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Hasei

(54) **MICROLENS, OPTICAL PLATE, DIFFUSING PLATE, LIGHT GUIDE PLATE, BACKLIGHT, PROJECTION SCREEN, PROJECTION SYSTEM, ELECTRO-OPTICAL DEVICE, ELECTRONIC APPARATUS, AND METHOD FOR MANUFACTURING A MICROLENS**

(75) Inventor: **Hironori Hasei**, Okaya (JP)

Correspondence Address:
HARNESS, DICKEY & PIERCE, P.L.C.
P.O. BOX 828
BLOOMFIELD HILLS, MI 48303 (US)

(73) Assignee: **Seiko Epson Corporation**, Tokyo (JP)

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(57) **ABSTRACT**

A method for manufacturing a microlens, comprises: discharging a liquid lens material on an optically transparent substrate; and hardening the lens material to provide the microlens; the microlens having different curvatures depending on where the lens material is discharged.

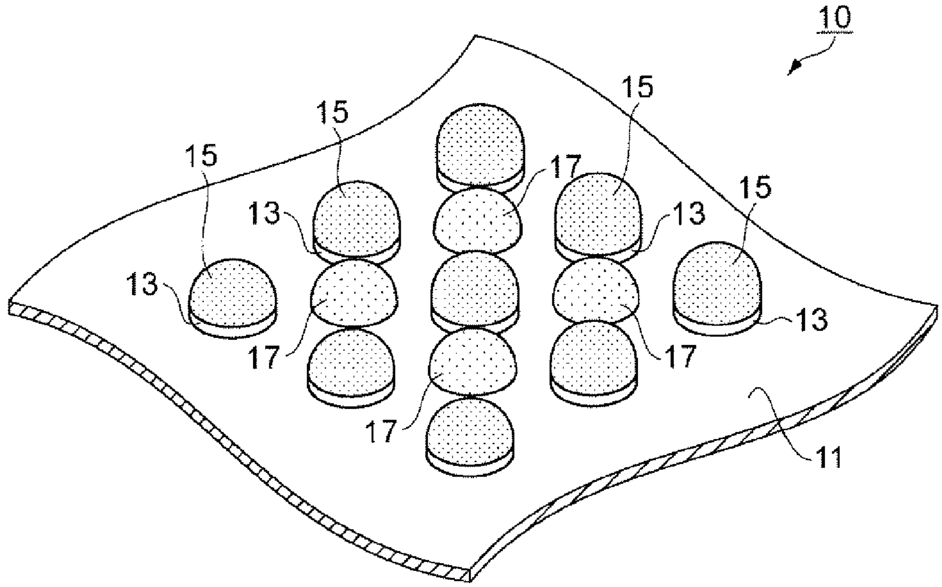

FIG. 1

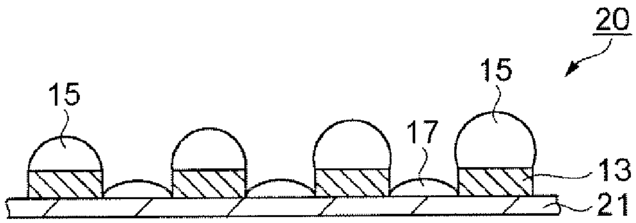

FIG. 2

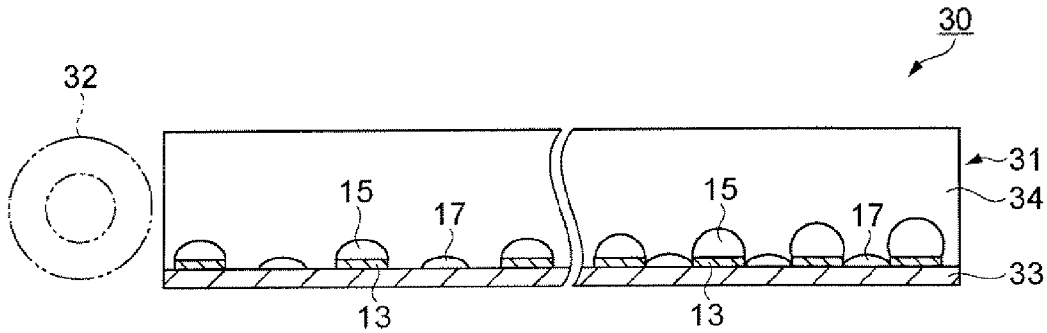

FIG. 3

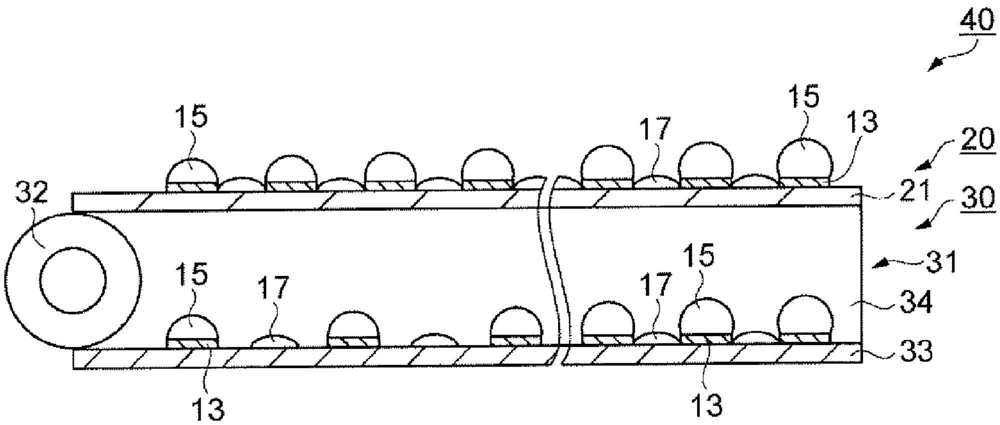
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FIG. 4

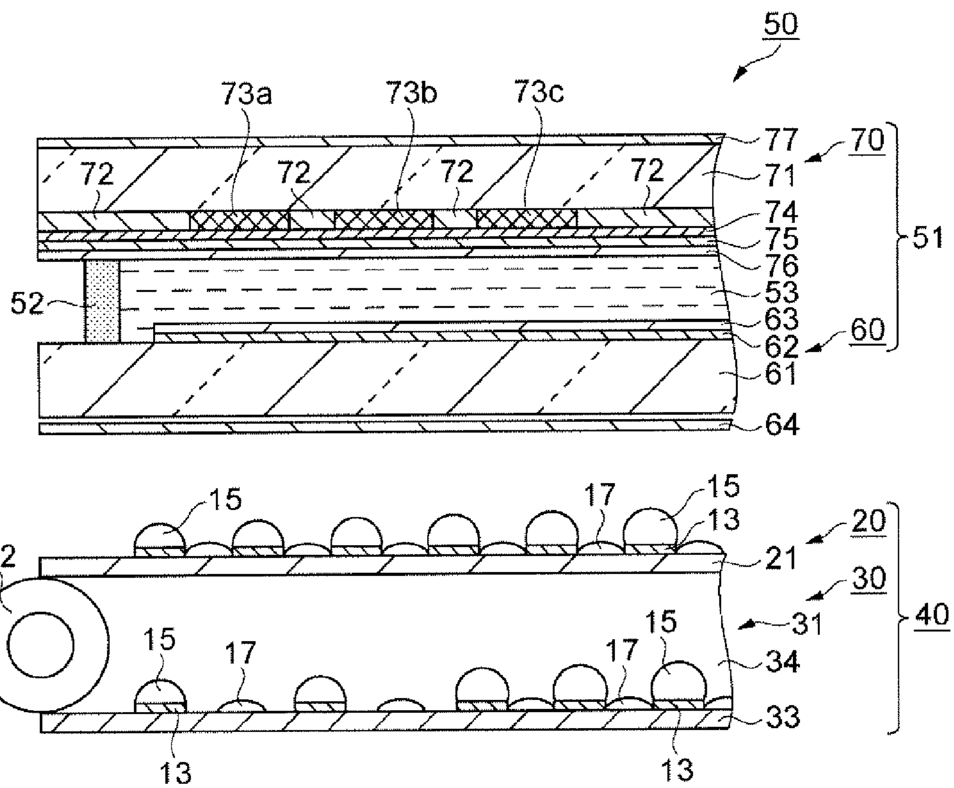
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FIG. 5

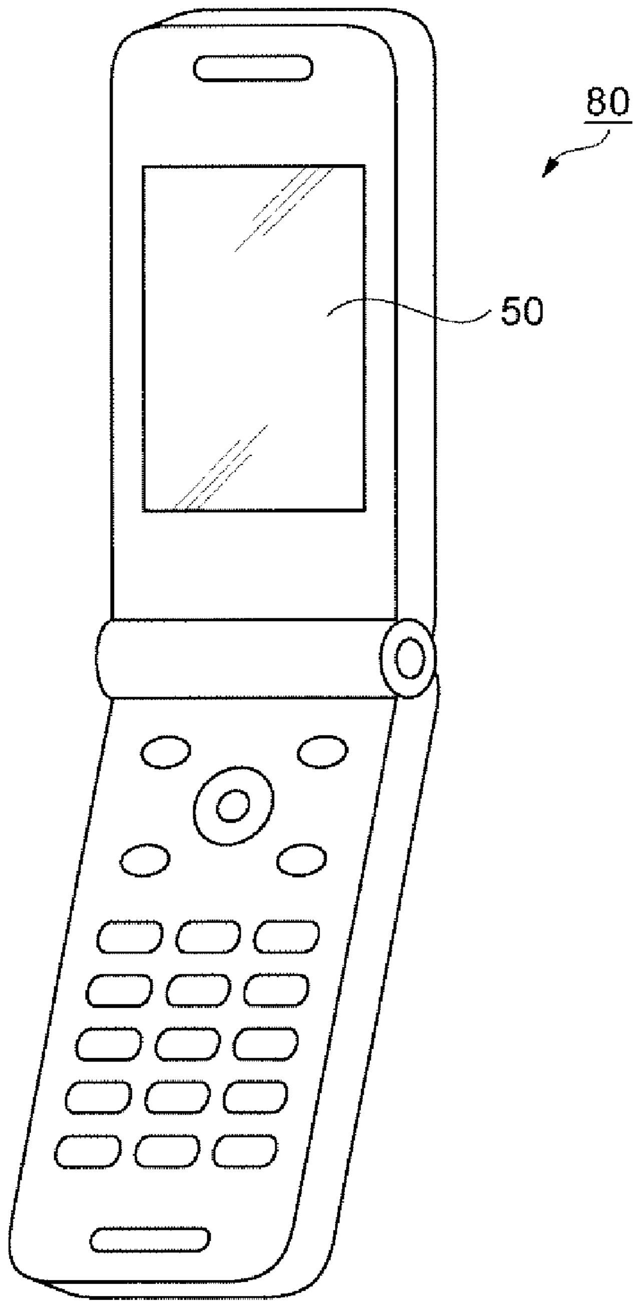

FIG. 6

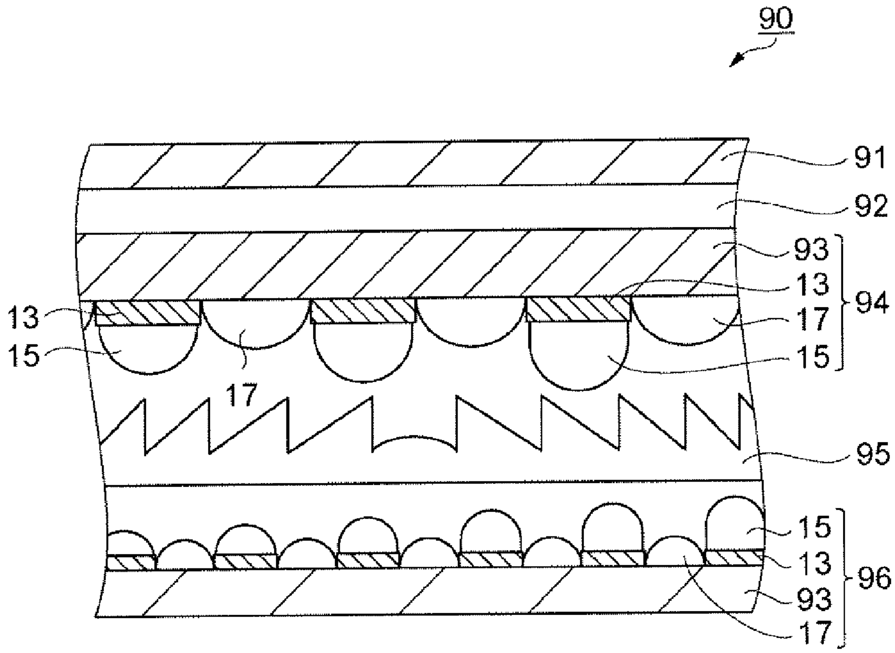
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FIG. 7

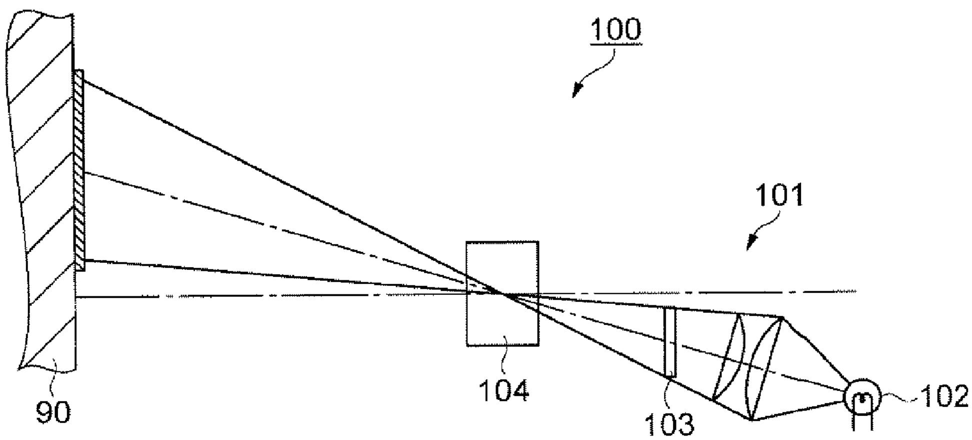
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FIG. 8

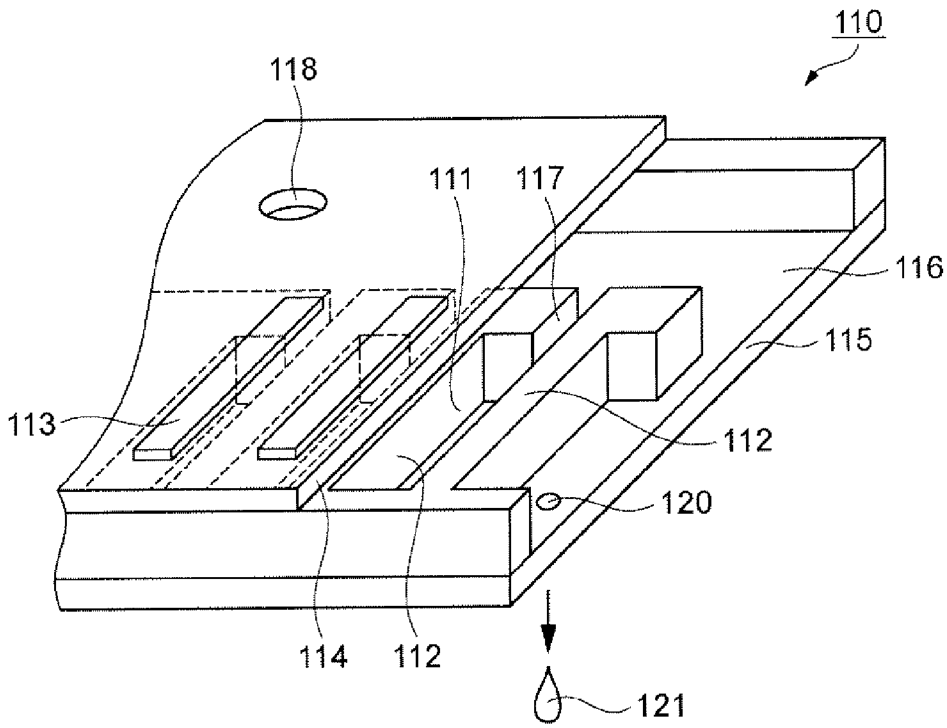
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FIG. 9A

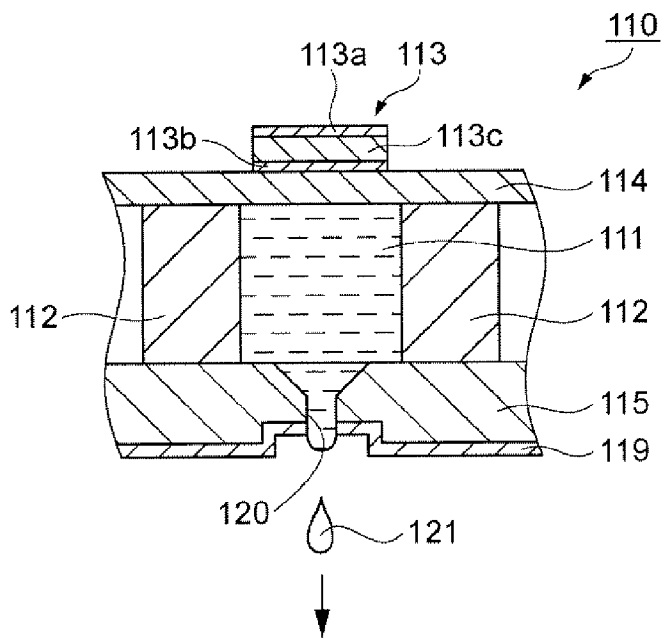
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FIG. 9B

FIG.10A

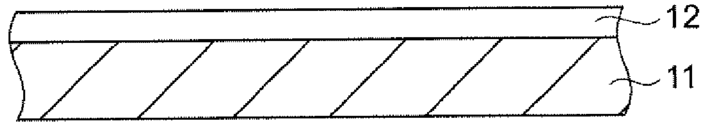


FIG.10B

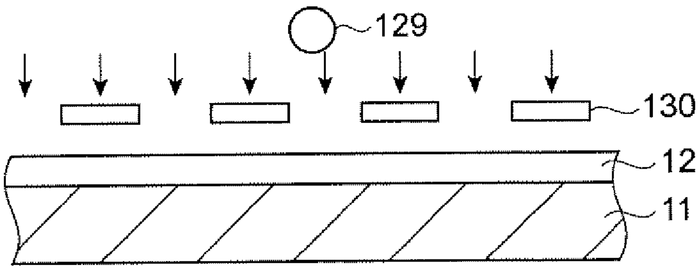


FIG.10C

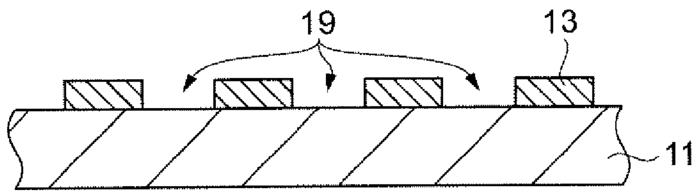


FIG.10D

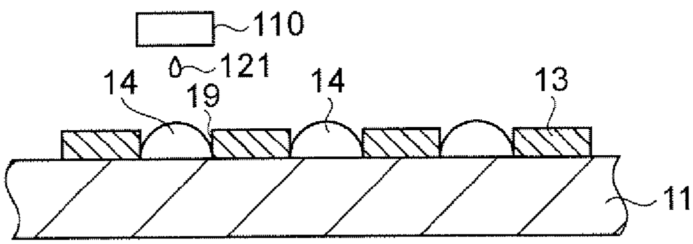


FIG.10E

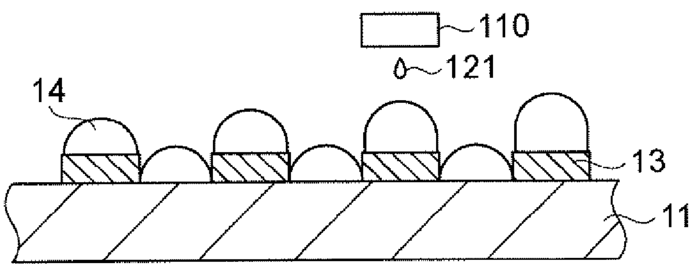
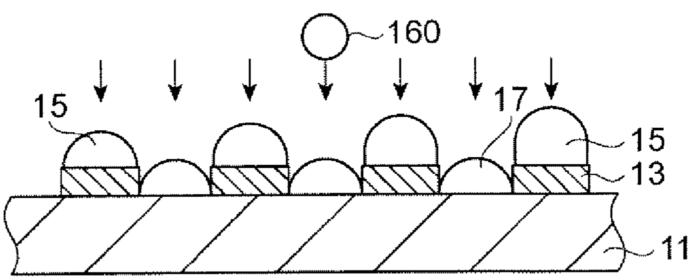


FIG.10F



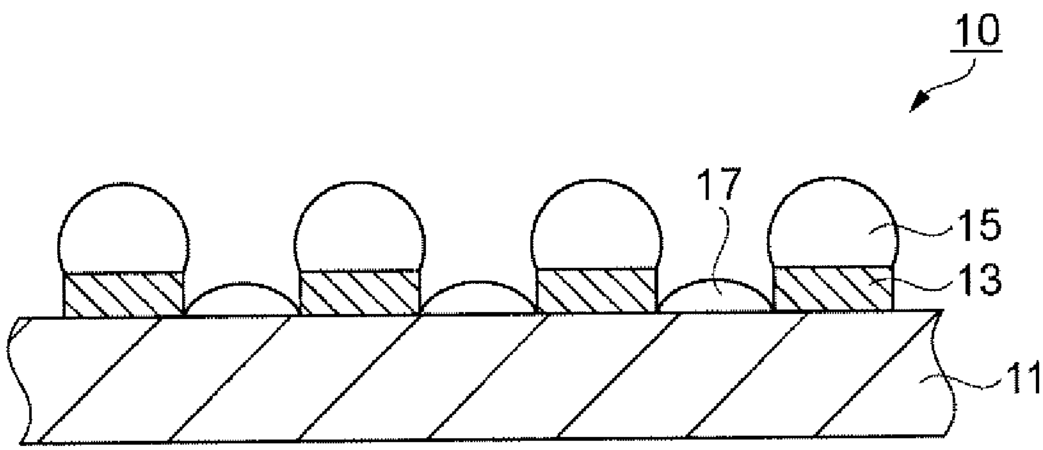


FIG.11

FIG.12A

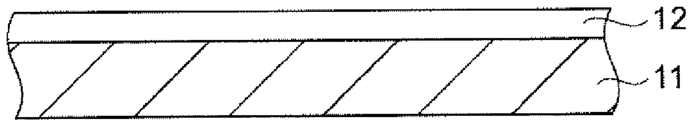


FIG.12B

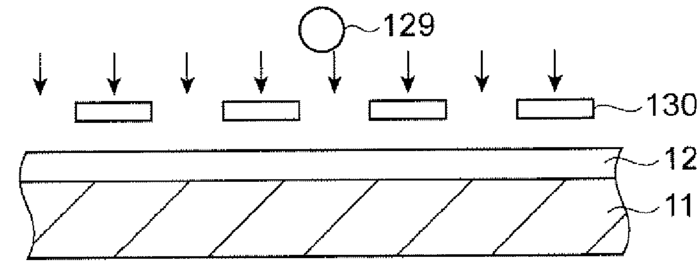


FIG.12C

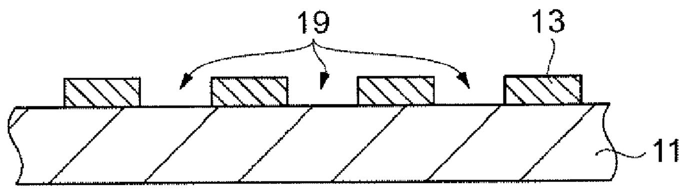


FIG.12D

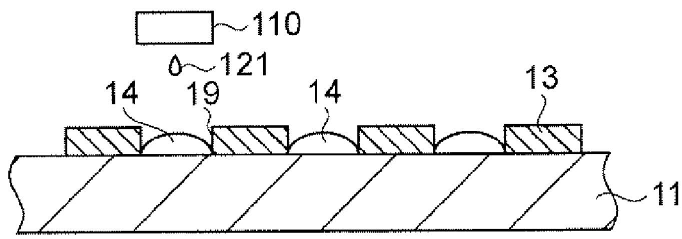


FIG.12E

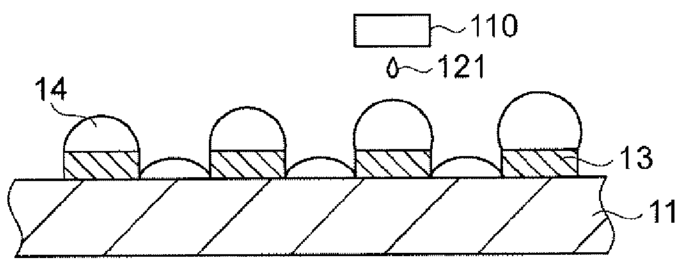
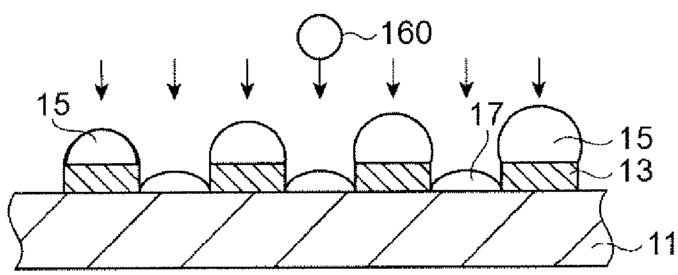


FIG.12F



MICROLENS, OPTICAL PLATE, DIFFUSING PLATE, LIGHT GUIDE PLATE, BACKLIGHT, PROJECTION SCREEN, PROJECTION SYSTEM, ELECTRO-OPTICAL DEVICE, ELECTRONIC APPARATUS, AND METHOD FOR MANUFACTURING A MICROLENS

BACKGROUND OF THE INVENTION

[0001] 1. Technical Field

[0002] The present invention relates to a microlens, an optical plate, a diffusing plate, a light guide plate, a backlight, a projection screen, a projection system, an electro-optical device, an electronic apparatus, and a method for manufacturing a microlens.

[0003] 2. Related Art

[0004] Backlights are used as light sources for notebook computers, mobile terminals, and other liquid crystal displays. High beam directivity and luminance are required for these applications.

[0005] Related art backlights have a microlens on their tops and a diffusing plate having micro projections on their bottoms to be in contact with the upper surface of a light guide plate. With this structure, a light beam emitted from an external light source is reflected for several times in the light guide plate and guided by the micro projections into the diffusing plate, so that the microlens can provide high beam directivity of the guided light. JP-A-10-39118 is an example of related art.

[0006] However, since the microlens of the related art diffusing plate is manufactured by molding or photolithography, it involves many manufacturing steps and high processing costs. JP-A-2005-71928 is another example of related art that shows a method for manufacturing a microlens easily by attaching a lens material to a substrate by droplet discharge and then hardening the material. There arises a problem again that beam directivity and luminance are hard to adjust with respect to multiple types of color elements, since the microlens is manufactured to have an almost identical curvature.

SUMMARY

[0007] An advantage of the invention is to provide a microlens, an optical plate, a diffusing plate, a light guide plate, a backlight, a projection screen, a projection system, an electro-optical device, an electronic apparatus, and a method for manufacturing a microlens that provide high luminance and beam directivity with respect to multiple types of color elements.

[0008] A method for manufacturing a microlens according to one aspect of the invention includes: discharging a liquid lens material on an optically transparent substrate; and hardening the lens material to provide the microlens. Here, the microlens has different curvatures depending on where the lens material is discharged.

[0009] In this method, the lens material is discharged on the substrate in the step of discharging the lens material and hardened in the subsequent step of hardening the lens material. Here, the microlens is provided to have different curvatures depending on where the lens material is discharged in the step of discharging the lens material. By using the light-collection property of the microlens having different curvatures, it is possible to optimize beam directivity with respect to multiple types of color elements, for example.

[0010] The method for manufacturing a microlens may also include providing liquid-repellent treatment to a surface of the substrate prior to discharging the lens material. In this case, the lens material is discharged to a repellent-treated area and a repellent-treatment-free area in the step of discharging the lens material to provide the microlens having different curvatures.

[0011] A lens material portion having a high curvature attributed to a liquid-repellent effect is provided by making both the repellent-treated and repellent-treatment-free areas in the step of providing liquid-repellent treatment and discharging a lens material portion to the repellent-treated area. Another lens material portion having a lower curvature than that of the lens material portion discharged on the repellent-treated area is provided by discharging another lens material portion to the repellent-treatment-free area. By hardening these lens material portions, the microlenses having different curvatures can be easily provided.

[0012] The method for manufacturing a microlens may also include providing an optically transparent convex on the substrate and a resulting concave between one convex and another adjacent convex prior to discharging the lens material. In this case, the lens material is discharged to the convex and the concave in the step of discharging the lens material to provide the microlens having different curvatures.

[0013] The convex and the concave are provided on the substrate in this step. The pinning effect of the lens material restrains the edge of a lens material portion discharged on the convex from spreading at the upper rim of the convex. It is therefore possible to provide the microlens having a higher curvature than another lens material portion discharged on the concave. Furthermore, high luminance can be achieved by densely arranging the microlenses.

[0014] According to the method for manufacturing a microlens, the curvatures of the microlens may be set to provide an almost identical light-collection rate in a position at a predetermined distance from the substrate in a light-emitting direction.

[0015] Accordingly, for example, when light is emitted to color elements, the rate of collecting light emitted from the microlens is almost fixed on the surfaces of the color elements. It is therefore possible to achieve high luminance and reduce uneven luminance.

[0016] A microlens according to another aspect of the invention is manufactured by any of the above-described method for manufacturing a microlens.

[0017] Accordingly, with the microlens having different curvatures, it is possible to optimize beam directivity and luminance with respect to multiple types of color elements.

[0018] An optical plate according to yet another aspect of the invention includes: an optically transparent substrate; and a plurality of microlenses provided on the substrate. At least one of the plurality of microlenses has a different curvature from a curvature of the other microlenses.

[0019] Accordingly, with the microlenses having different curvatures provided on the substrate, it is possible to optimize beam directivity with respect to multiple color elements, for example.

[0020] The optical plate may also include a convex provided on the substrate and a microlens provided on the convex. In this case, the microlenses provided on the substrate have a different curvature from a curvature of the microlens provided on the convex.

[0021] Accordingly, for example, an almost identical light-collection rate can be achieved on the surfaces of the color elements with the microlens having a high curvature provided on the convex and the microlenses having a low curvature provided on the substrate.

[0022] In the optical plate, the microlenses may have different curvatures depending on their heights from the substrate.

[0023] Accordingly, since the microlenses have different curvatures depending on their heights from the substrate, it is possible to optimize beam directivity based on the heights of the microlenses.

[0024] In the optical plate, the microlenses may have lower curvatures as their heights from the substrate decrease.

[0025] Accordingly, since the microlenses have lower curvatures as their heights from the substrate decrease, it is possible to increase distance to a light-collecting point.

[0026] The optical plate may be a diffusing plate.

[0027] Accordingly, with the microlenses having different curvatures, for example, it is possible to make an optimum adjustment to provide an almost identical rate to collect light emitted to color elements.

[0028] The optical plate may be a light guide plate also including: a reflector reflecting light emitted from an external light source; and a light guide part guiding the light emitted from the external light source to an entire surface thereof.

[0029] Accordingly, with the microlenses having different curvatures, it is possible to enhance scattering properties and improve beam directivity.

[0030] In the light guide plate, the microlenses may be provided to have higher curvatures with distance from the external light source emitting light from a side of the substrate.

[0031] Accordingly, with the microlenses having higher curvatures with distance from the external light source, it is possible to prevent a reduction in the amount of light and provide even luminance.

[0032] A projection screen according to still another aspect of the invention includes a Fresnel lens, and a lenticular sheet to which any of the above-described optical plate is applied.

[0033] Accordingly, a projection screen having good scattering properties can be provided.

[0034] A projection system according to yet another aspect of the invention includes the above-described projection screen.

[0035] Accordingly, a projection system that enhances visibility of images projected and provides high-quality images can be provided.

[0036] A backlight according to still another aspect of the invention includes at least one of the above-described optical plate and the above-described light guide plate.

[0037] Accordingly, a backlight that optimizes a light scattering efficiency can be provided with the microlens having different curvatures.

[0038] An electro-optical device according to still another aspect of the invention includes the above-described backlight.

[0039] Accordingly, an electro-optical device having high beam directivity can be provided.

[0040] An electronic apparatus according to still further aspect of the invention includes the above-described electro-optical device.

[0041] Accordingly, an electronic apparatus having high beam directivity can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0042] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0043] **FIG. 1** is a diagram schematically showing an optical plate.

[0044] **FIG. 2** is a sectional view schematically showing a diffusing plate.

[0045] **FIG. 3** is a sectional view schematically showing a light guide plate.

[0046] **FIG. 4** is a sectional view schematically showing a backlight.

[0047] **FIG. 5** is a sectional view schematically showing a liquid crystal display as an electro-optical device.

[0048] **FIG. 6** is a diagram schematically showing a mobile terminal as an electronic apparatus.

[0049] **FIG. 7** is a sectional view schematically showing a projection screen.

[0050] **FIG. 8** is a diagram schematically showing a projection system.

[0051] **FIGS. 9A and 9B** show a structure of a discharge head.

[0052] **FIG. 9A** is a perspective view with a part thereof broken down.

[0053] **FIG. 9B** is a sectional view showing major elements thereof.

[0054] **FIGS. 10A through 10F** show steps to manufacture a microlens.

[0055] **FIG. 11** is a sectional view schematically showing an optical plate according to one modification.

[0056] **FIGS. 12A through 12F** show steps to manufacture a microlens according to the modification.

DESCRIPTION OF THE EMBODIMENTS

[0057] Embodiments of the invention will be described with reference to the accompanying drawings.

Structure of Optical Plate

[0058] The structure of an optical plate according to one embodiment of the invention will be first described. **FIG. 1** is a diagram schematically showing an optical plate **10**.

[0059] Referring to **FIG. 1**, the optical plate **10** includes an optically transparent substrate **11**, an optically transparent convex **13** provided on the substrate **11**, a microlens **15** provided on the convex **13**, and a microlens **17** provided on the substrate **11**.

[0060] The substrate **11** is optically transparent and made of quartz, glass, acrylic resin, or polycarbonate, polyester or other transparent resin, for example.

[0061] The convex **13** is almost columnar in shape with an almost flat top. The convex **13** is provided in a plural number at almost even intervals on the substrate **11**. The convex **13** is optically transparent and made of, for example, acrylic resin, polyester resin, urethane resin, epoxy resin, polycarbonate resin, styrene resin, or novolac resin.

[0062] The microlens **15** is provided on each convex **13** to have different curvatures depending on where it is provided.

[0063] The microlens **17** is provided on the substrate **11** and is almost hemispherically shaped. The microlens **17** is provided almost evenly in the microlens **15** array provided almost evenly.

[0064] The microlenses **15** and **17** are made of, for example, ultraviolet-curing acrylic resin or ultraviolet-curing epoxy resin with a precursor, such as a polyimide precursor.

[0065] The ultraviolet-curing resin used here includes at least one of a prepolymer, oligomer, and monomer, and also includes a photopolymerization initiator.

[0066] Examples of the prepolymer or oligomer included in the ultraviolet-curing acrylic resin used here may include the following: epoxy acrylates, urethane acrylates, polyester acrylates, polyether acrylates, spiroacetal acrylates and other acrylates; and epoxy methacrylates, urethane methacrylates, polyester methacrylates, polyether methacrylates and other methacrylates.

[0067] Examples of the monomer may include the following: 2-ethylhexyl acrylate, 2-ethylhexyl methacrylate, 2-hydroxyethyl acrylate, 2-hydroxyethyl methacrylate, N-vinyl-2-pyrrolidone, carbitol acrylate, tetrahydrofurfuryl acrylate, isobornyl acrylate, dicyclopentenyl acrylate, 1,3-butanediol acrylate and other monofunctional monomers; 1,6-hexanediol diacrylate, 1,6-hexanediol methacrylate, neopentyl glycol acrylate, polyethylene glycol diacrylate, pentaerythritol diacrylate and other difunctional monomers; and trimethylolpropane triacrylate, trimethylolpropane trimethacrylate, pentaerythritol triacrylate, dipentaerythritol hexaacrylate and other multifunctional monomers.

[0068] Examples of the photopolymerization initiator used here may include the following: 2,2-dimethoxy-2-phenylacetophenone and other acetophenones; alpha-hydroxyisobutylphenone, p-isopropyl-alpha-hydroxyisobutylphenone and other butylphenones; p-tert-butyldichloroacetophenone, alpha, alpha- dichloro-4-phenoxyacetophenone and other halogenated acetophenones; benzophenone, N,N-tetraethyl-4,4-diaminobenzophenone and other benzophenones, benzyl, benzyl dimethyl ketal and other benzyls; benzoin, benzoin alkyl ether and other benzoins; 1-phenyl-1,2-propanedione-2-(o-ethoxycarbonyl)oxime and other oximes, 2-methylthioxanthone, 2-chlorothioxanthone and other xanthones; benzoin ether, isobutyl benzoin ether and other benzoin ethers; Michler's ketones; and other radically polymerizable compounds. The ultraviolet-curing acrylic resin that has been cured is advantageous in that it has high transparency.

[0069] Examples of the polyimide precursor may include polyamic acids and polyamic-acid long-chain alkyl esters. A polyimide resin produced by thermally hardening the polyimide precursor has 80% or more transparency in a visible light region and a high refractive index of 1.7 to 1.9, thereby providing a large lens effect.

Structure of Diffusing Plate

[0070] The structure of a diffusing plate as an optical plate according to an embodiment of the invention will now be described. **FIG. 2** is a sectional view schematically showing the diffusing plate. This diffusing plate **20** makes light from a light source (not shown) emitted evenly with respect to color elements.

[0071] Referring to **FIG. 2**, the diffusing plate **20** includes an optically transparent substrate **21**, the optically transparent convex **13** provided on the substrate **21**, the microlens **15** provided on the convex **13**, and the microlens **17** provided on the substrate **21**.

[0072] The substrate **21** is optically transparent and made of quartz, glass, acrylic resin, or polycarbonate, polyester or other transparent resin, for example. A matte finish is applied to the surface of the substrate **21** in consideration of its light-collection property.

[0073] The convex **13** is almost columnar in shape with an almost flat top. The convex **13** is provided in a plural number at almost even intervals on the substrate **21**. The convex **13** is optically transparent and made of, for example, acrylic resin, polyester resin, urethane resin, epoxy resin, polycarbonate resin, styrene resin, or novolac resin.

[0074] The microlens **15** is provided on each convex **13** to have different curvatures depending on where it is provided. For example, the microlens **15** is arranged in a way that its curvature increases with distance from a light source (not shown).

[0075] The microlens **17** is provided on the substrate **21** and is almost hemispherically shaped. The microlens **17** is provided almost evenly in the microlens **15** array provided almost evenly.

[0076] The microlenses **15** and **17** are made of, for example, ultraviolet-curing acrylic resin or ultraviolet-curing epoxy resin with a precursor, such as a polyimide precursor. Since the materials of the microlenses **15** and **17** are similar to the ones included in the above-described optical plate **10**, a detail description thereof is omitted.

Structure of Light Guide Plate

[0077] The structure of a light guide plate as an optical plate according to an embodiment of the invention will now be described. **FIG. 3** is a sectional view schematically showing the light guide plate. This light guide plate **30** diffuses light from an external light source **32** provided to the side of the light guide plate **30** to the entire surface of the light guide plate **30**.

[**0078**] Referring to **FIG. 3**, the light guide plate **30** includes an optically transparent substrate **34**, a reflector **33** reflecting light from the light source **32** in a direction toward a light guide part **31**, the convex **13** provided on the reflector **33**, the microlens **15** provided on the convex **13**, and the microlens **17** provided on the reflector **33**.

[**0079**] The light guide part **31** and the reflector **33** are unified by welding with pressure the light guide part **31** with the substrate **34** softened and the reflector **33** provided with the microlenses **15** and **17** and then hardening them.

[**0080**] The substrate **34** has an almost flat surface and is optically transparent. The substrate **34** is made of quartz, glass, acrylic resin, or polycarbonate, polyester or other transparent resin, for example.

[**0081**] The convex **13** is almost columnar in shape with an almost flat top. Referring to **FIG. 3**, the interval between one convex **13** and another adjacent convex **13** decreases with distance from the external light source **32**. The convex **13** is optically transparent and made of, for example, acrylic resin, polyester resin, urethane resin, epoxy resin, polycarbonate resin, styrene resin, or novolac resin.

[**0082**] The microlens **15** is provided to have different curvatures depending on where it is provided. For example, the microlens **15** is arranged in a way that its curvature increases with distance from the external light source **32**.

[**0083**] The microlens **17** provided on the reflector **33** is almost hemispherically shaped. The microlens **17** is provided almost evenly in the microlens **15** array provided almost evenly.

[**0084**] The microlenses **15** and **17** are made of, for example, ultraviolet-curing acrylic resin or ultraviolet-curing epoxy resin with a precursor, such as a polyimide precursor. Since their materials are similar to the ones included in the above-described optical plate **10**, a detail description thereof is omitted.

Structure of Backlight

[**0085**] A backlight according to an embodiment of the invention will now be described. **FIG. 4** is a sectional view schematically showing the backlight.

[**0086**] Referring to **FIG. 4**, this backlight **40** includes the light guide plate **30** disposed near the external light source **32**, and the diffusing plate **20** disposed to face the light guide plate **30**. The external light source **32** is a lighting device, such as a cold cathode fluorescent tube. Light from the external light source **32** is spread by the light guide plate **30** to its entire surface and emitted on the diffusing plate **20**. Upon receiving the light from the light guide plate **30**, the diffusing plate **20** is irradiated with the light evenly through the microlens **15**. The microlens **15** is arranged in a way that its curvature increases with distance from the external light source **32**. Therefore, the microlens **15** reflects the light emitted from the external light source **32** to emit the light from the entire surface of the light guide part **31**.

Structure of Electro-Optical Device

[**0087**] An electro-optical device according to an embodiment of the invention will now be described. **FIG. 5** is a sectional view schematically showing a liquid crystal display as the electro-optical device.

[**0088**] Referring to **FIG. 5**, this electro-optical device **50** includes the backlight **40** emitting light, and a liquid crystal display unit **51** displaying an image in response to the light emitted from the backlight **40**.

[**0089**] The backlight **40** includes the external light source **32**, the light guide plate **30** disposed near the external light source **32**, and the diffusing plate **20** disposed to face the light guide plate **30**.

[**0090**] In the liquid crystal display unit **51**, a lower substrate portion **60** is provided near the diffusing plate **20** included in the backlight **40**, while an upper substrate portion **70** is provided to face the lower substrate portion **60**. There is a gap defined by a sealant **52** between the lower substrate portion **60** and the upper substrate portion **70**. Sealed in the gap is a liquid crystal material **53**.

[**0091**] The lower substrate portion **60** includes a lower transparent substrate **61**, a display electrode **62** provided on the upper surface of the lower transparent substrate **61**, and a light distribution film **63** provided on the upper surface of the display electrode **62**. Provided on the side of the lower transparent substrate **61** remote from the display electrode **62** is a polarizer **64**.

[**0092**] The upper substrate portion **70** includes an upper transparent substrate **71**, a black matrix **72** provided on the side of the upper transparent substrate **71** facing the lower transparent substrate **61**, and color filters **73***a* (R), **73***b* (G), **73***c* (B) as color elements in regions defined by the black matrix **72**. The upper substrate portion **70** also includes a protection film **74** provided on the upper surfaces of the black matrix **72** and the color filters **73***a*, **73***b*, **73***c*, a common electrode **75** provided on the upper surface of the protection film **74**, and a light distribution film **63** provided on the upper surface of the common electrode **75**. Provided on the side of the upper transparent substrate **71** remote from the color filters **73***a*, **73***b*, **73***c* is a polarizer **77**.

[**0093**] The lower substrate portion **60** and the upper substrate portion **70** are bonded by the adhesion of the sealant **52**. Sealed in a gap between the substrate portions **60** and **70** defined by the height of the sealant **52** is the liquid crystal material **53**.

Structure of Electronic Apparatus

[**0094**] An electronic apparatus according to an embodiment of the invention will now be described. **FIG. 6** is a diagram schematically showing a mobile terminal as the electronic apparatus. Referring to **FIG. 6**, the electro-optical device **50** is incorporated as a display of this mobile terminal **80**.

Structure of Projection Screen

[**0095**] A projection screen according to an embodiment of the invention will now be described. **FIG. 7** is a sectional view schematically showing the projection screen (hereinafter simply referred to as the "screen").

[0096] Referring to **FIG. 7**, this screen **90** includes a film substrate **91**, an adhesive layer **92** provided on the film substrate **91**, a lenticular sheet **94** bonded by the adhesion of the adhesive layer **92** to serve as the optical plate **10**, a Fresnel lens **95** provided on the lenticular sheet **94**, and a scattering film **96** provided on the Fresnel lens **95** to serve as the optical plate.

[0097] The lenticular sheet **94** includes an optically transparent substrate **93**, a plurality of convexes each corresponding to the convex **13** provided on the substrate **93**, and the microlens **15** provided on each convex **13**. The microlens **15** has different curvatures depending on where it is provided. For example, the curvature of the microlens **15** increases with distance outward from the center of the screen **90**. Also, the microlens **17** is provided at almost even intervals on the substrate **93**.

[0098] The scattering film **96** includes the optically transparent substrate **93**, a plurality of convexes each corresponding to the convex **13** provided on the substrate **93**, and the microlens **15** provided on each convex **13**. Also, the microlens **17** is provided at almost even intervals on the substrate **93**.

[0099] The screen **90** according to the present embodiment is not limited to the example shown in **FIG. 7**. For example, it may include either the lenticular sheet **94** or the scattering film **96**. Even in this case, the scattering function of the lenticular sheet **94** is good enough to enhance the quality of images projected on the screen. Meanwhile, the scattering function of the scattering film **96** is good enough to scatter incoming (reflected) light that has been passed through the film and reflected toward the film, thereby preventing regular reflection. It is therefore possible to enhance visibility of images projected on the screen.

Structure of Projection System

[0100] A projection system according to an embodiment of the invention will now be described. **FIG. 8** is a diagram schematically showing the projection system.

[0101] Referring to **FIG. 8**, this projection system **100** includes a projector **101** and the screen **90** shown in **FIG. 7**. The projector **101** includes an external light source **102**, a liquid crystal light valve **103** disposed on the optical axis of light emitted from the light source **102** to modulate the light, and an imaging lens (imaging optics) **104** providing an image of the light that has passed through the liquid crystal light valve **103**. The liquid crystal light valve **103** modulates light with three (R, G, B) plates, for example. Here, a device to modulate light is not limited to the liquid crystal light valve **103**. A device that drives a micro reflector (by controlling its reflection angle) to modulate light from the light source may be used instead.

Method for Manufacturing a Microlens

[0102] A method for manufacturing a microlens according to an embodiment of the invention will now be described. **FIGS. 10A through 10F** show steps to manufacture a microlens.

[0103] A discharge head **110** shown in **FIGS. 10A through 10F** has a structure shown in **FIGS. 9A and 9B**. **FIG. 9A** is a perspective view with a part thereof broken down. **FIG. 9B** is a sectional view showing major elements thereof.

[0104] Referring to **FIG. 9A**, the discharge head **110** includes a vibrating plate **114** and a nozzle plate **115**. Provided between the vibrating plate **114** and the nozzle plate **115** is a reservoir **116** in which a functional liquid supplied through a hole **118** always fills. Also provided between the vibrating plate **114** and the nozzle plate **115** is a plurality of partitions **112**. An area surrounded by the vibrating plate **114**, the nozzle plate **115**, and a pair of partition walls **112** is a cavity **111**. Provided correspondingly to the nozzle **120**, the cavity **111** is provided in the same number as the nozzle **120**. The functional liquid is supplied from the reservoir **116** to the cavity **111** through a supply opening **117** placed between a pair of partition walls **112**.

[0105] Referring to **FIG. 9B**, an oscillator **113** corresponding to the cavity **111** is mounted on the vibrating plate **114**. The oscillator **113** includes a piezoelectric element **113***c* and a pair of electrodes **113***a* and **113***b* sandwiching the piezoelectric element **113***c*. By giving a driving voltage to the pair of electrodes **113***a* and **113***b*, the functional liquid is discharged as a droplet **121** through the corresponding nozzle **120**. Provided around the nozzle **120** is a functional-liquid-repellant layer **119**. It is a Ni-tetrafluoroethylene eutectoid plated layer, for example, that prevents any curved discharge of the droplet **121** and clogging of the nozzle **120**. Here, an electrothermal converting element may be used instead of the oscillator **113** to discharge the functional liquid. In this case, thermal expansion of the material liquid driven by the element is used to discharge the material liquid.

[0106] Referring now to **FIGS. 10A through 10F**, the method for manufacturing the microlenses **15** and **17** will be described.

[0107] Referring to **FIG. 10A**, a convex material **12** is provided to an almost even thickness on the upper surface of the substrate **11**. The substrate **11** has an almost flat surface and is optically transparent. The substrate **11** is made of quartz, glass, acrylic resin, or polycarbonate, polyester or other transparent resin, for example. The convex material **12** is optically transparent and made of, for example, acrylic resin, polyester resin, urethane resin, epoxy resin, polycarbonate resin, styrene resin, or novolac resin.

[0108] In the subsequent step of making a concave-convex pattern shown in **FIG. 10B**, the convex **13** as shown in **FIG. 10C** is provided with an exposure device **129**, a mask **130**, and a developer, for example. Making the convex **13** provides a concave **19** between one convex **13** and another adjacent convex **13**.

[0109] In the subsequent step of providing liquid-repellent treatment shown in **FIG. 10C**, liquid-repellent treatment is provided to the surface of the concave **19** and the convex **13** of the substrate **11**. Here, the liquid-repellent treatment may be provided only to the surface of the substrate **11** where the concave **19** is, and treatment to the convex **13** can be omitted. For the liquid-repellent treatment, CF_4 is used, for example.

[0110] In the subsequent step of discharging a lens material to the concave **19** shown in **FIG. 10D**, the droplet **121** of a liquid lens material **14** is discharged from the discharge head **110** toward the concave **19** to attach the lens material **14** to the concave **19**. Examples of the lens material **14** may include ultraviolet-curing acrylic resin and ultraviolet-curing epoxy resin with a precursor, such as a polyimide precursor.

[0111] In the subsequent step of discharging the lens material to the convex **13** shown in **FIG. 10E**, the droplet **121** of the liquid lens material **14** is discharged from the discharge head **110** toward the top of the convex **13** to attach the lens material **14** to the top of the convex **13**. Examples of the lens material **14** may include ultraviolet-curing acrylic resin and ultraviolet-curing epoxy resin with a precursor, such as a polyimide precursor. Here, the amount of discharge is controlled in consideration of desirable curvatures of the microlens **15** depending on the position of the convex **13** to which the material is discharged. Furthermore, the amount and speed of discharge are controlled to an extent that the lens material **14** does not fall down on the substrate **11** from the top of the convex **13**. The greater the amount of discharge, the higher the curvature of the microlens **15**.

[0112] In the subsequent step of hardening the lens material shown in **FIG. 10F**, the lens material **14** is hardened by being irradiated with ultraviolet rays from an ultraviolet radiation device **160**, thereby providing the microlenses **15** and **17**.

[0113] The present embodiment provides the following effects.

[0114] (1) Since the microlens **15** is provided to have desirable curvatures, it is possible to optimize scattering properties with respect to a plurality of color elements.

[0115] (2) Since the diffusing plate **20** is provided with the microlenses **15** and **17** that are densely arranged, it is possible to efficiently collect light emitted from the external light source **32** and provide a high-luminance display.

[0116] (3) Since the light guide plate **30** is provided in a way that the interval between one microlens **15** and another adjacent microlens **15** and the interval between one microlens **17** and another adjacent microlens **17** decrease with distance from the external light source **32**, it is possible to enhance scattering properties on the entire surface of the light guide part **31**.

[0117] It is understood that the invention is not limited to the embodiments described above, and the following modifications can be made.

First Modification

[0118] While the convex **13** is provided by photolithography in the step shown in **FIG. 10B**, the invention is not limited to this. For example, the convex **13** and the concave **19** may be provided by pressing the convex material **12** provided on the substrate **11** with a die or the like. The microlenses **15** and **17** may be provided to the convex **13** and the concave **19** in this manner.

Second Modification

[0119] While the lens material **14** is discharged on the concave **19** and the convex **13** and then hardened in the steps shown in **FIGS. 10D through 10F**, the invention is not limited to this. For example, the lens material **14** discharged on the concave may be hardened directly after it is discharged. Accordingly, it is possible to reduce a rate of defects arising between the steps because a portion of the lens material **14** discharged on the concave **19** and another portion of the lens material **14** discharged on the convex **13** get together.

Third Modification

[0120] While the microlens **17** is provided to have an almost fixed curvature in the steps shown in **FIGS. 10D and 10F**, the microlens **17** may be provided to have different curvatures. It is therefore possible to optimize scattering properties more precisely.

Fourth Modification

[0121] While the micro lens **17** is provided between one convex **13** and another adjacent convex **13** in the steps shown in **FIGS. 10D and 10F**, this can be omitted. Even in this case, it is possible to optimize scattering properties.

Fifth Modification

[0122] While the convex **13** is provided to have an almost fixed diameter in the above-described embodiment, the invention is not limited to this. For example, the convex **13** may have different diameters. It is therefore possible to easily provide the microlens **15** having different curvatures.

Sixth Modification

[0123] While the microlens **17** on the convex **13** included in the diffusing plate **20** has different curvatures, the invention is not limited to this. For example, the microlens may have different curvatures depending on its height as shown in **FIG. 11**. Referring to **FIG. 11**, the curvature of the microlens **17** is made smaller than the curvature of the microlens **15**. Accordingly, for example, it is possible to equalize light-collection distance to a display, such as a display panel, and provide a display with even luminance. **FIGS. 12A through 12F** show steps to manufacture a microlens according to the present modification.

[0124] The steps shown in **FIGS. 12A through 12C** are similar to the steps shown in **FIGS. 10A through 10C**, and a description thereof is omitted.

[0125] In the step of discharging the lens material to the concave **19** shown in **FIG. 12D**, the droplet **121** of the liquid lens material **14** is discharged from the discharge head **110** toward the concave **19** to attach the lens material **14** to the concave **19**. The discharge of the lens material **14** is controlled in consideration of the light-collection distance, so that a smaller curvature than that of the microlens **15** will be provided.

[0126] In the subsequent step of discharging the lens material to the convex **13** shown in **FIG. 12E**, the droplet **121** of the liquid lens material **14** is discharged from the discharge head **110** toward the top of the convex **13** to attach the lens material **14** to the top of the convex **13**. Here, the amount and speed of discharge are controlled to an extent that the material does not fall down on the substrate **11**. The microlens **15** having an almost fixed curvature is provided by controlling the amount of discharge to be almost fixed.

[0127] In the subsequent step of hardening the lens material shown in **FIG. 12F**, the lens material **14** is hardened by being irradiated with ultraviolet rays from the ultraviolet radiation device **160**, thereby providing the microlenses **15** and **17**.

What is claimed is:

1. A method for manufacturing a microlens, comprising:

discharging a liquid lens material on an optically transparent substrate; and hardening the lens material to provide the microlens;

the microlens having different curvatures depending on where the lens material is discharged.

2. The method for manufacturing a microlens according to claim 1, further comprising:

providing liquid-repellent treatment to a surface of the substrate prior to discharging the lens material;

the lens material being discharged to a repellent-treated area and a repellent-treatment-free area in discharging the lens material to provide the microlens having different curvatures.

3. The method for manufacturing a microlens according to claim 1, further comprising:

providing an optically transparent convex on the substrate and a resulting concave between one convex and another adjacent convex prior to discharging the lens material,

the lens material being discharged to the convex and the concave in discharging the lens material to provide the microlens having different curvatures.

4. The method for manufacturing a microlens according to claim 1,

the curvatures of the microlens being set to provide an almost identical light-collection rate in a position at a predetermined distance from the substrate in a light-emitting direction.

5. A microlens manufactured by the method for manufacturing a microlens according to claim 1.

6. An optical plate, comprising:

an optically transparent substrate; and

a plurality of microlenses provided on the substrate;

at least one of the plurality of microlenses having a different curvature from a curvature of the other microlenses.

7. The optical plate according to claim 6, further comprising:

a convex provided on the substrate; and

a microlens provided on the convex;

the microlenses provided on the substrate having a different curvature from a curvature of the microlens provided on the convex.

8. The optical plate according to claim 6, the microlenses having different curvatures depending on heights thereof from the substrate.

9. The optical plate according to claim 8,

the microlenses having lower curvatures as heights thereof from the substrate decrease.

10. The optical plate according to claim 7,

the optical plate being a diffusing plate.

11. The optical plate according to claim 10,

the optical plate being a light guide plate further including:

a reflector reflecting light emitted from an external light source; and

a light guide part guiding the light emitted from the external light source to an entire surface thereof.

12. The optical plate according to claim 11,

the microlenses having higher curvatures with distance from the external light source emitting light from a side of the substrate in the light guide plate.

13. A projection screen, comprising:

a Fresnel lens; and

a lenticular sheet to which the optical plate according to claim 6 is applied.

14. A projection system, comprising:

the projection screen according to claim 13.

15. A backlight, comprising:

at least one of the optical plate according to claim 6 and the light guide plate according to claim 12.

16. An electro-optical device, comprising:

the backlight according to claim 15.

17. An electronic appliance, comprising:

the electro-optical device according to claim 16.

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