Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3013923 A1 2019/02/16

(21) 3 013 923

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) Date de dépôt/Filing Date: 2018/08/10

(41) Mise à la disp. pub./Open to Public Insp.: 2019/02/16

(30) Priorité/Priority: 2017/08/16 (JP2017-157063)

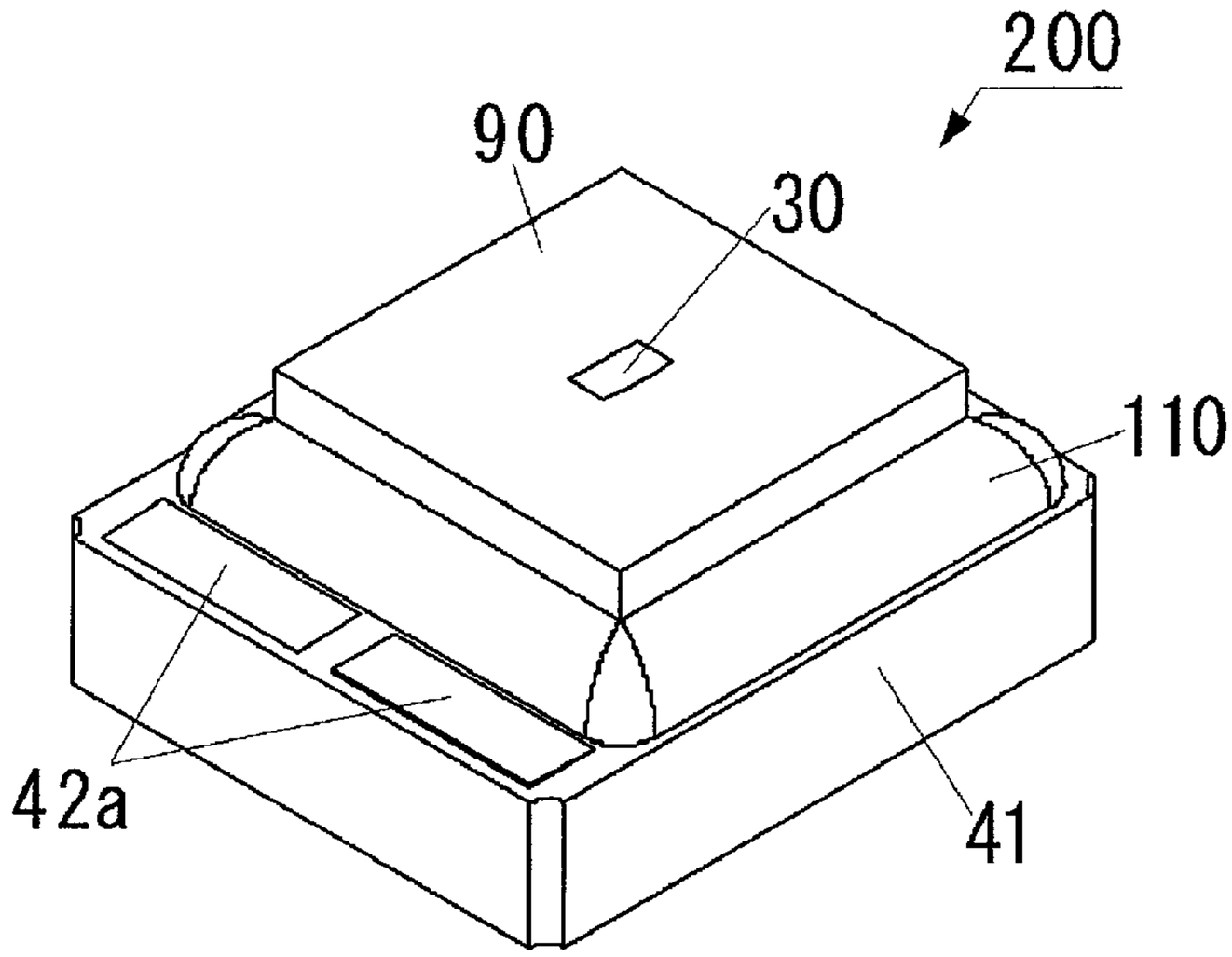
(51) Cl.Int./Int.Cl. *F21K 9/60* (2016.01), *F21K 9/00* (2016.01), *F21K 9/64* (2016.01), *F21K 9/68* (2016.01), *H01S 5/00* (2006.01)

(71) Demandeur/Applicant:
NICHIA CORPORATION, JP

(72) Inventeur/Inventor:
MIURA, SOICHIRO, JP...

(74) Agent: KIRBY EADES GALE BAKER

(54) Titre : DISPOSITIF EMETTEUR DE LUMIERE
(54) Title: LIGHT EMITTING DEVICE



(57) Abrégé/Abstract:
A light emitting device includes: one or more semiconductor laser elements, each configured to emit laser light; one or more light-reflecting parts, each having a light-reflecting surface configured to reflect the laser light emitted from a corresponding one of the

CA 3013923 A1 2019/02/16

(21) 3 013 923

(13) A1

(57) Abrégé(suite)/Abstract(continued):
one or more semiconductor laser elements; and a fluorescent part having a light-receiving surface configured to be irradiated with the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts; wherein an irradiated region is formed on the light-reflecting surface when the light- reflecting surface is irradiated with the laser light, the irradiated region including a first end and a second end opposite the first end; and wherein the light-reflecting surface of each of the one or more light-reflecting parts is arranged such that a portion of the laser light reflected at at least a first end of the irradiated region and a portion of the laser light reflected at a location other than the first end of the irradiated region are overlapped with each other on the light-receiving surface.

ABSTRACT

A light emitting device includes: one or more semiconductor laser elements, each configured to emit laser light; one or more light-reflecting parts, each having a light-reflecting surface configured to reflect the laser light emitted from a corresponding one of the one or more semiconductor laser elements; and a fluorescent part having a light-receiving surface configured to be irradiated with the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts; wherein an irradiated region is formed on the light-reflecting surface when the light-reflecting surface is irradiated with the laser light, the irradiated region including a first end and a second end opposite the first end; and wherein the light-reflecting surface of each of the one or more light-reflecting parts is arranged such that a portion of the laser light reflected at at least a first end of the irradiated region and a portion of the laser light reflected at a location other than the first end of the irradiated region are overlapped with each other on the light-receiving surface.

LIGHT EMITTING DEVICE

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] The present application claims priority under 35 U. S. C. §119 to Japanese Patent Application No. 2017-157063, filed August 16, 2017. The contents of this application are incorporated herein by reference in their entirety.

BACKGROUND

Technical Field

[0002] The present disclosure relates to a light emitting device.

Description of the Related Art

[0003] A light emitting device described in Japanese Patent Publication No. 2010-251686 includes a semiconductor laser, a mirror having a total reflection film, and a fluorescent material arranged above the mirror. Laser light emitted from the semiconductor laser is reflected by the mirror provided with the total reflection film and is irradiated to the fluorescent material (for example, see FIG. 3 of Japanese Unexamined Patent Application Publication No. 2010-251686).

SUMMARY

[0004] In such light emitting devices, optical intensity of the laser light is higher at a center portion than its peripheral portion on a light-receiving surface of a fluorescent material. In such cases, a large quantity of heat is generated at the center portion of the fluorescent material, which may result in a decrease in the conversion efficiency of the fluorescent material. Also, light emission intensity and/or color unevenness may occur in the light emitted from the fluorescent material.

[0005] A light emitting device according to an embodiment of the present disclosure includes one or more semiconductor laser elements, each configured to emit a laser light, one or more light-reflecting parts, each having a light-reflecting surface configured to reflect the laser light emitted from a corresponding one of the one or more semiconductor laser elements, and a fluorescent part having a light-receiving surface configured to be irradiated with the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts. An irradiated region is formed on the light-reflecting surface when the light-reflecting surface is irradiated with the laser light, and the irradiated region includes a first end and a second end opposite to the first end, located at two opposite ends of the irradiated region in a longitudinal direction. The light-reflecting surface of each of the one or more light-reflecting parts is arranged such

that a portion of the laser light reflected at at least a first end of the irradiated region and a portion of the laser light reflected at a location other than the first end of the irradiated region are overlapped with each other on the light-receiving surface.

[0008] The light emitting device according to certain embodiments can reduce degradation of the wavelength conversion efficiency of the fluorescent part and also can reduce uneven color and/or uneven distribution of light emission intensity in light emitted from the fluorescent part.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG 1 is a schematic perspective view of a light emitting device according to a first embodiment of the present invention.

FIG 2 is a schematic top view of the light emitting device according to the first embodiment.

FIG. 3 is a schematic cross-sectional view taken along line III-III of FIG. 2.

FIG 4 is a schematic perspective view of an optical element included in the light emitting device according to the first embodiment.

FIG. 5 is a diagram illustrating propagation of light emitted from a semiconductor laser element, reflected at a light-reflecting surface, and irradiated on a light-receiving surface of a fluorescent part, in the light emitting device according to the first embodiment.

FIG. 6 is a diagram showing a simulation result of light intensity distribution of light reflected at a conventional light-reflecting surface.

FIG. 7 is a diagram showing a light intensity distribution along the straight line between the points VII-VII indicated in FIG. 6.

FIG. 8 is a schematic perspective view illustrating a configuration in a recess defined in a base member of the light emitting device according to the first embodiment.

FIG. 9 is a schematic top view illustrating a configuration in a recess defined in a base member of the light emitting device according to the first embodiment.

FIG. 10 is a diagram showing a simulation result of light intensity distribution at a light-receiving surface of a fluorescent part in the light emitting device according to the first embodiment.

FIG. 11 is a diagram showing a light intensity distribution along the straight line between the points XI-XI indicated in FIG. 10.

FIG. 12 is a diagram showing a simulation result of light intensity distribution at a first region of light-receiving surface of a fluorescent part in the light emitting device according to the first embodiment.

FIG. 13 is a diagram showing a light intensity distribution along the straight line between the points XIII-XIII indicated in FIG. 12.

FIG. 14 is a diagram showing a simulation result of light intensity distribution at a second region of light-receiving surface of a fluorescent part in the light emitting device according to the first embodiment.

FIG. 15 is a diagram showing a light intensity distribution along the straight line between the points XV-XV indicated in FIG. 14.

FIG. 16 is a diagram showing a simulation result of light intensity distribution at a third region of light-receiving surface of a fluorescent part in the light emitting device according to the first embodiment.

FIG. 17 is a diagram showing a light intensity distribution along the straight line between the points XVII-XVII indicated in FIG. 16.

FIG. 18 is a cross-sectional view illustrating a light emitting element according to a second embodiment.

FIG. 19 is a schematic perspective view illustrating a configuration in a recess defined in a base member of the light emitting device according to a third embodiment.

FIG. 20 is a schematic top view illustrating a configuration in a recess defined in a base member of the light emitting device according to the third embodiment.

FIG. 21 is a diagram showing a simulation result of light intensity distribution at a first region of light-receiving surface of a fluorescent part in the light emitting device according to the third embodiment.

FIG. 22 is a diagram illustrating propagation of light emitted from a semiconductor laser element, reflected at a light-reflecting surface, and irradiated on a light-receiving surface of a fluorescent part, in the light emitting device according to the fourth embodiment.

FIG. 23 is a diagram illustrating propagation of light emitted from a semiconductor laser element, reflected at a light-reflecting surface, and irradiated on a light-receiving surface of a fluorescent part, in the light emitting device according to a fifth embodiment.

DETAILED DESCRIPTION

[0010] Certain embodiments of the present invention will be described below with reference to the accompanying drawings. The embodiments shown below are intended as illustrative to give a concrete form to technical ideas of the present invention, and the scope of the invention is not limited to those described below. The sizes and the

positional relationships of the members in each of the drawings are occasionally shown exaggerated for ease of explanation.

[0011] FIRST EMBODIMENT

FIG 1 is a schematic perspective view of a light emitting device 200 according to a first embodiment, FIG 2 is a schematic top view of the light emitting device 200, and FIG. 3 is a cross-sectional view taken along line III-III of FIG. 2. FIG 4 is a schematic perspective view of an optical element 20 that serves as a light-reflecting part 20 in the light emitting device 200. FIG. 5 is a cross-sectional diagram illustrating propagation of light emitted from a semiconductor laser element 10, reflected at a light-reflecting surface 21, and irradiated on a light-receiving surface of a fluorescent part 30, in the light emitting device 200.

[0012] As shown in FIG. 1 to FIG. 5, the light emitting device 200 includes one or more semiconductor laser elements 10, each configured to emit laser light having a far field pattern (hereinafter may be referred to as FFP) with an elliptic shape, a light-reflecting part 20 having a light-reflecting surface 21 configured to reflect the laser light, and a fluorescent part 30 having a light-receiving surface configured to be irradiated with the laser light reflected from the light-reflecting surface 21, the fluorescent part 30 being configured to emit fluorescent light upon being irradiated with the reflected laser light. In the light emitting device 200, a region of the light-reflecting surface 21 where the laser light is irradiated corresponds to the elliptic shape of the FFP and includes a first region 21a and a second region 21b. The FFP is divided in two or more regions in its longitudinal direction, including a first region 21a corresponding to a region at a first end of the FFP and a second region 21b corresponding to a region at a second end of the FFP that is opposite the first end. The first region 21a and the second region 21b are arranged such that a portion of the laser light reflected at the first region 21a at a location closer to the second region, and a portion of the laser light reflected at the second region 21b at a location away from the first region, are overlapped with each other on the light-receiving surface of the fluorescent part 30, and also a portion of the laser light reflected at the first region 21a at a location away from the first region 21a, and a portion of the laser light reflected at the second region 21b at a location closer to the first region 21a, are overlapped with each other on the light-receiving surface of the fluorescent part 30.

[0013] In the light emitting device 200, uneven distribution of light emission intensity and/or color unevenness in a light emitted from the fluorescent part 30 can be reduced,

while reducing degradation of the wavelength conversion efficiency of the fluorescent part 30. More details thereof will be described below.

[0014] Laser light emitted from the semiconductor laser element 10 (hereinafter may be referred to as "laser diode (LD) element 10") has a FFP of an elliptic shape that is longer in the layering direction of the semiconductor layers including the active layer and shorter in a direction perpendicular to the layering direction. The FFP in the present specification is obtained by measuring a light intensity distribution of the laser light in a plane parallel to the light emitting surface and at a certain distance from the light emitting surface of the LD element 10, and determined, for example, as a shape corresponding to a certain optical intensity such as at $1/e^2$ of the peak intensity. The laser light having such a FFP has an optical intensity greater at a center portion of the elliptic shape than at portions away from the center portion. In conventional light emitting devices, for example, the laser light emitted from an LD element is reflected at a light-reflecting surface inclined at 45 degrees to irradiate a light-receiving surface of a fluorescent part. In such cases, the reflected laser light is irradiated on the light-receiving surface of the fluorescent part while maintaining the light intensity distribution of the FFP. This can be seen in FIG. 6 and FIG. 7, which illustrate a simulation result of light intensity distribution of laser light reflected at a conventional light-reflecting surface. FIG. 7 is a diagram showing a light intensity distribution along the straight line between the points VII-VII indicated in FIG. 6, in which the optical intensity at the center portion is apparently greater than the peripheral portion. When such light is irradiated on the fluorescent part, the quantity of heat generated from the fluorescent part is greater at the portion of higher optical intensity than at its peripheral portion, which may result in degradation of the wavelength conversion efficiency of the fluorescent part. Further, a difference in the intensity of the laser light irradiated to the portions of the fluorescent part may result in the light emitting device having uneven optical intensity and/or color unevenness.

[0015] Accordingly, in the light emitting device 200, a first region 21a and a second region 21b are provided in a region of the light-reflecting surface 21 to be irradiated with the laser light such that the laser light reflected at the light-reflecting surface 21 is irradiated on the light-receiving surface of the fluorescent part 30 with a light intensity distribution approaching uniformity. As shown in FIG. 5, the first region 21a and the second region 21b are arranged such that a portion with lower light emission intensity in the laser light reflected at the first region 21a (in FIG. 5, laser light reflected near the left end of the first region 21a) and a portion with higher light emission intensity in the laser light reflected at the second region 21b (in FIG. 5, laser light reflected near the left

end of the second region 21a) are overlapped with each other on the light-receiving surface, and a portion with higher light emission intensity in the laser light reflected at the first region 21a (in FIG. 5, laser light reflected near the right end of the first region 21a) and a portion with lower light emission intensity in the laser light reflected at the second region 21b (in FIG. 5, laser light reflected near the right end of the second region 21a) are overlapped with each other. With this arrangement, the light intensity distribution of the laser light irradiated at the light-receiving surface of the fluorescent part 30 can approach uniformity. Accordingly, the light emitting device 200 can realize a reduction of uneven light emitting intensity and uneven color while reducing degradation of the wavelength conversion efficiency of the fluorescent part 30.

[0016] The components of the light emitting device body 200 will be described below.

[0017] Base Member 40

A base member 40 is for mounting one or more LD elements 10. In FIG. 3, a base member 40 formed with a recess is used, and an LD element 10 is disposed on the bottom surface in the recess.

[0018] For the base member 40, a material containing ceramics can be used. Examples of ceramics include aluminum oxide, aluminum nitride, silicon nitride, and a silicon carbide. In the case where the base member 40 and a cover 80 are fixed by welding, a portion of the base member to be in contact with the cover 80 (welding part 43) can be formed with a material that contains iron as its main component.

[0019] As shown in FIG. 8 and FIG. 9, the base member 40 provided with the recess includes a main part 41 made of an electrically insulating material, a first wiring part 42a and a second wiring part 42b respectively exposed from the main part 41 on the bottom surface of the recess, and the welding part 43 to be contact with the cover 80. The first electrode 42a to be electrically connected to the outside are exposed on a surface other than the lower surface of the main part 41, which allows the entire surface of the lower surface of the base member 40 can be used for mounting to other member such as a heat sink, thus facilitating dissipation of heat generated in the light emitting device 200.

[0020] The base member may include a base part and a frame part disposed on an upper surface of the base part. In such a case, one or more LD elements can be disposed on the upper surface of the base part and inward of the frame part. The wiring portions in such a case are preferably disposed on the upper surface of the base part and outside of the frame part, in view of heat dissipation performance of the light emitting device.

[0021] Semiconductor Laser Element 10

The one or more LD elements 10 are configured to emit laser light having a FFP of an elliptic shape. Each one of the LD elements 10 has a light emitting surface perpendicular to the lower surface of the base member 40, and is arranged such that a longitudinal direction of its FFP in a elliptic shape is perpendicular to the lower surface of the base member 40. With this arrangement, a larger surface of the LD element 10 can be arranged in parallel to the lower surface of the base member 40, which facilitates dissipation of heat generated from the LD element 10 to the base member 40 and a heat sink. The term "perpendicular" used above includes an inclination to some degree, such as that caused by misalignment at the time of mounting.

[0022] The LD element 10 having an emission peak wavelength in a range of 320 nm to 530 nm, typically in a range of 430 nm to 480 nm can be used. The LD element 10 of the range described above emits laser light of relatively high energy, which is likely to cause degradation of the wavelength conversion efficiency of the fluorescent part 30. Employing the light-reflecting surface 21 and the like of the present embodiment can yield advantageous effects when using such a LD element 10. For the LD element 10 of the range described above, a material including a nitride semiconductor can be preferably used. Examples thereof include at least one of GaN, InGaN, and AlGaN.

[0023] The one or more LD elements 10 are mounted on the base member 40 via a sub-mount 50. With this arrangement, a distance from the light emitting point on the light emitting surface of the LD element 10 to the mounting surface (the bottom surface of the recess in the case of the light emitting device 100) of the LD 10 on the base member 40 can be increased by the thickness of the mount 50. Accordingly, laser light of the LD element can be efficiently irradiated on the light-reflecting surface 21. The LD element 10 can be fixed on the sub-mount 50 by using an electrically conductive layer 60 of Au-Sn etc.

[0024] The sub-mount 50 is preferably made of a material having a thermal expansion coefficient between the thermal expansion coefficient of the base member 40 and the thermal expansion coefficient of the LD element. Accordingly, detachment of the LD element 10 and/or detachment of the sub-mount 50 can be reduced. When a material containing a nitride semiconductor is used for the LD element 10, a sub-mount 50 made of, for example, aluminum nitride or silicon carbide can be used.

[0025] As shown in FIG. 8 and FIG. 9, the LD element 10 is electrically connected to the second wiring portion 42b of the base member 40 via wires (i.e., thin metal wire) 70.

[0026] Light-reflecting Part 20

The light-reflecting part 20 is configured to reflect the laser light from the LD element 10 toward the fluorescent part 30. As in the light emitting device 200, when the laser light from the LD element 10 is reflected at the light-reflecting part 20, more uniform intensity of laser light can be irradiated on the light-receiving surface of the fluorescent part 30, while allowing a reduction in the thickness (the length in up-and down direction in FIG. 3) of the light emitting device 200, compared to the case of using a light-transmissive lens.

[0027] As shown in FIG. 3, an optical element 20 having at least one light-reflecting surface 21 is employed as the light-reflecting part 20. The base member 40 and the optical element 20 are provided separately, which allows for adapting a simpler structure for the base member 40 compared to the case in which a part of the base member is also used as the light-reflecting surface. On the other hand, the base member can be structured so that a part of the base member serves as the light-reflecting surface. In such a case, a need of a region for movement of a collet used to disposing the optical element can be eliminated, and thus the width of the recess in the base member can be reduced.

[0028] In the present specification, surfaces of the optical element 20 other than the upper surface and the lower surface are lateral surfaces. In the light emitting device 200, as shown in FIG. 3 and FIG. 4, one of four lateral surfaces of the optical element 20 located closer to the LD element 10 is the light-reflecting surface 21. Using a lateral surface located closer to the LD element 10 as the light-reflecting surface 21 can reduce the number of interfaces that the laser light to pass through, compared to the case where a lateral surface located away from the LD element 10 is used as the light-reflecting surface, accordingly, absorption of light by the optical element can be reduced.

[0029] The optical element 20 can include a main component that is resistant to heat, such as quartz or glass such as BK7, or a metal such as aluminum, and has a light-reflecting surface 21 made of a material having high reflectance such as a metal.

[0030] In the light emitting device 200, the light-reflecting surface 21 is formed to obtain more uniform light intensity distribution in the longitudinal direction of the elliptic FFP of the laser light irradiated on the light-receiving surface.

This is because the FFP of the laser light emitted from the LD element 10 tends to spread particularly in the longitudinal direction. The light-reflecting surface may be formed such that the light intensity distribution in the transverse direction also approaches uniformity, but in view of accuracy of the light-reflecting surface of the optical element and positional alignment with the LD element, the light-reflecting

surface 21 is preferably formed such that the light intensity distribution in the longitudinal direction of the elliptic FFP on the light-receiving surface approaches uniformity.

[0031] As shown in FIG. 4, a region of the light-reflecting surface 21 (region surrounded by the alternate long and short dashed line in FIG. 4) where the laser light is irradiated includes a first region 21a corresponding to a first end and a second region 21b corresponding to a second end that is opposite side of the first end of two or more portions of the elliptic shape of FFP that is divided in its longitudinal direction. Further, as shown in FIG. 4, the first region 21a and the second region 21b are arranged on the light-receiving surface of the fluorescent part 30 such that a portion of the laser light reflected at the first region 21a at a location closer to the second region 21b, and a portion of the laser light reflected at the second region 21b at a location away from the first region 21a, are overlapped with each other, and a portion of the laser light reflected at the first region 21a at a location away from the second region 21b, and a portion of the laser light reflected at the second region 21b at a location closer to the first region 21a, are overlapped with each other.

[0032] The first region 21a and the second region 21b are respectively arranged such that, on the light-receiving surface of the fluorescent part 30, the light intensity distribution of the laser light reflected at the first region 21a and the light intensity distribution of the laser light reflected at the second region 21b are in line symmetry to a direction corresponding to the longitudinal direction. That is, the first region 21a and the second region 21b are arranged such that the laser light reflected at the first region 21a and the second region 21b are overlapped with each other with a same width on the light-receiving surface. Accordingly, the light intensity distribution on the light-receiving surface can be facilitated to approach uniformity.

[0033] For example, as shown in FIG. 5, the area of the first region 21a that is located closer to the LD element 10 than the second region 21b is smaller than the area of the second region 21b. The first region 21a located closer to the LD element 10 has a greater distance, and thus a greater divergence, than that of the second region 21b to the light-receiving surface of the fluorescent part 30. Accordingly, the arrangement described above can facilitate overlapping of the first region 21a and the second region 21b with a same width on the light-receiving surface.

[0034] In the light emitting device 200, the region on the light-reflecting surface 21 to be irradiated with the laser light has a third region 21c located between the first region 21a and the second region 21b. As shown in FIG. 5, the third region 21c is arranged such that a portion of light reflected at the third region 21c at a location closer to the

first region 21a, and a portion of light reflected at the first region 21a at a location away from the second region 21b are overlapped with each other on the light-receiving surface of the fluorescent part 30, and also a portion of light reflected at the third region 21c at a location closer to the second region 21b, and a portion of light reflected at the second region 21b at a location away from the first region 21a are overlapped with each other on the light-receiving surface of the fluorescent part 30. That is, a portion with lower light emission intensity in the laser light reflected at the third region 21c (laser light reflected near the left end and the right end of the third region 21c in FIG. 5) and a portion with higher light intensity in the laser light reflected at the first region 21a and the second region 21b (laser light reflected near the right end of the first region 21a and laser light reflected near the left end of the second region 21b in FIG. 5) can be overlapped with each other. When the light-reflecting surface 21 has the third region 21c in addition to the first region 21a and the second region 21b, a degree of divergence of the light reflected at the light-reflecting surface 21 can be decreased compared to that when the light-reflecting surface 21 has only the first region 21a and the second region 21b. Accordingly, a need for an increase of the longitudinal length of the light-receiving surface of the fluorescent part 30 can be smaller with respect to an increase of the distance between the light-reflecting surface 21 and the light-receiving surface of the fluorescent part 30. Four or more regions may be provided on the light-reflecting surface 21 to be irradiated with the laser light.

[0035] The first region 21a, the second region 21b, and the third region 21c are arranged such that in the longitudinal direction of the FFP, the divergence angles of the laser light reflected at the first region 21a and the second region 21b are smaller than the divergence angle of the laser light reflected at the third region 21c. That is, the light-reflecting surface 21 is formed such that in the longitudinal direction of the elliptic FFP, outward spreading of a portion of light reflected at the third region 21c and having higher light emission intensity is facilitated while spreading of portions of light respectively reflected at the first region 21a and the second region 21b locations away from the third region 21c are reduced. With this arrangement, the light intensity distribution on the light-receiving surface can be made approaching uniformity while reducing spreading of the laser light irradiated on the light-receiving surface of the fluorescent part 30.

[0036] As shown in FIG. 4, the first region 21a, the second region 21b, and the third region 21c are flat surfaces. That is, the light-reflecting surface 21 is formed with three flat surfaces. This arrangement can facilitate the designing of the optical element

20. The first region, the second region, and the third region may each be a curved surface.

[0037] FIG. 10 is a diagram showing a simulation result of light intensity distribution at the light-receiving surface of the fluorescent part 30 in the light emitting device 200. FIG. 11 is a diagram showing a light intensity distribution along the straight line between the points XI-XI indicated in FIG. 10. FIG. 12 is a diagram showing a simulation result of light intensity distribution at the first region 21a of the light-receiving surface of the fluorescent part 30, and FIG. 13 is a diagram showing a light intensity distribution along the straight line between the points XIII-XIII indicated in FIG. 12. FIG. 14 is a diagram showing a simulation result of light intensity distribution at the second region 21b of the light-receiving surface of the fluorescent part 30, and FIG. 15 is a diagram showing a light intensity distribution along the straight line between the points XV-XV indicated in FIG. 14. FIG. 16 is a diagram showing a simulation result of light intensity distribution at the third region 21c of the light-receiving surface of the fluorescent part 30, and FIG. 17 is a diagram showing a light intensity distribution along the straight line between the points XVII-XVII indicated in FIG. 16. Next, the conditions of the simulation will be described with reference to FIG. 5. The distance between the light emitting point of the LD element and the light-reflecting surface 21 (more precisely, a first light-reflecting point) in a direction parallel to the lower surface of the optical element 20 and the lower surface of the LD element 10 was set to 0.45 mm, and the distance between the light-reflecting surface (i.e., the first light-reflecting point) and the light-receiving surface of the fluorescent part 30 in a direction perpendicular to the lower surface of the optical element 20 is set to 2.10 mm. The laser light emitted from the light emitting point propagating in parallel to the lower surface of the LD element 10 is irradiated at the first light-reflecting point of the light reflecting surface 21. In the case shown in FIG. 5, a light-transmissive member 82 having a thickness of 0.5 mm and a heat-releasing member 100 having a thickness of 0.43 mm are disposed between the first light-reflecting point and the fluorescent part 30. The width in the longitudinal direction of the light-receiving surface of the fluorescent part 30 (i.e., the length of the light-receiving surface of the fluorescent part 30 in a direction parallel to the light emitting point and the first light-reflecting point) was set to 1 mm, and the width of the transverse direction was set to 0.5 mm. Further, in the optical element 20, the angle between the lower surface and the first region 21a was set to 31.5 degrees, the angle between the lower surface and the second region 21b was set to 60 degrees, and the angle between the lower surface and the third region 21c was set to 45 degrees. The

length L1 of the first region 21a was set to 0.14 mm, the length L2 of the second region 21b was set to 0.36 mm, and the length L3 of the third region 21c was set to 0.27 mm. As shown in FIG. 11, the light emitting device 200 can produce the light intensity distribution of the laser light approaching uniformity at the light-receiving surface of the fluorescent part 30.

[0038] Cover 80

Combined with the base member 40, the cover 80 hermetically seals the space in which the LD element 10 is disposed. Accordingly, accumulation of dust attracted to the light emitting surface of the LD element 10 can be reduced. The cover 80 includes a support 81, a light-transmissive part 82, and a bonding member 83 bonding the support 80 and the light-transmissive part 82. The laser light reflected at the light-reflecting surface 21 is transmitted through the light-transmissive part 28 and is irradiated on the light-receiving surface of the fluorescent part30.

[0039] In the light emitting device 200, a material that contains a nitride semiconductor is used as the LD element, and the support 81 of the cover 80 and the base member 40 are fixed by welding. In this case, a material whose main component is iron can be used for the support 81. Also, in the light emitting device 200, an LD element 10 and an optical element 20 are disposed in a single space that is hermetically sealed by the base member 40 and the cover 80. With this arrangement, compared to light emitting devices that include an LD device mounted with an LD element and an optical element disposed outside of the LD device, an increase in the size of the light emitting device 200 can be reduced. For the light-transmissive part 82, for example, glass or sapphire can be used, and for the bonding material 83, for example, a low-melting point glass or a gold-tin-based solder can be used.

[0040] Fluorescent Part 30

The fluorescent part 30 has a light-receiving surface to which the laser light reflected at the light-reflecting surface 21 is irradiated, and is configured to emit fluorescent light upon the light-receiving surface being irradiated with the reflected laser light. In FIG. 3, the lower surface of the fluorescent part 30 is the light-receiving surface and the upper surface of the fluorescent part 30 is the light emitting surface. As shown in FIG. 3, the fluorescent part 30 is disposed above the light-transmissive part 82 of the cover 80.

[0041] The fluorescent part 30 contains a fluorescent material. Examples of the fluorescent material include a YAG fluorescent material, an LAG fluorescent material, and an α-sialon fluorescent material. Among those, a YAG phosphor that has good heat-resisting properties is preferable. The fluorescent part 30 is preferably made of an

inorganic material that has higher resistance to heat and/or light compared to an organic material, and thus reliability can be improved. Accordingly, higher resistance to heat and/or light can be obtained compared to the cases in which the fluorescent part includes an organic material; thus, reliability can be improved. For the fluorescent part 30 made of an inorganic material, phosphor ceramics or a single crystal of a fluorescent material can be used. For the phosphor ceramics, a sintered body of phosphor particles and an additive can be used. When phosphor ceramics of YAG phosphor is used, aluminum oxide can be used for the additive.

[0042] As shown in FIG. 2 and FIG. 3, the light-receiving surface of the fluorescent part 30 preferably has a shape that is elongated in one direction. For example, an elliptic shape or a rectangular shape can be employed. In view of mass productivity for the fluorescent part 30, a rectangular shape is preferably employed. When the light-receiving surface of such a shape is to be employed, the fluorescent part 30 and the semiconductor laser element 10 are preferably disposed such that the longitudinal direction of the fluorescent part 30 and the longitudinal direction of FFP of the laser light are in parallel to each other the laser, in order to irradiate the light-receiving surface of the fluorescent part 30 with the laser light having a shape elongated in one direction, reflected at the light-reflecting surface 21. This arrangement allows for a reduction of the distance between the region of the fluorescent part 30 irradiated with the laser light and an outer peripheral edge of the fluorescent part 30, thus facilitating dissipation of heat generated from the fluorescent part 30. Accordingly, degradation of the wavelength conversion efficiency of the fluorescent part 30 can be reduced.

[0043] First Light-shielding Part 90

The first light-shielding part 90 is to reduce emission of light from the regions other than the upper surface of the fluorescent part 30, and as shown in FIG. 3, disposed surrounding the lateral surfaces of the fluorescent part 30. The first light-shielding part 90 is disposed directly in contact with the fluorescent part 30. When the fluorescent part 30 includes a YAG phosphor, ceramics that contains aluminum oxide as its main component is preferably used for the first light-shielding part 90. With this arrangement, light from the fluorescent part 30 can be shielded while enhancing the bonding between the fluorescent part 30 and the first light-shielding part 90.

Aluminum oxide used for the first light-shielding part 90 is the same material as the sapphire that can be used for the heat dissipating member 100 to be described later below, but a region in the first light-shielding part 90 closer to the fluorescent part 30 has a lower sintered density, and thus contains voids. Even the same material is used, light from the fluorescent part 30 is reflected at the interfaces between the

particles of aluminum oxide or the like and voids, and thus light is not easily transmitted through the first light-shielding part 90.

[0044] Heat Dissipating Member 100

As shown in FIG. 3, the fluorescent part 30 and the first light-shielding part 90 are fixed to the cover 80 with the heat dissipating member 100 interposed therebetween. The upper surface of the heat dissipating member 100 is preferably directly in contact with the lower surfaces of the light-receiving surface of the fluorescent part 30 and the first light-shielding part 90. With this arrangement, the region of the fluorescent part 30 irradiated with the laser light and thus produce heat are in direct contact with each other, which can facilitate dissipation of heat produced from the fluorescent part 30. For the heat dissipating member 100, a light-transmissive member can be used and for example, sapphire, quartz, or silicon carbide can be used. Alternatively, the fluorescent part 30 may be arranged above the light-reflecting surface by fixing the first light-shielding part 90 and the heat dissipating member 100 with the use of a heat resistant metal material or the like.

[0045] Second Light-shielding Part 110

A second light-shielding part 110 is disposed on the lateral surfaces of the heat dissipating member 100. Accordingly, the amount of light passing through the lateral sides of the heat dissipating member 100 can be reduced. The second light-shielding part 100 can be formed with a resin material containing light scattering particles of, for example, titanium oxide.

[0046] SECOND EMBODIMENT

In FIG. 18 a schematic cross-sectional view of the light emitting device 300 according to a second embodiment is shown. The semiconductor light emitting element 300 has a substantially similar configuration as that of the light emitting device 200 described in the first embodiment, except for the aspects described below.

[0047] In the light emitting device 300, the light-reflecting surface of the optical element 20 is arranged at a side located away from the LD element 10. That is, the laser light is made incident into the optical element 20 through a lateral surface of the optical element 20 located close to the LD element 10, and is reflected at the light-reflecting surface 21, and emitted from the upper surface of the optical element 20. Even in such cases, the light intensity distribution of the laser light in the light-receiving surface approaching uniformity can be obtained. The optical element 20 can include, a main component, quartz or glass such as BK7, and has a light-reflecting surface made of a material having high reflectance such as a metal.

[0048] THIRD EMBODIMENT

FIG. 19 is a schematic perspective view illustrating a configuration in a recess formed in a base member 40 of the light emitting device 400 according to a third embodiment. The semiconductor light emitting element 400 has a substantially same configuration as that of the light emitting device 200 described in the first embodiment, except for those aspects described below.

[0049] The light emitting device 400 includes two LD elements 10 and two optical elements 20. The optical elements 20 are arranged such that the laser light emitted from each of the LD elements 10 is reflected at a light-reflecting surface 21 of corresponding one of the optical elements 10, and is irradiated on the light-receiving surface of a single fluorescent part 30. More specifically, the two LD elements 10 are disposed such that the light emitting surface of the LD elements are in parallel to each other, and the two optical elements 20 are disposed such that lateral surfaces of the two optical elements 20 facing each other are in parallel to each other. Further, a plane in parallel to any one of the lateral surfaces of the optical elements 20 and a plane in parallel to the light emitting surface of the corresponding LD elements 10 are at an angle other than perpendicular.

[0050] FIG. 21 is a diagram showing a simulation result of light intensity distribution at the light-receiving surface of the fluorescent part 30 in the light emitting device 400. As shown in FIG. 21, with the use of a plurality of LD elements 10, the optical intensity of laser light irradiated on the light-receiving surface of the fluorescent part 30 can be enhanced.

[0051] Also in the present embodiment, two opposite lateral surfaces defining the recess of the base member may be formed into light-reflecting surfaces, such that light from the LD elements are irradiated on the light-reflecting surfaces respectively. Also, the optical element used in the second embodiment can be used as each of the two optical elements.

[0052] FOURTH EMBODIMENT

FIG. 22 is a diagram illustrating propagation of light emitted from a semiconductor laser element 10, reflected at a light-reflecting surface 21, and irradiated on a light-receiving surface of a fluorescent part 30, in the light emitting device 500 according to a fourth embodiment. The semiconductor light emitting element 500 has a substantially similar configuration as that of the light emitting device 200 described in the first embodiment, except for those described below.

[0053] As shown in FIG. 22, in the light emitting device 500, a region of the light-reflecting surface 21 to be irradiated with the laser light includes a first region 21a corresponding to a first end and a second region 21b corresponding to a second end that

is opposite side of the first end of three portions of the elliptic shape of FFP that is divided in its longitudinal direction. The first region 21a is arranged such that the laser light reflected at the first region 21a and a portion of the laser light reflected at the third region 21c at a location closer to the first region 21a or to the second region 21b are overlapped with each other on the light-receiving surface of the fluorescent part 30. The second region 21b is arranged such that the laser light reflected at the second region 21b and a portion of the laser light reflected at the third region 21c at a location closer to the other of the first region 21a or the second region 21b are overlapped with each other on the light-receiving surface of the fluorescent part 30. That is, the first region 21a and the second region 21b are provided such that a portion of the laser light reflected at the first region 21a and a portion of the laser light reflected at the second region 21b are respectively overlapped with portions of the laser light reflected at the third region 21c on the light-receiving surface of the fluorescent part 30 at regions where the laser light reflected from the third region 21c has a lower light intensity.

[0054] As shown in FIG. 22, in the light emitting device 500, the first region 21a is arranged such that the laser light reflected at the first region 21a and a portion of the laser light reflected at the third region 21c at a location closer to the second region 21b are overlapped with each other on the light-receiving surface of the fluorescent part 30. The second region 21b is arranged such that the laser light reflected at the second region 21b and a portion of the laser light reflected at the third region 21c at a location closer to the first region 21a are overlapped with each other on the light-receiving surface of the fluorescent part 30. That is, the first region 21a and the second region 21b are arranged such that the light reflected at the first region 21a and the light reflected at the second region 21b cross each other before irradiated on the light-receiving surface of the fluorescent part 30. With this arrangement, a portion with lower light emission intensity in the laser light reflected at the first region 21a (in FIG. 22, laser light reflected near the left end of the first region 21a) and a portion with lower light emission intensity in the laser light reflected at the third region 21c (in FIG. 22, laser light reflected near the right end of the third region 21c) can be overlapped with each other, and a portion with lower light emission intensity in the laser light reflected at the second region 21b (in FIG. 22, laser light reflected near the right end of the second region 21b) and a portion with lower light emission intensity in the laser light reflected at the third region 21c (in FIG. 22, laser light reflected near the left end of the third region 21c) can be overlapped with each other. Accordingly, the light intensity of the laser light at the light-receiving surface of the fluorescent part 30 can be made close to uniform.

[0055] The light emitting device 500 may also be configured such that the laser light reflected at the first region and the laser light reflected at the second region are not cross each other. In other words, the light-reflecting surface may be arranged such that a portion of the laser light reflected at the third region at a location closer to the first region and a portion of the laser light reflected at the first region at a location closer to the third region are overlapped with each other, while a portion of the laser light reflected at the third region at a location closer to the second region and a portion of the laser light reflected at the second region at a location closer to the third region are overlapped with each other. Even in such cases, a portion of the laser light reflected at the third region and having lower light emission intensity can be overlapped with the laser light reflected at the first region and the laser light reflected at the second region, and thus a certain degree of effect can be obtained.

[0056] FIFTH EMBODIMENT

FIG. 23 is a diagram illustrating propagation of light emitted from a semiconductor laser element 10, reflected at a light-reflecting surface 21, and irradiated on a light-receiving surface of a fluorescent part 30, in the light emitting device 600 according to a fifth embodiment. The semiconductor light emitting element 600 has a substantially similar configuration as that of the light emitting device 200 described in the first embodiment, except for those described below.

[0057] The light emitting device 600 includes an optical element 20 having a light-reflecting surface 21 of a curved surface. The light-reflecting surface 21 of a curved surface is formed such that a divergent angle of the laser light reflected at the regions corresponding to both longitudinal ends of the FFP of an elliptic shape is smaller than a divergent angle of the laser light reflected at the regions corresponding to a center portion of the FFP, to obtain the light intensity distribution of the laser light at the light-receiving surface of the fluorescent part 30 approaching uniformity. That is, the light-reflecting surface 21 is disposed such that, in the longitudinal direction of the FFP of an elliptic shape, light in the vicinity of the center spreads outward, while reducing spreading of light in the vicinity of the both ends. Even in such cases, the light intensity distribution of the laser light at the light-receiving surface can be made close to uniform.

[0058] Other embodiments are described below.

A light emitting device includes one or more semiconductor laser elements, each configured to emit a laser light, one or more light-reflecting parts, each having a light-reflecting surface configured to reflect the laser light emitted from corresponding one of the one or more semiconductor laser elements, and a fluorescent part having a

light-receiving surface configured to be irradiated with the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts. An irradiated region is formed on the light-reflecting surface when the light-reflecting surface is irradiated with the laser light, and the irradiated region includes a first end and a second end opposite to the first end, located at two opposite ends of the irradiated region in a longitudinal direction. The light-reflecting surface of each of the one or more light-reflecting parts is arranged such that a portion of the laser light reflected at at least a first end of the irradiated region and a portion of the laser light reflected at a location other than the first end of the irradiated region are overlapped with each other on the light-receiving surface.

[0059] In the light emitting device, the light-reflecting surface of each of the one or more light-reflecting parts includes a plurality of regions positioned at different angles with respect to a lower surface of the light-reflecting part. The laser light from corresponding one of the one or more semiconductor laser elements is irradiated on the plurality of regions. An irradiated region is formed on the light-receiving surface when the laser light reflected at each of the one or more light-reflecting parts are irradiated on the light-receiving surface, the irradiated region on the light-receiving surface includes a first end. A portion of the laser light reflected at a location other than the first end of the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts is irradiated on at least the first end of the irradiated region on the light-receiving surface.

[0060] In the light emitting device, the one or more semiconductor laser elements are each configured to emit a laser light with a light intensity distribution higher at a center portion than at a peripheral portion of the irradiated region on the light-reflecting surface. The irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts comprises a first region including the first end and configured to reflect a portion of the laser light irradiated at least to the first end, and a second region including a second end located at an opposite side of the first end in the irradiated region, the second region is configured to reflect a portion of the laser light irradiated to the second end. A portion of the laser light reflected at locations closer to the center portion of the first region is irradiated to the light-receiving surface at locations closer to a first end of an irradiated region on the light-receiving surface. The closer the location of a portion of the laser light reflected at locations to the center portion of the second region, the closer the location of the reflected laser light irradiated to a second end located at an opposite side of the first end of the irradiated region on the light-receiving surface.

[0061] The light emitting devices described in the embodiments can be applied for lightings, lighting for vehicles, or the like.

[0062] It is to be understood that although the present invention has been described with regard to preferred embodiments thereof, various other embodiments and variants may occur to those skilled in the art, which are within the scope and spirit of the invention, and such other embodiments and variants are intended to be covered by the following claims.

WHAT IS CLAIMED IS:

1. A light emitting device comprising:

one or more semiconductor laser elements, each configured to emit laser light;

one or more light-reflecting parts, each having a light-reflecting surface configured to reflect the laser light emitted from a corresponding one of the one or more semiconductor laser elements; and

a fluorescent part having a light-receiving surface configured to be irradiated with the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts;

wherein an irradiated region is formed on the light-reflecting surface when the light-reflecting surface is irradiated with the laser light, the irradiated region including a first end and a second end opposite the first end; and

wherein the light-reflecting surface of each of the one or more light-reflecting parts is arranged such that a portion of the laser light reflected at at least a first end of the irradiated region and a portion of the laser light reflected at a location other than the first end of the irradiated region are overlapped with each other on the light-receiving surface.

2. The light emitting device according to claim 1, wherein:

the light-reflecting surface of each of the one or more light-reflecting parts comprises a plurality of regions positioned at different angles with respect to a lower surface of the light-reflecting part;

the laser light from each of the one or more semiconductor laser elements is irradiated on the plurality of regions of a corresponding light-reflecting surface;

an irradiated region is formed on the light-receiving surface when the laser light reflected at each of the one or more light-reflecting parts is irradiated on the light-receiving surface, the irradiated region on the light-receiving surface includes a first end; and

a portion of the laser light reflected at a location other than the first end of the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts is irradiated on at least the first end of the irradiated region on the light-receiving surface.

3. The light emitting device according to claim 2, wherein:

each of the one or more semiconductor laser elements is configured to emit laser light with a light intensity distribution higher at a center portion than at a peripheral portion of the irradiated region on the light-reflecting surface;

the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts comprises a first region including the first end and configured to reflect a portion of the laser light irradiated at least to the first end, and a second region including the second end of the irradiated region, the second region being configured to reflect a portion of the laser light irradiated to the second end;

a portion of the laser light reflected at locations closer to the center portion of the first region is irradiated to the light-receiving surface at locations closer to the first end of the irradiated region on the light-receiving surface; and

the closer the location of a portion of the laser light reflected at locations to the center portion of the second region, the closer the location of the reflected laser light irradiated to a second end located at an opposite side of the first end of the irradiated region on the light-receiving surface.

4. The light emitting device according to claim 3, wherein:

each of the one or more semiconductor laser elements is configured to emit a laser light having a far field pattern of an elliptic shape;

the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts has an elliptic shape that corresponds to the elliptic shape of the far field pattern irradiated on the light-reflecting surface, the irradiated elliptic shape of the far field pattern comprises two or more regions that include the first region and the second region, in a longitudinal direction of the elliptic shape;

the first region and the second region are arranged such that:

a portion of the laser light reflected at the first region at a location closer to the second region and a portion of the laser light reflected at the second region at a location away from the first region, are overlapped with each other on the light-receiving surface of the fluorescent part, and

a portion of the laser light reflected at the first region at a location away from the second region, and a portion of the laser light reflected at the second region at a location closer to the first region are overlapped with each other on the light-receiving surface of the fluorescent part.

5. The light emitting device according to claim 4, wherein:

the plurality of regions of the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts further includes a third region located between the first region and the second region;

the third region is arranged such that:

a portion of the laser light reflected at the third region at a location closer to the first region and a portion of the laser light reflected at the first region at a location away from the second region are overlapped with each other on the light receiving surface of the fluorescent part, and

a portion of the laser light reflected at the third region at a location closer to the second region and a portion of the laser light reflected at the second region at a location closer to the first region are overlapped with each other on the light receiving surface of the fluorescent part.

6. The light emitting device according to claim 3 wherein:

each of the one or more semiconductor laser elements is configured to emit a laser light having a far field pattern of an elliptic shape;

the irradiated region on the light-reflecting surface of each of the one or more light-reflecting parts has an elliptic shape that corresponds to the elliptic shape of the far field pattern irradiated on the light-reflecting surface, the irradiated elliptic shape of the far field pattern comprises three regions, including a first region, a second region, and a third region in a longitudinal direction;

the third region is located between the first region and the second region;

the first region is arranged such that a portion of the laser light reflected at the first region and a portion of the laser light reflected at the third region at a location closer to the first region or the second region are overlapped with each other on the light-receiving surface of the fluorescent part; and

the second region is arranged such that a portion of the laser light reflected at the second region and a portion of the laser light reflected at the third region at a location closer to the other of the first region or the second region are overlapped with each other on the light-receiving surface of the fluorescent part.

7. The light emitting device according to claim 6, wherein the first region is arranged such that a portion of the laser light reflected at the first region and a portion of the laser light reflected at the third region at a location closer to the second region are overlapped with each other on the light-receiving surface of the fluorescent part; and the second region is arranged such that the laser light reflected at the second region and a

portion of the laser light reflected at the third region at a location closer to the first region are overlapped with each other on the light-receiving surface of the fluorescent part.

8. The light emitting device according to any one of claims 3 to 7, wherein the first region and the second region are respectively arranged such that a light intensity distribution of the laser light reflected at the first region and a light intensity distribution of the laser light reflected at the second region have line symmetry in a direction corresponding to the longitudinal direction on the light receiving surface of the fluorescent part.

9. The light emitting device according to any one of claims 3 to 8, wherein the first region and the second region are flat surfaces.

10. The light emitting device according to any one of claims 3 to 9, wherein:

compared to the second region, the first region is located closer to corresponding one of the one or more semiconductor laser elements; and

an area of the first region is smaller than an area of the second region.

11. The light emitting device according to claim 1 wherein:

each of the one or more semiconductor laser elements is configured to emit a laser light having a far field pattern of an elliptic shape; and

the light-reflecting surface has a curved surface, and the curved surface is configured such that divergent angles of the laser light reflected at the regions corresponding to both ends in a longitudinal direction of the elliptic shape of the far field pattern are smaller than a divergent angle of the laser light reflected at the region corresponding to a center portion in the longitudinal direction of the elliptic shape of the far field pattern, to obtain a light intensity distribution of the laser light at the light-receiving surface of the fluorescent part approaching uniformity.

12. The light emitting device according to claim 1, wherein each of the light-reflecting parts is an optical element having at least one light-reflecting surface.

13. The light emitting device according to any one of claims 1 to 12 wherein:

the light-receiving surface of the fluorescent part has a rectangular shape that is elongated in one direction;

the laser light is irradiated in a shape that is elongated in one direction on the light-receiving surface of the fluorescent part; and

the fluorescent part and the one or more semiconductor laser elements are disposed such that a longitudinal direction of the light-receiving surface of the fluorescent part and a longitudinal direction of the laser light reflected at the light-reflecting surface of each of the one or more light-reflecting parts are parallel to each other.

14. The light emitting device according to any one of claims 1 to 13, wherein the irradiated region on the light-reflecting surface is irradiated with the laser light having an intensity $1/e^2$ or greater with respect to a peak intensity value of the laser light.

FIG. 1

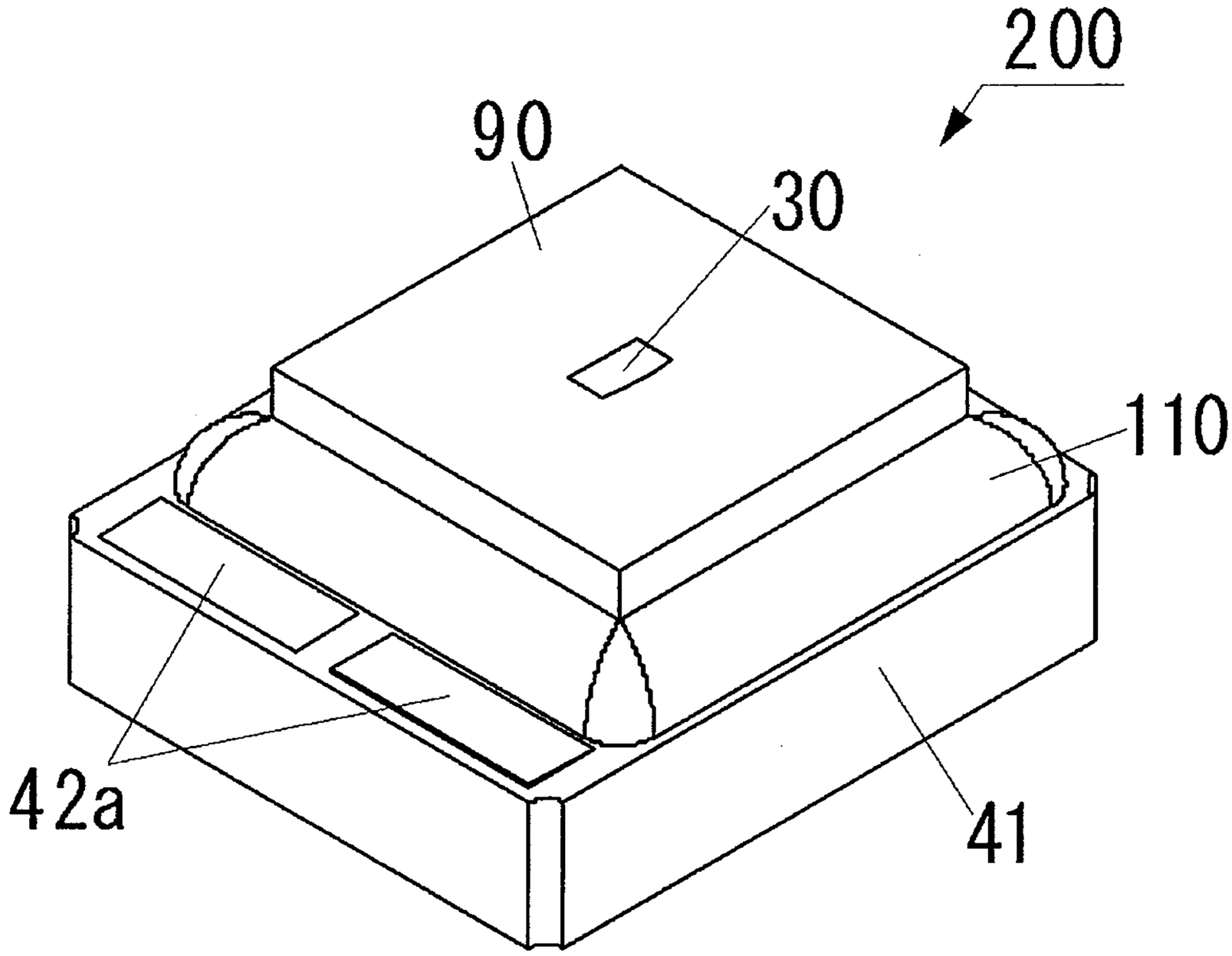


FIG.2

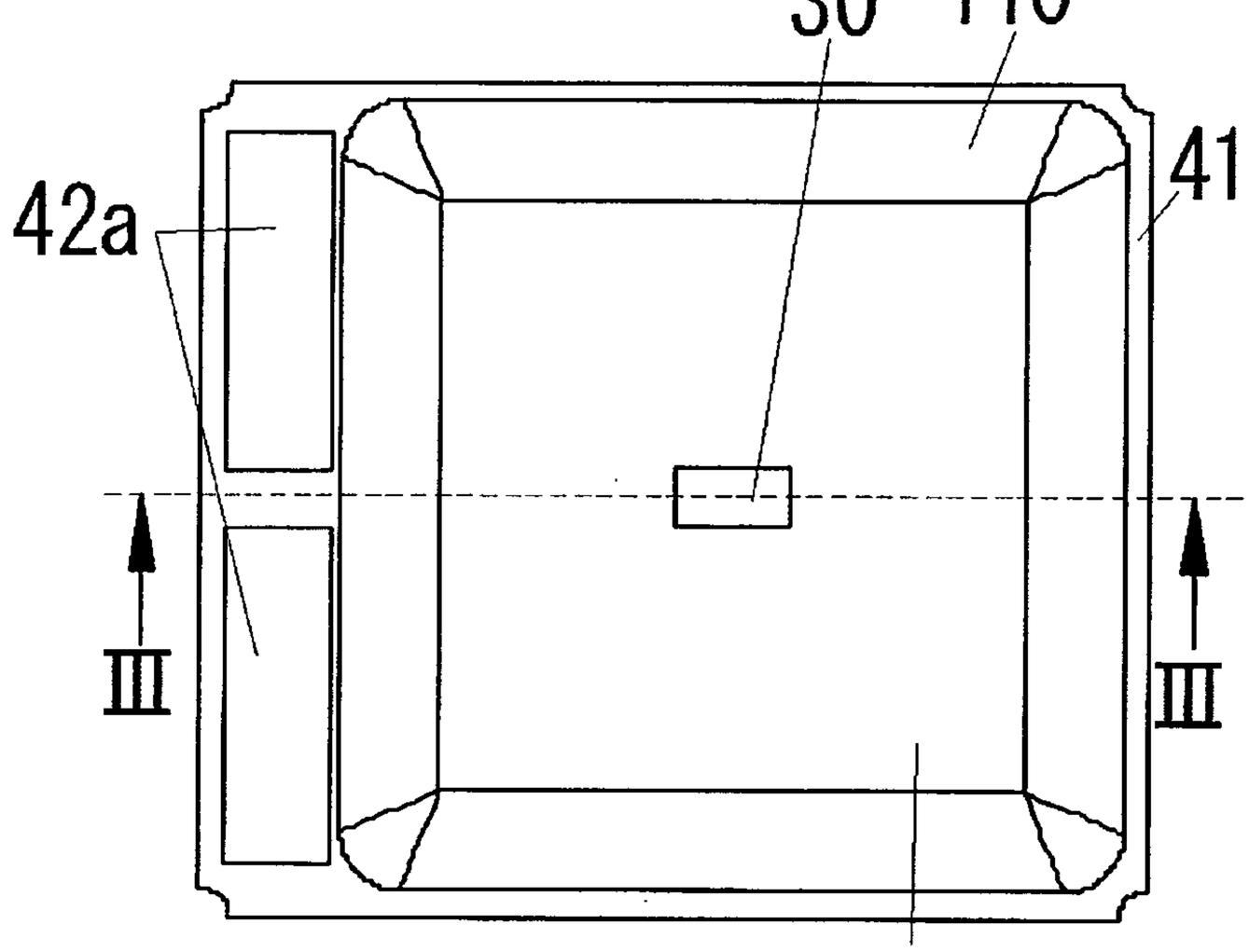

30
110
41
42a
III
III
90

FIG. 3

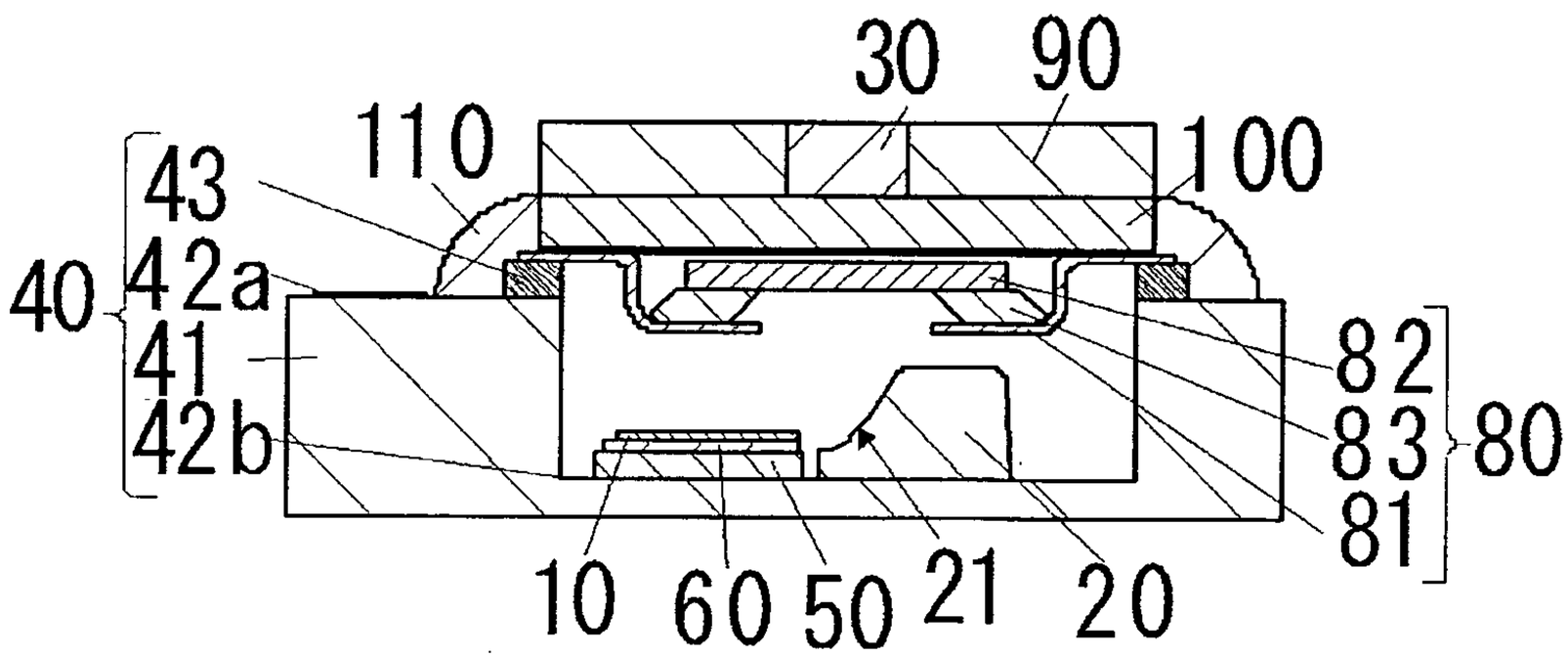

30
90
110
100
43
40
42a
41
42b
82
83
80
81
10
60
50
21
20

FIG. 4

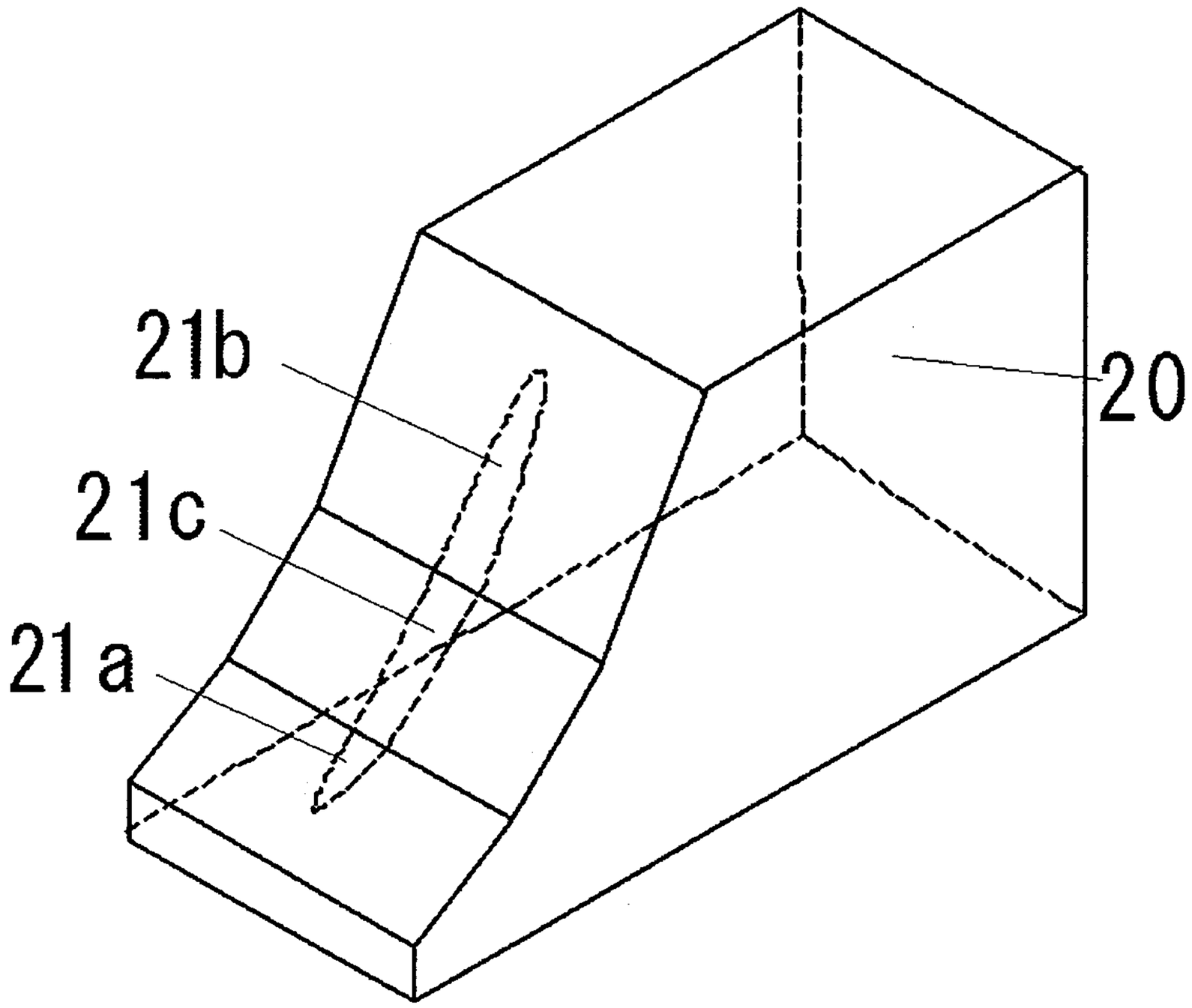


FIG. 5

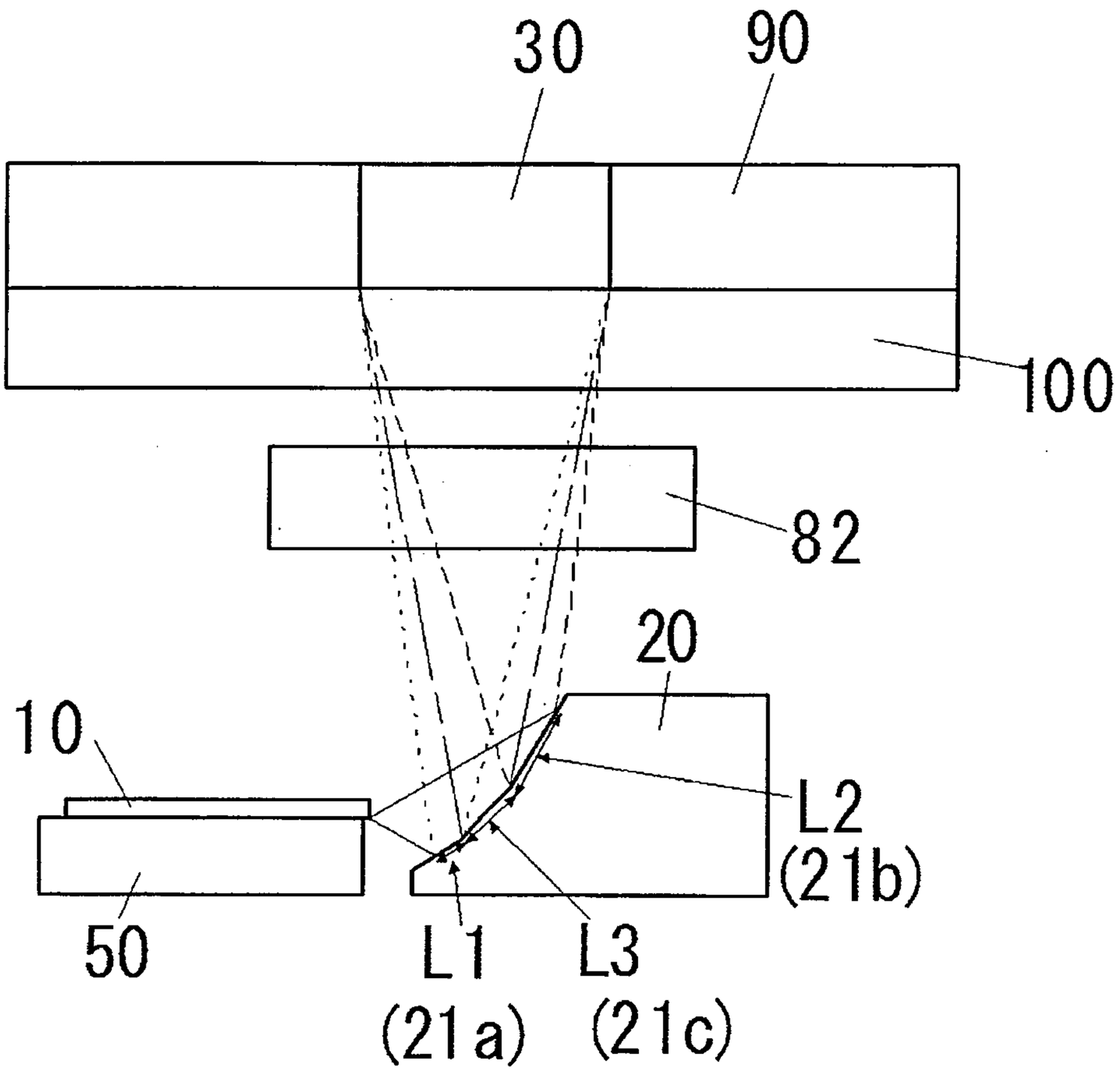


FIG. 6

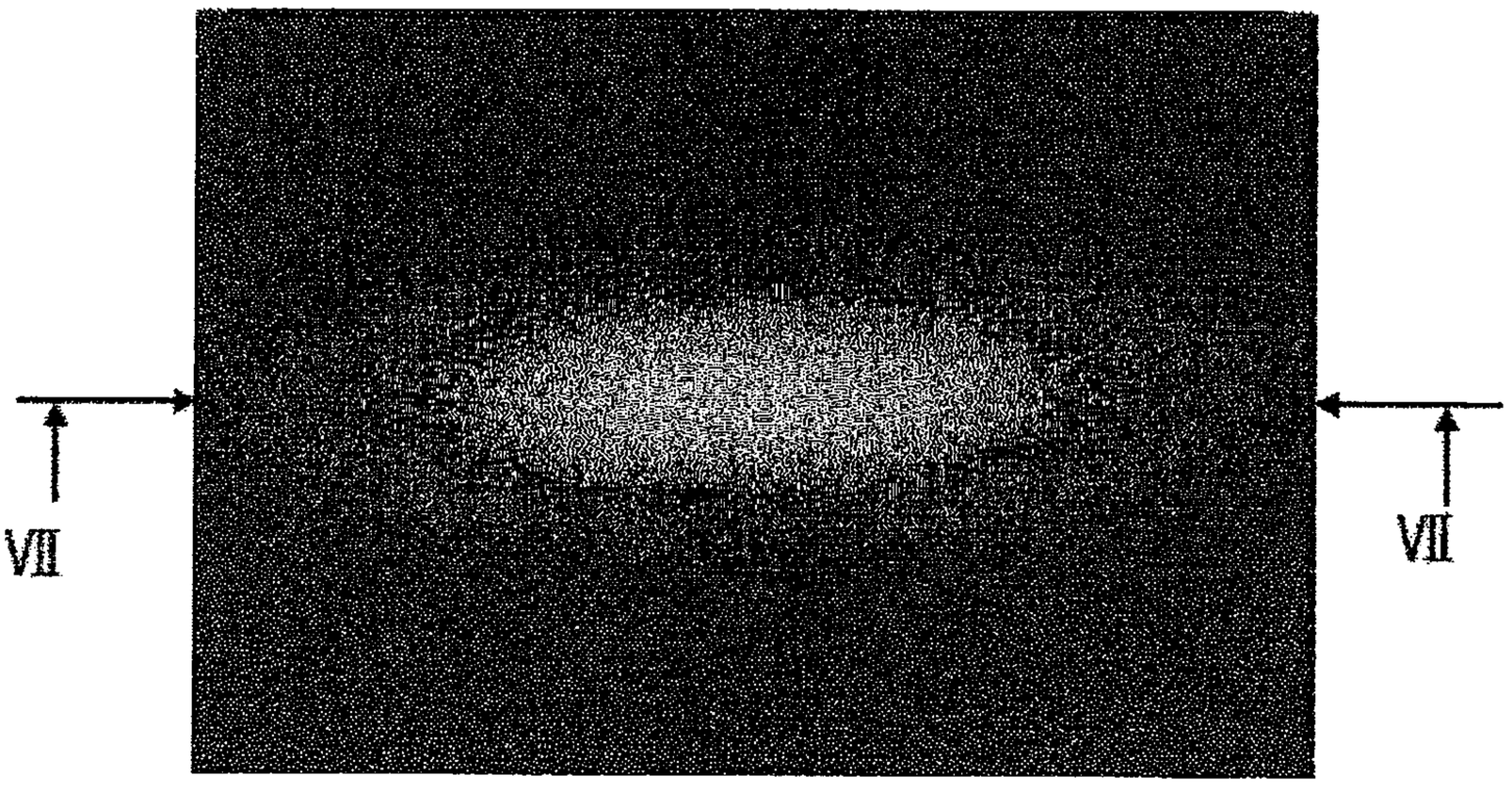


FIG. 7

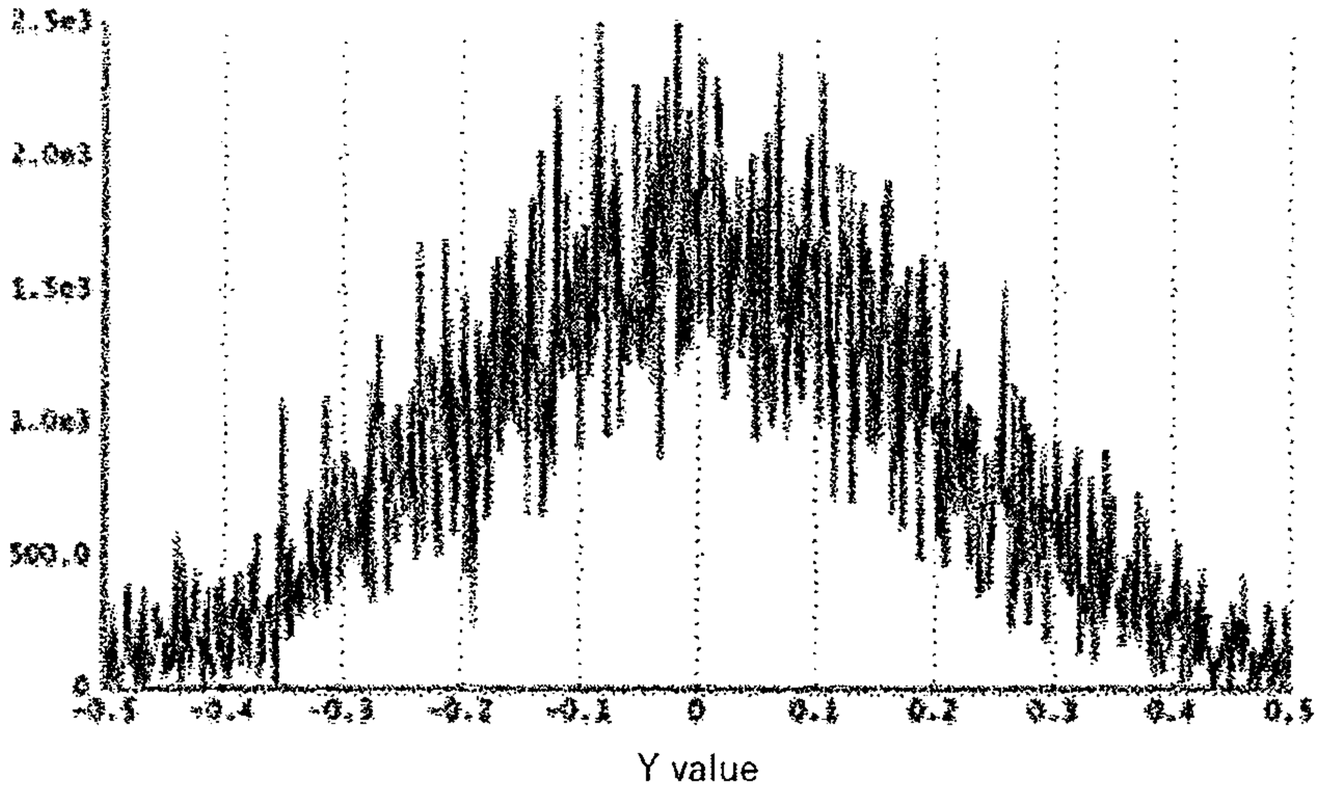

2.5e3
2.0e3
1.5e3
1.0e3
500.0
0
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Y value

FIG. 8

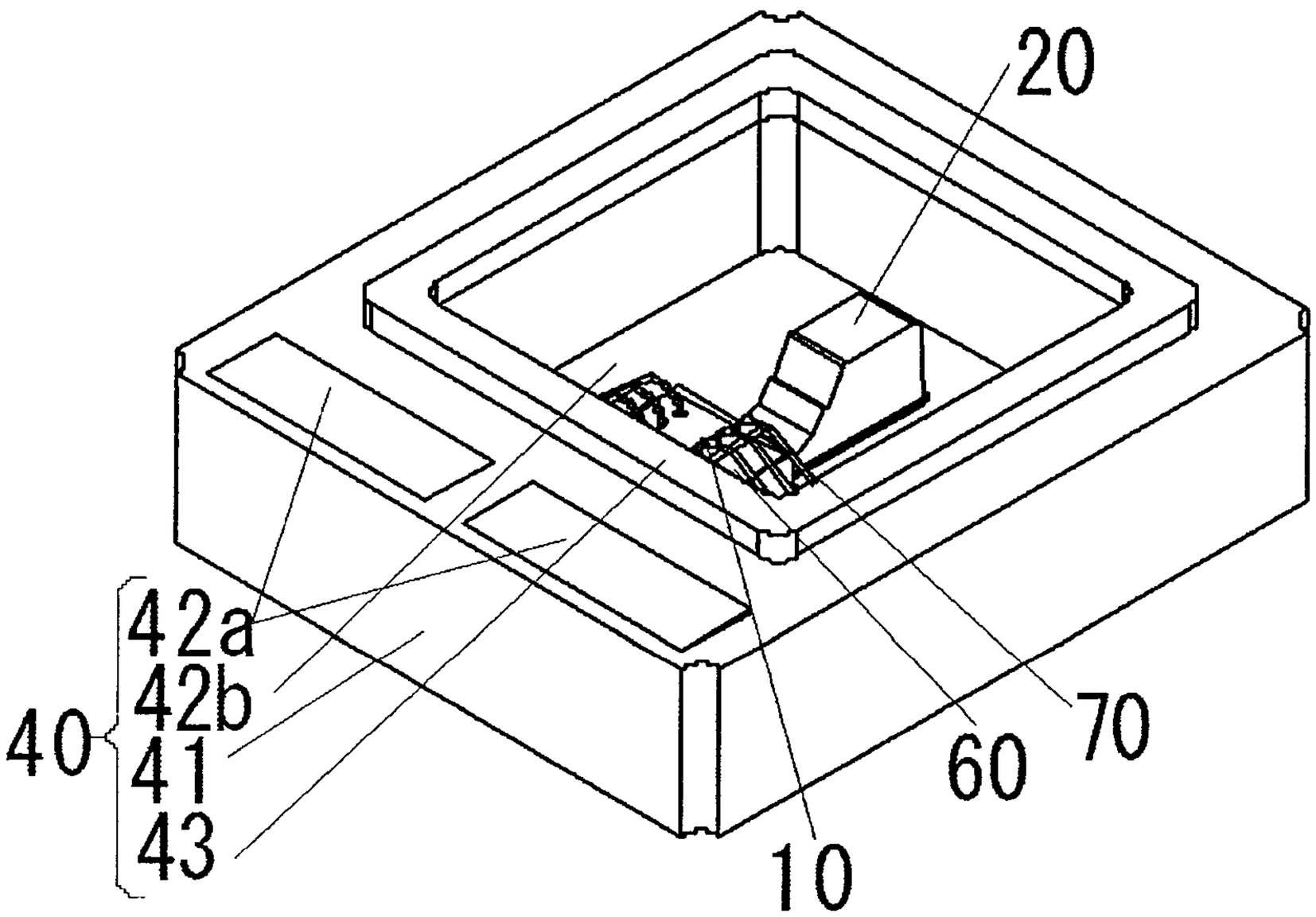

20
40
42a
42b
41
43
10
60
70

FIG. 9

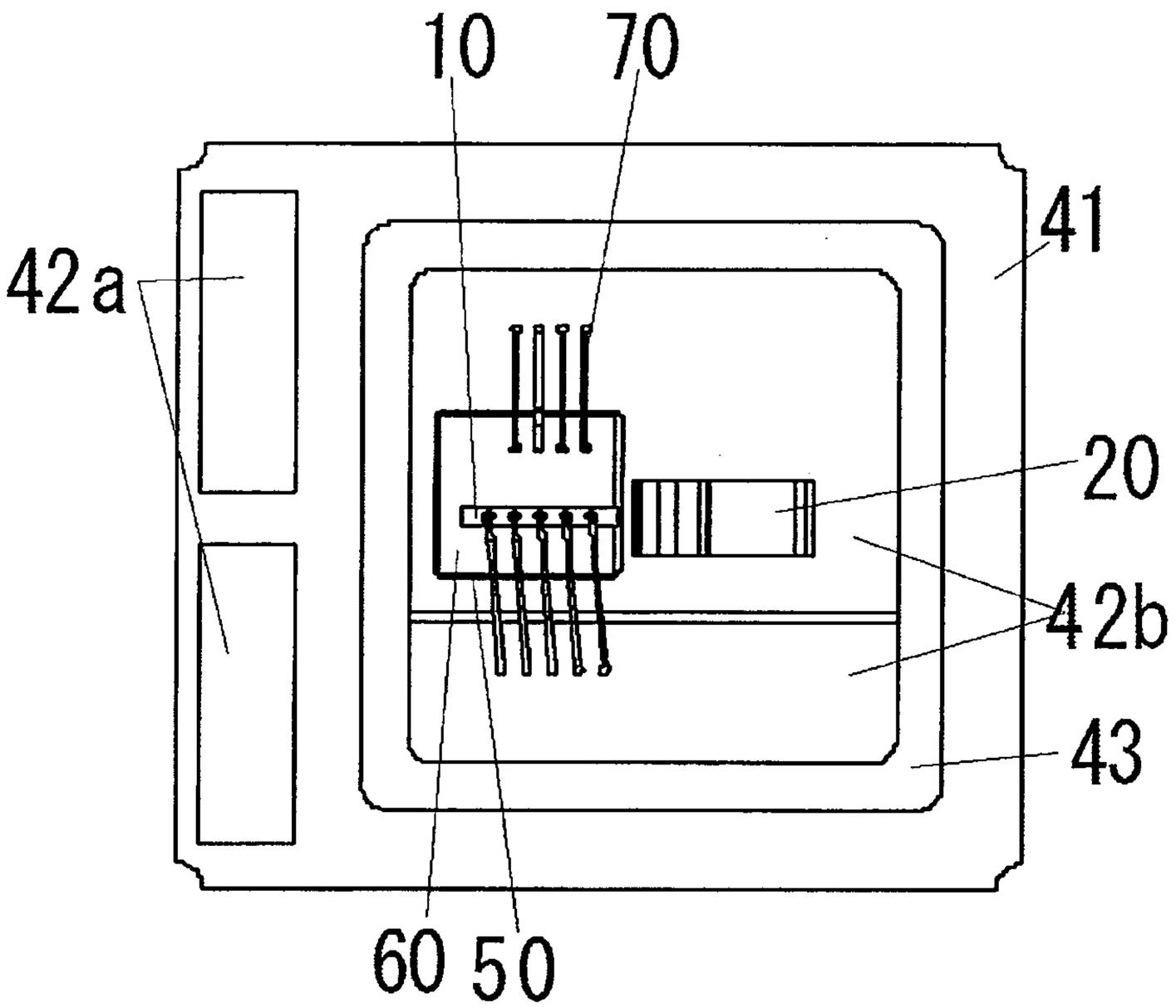


FIG. 10

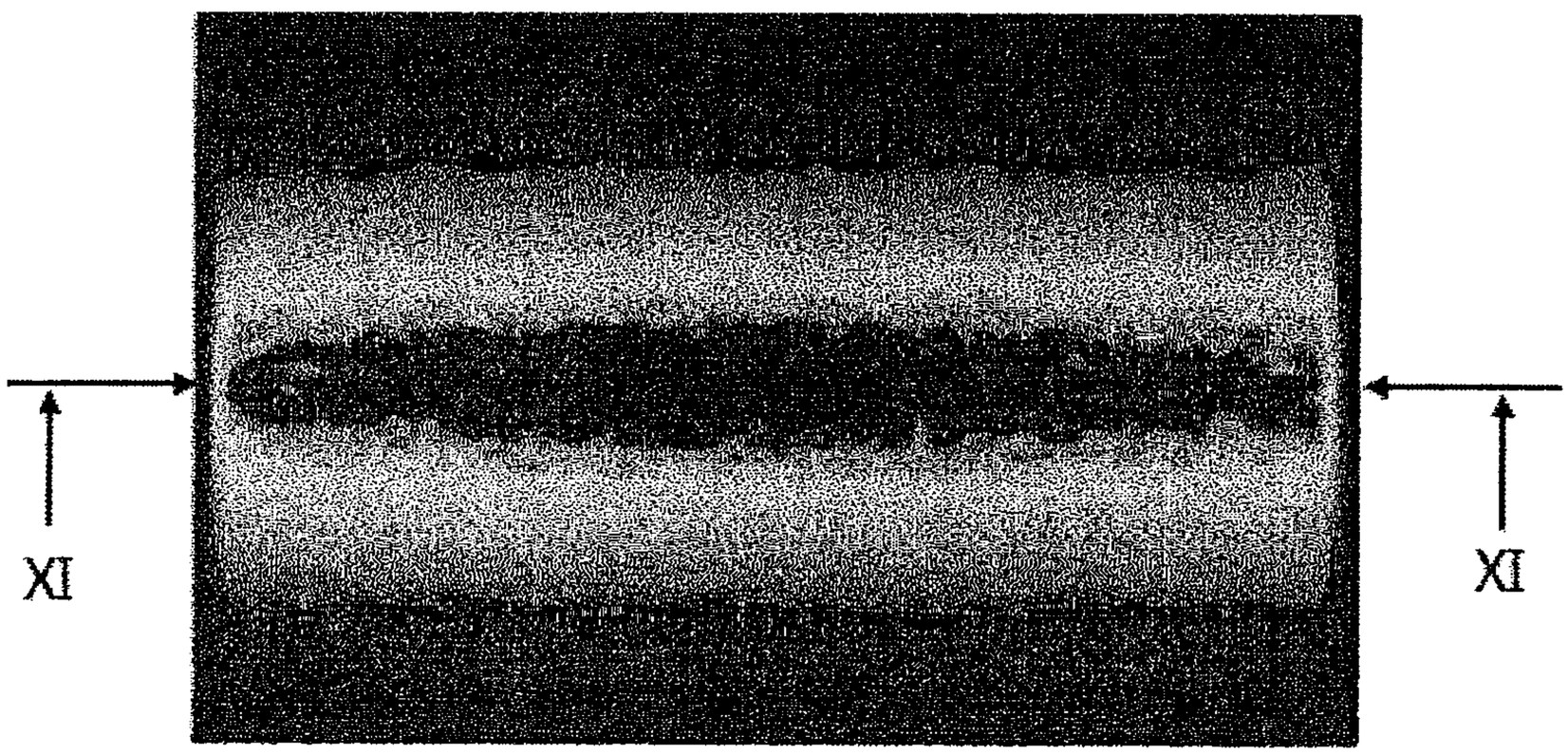


FIG. 11

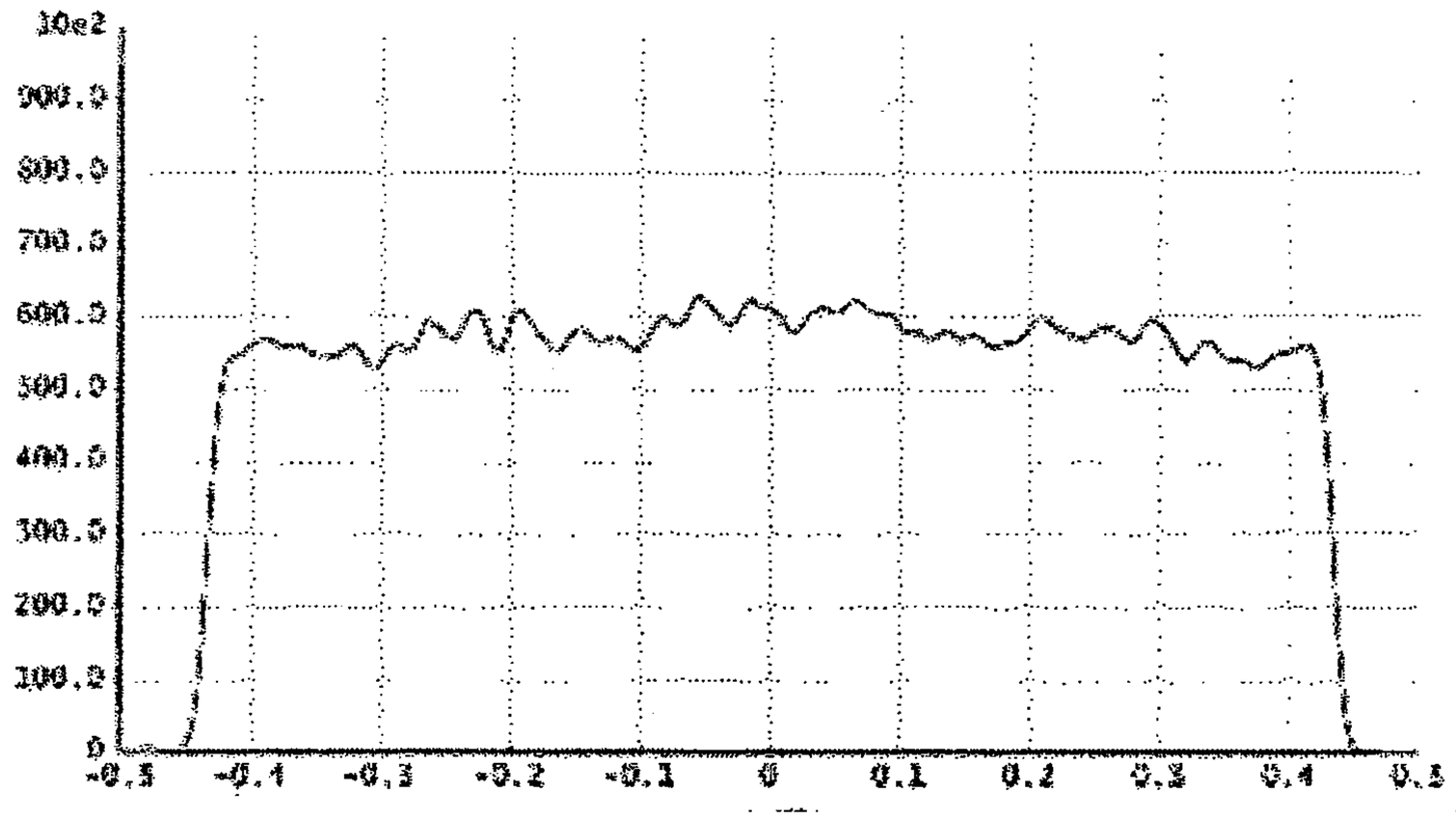

10e2
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

FIG. 12

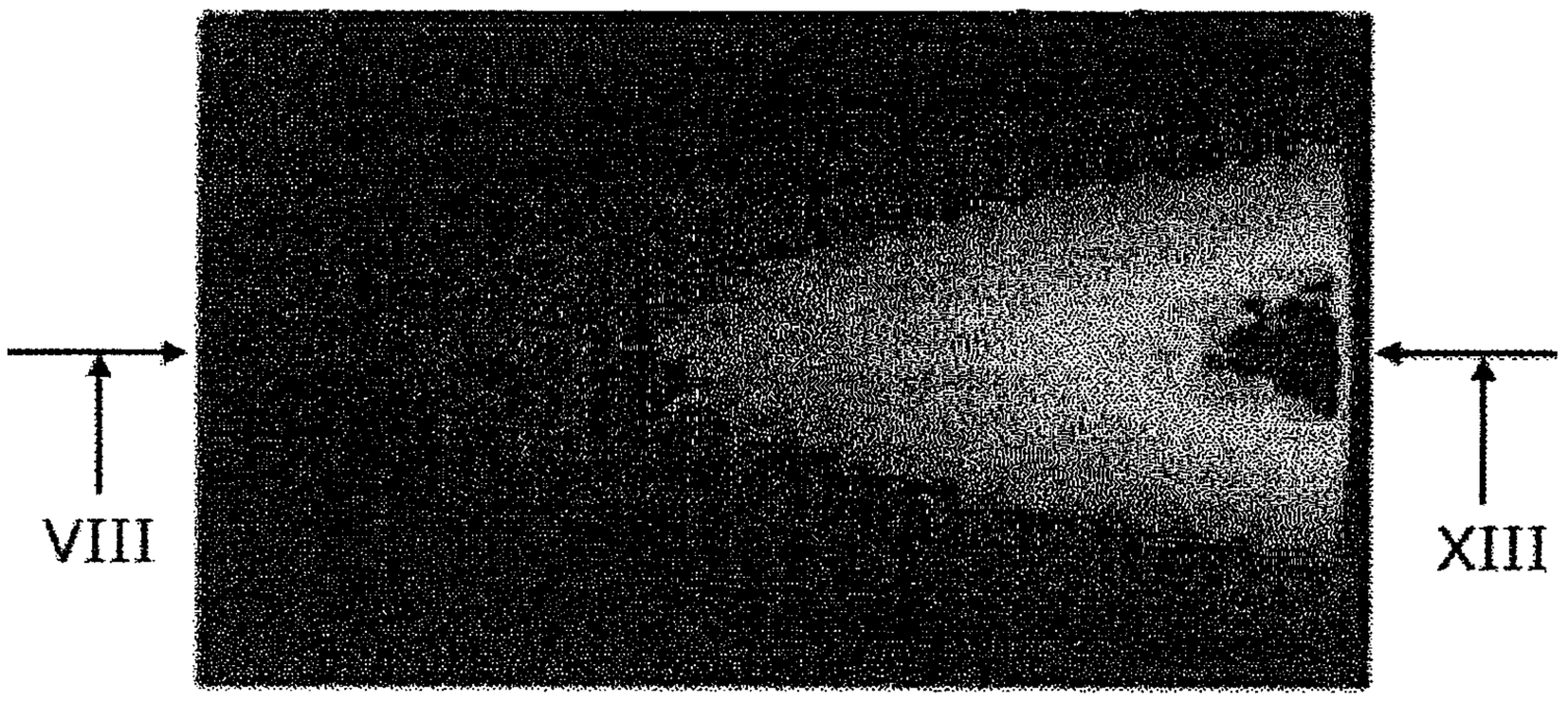

VIII
XIII

FIG. 13

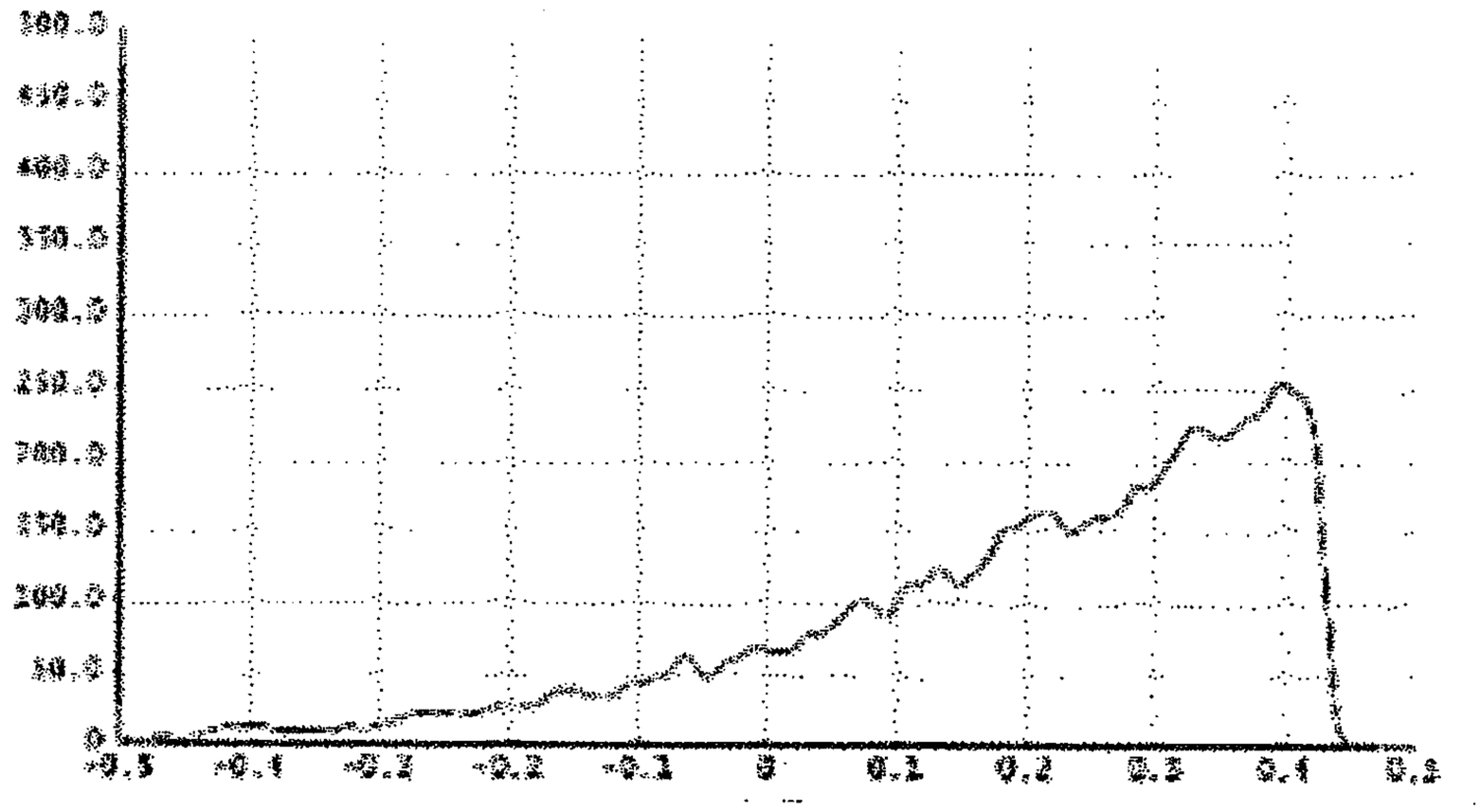


FIG. 14

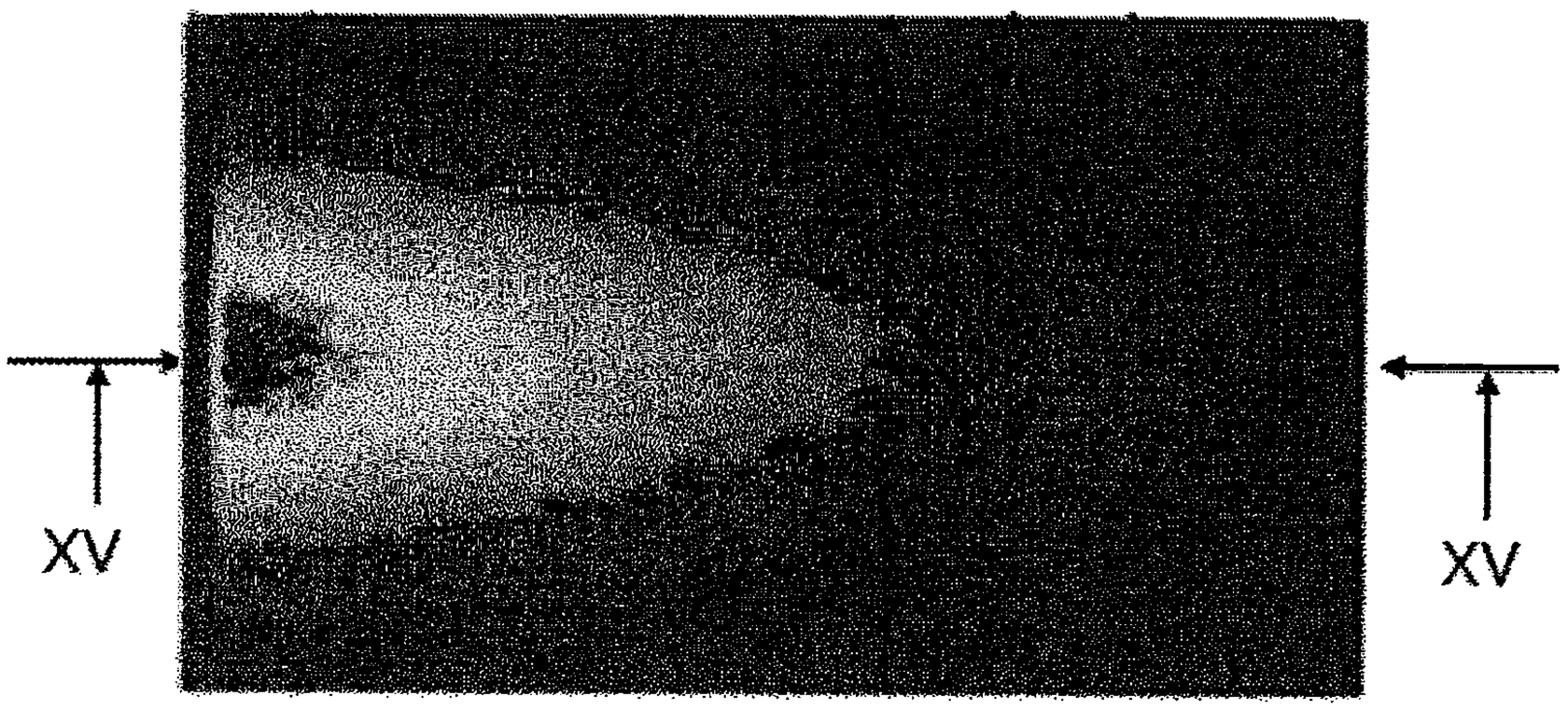


FIG. 15

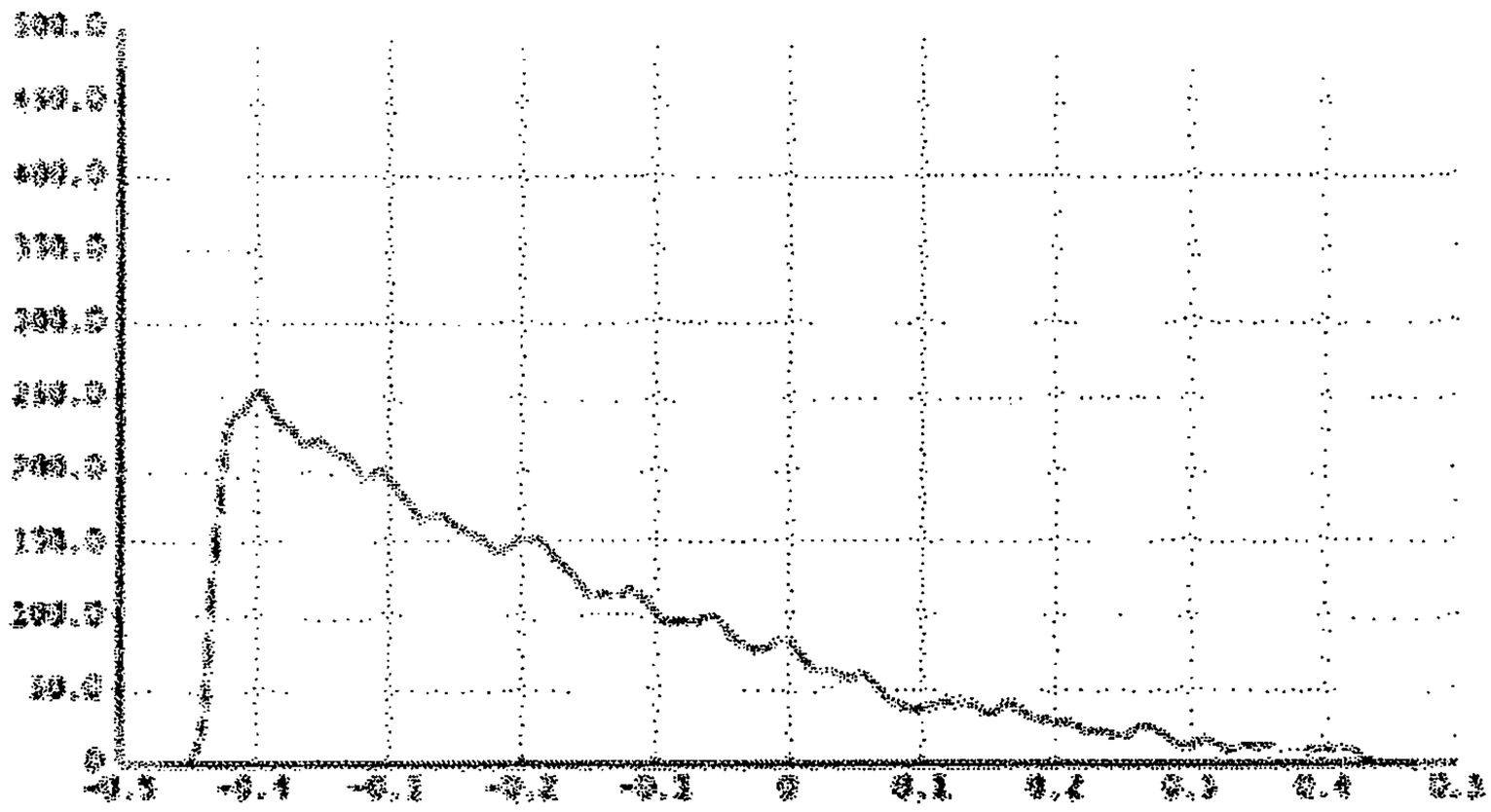


FIG. 16

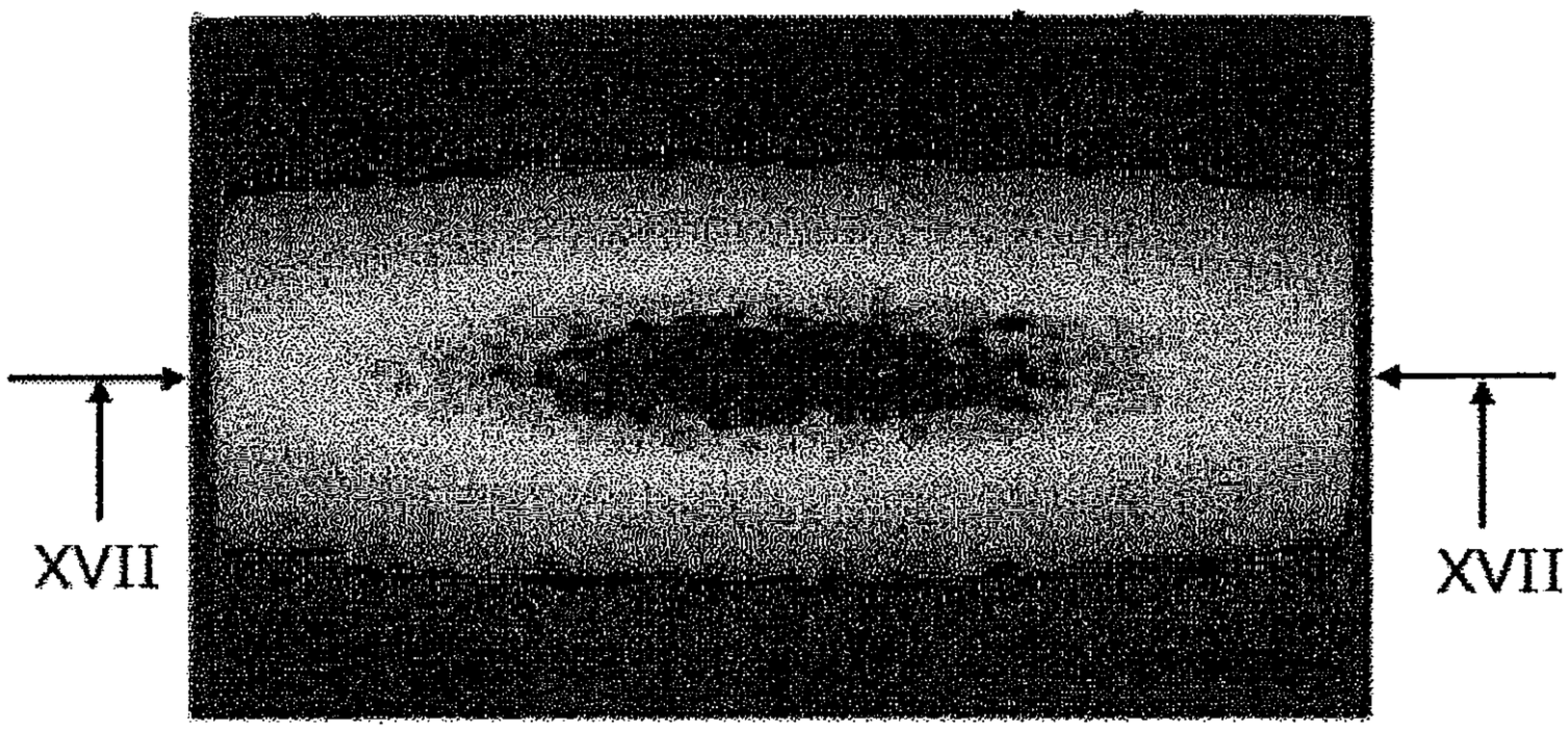


FIG. 17

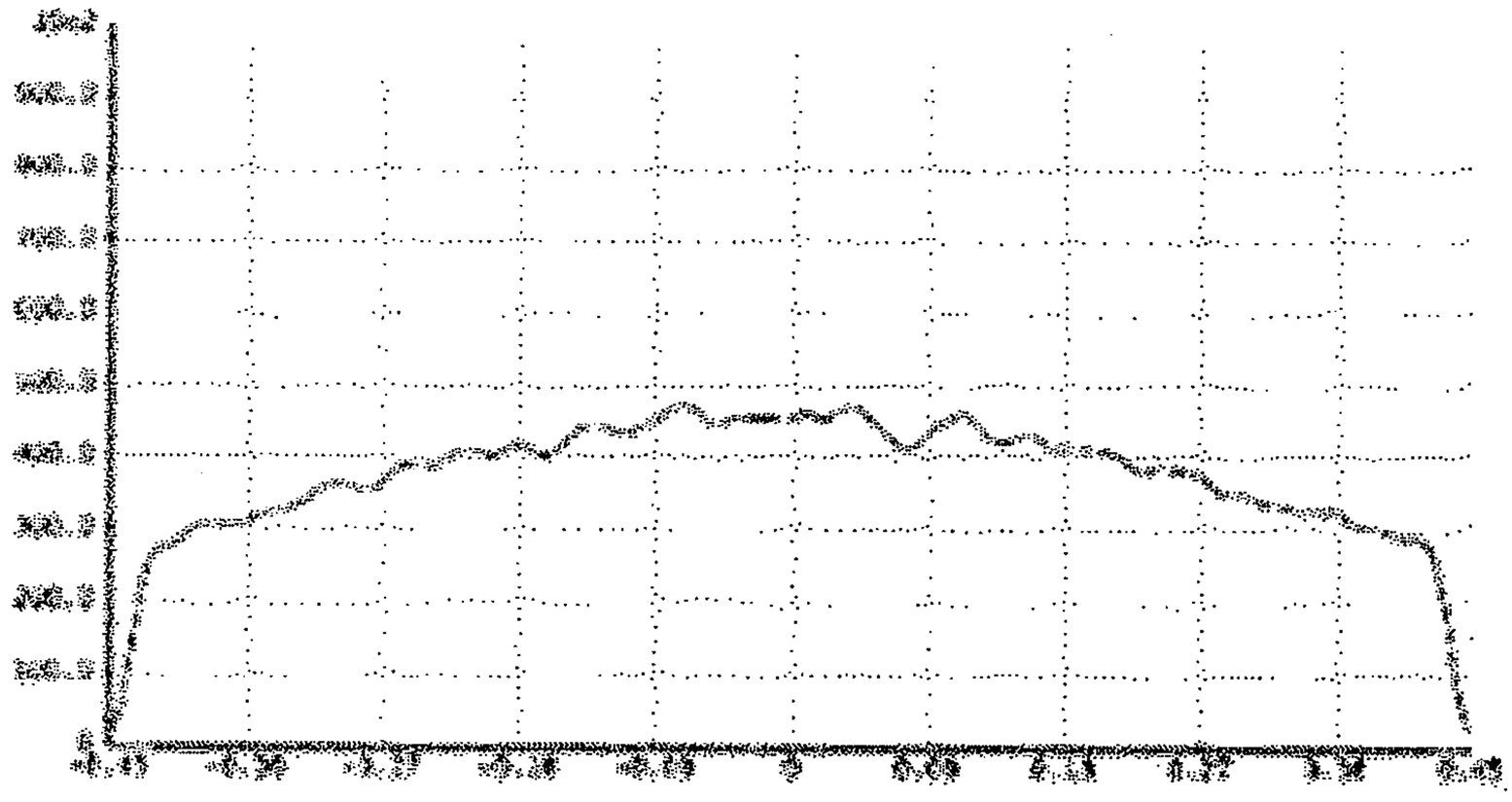


FIG. 18

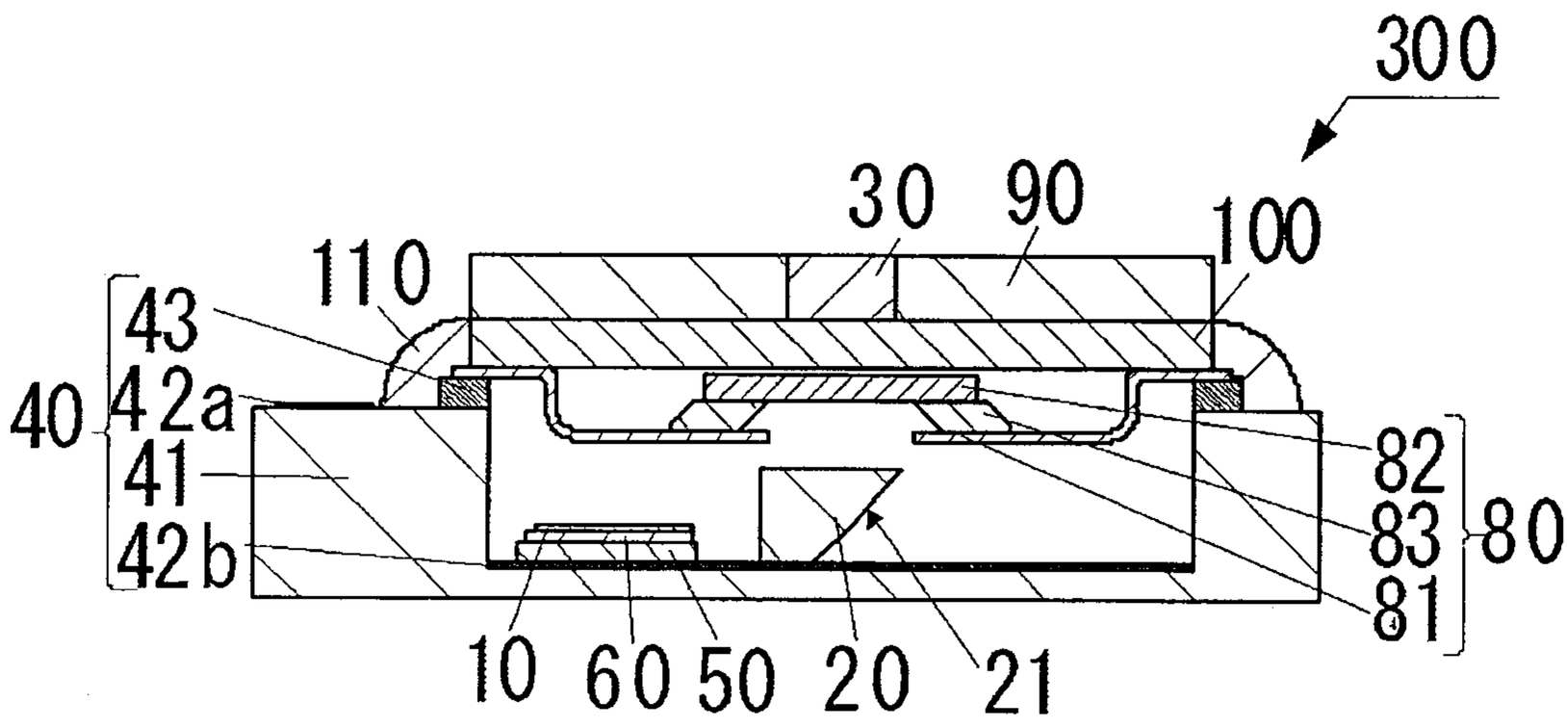


FIG. 19

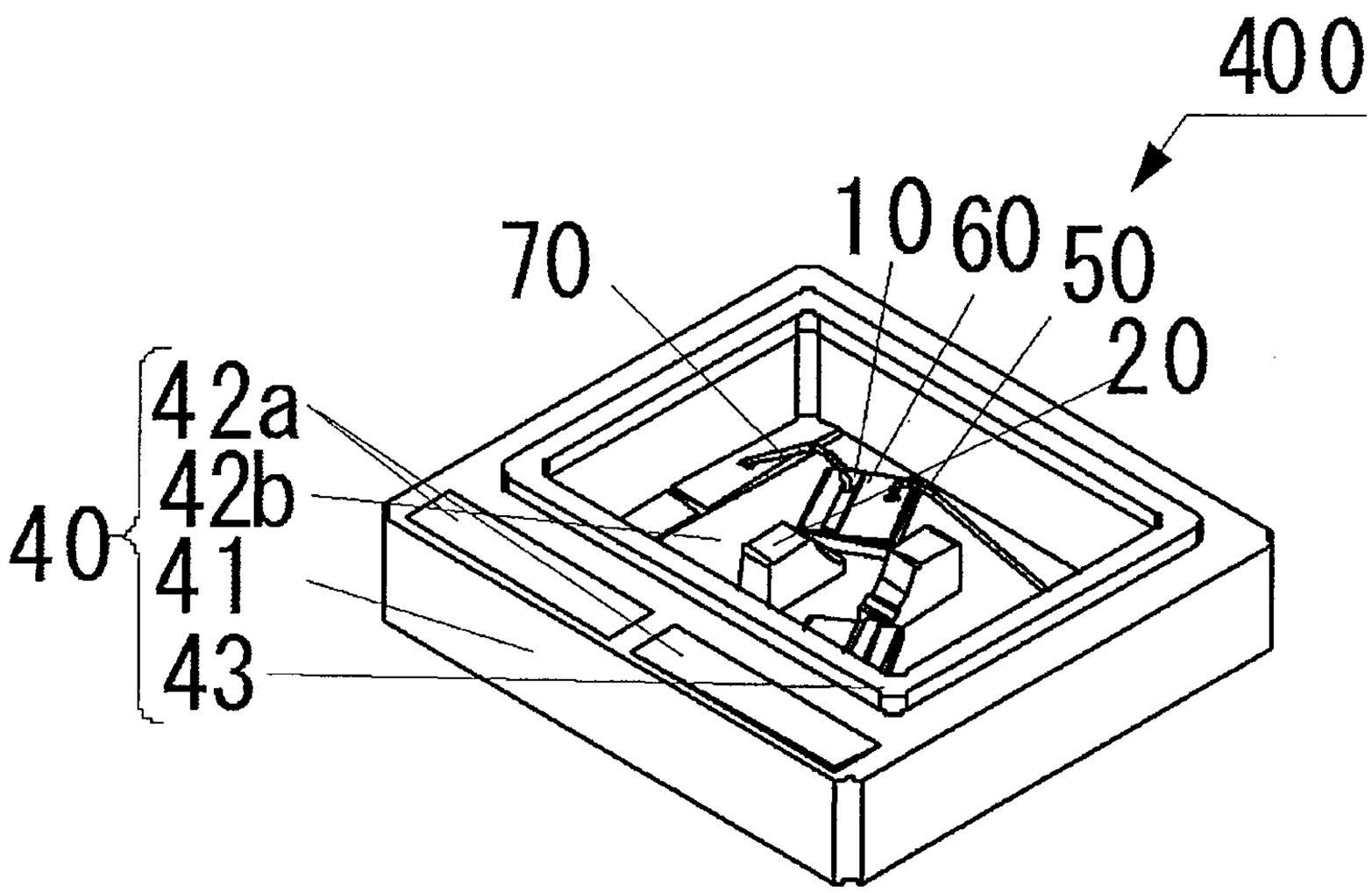


FIG. 20

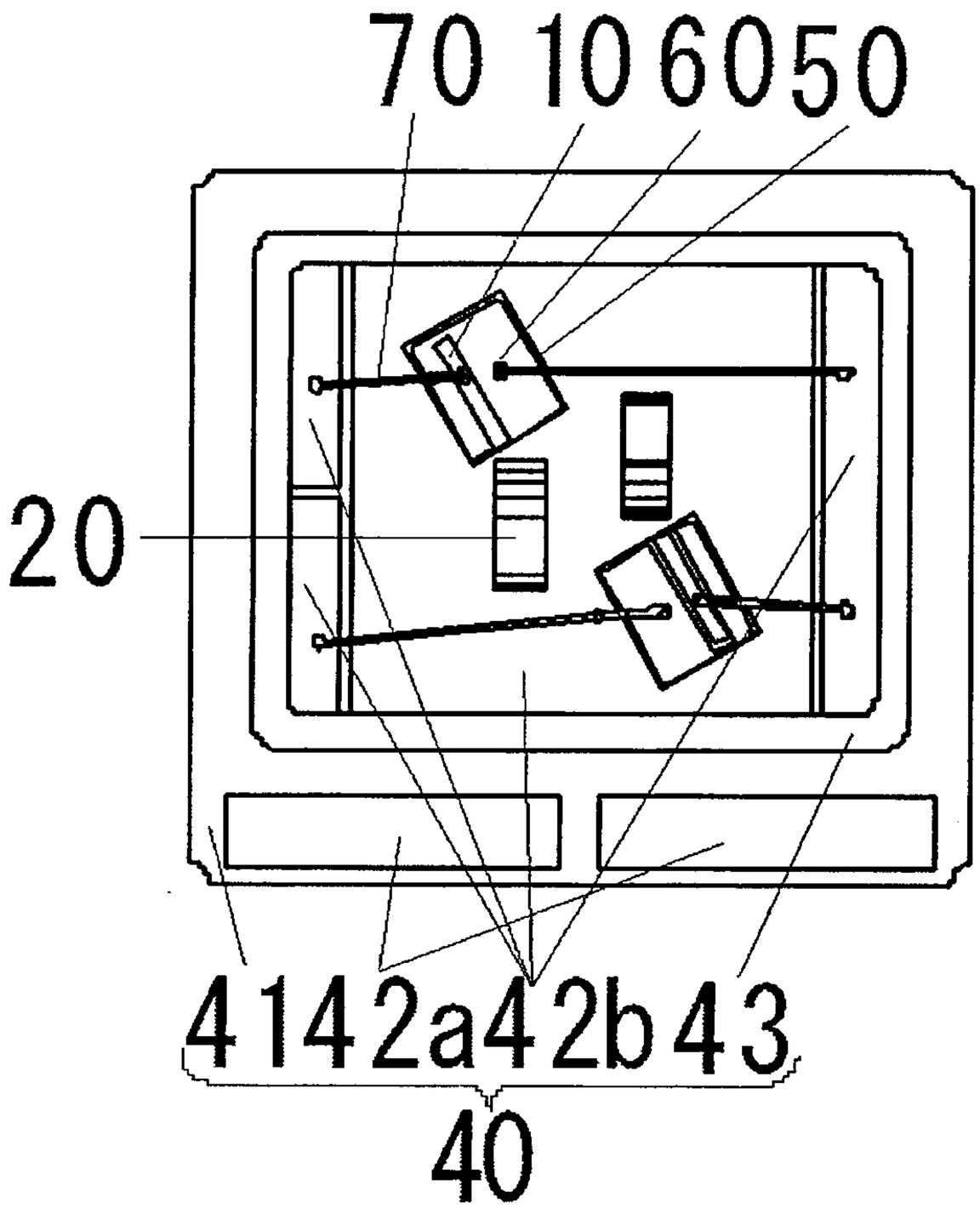


FIG. 21

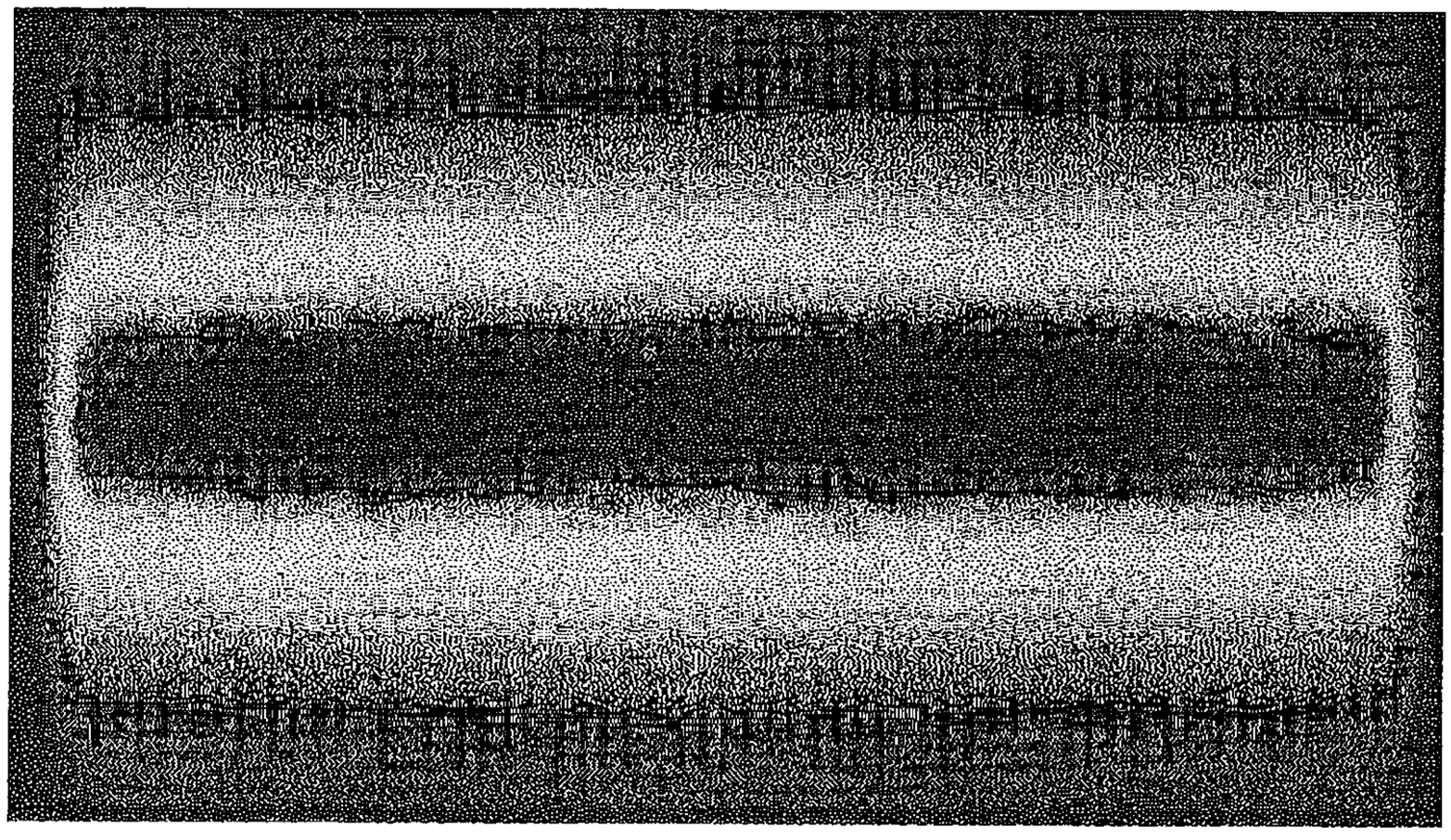


FIG. 22

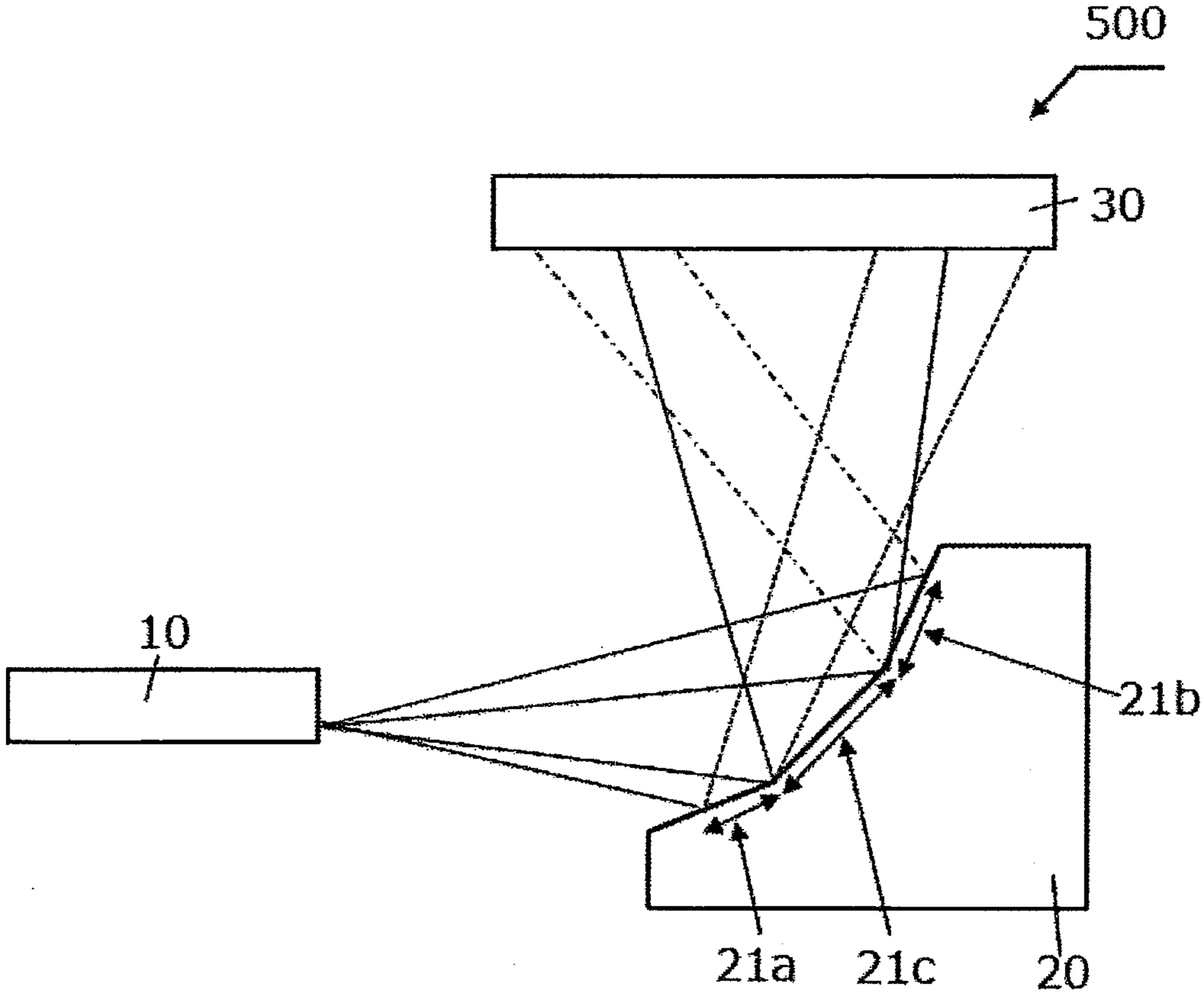
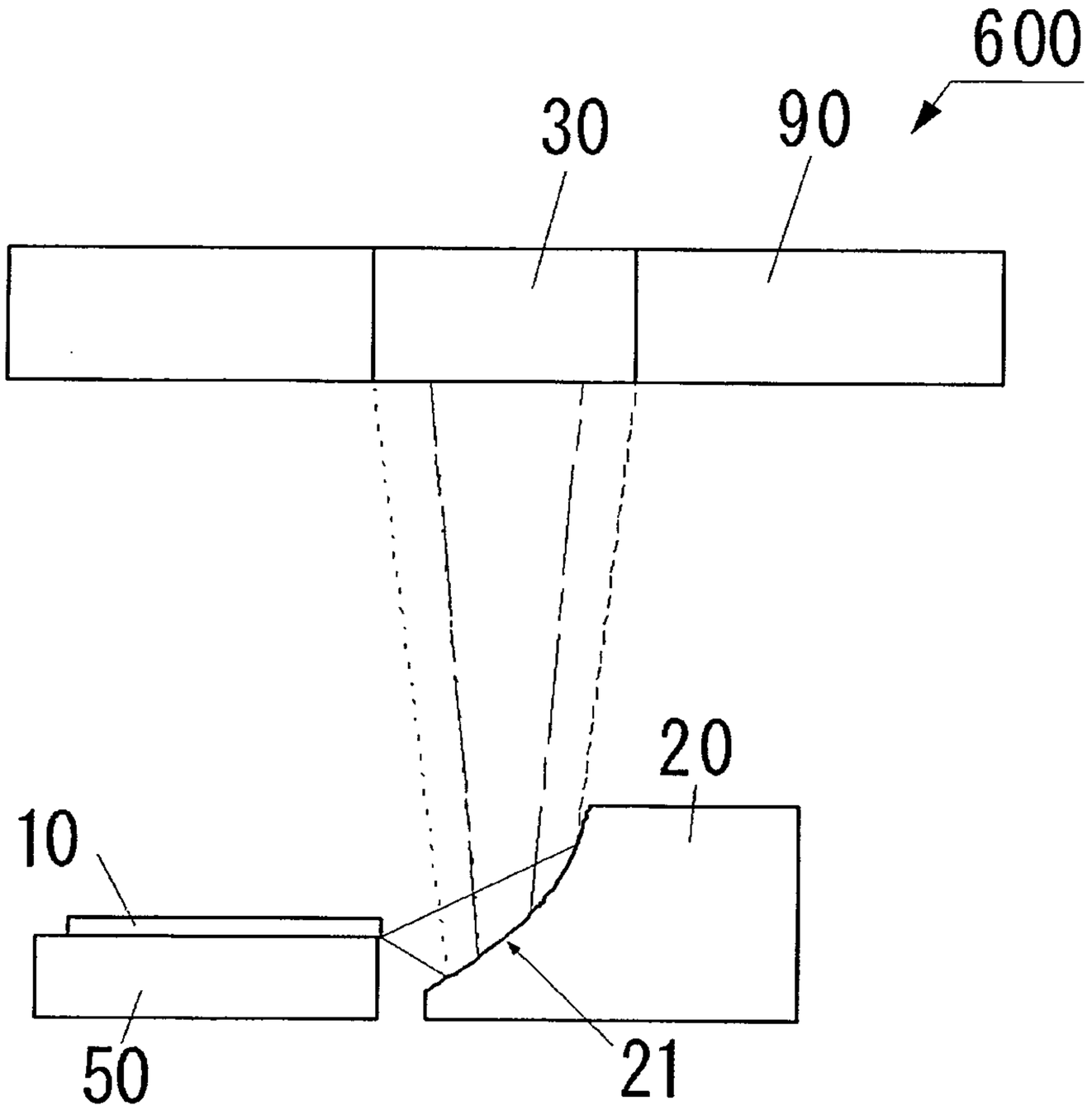
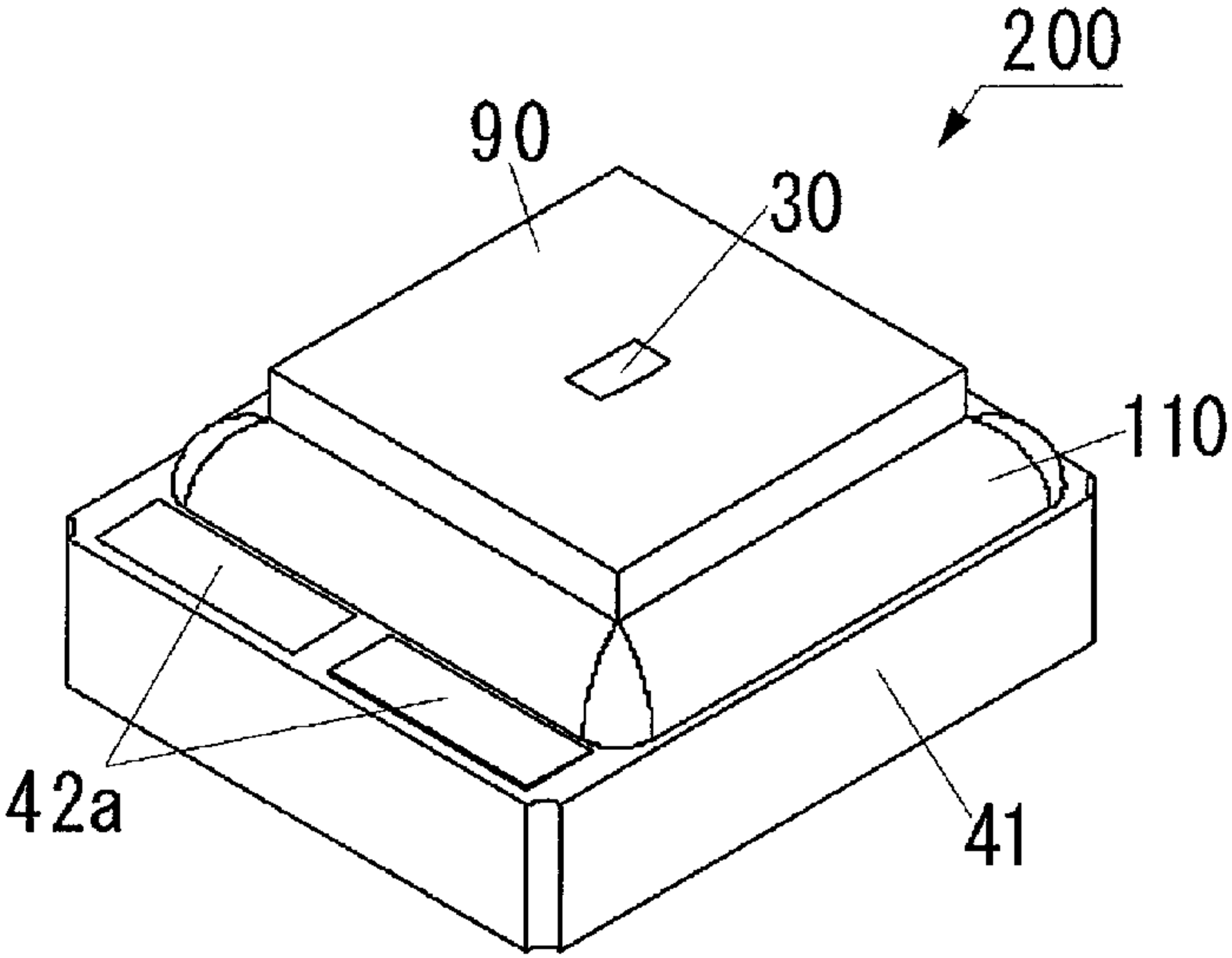


FIG. 23




200
90
30
110
42a
41