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(54) **OPTICAL SCANNING DEVICE**

(57) There is provided a headlight unit 1 configured to make phosphors emit light efficiently. The headlight unit 1 includes a laser-light emission device 14, a light deflector 15, a phosphor panel 20, and a projector lenses 19 in order along a light traveling path. The rotational position of a light emitting unit 45 of the laser-light emis-

sion device 14 about an optical axis is so set that the minor axis direction of an optical spot Sp generated on a light incident surface 41 of the phosphor panel 20 will be a direction along a scanning direction Hc of the optical spot Sp on the light incident surface 41.

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to an optical scanning device including a MEMS (Micro Electro Mechanical Systems) light deflector.

Description of the Related Art

[0002] A vehicle headlight including an MEMS light deflector and a phosphor panel is known (e.g., Japanese Patent No. 5577138). In the vehicle headlight, emitted light from the light deflector scans a light incident surface of the phosphor panel in which phosphors are housed, and is emitted from a light emitting surface on the side opposite to the light incident surface. When passing through the phosphor panel, the light is changed to a desired frequency (color) by the phosphors inside the phosphor panel.

[0003] The fluorescence lifetime of the phosphors will be schematically described. When light such as laser light is irradiated onto the phosphors, the electrons of fluorescent molecules are excited, and the vibration level of electrons is moved immediately from the ground state to the excited state. After that, excess energy of electrons is dissipated and hence the vibration level of electrons drops to a vibration level as the lowest order of a first excited state. Then, fluorescence is emitted from the phosphors in a process where the electrons return from the lowest-order vibration level to the level of the ground state.

[0004] The fluorescence lifetime is defined as a time period from the time of starting the excitation of the phosphors by the excitation light until the intensity of the fluorescence emitted by the phosphors becomes $1/e$ (where 1 is the fluorescence intensity at a peak, and e is the base of natural logarithm) after exceeding the peak. The fluorescence lifetime can also be figured out as a time period from the time of starting the excitation of the phosphors, composed of sufficiently many, N fluorescent molecules, by the excitation light until the number of fluorescent molecules remaining in the excited state among the N fluorescent molecules becomes N/e .

[0005] During a period in which the phosphors are in the excited state, the phosphors are not excited even when the excitation light is irradiated. In other words, in order to excite the phosphors, it is necessary to wait until the phosphors returns to the ground state. Therefore, the irradiation of excitation light to the phosphors in the excited state leads to the waste of energy of the excitation light.

[0006] In the conventional optical scanning device, since the excitation light that enters the light incident surface of the phosphor panel from the light deflector is not managed and controlled in relationship to the fluores-

cence lifetime, the irradiation time of the phosphors inside the phosphor panel reaches several times the fluorescence lifetime or more. As a result, a considerable amount of light energy of the light source is wasted.

SUMMARY OF THE INVENTION

[0007] It is an object of the present invention to provide an optical scanning device configured to make phosphors emit light efficiently.

(First Aspect of Present Invention)

[0008] An optical scanning device of a first aspect includes:

a light source device having a light emitting unit to emit light from the light emitting unit;
a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface;
a projector unit configured to adjust light emitted from the light emitting surface of the phosphor panel and project the light to an irradiation area;
a light deflector having a mirror unit capable of turning reciprocally about first and second rotation axial lines orthogonal to each other, and actuators to turn the mirror unit reciprocally about the first and second rotation axial lines, the light deflector configured to reflect, by the mirror unit, incident light from the light emitting unit of the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel in first and second scanning directions corresponding to reciprocal turning directions of the mirror unit about the first and second rotation axial lines; and
a drive voltage generating unit configured to generate drive voltages of the actuators so that reciprocal turning of the mirror unit about the first rotation axial line will be done at a resonant frequency as natural vibration of the mirror unit, and reciprocal turning of the mirror unit about the second rotation axial line is done at a non-resonant frequency different from the resonant frequency,
wherein longer and shorter ones of two radial directions of an excitation light spot are defined as a major axis direction and a minor axis direction, respectively, where the two radial directions are perpendicular to each other, and the excitation light spot is generated on the light incident surface of the phosphor panel by the reflected light from the light deflector to excite the phosphors in the light transmission part, and a rotational position of the light emitting unit of the light source device about an optical axis of the emitted light from the light emitting unit is so set that the minor axis direction of the excitation light spot will be a direction along the first scanning direction of the excitation light spot on the light incident sur-

face.

[0009] According to the optical scanning device of the first aspect, the rotational position of the light emitting unit of the light source device about the optical axis is so set that the minor axis direction of the excitation light spot will be a direction along the first scanning direction of the excitation light spot on the light incident surface. Thus, since the time of the excitation light spot to pass through each phosphor is reduced while irradiating many phosphors in the major axis direction on the light incident surface of the phosphor panel, the phosphors can be made to emit light efficiently.

[0010] It is preferred that the optical scanning device of the first aspect should further include:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that a first scanning area of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spots will be on an inner side of the second scanning area; and diameter-reducing lens elements to make the diameter of the excitation light spot of the first irradiation system smaller than that of the excitation light spot of the second irradiation system.

[0011] According to this structure, the optical scanning device further includes the first and second irradiation systems in such a manner that the excitation light spot of the first irradiation system in the first scanning area smaller on the common light incident surface has a smaller diameter than that of the excitation light spot of the second irradiation system in the second scanning area larger than the first scanning area. Thus, since the total continuous irradiation time of the excitation light spot of the first irradiation system is reduced, the phosphors can be made to emit light efficiently without increasing the scanning speed of the excitation light spot of the first irradiation system much more than the scanning speed of the excitation light spot of the second irradiation system.

(Second Aspect of Present Invention)

[0012] An optical scanning device of a second aspect includes:

a light source device;
a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface;
a projector unit configured to adjust light emitted from the light emitting surface of the phosphor panel and project the light to an irradiation area;

a light deflector having a mirror unit capable of turning reciprocally about a rotation axial line, and actuators to turn the mirror unit reciprocally about the rotation axial line, the light deflector configured to reflect, by the mirror unit, incident light from the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel; and

a light source control unit configured to control ON and OFF of the light source device, wherein when an excitation light spot generated on the light incident surface by the reflected light from the light deflector and used as an excitation source of the phosphors in the light transmission part scans in a scanning direction, the placing position and dimensions of the excitation light spot are so set that the scanning speed of the excitation light spot over the entire light incident surface will be higher than a reference scanning speed at which the total continuous irradiation time as a time of continuously irradiating all phosphors having an average particle diameter becomes equal to a fluorescence lifetime of the phosphors.

[0013] According to the optical scanning device of the second aspect, the placing position and dimensions of the excitation light spot are so set that the scanning speed of the excitation light spot over the entire light incident surface will be higher than the reference scanning speed. In other words, the scanning surface scanned by the excitation light spot at a speed equal to or lower than the reference scanning speed is located outside of the light incident surface. As a result, the phosphors inside the phosphor panel can be made to emit light efficiently.

[0014] It is preferred that the optical scanning device of the second aspect should be such that longer and shorter ones of two radial directions of the excitation light spot on the light incident surface are defined as a major axis direction and a minor axis direction, respectively, where the two radial directions are perpendicular to each other, and the rotational position of a light emitting unit of the light source device about an optical axis of the emitted light from the light emitting unit is so set that the minor axis direction of the excitation light spot will be a direction along the scanning direction of the excitation light spot on the light incident surface.

[0015] According to this structure, the rotational position of the light emitting unit of the light source device about the optical axis is so set that the minor axis direction of the excitation light spot will be a direction along the scanning direction of the excitation light spot on the light incident surface. Thus, since the time of the excitation light spot to pass through each phosphor is reduced while irradiating many phosphors in the major axis direction on the light incident surface of the phosphor panel, the phosphors can be made to emit light efficiently.

[0016] It is preferred that the optical scanning device of the second aspect should further include a diameter-

reducing lens element arranged between the light source device and the light deflector to reduce the diameter of the excitation light spot to make the total continuous irradiation time shorter than the fluorescence lifetime.

[0017] According to this structure, since the diameter of the excitation light spot is reduced by the diameter-reducing lens element, the total continuous irradiation time is made shorter. This can suppress a rise in the temperature of the optical spot, and hence prevent the phosphors from decreasing the rate of absorption of the excitation light (temperature quenching).

[0018] It is preferred that the optical scanning device of the second aspect should further include:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that a first scanning area of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spots will be on the inner side of the second scanning area; and diameter-reducing lens elements configured to make the diameter of the excitation light spot of the first irradiation system smaller than that of the excitation light spot of the second irradiation system.

[0019] According to this structure, the optical scanning device further includes first and second irradiation system in such a manner that the excitation light spot of the first irradiation system in the first scanning area smaller on the common light incident surface has a smaller diameter than that of the excitation light spot of the second irradiation system in the second scanning area larger than the first scanning area. Thus, since the total continuous irradiation time of the excitation light spot of the first irradiation system is reduced, the phosphors can be made to emit light efficiently without increasing the scanning speed of the excitation light spot of the first irradiation system much more than the scanning speed of the excitation light spot of the second irradiation system.

[0020] It is preferred that the optical scanning device of the second aspect should further include:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that each of first and second scanning areas respectively generated on the light incident surface as scanning areas of optical spots will be formed into a rectangle to make a side scanned by the excitation light spot at a high speed longer than a side scanned at a low speed; and mirror control units each configured to control a mirror unit of the light deflector through the actuators of the light deflector of each of the first and the second

irradiation systems so that long sides of the first and the second scanning areas will be equal to each other, and a short side of the first scanning area will be shorter than that of the second scanning area.

[0021] According to this structure, the optical scanning device includes the first and second irradiation systems, the long-side direction scanning speeds of the excitation light spots in the first and second scanning areas are equal to each other, and the short-side direction scanning speed of the excitation light spot in the first scanning area is made slower than the short-side direction scanning speed of the excitation light spot in the second scanning area. This can increase the density of short-side direction scanning lines in the first scanning area to increase the fluorescence intensity of the first scanning area on the inner side more smoothly than the fluorescence intensity of the second scanning area on the outer side.

(Third Aspect of Present Invention)

[0022] An optical scanning device of a third aspect includes:

a light source device;
a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface;
a projector unit configured to adjust light emitted from the light emitting surface of the phosphor panel and project the light to an irradiation area;
a light deflector having a mirror unit capable of turning reciprocally about a rotation axial line, and actuators to turn the mirror unit reciprocally about the rotation axial line, the light deflector configured to reflect, by the mirror unit, incident light from the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel; and
a light source control unit configured to control ON and OFF of the light source device,
wherein the optical scanning device further includes:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that each of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spot will be formed into a rectangle to make a side scanned by the excitation light spot at a high speed longer than a side scanned at a low speed; and
mirror control units each configured to control a mirror unit of the light deflector through the actuators of the light deflector of each of the first and the second irradiation systems so that long

sides of the first and the second scanning areas will be equal to each other, and a short side of the first scanning area will be shorter than that of the second scanning area.

[0023] According to the optical scanning device of the third aspect, the optical scanning device includes the first and second irradiation systems, the long-side direction scanning speeds of the excitation light spots in the first and second scanning areas are equal to each other, and the short-side direction scanning speed of the excitation light spot in the first scanning area is made slower than the short-side direction scanning speed of the excitation light spot in the second scanning area. This can increase the density of short-side direction scanning lines in the first scanning area to increase the fluorescence intensity of the first scanning area on the inner side more smoothly than the fluorescence intensity of the second scanning area on the outer side.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

FIG. 1 is a perspective view of one half part when a headlight unit 1 is divided into two parts by a plane of symmetry.

FIG. 2 is a sectional view when the headlight unit 1 is cut along the plane of symmetry.

FIG. 3 is a perspective view when a light deflector is viewed diagonally from the front.

FIG. 4A is an explanatory chart related to the relationship between a change in the vibration level of electrons of phosphors, and absorption and emission of vibrational energy.

FIG. 4B and FIG. 4C are explanatory charts illustrating changes in fluorescence intensity after respective phosphors are excited, where the changes are indicated using relative values with a peak value set to 1, and the natural logarithmic values.

FIG. 5A is a diagram when a light incident surface of a phosphor panel is viewed from the side of a rear assembly.

FIG. 5B is a waveform chart of first drive voltage as voltage supplied to an inner actuator of the light deflector.

FIG. 5C is a waveform chart of second drive voltage as voltage supplied to an outer actuator of the light deflector.

FIG. 6A is an explanatory diagram of a total continuous irradiation time.

FIG. 6B is a graph illustrating changes in fluorescence intensity when the total continuous irradiation time is long.

FIG. 6C is a graph illustrating continuous irradiation times related to two reciprocal turning frequencies of a mirror unit about a first rotation axial line at horizontal axis coordinates on a light incident surface.

FIG. 7A is an explanatory diagram when an elongated optical spot is generated.

FIG. 7B and FIG. 7C are diagrams illustrating optical spots generated on the light incident surface at each rotating angle of a light emitting unit of a laser-light emission device about the optical axis.

FIG. 8A and FIG. 8B are explanatory diagrams of the total continuous irradiation time when the major axis direction and minor axis direction of each optical spot is aligned with the scanning direction.

FIG. 8C is an explanatory diagram when an optical spot Sp is scanned by aligning the minor axis direction of the optical spot with the scanning direction.

FIG. 9 is a diagram when a light incident surface used in another embodiment to reduce the total continuous irradiation time is viewed from the side of the rear assembly.

FIG. 10A is a graph illustrating the effect of using longitudinal scanning and a light incident surface narrow in width to reduce the total continuous irradiation time.

FIG. 10B is a graph illustrating that total continuous irradiation time < fluorescence lifetime is achieved in scanning of the optical spot on the light incident surface.

FIG. 11 is a diagram illustrating optical spot scanning areas generated by two headlight units on a light incident surface of the phosphor panel.

FIG. 12A is a diagram illustrating a case where SPOT is in a standard position.

FIG. 12B is a diagram illustrating a case where SPOT is in a position displaced to one side.

FIG. 13 is a structural diagram of another headlight unit.

FIG. 14 is a diagram illustrating optical spot scanning areas generated on a light incident surface of the phosphor panel by two headlight units inside one vehicle headlight.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] FIG. 1 is a perspective view of one half part when a headlight unit 1 is divided into two parts by a plane of symmetry, and FIG. 2 is a sectional view when the headlight unit 1 is cut along the plane of symmetry.

[0026] Two headlight units 1 are equipped for each of right and left vehicle headlights. Thus, the vehicle has four headlight units 1 in total. Each headlight unit 1 is equipped with two irradiation systems 13a, 13b to be described later. Thus, a total of eight irradiation systems are equipped in the vehicle. Each irradiation system can set an irradiation area individually. It is assumed that the relationship among irradiation areas of the total of eight irradiation systems can be a case where a predetermined number of irradiation areas partially overlap with one another, a case where one irradiation area is included in another irradiation area, or a case where another predetermined number of irradiation areas match one another.

[0027] In FIG. 1 and FIG. 2, the headlight unit 1 includes a front assembly 2 mounted in a front-end portion of a unit mounting hole formed in a depressed area adapted to mounting the vehicle headlight and provided at the front of an unillustrated vehicle body, and a rear assembly 3 mounted at the back of the unit mounting hole. The front assembly 2 and the rear assembly 3 are so arranged that the center lines of the assemblies will be aligned with the center line of the unit mounting hole.

[0028] The front assembly 2 includes a lens holder 7, an annular cap 8, and a laser holder 9. The annular cap 8 is assembled to the lens holder 7 in such a manner that the inner peripheral portion of the annular cap 8 is screwed onto the outer peripheral portion of the front end of the lens holder 7. The laser holder 9 is assembled to the lens holder 7 in such a manner that the inner peripheral portion of the front end of the laser holder 9 is screwed onto the outer peripheral portion of the rear end of the lens holder 7.

[0029] The headlight unit 1 has irradiation systems 13a, 13b, which can set irradiation areas independently, in a positional relationship of the upper side and down side, respectively. The irradiation system 13a includes a laser-light emission device 14a fixed to an upper portion on the inner periphery of the rear end of the laser holder 9, a condenser lens 16a mounted in an emitting unit of the laser-light emission device 14a, and a light deflector 15a fixed to an upper inclined face in a central portion of the front of the rear assembly 3. The irradiation system 13b includes a laser-light emission device 14b fixed to a lower portion on the inner periphery of the rear end of the laser holder 9, a condenser lens 16b mounted in an emitting unit of the laser-light emission device 14b, and a light deflector 15b fixed to a lower inclined face in a central portion of the front of the rear assembly 3.

[0030] Projector lenses 19a to 19d are arranged on the inner periphery of the lens holder 7 to align the center lines with one another in the front-rear direction in order from front to rear. The rim of the projector lens 19a is fixed to the front end of the lens holder 7 by the annular cap 8. The other projector lenses 19b to 19d are positioned in the direction of the center line of the lens holder 7 by step parts or fitting rings on the inner peripheral side of the lens holder 7, and fixed to the inner peripheral side of the lens holder 7.

[0031] A phosphor panel 20 is formed into the shape of a rectangular flat plate, the center line thereof is aligned with the center line of the front assembly 2, and the periphery thereof is mounted in a rectangular opening portion at the center of the laser holder 9. The phosphor panel 20 includes a pair of transparent plates on both sides in the thickness direction, and a light transmission part formed between the pair of transparent plates to house granular phosphors. The light incident surface 41 (FIG. 5A) of the phosphor panel 20 is formed on one transparent plate on the rear side to face the rear assembly 3. The light emitting surface of the phosphor panel 20 is formed on the other transparent plate on the front

side to face the rear surface of the projector lens 19d.

[0032] In the irradiation system 13a, light (e.g., blue light) emitted from the laser-light emission device 14a enters the light deflector 15a along an optical path 22a.

The light deflector 15a reflects the incident light, and the reflected light enters the light incident surface 41 (FIG. 5A and FIG. 5B) of the phosphor panel 20 along an optical path 23a. In the irradiation system 13b, light emitted from the laser-light emission device 14b (the same color as that of emitted light from the laser-light emission device 14a) enters the light deflector 15b along an optical path 22b. The light deflector 15b reflects the incident light, and the reflected light enters the light incident surface 41 of the phosphor panel 20 along an optical path 23b.

[0033] The projector lenses 19a to 19d and the phosphor panel 20 constitute a device common to the irradiation systems 13a, 13b. Light emitted from the light emitting surface as the front surface of the phosphor panel 20 passes through an array of the projector lenses 19a to 19d in order from rear to front, and is emitted from the front surface of the projector lens 19a toward a predetermined irradiation area ahead of the vehicle.

[0034] In the following, the irradiation systems 13a, 13b are collectively called the "irradiation system 13" unless otherwise the irradiation systems 13a, 13b are particularly distinguished. Likewise, when the laser-light emission devices 14a, 14b are not particularly distinguished, the laser-light emission devices 14a, 14b are collectively called the "laser-light emission device 14." When the light deflectors 15a, 15b are not particularly distinguished, the light deflectors 15a, 15b are collectively called the "light deflector 15." When the condenser lenses 16a, 16b are not particularly distinguished, the condenser lenses 16a, 16b are collectively called the "condenser lens 16." When the optical paths 22a, 22b are not particularly distinguished, the optical paths 22a, 22b are collectively called the "optical path 22." When the optical paths 23a, 23b are not particularly distinguished, the optical paths 23a, 23b are collectively called the "optical path 23."

[0035] For example, the laser-light emission device 14 has a laser diode as a light source. The center line of the optical path 22 is an optical axis of emitted light from the laser-light emission device 14. The center line of the optical path 23 is an optical axis of emitted light from the light deflector 15 or an optical axis of incident light onto the phosphor panel 20.

[0036] Note that the emitted light and the incident light are such that the same light becomes the emitted light when the emitting side device is used as the reference device, or becomes the incident light when the incident side device is used as reference. For example, light on the optical path 22 is emitted light based on the laser-light emission device 14, or incident light based on the light deflector 15.

[0037] FIG. 3 is a perspective view when the light deflector 15 is viewed diagonally from the front. The light deflector 15 as a MEMS device includes a mirror unit 32 arranged pivotably on the center, an inner rectangular

frame 33 that surrounds the mirror unit 32 externally, and an outer rectangular frame 34 that surrounds the inner rectangular frame 33 externally. The light deflector 15 reflects, on a mirror surface 32a of the mirror unit 32, light entering from the laser-light emission device 14 along the optical path 22, and emits the reflected light from the mirror surface 32a toward the phosphor panel 20 along the optical path 23.

[0038] Here, for the sake of describing the structure of the light deflector 15, a long-side direction X, a short-side direction Y, and a thickness direction Z mutually orthogonal to one another are defined for the light deflector 15. The long-side direction X and the short-side direction Y are directions parallel to the long side and short side of the outer rectangular frame 34, respectively. The thickness direction Z is the thickness direction of the outer rectangular frame 34. Since the light deflector 15 is made using MEMS technology, the light deflector 15 has a laminated structure. The thickness direction Z of the light deflector 15 corresponds to the laminated direction of the laminated structure of the light deflector 15.

[0039] It is assumed that the front side of the light deflector 15 is a side on which the incident light from the laser-light emission device 14 enters the light deflector 15 (= a side on which the reflected light to the phosphor panel 20 is emitted) in the thickness direction Z, and the back side of the light deflector 15 is a side opposite to the front side in the thickness direction Z. The positive sides of the long-side direction X and the short-side direction Y are the right side and upper side of the light deflector 15 as viewed from the front, respectively. The positive side of the thickness direction Z is a direction from the back side to the front side of the light deflector 15.

[0040] A pair of torsion bars (elastic beams) 35a, 35b are arranged on one side in the short-side direction Y (the upper side of the light deflector 15 in the front view) of the mirror unit 32 and on the other side (the lower side of the light deflector 15 in the front view) to couple the mirror unit 32 and the inner rectangular frame 33.

[0041] The inner actuators 36a, 36b are arranged together on one side for the mirror unit 32 in the short-side direction Y, and on one side (left side of the light deflector 15 in the front view) and the other side (right side of the light deflector 15 in the front view) for the torsion bar 35a in the long-side direction X, respectively. The inner actuators 36c, 36d are arranged together on the other side for the mirror unit 32 in the short-side direction Y, and on one side and the other side for the torsion bar 35b in the long-side direction X, respectively.

[0042] In the following, when the torsion bars 35a, 35b are not particularly distinguished, the torsion bars 35a, 35b are collectively called the "torsion bar 35." When the inner actuators 36a to 36d are not particularly distinguished, the inner actuators 36a to 36d are collectively called the "inner actuator 36." The inner actuator 36 extends in the long-side direction X to couple the torsion bar 35 and the inner rectangular frame 33. The inner actuator 36 is a piezoelectric actuator made up as a un-

imorph cantilever.

[0043] The outer actuators 37a, 37b are arranged on one side and the other side for the inner rectangular frame 33 in the long-side direction X, respectively, and reside between the inner rectangular frame 33 and the outer rectangular frame 34 to couple the inner rectangular frame 33 and the outer rectangular frame 34. When the outer actuators 37a, 37b are not particularly distinguished, the outer actuators 37a, 37b are collectively called the "outer actuator 37." The outer actuator 37 is made up of plural unimorph piezoelectric cantilevers coupled in series along a meander line (concertina line).

[0044] Plural electrode pads 38a, 38b are formed on one-side and the other short-side surfaces in the long-side direction X of the outer rectangular frame 34, respectively, and connected to the electrodes of an electric structure in the inner actuator 36 or the like through wiring (not illustrated) formed along the surface of the light deflector 15 and a wiring layer (not illustrated, which is typically ground wiring) embedded in the light deflector 15. The electrode pads 38a, 38b are also connected outside of the light deflector 15 to a drive voltage generating unit (not illustrated) that generates drive voltage to the inner actuator 36 and the outer actuator 37 (applied voltage to piezoelectric membranes included in the actuators). In the following, when the electrode pads 38a, 38b are not particularly distinguished, the electrode pads 38a, 38b are collectively called the "electrode pads 38."

[0045] The incident light from the laser-light emission device 14 onto the mirror surface 32a of the mirror unit 32 of the light deflector 15 enters the mirror unit 32 along the fixed optical path 22 regardless of the turning angle of the mirror unit 32. The mirror unit 32 can reciprocally turn about a first rotation axial line 50 (FIG. 8C) as an axial line of the torsion bar 35 by the actuation of the inner actuator 36. Further, the mirror unit 32 can reciprocally turn about a second rotation axial line 51 (FIG. 8C), perpendicular to the first rotation axial line 50 and parallel to the mirror surface 32a of the mirror unit 32, by the actuation of the outer actuator 37. When the mirror unit 32 faces directly forward, the first and second rotation axial lines 50, 51 are approximately parallel to the short-side direction Y and the long-side direction X, respectively, and the normal line of the mirror surface 32a is parallel to the thickness direction Z.

[0046] For example, the reciprocal turning frequency of the mirror unit 32 about the first rotation axial line 50 is 16 kHz, and the reciprocal turning frequency of the mirror unit 32 about the second rotation axial line 51 is 60 Hz. The reciprocal turning of the mirror unit 32 about the first rotation axial line 50 as reciprocal turning at a high frequency becomes resonant driving to drive at a resonant frequency as the natural resonance frequency of the mirror unit 32. The frequency of first drive voltage (FIG. 5B) as supply voltage to the inner actuator 36 by resonant driving is set to the natural resonance frequency (resonant frequency) of the mirror unit 32 having a sinusoidal waveform. Thus, the mirror unit 32 is driven by the

inner actuator 36 to turn reciprocally about the first rotation axial line stably at the resonant frequency.

[0047] On the other hand, the reciprocal turning of the mirror unit 32 about the second rotation axial line 51 as reciprocal turning at a low frequency becomes non-resonant driving without using the natural vibration of the mirror unit 32. The frequency of second drive voltage (FIG. 5C) as supply voltage to the inner actuator 36 by non-resonant driving becomes a non-resonant frequency different from the natural resonance frequency (resonant frequency) of the mirror unit 32, which has, for example, a sawtooth waveform. The waveform of the second drive voltage as the supply voltage to the inner actuator 36 may be any waveform, such as a sinusoidal waveform or a triangular waveform, as long as the second drive voltage contains a monotonically increasing range and a monotonically decreasing range in one cycle. Note that the resonant frequency of the reciprocal turning of the mirror unit 32 about the first rotation axial line is decided by the dimensions, weights, materials, and the like of the mirror unit 32 and the torsion bar 35.

[0048] The light incident on the light incident surface 41 (FIG. 5A) of the phosphor panel 20 from the light deflector 15 scans on the light incident surface 41 in a horizontal axis H direction and a vertical axis V direction. The light deflector 15 is mounted on the rear assembly 3 to associate the long-side direction X, the short-side direction Y, and the thickness direction Z (FIG. 3) of the light deflector 15 with the horizontal axis H and the vertical axis V of the light incident surface 41 so that scanning over the light incident surface 41 with the incident light in the horizontal axis H direction will correspond to reciprocal turning of the mirror unit 32 about the first rotation axial line 50 (FIG. 8C) by the inner actuator 36 in the light deflector 15, and scanning in the vertical axis V direction will correspond to reciprocal turning of the mirror unit 32 about the second rotation axial line 51 (FIG. 8C) by the outer actuator 37 in the light deflector 15.

[0049] The light incident on the light incident surface 41 of the phosphor panel 20 is emitted from the light emitting surface of the phosphor panel 20 via the light transmission part that houses the phosphors of the phosphor panel 20. Then, the light moves through the array of the projector lenses 19a to 19d from rear to front, and a trajectory of light on the light incident surface 41 is projected from the projector lens 19a to a predetermined irradiation area ahead of the headlight unit 1.

[0050] FIG. 4A to FIG. 4C are explanatory charts related to the fluorescence lifetime.

FIG. 4A is an explanatory chart related to the relationship between a change in vibration level of electrons of the phosphors, and the absorption and emission of vibrational energy. In regard to the vibration level *s* of electrons of the phosphors, S0 denotes a ground state, S1 denotes a first excited state, and S2 denotes a second excited state. The electrons of the phosphors have three orders of vibration levels in the ground state, the first excited state, and the second excited state, respectively. In FIG.

4A, "absorption" and "emission (fluorescence)" indicate that the respective electrons of the phosphors absorb and emit vibrational energy. The phosphors emit fluorescence when vibrational energy is emitted.

[0051] When excitation light is irradiated, the vibration level of the electrons of the phosphors increases from S0 to S1 or S2. At this time, the excitation energy of the excitation light is converted to the vibrational energy of the phosphors. The time required for the phosphors to absorb the excitation energy of the excitation light and for the vibration level of the electrons to move from the ground state to the excited state is just in the order of femtoseconds.

[0052] After that, the fluorescent molecules in the lowest-order vibration level of the first excited state S1 dissipate excess energy to drop to the lowest-order vibration level of the first excited state S1. This state is most stable in the process of excitation, and the staying time in the lowest-order vibration level is in a range from several tens of nanoseconds to a few nanoseconds. Then, in the process in which the electrons of the phosphors return from the lowest-order vibration level of S1 to the vibration level of the ground state, the phosphors emit energy. The emitted energy at the time is converted to fluorescence. In general, the fluorescence is light (e.g., white light) lower in wavelength than the emitted light (e.g., blue light) from the laser-light emission device 14.

[0053] FIG. 4B and FIG. 4C illustrate changes in fluorescence intensity after the phosphors are excited. In both of FIG. 4B and FIG. 4C, the abscissa indicates time *t*. The ordinate in FIG. 4B indicates the fluorescence intensity as a relative value with a peak value set to 1, and the ordinate in FIG. 4C indicates a value after the relative value in FIG. 4B is converted to a natural logarithmic value, where "e" is the base of the natural logarithm.

[0054] According to FIG. 4B and FIG. 4C, when the excitation light is irradiated to the phosphors at *t* = 0, the fluorescence intensity increases rapidly to the peak value, and after that, decreases slowly. The fluorescence intensity reaches the peak value from *t* = 0, and further becomes 1/e at *t* = *t_a*. The fluorescence lifetime τ is defined as the time from *t* = 0 to *t* = *t_a*.

[0055] When a sufficiently large number of *N* phosphors start being excited at *t* = 0, the fluorescence lifetime τ means that about 37% (1/e) of fluorescent molecules in the total number *N* of fluorescent molecules of all the phosphors are in the excited state at *t* = *t_a* after the fluorescence lifetime τ has passed from *t* = 0, and about 63% (1-1/e) of remaining fluorescent molecules return to the ground state.

[0056] FIG. 5A and FIG. 5B are explanatory diagrams related to scanning of an optical spot *S_p* on the light incident surface 41. Note that FIG. 5A, FIG. 5B, and FIG. 6A to FIG. 6C are to point out the problems with the light deflector 15 when scanning of the optical spot *S_p* is done regardless of the fluorescence lifetime, and to be excluded from embodiments of the present invention. However, the first drive voltage in FIG. 5B and the second drive

voltage in FIG. 5C are applied to the embodiments of the present invention.

[0057] FIG. 5A is a diagram of the light incident surface 41 of the phosphor panel 20 as viewed from the side of the rear assembly 3. The light incident surface 41 is set to be a rectangle. H and V denote the horizontal axis and vertical axis as the coordinate axes. The long side and short side of the light incident surface 41 are set to be parallel to the horizontal axis H and vertical axis V, respectively. The long side and short side of the light incident surface 41 correspond to the sides to be scanned with the optical spot Sp at high speed and low speed.

[0058] An origin O is set to the center of the light incident surface 41 (an intersecting point of the diagonal lines of the rectangular light incident surface 41). The horizontal axis H and the vertical axis V are orthogonal to each other at the origin O. The origin O becomes a reference position (0, 0) as the origin of the coordinate system of the horizontal axis H and the vertical axis V. For example, the lengths of the long side and short side of the light incident surface 41 are 19 mm and 2.4 mm, respectively.

[0059] In FIG. 5A, Kr denotes a track (trajectory) of the optical spot Sp on the light incident surface 41, where Sp denotes an optical spot generated on the light incident surface 41 by the incident light entering the light incident surface 41 from the light deflector 15.

[0060] The track Kr moves from one end to the other end of the light incident surface 41 in the vertical axis V direction while coming and going between both ends of the light incident surface 41 in the horizontal axis H direction. The optical spot Sp moves on the light incident surface 41 along the track Kr in conjunction with the reciprocal turning of the mirror unit 32 of the light deflector 15 about the first and second rotation axial lines 50, 51.

[0061] When the incident light from the light deflector 15 is irradiated to the light incident surface 41, an irradiation area is generated on the light incident surface 41, where the intensity of light is the maximum at the irradiation center, and as the incident light moves away from the irradiation center, the intensity of light is gradually decreases and finally becomes zero.

[0062] The optical spot Sp is defined as a portion obtained by extracting, from the entire irradiation area, a portion of the irradiation area, not the whole of the irradiation area, to act as light (excitation light) capable of exciting the phosphors of the phosphor panel 20 in the irradiation area. In addition, when the incident light from the light deflector 15 is irradiated to the light incident surface 41, the irradiation area shines brightly. The optical spot Sp means a portion acting as the excitation light of the phosphors in the irradiation area, and a portion outside of the optical spot Sp in the irradiation area cannot excite the phosphors though the portion has predetermined illuminance (> 0).

[0063] The drive voltages that cause reciprocal turning of the mirror unit 32 of the light deflector 15 about the first and second rotation axial lines 50, 51 will be described with reference to FIG. 5B and FIG. 5C. FIG. 5B

illustrates the waveform of first drive voltage output by a mirror control unit (which also serves as the drive voltage generating unit) outside of the light deflector 15 to the inner actuator 36 of the light deflector 15. The first drive voltage has a sinusoidal waveform. When receiving the first drive voltage, the inner actuator 36 reciprocally turns the mirror unit 32 about the first rotation axial line 50. The first drive voltage is, for example, 16 kHz. The frequency of the first drive voltage is set to be a resonant frequency as the natural resonance frequency of the mirror unit 32 about the first rotation axial line 50. Along with the reciprocal turning of the mirror unit 32 about the first rotation axial line, the optical spot Sp reciprocally turns on the light incident surface 41 in the horizontal axis H direction to form reciprocating paths of the track Kr in the horizontal axis H direction.

[0064] FIG. 5C illustrates the waveform of second drive voltage as voltage to be supplied to the outer actuator 37 of the light deflector 15. The second drive voltage has a sawtooth waveform. In other words, the second drive voltage gradually increases with time, and when reaching the peak, the second drive voltage falls instantly, repeating this, for example, at 60 Hz.

[0065] The first drive voltage and the second drive voltage are supplied to the inner actuator 36 and the outer actuator 37 from an unillustrated mirror control unit. The mirror control unit includes a power supply and is generally incorporated in the headlight unit 1. However, the mirror control unit may be provided as an external mirror control unit of the headlight unit 1 in such a manner that the output terminals of the first drive voltage and second drive voltage of the mirror control unit are connected by wiring to the input terminals of the first drive voltage and second drive voltage of the headlight unit 1.

[0066] When receiving the second drive voltage, the outer actuator 37 reciprocally turns the mirror unit 32 about the second rotation axial line 51. Along with the reciprocal turning of the mirror unit 32 about the second rotation axial line 51, the optical spot Sp gradually decreases on the light incident surface 41 in the vertical axis V direction, and when reaching the lower side of the light incident surface 41, the optical spot Sp goes up to the upper side instantly.

[0067] FIG. 6A to FIG. 6C are explanatory diagrams related to the relationship between the optical spot Sp and a phosphor 43. FIG. 6A is an explanatory diagram of a total continuous irradiation time T, where Hc denotes the scanning direction of the optical spot Sp. Among the courses of the optical spot Sp in two plus and minus directions of the horizontal axis H direction along the track Kr in FIG. 5A, the scanning direction Hc indicates the plus direction of the horizontal axis H direction (FIG. 5A and FIG. 5B).

[0068] Although the optical spot Sp also scans in the vertical axis V direction (second scanning direction) on the light incident surface 41, the scanning frequency = 16 kHz in the horizontal axis H direction (first scanning direction) is sufficiently high, compared with the scanning

frequency = 60 Hz in the vertical axis V direction on the light incident surface 41. Therefore, the scanning direction Hc can be considered to be approximately parallel to the horizontal axis H through slightly having a component in the vertical axis V direction.

[0069] Da denotes the diameter of the optical spot Sp in the scanning direction Hc.

Db denotes a mean particle diameter of the phosphor 43 in the scanning direction Hc. Here, spot diameter Da > particle diameter Db. As will be described later with reference to FIG. 8A to FIG. 8C, the optical spot Sp specifically has an elongated shape. Therefore, if the mounting position of the laser-light emission device 14 into the laser holder 9 is not set to a predetermined position, Da may become a maximum of 400 μm . On the other hand, the phosphor 43 is, for example, ce (ceramic) in YAG (yttrium, aluminium, garnet).

The YAG phosphor 43 is such that the particle diameter Db is 20 μm and the fluorescence lifetime τ is 60 ns.

[0070] Since spot diameter Da > particle diameter Db, an interval of time in which the entire phosphor 43 is included inside the optical spot Sp and continuously irradiated (hereinafter called the "total continuous irradiation time") T exists as the optical spot Sp scans in the scanning direction Hc on the light incident surface 41.

[0071] The optical spot Sp indicated by the broken line is illustrated at a position on the light incident surface 41 at $t = 0$ when the front end thereof in the traveling direction is aligned with the front end of the phosphor 43. The optical spot Sp indicated by the solid line is illustrated at a position on the light incident surface 41 at $t = t_1$ when the rear end thereof in the traveling direction is aligned with the rear end of the phosphor 43. Therefore, the total continuous irradiation time $T = T_1 (= t_1 - 0)$.

[0072] FIG. 6B illustrates changes in fluorescence intensity when the total continuous irradiation time $T = T_1$. It is assumed that $2\tau < T_1 < 3\tau$. As mentioned above, when the optical spot Sp as the excitation light is irradiated, the phosphor immediately reaches a peak value of the fluorescence intensity (in the order of femtoseconds). On the other hand, once the phosphor 43 goes into the excited state, the phosphor 43 cannot absorb energy from excitation light until the phosphor 43 returns to the ground state even if the excitation light continues to be irradiated. In other words, the excitation light cannot be converted to fluorescence.

[0073] In the example of FIG. 6B, the number of fluorescence emissions from the phosphor 43 is three. In FIG. 6B, the phosphor 43 absorbs energy from the excitation light only at three times indicated with "EXCITATION." Thus, most of the irradiation energy of the optical spot Sp in the total continuous irradiation time T_1 during which the phosphor 43 is irradiated by the optical spot Sp is wasted. This waste is called luminance quenching. Further, when being irradiated by the optical spot Sp continuously in a long time, the phosphor 43 increases in temperature to reduce the conversion efficiency of fluorescence emission. This reduction of conversion efficien-

cy is called temperature quenching. Thus, $T_1 \geq \tau$ is not desired from the standpoint of the occurrence of luminance quenching and temperature quenching.

[0074] FIG. 6C illustrates the total continuous irradiation time T at each position on the light incident surface 41 when the spot diameter Da is 400 μm , the particle diameter Db is 20 μm , and the reciprocal turning frequencies of the mirror unit 32 about the first rotation axial line are 16 kHz and 33 kHz. The coordinate positions in the horizontal axis direction on the abscissa indicate a range of -0.5 mm to 9.5 mm. The coordinate position = 0 in the horizontal axis direction corresponds to the position of the origin O in FIG. 5A. FIG. 6C illustrates the total continuous irradiation time T of almost the right half of the light incident surface 41 in FIG. 5A. Since the light incident surface 41 is symmetric about the vertical axis V, the total continuous irradiation time T of the left half of the light incident surface 41 in FIG. 5A is plotted by replicating each characteristic curve in FIG. 6C with reference to the straight line of the coordinate position = 0 in the horizontal axis direction. Note that the characteristic curves indicated with A 1 and A2 in FIG. 6C are characteristic curves when the optical spot Sp is scanned on the light incident surface 41 by transverse scanning defined in FIG. 7A.

[0075] The scanning speed of the optical spot Sp is peaked at the center of the light incident surface 41 as the origin in the horizontal axis H direction (see FIG. 5A), i.e., at the horizontal-axis H coordinate = 0, and becomes a minimum of 0 at both ends of the light incident surface 41 in the horizontal axis H direction because the scanning direction is reversed. Thus, the total continuous irradiation time T becomes the shortest at the center of the light incident surface 41 in the horizontal axis H direction, and the longest at both ends of the light incident surface 41 in the horizontal axis H direction.

[0076] In FIG. 6C, the straight line of the total continuous irradiation time $T = 60$ ns (the fluorescence lifetime of YAG) is illustrated as reference. From FIG. 6C, it is found that the total continuous irradiation time $T < 60$ ns (the fluorescence lifetime of YAG) cannot be achieved in this structure of the headlight unit 1 even if the reciprocal turning frequency of the mirror unit 32 about the first rotation axial line on the light deflector 15 is changed from 16 kHz to 33 kHz about the twice the frequency at all positions on the light incident surface 41. Because of the structure of the light deflector 15, it is unreasonable to set reciprocal turning frequency of the mirror unit 32 about the first rotation axial line three times or more of 16 kHz in order to set the total continuous irradiation time $T < 60$ ns.

[0077] FIG. 7A to FIG. 7C are explanatory diagrams related to the relationship between a light emitting unit 45 of the laser-light emission device 14 and the optical spot Sp. FIG. 7A to FIG. 7C, and FIG. 8A to FIG. 8C are to describe the meaning of the transverse scanning of the optical spot Sp in the embodiment of the present invention.

[0078] FIG. 7A is an explanatory diagram when an elongated optical spot Sp is generated. Since the laser-light emission device 14 is semiconductor laser, the cross section of emitted light from the semiconductor laser (cross section cut in a direction perpendicular to the optical axis direction) becomes an ellipse, not a circle. Thus, the light emitting unit 45 of the laser-light emission device 14 is formed into a horizontally long shape to fit the elongated cross section of the emitted light.

[0079] The light emitting unit 45 of the laser-light emission device 14 has a specific shape different from the circle. Further, the condenser lens 16 is provided on the optical path 22 between the laser-light emission device 14 and the light deflector 15. Thus, the optical spot Sp on the light incident surface 41 is not a circle, which is an elongated shape of 400 μm in the major axis direction and 50 μm in the minor axis direction as illustrated in FIG. 7B and FIG. 7C.

[0080] In FIG. 7A, emitted light is widened largely from the optical axis (which agrees with the center line of the light emitting unit 45) as the emitted light travels from the light emitting unit 45 of the laser-light emission device 14 toward the condenser lens 16, but this is more exaggerated than the actual situation. The light emitting unit 45, i.e., the laser-light emission device 14 is rotated about the optical axis to change the rotational position of the optical spot Sp about the optical axis. In FIG. 7A, the light widths indicated by the solid line and broken line correspond to the minor axis direction and major axis direction among the radial directions perpendicular to the optical spot Sp, respectively.

[0081] FIG. 7B illustrates an optical spot Sp generated on the light incident surface 41 when the rotating angle of the light emitting unit 45 of the laser-light emission device 14 about the optical axis is set to a predetermined value α . In this case, the horizontal scanning direction Hc, i.e., the scanning direction by resonant driving using natural vibration (resonance vibration) is aligned with the major axis direction of the optical spot Sp having an elongated shape. The laser-light emission device 14 is mounted on the laser holder 9 by rotating the light emitting unit 45 of the laser-light emission device 14 about the optical axis by 90 degrees from a predetermined value α in Fig. 7B to change the rotating angle to $\alpha + 90$ degrees. As a result, as illustrated in FIG. 7C, the minor axis direction of the elongated optical spot Sp can be aligned with the scanning direction by resonant driving using the horizontal scanning direction Hc, i.e., the natural vibration (resonance vibration).

[0082] FIG. 8A to FIG. 8C are explanatory diagrams of the total continuous irradiation time T of the optical spot Sp. FIG. 8A and FIG. 8B are explanatory diagrams of the total continuous irradiation time T when the major axis direction and minor axis direction of the optical spot Sp are aligned with the scanning direction Hc, respectively. Like in the description with reference to FIG. 7A to FIG. 7C, the major axis and minor axis of the optical spot Sp are assumed to be 400 μm and 50 μm , respec-

tively. Further, the particle diameter of the phosphor 43 is assumed to be 20 μm . In the following, the scanning systems when scanning is performed by aligning the major axis direction and minor axis direction of the optical spot Sp with the scanning direction Hc on the light incident surface of the phosphor panel 20 such as the light incident surface 41 are respectively called "transverse scanning" and "longitudinal scanning" accordingly.

[0083] In FIG. 8A and FIG. 8B, each of optical spots Sp1, Sp3 is illustrated at a position when the front end thereof is aligned with the front end of the phosphor 43 in the scanning direction Hc. Each of optical spots Sp2, Sp4 is illustrated at a position when the rear end thereof is aligned with the rear end of the phosphor 43 in the scanning direction Hc. In FIG. 8A, Co1 and Co2 indicate the centers of the optical spots Sp1, Sp2 in the scanning direction Hc, respectively.

[0084] The total continuous irradiation time T at the time of transverse scanning of the optical spot Sp is calculated as a time required for the center of the optical spot Sp to move 380 μm as distance between Co1 and Co2 in the scanning direction Hc. On the other hand, the total continuous irradiation time T when the minor axis direction of the optical spot Sp is aligned with the scanning direction Hc is calculated as a time required for the center of the optical spot Sp moves 30 μm as distance between the center position of the optical spot Sp3 and the center position of the optical spot Sp4 in the scanning direction Hc. As a result, as described with reference to FIG. 7C, the rotational position of the light emitting unit 45 is set to $\alpha + 90$ degrees. It can be understood that the total continuous irradiation time T is reduced at the time of longitudinal scanning of the optical spot Sp on the light incident surface 41 to achieve total continuous irradiation time $T < \text{fluorescence lifetime } \tau$.

[0085] FIG. 8C is an explanatory diagram when the optical spot Sp is scanned by aligning the minor axis direction of the optical spot Sp on the light incident surface 41 with the scanning direction Hc, i.e., the scanning direction by resonant driving using natural vibration (resonance vibration) based on the discussions on FIG. 8A and FIG. 8B. On the light deflector 15, the mirror unit 32 reciprocally turns about the first rotation axial line 50 and the second rotation axial line 51.

[0086] The optical spot Sp reciprocally scans in the horizontal axis H direction on the light incident surface 41 in conjunction with the reciprocal turning of the mirror unit 32 about the first rotation axial line 50, and reciprocally scans in the vertical axis V direction on the light incident surface 41 in conjunction with the reciprocal turning of the mirror unit 32 about the second rotation axial line 51. The optical spot Sp scans in the scanning direction Hc as the sum of reciprocal scanning in the horizontal axis H direction and the vertical axis V direction. Thus, scanning of the optical spot Sp in the scanning direction Hc contains a scanning component in the horizontal axis H direction and a scanning component in the vertical axis V direction. However, since the reciprocal turning fre-

quency of the mirror unit 32 about the second rotation axial line 51 is sufficiently lower than the reciprocal turning frequency of the mirror unit 32 about the first rotation axial line 50, the scanning direction Hc is nearly the horizontal axis H direction as the scanning direction by resonant driving.

[0087] Thus, when longitudinal scanning is performed on the optical spot Sp, scanning of total continuous irradiation time $T < \text{fluorescence lifetime } \tau$ using the optical spot Sp is realized in at least a portion of the scanning area on the light incident surface 41 to enable phosphors to emit light efficiently. Further, when longitudinal scanning is performed on the optical spot Sp, more phosphors can be excited in the vertical axis V direction than those when transverse scanning is performed.

[0088] FIG. 9 is a diagram of a light incident surface 411 as viewed from the side of the rear assembly 3, which is used in another embodiment to reduce the total continuous irradiation time T. The light incident surface 411 in FIG. 9 is formed by reducing both end ranges in the horizontal axis H by about 15 percent, respectively, compared with the light incident surface 41 in FIG. 5A. Note that the dimensions of the light incident surface 411 are equal to the dimensions of the light incident surface 41 in the vertical axis V direction. The distance from the origin O to both ends of the light incident surface 411 in the horizontal axis H direction is reduced to 8.0 mm from 9.5 mm as the distance from the origin O to both ends of the light incident surface 41 in the horizontal axis H direction.

[0089] However, the first drive voltage of the inner actuator 36 in the light deflector 15 is controlled by an unillustrated mirror control unit inside the vehicle headlight equipped with the headlight unit 1 to make the reciprocal turning of the mirror unit 32 about the first rotation axial line 50 on the light deflector 15 identical to that when the optical spot Sp is scanned on the light incident surface 41 regardless of using the light incident surface 411 instead of the light incident surface 41. On the other hand, in a period during which the optical spot Sp is generated outside of the light incident surface 411 in the horizontal axis H direction, i.e., in a period during which the optical spot Sp is generated on parts cut off from the light incident surface 41, the laser-light emission device 14 is turned off by the light source control unit. Thus, the light incident surface 411 is such that the optical spot Sp is scanned at a scanning speed higher than a reference scanning speed (a scanning speed corresponding to a boundary L in FIG. 10A to be described later) on the front surface thereof.

[0090] FIG. 10A and FIG. 10B are charts for describing the effects when longitudinal scanning and the light incident surface 411 narrow in width are used. FIG. 10A is a graph illustrating the effect of reducing the total continuous irradiation time T when longitudinal scanning and the light incident surface 411 narrow in width are used. Like the abscissa in FIG. 6C, the abscissa in FIG. 10A indicates coordinate positions in the horizontal axis H direction with respect to the origin O (FIG. 9). Since the

light incident surface 411 is a range included in the light incident surface 41, the total continuous irradiation time T of longitudinal scanning of the optical spot Sp on the light incident surface 411 is indicated as a total continuous irradiation time T in an area of the graph to the left of the boundary L drawn at a coordinate position of 8.0 mm in the horizontal axis H direction among the total continuous irradiation times T of longitudinal scanning of the optical spot Sp on the light incident surface 41.

[0091] In FIG. 10A, the terms "transverse" and "longitudinal" at B1 to B5 (except B3) mean transverse scanning of the optical spot Sp in FIG. 8A and longitudinal scanning of the optical spot Sp in FIG. 8B, respectively. 16 kHz and 33 kHz mean the frequencies of reciprocal turning of the mirror unit 32 about the first rotation axial line 50 on the light deflector 15. Like A3 in FIG. 6C, B3 is the total continuous irradiation time T corresponding to τ of ce (ceramic) in YAG (yttrium, aluminium, garnet). Note that the characteristic curves B4 and B5 in FIG. 10A are obtained when the optical spot Sp is scanned on the light incident surface 41 by transverse scanning, which match the characteristic curves A1 and A2 in FIG. 6C.

[0092] As described with reference to FIG. 6C, since the scanning direction is reversed in both end portions of the horizontal axis H direction in the scanning range of the optical spot Sp in the horizontal axis H direction, the scanning speed drops sharply, and this causes an increase in total continuous irradiation time T.

[0093] Therefore, like the light incident surface 411 in FIG. 9, the light incident surface is so made that both end ranges of the light incident surface 41, where the scanning speed of the optical spot Sp in the horizontal axis H direction is reduced (a range of horizontal-axis H coordinates to the right of the boundary L in FIG. 10A on the light incident surface 41) are cut off.

[0094] In FIG. 10A, the total continuous irradiation time T at each coordinate position of the horizontal axis H direction in each of the characteristic curves B1 to B5 corresponds to the scanning speed of the optical spot Sp. It is found from FIG. 10A that the characteristics of total continuous irradiation time T at longitudinal 16 kHz (B1) and longitudinal 33 kHz (B2) are such that the total continuous irradiation time T (corresponding to the scanning speed) in each area range inside the boundary L (ends of the light incident surface 411 in the horizontal axis H direction) is less than the fluorescence lifetime τ (60 ns). As a result, it is found that, if the optical spot Sp is scanned on the light incident surface 411 in the characteristic curves B4 and B5 at a scanning speed higher than the scanning speed corresponding to the boundary L, the scanning of the optical spot Sp on the light incident surface 411 can achieve total continuous irradiation time $T < \text{fluorescence lifetime } \tau$ as illustrated in FIG. 10B.

[0095] FIG. 11 illustrates optical spot scanning areas 55a to 55c generated on a light incident surface 53 by two headlight units 1. The light incident surface 53 is assumed to be a light incident surface obtained by synthesizing light incident surfaces 411 (FIG. 9) in the two head-

light units 1. On the other hand, a light incident surface 52 is assumed to be a light incident surface obtained by synthesizing light incident surfaces 41 (FIG. 9) in the two headlight units 1. As mentioned above, a vehicle equipped with headlight units 1 includes one headlight device on each of the right and left sides, and each headlight device includes two headlight units 1, respectively.

[0096] The optical spot scanning areas 55a to 55c in FIG. 11 correspond to an optical spot scanning area generated by the two headlight units 1 on either of the right and left sides altogether. When the two headlight units 1 on either of the right and left sides are called first and second headlight units 1, respectively, two irradiation systems 13 in the first headlight unit 1 generate the optical spot scanning areas 55a and 55b, respectively, and two irradiation systems 13 in the second headlight unit 1 generate the optical spot scanning areas 55b and 55c, respectively.

[0097] In FIG. 11, although the optical spot scanning areas 55a to 55c are illustrated on one light incident surface 53, FIG. 11 illustrates the optical spot scanning areas 55a to 55c together on the light incident surface 53 by integrating the light incident surface of the first headlight unit 1 and the light incident surface of the second headlight unit 1 into one light incident surface 53. The dimensions of the light incident surface 53 in the horizontal axis H direction and the vertical axis V direction are the same as those of the light incident surface 41.

[0098] Optical spots Spa to Spc in corresponding irradiation systems 13 are scanned in the optical spot scanning areas 55a to 55c, respectively. The optical spot scanning areas 55a to 55c are so set that the dimensions thereof in the horizontal axis H direction will be equal to the dimensions of the light incident surface 53 in the horizontal axis H direction. Further, the dimensions of the optical spot scanning areas 55a to 55c are set to increase in the vertical axis V direction in this order. Scanning light beams corresponding to the optical spot scanning areas 55a to 55c are emitted from the vehicle headlights equipped with the headlight units 1. These scanning light beams correspond to the optical spot scanning areas 55a to 55c to scan irradiation areas overlapped like the optical spot scanning areas 55a to 55c illustrated in FIG. 11. The irradiation areas generated ahead of the vehicle headlights based on the optical spot scanning areas 55a to 55c correspond to a spot irradiation area (SPOT), an intermediate irradiation area (MID), and a widespread irradiation area (WIDE), respectively.

[0099] In order to generate the optical spot scanning areas 55a to 55c on the light incident surface 53, the turning frequencies and turning angle ranges of the mirror unit 32 about the first rotation axial line 50 on the light deflector 15 of each irradiation system 13 are set equal to one another regardless of the irradiation system 13. On the other hand, the turning frequencies of the mirror unit 32 about the second rotation axial line 51 on the light deflector 15 of each irradiation system 13 are set equal, but the turning angle ranges are set to increase in order

of the optical spot scanning areas 55a to 55c. The turning angle ranges of the mirror unit 32 about the second rotation axial line 51 on the light deflector 15 in each irradiation system 13 are adjusted by the second drive voltage (FIG. 5C). As the turning angle range becomes larger, the peak value of the second drive voltage increases.

[0100] In the vehicle headlight, such an illuminance distribution that the illuminance is high at the center and decreases toward the periphery in each irradiation area ahead of the vehicle is desired. In other words, the intensity of the optical spot Sp as excitation light irradiated to the light incident surface 41 of the phosphor panel 20 is enhanced when passing through the vicinity of the center of the phosphor panel 20. Therefore, it is required to keep high conversion efficiency of the phosphors in the vicinity of the center of the phosphor panel 20 in order to generate irradiated light with small chromaticity differences. In order to keep the conversion efficiency of the phosphors partially at a high level, it is only necessary to increase the speed of the optical spot Sp to pass through an area, in which the conversion efficiency of the phosphors is desired to be enhanced on the light incident surface 41, i.e., to increase the scanning speed.

[0101] On the other hand, the resonant frequency as the natural resonance frequency of the mirror unit 32 about the first rotation axial line is constant, i.e., the scanning speed needs to be increased when the scanning width is wide with the same scanning frequency. Therefore, in the scanning of the optical spot Sp on the light incident surface 41 in the horizontal axis H direction, i.e., scanning using the resonant frequency, the scanning speed of one optical spot wider in scanning width in the horizontal axis H direction is increased near horizontal-axis H coordinate = 0. On the other hand, the optical spot scanning areas 55a and 55b are narrower in scanning width than that of the optical spot scanning area 55c in the vertical axis V direction, but are set to the same scanning width as each other in the horizontal axis H direction. Thus, the optical spots Spa and Spb are scanned at high scanning speed equal to that for the optical spot Spc near horizontal-axis H coordinate = 0 to keep high conversion efficiency of the phosphors in the vicinity of the center of the light incident surface 41.

[0102] In both end portions of the optical spot scanning areas 55a and 55b in the horizontal axis H direction, the laser-light emission devices 14 may be turned off (lights-out state) to stop the emission of light from the laser-light emission device 14. This is because the illuminance in the both end portions is not required to be high compared with the illuminance at the center. As a variation, if the intensity of emitted light from the laser-light emission device 14 is controlled, control to change the positions and virtual widths of the optical spot scanning areas 55a and 55b in the horizontal axis H direction can be performed. This control will be described in detail later with reference to FIG. 12A and FIG. 12B.

[0103] Returning to FIG. 11, since the dimensions of the optical spot scanning areas 55a to 55c are equal in

the horizontal axis H direction, and the dimensions of the optical spot scanning areas 55a to 55c in the vertical axis V direction are increased in this order, the illuminance decreases in order of the optical spot scanning areas 55a to 55c. Since the optical spot scanning area 55a overlaps with the optical spot scanning areas 55b and 55c, the illuminance particularly increases in the range of the optical spot scanning area 55a.

[0104] In the following, the optical spot scanning areas 55a to 55c are collectively called the "optical spot scanning area 55" unless otherwise the optical spot scanning areas 55a to 55c are particularly distinguished. As described in connection with the light incident surface 411, the optical spot Sp of each optical spot scanning area 55 is scanned longitudinally even on the light incident surface 53. Further, it is preferred that both ends of the light incident surface 53 in the horizontal axis H direction should be located inside the scanning range (i.e., on the side of the origin O from the boundary L in FIG. 10A and FIG. 10B (the left boundary L is omitted in FIG. 10A) in the horizontal axis H direction), where the total continuous irradiation time T corresponding to the scanning speed of each optical spot Sp in the scanning direction Hc becomes total continuous irradiation time $T < \text{fluorescence lifetime } \tau$. This can prevent the waste of excitation light energy of the optical spot Sp to the phosphor 43 inside the phosphor panel 20.

[0105] FIG. 12A and FIG. 12B are explanatory diagrams of the control to change the virtual positions and virtual widths of the optical spot scanning areas 55a and 55b in the horizontal axis H direction by adding intensity control of laser light (emitted light) emitted from the laser-light emission device 14 to the optical spot scanning areas 55a to 55c in FIG. 11. The optical spot scanning areas 55a to 55c in FIG. 11 are indicated by SPOT, MID, and WIDE in FIG. 12A and FIG. 12B, respectively. The optical spot scanning areas 55a and 55b (SPOT and MID) have the same width as the optical spot scanning area 55c (WIDE) in the horizontal axis H direction in FIG. 11, while MID is more reduced than WIDE and SPOT is further more reduced than MID in terms of the widths in the horizontal axis H direction in FIG. 12A and FIG. 12B.

[0106] In FIG. 12A and FIG. 12B, the boundary between SPOT and MID is indicated by a solid-line rectangular frame. In FIG. 11, the boundary between both ends of the optical spot scanning area 55a (SPOT) and the optical spot scanning area 55b (MID) in the horizontal axis H direction matches with the boundary of the optical spot scanning area 55c (WIDE). On the other hand, in FIG. 12A and FIG. 12B, when the optical spots Spa and Spb (FIG. 11) scan outside of the frames in FIG. 12A and FIG. 12B in the horizontal axis H direction, corresponding laser-light emission devices 14 are turned off (lights-out state) not to irradiate scanning light to corresponding irradiation areas. During the period when the optical spots Spa and Spb scan outside of the frames in FIG. 12A and FIG. 12B in the horizontal axis H direction, the intensity of emitted light from the laser-light emission devices 14

can also be made weaker than that during the period of scanning inside of the frames while keeping the corresponding laser-light emission devices 14 turned on (lighting state) without being turned off (lights-out state). To the contrary, the intensity of emitted light from the laser-light emission devices 14 can be made stronger during the period of scanning inside of the frames in FIG. 12A and FIG. 12B in the horizontal axis H direction during the period of scanning outside of the frames to generate virtual SPOT and MID.

[0107] In FIG. 12A and FIG. 12B, entities in the irradiation areas by the headlight units 1 are also illustrated to make the displacement of SPOT understandable, where 78 indicates a preceding vehicle ahead of an own vehicle equipped with the headlight units 1 on a vehicle lane 82 of a curved road 81 on which the own vehicle is running.

[0108] SPOT in FIG. 12A is illustrated in a standard position the center of which exists on the center line of the own vehicle in the horizontal direction. When the own vehicle is running on a straight road, SPOT is in the standard position.

[0109] The center of SPOT in FIG. 12B is displaced by a predetermined amount $K\alpha$ on the inner side of the curved road 81 from the center line in the horizontal direction of the own vehicle. The own vehicle is equipped with a camera, a steering control-angle sensor, and the like. The relative position of the preceding vehicle 78 to the own vehicle is detected by performing known analytical processing on images captured with the camera. Further, the fact that the own vehicle is running on the curved road 81 can be detected from a detection signal and the like from the steering control-angle sensor that detects the steering control angle of the steering wheel operated by a driver of the own vehicle.

[0110] Thus, during the period when the own vehicle is running on the curved road 81, the center of SPOT is displaced, by an amount of displacement corresponding to the curvature of the curved road 81, from the center in the horizontal direction of the own vehicle to the inner side (turning side) of the curved road 81 in the horizontal axis H direction. As a result, as illustrated in FIG. 12B, the driver can have visual contact with the preceding vehicle 78 clearly even on the curved road 81 while keeping the preceding vehicle 78 inside SPOT.

[0111] In FIG. 12A and FIG. 12B, displacement control based on the situation related to vehicle driving is not performed on MID, and the relative position of MID to the center line in the horizontal direction of the own vehicle is fixed like in the case of WIDE.

[0112] FIG. 13 is a structural diagram of another headlight unit. A different point of the headlight unit from the headlight unit 1 is that the headlight unit has spot diameter-changing lenses 62a, 62b as diameter-reducing lens elements added to the headlight unit 1 on the optical paths 22a, 22b, respectively. In the following, the spot diameter-changing lenses 62a, 62b are collectively called the "spot diameter-changing lens 62" unless oth-

erwise the spot diameter-changing lenses 62a, 62b are particularly distinguished.

[0113] FIG. 14 illustrates optical spot scanning areas 65a to 65c generated on the light incident surface 53 by two headlight units inside the same vehicle headlight. Like the light incident surface 53 in FIG. 11, the light incident surface 53 means that two light incident surfaces 411 (FIG. 9) are synthesized.

[0114] The optical spot scanning areas 65a to 65c in FIG. 14 correspond to an optical spot scanning area generated by the two headlight units on either of the right and left sides altogether. When the two headlight units on either of the right and left sides are called first and second headlight units, respectively, two irradiation systems 13 in the first headlight unit generate the optical spot scanning areas 65a and 65b, and two irradiation systems 13 in the second headlight unit generate the optical spot scanning areas 65b and 65c, respectively.

[0115] In FIG. 14, although the optical spot scanning areas 65a to 65c are illustrated on one light incident surface 53, FIG. 14 illustrates the optical spot scanning areas 65a to 65c together on the light incident surface 53 by integrating the light incident surface 41 (FIG. 5A) of the first headlight unit and the light incident surface 41 (FIG. 5A) of the second headlight unit into one light incident surface 53. The dimensions of the light incident surface 53 in the horizontal axis H direction and the vertical axis V direction are the same as those of the light incident surface 411 (FIG. 9). Like in FIG. 11, a light incident surface 52 obtained by integrating the light incident surfaces 41 in FIG. 9 is illustrated as reference.

[0116] Optical spots Spa to Spc in corresponding irradiation systems 13 are scanned in the optical spot scanning areas 65a to 65c. Further, the dimensions of the optical spot scanning areas 65a to 65c are increased in the horizontal axis H direction and the vertical axis V direction in this order. The optical spots Spa to Spc are all longitudinal optical spots. The dimensions of the largest optical spot scanning area 65c in the horizontal axis H direction and the vertical axis V direction is set equal to the dimensions of the light incident surface 53 in the horizontal axis H direction and the vertical axis V direction.

[0117] In order to generate the optical spot scanning areas 65a to 65c on the light incident surface 53, the turning frequencies of the mirror unit 32 about the first rotation axial line 50 on the light deflector 15 of each irradiation system 13 are set equal to one another regardless of the irradiation system 13. On the other hand, the turning angle ranges are increased in order of the optical spot scanning areas 65a to 65c. Further, the turning frequencies of the mirror unit 32 about the second rotation axial line 51 on the light deflector 15 of each irradiation system 13 are set to be equal to one another regardless of the irradiation system 13, but the turning angle ranges are set to increase in order of the optical spot scanning areas 65a to 65c. The turning angle ranges of the mirror unit 32 about the first rotation axial line 50 and the second rotation axial line 51 on the light deflector

15 of each irradiation system 13 are adjusted by the first drive voltage (FIG. 5B) and the second drive voltage (FIG. 5C). As the turning angle range becomes larger, the peak-to-peak value of the first and second drive voltages increases.

[0118] Scanning light beams corresponding to the optical spot scanning areas 65a to 65c are emitted from the vehicle headlights equipped with the headlight units. these scanning light beams correspond to the optical spot scanning areas 65a to 65c to scan irradiation areas overlapped like the optical spot scanning areas 65a to 65c illustrated in FIG. 14. The irradiation areas generated ahead of the vehicle headlights based on the optical spot scanning areas 65a to 65c correspond a spot irradiation area, an intermediate irradiation area, and a widespread irradiation area, respectively.

[0119] In FIG. 14, the optical spots Spa to Spc are optical spots Sp to scan the optical spot scanning areas 65a to 65c, respectively. In the following, the optical spots Spa to Spc are collectively called the "optical spot Sp" unless otherwise the optical spots Spa to Spc are particularly distinguished. Further, the optical spot scanning areas 65a to 65c are collectively called the "optical spot scanning area 65" unless otherwise the optical spot scanning areas 65a to 65c are particularly distinguished.

[0120] The spot diameter-changing lens 62 (FIG. 13) adjusts the amount of light from an aperture of the laser-light emission device 14 so that the optical spot Sp having a size (diameter) set in the irradiation system with the spot diameter-changing lens 62 provided therein will be formed in a corresponding optical spot scanning area 65 (in FIG. 14, as the optical spot scanning area 65 is larger, a larger optical spot Sp is formed).

[0121] As the optical spot Sp has a smaller diameter, the total continuous irradiation time T decreases. Therefore, the optical spot Sp can be made smaller for the smaller optical spot scanning area 65 to keep the conversion efficiency of the phosphors without increasing the scanning speed so much even when the optical spot scanning area has a short length in the scanning direction Hc. Thus, the size of each of the optical spots Spa to Spc is increased in this order according to the size of each of the optical spot scanning areas 65a to 65c.

[0122] A relationship between the dimensions of the optical spot scanning areas 65a, 65b and the scanning speeds of the optical spots Spa, Spb in the horizontal axis H direction will be described. Since the relationship between the dimensions of the optical spot scanning area 65a in the horizontal axis H direction and the scanning speed of the optical spot Spa is the same as the relationship between the dimensions of the optical spot scanning area 65b in the horizontal axis H direction and the scanning speed of the optical spot Spb, only the former relationship will be described.

[0123] Like the optical spot Sp in the case of the light incident surface 411, it is preferred that both ends of the optical spot scanning area 65a in the horizontal axis H direction should be included in a scanning range of the

optical spot Spa for the optical spot scanning area 65a, where the total continuous irradiation time T corresponding to the scanning speed in the scanning direction Hc becomes total continuous irradiation time $T < \text{fluorescence lifetime } \tau$. In regard to the optical spot Spa, the waste of excitation light energy of the optical spot Sp to the phosphor 43 inside the phosphor panel 20 can be prevented. The same applies to the relationship between the optical spot scanning area 65b and the optical spot Spb, and the relationship between the optical spot scanning area 65c and the optical spot Spc.

[0124] While the present invention has been described in connection with the embodiments, the present invention is not limited to the illustrated embodiments, and various modification forms are included within the gist of the present invention.

[0125] In the embodiments, the headlight unit 1 is described as an example of the optical scanning device. However, the optical scanning device of the present invention is not limited to the headlight unit 1, and can also be applied to an illuminating device that illuminates the exterior or the interior, a projector that generates an image in an area such as an image projection screen, and the like.

[0126] As a light source device having a light emitting unit, a blur laser-light emission device 14 having the light emitting unit 45 is included in the embodiments. Any light source device other than the blur laser-light emission device 14, such as any color laser-light emission device other than blur laser, an RGB laser, or an LED (Light Emitting Diode) can be adopted as the light source device of the present invention.

[0127] In the embodiments, projector lenses 19a to 19d that irradiate light to irradiation areas are provided as projector units that adjust light emitted from the light emitting surface of the phosphor panel to project the light to the irradiation areas. The projector units of the present invention may be collimator lenses. The number and arrangement of projector lenses as the projector units can also be changed depending on the situation.

[0128] In the embodiments, the optical spot Sp as an excitation light spot that is the excitation source of phosphors has a line-symmetric shape. However, the excitation light spot of the present invention may not have the line-symmetric shape as long as the excitation light spot has the major axis direction and the minor axis direction.

[0129] In the embodiments, the light source control unit that controls the ON and OFF of the light source device is provided in the headlight unit 1, 61. However, the light source control unit of the present invention may be an external light source control unit provided outside the headlight unit 1, 61 and connected by wiring to the laser-light emission device 14 of the headlight unit 1, 61.

[0130] In the embodiments, the scanning speed corresponding to the boundary L in FIG. 10A is described as the reference scanning speed at which the total continuous irradiation time as the time of continuously irradiating all the phosphors having an average particle di-

ameter becomes equal to the fluorescence lifetime of the phosphors. The scanning speed corresponding to the boundary L in FIG. 10A is not fixed and is changed diversely depending on the types of phosphors, the placing position of the laser-light emission device 14, the type of emitted light, and the like under the environment in which the optical scanning device is provided.

[0131] In the embodiments, the scanning direction Hc as the direction along the scanning direction of the optical spot Sp approximately matches the horizontal axis H direction. The present invention includes a case where the scanning direction Hc is a direction with a predetermined inclined angle with respect to the horizontal axis H, and a case where the scanning direction Hc is the vertical axis V direction.

[0132] In the embodiments, the spot diameter-changing lens 62 (FIG. 13) is provided as the diameter-reducing lens element that reduces the diameter of each excitation light spot. However, the diameter-reducing lens element of the present invention can be mounted on the laser-light emission device 14, rather than provided in the middle of the optical path 22.

[0133] In the embodiments, the headlight unit 1, 61 includes the irradiation systems 13a, 13b as the first and second irradiation systems. However, the optical scanning device of the present invention can also include only one irradiation system, or three or more irradiation systems.

[0134] In the embodiments, the light incident surface 41 of the phosphor panel 20, and the like are formed in a rectangular shape. However, the light incident surface of the phosphor panel of the present invention can also be applied to any shape other than the rectangle (such as the parallelogram, the square, and a diamond shape).

[0135] In the embodiments, the inner actuator 36 and the outer actuator 37 of the light deflector 15 as actuators, and the light source control unit that controls the ON and OFF of the laser-light emission device 14 are described to be separate entities. However, a control unit of the present invention may serve as both the mirror control unit of the light deflector and the light source control unit.

[0136] In the embodiments, the inner actuator 36 and the outer actuator 37 for the light deflector 15 are both piezoelectric actuators that deform piezoelectric membranes under the control of applied voltage to the piezoelectric membrane to relatively displace both ends of the cantilever bodies in the long-side direction on which the piezoelectric membranes are fixed in order to displace a target to be acted upon by this relative displacement. The actuators of the present invention may be of any drive type other than the piezoelectric type as long as the actuators can reciprocally turn the mirror unit about the first and second rotation axial lines orthogonal to each other. For example, electromagnetic or electrostatic actuators can be adopted.

Claims

1. An optical scanning device comprising:

a light source device having a light emitting unit to emit light from the light emitting unit;
 a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface;
 a projector unit configured to adjust light emitted from the light emitting surface of the phosphor panel and project the light to an irradiation area;
 a light deflector having a mirror unit capable of turning reciprocally about first and second rotation axial lines orthogonal to each other, and actuators to turn the mirror unit reciprocally about the first and second rotation axial lines, the light deflector configured to reflect, by the mirror unit, incident light from the light emitting unit of the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel in first and second scanning directions corresponding to reciprocal turning directions of the mirror unit about the first and second rotation axial lines; and
 a drive voltage generating unit configured to generate drive voltages of the actuators so that reciprocal turning of the mirror unit about the first rotation axial line will be done at a resonant frequency as natural vibration of the mirror unit, and reciprocal turning of the mirror unit about the second rotation axial line is done at a non-resonant frequency different from the resonant frequency,
 wherein longer and shorter ones of two radial directions of an excitation light spot are defined as a major axis direction and a minor axis direction, respectively, where the two radial directions are perpendicular to each other, and the excitation light spot is generated on the light incident surface of the phosphor panel by the reflected light from the light deflector to excite the phosphors in the light transmission part, and a rotational position of the light emitting unit of the light source device about an optical axis of the emitted light from the light emitting unit is so set that the minor axis direction of the excitation light spot will be a direction along the first scanning direction of the excitation light spot on the light incident surface.

2. The optical scanning device according to claim 1, further comprising:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second

irradiation systems are so set that a first scanning area of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spots will be on an inner side of the second scanning area; and
 diameter-reducing lens elements to make a diameter of the excitation light spot of the first irradiation system smaller than that of the excitation light spot of the second irradiation system.

3. An optical scanning device comprising:

a light source device;
 a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface;
 a projector unit configured to adjust light emitted from the light emitting surface of the phosphor panel and project the light to an irradiation area;
 a light deflector having a mirror unit capable of turning reciprocally about a rotation axial line, and actuators to turn the mirror unit reciprocally about the rotation axial line, the light deflector configured to reflect, by the mirror unit, incident light from the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel; and
 a light source control unit configured to control ON and OFF of the light source device, wherein, in the case where an excitation light spot generated on the light incident surface by the reflected light from the light deflector and used as an excitation source of the phosphors in the light transmission part scans in a scanning direction, a placing position and dimensions of the excitation light spot are so set that a scanning speed of the excitation light spot over the entire light incident surface will be higher than a reference scanning speed at which a total continuous irradiation time as a time of continuously irradiating all phosphors having an average particle diameter becomes equal to a fluorescence lifetime of the phosphors.

4. The optical scanning device according to claim 3, wherein longer and shorter ones of two radial directions of the excitation light spot on the light incident surface are defined as a major axis direction and a minor axis direction, respectively, where the two radial directions are perpendicular to each other, and a rotational position of a light emitting unit of the light source device about an optical axis of the emitted light from the light emitting unit is so set that the minor axis direction of the excitation light spot will be a direction along a scanning direction of the excitation light spot on the light incident surface.

5. The optical scanning device according to claim 3 or 4, further comprising
a diameter-reducing lens element arranged between the light source device and the light deflector to reduce a diameter of the excitation light spot to make the total continuous irradiation time shorter than the fluorescence lifetime. 5
6. The optical scanning device according to any one of claims 3 to 5, further comprising: 10
- first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that a first scanning area of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spots will be on an inner side of the second scanning area; and 15
- diameter-reducing lens elements configured to make a diameter of the excitation light spot of the first irradiation system smaller than that of the excitation light spot of the second irradiation system. 20 25
7. The optical scanning device according to any one of claims 3 to 5, further comprising: 30
- first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that each of first and second scanning areas respectively generated on the light incident surface as scanning areas of optical spots will be formed into a rectangle to make a side scanned by the excitation light spot at a high speed longer than a side scanned at a low speed; and 35 40
- mirror control units each configured to control a mirror unit of the light deflector through the actuators of the light deflector of each of the first and the second irradiation systems so that long sides of the first and the second scanning areas will be equal to each other, and a short side of the first scanning area will be shorter than that of the second scanning area. 45 50
8. An optical scanning device comprising:
- a light source device;
- a phosphor panel having a light transmission part that houses phosphors between a light incident surface and a light emitting surface; 55
- a projector unit configured to adjust light emitted from the light emitting surface of the phosphor

panel and project the light to an irradiation area; a light deflector having a mirror unit capable of turning reciprocally about a rotation axial line, and actuators to turn the mirror unit reciprocally about the rotation axial line, the light deflector configured to reflect, by the mirror unit, incident light from the light source device, and cause the reflected light to scan on the light incident surface of the phosphor panel; and
a light source control unit configured to control ON and OFF of the light source device, wherein the optical scanning device further comprises:

first and second irradiation systems each having the light source device and the light deflector separately and both sharing the phosphor panel and the projector unit, where the first and second irradiation systems are so set that each of first and second scanning areas respectively generated on the light incident surface as scanning areas of excitation light spot will be formed into a rectangle to make a side scanned by the excitation light spot at a high speed longer than a side scanned at a low speed; and
mirror control units each configured to control a mirror unit of the light deflector through the actuators of the light deflector of each of the first and the second irradiation systems so that long sides of the first and the second scanning areas will be equal to each other, and a short side of the first scanning area will be shorter than that of the second scanning area.

FIG.1

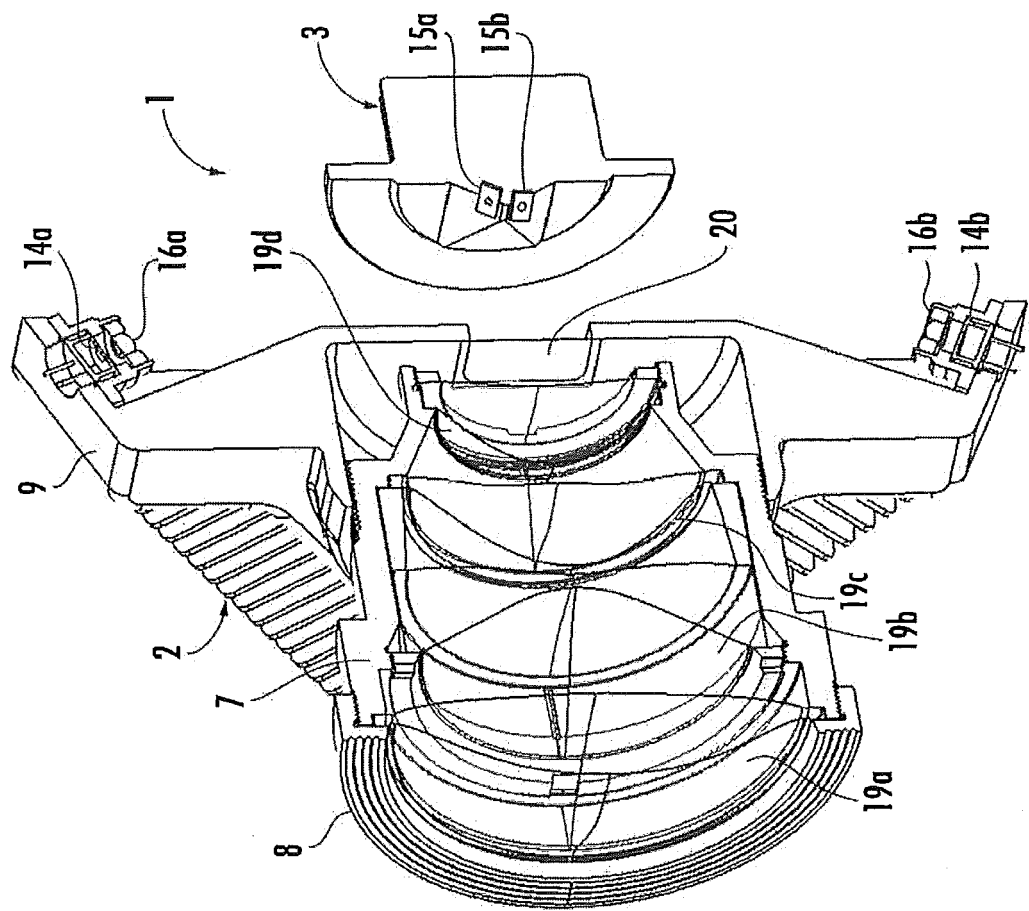


FIG. 2

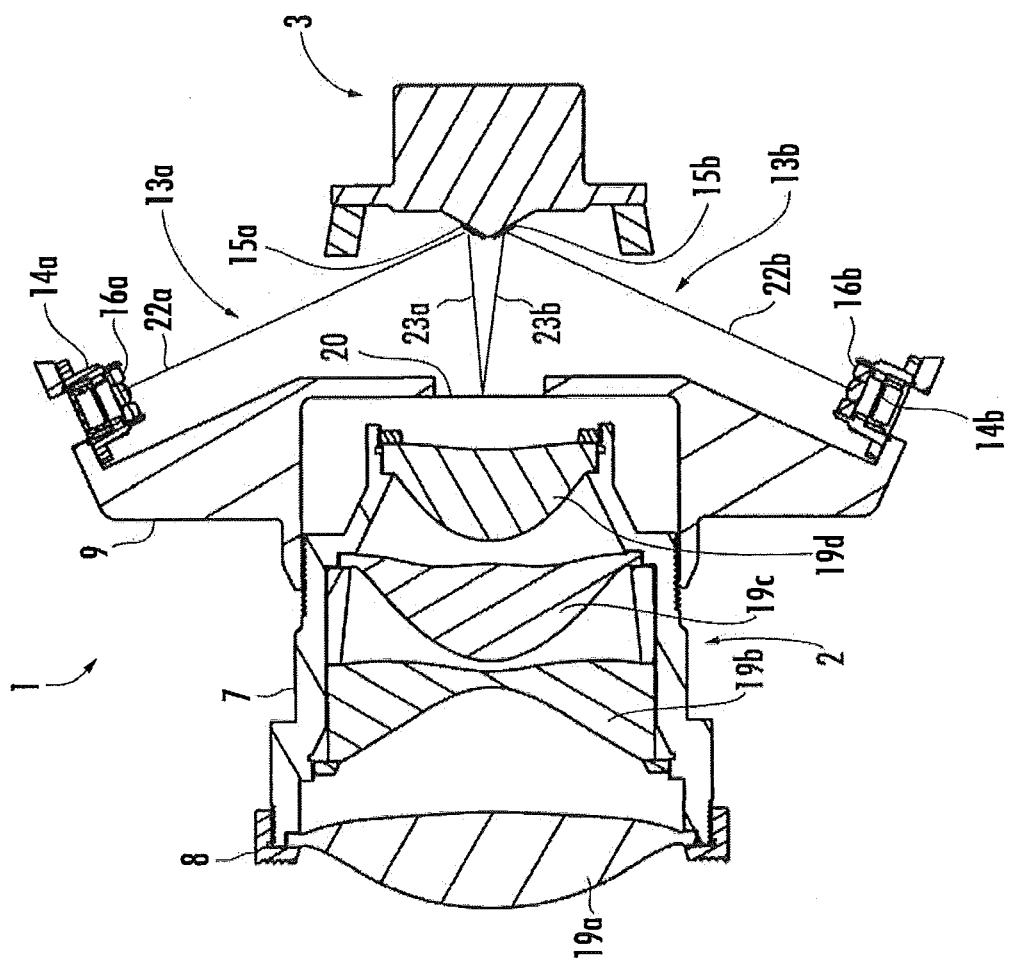


FIG. 3

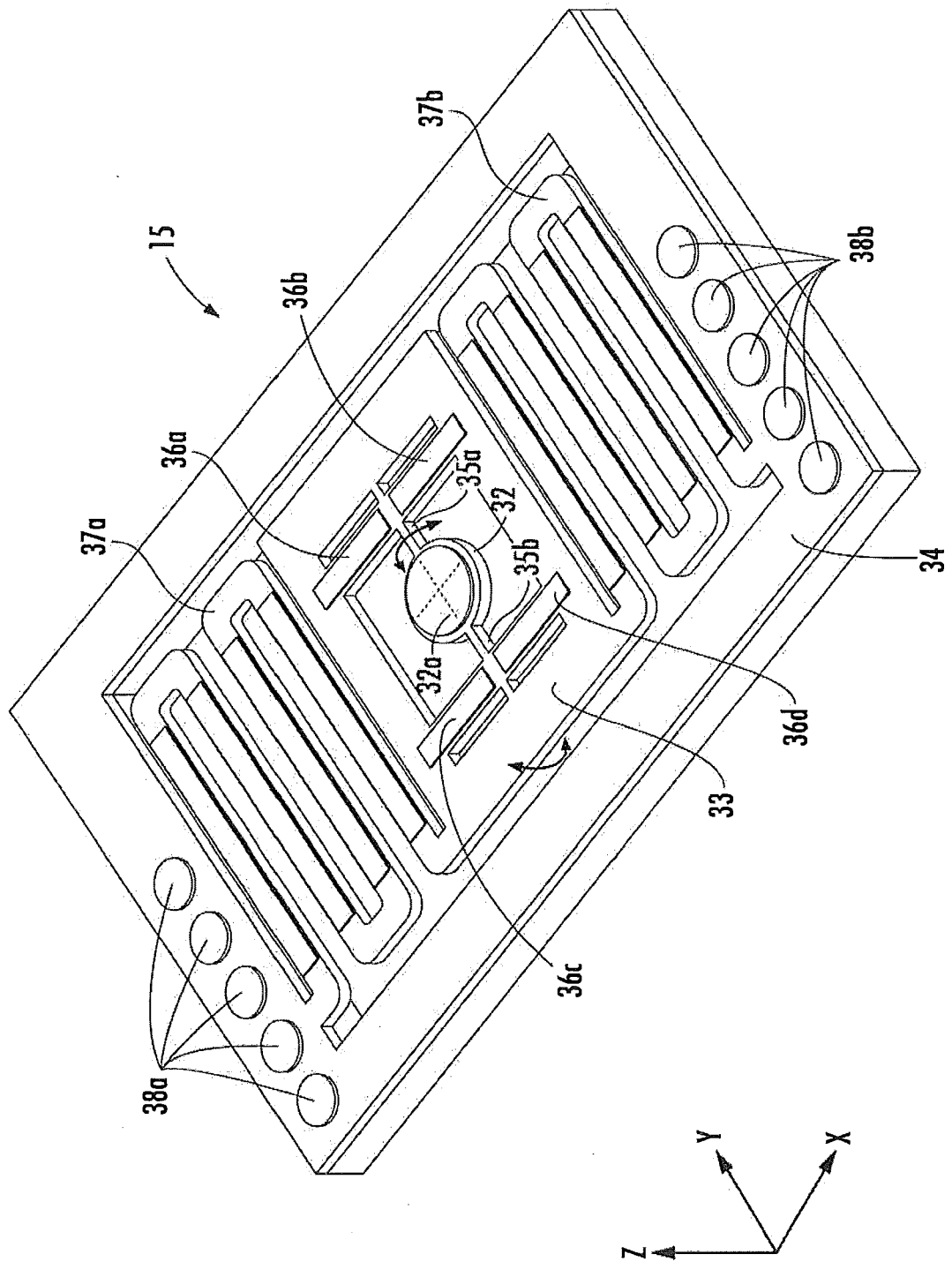


FIG.4A

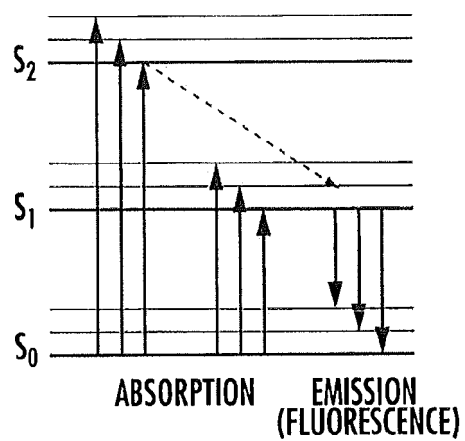


FIG.4B

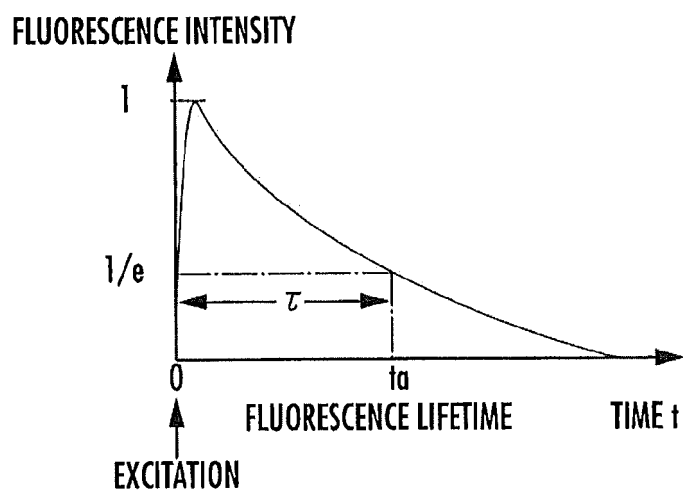


FIG.4C

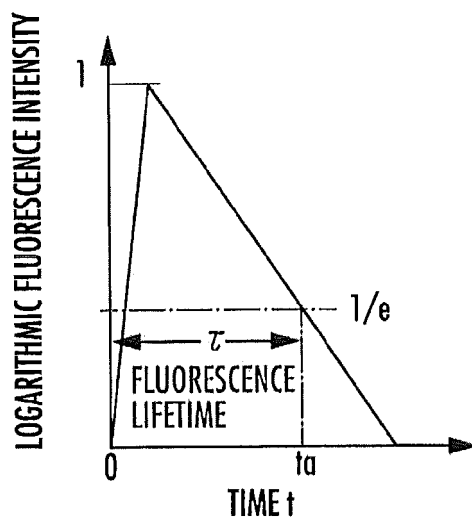


FIG.5A

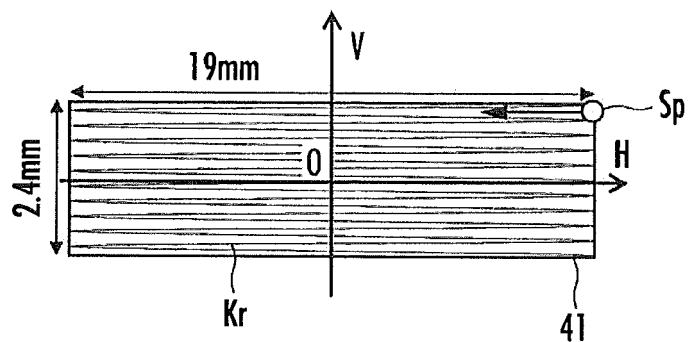


FIG.5B

FIRST DRIVE VOLTAGE OF LIGHT DEFLECTOR

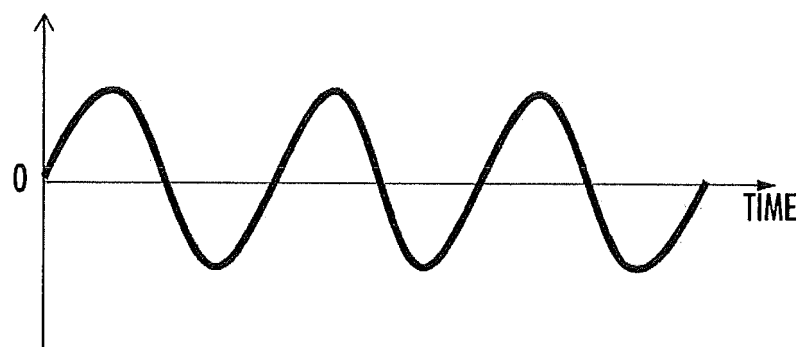


FIG.5C

SECOND DRIVE VOLTAGE OF LIGHT DEFLECTOR

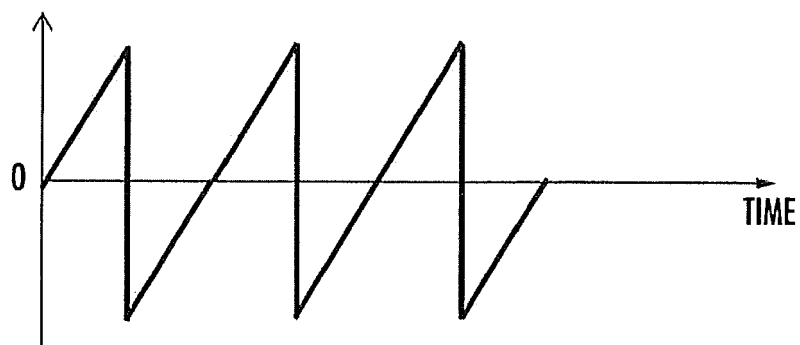


FIG.6A

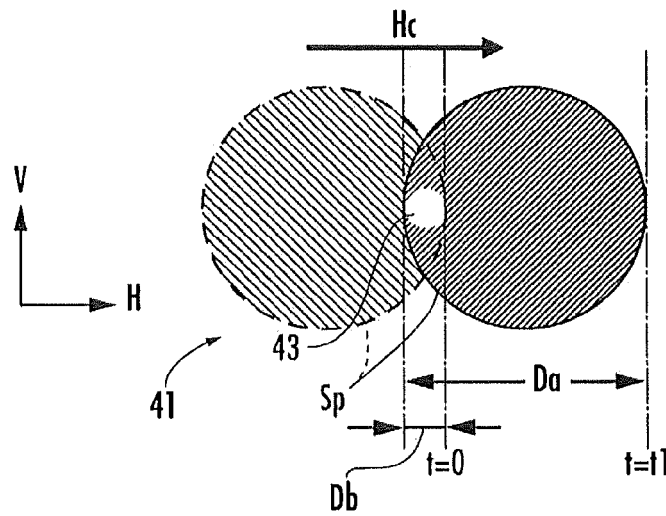


FIG.6B

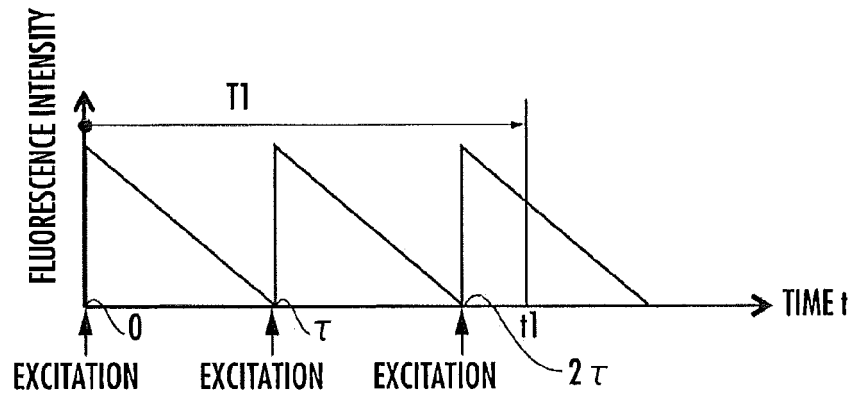


FIG.6C

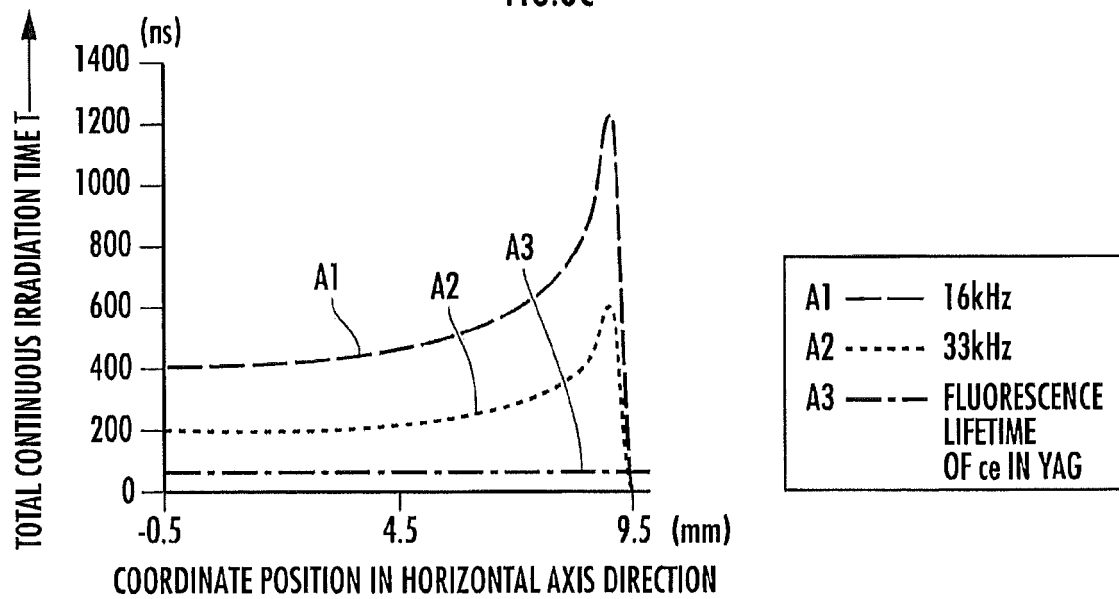


FIG.7A

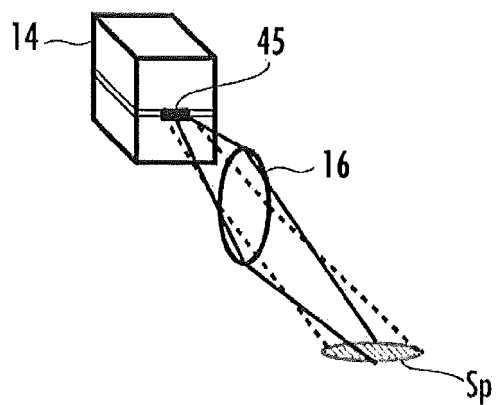


FIG.7B

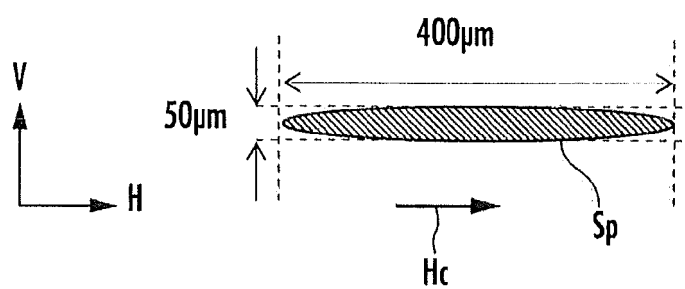


FIG.7C

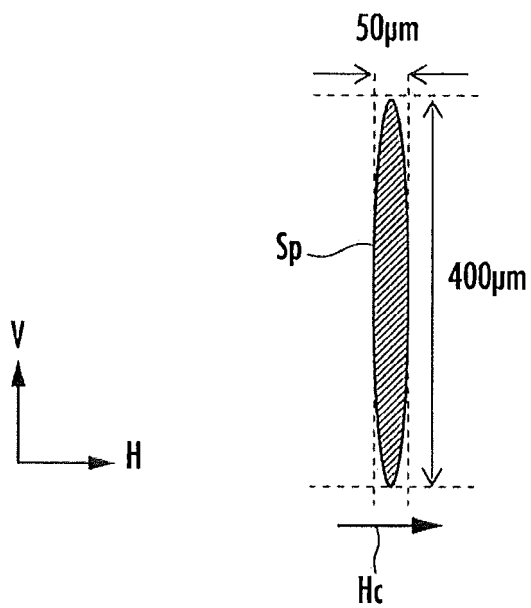


FIG.8A

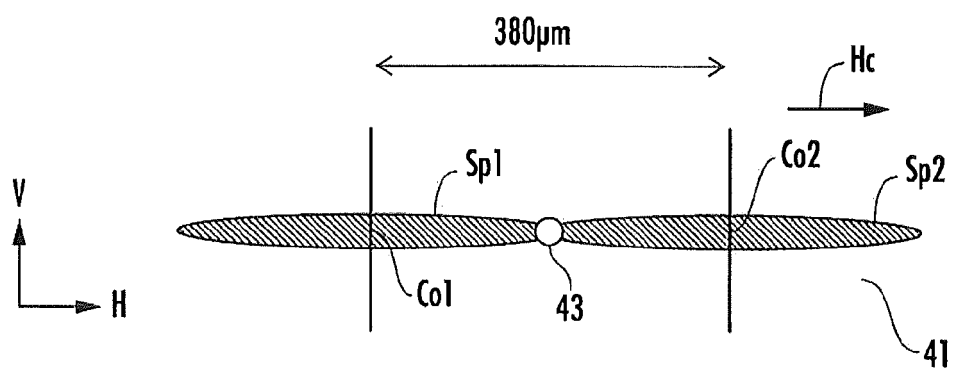


FIG.8B

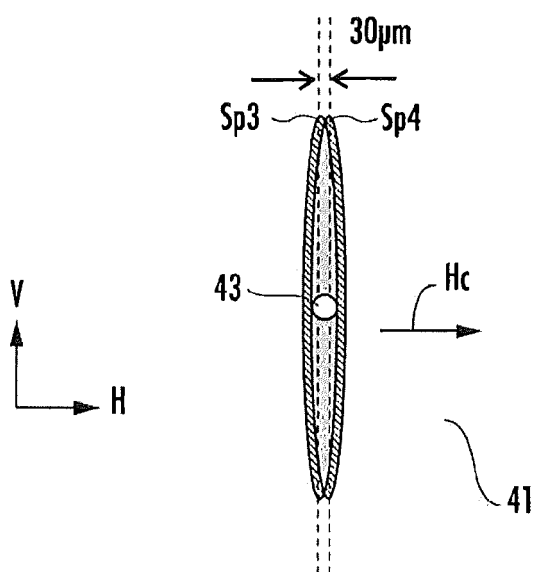


FIG.8C

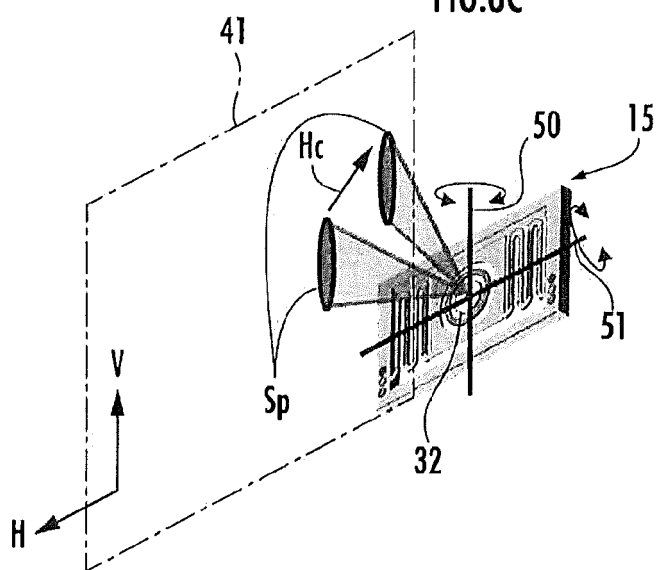


FIG.9

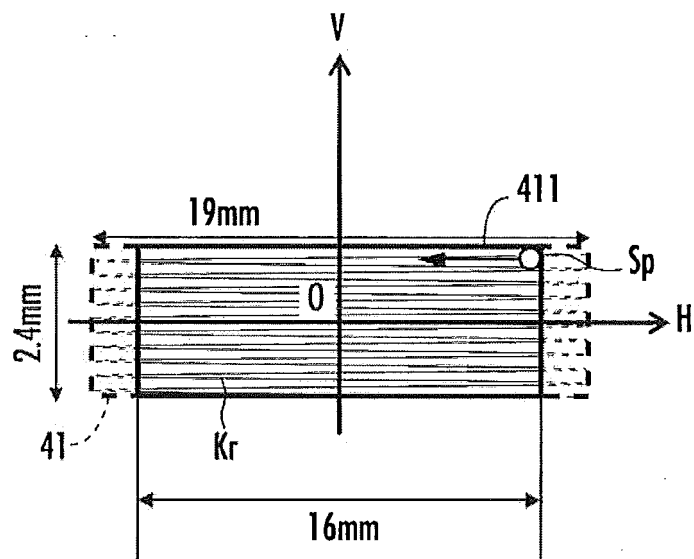


FIG.10A

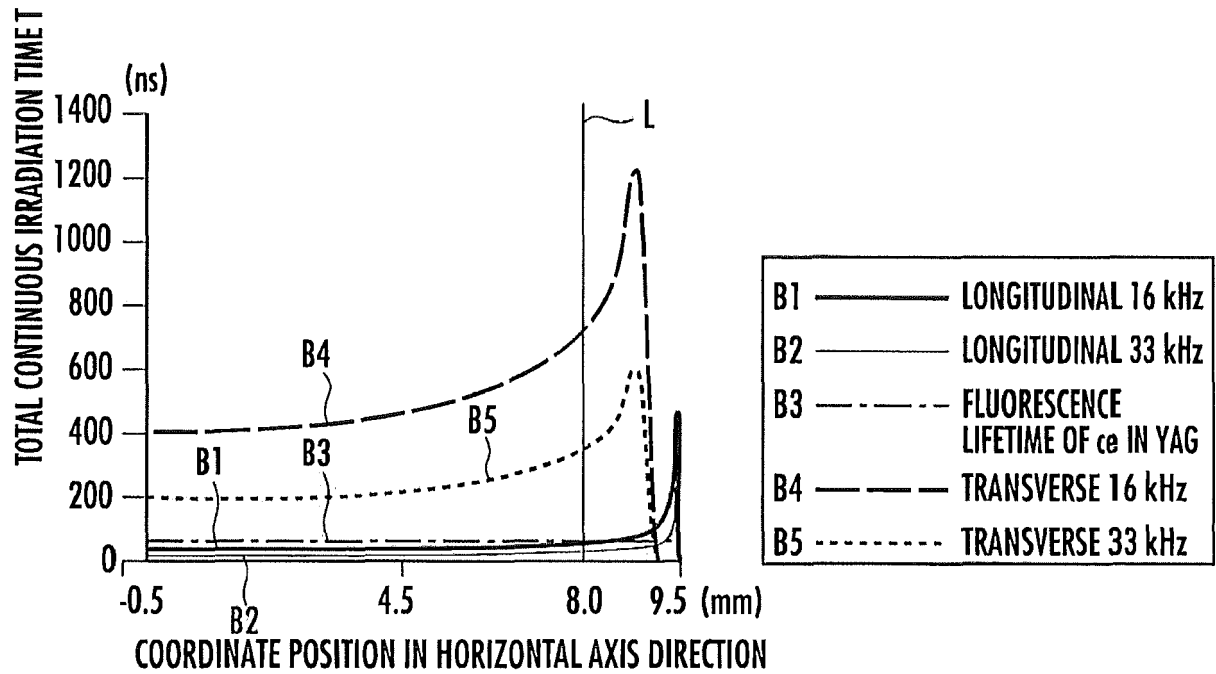


FIG.10B

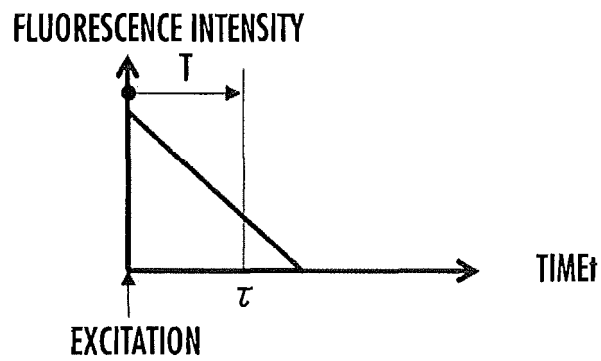


FIG.11

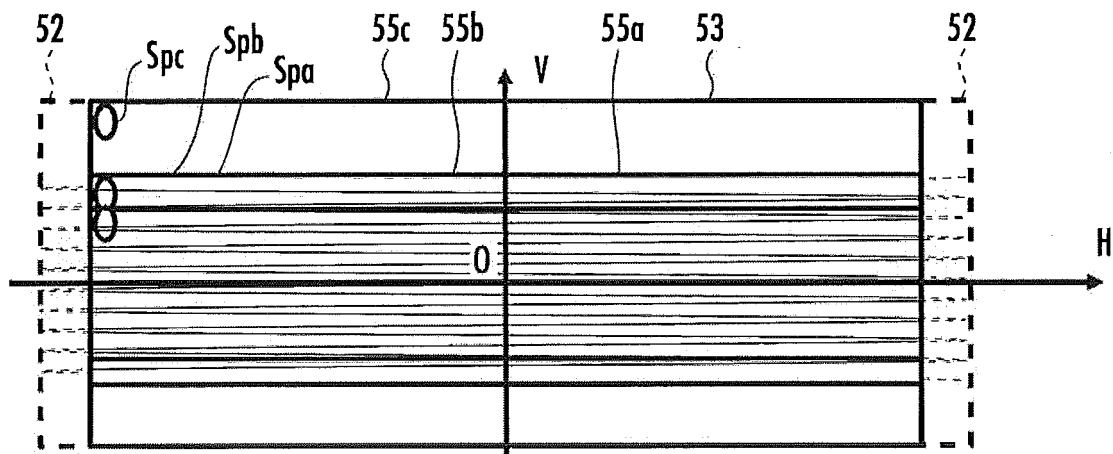


FIG.12A

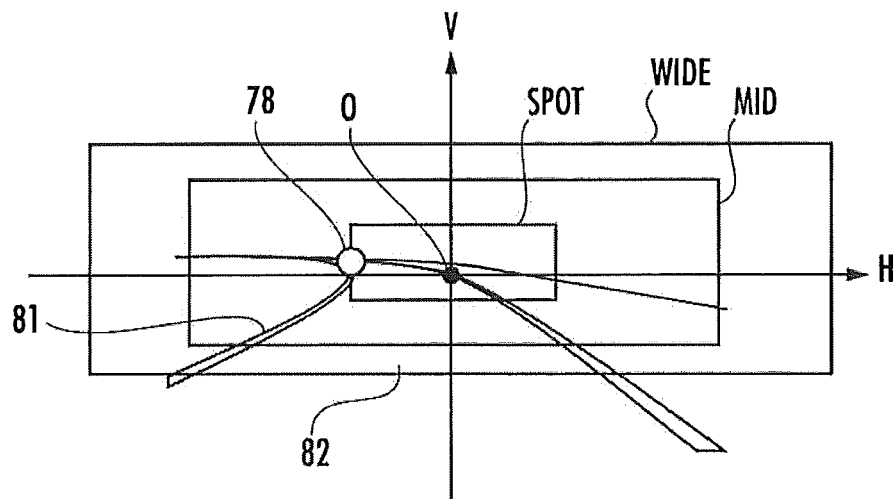


FIG.12B

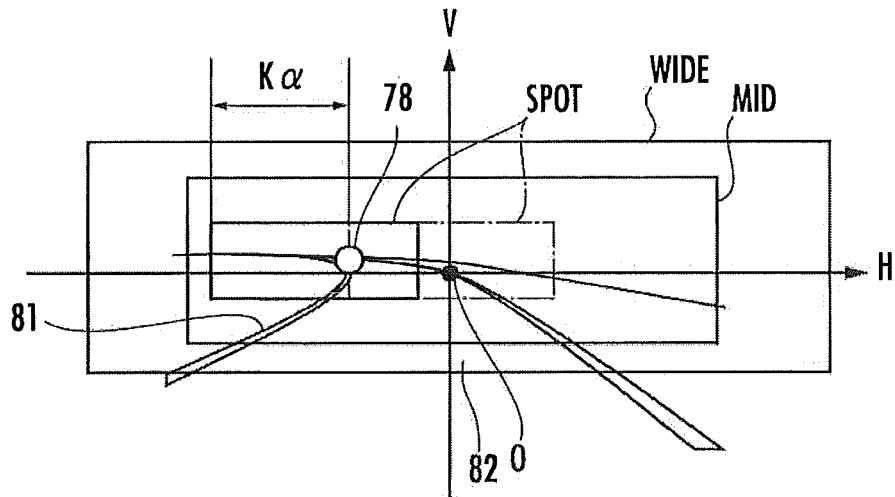


FIG.13

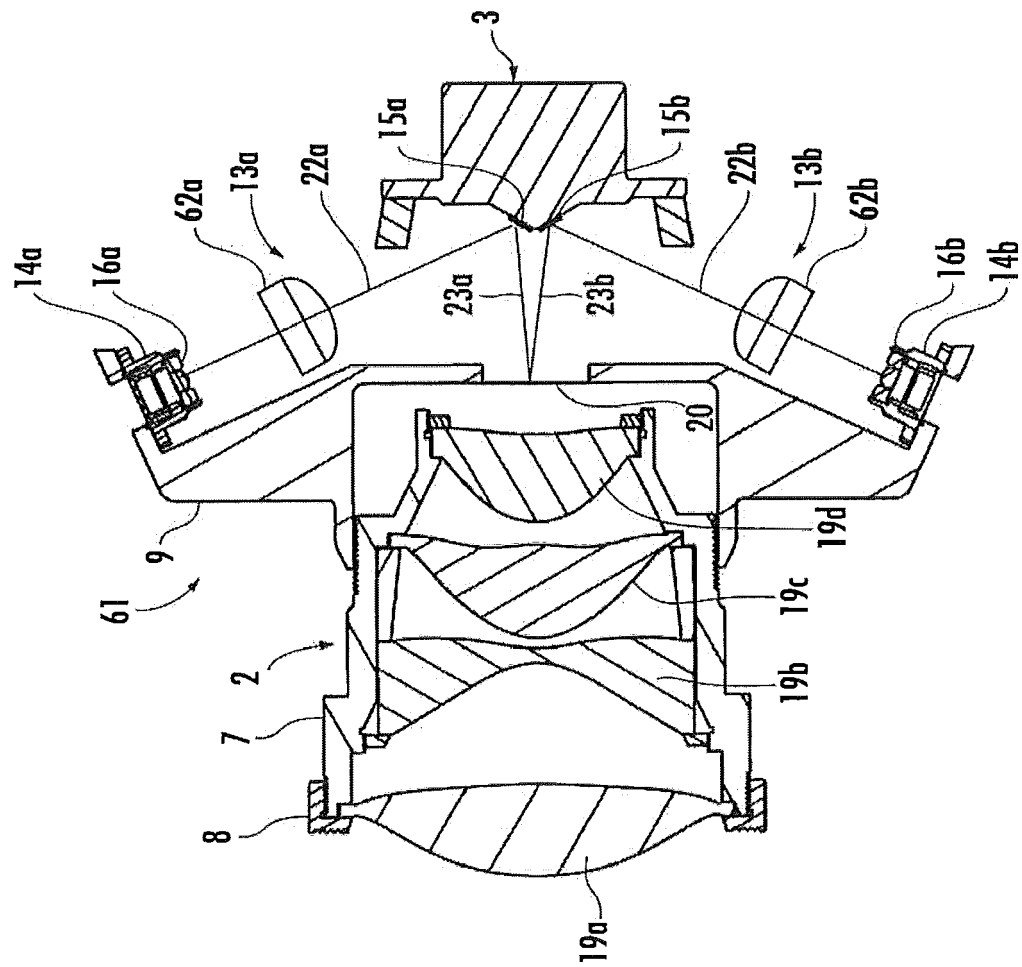
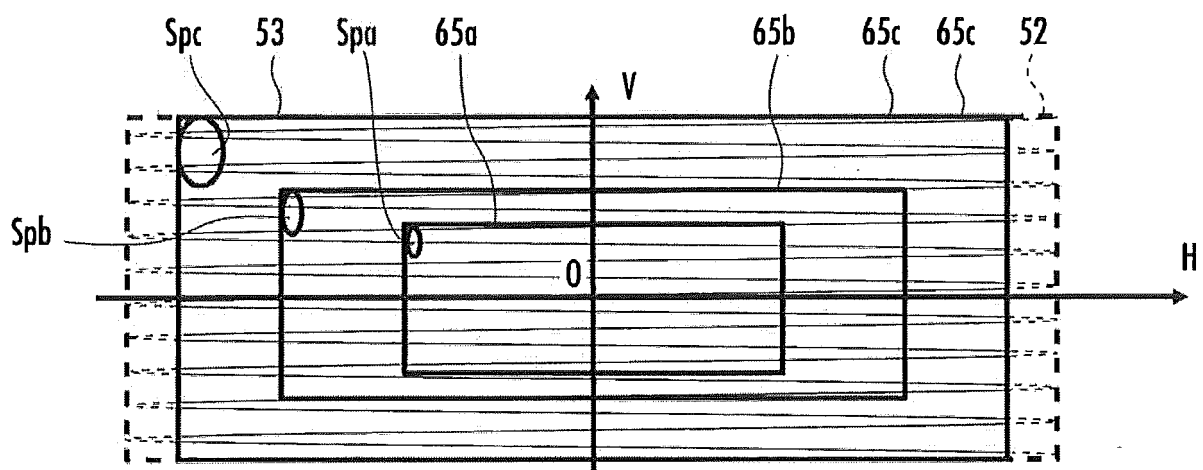


FIG.14



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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