present invention is to provide a liquid crystal display device of high picture quality with substantially eliminated residual image.

In accordance with one aspect of the present invention there is provided a liquid crystal display device comprising: a plurality of display picture elements, each being composed of electrodes on a substrate; an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and substantially similar products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ are provided for respective ones of the liquid crystal layer, the orienting film, and the insulating film.

In accordance with another aspect of the present invention there is provided a liquid crystal display device comprising: a plurality of display picture elements, each being composed of electrodes on a substrate; an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and a ratio of the maximum value to the minimum value of respective products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ of the liquid crystal layer, the orienting film, and the insulating film is in a range of 1 - 100.

In accordance with yet another aspect of the present invention there is provided a liquid crystal display device comprising: a plurality of display picture elements, each being composed of electrodes on a substrate; an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; respective products $((\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$ of a specific dielectric constant ϵ_r and a specific resistivity ρ of the liquid crystal layer, the orienting film, and the insulating film have a relationship expressed by the following equations (1) to (3):

$$0.1 \le (\epsilon_r\rho)_{LC}/(\epsilon_r\rho)_{AF} \le 10 \qquad (1)$$

$$0.1 \le (\epsilon_r\rho)_{LC}/(\epsilon_r\rho)_{PAS} \le 10 \qquad (2)$$

$$0.1 \le (\epsilon_r\rho)_{AF}/(\epsilon_r\rho)_{PAS} \le 10 \qquad (3).$$

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device comprising: a plurality of display picture elements, each being composed of electrodes on a substrate; an orienting film for a liquid crystal layer formed on the substrate via an insulating film, said substrate being arranged so as to face another substrate on which another orienting film is formed, a liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and a sum of film thickness of said orienting film and said insulating film on the substrate is in a range of 0.5 - 3 μm.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device having a plurality of switching elements, comprising:a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field having a component substantially in parallel with said one of said pair of substrates; and an insulating film formed on said electrode structure, said insulating film including an organic layer and an inorganic layer.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device having a plurality of switching elements, comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field substantially in parallel with said one of said pair of substrates; and an orienting film for controlling an orientation of liquid crystal molecules of said liquid crystal layer, said orientation film being formed on said one of said pair of substrates directly or via an insulating layer; wherein respective products $(\epsilon_r\rho)_{LC}$ and $(\epsilon_r\rho)_{PAS}$ are substantially equal, the respective products being of a specific dielectric constant ϵ_r and a specific resistivity ρ provided for respective ones of the liquid crystal layer, the orienting film, and the insulating layer.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device having a plurality of switching elements, comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field substantially in parallel with said one of said pair of substrates; and an orienting film for controlling an orientation of liquid crystal molecules of said liquid crystal layer, said orientation film being formed on said one of said pair of substrates directly or via an insulating layer; wherein a ratio of a maximum value to a minimum value of respective products of one of $(\epsilon_r\rho)_{LC}/(\epsilon_r\rho)_{PAS}$ and $(\epsilon_r\rho)_{PAS}/(\epsilon_r\rho)_{LC}$ is in a range of 1 to 100, the respective products being of a specific dielectric constant ϵ_r and a specific resistivity ρ provided for respective ones of the liquid crystal layer, the orienting film and the insulating film.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field having a component predominantly parallel with said one of said pair of substrates; an insulating layer formed on said electrode structure; an orienting film formed on said insulating layer; wherein a sum of film thickness of said insulating layer and said orienting film is equal to or less than 3 μm.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field having a component predominantly parallel with said one of said pair of substrates; an insulating layer formed on said electrode structure; an orienting film formed on said insulating layer; wherein a ratio of a product of a specific resistivity and a specific dielectric constant of said orienting film to a product of a specific resistivity and a specific dielectric constant of said insulating layer is less than 100.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field having a component predominantly parallel with said one of said pair of substrates; wherein a product of a specific dielectric constant ϵ_r and a specific resistivity ρ of said liquid crystal layer is in a range from 10^9 $\Omega\cdot$cm to 10^{15} $\Omega\cdot$cm.

In accordance with still yet another aspect of the present invention there is provided a liquid crystal display device having a plurality of switching elements, comprising: a pair of substrates; a liquid crystal layer interposed between said pair of substrates; an electrode structure formed on one of said pair of substrates for generating an electric field substantially in parallel with said one of said pair of substrates; an insulating layer formed on said electrode structure; a color filter formed on said insulating layer; and an orienting film formed on said color filter for controlling an orientation of liquid crystal molecules of said liquid crystal layer.

To solve these problems, the invention comprises various means.

In a liquid crystal display device of the present invention, the thickness of the insulating film is preferably in the range of 0.4 - 2 μm.

Further, in a liquid crystal display device of the present invention, the orienting film is preferably made of an organic material, and the insulating film is preferably made of an inorganic material. Furthermore, the orienting film is preferably made of an organic material, and the insulating film preferably has a double layer structure made of an inorganic material and an organic material.

Further, in a liquid crystal display device of the present invention, the orienting film is preferably made of an organic material and the insulating film is preferably made of an inorganic material, and the orienting film made of the organic material is preferably thicker than the insulating material made of the inorganic material.

Further, both the orienting film and the insulating film are preferably composed of organic material, and both the orienting film and the insulating film are preferably composed of the same material. Furthermore, one side of a plane of the orienting film that abuts the liquid crystal is flat.

In order to realize a color display having a high picture quality, a color filter is preferably provided on either one of the substrates, and the insulator is preferably inserted between the color filter and the liquid crystal layer. Further, a film having the function of flatten steps on the color filter is preferably composed of organic material, and a film composed of inorganic material is preferably formed on the film of organic material. Furthermore, the orienting film is preferably located on the substrate having the color filter via the intermediary of a layer composed of inorganic material.

In the drawings:

FIGs. 1(a) to (d) are schematic illustrations for explaining the operation of a liquid crystal in a liquid crystal display device supplied with in-plane switching to the substrate according to an embodiment of the present invention,

FIG. 2 is a schematic illustration indicating angles formed by an orienting direction of a molecular longitudinal axis on a boundary plane to an electrical field direction, and by a transmitting axis of a polarizer to the electrical field direction in a liquid crystal display device supplied with a horizontal electric field to the substrate according to an embodiment of the present invention,

FIG. 3 is a plan view and cross sections of a picture element unit (1),

FIG. 4 is a plan view and cross sections of a picture element unit (2),

FIG. 5 is a plan view and cross sections of a picture element unit (3),

FIG. 6 is a plan view and cross sections of a picture element unit (4),

FIG. 7 is a diagram indicating a typical example of a system composition in a liquid crystal display device according to an embodiment of the present invention,

FIG. 8 is a set of schematic illustrations indicating the fraction law of electric force line, and variation of a horizontal electric field strength in a liquid crystal layer depending on relative dielectric constant and the thickness of the layer in respective layers,

FIG. 9(a) is a graph indicating relationships among the maximum value of products $\epsilon\rho$ of respective specific resistivity ρ and a specific dielectric constant ϵ, and residual image characteristics of a liquid crystal insulating film, and an orienting film,

FIG. 9(b) is a graph indicating relationships among the ratio of the maximum value and the minimum value of products $\epsilon\rho$ of respective specific resistivity ρ and specific dielectric constant ϵ and the residual image characteristics of the liquid crystal insulating film, and the orienting film,

FIG. 10(a) is a graph indicating a relationship between a sum of the film thickness of the insulating film and the orienting film, and the results of residual image evaluation,

FIG. 10(b) is a graph indicating a relationship between a sum of the film thickness of the insulating film and the orienting film, and the transmission factor, and

FIGs. 11(a) and (b) are model graphs indicating relationships between the charging process and the discharging process of an electric charge, and residual image characteristics.

The principle of an in-plane switching system wherein an electric field is supplied in a direction parallel to a substrate will now be explained, and subsequently the operation of embodiments of the present invention are explained.

At the beginning, definitions of an angle ϕ_P, which is the angle formed by the polarized light transmitting axis of a polarizer to the direction of the electric field, and an angle ϕ_{LC}, which is the angle formed by the direction of the liquid crystal major axis (optical axis) in the vicinity of liquid crystal boundary to the direction of the electric field are shown in FIG. 2. The polarizer and the liquid crystal boundary exist as pairs at each of an upper side and a lower side, respectively.

Therefore, the angles are expressed as ϕ_{P1}, ϕ_{P2}, ϕ_{LC1}, and ϕ_{LC2}, if necessary. FIG. 2 corresponds to a front view of FIG. 1 which is explained later.

FIGs. 1(a) and 1(b) are side cross sections indicating liquid crystal operation in a liquid crystal panel of the present invention, and FIGs. 1(c) and 1(d) are front view of the respective FIGs. 1(a) and 1(b). In FIG. 1, the active elements are omitted. Further, strip-shaped electrodes form a plurality of picture elements, but only one picture element is shown in FIG. 1. A side cross section of a cell under no voltage is shown in FIG. 1(a), and the front view of FIG. 1(a) is shown in FIG. 1(c). Linear signal electrodes 3, 4, and a common electrode 5 are formed at the inside of one pair of transparent substrates 1, an insulating film 7 is provided on the substrates and the electrodes, and an orienting film 8 is supplied and processed for orientation on the insulating film

7. A liquid crystal composition is held between the substrates. A bar-shaped liquid crystal molecule 12 is oriented so as to have a small angel to a longitudinal direction of the strip-shaped electrodes, that is 45 degrees < ϕ_{LC} < 135 degrees, or, -45 degrees < ϕ_{LC} < -135 degrees, when no electric field is applied. An example is explained hereinafter when the orienting direction of the liquid crystal molecule at the upper and the lower boundaries is parallel, that is $\phi_{LC1} = \phi_{LC2}$. Further, the dielectric anisotropy of the liquid crystal composition is assumed as being positive.

Next, when an electric field 9 is applied, the liquid crystal molecule changes its orienting direction to the direction of the electric field, as shown in FIGs. 1(b) and 1(d). Therefore, the optical transmission becomes changeable by applying an electric field when the polarizer 2 is arranged at a designated angle 11. As explained above, in accordance with the present invention, a display giving contrast becomes possible without the transparent electrodes. The dielectric anisotropy of the liquid crystal composition is assumed to be positive in the present description, but negative anisotropy is also usable. In the case of negative anisotropy, the liquid crystal molecule is oriented at a first oriented condition so as to have a small angle, ϕ_{LC} to a vertical direction to the longitudinal direction of the strip-shaped electrodes, that is -45 degrees < ϕ_{LC} < 45 degrees, or, 135 degrees < ϕ_{LC} < 225 degrees.

In FIG. 1, an example is shown wherein a common electrode is a different layer from the signal electrode and the picture element electrode, but the common electrode can be in the same layer as the signal electrode and the picture element electrode. A typical example of a picture element structure when the common electrode is in the same layer with the picture element electrode is shown in FIG. 3, and typical examples of a picture element structure when the common electrodes are in different layers from the picture element electrodes are shown in FIGs. 4 and 5. Further, even if the common electrode is not provided, the scanning electrode can be given the same function as that of the common electrode. However, the gist of the present invention as explained hereinafter is in insulating materials for composing the liquid crystal element, and is applicable to various electrode structures and thin film transistor structures.

As explained in the above first means a liquid crystal display device having a high picture quality with substantially eliminated residual images can be obtained by employing the necessary time for recovering the brightness of the display device after displaying an identical drawing pattern for 30 minutes, as less than five minutes. The residual images are induced when polarization is generated in the liquid crystal layer, the orienting film, or the insulating film for any reason. Therefore, the residual images can be reduced concretely, as explained in the above second means, by making respective products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and/or $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ of the respective liquid crystal layer, the orienting film, and/or the insulating film equal to or less than 8×10^{15} Ω·cm, because the accumulated electric charge can be relaxed quickly. A model graph indicating the principle of residual image reduction in the above case is shown in FIG. 11(a). That means, the residual image can be reduced because the relaxing speed is fast, even if the electric charge has accumulated, and the electric charge is discharged quickly. Further, the residual image can be reduced by decreasing the accumulated electric charge as shown in FIG. 11(b) even if the relaxing speed is slow. Therefore, the residual image problem can be improved by making the respective surface resistance of the orienting film and/or the insulating film equal to or less than 2.5×10^{18} Ω/□ in order to decrease the accumulating electric charge as stated in the above third means. Furthermore, as stated in the above fourth, sixth, and seventh means, the residual image can be further reduced by substantially equalizing the products of the specific dielectric constant ϵ_r and the specific resistivity ρ of the liquid crystal layer, the orienting film, and the insulating layer. As described previously, the residual image is induced when polarization is generated in the liquid crystal layer, the orienting film, or the insulating film by any reason. And, the polarization in the respective layer and films interfere with each other so that the polarization generated in the orienting film generates secondary polarization in the liquid crystal layer.

For instance, if any polarization remains in the orienting film in a relaxation process of polarization of the liquid crystal layer, the polarization in the orienting film effects the liquid crystal layer to prevent the relaxation of the polarization in the liquid crystal layer. Accordingly, in order to proceed with the relaxation generated in the respective layer or films without interfering with each other, the respective relaxation times must be equal. The present inventors have found that the above described principle can be applied significantly in the method wherein the electric field is supplied in a direction parallel to the substrate, that is, the in-plane switching method. In the in-plane switching method, the electric equivalent circuits corresponding to the respective liquid crystal layer, the insulating film, and the orienting film are connected in parallel.

Therefore, for instance, when a product ($\epsilon_r \rho$) of the specific dielectric constant ϵ_r and the specific resistivity ρ for the orienting film or the insulating film is larger than that for the liquid crystal layer, the residual voltage in the orienting film or the insulating film is supplied to the liquid crystal layer as an extra voltage, and, consequently, a residual image is induced. Furthermore, considering that the resistance R can be expressed by the equation, $R = \rho d/S$ (where ρ: the specific resistivity, d: the length in the direction of the electric field, S: the vertical cross section area to the electric field), the in-plane switching system has a significantly larger resistance in the element structure than the method wherein the electric field is supplied to the substrate perpendicularly. That means, the residual direct current component in the in-plane switching system is remarkably large. In this case, a combination of the fourth means, the sixth means or the seventh means with the second means as the fifth means makes it possible to relax the accumulated charge in a short time without interfering with the liquid crystal layer, the orienting film, and/or the insulating film in the relaxing of the accumulated charge.

Therefore, the combination is an effective means for reducing the residual image.

The above principle can be established in the in-plane switching system irrelevant to whether the simple matrix driving method or the active matrix driving method is used.

Further, the resistance components of the orienting film and the insulating film at each picture element can be decreased by making the sum of the thicknesses of a film having the function to orient the liquid crystal (orienting film) and a film having the functions of insulating electrically and protecting the electrodes group (insulating film) within the range of from 0.5 μm to 3 μm, desirably from 0.7 μm to 2.8 μm. Actually, the thickness of the insulating film is desirably selected in the range from 0.4 μm to 2 μm, as described in the above tenth means, in order to deduce additional effects of the steps on the substrate on which the electrodes group is mounted. As explained previously, in a method wherein the direction of the electric field supplied to the liquid crystal is approximately parallel to the substrate plane, the equivalent circuits corresponding to the respective liquid crystal layer, the insulating film, and the orienting film are connected in parallel.

Accordingly, the voltage remained in the orienting film and the insulating film is supplied directly to the liquid crystal layer. Considering that the residual images are generated by residual voltage in the orienting film and the insulating film to the liquid crystal layer, the residual voltage in the orienting film and the insulating film to the liquid crystal layer, the residual voltage in the orienting film and the insulating film can be reduced and excessive voltage applied to the liquid crystal layer can be eliminated by decreasing the resistance components equivalent to the orienting film and the insulating film at each picture element. In order to decrease the resistance components in the orienting film and the insulating film, the film thicknesses of the orienting film and the insulating film must be increased for enlarging the cross sectional area perpendicular to the direction of the electric field.

The insulating film can be formed with a reliable inorganic material, and the orienting film can be formed with an organic material. Further, the insulating film can be formed in a double layer structure that is composed of an inorganic material layer and a relatively easily shapable organic material layer.

FIG. 8 is a schematic illustration indicating the variation in the line of electric force in a liquid crystal layer depending on the magnitude of the dielectric constant in each layer. The smaller the dielectric constants in the orienting film and the insulating film relative to the dielectric constant of the liquid crystal layer, the more ideal an in-plane switching can be realized.

Accordingly, an electric field component horizontal to the substrate plane can be utilized effectively by replacing as much as possible a layer of inorganic material with a layer of organic material having a low dielectric constant. Further, the above effect can be realized by making the insulating film with an organic material. Furthermore, fabricating the insulating film and the orienting film from the same material realizes a high efficiency in the manufacturing process. In order to improve the picture quality in a liquid crystal display device, the flattening surface plane of the orienting film abutting on the liquid crystal is important. By the flattening, the steps at the surface plane can be eliminated, and light leakage can be suppressed by making the effects of rubbing uniform all through the surface plane.

In order to realize a color display by the in-plane switching system, it is only necessary that the insulating film must be inserted between a color filter and the liquid crystal layer. A conductive body in the interval between the color filter and the liquid crystal destroys the horizontal electric field.

Generally, an organic material, such as an epoxy resin is used as a flattening film for color filter, and transparent electrodes are provided on the flattening film. However, the transparent electrodes are not necessary in the in-plane switching system as stated previously; the flattening film can contact the orienting film directly. In this case, the printability of the orienting film sometimes causes troubles. Therefore, a layer of an inorganic material, such as silicon nitride, provided on an upper portion of the flattening film is effective in improving printability. The color filter is not necessarily provided on facing planes of the substrates on which the electrodes group existed. Rather, the preciseness of alignment can be improved by providing the color filter on the substrate plane on which the active elements and electrodes group are mounted.

Embodiment 1

FIG. 3 indicates the structure of an electrode for a picture element unit in the first embodiment of the present invention. A scanning signal electrode 13 made of aluminum was formed on a polished glass substrate, and surface of the scanning signal electrode was coated with an alumina film, i.e. an anodic oxide film of aluminum. A gate silicon nitride (gate SiN) film 6 and an amorphous silicon (a-Si) film 14 were formed so as to cover the scanning signal electrode, and a n-type a-Si film, a picture element electrode 4, and an image signal electrode 3 were formed on the a-Si film. Further, a common electrode 5 was provided in the same layer as the picture element electrode and the image signal electrode. The picture element electrode and the signal electrode had a structure, as shown in FIG. 3, parallel to the strip-shaped common electrode and crossing the scanning signal electrode, and a thin film transistor 15 and a group of metallic electrodes were formed at one end of the substrate. In accordance with the above structure, an electric field 9 could be applied between the picture element electrode and the common electrode at one end of the substrate in a direction approximately parallel to the substrate plane. All of the electrodes on the substrate were made of aluminum. But any of a metallic material having a low electric resistance, such as chromium, copper, and others can be used. The number of the picture elements was 40 (x3) x 30 (i.e. n = 120, m = 30), and pitches of the picture elements were 80 μm in width (i.e. between common electrodes) and 240 μm in length (i.e. between gate electrodes). The width of the common electrode was made 12 μm, which was narrower than the gap between adjacent common electrodes, in order to secure a large opening fraction. Three strip-shaped color filters of respectively red (R), green (G), and blue (B) were provided on a substrate facing the substrate having a thin film transistor. On the color filters, transparent resin was laminated in order to flatten the surface of the color filter. As the material for the above transparent resin, an epoxy resin was used. Further, an orientation controlling film made of a polyamide group resin was applied on the transparent resin. A driving LSI was connected to the panel, as shown in FIG. 7, a vertical scanning circuit 20 and an image signal driving circuit 21 were connected to the TFT substrate, and the active matrix was driven by being supplied with a scanning signal voltage, image signal voltage, and timing signal from a power source circuit and a controller 22.

The directions of the upper and the lower boundary planes were approximately mutually parallel and formed an angle of 15 degrees ($\phi_{LC1} = \phi_{LC2} = 15°$) to the direction of the applied electrical field (FIG. 2). A gap d was kept by holding dispersed spherical polymer beads between the substrates at 6.5 μm intervals under the liquid crystal filled condition. The panel was held between two polarizers (made by Nitto Denko Co., G1220DU), the polarizing light transmitting axis of one of the polarizers was selected as approximately parallel to a rubbing direction, i.e. $\phi_{P1} = 15°$, and the axis of the other polarizer was selected as perpendicular to the rubbing direction, i.e. $\phi_{P2} = -75°$. Accordingly, normal closed characteristics were obtained.

Between the substrates, a liquid crystal ZLI-2806 (made by Merck Co.) containing trans, trans-4,4'-dipentyl-trans-1,1'-dicyclohexane-4-carbonitrile as the main component having a negative dielectric anisotropy $\Delta\epsilon$, was held. The liquid crystal had a specific resistivity of 5.1×10^{11} Ωcm and an average specific dielectric constant of 6.5 Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 2.5×10^{13} Ωcm and specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-aminophenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 7.5×10^{13} Ωcm and its average specific dielectric constant was 2.9. Accordingly, the respective products ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film respectively was less than 8×10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min})$, was less than 100.

The residual image was evaluated by visual observation with five rankings. An identical figure pattern was displayed for thirty minutes, and samples were classified by the time necessary for recovering brightness after switching off the display. Samples were evaluated and classified as follows;

A sample of rank 5 was one necessitating more than five minutes for recovering brightness, rank 4 was from one minute to less than five minutes, rank 3 was from 30 seconds to less than one minute, rank 2 was less than 30 seconds, but the generation of some residual image was observed, and rank 1 was no residual image at all.

The sample in the present embodiment 1 was evaluated as rank 1 because no residual image was observed.

The present invention preferably relates to the specific dielectric constant and the specific resistivity of the insulating material composing the element, and accordingly, the present invention is applicable to various structures of electrodes and TFTs.

Embodiment 2

FIG. 4 indicates the structure of electrode for a picture element unit in the second embodiment of the present invention. A scanning signal electrode 13 and a common electrode 5 made of aluminum were formed on a polished glass substrate, and the surface of the scanning signal electrode was coated with an alumina film, i.e. an anodic oxide film of aluminum. A gate silicon nitride (gate SiN) film 6 was formed so as to cover the scanning signal electrode and the common electrode. Subsequently, an amorphous silicon (a-Si) film 14, and n-type a-Si film were formed on the a-Si film. Further, a picture element electrode 4, and a signal electrode 3 were formed. Accordingly, the picture element electrode and the common electrode were in mutually different layers. The picture element electrode had a H-shaped structure, as shown in FIG. 4, and the common electrode has a cruciform structure. A part of each electrode had a structure working as a capacitance element. In accordance with the above structure, an electric field could be applied between the picture element electrode and the common electrode at one end of the substrate in a direction approximately parallel to the substrate plane. All of the electrodes on the substrate were made of aluminum. But any metallic material having a low electric resistance, such as chromium, copper, and others can be used. The number of picture elements was 320 x 160, and the pitches of the picture elements were 100 μm in width (i.e. between signal electrodes) and 300 μm in length (i.e. between scanning electrodes). Driving transistors were connected to the panel, as shown in FIG. 7, a vertical scanning circuit 20 and an image signal driving circuit 21 were connected to the TFT substrate, and the active matrix was driven by being supplied with a scanning signal voltage, an image signal voltage, and a timing signal from a power source circuit and a controller 22.

The directions of the upper and the lower boundary planes were approximately mutually parallel, and formed an angle of 105 degrees ($\phi_{LC1} = \phi_{LC2} = 105°$) to the direction of the applied electric field (FIG. 2). A gap d was kept by holding dispersed spherical polymer beads between the substrates at 4.2 μm at intervals under a liquid crystal filled condition. The panel was held between two polarizers (made by Nitto Denko Co., G1220DU), the polarizing light transmitting axis of one of the polarizer being selected as approximately parallel to a rubbing direction, i.e. $\phi_{P1} = 105°$, and the axis of the other polarizer being selected as perpendicular to the rubbing direction, i.e. $\phi_{P2} = 15°$. Accordingly, a normal closed characteristic was obtained.

Between the substrates, a liquid crystal of which the main component was a compound containing three fluoro groups at terminals having a positive dielectric anisotropy $\Delta\epsilon$ was held. The liquid crystal had a specific resistivity of 5.0 x 10^{14} Ωcm and an average specific dielectric constant of 6.1. Silicon nitride (SiN) was used for an insulating film, and its specific resistivity was 3.0 x 10^{14} Ωcm and specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-aminophenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 1.0 x 10^{14} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective product ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film, respectively, was less than 8 x 10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min})$, was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in respect of residual image, no residual image being observed at all.

Embodiment 3

The composition of the present embodiment was the same as embodiment 2 except for the following matters;

The insulating film had a double layer structure composed of an inorganic silicon nitride (SiN) layer and an organic epoxy resin layer, and a compound, RN-718 (made by Nissan Chemical Co.), was applied to the insulating film having two layers as the orienting film. The insulating film had a specific resistivity of 9.1 x 10^{13} Ωcm and a specific dielectric constant of 3.1. And the liquid crystal had a specific resistivity of 1.0 x 10^{12} Ωcm and a specific dielectric constant of 6.1.

Accordingly, the respective product ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film, respectively, was less than 8 x 10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, ($(\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min}$), was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed.

Embodiment 4

FIG. 5 indicates the structure of an electrode for a picture element unit in the fourth embodiment of the present invention. A thin film transistor element 15 comprises a picture element electrode 4, a signal electrode 3, a scanning electrode 13 and amorphous silicon 14. A common electrode 5 was in the same layer as the scanning electrode, and was formed by making a pattern from the same metallic layer. Further, the picture element electrode and the signal electrode were also formed by making a pattern from the same metallic layer. A capacitative element was formed from a structure holding a gate silicon nitride (gate SiN) film 6 with the picture element electrode and the common electrode in a region connecting the two common electrodes 5. The picture element electrode 4 is arranged between the two common electrodes 5, as show in the front cross section (FIG. 5, A-A'). The pitches of the picture elements were 69 μm in width (i.e. between signal wiring electrodes) and 207 μm in length (i.e. between scanning wiring electrodes). The width of the respective electrodes was 10 μm. In order to secure a large opening fraction, the widths of the picture element electrode independently formed for a picture element unit and a portion extended in a longitudinal direction of the signal wiring electrode of the common electrode were made narrow, such as 5 μm and 8 μm, respectively. In order to realize as large an opening fraction as possible, the common electrode and the signal electrode were somewhat overlapped (1 μm) via the insulating film. Accordingly, a black matrix structure 16, wherein shading was provided only in the direction along the scanning wiring electrode, was formed. Consequently, the gap between the common electrode and the picture element electrode became 20 μm, and the length of the opening in the longitudinal direction became 157 μm, and a large opening fraction, such as 44.0%, was obtained. The number of picture elements was 320 x 160 with 320 signal wiring electrodes and 160 wiring electrodes. Driving transistors were connected to the panel, as shown in FIG. 7, a vertical scanning circuit 20 and an image signal driving circuit 21 were connected to the TFT substrate, and the active matrix was driven by being supplied with a scanning signal voltage, an image signal voltage, and a timing signal from a power source circuit and a controller 22.

The insulating film was composed of a single layer made by an organic epoxy resin, and a compound, RN-718 (made by Nissan Chemical Co.), was applied to the insulating film as an orienting film. In this case, the insulating film had a specific resistivity of 1.5×10^{12} Ωcm and a specific dielectric constant of 3.0. The orienting film had a specific resistivity of 4.0×10^{13} Ωcm and its specific dielectric constant was 3.1. The liquid crystal had as specific resistivity of 1.5×10^{13} Ωcm and its specific dielectric constant was 6.1.

Accordingly, the respective products ($\epsilon_r \rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film, respectively, were less than 8×10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min})$, was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed.

Embodiment 5

The composition of this embodiment is the same as embodiment 4 except for the following matters;

A color filter was formed in the insulating film. First, a silicon nitride (SiN) layer was formed, and subsequently the color filter was provided by printing. Further, an epoxy resin was applied in order to flatten the surface. A compound, RN-718 (made by Nissan Chemical Co.), was then applied to the insulating film as an orienting film. The insulating film of the present embodiment had a specific resistivity of 4.4×10^{11} Ωcm and a specific dielectric constant of 3.9. The orienting film had a specific resistivity of 4.9×10^{13} Ωcm and a specific dielectric constant of 3.1. And the liquid crystal had a specific resistivity of 1.6×10^{13} Ωcm and a specific dielectric constant of 6.1.

Accordingly, the respective products $(\epsilon_r\rho)$ of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film, respectively, were less than 8×10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min})$, was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed.

Embodiment 6

The composition of this embodiment is the same as embodiment 5 except for the following matters;

In order to increase the flatness of the orienting film plane abutting the liquid crystal, the thickness of the orienting film was set five times, 5000 Å, the thickness (1000 Å) used in the above embodiment 5. Therefore, the flatness of the plane was increased, steps on the plane were decreased, and lapping treatment was performed uniformly. Consequently, light leakage at the step portion was eliminated.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed, and the contrast was improved relative to that of embodiment 5.

Embodiment 7

The composition of this embodiment is the same as embodiment 6 except for the following matters;

The printability of polyamide orienting film on an epoxy resin layer is not necessarily preferable. Therefore, a silicon nitride (SiN) film, an inorganic material film, was formed on the epoxy resin which had the functions of flattening the color filter and as an insulating film. By this treatment, the printability of the orienting film was improved.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed, and the contrast was improved relative to that of embodiment 5, the printability of the orienting film was improved, and the production yield was increased.

Embodiment 8

The composition of this embodiment is the same as embodiment 4 except for the following matters;

A color filter was formed in the insulating film. First, a silicon nitride (SiN) layer was formed, and subsequently the color filter was provided by printing. Further, an epoxy resin was applied in order to flatten the surface. A compound, RN-718 (made by Nissan Chemical Co.), was then applied to the insulating film as an orienting film. The insulating film of the present embodiment had a specific resistivity of 4.4×10^{11} Ωcm and a specific dielectric constant of 3.9. The orienting film had a specific resistivity of 4.9×10^{13} Ωcm and a specific dielectric constant of 3.1. And the liquid crystal had a specific resistivity of 1.6 x 10^{13} Ωcm and a specific dielectric constant of 6.1.

Accordingly, the respective products ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film, respectively, were less than 8 x 10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r\rho)_{max}/(\epsilon_r\rho)_{min})$, was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed.

Embodiment 9

FIG. 6 indicates the structure of an electrode for a picture element unit in the ninth embodiment of the present invention. In this embodiment, thin film transistors were not provided in the picture element units. A scanning signal electrode 13 and a signal electrode 3 were in mutually different layers. Each electrode was connected respectively to a scanning circuit driver and an image signal circuit driver, and the matrix was driven in a simple time-shared manner.

The directions of the upper and the lower boundary planes were approximately mutually parallel, and formed an angle of 105 degrees (ϕ_{LC1} = ϕ_{LC2} = 105°) to the direction of the applied electric field (FIG. 2). A gap d was kept by holding dispersed spherical polymer beads between the substrates at 4.2 μm intervals under a liquid crystal filled condition. The panel was held between two polarizers (made by Nitto Denko Co., G1220DU), the polarizing light transmitting axis of one of the polarizers being selected as approximately parallel to the rubbing direction, i.e. ϕ_{P1} = 105°, and the axis of the other polarizer being selected as perpendicular to the rubbing direction, i.e. ϕ_{P2} = 15°. Accordingly, a normal closed characteristic was obtained.

In this embodiment, a liquid crystal, of which the main component was a trifluoro compound containing three fluoro groups at terminals, having a specific resistivity of 1.0 x

10^{14} Ωcm and an average specific dielectric constant of 6.1 was used. Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 1.0 x 10^{12} Ωcm and specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-amino-phenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 2.2 x 10^{13} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective products ($\epsilon_r \rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film were less than 8 x 10^{15} Ωcm, and the ratio of the maximum value and the minimum value of the three bodies, $((\epsilon_r \rho)_{max}/(\epsilon_r \rho)_{min})$, was less than 100.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 1 in residual image, no residual image being observed.

Embodiment 10

The composition of this embodiment is the same as embodiment 1 except for the following matters;

A liquid crystal having a specific resistivity of 2.0 x 10^{11} Ωcm and an average specific dielectric constant of 6.5. Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 3.0 x 10^{13} Ωcm and its specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-amino-phenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 1.0 x 10^{13} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective products ($\epsilon_r \rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film were less than 8 x 10^{15} Ωcm.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 3 in residual image, i.e. a residual image time within one minute.

Embodiment 11

The composition of this embodiment is the same as embodiment 2 except for the following matters;

The liquid crystal had a specific resistivity of 2.0 x 10^{14} Ωcm and an average specific dielectric constant of 6.1. Silicon dioxide (SiO_2) was used for the insulating film, and its specific resistivity was 1.0 x 10^{13} Ωcm and its specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-aminophenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 2.0 x 10^{12} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective products ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film were less than 8 x 10^{15} Ωcm. The active matrix type liquid crystal display device as obtained above was evaluated as rank 4 in residual image, i.e. the residual image time was within five minutes.

Embodiment 12

The composition of this embodiment is the same as embodiment 2 except for the following matters;

The liquid crystal had a specific resistivity of 2.0 x 10^{13} Ωcm and an average specific dielectric constant of 6.1. Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 1.0 x 10^{15} Ωcm and its specific dielectric constant was 8. The orienting film was formed with a compound RN-718 (made by Nissan Chemical Co.), and its specific resistivity was 3.2 x 10^{12} Ωcm and its average specific dielectric constant was 3.1.

Accordingly, the respective products ($\epsilon_r\rho$) of specific resistivity ρ and specific dielectric constant ϵ_r of the liquid crystal layer, the insulating film, and the orienting film were less than 8 x 10^{15} Ωcm. The active matrix type liquid crystal display device as obtained above was evaluated as rank 4 in residual image, i.e. the residual image time was within five minutes.

Embodiment 13

FIG. 5 indicates the structure of an electrode for a picture element unit in the thirteenth embodiment of the present invention. A thin film transistor 15 was composed of a picture element electrode 4, a signal electrode 3, a scanning electrode 13, and amorphous silicon 14. A common electrode 5 was in the same layer with the scanning electrode, and a pattern was made of the same metal layer. Further, the picture element electrode and the signal electrode were formed by a pattern made of a same metal. A capacitance element was formed as a structure, wherein a gate silicon nitride (gate SiN) film 6 was inserted between the picture element electrode and the common electrode in a region where the two common electrodes 5 are connected. The picture element electrode was arranged between the two common electrodes 5, as shown as a plan cross-section in FIG. 5, A-A'. The picture elements had pitches of 69 μm in the horizontal direction (i.e. between signal wiring electrodes) and 207 μm in the vertical direction (i.e. between scanning wiring electrodes). The width of all the electrodes was 10 μm, respectively.

In order to improve the opening fraction, the signal wiring electrode of the picture element electrode formed independently for a picture element unit and the common electrode in the direction along the longitudinal direction of the signal wiring electrode had a somewhat narrower width at an extended portion, i.e. respectively 5 μm and 8 μm. In order to realize as large an opening fraction as possible, the common electrode and the signal electrode were overlapped somewhat (1 μm) through the intermediary of the insulating film.

Accordingly, a black matrix structure 16 wherein light was shielded only in the direction along the scanning wiring electrode was adopted. In accordance with this structure, the gap between the common electrode became 20 μm, the longitudinal length of the opening became 157 μm, and consequently, a large opening fraction, such as 44.0%, was obtained.

The number of picture elements was 320 x 160 with 320 signal wiring electrodes and 160 wiring electrodes.

A driving LSI was connected to the panel, as shown in FIG. 7, a vertical scanning circuit 20 and an image signal driving circuit 21 were connected to the TFT substrate, and the active matrix was driven by being supplied with a scanning signal voltage, an image signal voltage, and a timing signal from a power source circuit and a controller 22.

In this embodiment, an insulating film of 0.4 μm thick was formed with silicon nitride (SiN). As for the orienting film, a polyamide orienting film made from 4, 4'-diamino-diphenylether and pyromellitic acid dianhydride was used. The thickness of the orienting film was 0.1 μm, and accordingly the total thickness of the insulating film and the orienting film was 0.5 μm.

Between the substrates, a nematic liquid crystal composition having a positive dielectric anisotropy $\Delta\epsilon$ of 4.5 and birefringence Δn of 0.072 (589 nm, 20°C) was inserted.

The direction of the upper and the lower boundary planes were approximately mutually parallel, and formed an angle of 95 degrees $\phi_{LC1} = \phi_{LC2} = 95°$) to the direction of the applied electric field. A gap d was kept by holding dispersed spherical polymer beads between the substrates at 4.5 μm intervals under a liquid crystal filled condition. Therefore, $\Delta n \cdot d$ is 0.324 μm. The panel was held between two polarizers (made by Nitto Denko Co., G1220DU), the polarizing light transmitting axis of one of the polarizer being selected as approximately parallel to the rubbing direction, i.e. ϕ_{P1} = 95°, and the axis of the other polarizer being selected as perpendicular to the rubbing direction, i.e. ϕ_{P2} = 5°. Accordingly, a normal closed characteristic was obtained.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11. The transparency was evaluated by the transmission factor at 400 nm.

Embodiment 14

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment, silicon dioxide (SiO_2) was used for the insulating film, and its thickness was 1.2 μm. As for the orienting film, a polyamide orienting film made from 4, 4'-diaminodiphenylether and pyromellitic acid dianhydride was used. The thickness of the orienting film was 0.3 μm, and accordingly the total thickness of the insulating film and the orienting film was 1.5 μm.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 15

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment, the orienting film had a double layer structure comprising inorganic silicon nitride (SiN) and organic epoxy resin. The thickness of the silicon nitride layer and the epoxy resin layer was 1.0 μm and 0.6 μm, respectively. Further, as for the orienting film, an orienting film composition RN-718 (made by Nissan Chemical Co.) was used, and its thickness was 0.2 μm. Accordingly, the total thickness of the insulating film and the orienting film was 1.8 μm.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 16

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment, the orienting film had a double layer structure comprising inorganic silicon nitride (SiN) and organic epoxy resin. The thickness of the silicon nitride layer and the epoxy resin layer was 0.3 μm and 1.5 μm, respectively. Further, as for the orienting film, the composition RN-718 (made by Nissan Chemical Co.) was used, and its thickness was 0.2 μm. Accordingly, the total thickness of the insulating film and the orienting film was 2.0 μm.

The residual image of the active matrix liquid crystal display device obtained in the above manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 17

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment, silicon dioxide (SiO_2) was used for the insulating film, and its thickness was 0.2 μm. As for the orienting film, a polyamide orienting film made from 4, 4'-diaminodiphenylether and pyromellitic acid dianhydride was used. The thickness of the orienting film was 2.0 μm, and accordingly the total thickness of the insulating film and the orienting film was 2.2 μm.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 18

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment, epoxy resin was used for the insulating film, and its thickness was 1.8 μm. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-aminophenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its thickness was 0.5 μm. Accordingly, the total thickness of the insulating film and the orienting film was 2.3 μm.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 19

The composition of this embodiment is the same as embodiment 13 except for the following matters;

In this embodiment the insulating film and the orienting film were made of the same material, i.e. a polyamide orienting film made from 2, 2-bis [4-(p-aminophenoxy) phenylpropane] and pyromellitic acid dianhydride, which functions both for the insulating film and the orienting film. This was 2.8 μm thick.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 20

The composition of this embodiment is the same as embodiment 13 except for the following matters;

A color filter was formed in the insulating film. First, a silicon nitride (SiN) film was formed, and the color filter was provided on the silicon nitride film by printing. Further, an epoxy resin was applied in order to flatten the film surface. Subsequently, the orienting film was formed by applying an orienting film composition RN-718 (made by Nissan Chemical Co.).

The thickness of the silicon nitride layer and the epoxy resin layer was 0.3 μm and 1.5 μm, respectively. Further, the orienting film composition was 0.2 μm thick.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 21

The composition of this embodiment is the same as embodiment 20 except for the following matters;

In order to make the orienting film surface abutting the liquid crystal flatter, the epoxy resin layer was made 0.3 μm thick and the orienting film composition RN-718 was 0.7 μm thick. Accordingly, the flatness of the surface was improved, and the lapping treatment was performed more uniformly because of decreased steps at the surface. As a result, light leakage was eliminated.

The residual image of the device obtained in this manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. Further, the contrast was increased relative to that of embodiment 17.

Embodiment 22

The composition of this embodiment is the same as embodiment 20 except for the following matters;

The printability of polyamide orienting film on epoxy resin layer is not necessarily preferable. Therefore, an inorganic silicon nitride (SiN) film 0.3 μm thick was formed on an epoxy resin layer 1.5 μm thick, which was applied for flattening of the color filter and for the insulating film. Therefore, the printability of the orienting film was improved. At that time, the orienting film composition RN-718 was 0.1 μm thick.

The residual image of the active matrix liquid crystal display device obtained in the above manner was evaluated as rank 1, as shown in FIG. 10, no residual image being observed. The contrast was increased relative to that of embodiment 17, and the production yield was increased by the improvement of the printability of the orienting film.

Embodiment 23

FIG. 6 indicates the structure of electrode for a picture element unit in the twenty third embodiment of the present invention. In this embodiment, thin film transistors were not provided in the picture element units. A scanning signal electrode 13 and a signal electrode 3 were in mutually different layers. Each electrode was connected respectively to a scanning circuit driver and an image signal circuit driver, and the matrix was driven in a simple time-shared manner.

The directions of the upper and the lower boundary planes were approximately mutually parallel, and formed an angle of 105 degrees ($\phi_{LC1} = \phi_{LC2} = 105°$) to the direction of the applied electric field (FIG. 2). A gap d was kept by holding dispersed spherical polymer beads between the substrates at 4.2 μm intervals under a liquid crystal filled condition. The panel was held between two polarizers (made by Nitto Denko Co., G1220DU), the polarizing light transmitting axis of one of the polarizer being selected as approximately parallel to a rubbing direction, i.e. $\phi_{P1} = 105°$, and the axis of the other polarizer being selected as perpendicular to the rubbing direction, i.e. $\phi_{P2} = 15°$. Accordingly, a normal closed characteristic was obtained.

As for the orienting film, a silicon nitride (SiN) film 0.7 μm thick was formed. And an orienting film of RN-422 (made by Nissan Chemical Co.) 0.9 μm thick was formed on the insulating film.

The device as obtained above was evaluated as rank 1 in the evaluation of residual image, no residual image being observed. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Embodiment 24

The composition of this embodiment is the same as embodiment 10 except for the following matters;

In this embodiment, a silicon nitride (SiN) film was used for the insulating film, and its thickness was 0.3 μm. As for the orienting film, a polyamide orienting film made from 4, 4'-diaminodiphenylether and pyromellitic acid dianhydride was used. The thickness of the orienting film was 0.1 μm, and, accordingly, the total thickness of the insulating film and the orienting film was 0.4 μm.

The residual image of the device obtained in the above manner was evaluated as rank 3, as shown in FIG. 10, the residual image time being within one minute. Further, the transparency of the insulating film and the orienting film maintained a more than 90% transmission factor, as shown in FIG. 11.

Organic films used in the present invention for the insulating film and the orienting film are not restricted by the organic polymers described in the embodiments. In addition to polyamide and epoxy group polymers, polyesters, polyurethanes, polyvinyl alcohols, polyamides, silicones, acrylates, olefin-sulfon group polymers, and the like can be used, regardless of its photosensitivity. Further, surface treating agents, for instance, amino group silane coupling agents, such as γ-aminopropyl triethoxysilane, δ-aminopropyl methyldiethoxysilane, and N-ß(aminoethyl) γ-aminopropyl trimethoxysilane, epoxy group silane coupling agents, titanate coupling agents, aluminum alcoholates, aluminum chelates, and zirconium chelates can be mixed or reacted with the organic polymers. But, the present invention is not restricted by the above examples.

Further, the material for the inorganic film is not restricted to only silicon nitride and silicon dioxide, but also germanium nitride, germanium oxide, aluminum nitride, and aluminum oxide can be used. However, the present invention is not restricted by the above examples.

Comparative example 1

The composition of this example is the same as embodiment 2 except for the following matters;

The liquid crystal had a specific resistivity of 2.0 x 10^{14} Ωcm and an average specific dielectric constant of 6.1. Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 6 x 10^{15} Ωcm and its specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-amino-phenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 2.0 x 10^{12} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective products ($\epsilon_r \rho$) of the specific resistivity ρ and the specific dielectric constant ϵ_r of the liquid crystal layer and the orienting film were less than 8 x 10^{15} Ωcm, but the product ($\epsilon_r \rho$) of the specific resistivity ρ and the specific dielectric constant ϵ_r of the insulating film was larger than 8 x 10^{15} Ωcm.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 5 in the evaluation of residual image, i.e. the residual image time was beyond five minutes.

Comparative example 2

The composition of this example is the same as embodiment 2 except for the following matters;

The liquid crystal had a specific resistivity of 6.3 x 10^{12} Ωcm and an average specific dielectric constant of 6.1. Silicon nitride (SiN) was used for the insulating film, and its specific resistivity was 2 x 10^{15} Ωcm and its specific dielectric constant was 8. As for the orienting film, a polyamide orienting film made from 2, 2-bis [4-(p-amino-phenoxy) phenylpropane] and pyromellitic acid dianhydride was used, and its specific resistivity was 5.5 x 10^{12} Ωcm and its average specific dielectric constant was 2.9.

Accordingly, the respective products ($\epsilon_r \rho$) of the specific resistivity ρ and the specific dielectric constant ϵ_r of the liquid crystal layer and the orienting film were less than 8 x 10^{15} Ωcm, but the product ($\epsilon_r \rho$) of the specific resistivity ρ and the specific dielectric constant ϵ_r of the insulating film was larger than 8 x 10^{15} Ωcm.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 5 in the evaluation of residual image, i.e. the residual image time was beyond five minutes.

Comparative example 3

The composition of this example is the same as embodiment 10 except for the following matters;

In the present example, silicon nitride (SiN) was used for the insulating film, and its thickness was 2.1 μm. As for the orienting film, a polyamide orienting film made from 4, 4'-diaminodiphenylether and pyromellitic acid dianhydride was used. The thickness of the orienting film was 1.0 μm, and, accordingly, the total thickness of the insulating film and the orienting film was 3.1 μm.

The residual image of the active matrix liquid crystal display device obtained in the above manner was evaluated as rank 1, as shown in FIG. 10(a), but the transparency of the insulating film and the orienting film was less than a 90% transmission factor, as shown in FIG. 10(b).

Comparative example 4

The composition of this example is the same as embodiment 10 except for the following matters;

In the present example, silicon nitride (SiN) was used for the insulating film, and its thickness was 0.1 μm. As for the orienting film, RN-718 was used. The thickness of the orienting film was 0.1 μm, and, accordingly, the total thickness of the insulating film and the orienting film was 0.2 μm.

The active matrix type liquid crystal display device as obtained above was evaluated as rank 5 in the evaluation of residual image, i.e. the residual image time was beyond five minutes.

In accordance with the present invention, a liquid crystal display device of a high picture quality with substantially eliminated residual image can be obtained by making the brightness recovery time within five minutes after displaying the same figure and/or character pattern for 30 minutes.

Claims:

1. A liquid crystal display device comprising:

a plurality of display picture elements, each being composed of electrodes on a substrate;

an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and

substantially similar products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ are provided for respective ones of the liquid crystal layer, the orienting film, and the insulating film.

2. A liquid crystal device as claimed in claim 1, wherein said orienting film is formed on said substrate via an insulating layer.

3. A liquid crystal display device as claimed in claim 1, wherein said products are in a range of 1×10^9 Ω·cm - 8×10^{15} Ω·cm.

4. A liquid crystal display device comprising:

a plurality of display picture elements, each being composed of electrodes on a substrate;

an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and a ratio of the maximum value to the minimum value of respective products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ of the liquid crystal layer, the orienting film, and the insulating film is in a range of 1 - 100.

5. A liquid crystal display device comprising:

a plurality of display picture elements, each being composed of electrodes on a substrate;

an orienting film for a liquid crystal layer formed on the substrate directly or via an insulating layer, said substrate being arranged so as to face another substrate on which another orienting film is formed, the liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer;

respective products ($(\epsilon_r\rho)_{LC}$, $(\epsilon_r\rho)_{AF}$, and $(\epsilon_r\rho)_{PAS}$) of a specific dielectric constant ϵ_r and a specific resistivity ρ of the liquid crystal layer, the orienting film, and the insulating film have a relationship expressed by the following equations (1) to (3):

$$0.1 \le (\epsilon_r\rho)_{LC}/(\epsilon_r\rho)_{AF} \le 10 \quad (1)$$

$$0.1 \le (\epsilon_r\rho)_{LC}/(\epsilon_r\rho)_{PAS} \le 10 \quad (2)$$

$$0.1 \le (\epsilon_r\rho)_{AF}/(\epsilon_r\rho)_{PAS} \le 10 \quad (3).$$

6. A liquid crystal display device comprising:

a plurality of display picture elements, each being composed of electrodes on a substrate;

an orienting film for a liquid crystal layer formed on the substrate via an insulating film, said substrate being arranged so as to face another substrate on which another orienting film is formed, a liquid crystal layer being held between said two substrates, and said electrodes being composed so as to generate an electric field substantially parallel to said substrates and to the liquid crystal layer; and a sum of film thickness of said orienting film and said insulating film on the substrate is in a range of 0.5 - 3 μm.

7. A liquid crystal display device as claimed in any of claims 2 and 6, wherein said display picture elements are composed of scanning signal electrodes, image signal electrodes, picture element electrodes, and active elements on said substrate.

8. A liquid crystal display device as claimed in claim 6, wherein the film thickness of said insulating film is in a range of 0.4 - 2 μm.

9. A liquid crystal display device as claimed in any of claims 2 and 6, wherein said orienting film is of organic material and said insulating layer is of inorganic material.

10. A liquid crystal display device as claimed in any of claims 2 and 6, wherein said orienting film is of organic material and said insulating layer has a double layer structure of inorganic material and organic material.

11. A liquid crystal display device as claimed in any of claims 2 and 6, wherein said orienting film is a layer of organic material and said insulating layer is of inorganic material, and the layer composed of said organic material is thicker than the layer composed of said inorganic material.

12. A liquid crystal display device as claimed in any of claims 2 and 6, wherein both of said orienting film and said insulating layer are of organic material.

13. A liquid crystal display device as claimed in any of claims 2 and 6, wherein a surface plane of said orienting film abutting said liquid crystal layer is flat.

14. A liquid crystal display device as claimed in any of claims 2 and 6, wherein both of said orienting film and said insulating layer are made of the same material.

15. A liquid crystal display device as claimed in any of claims 2 and 6, wherein a color filter is provided on either one of said substrates, and the insulating layer is provided between said color filter and the liquid crystal layer.

16. A liquid crystal display device as claimed in any of claims 2 and 6, wherein a flattening film having a function to flatten steps on a color filter surface is provided and is of organic material, and an inorganic film is formed on said flattening film.

17. A liquid crystal display device as claimed in any of claims 2 and 6, wherein an orienting film on a substrate having a color filter is formed via a layer composed of inorganic material.

18. A liquid crystal display device as claimed in any of claims 2 and 6, wherein a color filter is formed on a substrate which has scanning signal electrodes, image signal electrodes, picture element electrodes, and active elements for said picture elements, and said insulating layer exists between said color filter and the liquid crystal layer.

19. A liquid crystal display device as claimed in any of claims 2 and 6, further comprising means for inputting information, means for calculating or processing said information in a designated manner, a device for outputting the processed information, a device for storing the processed information, and an internal power source.

20. A liquid crystal display device having a plurality of switching elements, comprising:

a pair of substrates;

a liquid crystal layer interposed between said pair of substrates;

an electrode structure formed on one of said pair of substrates for generating an electric field substantially in parallel with said one of said pair of substrates; and

an insulating film formed on said electrode structure, said insulating film including an organic layer and an inorganic layer and an orienting film formed on said insulating film.

21. A liquid crystal display device according to claim 20, wherein the inorganic layer contacts the electrode structure and the organic layer is formed on the inorganic layer.

22. A liquid crystal display device according to claim 21, wherein

a sum of film thickness of said orienting film and said insulating layer is in a range of 0.9 to 3 μm.

23. A liquid crystal display device according to claim 22, wherein said orienting film includes said organic layer of said insulating film.

24. A liquid crystal display device according to claim 23, wherein a sum of film thickness of said orientation layer and said insulating film is in a range of 0.4 μm to 3 μm.

25. A liquid crystal display device according to claim 23, wherein a film thickness of said orientation layer is in a range of 0.4 μm to 2 μm.

26. A liquid crystal display device comprising:

a pair of substrates;

a liquid crystal layer interposed between said pair of substrates;

an electrode structure formed on one of said pair of substrates for generating an electric field predominantly parallel with said one of said pair of substrates;

an insulating layer formed on said electrode structure;

an orienting film formed on said insulating layer;

wherein

a sum of film thickness of said insulating layer and said orienting film is equal to or less than 3 μm.

27. A liquid crystal display device comprising:

a pair of substrates;

a liquid crystal layer interposed between said pair of substrates;

an electrode structure formed on one of said pair of substrates for generating an electric field predominantly parallel with said one of said pair of substrates;

an insulating layer formed on said electrode structure;

an orienting film formed on said insulating layer;

wherein

a ratio of a product of a specific resistivity and a specific dielectric constant of said orienting film to a product of a specific resistivity and a specific dielectric constant of said insulating layer is less than 100.

28. A liquid crystal display device comprising:

a pair of substrates;

a liquid crystal layer interposed between said pair of substrates;

an electrode structure formed on one of said pair of substrates for generating an electric field predominantly parallel with said one of said pair of substrates;

wherein

a product of a specific dielectric constant ϵ_r and a specific resistivity ρ of said liquid crystal layer is in a range from 10^9 $\Omega\cdot$cm to 10^{15} $\Omega\cdot$cm.

29. A liquid crystal display device as claimed in claim 28, wherein

an insulating layer is further formed on said electrode structure, and

a product of a specific dielectric constant ϵ_r and a specific resistivity ρ of said insulating layer is in a range from 10^9 Ω·cm to 10^{15} Ω·cm.

30. A liquid crystal display device as claimed in claim 29, wherein

an orienting film is further formed on said insulating layer, and

a product of a specific dielectric constant ϵ_r and a specific resistivity ρ of said orienting film is in a range from 10^9 Ω·cm to 10^{15} Ω·cm.

31. A liquid crystal display device having a plurality of switching elements, comprising:

a pair of substrates;

a liquid crystal layer interposed between said pair of substrates;

an electrode structure formed on one of said pair of substrates for generating an electric field substantially in parallel with said one of said pair of substrates;

an insulating layer formed on said electrode structure;

a color filter formed on said insulating layer; and

an orienting film formed on said color filter for controlling an orientation of liquid crystal molecules of said liquid crystal layer, wherein a sum of film thickness of said orienting film and said insulating layer is equal to or less than 3 μm.

32. A liquid crystal display device according to claim 31, wherein said orienting film includes a flattening film for flattening said color filter.

33. A liquid crystal display device according to claim 32, wherein one surface layer of said flattening film adjacent to said color filter is an organic material.

34. A liquid crystal display device according to claim 33, wherein said organic material includes an epoxy resin.

35. A liquid crystal display device according to claim 33, wherein another surface layer of said flattening film adjacent to said liquid crystal layer is an inorganic material.

36. A liquid crystal display device according to claim 35, wherein said inorganic material includes silicon nitride.

37. A liquid crystal display device according to claim 31, wherein a sum of film thickness of said orienting film and said insulating layer is 0.5 μm to 3 μm.

38. A liquid crystal display device according to claim 31, wherein a film thickness of said orienting film is in a range of 0.4 μm to 2 μm.

FIG. 1(a)

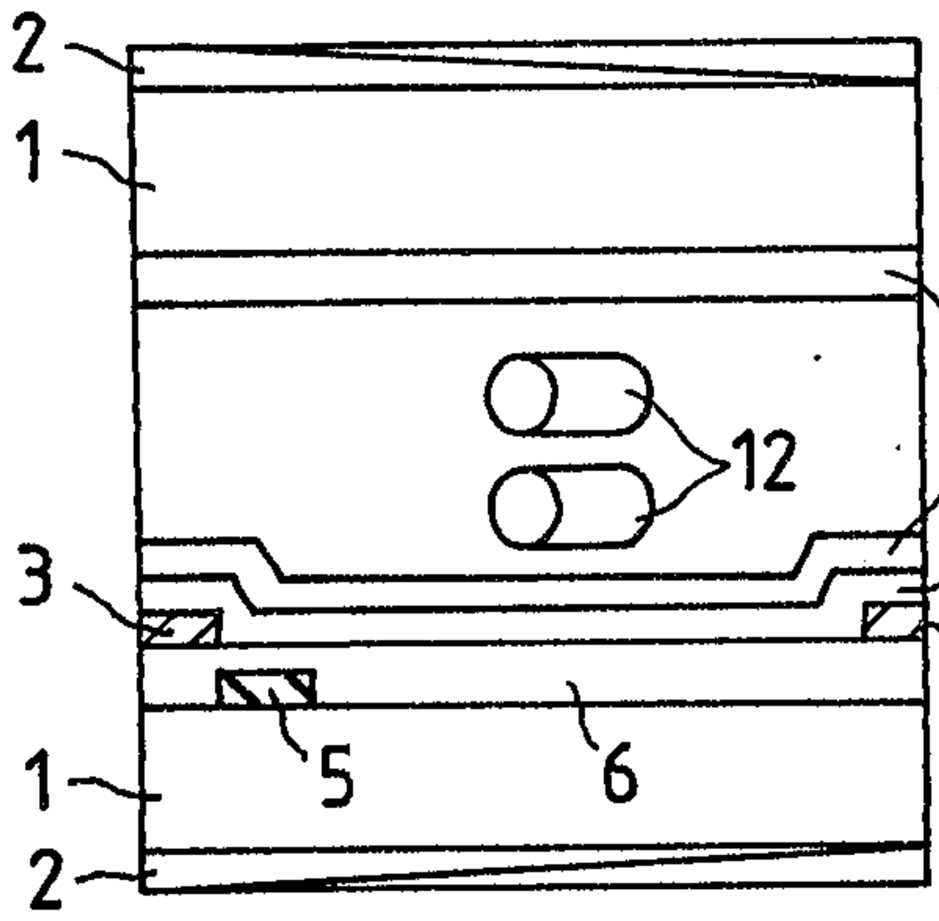

FIG. 1(b)

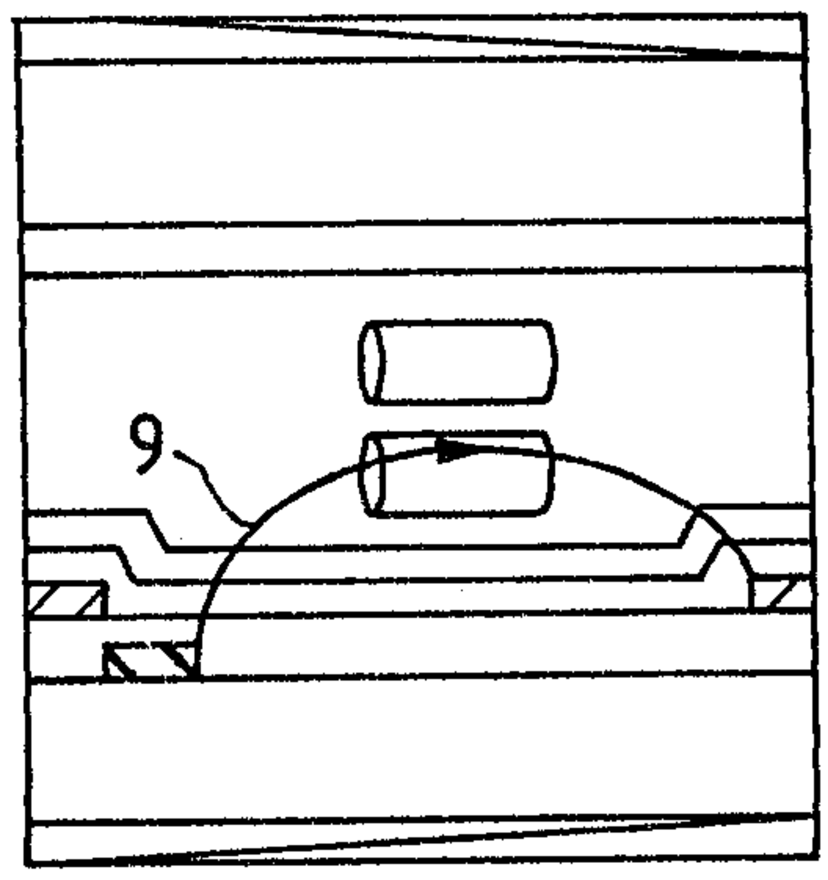

FIG. 1(c)

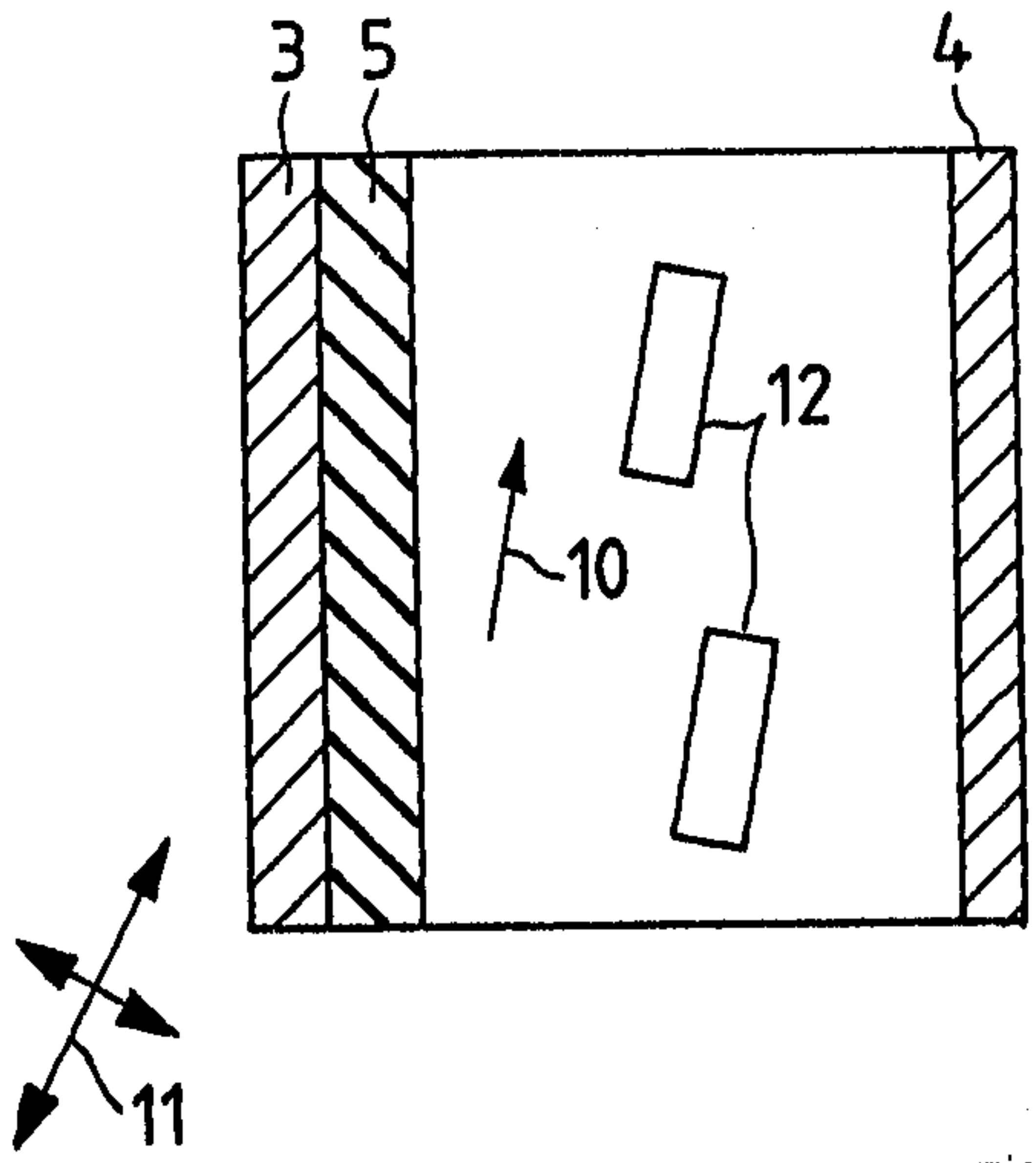

FIG. 1(d)

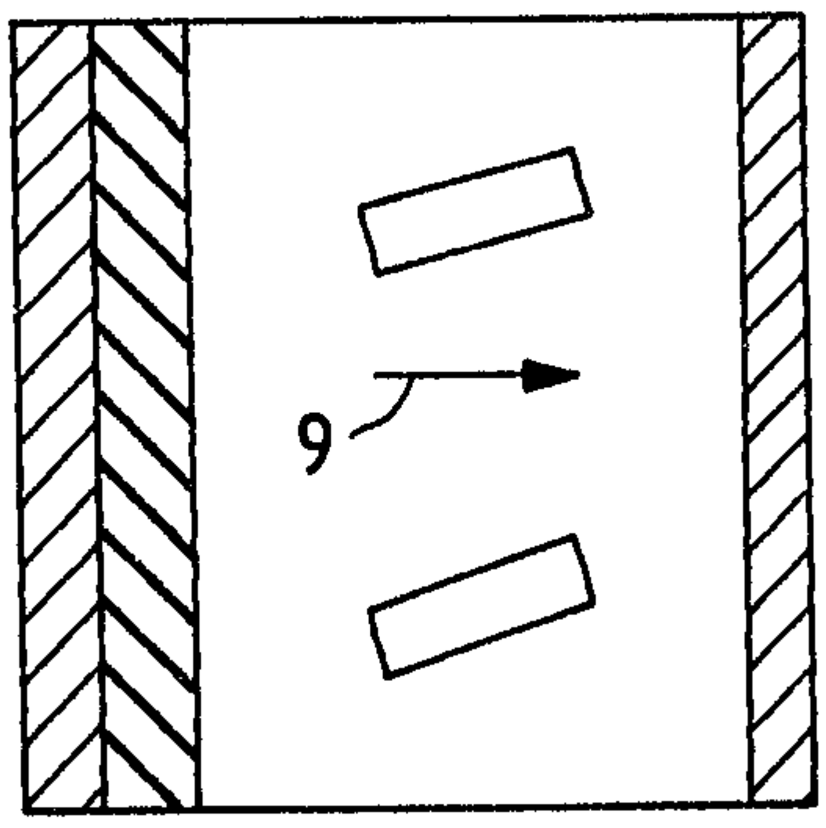

FIG. 2

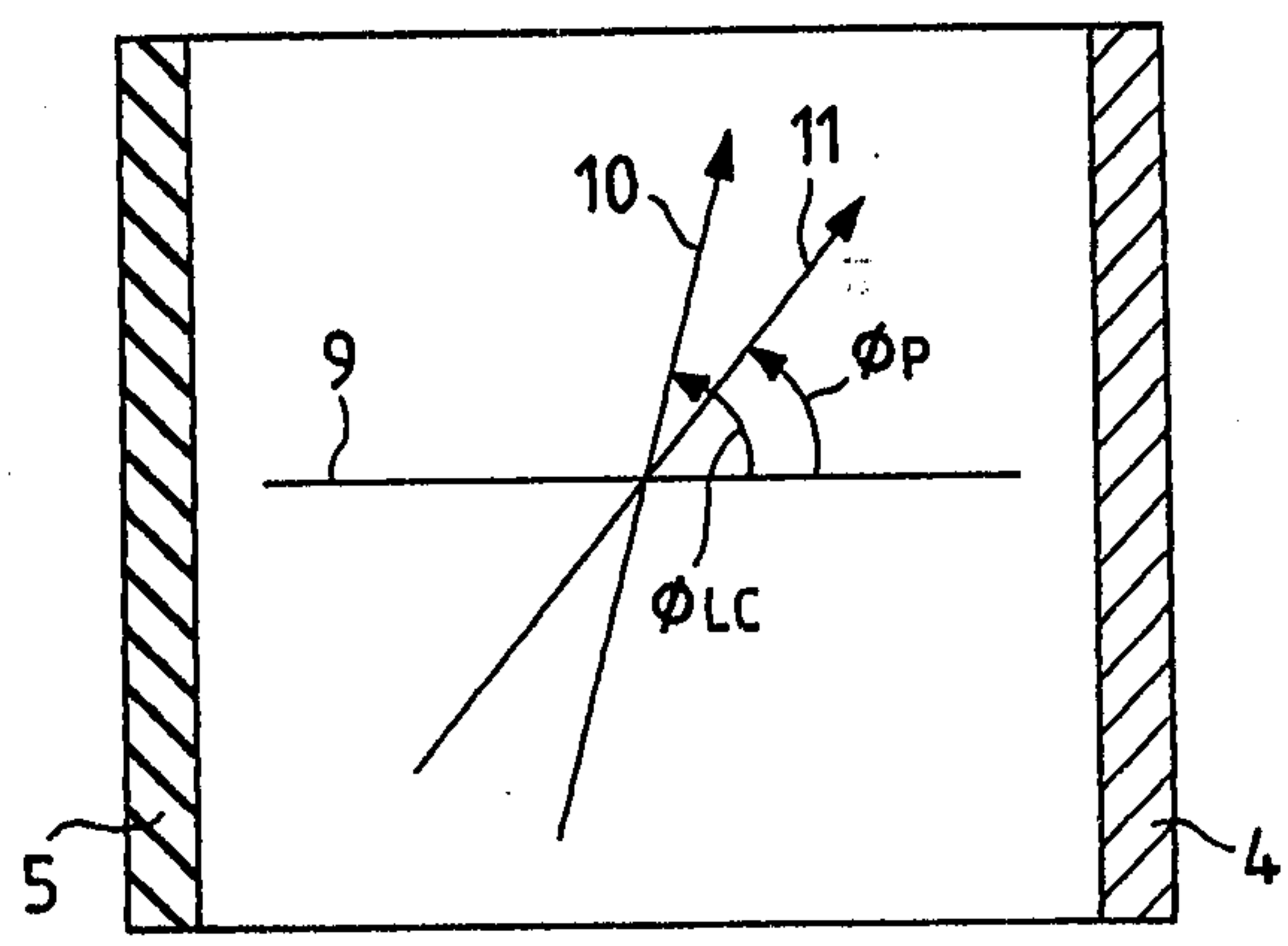

FIG. 3

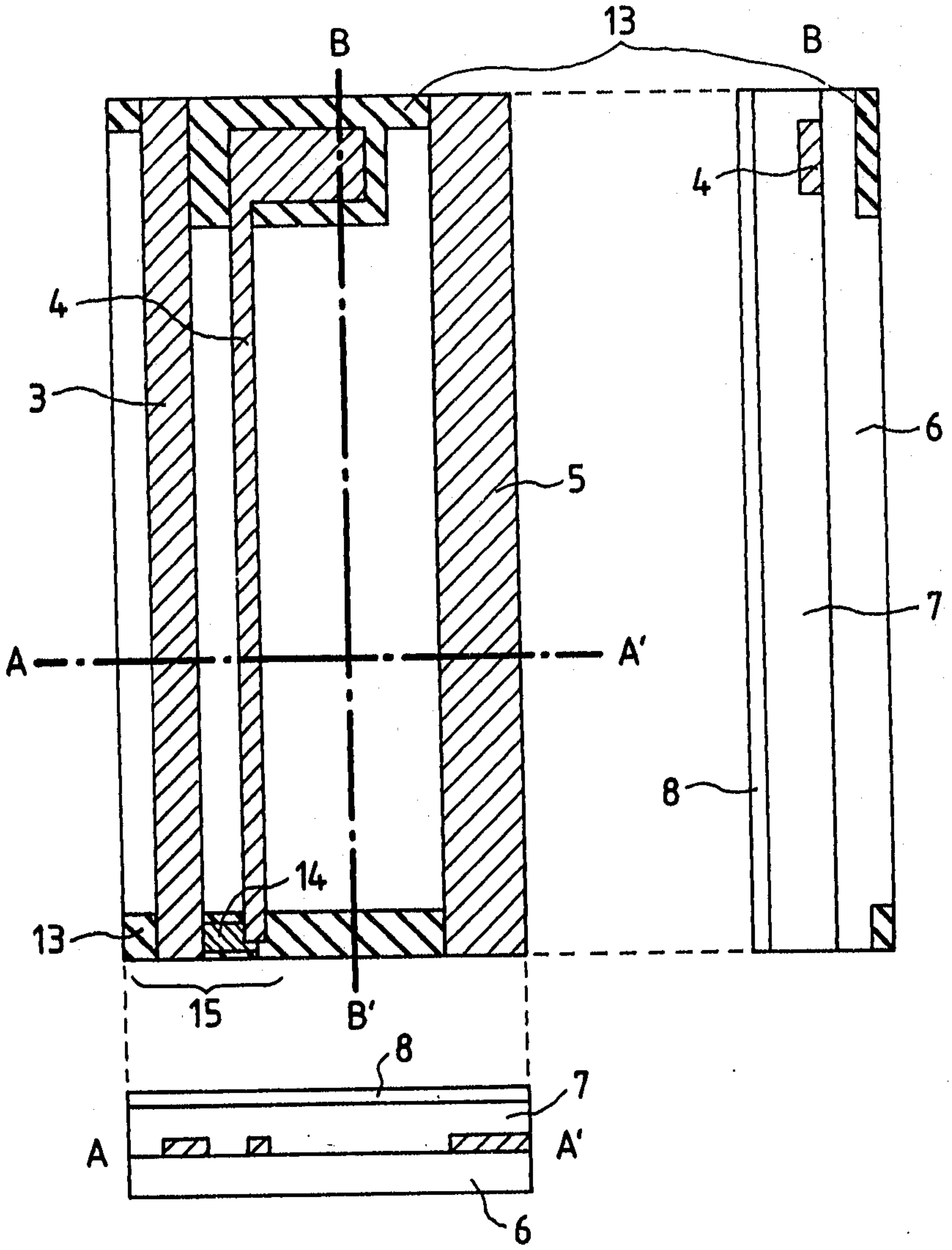

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FIG. 4

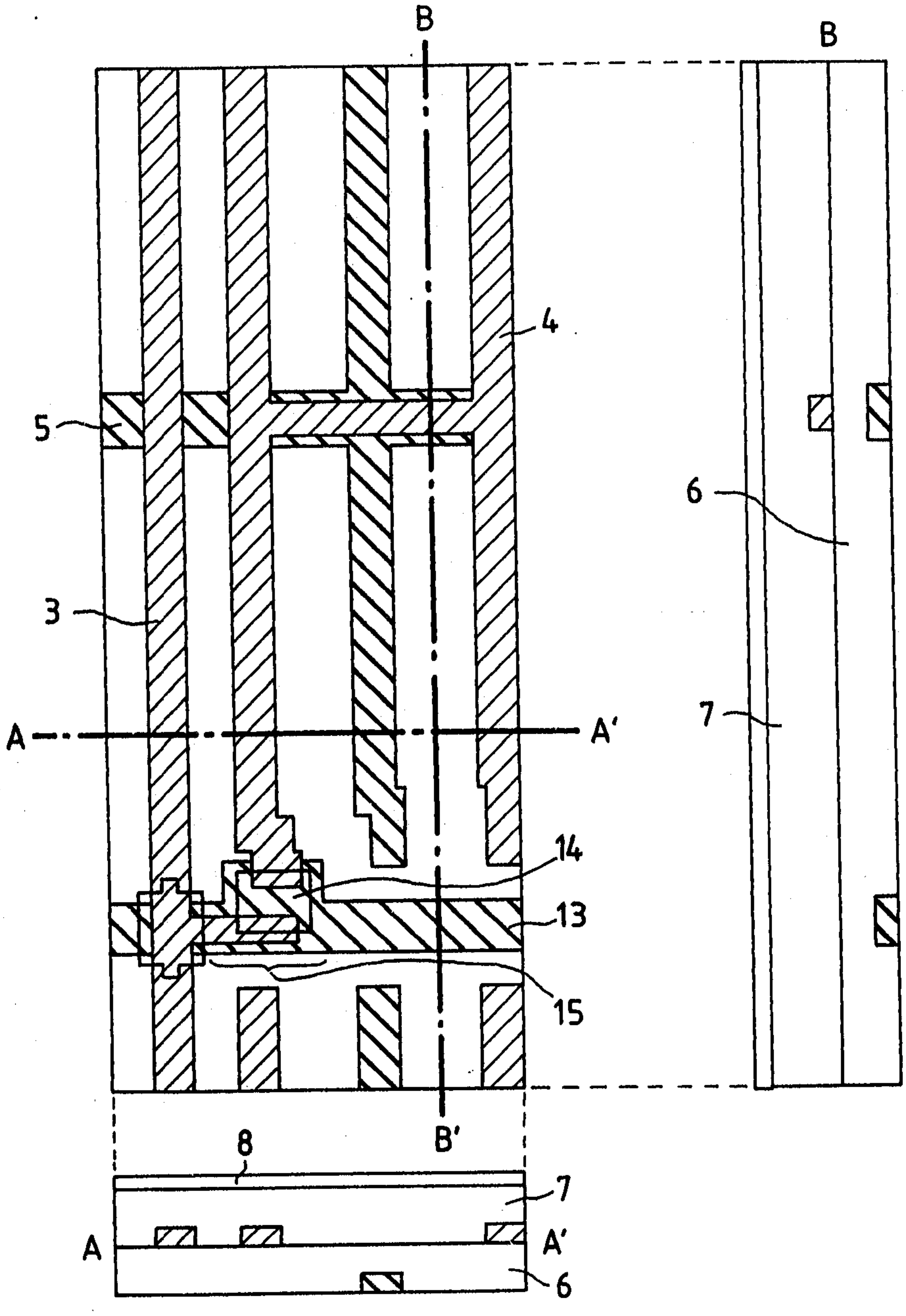


FIG. 5

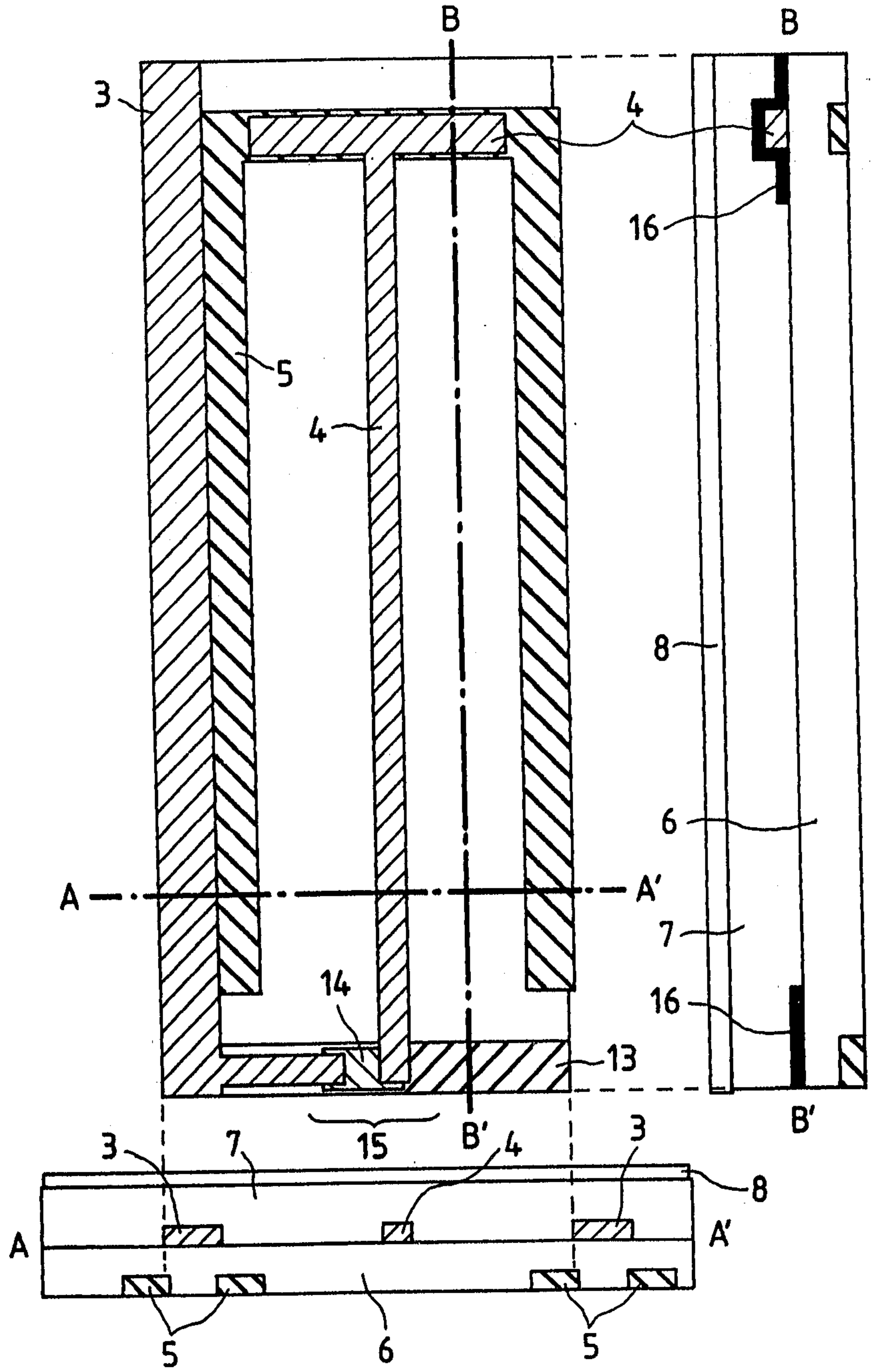


FIG. 6

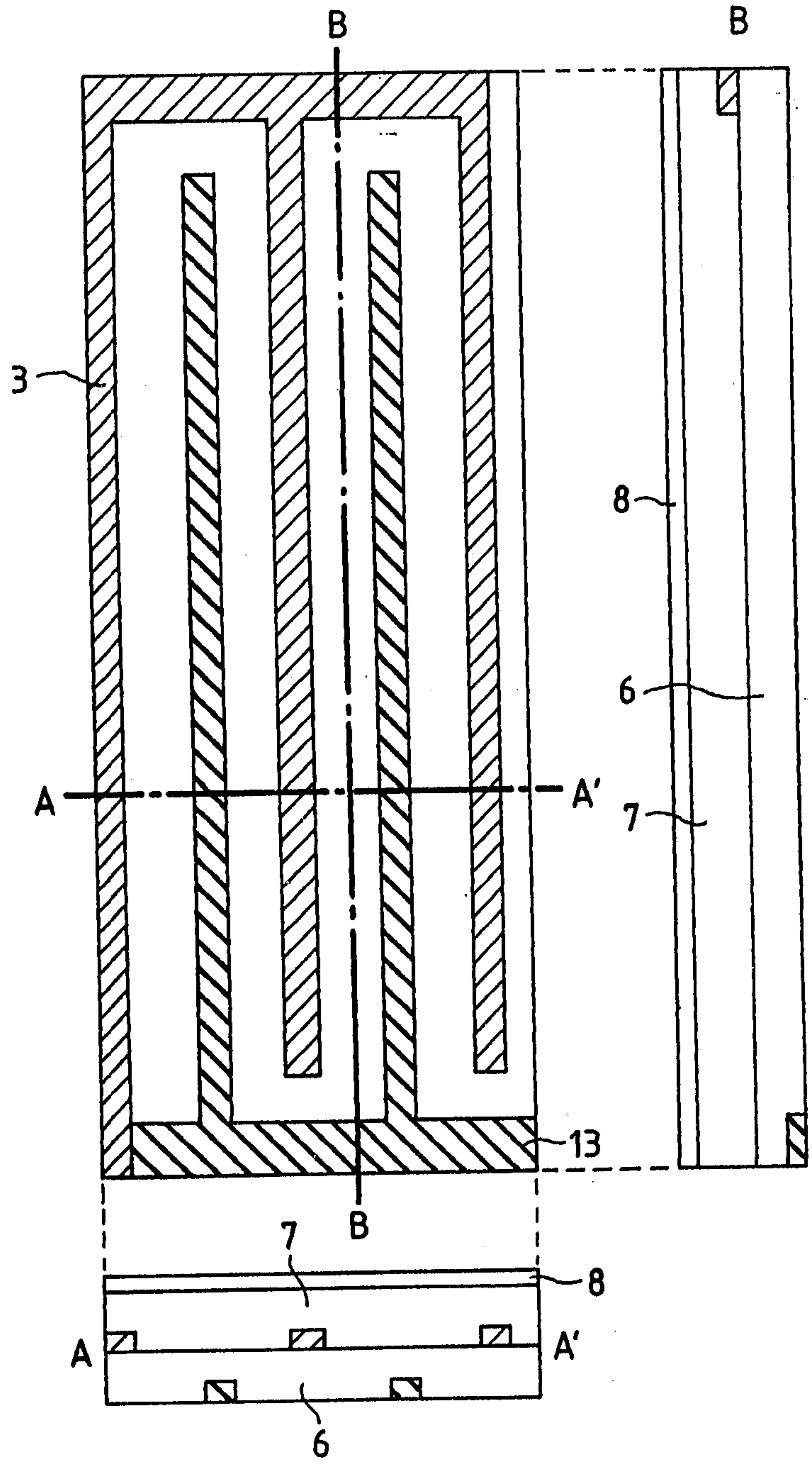


FIG. 7

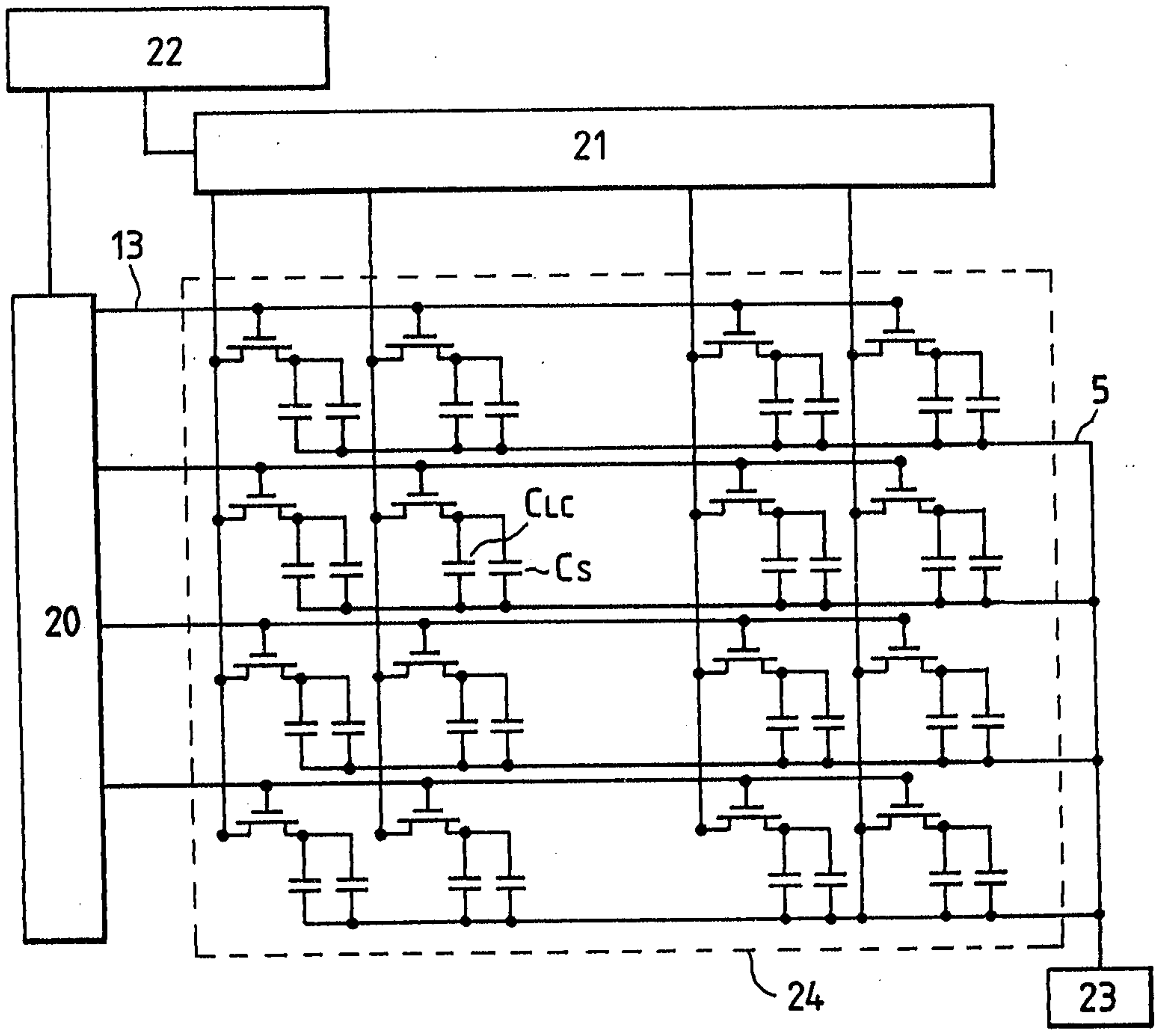
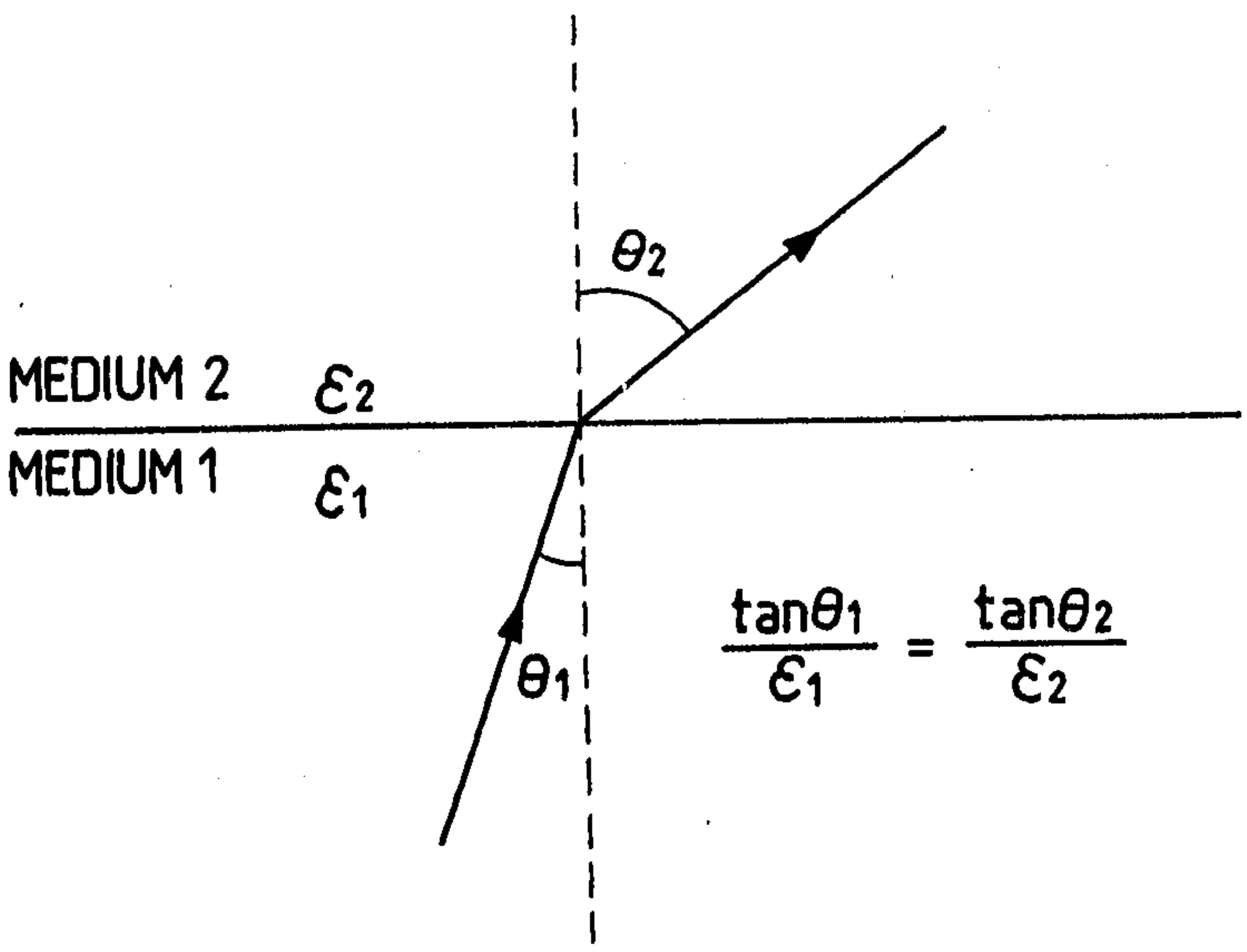


FIG. 8


θ2
MEDIUM 2 ε2
MEDIUM 1 ε1
θ1
$\frac{\tan\theta_1}{\varepsilon_1} = \frac{\tan\theta_2}{\varepsilon_2}$

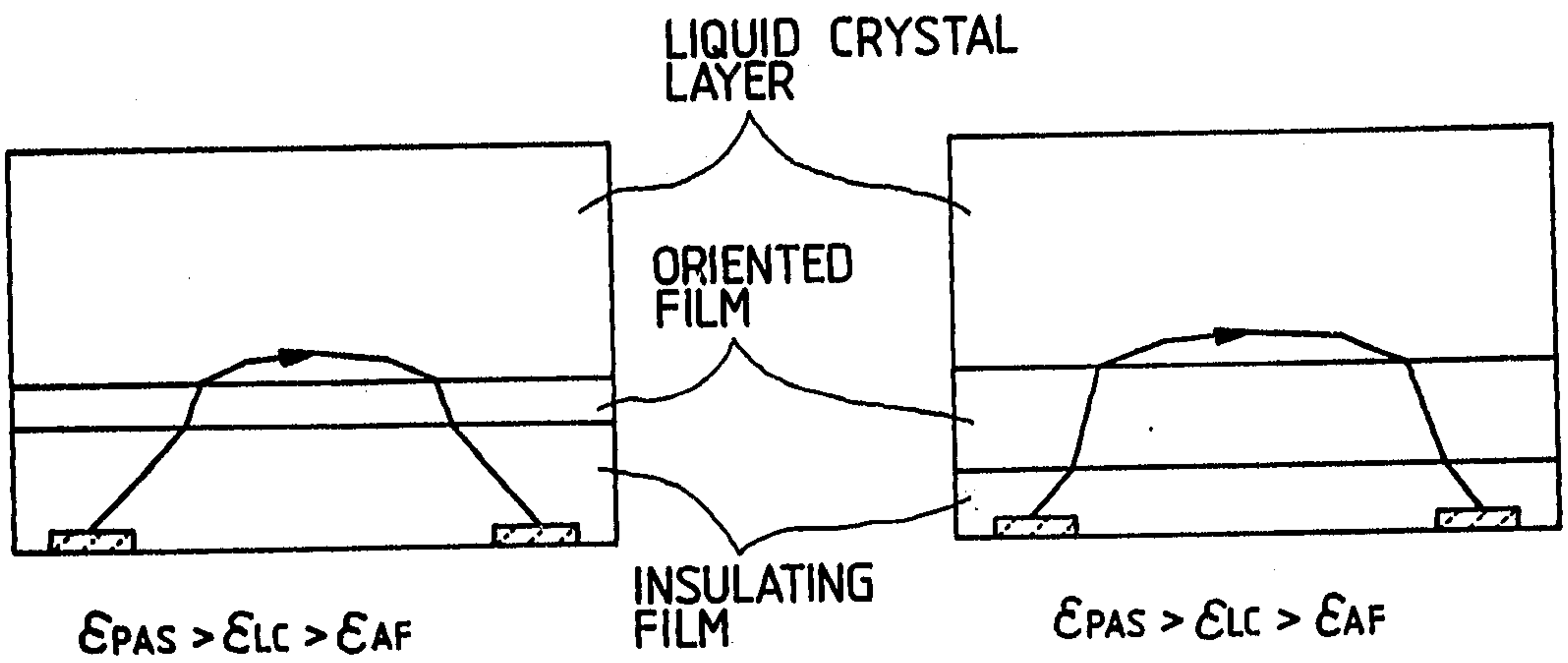

LIQUID CRYSTAL LAYER
ORIENTED FILM
INSULATING FILM
εPAS > εLC > εAF
εPAS > εLC > εAF

FIG. 9(a)

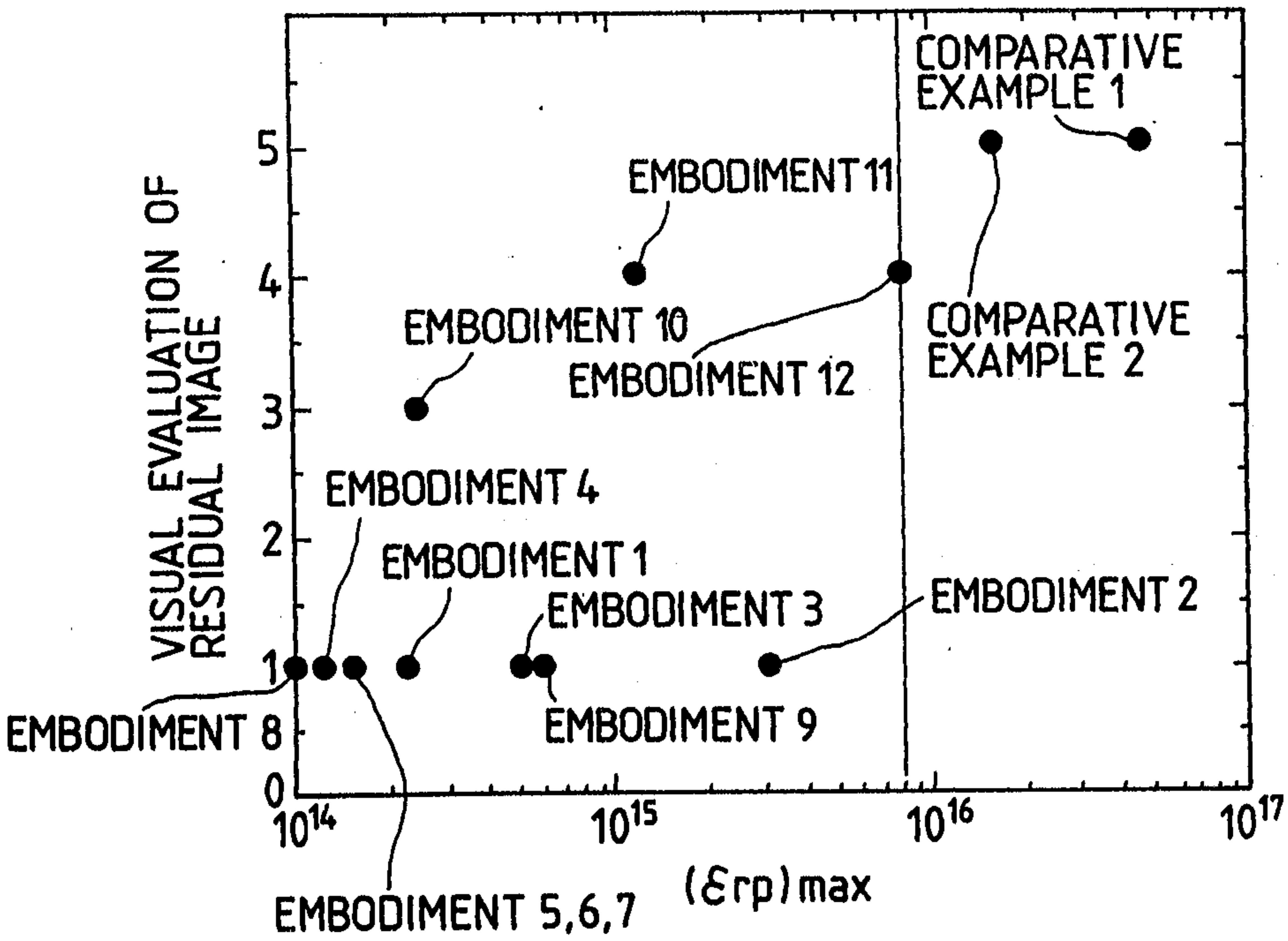


FIG. 9(b)

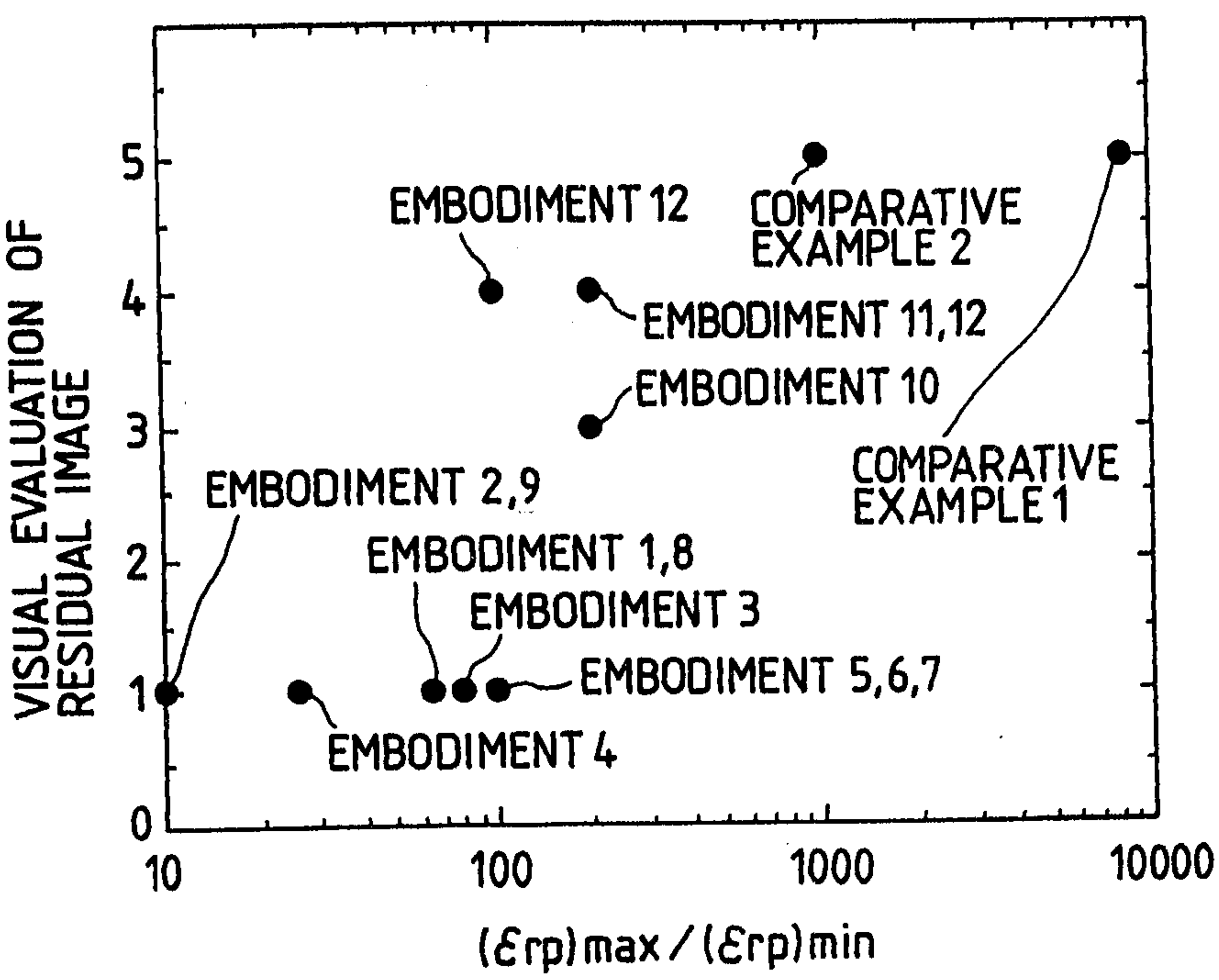


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FIG. 10(a)

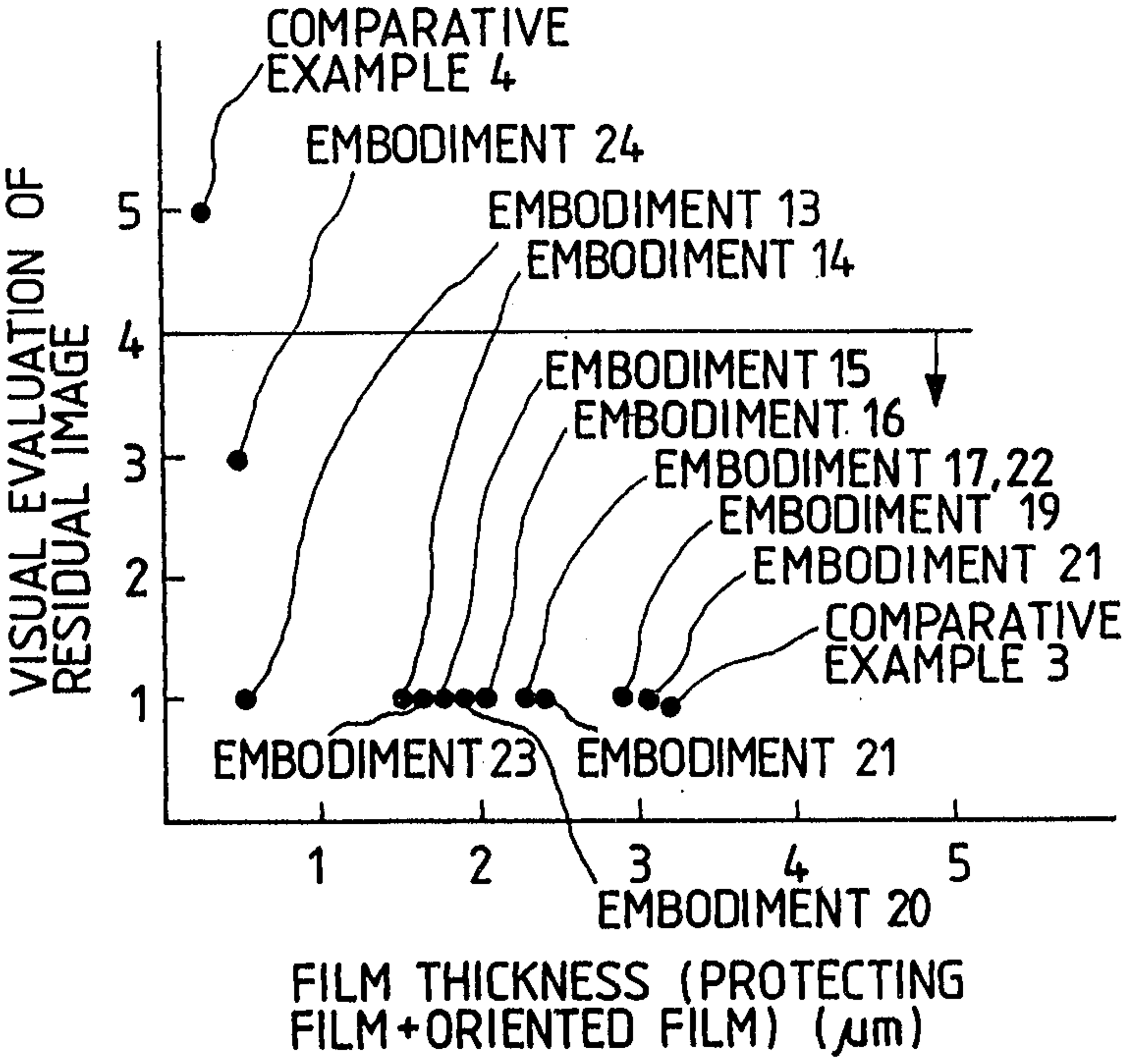

FIG. 10(b)

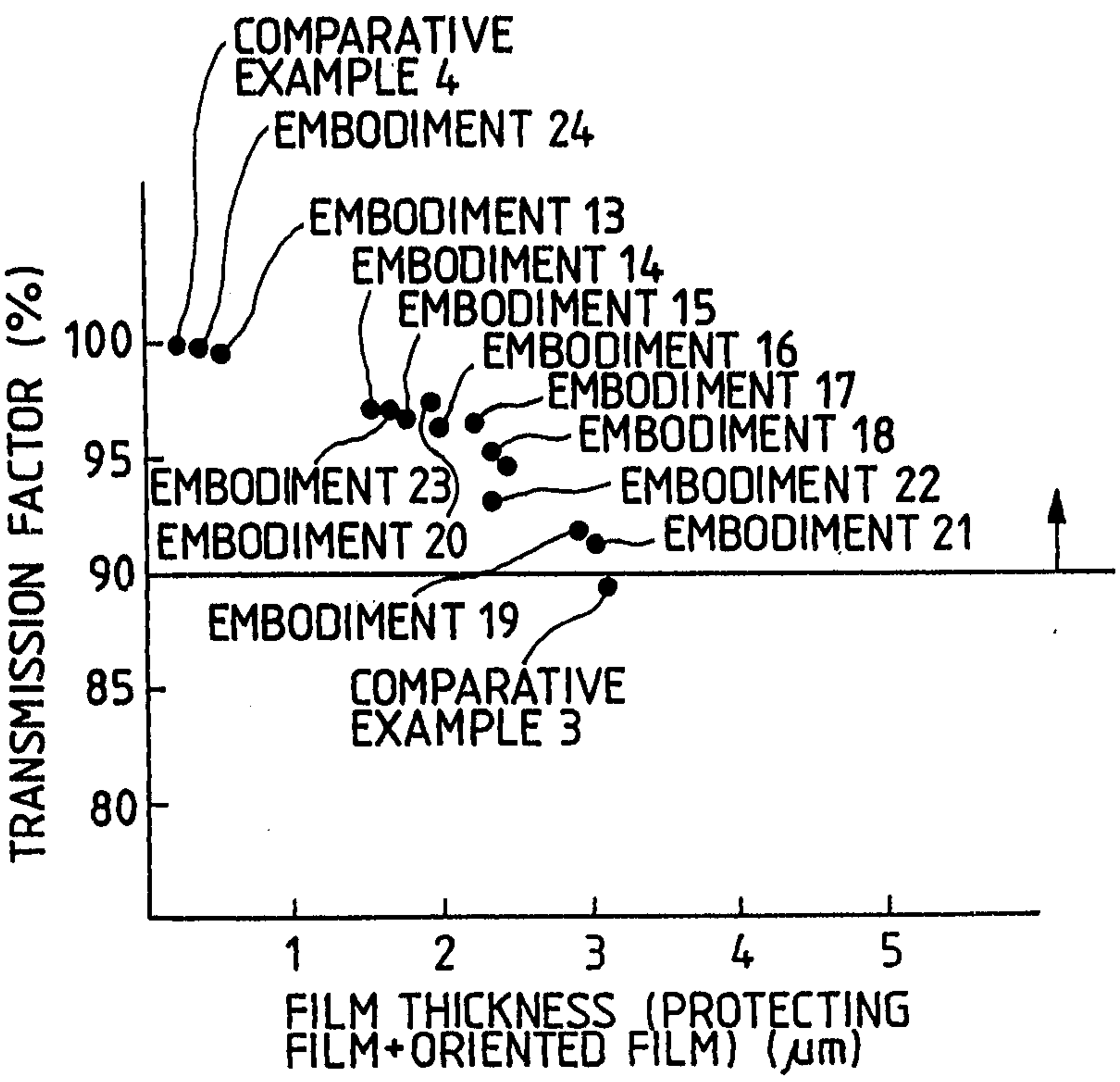

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FIG. 11(a)

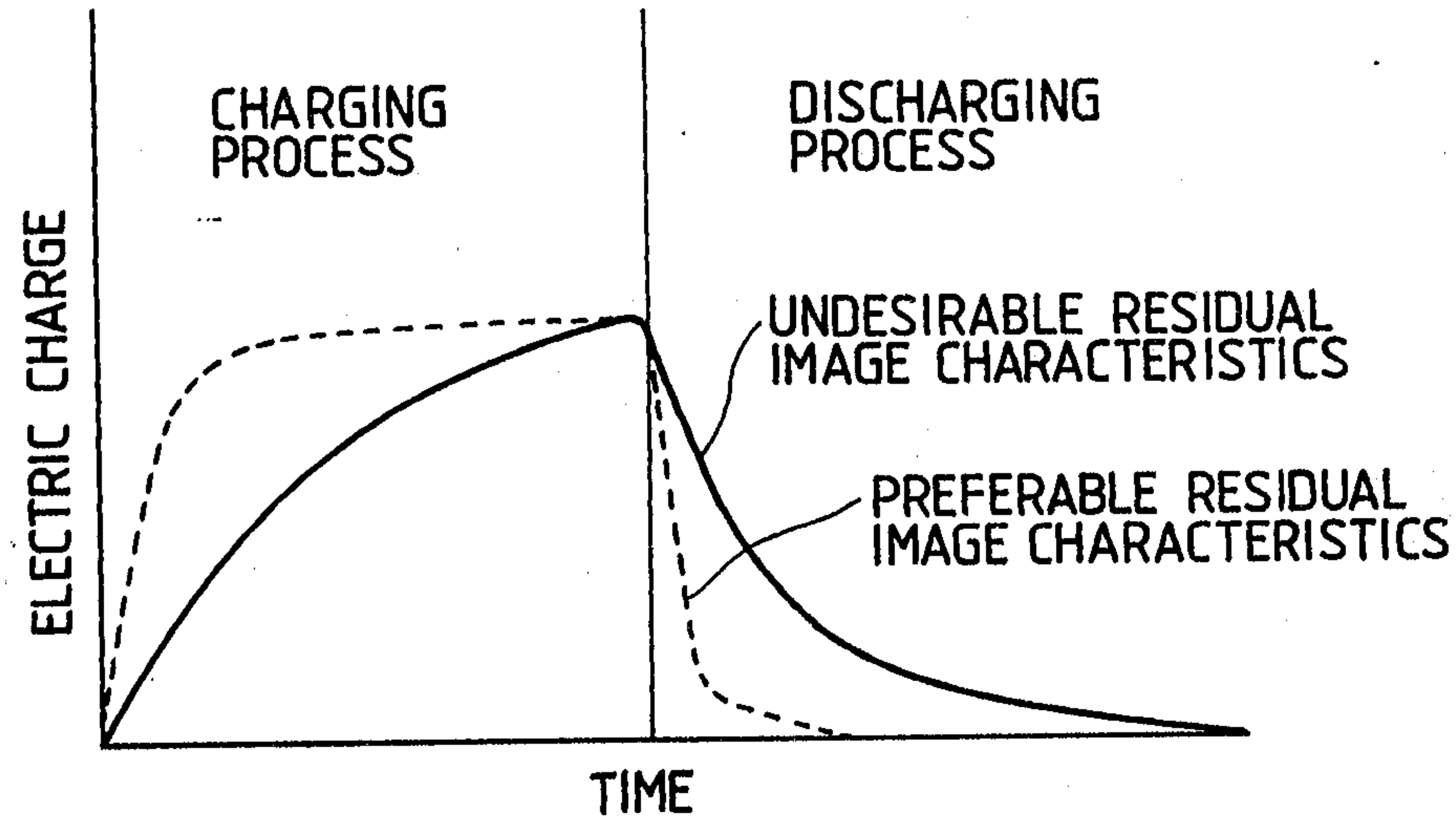
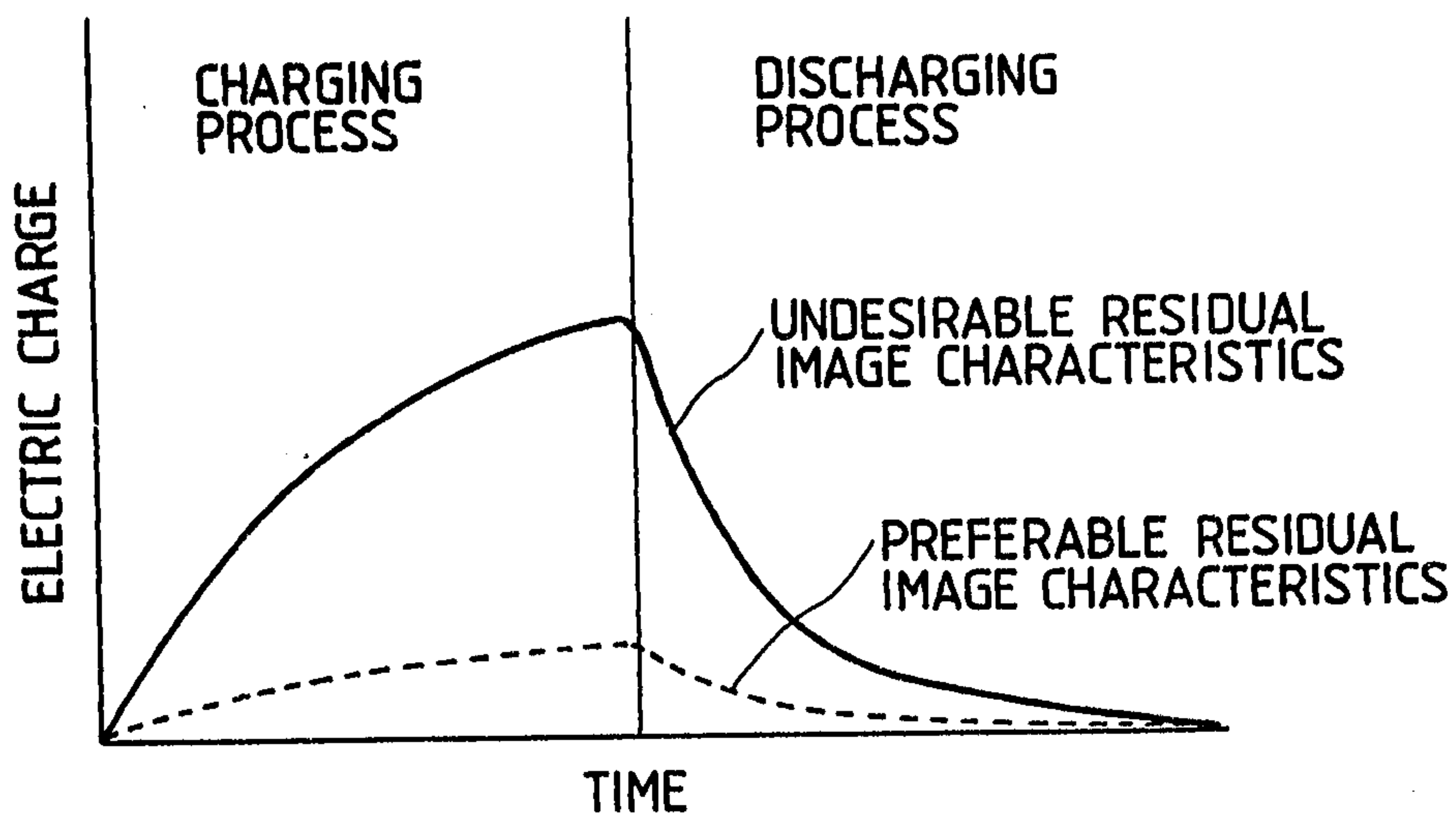
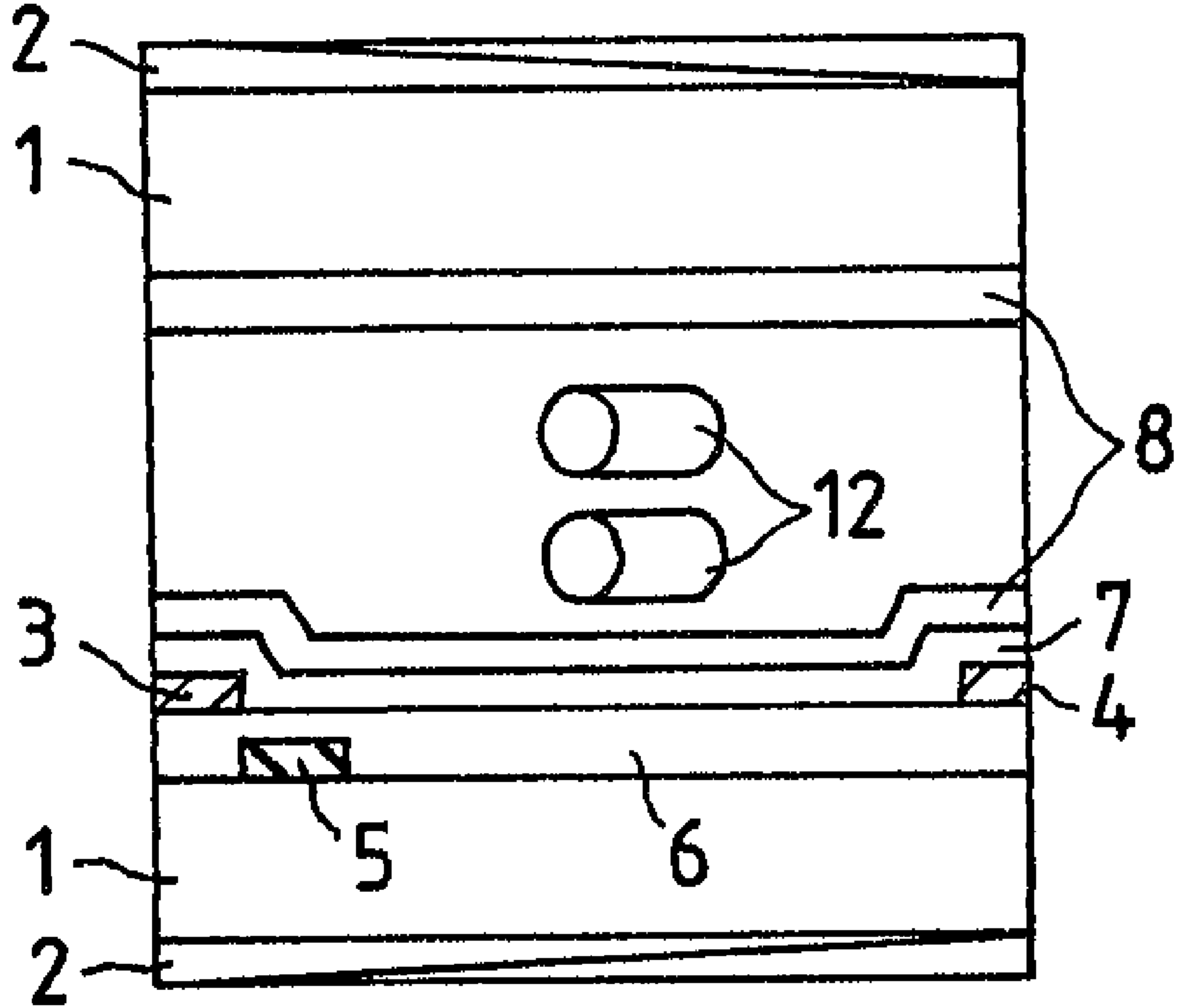


FIG. 11(b)





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