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Description

Technical Field

[0001] The present invention relates to an optical element in which two different voltages are applied between an electrode provided on a substrate constituting a liquid crystal cell and an electrode provided outside the substrate to control the orientation of liquid crystal molecules and in which specific optical properties can be easily adjusted.

Background Art

[0002] Liquid crystal has fluidity as liquid and exhibits anisotropy in electro-optical properties. The orientation of liquid crystal molecules can be controlled in various ways. The properties of the liquid crystal have been utilized, developing thin and light weight, flat-type display devices have been remarkably developed in recent years. The orientation of the liquid crystal molecules can be easily controlled if two glass plates constituting a liquid crystal element and having a transparent conductive film are surface-treated and if a voltage is externally applied. The refractive index of any liquid crystal element of this type can be continuously varied from the value it exhibits to extraordinary light to the value it exhibits to ordinary light. This is an excellent property not present in other optical materials.

[0003] Focus-variable lenses have been proposed, each of which has the effective refractive index varied (see Patent Document 1 and Non-Patent Documents 1 and 2). Glass substrates having transparent electrodes are bent by utilizing the electro-optical effect of nematic liquid crystal. The liquid crystal layer is thereby shaped like a lens, unlike in the element structure incorporated in the ordinary liquid crystal display. A voltage is applied across the electrodes, controlling the orientation of the liquid crystal molecules. The effective refractive index of the lens is thereby varied.

[0004] A method is available in which a spatial distribution of refractive index is imparted to an optical medium, thereby attaining a lens effect. Such optical media, known as SELFOC (GRIN) lenses, are commercially available. In a nematic liquid crystal cell, the liquid crystal molecules are oriented in the direction of an electric field. Methods of providing liquid crystal lenses that exhibit a spatial distribution of refractive indices have been reported (see Patent Document 2, Patent Document 3, and Non-Patent Documents 3 and 4). In these methods, an electrode having a circular pattern is used, generating an axially symmetrical non-uniform electric field, and obtaining such a liquid crystal lens by utilizing the effect of the liquid-crystal molecular orientation.

[0005] As Patent Document 4 discloses, a mesh-like macromolecule network in the liquid crystal in order to improve the properties of the liquid crystal. It is comparatively easy to modify such a lens using liquid crystal into a microlens array that comprises a number of tiny, so-called microlenses arranged two-dimensionally, thus forming a flat plate.

[0006] It has been proposed that, in a liquid crystal microlens, a pair of electrodes should be provided outside the electrode of a circular pattern to improve the lens properties (see Non-Patent Document 5). Further, a method has been proposed, in which an insulating layer is inserted between a liquid crystal layer and an electrode having a circular pattern, and the requirement that the ratio of the diameter of the circular pattern to the thickness of the liquid crystal layer should be 2:1 to about 3:1 to impart optimal properties to a microlens is mitigated (see Non-Patent Documents 6 and 7).

[0007] On the other hand, an optical apparatus has been proposed, which uses a liquid crystal element instead of a lens mirror (see Patent Document 5). In this apparatus, an imaging device detects an optical image obtained by an optical system having a focusing unit with an aberration-correcting mechanism, and the aberration is determined from a signal generated by the imaging device. A signal for correcting the aberration is generated, thereby correcting the aberration occurring in the optical system due to a sway of the atmosphere, in order to provide an optical image that is not distorted. Further, an electric-field controlled, anamorphic liquid crystal lens having an elliptical distribution of refractive index has been proposed as a lens that utilizes a liquid-crystal optical element (see Non-Patent Document 8).

[0008] Unlike the ordinary optical element, which is a passive element, these optical elements using liquid crystal can provide lenses that can adjust properties, such as focal distance, and the aberration of an optical system.

[0009] Polymerization-curable liquid crystal can be used as liquid crystal material. In this case, the liquid crystal is polymerized and is thereby cured, providing a polymer lens, after the focal distance is adjusted (see Patent Document 6).

[0010] The article "Improvement of Optical Properties and Beam Steering Functions in a Liquid Crystal Microlens with an Extra Controlling Electrode by a Planar Structure" of NOSE et al discloses reflective lens according to the preamble of claim 1. The article does not disclose a third electrode that is spaced apart from the upper electrodes by another insulation layer. It is difficult to produce lenses with the big diameter based on the technology of this document.

[0011] US 2002/0145701 A1 discloses a liquid crystal adaptive lens with closed-loop electrodes and related fabrication methods and control methods. This liquid crystal lens is based of the ring-shaped electrodes giving race to a Fresnelstructure in the liquid crystal layer. The adaptive lens descripted in this document relates to a different approach to achieve a refractive optical element.

Pat. Doc. 1: Jpn. Pat. Appln. KOKAI Publication No. 54-151854

Pat. Doc. 2: Jpn. Pat. Appln. KOKAI Publication No. 11-109303

Pat. Doc. 3: Jpn. Pat. Appln. KOKAI Publication No. 11-109304

Pat. Doc. 4: Jpn. Pat. Appln. KOKAI Publication No. 10-239676

Pat. Doc. 5: Jpn. Pat. Appln. KOKAI Publication No. 03-265819

Pat. Doc. 6: Jpn. Pat. Appln. KOKAI Publication No. 09-005695

Non-Pat. Doc. 1: S. Sato, "Liquid-crystal lenscell with variable focal length", Japanese Journal of Applied Physics, 1979, Vol. 18, pp. 1679-1683

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Non-Pat. Doc. 3: T. Nose and S. Sato, "A liquid-crystal micro lens obtained with a non uniform electric field", Liquid Crystals, 1989, pp. 1425-1433

Non-Pat. Doc. 4: S. Sato, "The world of liquid crystal", Sangyo Tosho Co., Ltd., Apr. 15, 1994, pp. 186-189

Non-Pat. Doc. 5: M. Honma, T. Nose and S. Sato, "Enhancement of numerical aperture of liquid crystal microlenses using a stacked electrode structure", Japanese Journal of Applied Physics, August 2000, Vol. 39, No. 8, pp. 4799-4802

Non-Pat. Doc. 6: M. Ye and S. Sato, "Optical properties of liquid crystal lens of any size", Preliminary reports, 49th meeting of the Applied Physics Society, Mar. 2002, 28p-X-10, p. 1277

Non-Pat. Doc. 7: M. Ye and S. Sato, "Optical properties of liquid crystal lens of any size", Japanese Journal of Applied Physics, May 2002, Vol. 41, No. 5, pp. L571-L573

Non-Pat. Doc. 8: Y. Yokoyama, M. Ye and S. Sato, "Electrically controllable liquid crystal anamorphic lens", 2004 preliminary reports, meeting of the Society of Liquid Crystal, Japan, Sep. 26, 2004

Disclosure of Invention

[0012] The liquid crystal lens having a lens-shaped liquid crystal layer, the liquid crystal microlens utilizing the spatial refractive-index distribution of liquid crystal molecules, achieved by an axially symmetrical non-uniform electric field and generated by a circular-pattern electrode, a method in which a pair of electrodes are provided outside a circular-pattern electrode, as proposed in Non-Patent Document 5, and a structure in which an insulating layer is provided between a liquid crystal layer and a circular-pattern electrode, as proposed in Non-Patent Documents 6 and 7, all described above, can attain good optical properties. They have a problem, however. They can hardly acquire good properties over a wide range of the voltage applied.

[0013] Accordingly, an object of one embodiment of this invention is to provide an optical element that has good optical properties, which can be changed easily and greatly while being maintained.

[0014] An object of another embodiment of this invention is to provide an optical element in which the focus can be moved in a three-dimensional fashion.

[0015] An object of still another embodiment of this invention is to provide such optical properties as can be controlled for either convex lenses or concave lenses.

[0016] To solve the above-mentioned problem, an optical element according to this invention comprises basically a first substrate having a first electrode, a second substrate, a second electrode arranged outside the second substrate and having a hole, and a liquid crystal layer provided between the first substrate and the second substrate and constituted by liquid crystal molecules oriented in one direction. A first voltage is applied between the first electrode and the second electrode, controlling the orientation of the liquid crystal molecules, whereby the optical element operates. In the optical element, a third electrode is arranged outside the second electrode and provided on an insulating layer, and a second voltage, which is independent of the first voltage, is applied to the third electrode, thereby controlling the optical properties.

[0017] Owing to the means described above, the focal position can be greatly varied by electrical control, without mechanically moving the lens back and forth as in the conventional optical element.

Brief Description of Drawings

[0018]

FIG. 1A is a sectional view showing the configuration of an embodiment of an optical element according to the present invention;

FIG. 1B is a plan view showing the configuration of the embodiment of the optical element according to this invention;

FIG. 2 is a diagram showing a potential distribution in the element, and thus explaining the function of the optical element according to this invention;

FIG. 3A is a diagram showing a first example in which the potential distribution changes in the optical element according to this invention, and thus explaining the function of the optical element;

FIG. 3B is a diagram showing a second example in which the potential distribution changes in the optical element according to this invention, and thus explaining the function of the optical element;

FIG. 4 is a diagram showing how a light wave passing through the optical element according to this invention changes in optical phase, as viewed in the optical axis of the optical element;

FIG. 5 is a diagram showing how a light wave passing through the optical element according to this invention changes in optical phase, and thus explaining the function of the optical element;

FIG. 6 is a diagram showing how the focal distance changes with the control voltage, and thus explaining the function of the optical element according to this invention;

FIG. 7 is a sectional view showing the configuration of another embodiment of the optical element according to the present invention;

FIG. 8A is a sectional view showing the configuration of a further embodiment of the optical element according to the present invention;

FIG. 8B is a plan view showing the configuration of the further embodiment of the optical element according to this invention;

FIG. 9A is a sectional view showing the configuration of another embodiment of the optical element according to the present invention;

FIG. 9B is a plan view showing the configuration of the other embodiment of the optical element according to this invention;

FIG. 10A is a diagram explaining the specific configuration of the control unit shown in FIG. 9;

FIG. 10B is a diagram explaining how the focus of the liquid crystal lens is moved in the control unit shown in FIG. 9;

FIG. 11 is a diagram showing the potential applied to the split electrode shown in FIG. 10 and the x-direction movement of the focus, both actually measured;

FIG. 12 is a diagram showing the potential applied to the split electrode shown in FIG. 10 and the y-direction moment of the focus, both actually measured;

FIG. 13 is a diagram showing the potential applied to the split electrode shown in FIG. 10 and the movement of the focus in a direction at an angle to the x-direction and the y-direction, both the potential and the movement having been actually measured;

FIG. 14A is a sectional view showing the configuration of a further embodiment of the optical element according to the present invention;

FIG. 14B is a plan view showing the configuration of the further embodiment of the optical element according to this invention;

FIG. 15 is a diagram showing a potential distribution in the optical element of FIGS. 14A and 14B, and thus explaining the function of this optical element;

FIG. 16A is a diagram showing a first example in which the potential distribution changes in the optical element of FIGS. 14A and 14B, and thus explaining the function of this optical element according;

FIG. 16B is a diagram showing a second example in which the potential distribution changes in the optical element of FIGS. 14A and 14B, and thus explaining the function of this optical element;

FIG. 17 is a diagram showing how a light wave passing through the optical element of FIG. 14 changes in optical phase, and thus explaining the function of this optical element;

FIG. 18 is a diagram showing how the focal distance changes with the control voltage, and thus explaining the function of the optical element shown in FIG. 14; and

FIG. 19 is a diagram showing the configuration of another embodiment of the optical element according to the present invention.

Best Mode for Carrying Out the Invention

[0019] Embodiments of the present invention will be described in detail, with reference to the accompanying drawings. FIGS. 1A and 1B, number 111 designates a first substrate (transparent glass plate). A first electrode 21 (made of ITO) is formed on the inner surface of the first substrate 111. On the side of the first electrode 21, a second substrate 112 (transparent glass plate) is arranged, facing the first electrode 21 and extending parallel thereto. Outside the second substrate 112, a second electrode 22 (made of Al) is formed. As shown in FIG. 1B, the second electrode 22 has a circular hole 222 (having a diameter of, for example, 4.5 mm).

[0020] A liquid crystal layer 311 (having a thickness of, for example, 130 μm) is formed between the first electrode 21, which is formed on the first substrate 111, and the second substrate 112. Reference numbers 41 and 42 denote spacers that define the liquid crystal layer 311.

[0021] Further, an insulating layer 113 (e.g., glass layer as thin as, for example, 70 μm) is provided on the upper surface of the second electrode 22, and a third electrode 23 (made of ITO) is formed on the insulating layer 113. A protective layer 114 (made of glass) is arranged on the upper surface of the third electrode 23. Those surfaces of the first and second substrates, which contact the liquid crystal layer, are coated with polyimide and have been rubbed in the x-axis direction.

[0022] To make the optical element function as a liquid crystal lens, a first voltage Vo is applied between the first electrode 21 and the second electrode 22. To apply the first voltage Vo, a second voltage Vc is initially set to 0 V and the first voltage Vo is set to an appropriate value. The voltage Vo is applied from a voltage-applying unit 51. The voltage is set to such a value as will impart optimum optical properties (hereinafter referred to as first-stage optical properties) to the lens. Next, a second voltage Vc, which is independent of the first voltage Vo, is applied between the first electrode 21 and the third electrode 23. The second voltage Vc is output from a voltage-applying unit 52. If the second voltage Vc is varied, the optical properties (hereinafter referred to as second-stage optical properties) of the lens can be controlled. Note that Vo and Vc are identical in frequency and phase.

[0023] In the present invention, the second-stage optical properties are changed from the values at which the focal distance is very short to the values at which the focal distance is infinitely long or almost infinitely long. The focal distance can vary over a broad range. Hence, the present invention is practically valuable and can be applied to various uses.

[0024] FIG. 2 shows a potential distribution in the space between the first and second electrodes, which is observed when Vo = 70 V (fixed value for optimal properties) is applied between the first electrode 21 and the second electrode 22 and the second voltage (control voltage) Vc = 10 V is applied to the third electrode 23. In FIG. 2, z is the optical-axis direction, and y is the direction intersecting at right angles with the optical axis. Note that z, y and x are identical to z, y and x shown in FIG. 1. If the equipotential lines define a steep gradient, the lens will have.a short focal distance. If they define a gentle gradient, the lens will have a long focal distance.

[0025] FIG. 3A and FIG. 3B show other potential distributions, i.e., two potential distributions that may be observed in the liquid crystal layer. FIG. 3A shows a potential distribution that is observed when Vo = 70 V (a fixed value for optimum properties) is applied between the first electrode 21 and the second electrode 22 and the second voltage (control voltage) Vc = 10 V is applied between the first electrode 21 and the third electrode 23. FIG. 3B shows a potential distribution that is observed when the control voltage is varied and the second voltage (control voltage) Vc = 20 V is applied. This change in the potential distribution corresponds to the inclination angle of the liquid crystal molecules and to the refractive angle of light. The focal distance is longer in the state of FIG. 3B than in the state of FIG. 3A.

[0026] In FIG. 4, A, B, C and D show how the phase of a light wave is distributed as viewed in the optical axis of the optical element according to this invention. More precisely, A, B, C and D show how the phase distribution of the light wave changes as the control voltage Vc applied to the third electrode 23 is varied to 0 V, 20 V, 40 V and 60 V, while applying the fixed voltage Vo = 70 V to the first electrode 21 and second electrode 22. As seen from A to D in FIG. 4, the higher the control voltage Vc, the longer the spaces between the interference fringes. The longer the spaces between the interference fringes, the less prominent the refraction of the light will be and, hence, the longer the focal distance will be.

[0027] FIG. 5 shows how a light wave passing through a liquid crystal lens comes to have an optical phase delay ϕ. Basically, the light has square-distribution characteristic. Therefore, its phase delay gradually decreases outwards from the y axis. As the control voltage (second voltage) is increased, the phase difference between the center of the lens and the periphery thereof decreases. Thus, the focal distance is longer when Vc = 50 V than when Vc = 10 V.

[0028] FIG. 6 represents the relation between the change in the focal distance of the optical element according to this invention and the control voltage Vc mentioned above. The focal distance varies as the control voltage Vc is changed. The present invention is not limited to the embodiment described above.

[0029] FIG. 7 shows the configuration of another embodiment of the present invention. The components identical to those shown in FIG. 1 are denoted by the same reference numbers. This embodiment differs from the first embodiment in the structure of the liquid crystal layer 311. In the present embodiment, the liquid crystal layer 311 is composed of a first liquid crystal layer 311a, a second liquid crystal layer 311b, and an insulating layer 312 (made of transparent glass). The first and second liquid crystal layers 311a and 311b are spaced apart, with the insulating layer 312 interposed between them.

[0030] Thus configured, the liquid crystal layer 311 can respond at an extremely high speed. The response speed of any liquid crystal layer is inversely proportional to the square of the layer thickness. Hence, the layer 311 can respond to a control signal four times faster than the element of FIG. 1, because it comprises two liquid crystal layers, i.e., the first layer 311a and the second layer 311b.

[0031] Having a two-layer structure, the liquid crystal layer 311 can achieve the following advantage. If the liquid crystal layers 311a and 311b have been rubbed in the same direction, the liquid crystal molecules are oriented in the same direction in both layers 311a and 311b. As a result, the lens can acquire a magnifying power twice as large as that of a single-layer lens. In other words, it can attain the same effect as two lenses combined together and can, therefore, a short focal distance.

[0032] Further, the lens can function as a liquid crystal element without a polarizing plate if the liquid crystal layers 311a and 311b have been rubbed in two directions intersecting at right angles, respectively.

[0033] FIG. 8A and FIG. 8B show still another embodiment of the present invention. This optical element is composed of two elements that are identical to the element shown in FIG. 7. It is a two-unit structure having an upper unit and a lower unit that are symmetrical to each other. The components (first element unit) identical to those shown in FIG. 7 are designated by the same reference numerals. The first and second element units share the second and third electrodes 22 and 23. The second element unit is laid on the first element unit. The second element unit has substrates 111-2 and 112-2, an electrode 21-2, a first liquid crystal layer 311a-1, a second liquid crystal layer 311b-2, an insulating layer 312-2, a common second electrode 22, and a common third electrode 23. In this embodiment, a gap G is provided between the second electrode 22 and the third electrode 23, because these electrodes 22 and 23 lie in the same plane. The second electrode 22 has a slit 23a that extends from its hole to one of its sides. A lead line 23a is led from the third electrode 23, through the slit 23a. A control voltage Vc is applied through the lead line 23a.

[0034] The upper liquid crystal layer and the lower liquid crystal layer, which are symmetrical to each other, may be composed of two or more layers each. If this is the case, the lens power and the response speed will be further improved.

[0035] In the present invention, the liquid crystal layers may be made of material of two-frequency driven type, which that functions as N-type when driven by a high-frequency signal (tens of kilohertz) and as P-type when driven by a low-frequency signal (about 100 Hz). If the liquid crystal layers are made of such material, the response speed of the orienting operation of liquid crystal molecules can be raised.

[0036] FIG. 9A and FIG. 9B show another embodiment of the present invention. In the embodiment shown in FIGS. 1A and 1B, a fixed voltage is applied to the second electrode 22. In this embodiment, the second electrode 22 is divided into two or more segments, for example four electrode segments 22a to 22d as shown in FIG. 9B. The voltages applied to these electrodes can be minutely changed by a control unit 55. In any other respect, this embodiment is identical to the embodiment of FIGS. 1A and 1B.

[0037] FIG. 10A shows the configuration of the control unit 55. FIG. 10B explains how the focus moves when the control unit 55 controls the position of the focus.

[0038] The voltage applied to the electrode segment 22a comes from the sliding tap of a variable resistor 55a. Its value is ranges from voltage +V and voltage -V. Similarly, the voltage applied to the electrode 22b comes from the sliding tap of a variable resistor 55b and ranges voltage +V and voltage -V; the voltage applied to the electrode 22c comes from the sliding tap of a variable resistor 55c and ranges voltage +V and voltage -V; and the voltage applied to the electrode 22c comes from the sliding tap of a variable resistor 55d and ranges voltage +V and voltage -V.

[0039] As the voltages applied to the electrode segments 22a to 22d are minutely changed, the focus can be moved in the x-axis direction or the y-axis direction, or in both directions. In addition, the focus can be moved in the z-axis direction. Thus, the focal position can be controlled in a three-dimensional fashion.

[0040] In FIG. 11, A and B show how the focal position is controlled in the x-axis direction while being held in the focal plane, by adjusting the voltage Vc. More precisely, A in FIG. 11 shows how the focus moves in a space as the voltage applied to the second electrode 22 is changed. B in FIG. 12 shows the position the focus takes in the focal plane.

[0041] In FIG. 12, A and B show how the focal position is controlled in the y-axis direction. More precisely, A in FIG. 12 shows how the focus moves in a space as the voltage applied to the second electrode 22 is changed. B in FIG. 12 shows the distance the focus moves.

[0042] In FIG. 13, A and B show how the focal position is controlled in the x-axis direction and the y-axis direction. Namely, A in FIG. 13 shows the voltage applied to the second electrode 22, and B in FIG. 13 shows the distance the focus moves.

[0043] This invention is not limited to the embodiments described above. In these embodiments, the liquid crystal lens functions as a convex lens. Nonetheless, the liquid crystal lens can be easily made to work as a concave lens, too, according to the present invention.

[0044] FIGS. 14A and 14B shows an embodiment in which the liquid crystal lens functions as a concave lens. In this case, a voltage-applying unit 61 applies a constant AC voltage Vo between the first electrode 21 and the third electrode 23, and a voltage-applying unit 62 applies the voltage Vc between the first electrode 21 and the second electrode 22. The voltage Vc can be varied. In any other respect, this embodiment is identical to the embodiment shown in FIGS. 1A and 1B.

[0045] FIG. 15 depicts a potential distribution observed when the voltage Vo = 60 V (i.e., fixed value for attaining optical properties) is applied between the first electrode 21 and the third electrode 23 and the second voltage (control voltage) Vc = 10 V is applied between the first electrode 21 and the second electrode 22. In FIG. 15, z is the direction in which the optical axis extends, and y is a direction intersecting at right angles with the optical axis. Note, z, y and x are identical to their equivalents shown in FIGS. 1A and 1B. The potential distribution is inverse to the distribution shown in FIG. 2. This means that the liquid crystal lens works as a concave lens.

[0046] FIG. 16A and FIG. 116B show different potential distributions. FIG. 16A shows a potential distribution observed when Vo = 60 V (i.e., fixed value for attaining optical properties) is applied between the first electrode 21 and the third electrode 23 and the second voltage (control voltage) Vc = 5 V is applied between the second electrode 22. FIG. 16B shows a potential distribution observed when the second voltage (control voltage) Vc is changed to 20V and applied. The change in this potential difference corresponds to the inclination angle of the liquid crystal molecules and also to the refractive angle of light. The potential distributions shown in FIGS. 16A and 16B are inverse to those shown in FIGS. 3A and 3B. This means that the liquid crystal lens works as a concave lens.

[0047] FIG. 17 shows how light has an optical phase delay ϕ as it passes through the liquid crystal lens. Basically, the phase delay of a light wave has square-distribution characteristic. Therefore, its phase delay gradually decreases outwards from the y axis. As the control voltage (second voltage) is changed, the phase difference between the center of the lens and the periphery thereof is controlled. That is, the concave-lens property can be varied.

[0048] FIG. 18 is a diagram showing how the focal distance changes with the control voltage Vc described above. When the control voltage Vc is varied, the focal distance is changed.

[0049] The present invention is not limited to the embodiments described above, in which the liquid crystal lens is either a convex lens or a concave lens. In the present invention, a convex lens and a concave lens may be used in combination.

[0050] FIG. 19 shows a multi-function lens that is a combination of the embodiment of FIGS. 1A and 1B (i.e., an embodiment that functions as a convex lens) and the embodiment of FIGS. 9A and 9B (i.e., an embodiment in which the focal position can be controlled in a three-dimensional fashion) and the embodiment of FIGS. 14A and 14B (i.e., an embodiment that functions as a concave lens). The function of this lens can be switched the switch 64 and 65, between the convex-lens function and the concave-lens function. While the lens is functioning as a convex lens, the voltages applied to the segments of the second electrode are minutely adjusted independently of one another, thereby to the focus in a three-dimensional fashion. While the lens is functioning as a concave lens, too, the voltages applied to the segments of the second electrode may be controlled independently of one another.

[0051] The present invention is not limited to the embodiments described above. The components of any embodiment can be modified in various manners in reducing the invention to practice, without departing from the sprit or scope of the invention. Further, the components of any embodiment described above may be combined, if necessary, in various ways to make different inventions. For example, some of the component of any embodiment may not be used. Moreover, the components of the different embodiments may be combined in any desired fashion. The shape of the third electrode may be defined by a sine-wave function, the superimposed function of a sine-wave function, or an any power function. In the embodiments described above has one liquid crystal lens. Nonetheless, a plurality of liquid crystal lenses may be arranged, forming a linear array or a two-dimensional array.

Industrial Applicability

[0052] Optical elements according to the present invention can be used in various ways. They may be used as magnifying lenses or in the visual-sense unit for use in robots.

Claims

1. A liquid crystal lens comprising:

a first substrate (111) having a first electrode (21);
a second substrate (112) which faces the first electrode of the first substrate and extending in parallel to the first electrode (21);
a second electrode arranged outside the second substrate (112) and
having a hole (222) on an opposite side to the first substrate;
a liquid crystal layer (311) provided between the first substrate (111) and
the second substrate (112), and constituted by oriented liquid crystal molecules and an insulating layer (113) on the second electrode of the second substrate; **characterized by** further comprising a third electrode (23) on the insulating layer which substantially covers or fills the hole;
a first voltage-applying circuit (51) configured to apply a first voltage (Vo) between the first and second electrodes (21, 22) to control orientation of the liquid crystal molecules; and
a second voltage-applying circuit (52) configured to apply a second voltage (Vc) between the first and third electrodes (21, 23), the second voltage being independent of the first voltage, wherein the first voltage has a fixed value, and the second voltage is changed to achieve second stage optical properties , namely a change of a focal distance, or the second voltage has a fixed value, and.the first voltage is changed to achieve the second-stage optical properties, namely a change of a focal distance.

2. The liquid crystal lens of claim 1, wherein:

The third electrode (23), which substantially fills the hole (222), is arranged on the same plane as the second electrode (22),
further comprising:

A third substrate (112-2) symmetrical to the second substrate (112), with the second electrode (22) and a third electrode (23) portion substantially filling the hole (22) in the second electrode being interposed(112) (112-2) between the second substrate and the third substrate;
a fourth substrate (111-2) having a second liquid crystal layer and a fourth electrode (21-2), the second liquid crystal layer and the fourth electrode (21-2) being symmetrical to the first liquid crystal layer and the first substrate (21-1), with the second electrode (22), the third electrode (23) portion substantially filling the hole (22) in the second electrode and the third substrate (112-2) being interposed(112) between the second substrate and the second liquid crystal layer,
wherein the first voltage-applying circuit (51) is further configured to apply the first voltage (Vo) between the fourth electrode (21-2) and the second electrode (22) to control the orientation of the liquid crystal molecules; and
the second voltage-applying circuit (52) is further configured to apply the second voltage (Vc) to the third electrode (23).

3. The liquid crystal lens of claim 1 or 2, further comprising:

A circuit configured to vary the second voltage (Vc), with the first voltage (Vo) being fixed, such that the optical properties provide a convex lens;

and

a circuit configured to vary the first voltage (Vo), with the second voltage (Vc) being fixed, such that the optical properties provide a concave lens.

4. The liquid crystal lens of claim 3, further comprising:

A switch configured to switch between the first voltage-applying circuit and the second voltage-applying circuit.

Patentansprüche

1. Flüssigkristalllinse mit:

einem ersten Substrat (111), das eine erste Elektrode (21) aufweist;

einem zweiten Substrat (112), das gegenüber der ersten Elektrode des ersten Substrats angeordnet ist und sich parallel zur ersten Elektrode (21) erstreckt;

einer zweiten Elektrode, die außerhalb des zweiten Substrats (112) angeordnet ist und ein Loch (222) aufweist, das sich auf einer dem ersten Substrat gegenüberliegenden Seite befindet;

einer Flüssigkristalllage (311), die zwischen dem ersten Substrat (111) und

dem zweiten Substrat (112) angeordnet ist und aus orientierten Flüssigkristallmolekülen aufgebaut ist; und einer Isolationslage (113) auf der zweiten Elektrode des zweiten Substrats; **dadurch gekennzeichnet, dass** sie zusätzlich das Folgende aufweist:

eine dritte Elektrode (23) auf der Isolationslage, die das Loch im Wesentlichen abdeckt oder ausfüllt;

einem ersten Spannungs-Schaltkreis (51), der eingerichtet ist zum Abgeben einer ersten Spannung (Vo) zwischen der ersten und der zweiten Elektrode (21, 22), um die Orientierung der Flüssigkristallmoleküle zu steuern; und einem zweiten Spannungs-Schaltkreis (52), der ausgebildet ist zum Anlegen einer zweiten Spannung (Vc) zwischen der ersten und der dritten Elektrode (21, 23), wobei die zweite Spannung von der ersten Spannung unabhängig ist, wobei die erste Spannung einen festgelegten Wert hat und

wobei die zweite Spannung geändert wird, um eine zweite Art an optischen Eigenschaften, nämlich eine Änderung im Fokusabstand, zu erreichen, oder

wobei die zweite Spannung einen festen Wert hat und die erste Spannung verändert wird, um die optischen Eigenschaften der zweiten Art, nämlich die Änderungen des Fokusabstands, zu erreichen.

2. Flüssigkristalllinse nach Anspruch 1, wobei die dritte Elektrode (23), die das Loch (222) im Wesentlichen ausfüllt, auf der gleichen Ebene angeordnet ist wie die zweite Elektrode (22), wobei die Flüssigkristalllinse zudem das Folgende aufweist:

ein drittes Substrat (112-2), das symmetrisch zu dem zweiten Substrat (112) aufgebaut ist, wobei die zweite Elektrode (22) und ein dritter Elektrodenabschnitt (23) im Wesentlichen das Loch (22) in der zweiten Elektrode, die zwischen (112) (112-2) dem zweiten Substrat und dem dritten Substrat ausgebildet ist, ausfüllt;

ein viertes Substrat (111-2), das eine zweite Flüssigkristalllage und eine vierte Elektrode (21-2) aufweist, wobei die zweite Flüssigkristalllage und

die vierte Elektrode (21-2) symmetrisch zu der ersten Flüssigkristalllage und dem ersten Substrat (21-1) aufgebaut sind, wobei die zweite Elektrode (22), der dritte Elektrodenabschnitt (23), der das Loch (22) in der zweiten Elektrode ausfüllt, und das dritte Substrat (112-2) zwischen dem zweiten Substrat und der zweiten Flüssigkristalllage angeordnet sind,

wobei der erste Spannungs-Schaltkreis (51) zudem so ausgebildet ist, dass er die erste Spannung (V_0) zwischen die vierte Elektrode (21-2) und die zweite Elektrode (22) anlegt, um die Orientierung der Flüssigkristallmoleküle zu steuern; und

wobei der zweite Spannungs-Schaltkreis (52) zudem so ausgebildet ist,

dass er die zweite Spannung (Vc) an die dritte Elektrode (23) anlegt.

3. Flüssigkristalllinse nach Anspruch 1 oder 2, die das Folgende zusätzlich enthält:

einen Schaltkreis, der eingerichtet ist zum Variieren der zweiten Spannung (Vc), wobei die erste Spannung (Vo) festgelegt ist, sodass die optischen Eigenschaften zu einer konvexen Linse führen; und

einen Schaltkreis, der eingerichtet ist zum Verändern der ersten Spannung (Vo), wobei die zweite Spannung (Vc) festgelegt ist, sodass die optischen Eigenschaften zu einer konkaven Linse führen.

4. Die Flüssigkristalllinse gemäß Anspruch 3, die zudem das Folgende enthält:

einen Schalter, der ausgebildet ist zum Umschalten zwischen dem ersten Spannungs-Schaltkreis und dem zweiten Spannungs-Schaltkreis.

Revendications

1. Lentille à cristaux liquides comprenant :

un premier substrat (111) ayant une première électrode (21) ;
un deuxième substrat (112) qui fait face à la première électrode du premier substrat et s'étendant en parallèle à la première électrode (21) ;
une deuxième électrode agencée à l'extérieur du deuxième substrat (112) et ayant un trou (222) sur un côté opposé au premier substrat ;
une couche de cristaux liquides (311) prévue entre le premier substrat (111) et le deuxième substrat (112), et constituée par des molécules de cristaux liquides orientées et une couche isolante (113) sur la deuxième électrode du deuxième substrat ; **caractérisée en ce qu'**elle comprend en outre
une troisième électrode (23) sur la couche isolante qui couvre ou remplit essentiellement le trou ;
un premier circuit d'application de tension (51) configuré pour appliquer une première tension (Vo) entre les première et deuxième électrodes (21, 22) pour contrôler l'orientation des molécules de cristaux liquides ; et
un deuxième circuit d'application de tension (52) configuré pour appliquer une deuxième tension (Vc) entre les première et troisième électrodes (21, 23), la deuxième tension étant indépendante de la première tension, où la première tension a une valeur fixe, et la deuxième tension est modifiée pour obtenir des propriétés optiques de deuxième étage, à savoir une modification d'une distance focale, ou la deuxième tension a une valeur fixe, et la première tension est modifiée pour obtenir les propriétés optiques de deuxième étage, à savoir une modification d'une distance focale.

2. Lentille à cristaux liquides de la revendication 1, dans laquelle :

la troisième électrode (23), qui remplit essentiellement le trou (222), est agencée sur le même plan que la deuxième électrode (22), comprenant en outre :

un troisième substrat (112-2) symétrique au deuxième substrat (112), avec la deuxième électrode (22) et une partie de troisième électrode (23) remplissant essentiellement le trou (22) dans la deuxième électrode étant interposées (112) (112-2) entre le deuxième substrat et le troisième substrat ;
un quatrième substrat (111-2) ayant une deuxième couche de cristaux liquides et une quatrième électrode (21-2), la deuxième couche de cristaux liquides et la quatrième électrode (21-2) étant symétriques à la première couche de cristaux liquides et au premier substrat (21-1), avec la deuxième électrode (22), la partie de troisième électrode (23) remplissant essentiellement le trou (22) dans la deuxième électrode et le troisième substrat (112-2) étant interposés (112) entre le deuxième substrat et la deuxième couche de cristaux liquides,
dans laquelle le premier circuit d'application de tension (51) est en outre configuré pour appliquer la première tension (Vo) entre la quatrième électrode (21-2) et la deuxième électrode (22) pour contrôler l'orientation des molécules de cristaux liquides ; et
le deuxième circuit d'application de tension (52) est en outre configuré pour appliquer la deuxième tension (Vc) à la troisième électrode (23).

3. Lentille à cristaux liquides de la revendication 1 ou 2, comprenant en outre :

un circuit configuré pour faire varier la deuxième tension (Vc), avec la première tension (Vo) étant fixe, de sorte que les propriétés optiques fournissent une lentille convexe ; et
un circuit configuré pour faire varier la première tension (Vo), avec la deuxième tension (Vc) étant fixe, de sorte que les propriétés optiques fournissent une lentille concave.

4. Lentille à cristaux liquides de la revendication 3, comprenant en outre :

un commutateur configuré pour commuter entre le premier circuit d'application de tension et le deuxième circuit d'application de tension.

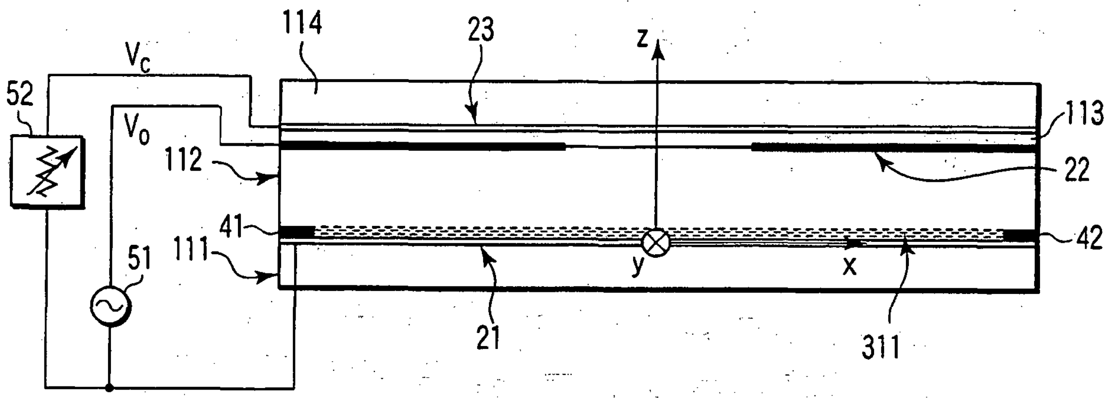


FIG. 1A

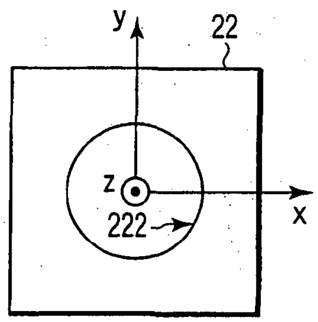
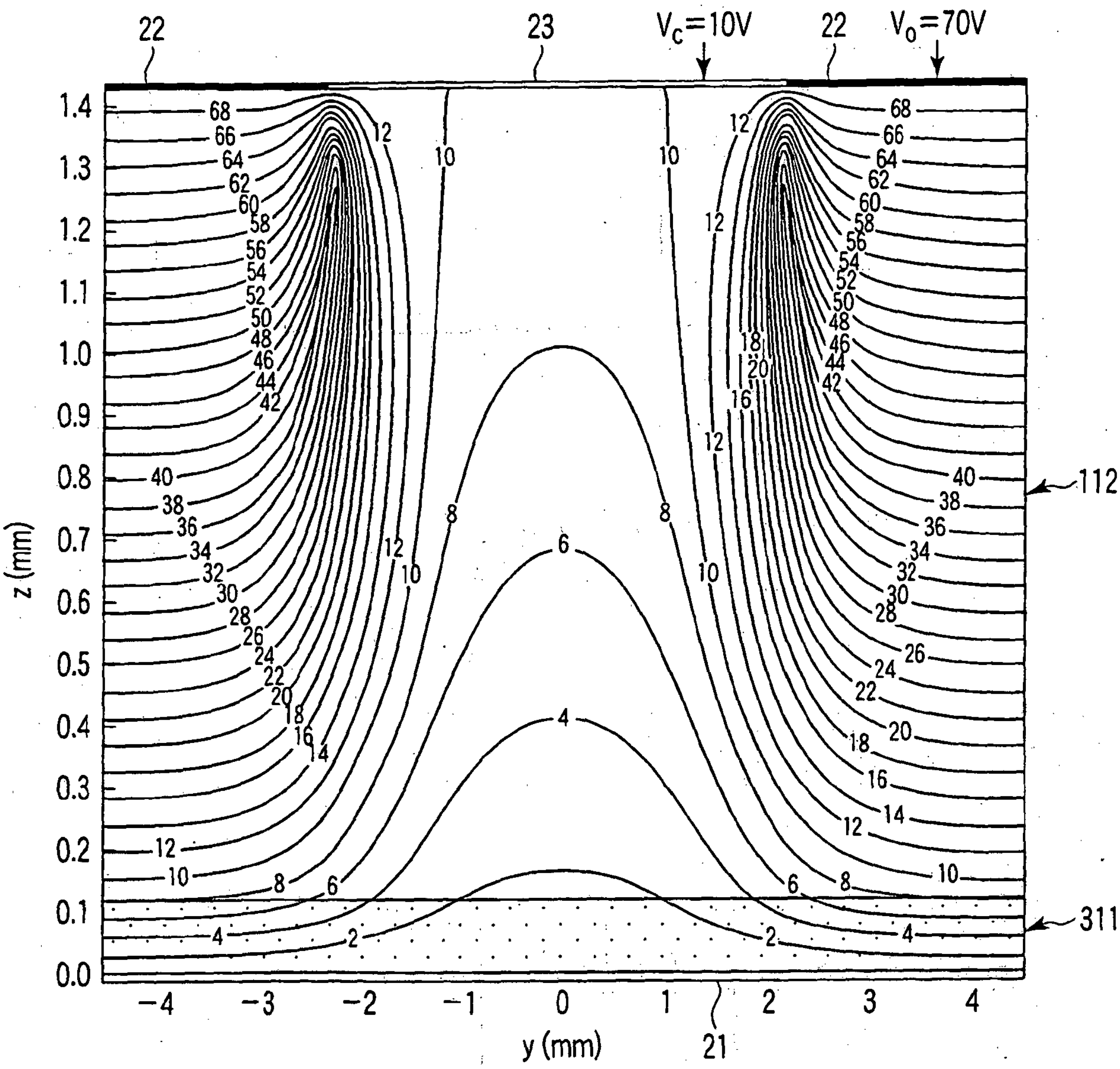


FIG. 1B



F I G. 2

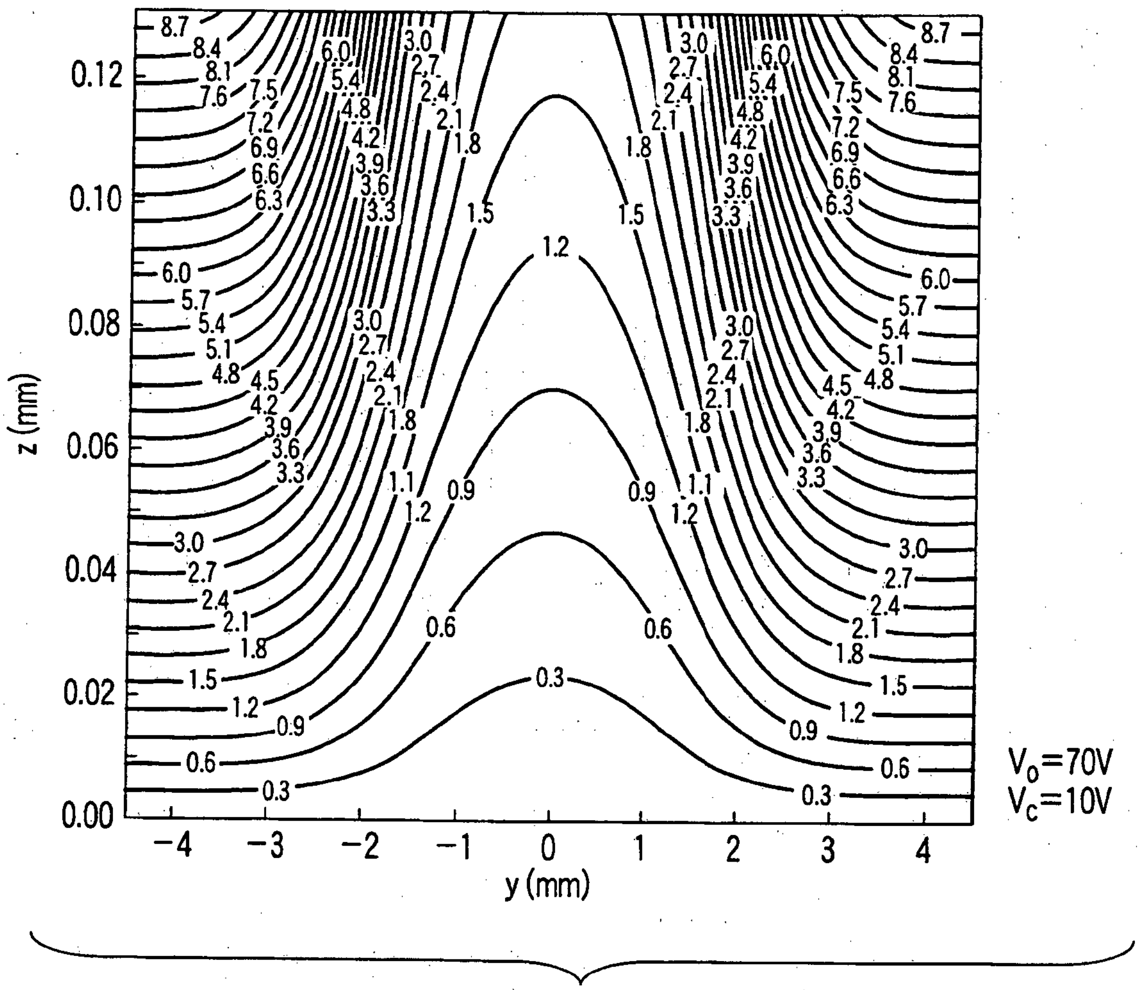
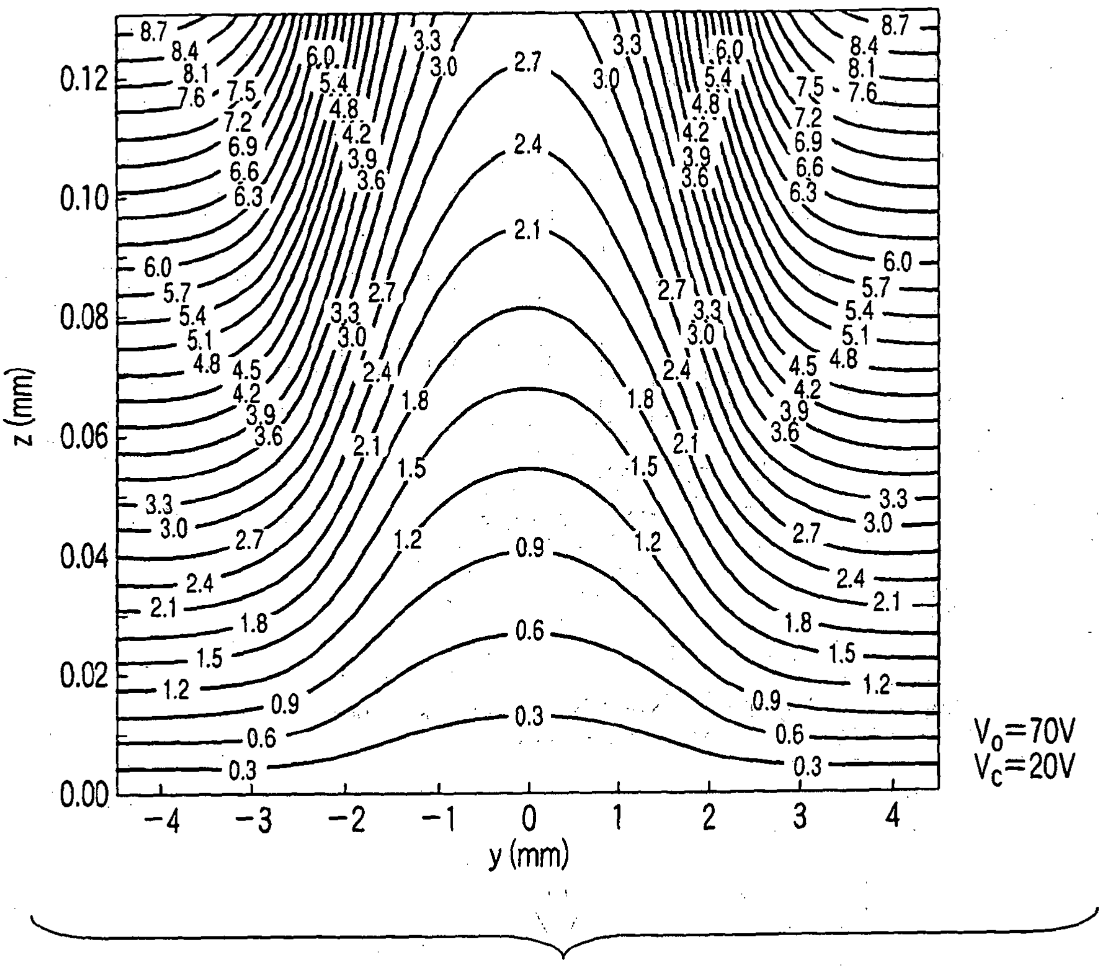


FIG.3A



F I G. 3B

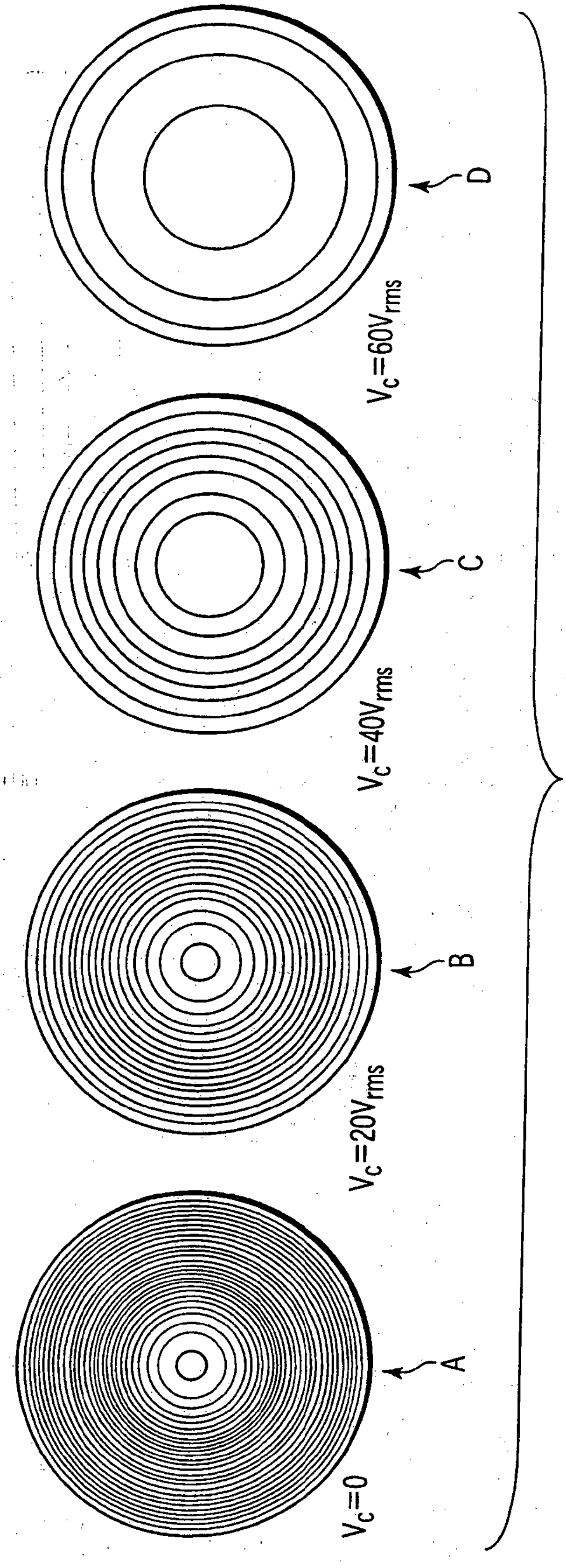
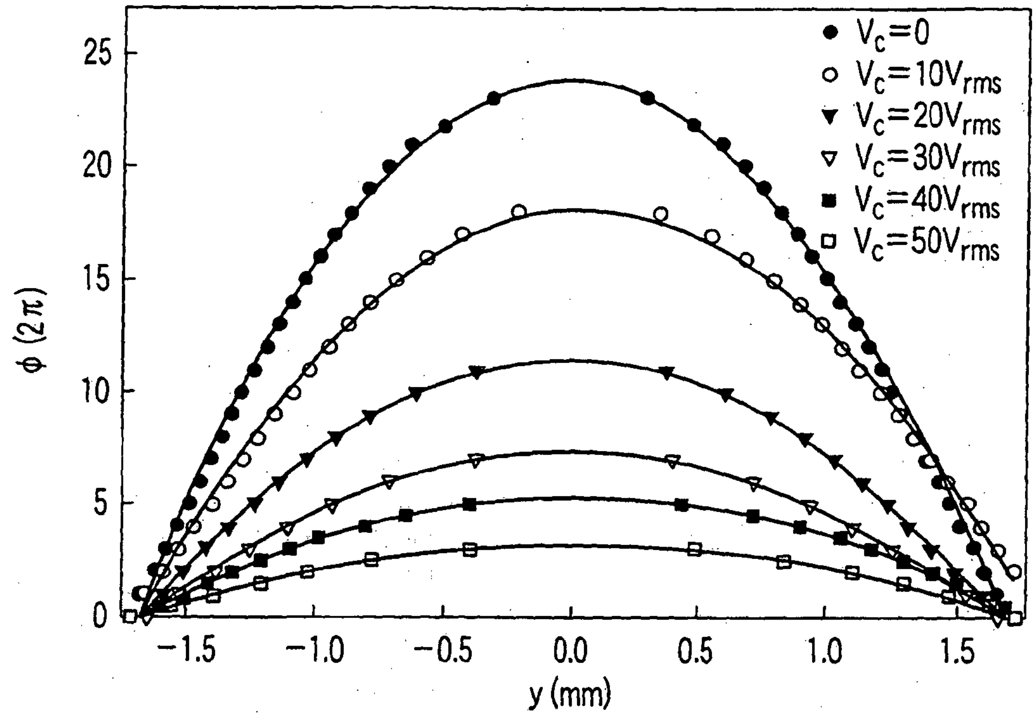
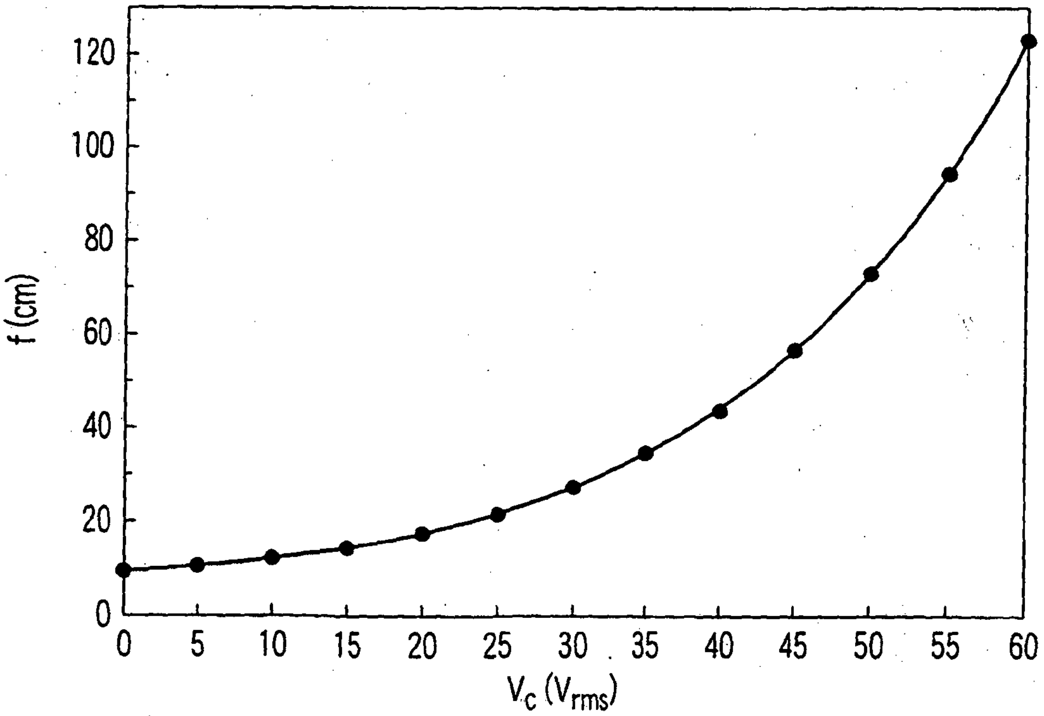


FIG. 4



Vc=0
Vc=10Vrms
Vc=20Vrms
Vc=30Vrms
Vc=40Vrms
Vc=50Vrms
φ (2π)
y (mm)

FIG.5



f (cm)
Vc (Vrms)

FIG.6

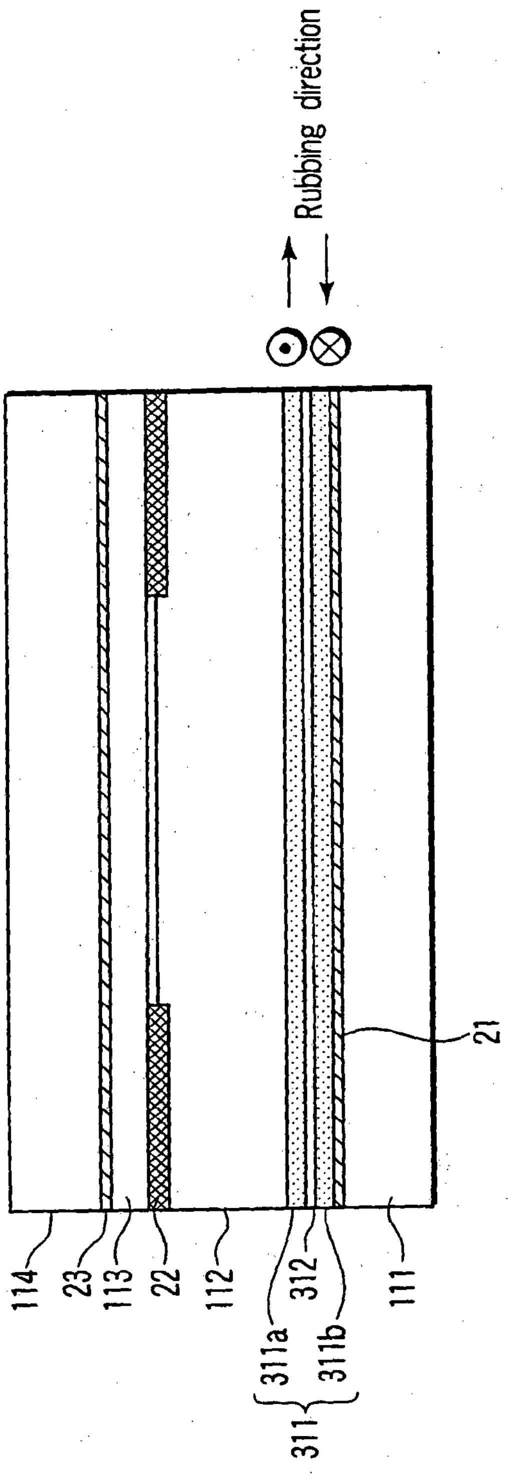


FIG.7

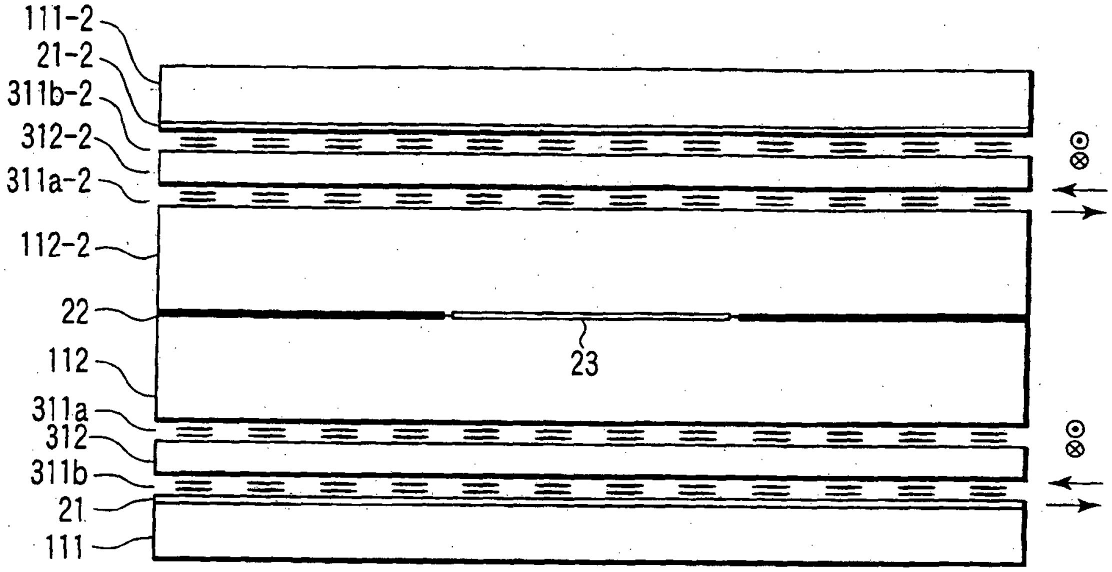

111-2
21-2
311b-2
312-2
311a-2
112-2
22
23
112
311a
312
311b
21
111

FIG. 8A

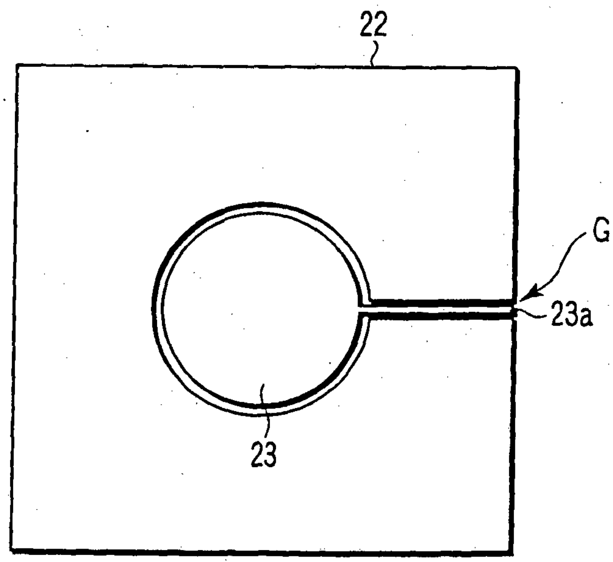

22
G
23a
23

FIG. 8B

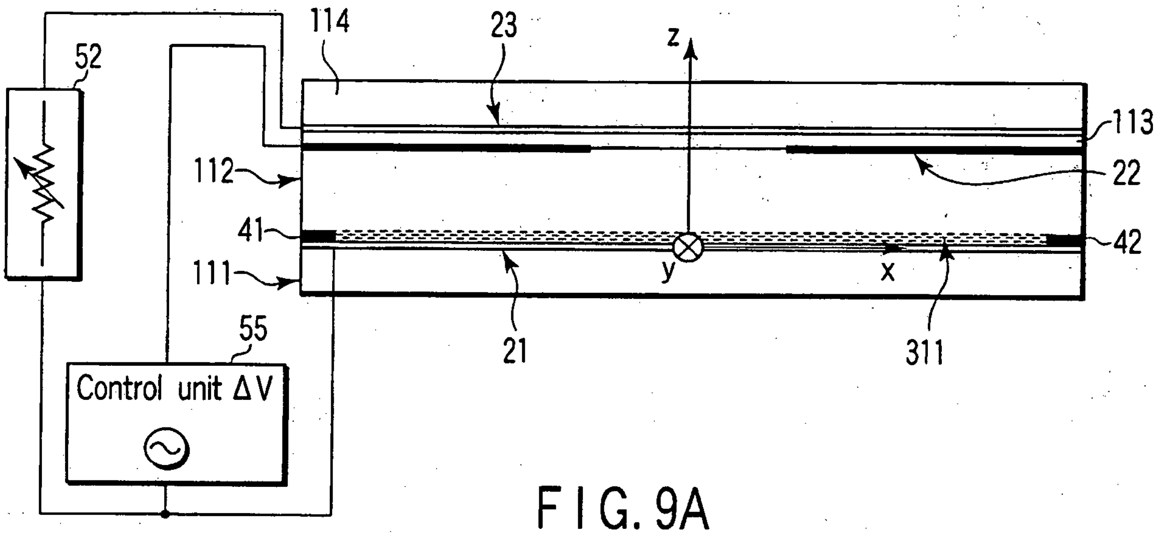

114
23
z
52
113
112
22
41
42
111
y
x
55
21
311
Control unit ΔV

FIG. 9A

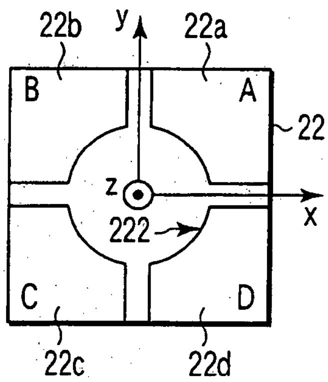

22b
y
22a
B
A
22
z
x
222
C
D
22c
22d

FIG. 9B

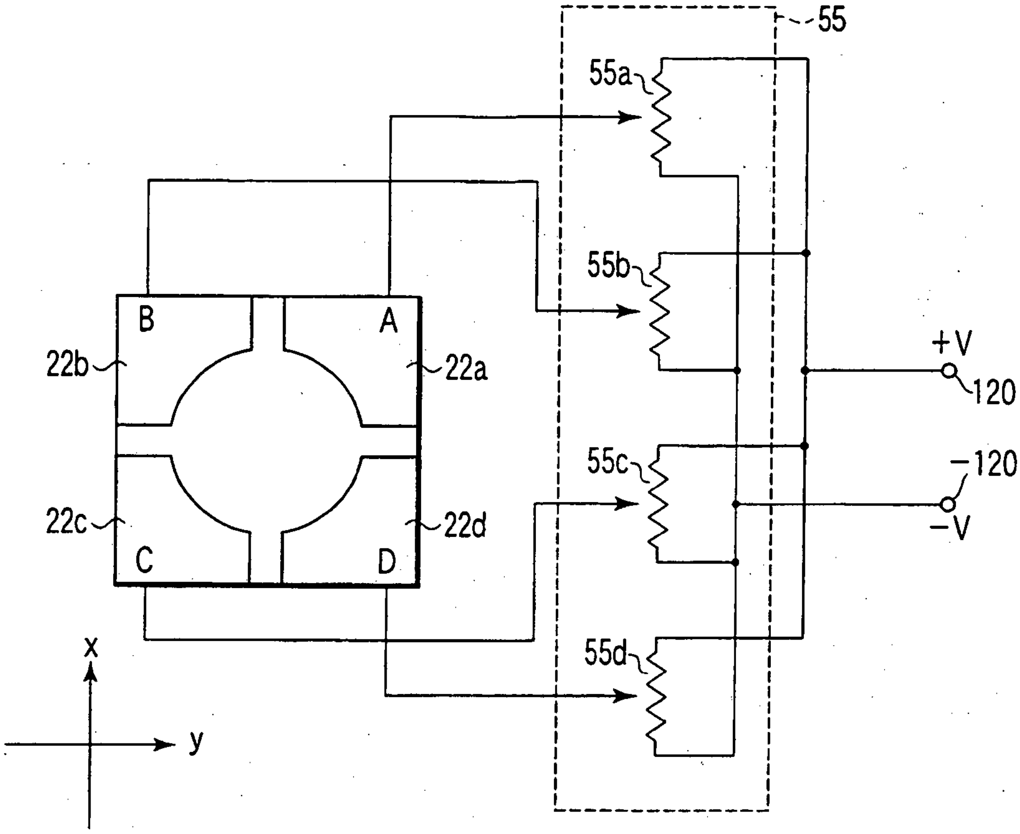


FIG. 10A

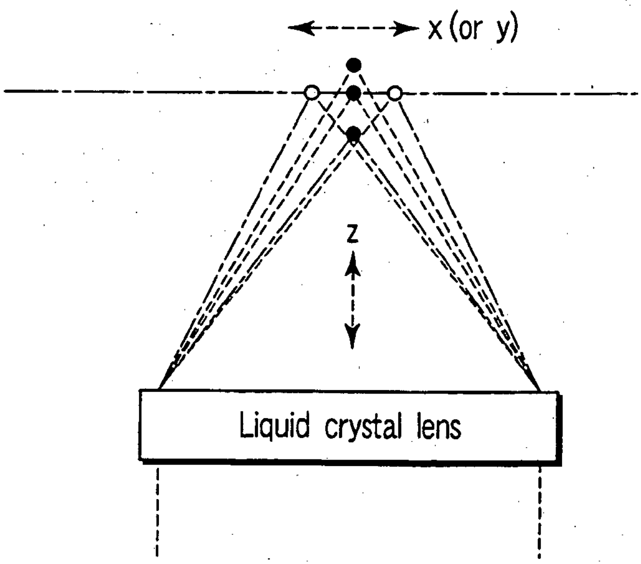


FIG. 10B

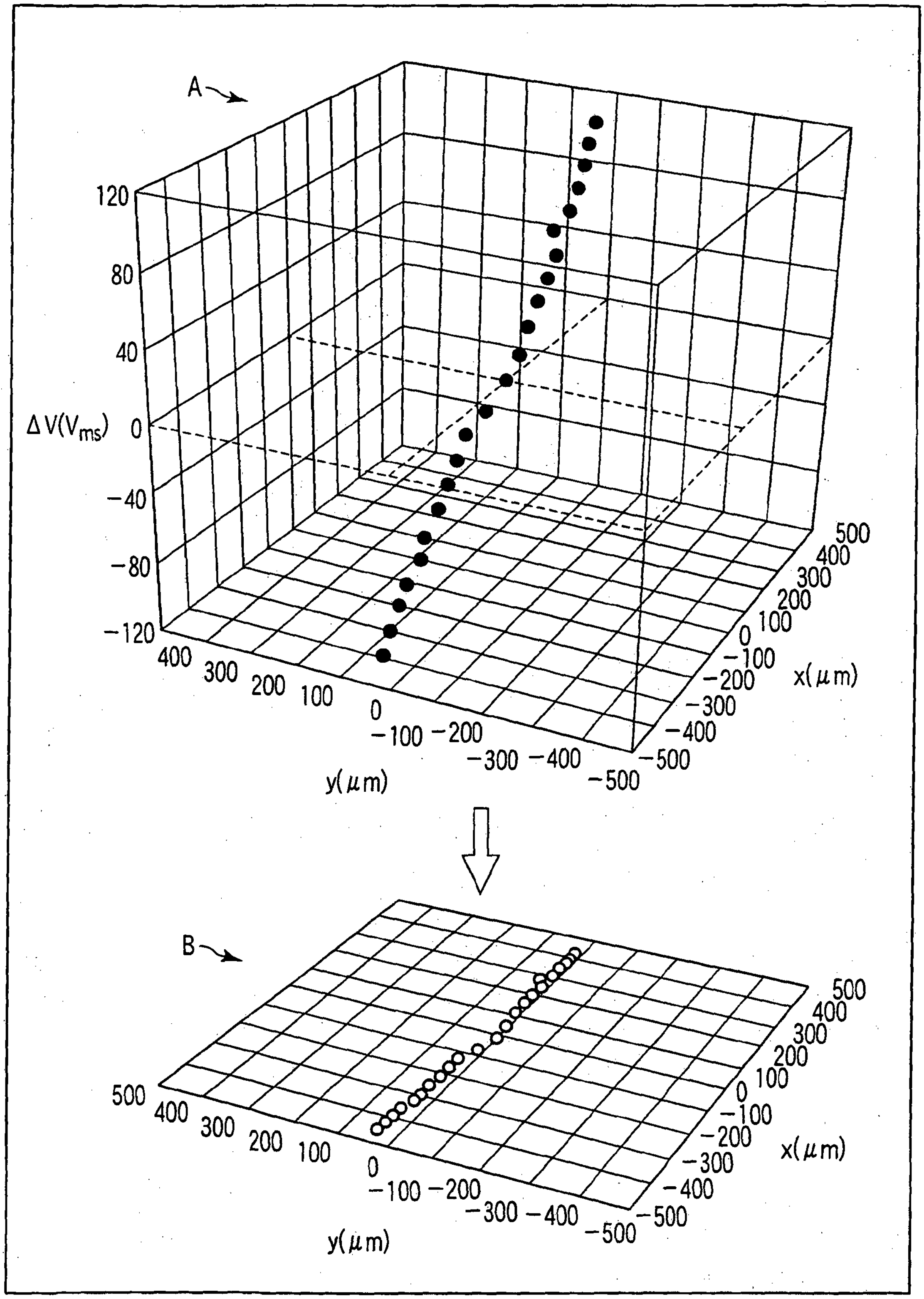

A
120
80
40
ΔV(Vms) 0
−40
−80
−120
400 300 200 100 0 −100 −200 −300 −400 −500
y(μm)
500 400 300 200 100 0 −100 −200 −300 −400 −500
x(μm)
B
500 400 300 200 100 0 −100 −200 −300 −400 −500
y(μm)
500 400 300 200 100 0 −100 −200 −300 −400 −500
x(μm)

FIG. 11

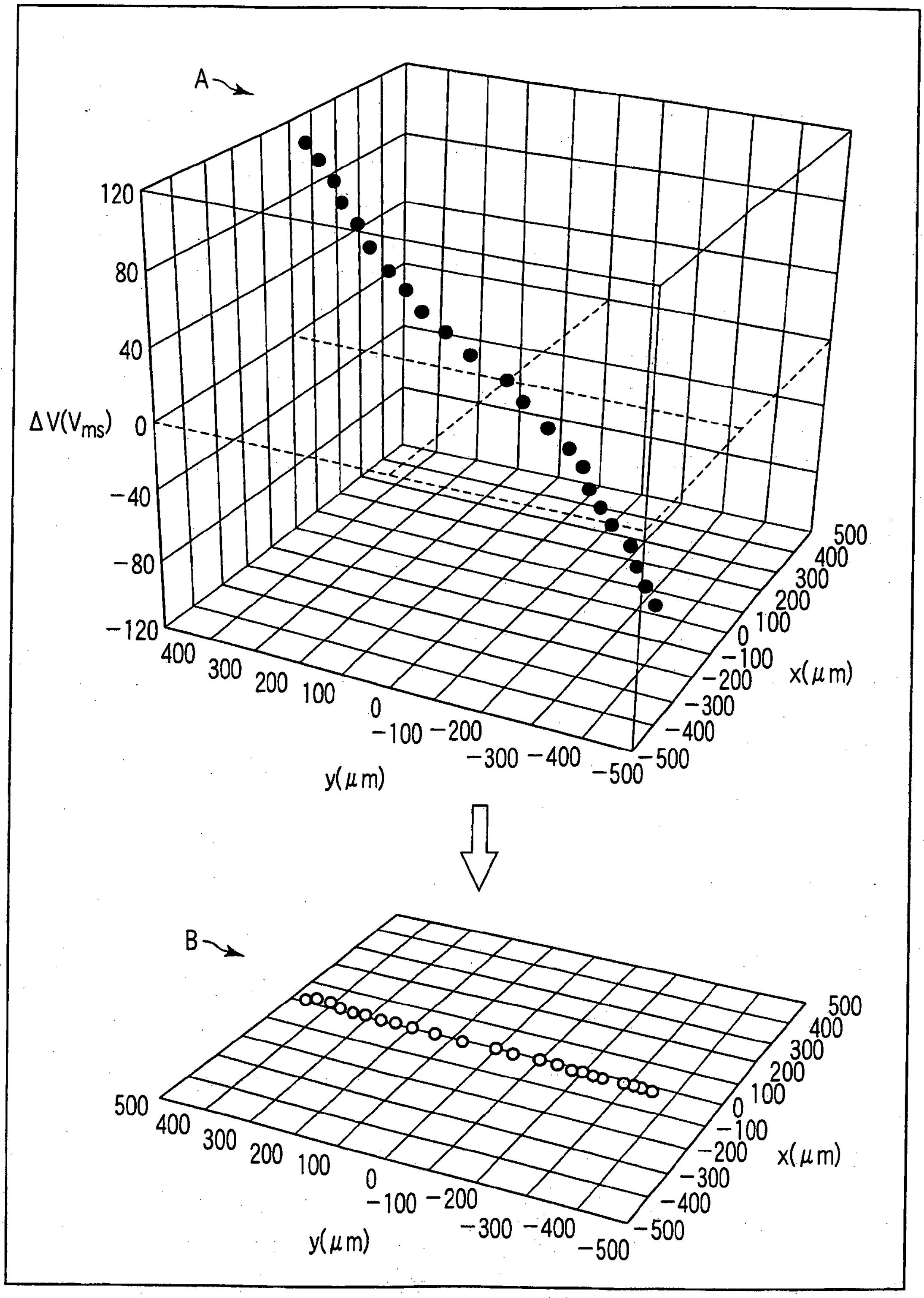

A
120
80
40
ΔV(Vms) 0
−40
−80
−120
400 300 200 100 0 −100 −200 −300 −400 −500
y(μm)
500 400 300 200 100 0 −100 −200 −300 −400 −500
x(μm)
B
500
400 300 200 100 0 −100 −200 −300 −400 −500
y(μm)
500 400 300 200 100 0 −100 −200 −300 −400 −500
x(μm)

FIG. 12

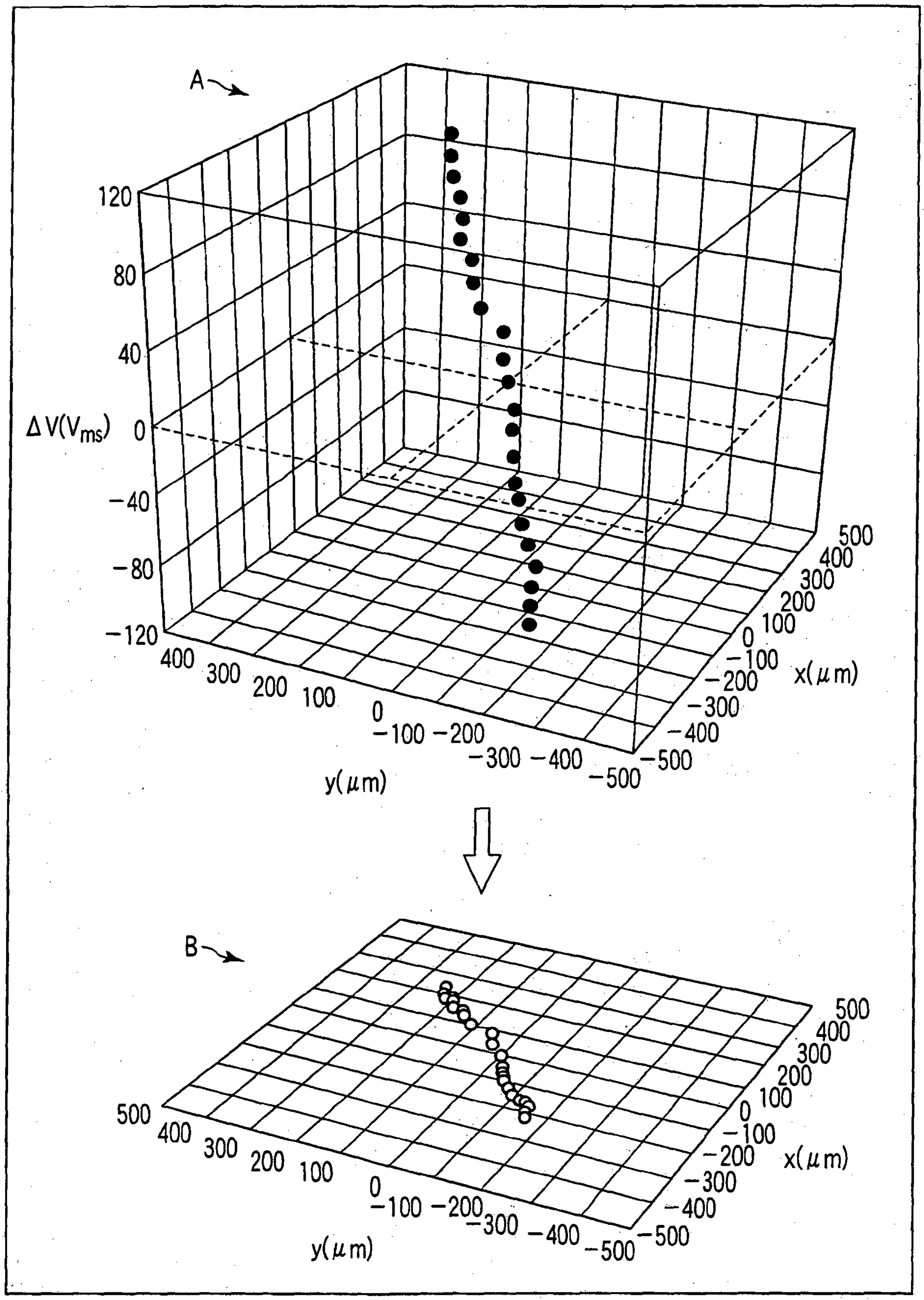

A
120
80
40
ΔV(Vms)
0
-40
-80
-120
400 300 200 100 0 -100 -200 -300 -400 -500
y(μm)
500 400 300 200 100 0 -100 -200 -300 -400 -500
x(μm)
B
500
400 300 200 100 0 -100 -200 -300 -400 -500
y(μm)
500 400 300 200 100 0 -100 -200 -300 -400 -500
x(μm)

FIG. 13

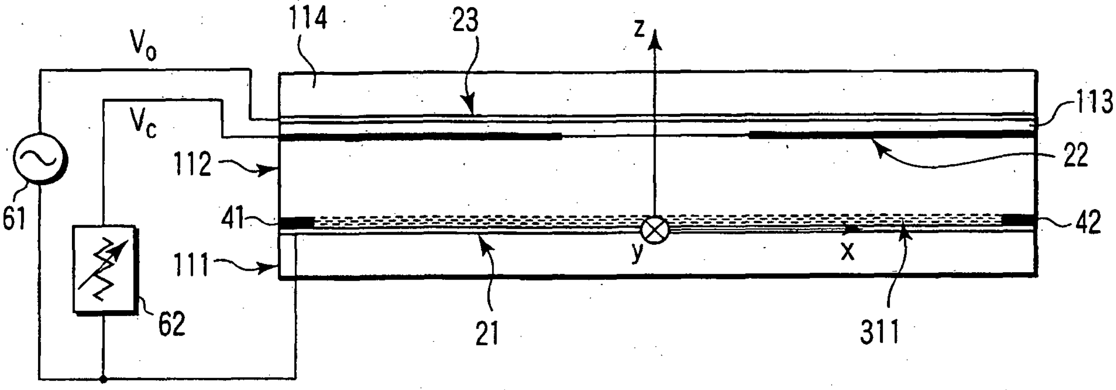


FIG. 14A

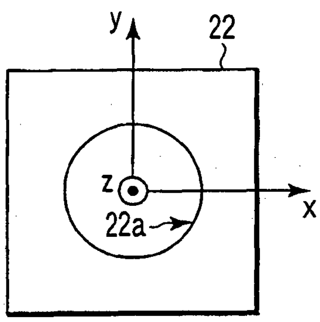


FIG. 14B

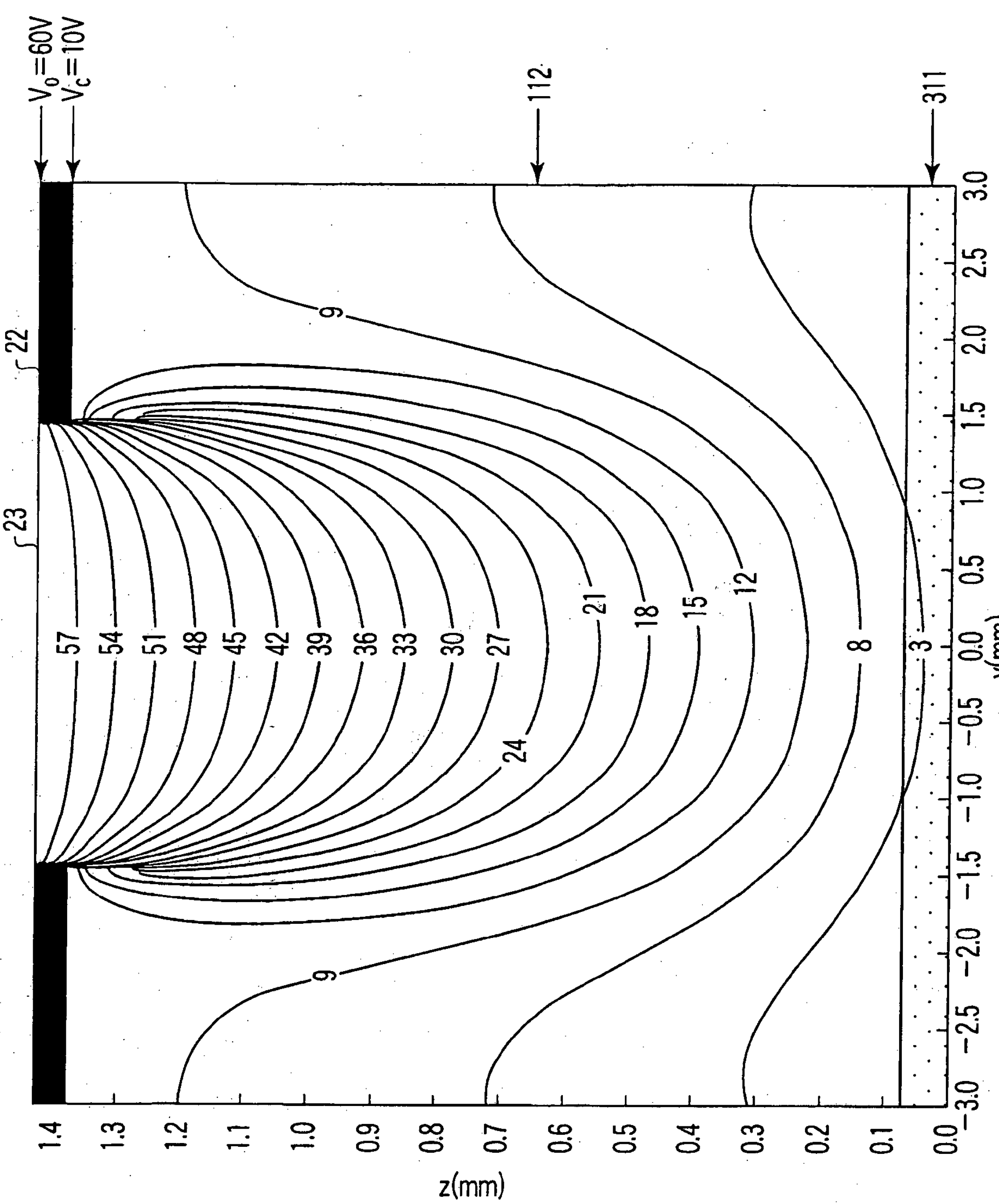

V0=60V
Vc=10V
22
23
112
311
z(mm)
y(mm)
57
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
8
3

FIG. 15

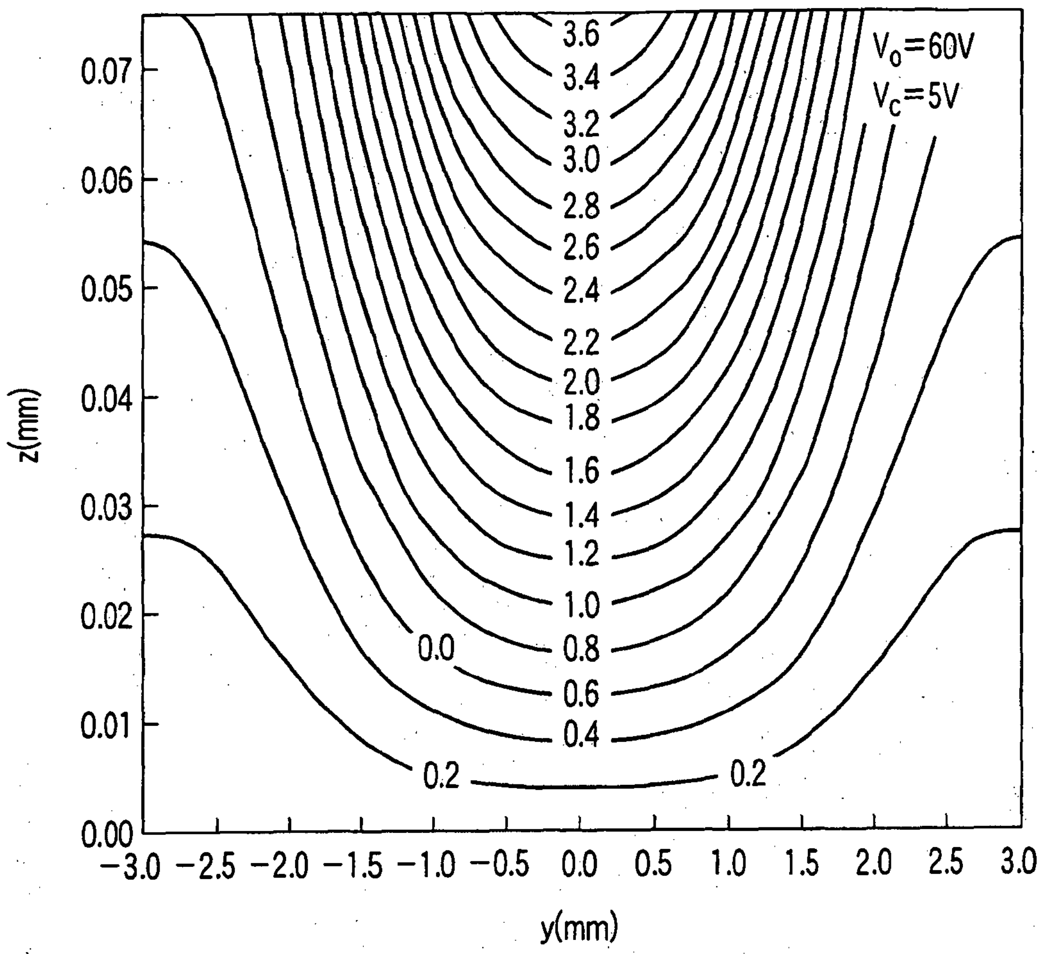
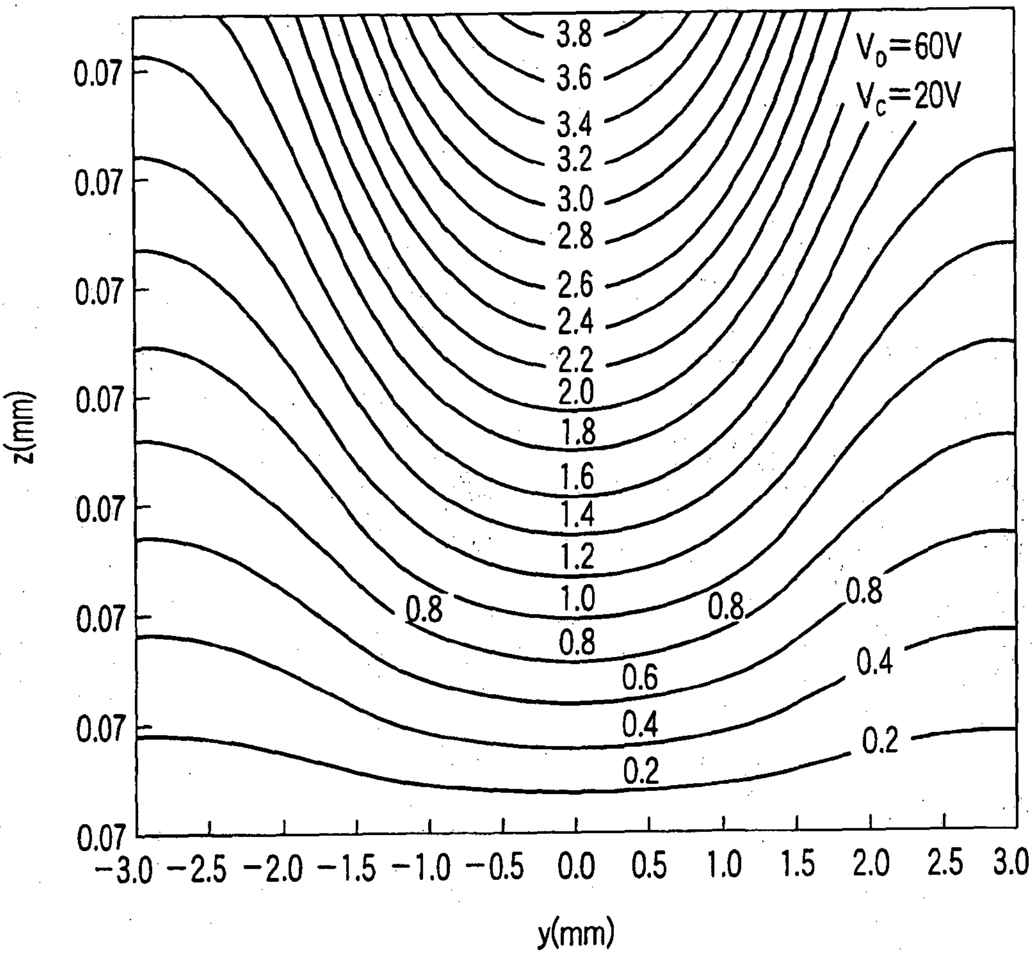

3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.2
0.0
V_0=60V
V_C=5V
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
z(mm)
−3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0
y(mm)

FIG. 16A



V0=60V
VC=20V
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.8
0.8
0.8
0.6
0.4
0.4
0.2
0.2
0.07
0.07
0.07
0.07
0.07
0.07
0.07
0.07
z(mm)
−3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0
y(mm)

FIG. 16B

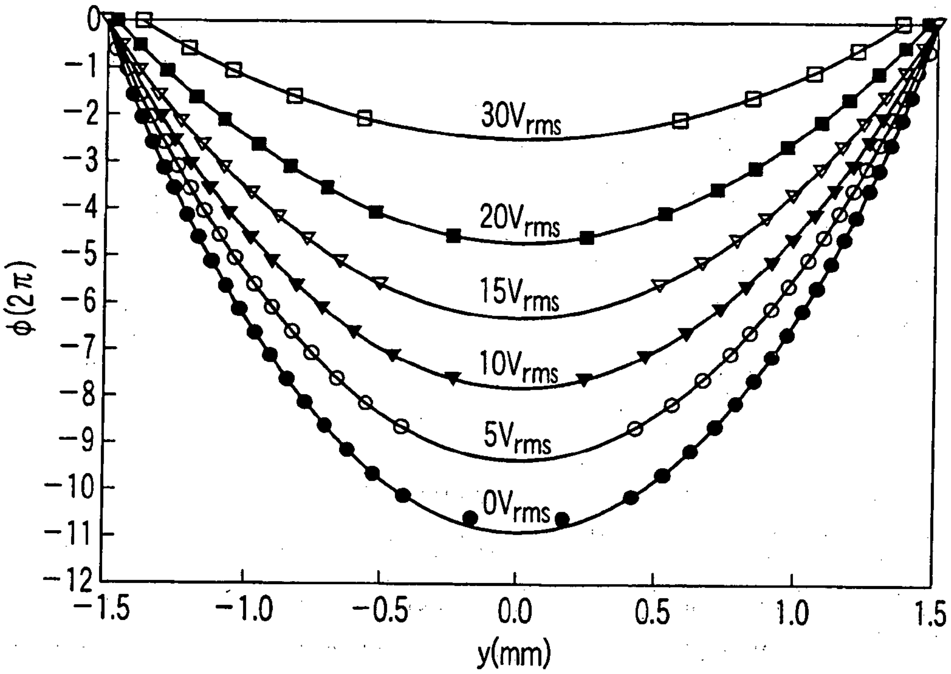

0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
$\phi(2\pi)$
30Vrms
20Vrms
15Vrms
10Vrms
5Vrms
0Vrms
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
y(mm)

FIG. 17

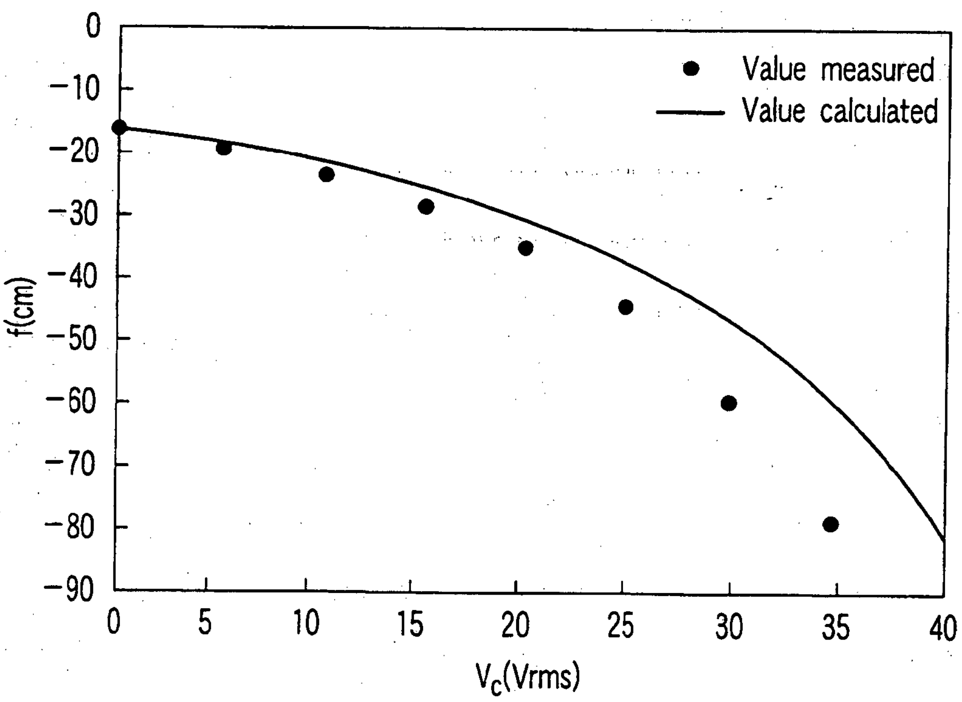

0
−10
−20
−30
−40
−50
−60
−70
−80
−90
f(cm)
Value measured
Value calculated
0
5
10
15
20
25
30
35
40
Vc(Vrms)

FIG. 18

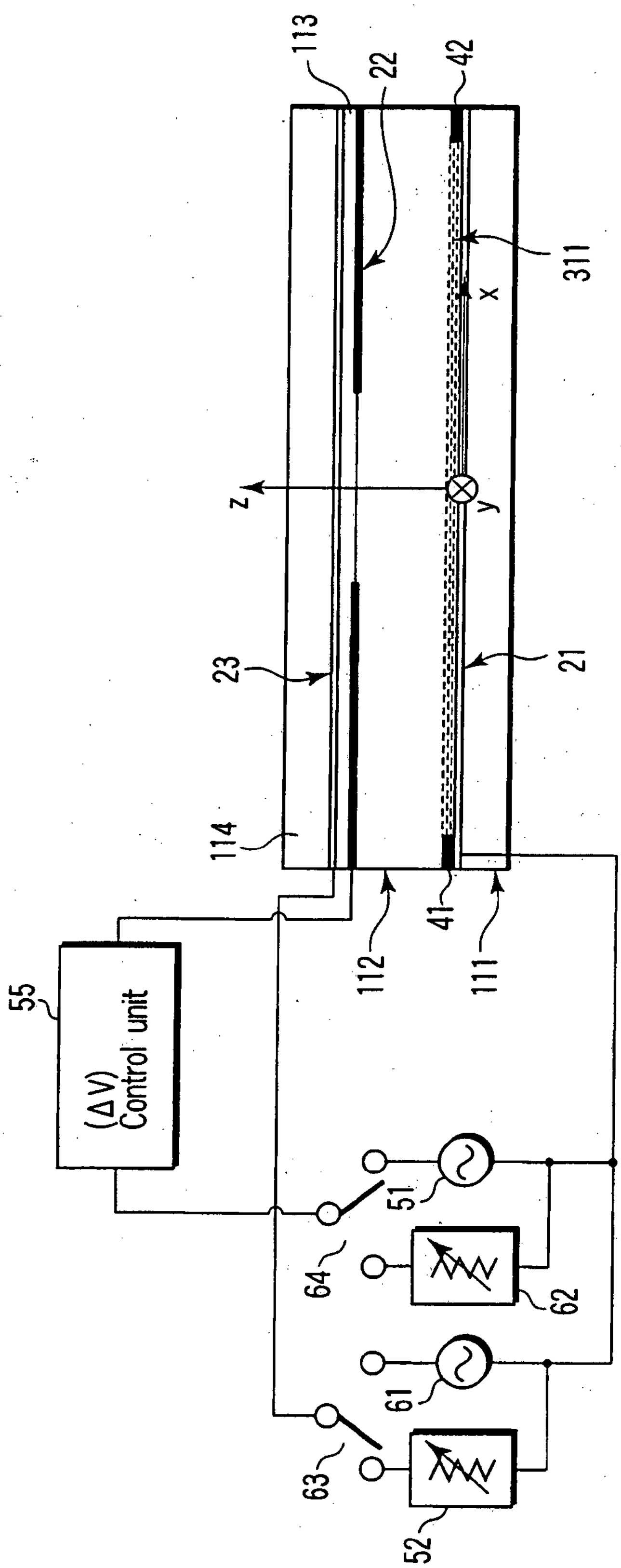

113
22
42
311
x
z
y
23
21
114
112
41
111
55
(ΔV)
Control unit
51
64
62
61
63
52

FIG. 19

REFERENCES CITED IN THE DESCRIPTION

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- **S. SATO.** The world of liquid crystal. Sangyo Tosho Co., Ltd, 15 April 1994, 186-189 **[0011]**
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