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LIGHT DIFFUSION DEVICE

Abstract

A light diffusion device comprises: an optical transmission cable which transmits a laser beam emitted from a laser oscillator and outputs the transmitted laser beam from an output surface at a leading end thereof; and a covering layer which has a function of absorbing the laser beam and/or a function of diffusing light and which covers the optical transmission cable. The covering layer has a leading end that protrudes in the output direction of light by a length required for cutting off the peripheral portion of said light.

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Background/Summary

[0001] This application is based on and claims the benefit of priority to Japanese Patent Application No. 2022-180691 and 2022-180692 filed on Nov. 11, 2022 and is a Continuation application of PCT Application No. PCT/JP2023/039804 filed on Nov. 6, 2023. The entire contents of each application are hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to a light diffusion device.

BACKGROUND ART

[0003] Conventionally, in the medical field, a light diffusion device has been used for insertion into a human body to irradiate cells with light. For example, Patent Document 1 discloses a device including a fiber core, a cladding enclosing the fiber core, an open cavity, and a covering.

CITATION LIST

Patent Document

[0004] Patent Document 1: Japanese Unexamined Patent Application, Publication No. 2020-72969

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

[0005] Incidentally, a light diffusion device is used, for example, in photoimmunotherapy and photodynamic therapy, which are cancer treatment methods,

for inserting the distal end side of an optical transmission cable into a human body to irradiate laser light onto a drug that has been administered to the human body and reached cancer cells. At this time, from the viewpoint of treatment efficiency, it is desirable to make the light intensity distribution of the laser light emitted from the optical transmission cable more uniform in a region within a predetermined radius from the center of the laser light. In the device of Patent Document 1, although light having a flat-top light intensity distribution can be irradiated, it is necessary to provide a sealed open cavity or the like between the covering and the cladding, and there is room for improvement in terms of processability.

[0006] An object of the present invention is to provide a light diffusion device that can be easily produced and can irradiate light with a flat-top light intensity distribution.

Means for Solving the Problems

[0007] (1) A light diffusion device includes an optical transmission cable configured to transmit light emitted from a light source and emit the transmitted light from an emission surface of a distal end part, and a covering layer that has at least one of a function of absorbing the light or a function of scattering the light and that covers the optical transmission cable. The covering layer has a distal end part that protrudes by a required length for cutting a peripheral edge part of the light, in a direction in which the light is emitted.

[0008] (2) In the light diffusion device according to (1), the optical transmission cable includes a core and a cladding formed on an outer periphery of the core. The required length is calculated by the following Equation (1):

[00001] $Y = (1/\mathrm{NA}^2 - 1)^{1/2} \times d2 \quad \text{Equation(1)}$

where Y is the required length, NA is an aperture coefficient of the optical transmission cable, and d2 is a thickness of the cladding.

[0009] (3) In the light diffusion device according to (1) or (2), the optical transmission cable includes a core and a cladding formed on an outer periphery of the core. The cladding has a thickness of 1/10 or less of an outer diameter of the core. The covering layer has a thickness greater than that of the cladding.

[0010] (4) In the light diffusion device according to any one of (1) to (3), the emission surface of the optical transmission cable is inclined with respect to an axial direction of the optical transmission cable.

[0011] (5) In the light diffusion device according to any one of (1) to (4), the covering layer has a refractive index equal to or greater than a refractive index of a covering material of the optical transmission cable.

[0012] (6) In the light diffusion device according to any one of (1) to (5), wherein the covering layer has a refractive index of 1.53 or more.

[0013] (7) The light diffusion device according to any one of (1) to (6) further includes a reflective member having a refractive surface that refracts the light emitted from the emission surface, and a tubular member made of resin into which the optical transmission cable and the reflective member are inserted. The refractive surface is disposed at a predetermined distance from the emission surface in the tubular member and is inclined with respect to an axial direction of the optical transmission cable. The light emitted from the emission surface is emitted in a direction that is inclined at a predetermined angle or more with respect to the axial direction of the optical transmission cable.

[0014] (8) In the light diffusion device according to any one of (1) to (7), the reflective member is a rod-shaped member made of quartz or silicon and is spaced apart from the optical transmission cable in the tubular member. The refractive surface is formed on an end part of the rod-shaped member on a side adjacent to the optical transmission cable.

[0015] (9) In the light diffusion device according to any one of (1) to (8), the refractive surface includes a vapor-deposited metal.

[0016] (10) In the light diffusion device according to any one of (1) to (9), the optical transmission cable is a plastic fiber including a core having an outer diameter of 500 μm or more, and a cladding made of resin and formed on an outer periphery of the core. An outer diameter of the refractive surface viewed from the axial direction of the optical transmission cable is larger than the outer diameter of the core.

[0017] (11) In the light diffusion device according to any one of (1) to (10), wherein an unevenness of the refractive surface on which the light is incident is equal to or less than a wavelength of the light generated from the light source.

[0018] (12) In the light diffusion device according to any one of (1) to (11), the refractive surface is formed in a curved surface shape that is concave with respect to the emission surface.

Effects of the Invention

[0019] According to the present invention, it is possible to provide a light diffusion device that can be easily produced and can irradiate light with a flat-top light intensity distribution.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a side view schematically showing an appearance of a light diffusion device according to a first embodiment;

[0021] FIG. **2** is a longitudinal sectional view schematically showing the light diffusion device according to the first embodiment;

[0022] FIG. **3** is a cross-sectional view taken along line III-III of FIG. **1**;

[0023] FIG. **4** is a longitudinal sectional view schematically showing a light diffusion device according to a second embodiment;

[0024] FIG. **5** is a side view schematically showing an appearance of a light diffusion device according to a third embodiment;

[0025] FIG. **6** is a longitudinal sectional view schematically showing the light diffusion device according to the third embodiment;
[0026] FIG. **7** schematically shows a light diffusion device according to a fourth embodiment, and is a side view of the light diffusion device mainly irradiating laser light to the side;
[0027] FIG. **8** schematically shows a light diffusion device according to the fourth embodiment, and is a side view of the light diffusion device that mainly irradiates laser light rearward;
[0028] FIG. **9** is a side view schematically showing a light diffusion device according to a fifth embodiment;
[0029] FIG. **10** is a side view schematically showing a light diffusion device according to a sixth embodiment;
[0030] FIG. **11** is a side view schematically showing a light diffusion device according to a seventh embodiment;
[0031] FIG. **12** is a side view schematically showing a light diffusion device according to an eighth embodiment;
[0032] FIG. **13** is a graph showing a light intensity distribution of Example 1;
[0033] FIG. **14** is a graph showing a light intensity distribution of Example 2; and
[0034] FIG. **15** is a graph showing a light intensity distribution of a comparative example.

PREFERRED MODE FOR CARRYING OUT THE INVENTION

[0035] Hereinafter, embodiments of the present invention will be described with reference to the drawings. The present invention is not limited to the following embodiments. The drawings referred to in the following description merely schematically show shapes, sizes, and positional relationships so that the contents of the present disclosure can be understood. That is, the present invention is not limited to only the shapes, sizes, and positional relationships illustrated in the drawings.

First Embodiment

[0036] A light diffusion device **1** according to a first embodiment of the present invention will be described with reference to FIGS. **1** to **3**. FIG. **1** is a side view of the light diffusion device **1**. FIG. **2** is a longitudinal sectional view of the light diffusion device **1**. FIG. **3** is a cross-sectional view taken along line III-III shown in FIG. **1**. In FIG. **1**, an optical transmission cable **10** covered with a covering layer **20** and a core **13** in the optical transmission cable **10** are indicated by broken lines.
[0037] The light diffusion device **1** of the present embodiment is mounted on a medical device for performing photoimmunotherapy, which is a method for treating cancer. The photoimmunotherapy treats cancer by administering to a human body a drug composed of an antibody that binds to cancer cells and a substance that reacts to light, and then irradiating the drug bound to the cancer cells with laser light L to destroy the cancer cells. The light diffusion device **1** is inserted into, for example, a conduit provided in an endoscope, and is used in a state where the distal end part thereof is exposed to the outside. The present invention is not limited to photoimmunotherapy, and can be used for photodynamic therapy.
[0038] As shown in FIGS. **1** and **2**, the light diffusion device **1** includes a laser oscillator (not shown) as a light source, an optical transmission cable **10**, and a covering layer **20**. The covering layer may be a resin or a metal in which a part of light is scattered by slight unevenness on the order of wavelength on the surface.
[0039] The laser oscillator includes a semiconductor laser, generates laser oscillation by energizing the semiconductor laser, and generates laser light L. The laser oscillator generates red laser light L having a wavelength of 600 nm or more and 700 nm or less.
[0040] The optical transmission cable **10** is an optical fiber cable having an optical transmission path through which the laser light L emitted from the laser oscillator is transmitted. The laser oscillator is disposed on the proximal end part side of the optical transmission cable **10**, and the covering layer **20** is provided on a distal end part **11** side. The optical transmission cable **10** transmits the laser light L generated in the laser oscillator through the optical transmission path and

emits the laser light L from an emission surface **12** at the distal end part **11**. The emission surface **12** of the present embodiment is a surface perpendicular to the axial direction X of the optical transmission cable **10**. The axial direction X of the optical transmission cable **10** in the present specification means the axial direction of the optical transmission cable **10** at the distal end part **11**.
[0041] The optical transmission cable **10** according to the present embodiment is a plastic fiber, and includes the core **13** and a cladding **14** made of resin, formed on the outer periphery of the core **13**. Examples of the resin forming the cladding **14** include PTFE and PVDF. In the present embodiment, the emission surface **12** of the optical transmission cable **10** is the surface of the core **13** at the distal end part **11**. The laser light L is emitted so that its optical axis is parallel to the axial direction X of the optical transmission cable **10**.
[0042] The outer diameter d1 of the core **13** of the optical transmission cable **10** is preferably 250 μm or more. In the present embodiment, the outer diameter d1 of the core **13** is 500 μm. The optical transmission cable **10** of the present embodiment is a single-core optical fiber, but may be a multi-core optical fiber. The shape of the core **13** may be an ellipse or a rectangle other than a perfect circle when viewed from the axial direction X of the optical transmission cable **10**. The optical transmission cable **10** may be an optical fiber made of quartz in which the core **13** and the cladding **14** are made of quartz, or may be a polymer clad optical fiber in which the core **13** is made of quartz and the cladding **14** is made of resin. Examples of the quartz-based material forming the core include quartz in which the core is not doped with impurities and quartz doped with germanium. Examples of the resin forming the cladding include fluorine-based resins such as PTFE, PVDF, and ETFE, polyimide, silicone, and copolymers thereof.
[0043] The thickness d2 of the cladding **14** is preferably 1/10 or less of the outer diameter d1 of the core **13** from the viewpoint of reducing the diameter of the optical transmission cable **10** while efficiently emitting the laser light L. In the present embodiment, the thickness d2 of the cladding **14** is 25 μm. Although the laser light L is transmitted through the core **13**, a part of the laser light L reflected by the cladding **14** may leak to the cladding **14** and propagate as cladding mode light. The optical transmission cable **10** includes a covering material (not shown) that covers the cladding **14** to protect the optical transmission cable **10** itself.
[0044] The covering layer **20** has at least one of a function of absorbing the laser light L or a function of scattering the laser light L. For example, the covering layer **20** has a refractive index higher than that of the cladding **14**, and absorbs or scatters the cladding mode light leaking from the cladding **14** or the laser light L emitted from the emission surface **12**.
[0045] The covering layer **20** covers at least the distal end part **11** side of the optical transmission cable **10**. The covering layer **20** of the present embodiment is formed of a cylindrical tube made of resin. The covering layer **20** covers the cladding **14** in a state where the inner peripheral surface **22** thereof is in contact with the covering material that covers the outer peripheral surface **141** of the cladding **14**. The covering layer **20** extends in a direction in which the laser light L is emitted beyond the distal end part **11** of the optical transmission cable **10**. That is, a distal end part **21** of the covering layer **20** in the axial direction X of the optical transmission cable **10** is located so as to protrude past the distal end part **11** in the direction in which the laser light L is emitted. In the present embodiment, the covering layer **20** extends in a direction in which the laser light L is emitted beyond the distal end part **11** of the optical transmission cable **10**. That is, the distal end part **21** of the covering layer **20** is located at a position beyond the distal end part **11** of the optical transmission cable **10** in the direction in which the light is emitted.
[0046] Here, from the viewpoint of the treatment efficiency, the light intensity distribution of the laser light L emitted from the emission surface **12** is desirably a flat top intensity distribution in which the variation of the light intensity in a range of a predetermined radius from the center of the laser light L is small, and the light intensity sharply decreases beyond the range of the predetermined radius, rather than an intensity distribution close to a Gaussian distribution. In the light diffusion device **1** of the present embodiment, the covering layer **20** covering the outer

periphery of the optical transmission cable **10** absorbs or scatters the laser light L or the cladding mode light emitted from the distal end part **11** in a direction inclined obliquely with respect to the axial direction X of the optical transmission cable **10**, thereby realizing a flat-top light intensity distribution.

[0047] The distal end part **21** of the covering layer **20** protrudes in the direction in which the laser light L is emitted by a required length Y for cutting off the peripheral edge part of the laser light L. The required length Y indicates the distance d3 between the distal end part **21** of the covering layer **20** and the distal end part **11** of the optical transmission cable **10** in the axial direction X of the optical transmission cable **10** in FIG. **2**. The required length Y may be calculated by the following Equation (1) using the aperture coefficient NA of the optical transmission cable **10** and the thickness d2 of the cladding **14**, for example. Y=(1/NA.sup.2−1).sup.1/2×d2 Equation (1)

[0048] The above Equation (1) is obtained from the following Equation (2). That is,

[00002] $NA = \sin \quad = d2/(d2^2 + Y^2)$ Equation(2)

[0049] As shown in FIG. **2**, θ is a spread angle of the laser light L emitted from the emission surface **12**. That is, by protruding the covering layer **20** in the direction in which the laser light L is emitted by the length Y obtained by the above Equation (1), it is possible to cut the light that spreads at a wider angle with respect to the optical axis of the laser light L than the spread angle of the laser light L. Therefore, while maintaining the intensity of the laser light, the light intensity distribution within a predetermined radius from the center of the laser light L can be made more uniform, and flat-top light can be irradiated. The above Equation (1) can be applied to a single-core optical fiber or a multi-core optical fiber.

TABLE-US-00001 TABLE 1 Type of Aperture Refractive index Protruding amount optical fiber Core Cladding coefficient of cladding of covering layer Plastic fiber Methacrylic resin Fluorine-based resin 0.485~0.50 1.35 18 μm< Polymer clad fiber Quartz Polymer 0.37~0.43 1.35 25 μm< Polymer clad fiber Quartz Silicone 0.37~0.43 1.43 25 μm< Optical fiber Quartz Quartz MM0.2~0.275 1.375~1.72 49 μm< made of quartz

[0050] Table 1 shows the relationship between the type of the optical fiber, i.e., the type of the optical transmission cable **10**, the aperture coefficient NA, the types of the materials forming the core **13** and the cladding **14**, etc., and the protruding amount of the covering layer **20**, which is the length Y obtained by the above Equation (1). Table 1 shows the protruding amount of the covering layer **20** when the thickness d2 of the cladding **14** is 10 μm. As shown in Table 1, for example, in a plastic fiber in which the core **13** is formed of a methacrylic resin and the cladding **14** is formed of a fluorine-based resin, the protruding amount of the covering layer **20** obtained by the above Equation (1) is 18 μm. By using the above Equation (1), it is possible to obtain an appropriate protruding amount of the covering layer **20** for forming flat-top light according to the type of the optical fiber. It is also possible to cut the light on the peripheral edge part side of the laser light according to the application of the optical fiber based on the obtained protruding amount. In this case, although the entire intensity of the emitted light decreases, the light is more flat-topped.

[0051] The thickness d4 of the covering layer **20** is preferably larger than the thickness d2 of the cladding **14**. The thickness d4 of the covering layer **20** is preferably 1/10 of the outer diameter d1 of the core **13** and about twice the thickness d2 of the cladding **14** from the viewpoint of concentrating the light intensity distribution toward the center side while suppressing the thickness of the light diffusion device **1** in the radial direction. In the present embodiment, the thickness d4 of the covering layer **20** is 50 μm.

[0052] The tube made of resin, forming the covering layer **20** may be, for example, a nylon tube, a polytetrafluoroethylene (PTFE) tube, or a tube having an inner layer formed of PTFE and an outer layer formed of polyimide (hereinafter referred to as a PTFE/polyimide tube). The PTFE/polyimide tube may have, for example, a thickness of 25 μm of a PTFE layer as an inner layer and a thickness of 25 μm of a polyimide layer as an outer layer. The term “nylon tube” includes both tubes composed of nylon only and tubes composed mainly of nylon, and the term “PTFE tube” includes both tubes composed of PTFE only and tubes composed mainly of PTFE. In the present embodiment, the covering layer **20** is formed of a nylon tube.

[0053] In addition to the above, examples of the resin forming the covering layer **20** include fluorine-based resins other than PTFE, such as ETFE, silicone resins, polymethyl methacrylate resins, acrylic resins, epoxy resins, and polycarbonates. The refractive index of the resin forming the covering layer **20** is 1.35 for ETFE, 1.43 for silicone resin, 1.49 for polymethyl methacrylate resin, 1.50 for acrylic resin, 1.53 for nylon resin, 1.57 for epoxy resin, and 1.59 for polycarbonate. The refractive index of the covering layer **20** is preferably equal to or greater than the refractive index of the covering material of the optical transmission cable **10**. The refractive index of the covering layer **20** is preferably 1.53 or more. The refractive indexes are values obtained by a method in accordance with JIS K7142:2014.

Second Embodiment

[0054] Next, a light diffusion device **1**A according to a second embodiment will be described with reference to FIG. **4**. FIG. **4** is a sectional view schematically showing the light diffusion device **1**A according to the second embodiment. In the following description of the second embodiment, components corresponding to those of the first embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0055] The light diffusion device **1**A of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**A, and a covering layer **20**A. The light diffusion device **1**A according to the present embodiment differs from the light diffusion device **1** according to the first embodiment mainly in the features of the distal end part sides of the optical transmission cable and the covering layer.

[0056] The distal end part **11**A of the optical transmission cable **10**A is formed by cutting obliquely with respect to the axial direction X of the optical transmission cable **10**A. That is, an emission surface **12**A of the distal end part **11**A is inclined with respect to the axial direction X of the optical transmission cable **10**. Accordingly, as shown in FIG. **4**, laser light L emitted from the emission surface **12**A is emitted in a direction (in FIG. **4**, an obliquely upper right direction in the figure) inclined at a predetermined angle or more with respect to the axial direction X of the optical transmission cable **10**A.

[0057] The covering layer **20**A is formed of a cylindrical tube made of resin. A distal end part **21**A of the covering layer **20**A is formed by cutting the cylindrical tube obliquely with respect to the axial direction X of the optical transmission cable **10**A. That is, the distal end part **21**A is inclined with respect to the axial direction X of the optical transmission cable **10**A. Specifically, the distal end part **21**A of the covering layer **20**A is formed such that a part **211**A located on the side in the direction in which the laser light L is emitted (hereinafter, referred to as an emission side part) is located closest to the proximal end part side of the optical transmission cable **10**A and the distal end part **21**A extends in a direction away from the optical transmission cable **10**A in the axial direction X of the optical transmission cable **10**A as the distance from the emission side part **211**A increases. In other words, the distance d5 between the distal end part **21**A and the distal end part **11**A in the axial direction X of the optical transmission cable **10**A increases as the distance from the emission side part **211**A increases. That is, the distal end part **21**A is inclined in a direction opposite to the distal end part **11**A of the optical transmission cable **10**A. The covering layer **20** is formed at a position where at least the centers of the laser light L emitted from the emission surface **12**A do not overlap.

[0058] The emission side part **211**A of the distal end part **21**A of the covering layer **20**A protrudes by a required length Y for cutting the peripheral edge part of the laser light L in the direction in which the laser light L is emitted. In FIG. **4**, the required length Y indicates the distance d5 between the emission side part **211**A of the distal end part **21**A of the covering layer **20**A and the emission side part **211**A of the distal end part **11**A of the optical transmission cable **10**A in the axial direction

X of the optical transmission cable **10**A. The required length Y may be calculated by the above Equation (1).

Third Embodiment

[0059] Next, a light diffusion device **1**B according to a third embodiment will be described with reference to FIGS. **5** and **6**. FIG. **5** is a side view schematically showing an appearance of the light diffusion device **1**B according to the third embodiment. FIG. **6** is a sectional view schematically showing the light diffusion device **1**B according to the third embodiment. In the following description of the third embodiment, components corresponding to those of the first embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0060] The light diffusion device **1**B of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**, a covering layer **20**, a refractive member **30** as a reflective member, and a holding member **40**. The light diffusion device **1**B of the present embodiment mainly differs from that of the first embodiment in that it includes the refractive member **30** and the holding member **40** as a tubular member.

[0061] The refractive member **30** is a lens that refracts laser light L emitted from an emission surface **12** of the optical transmission cable **10**. The refractive member **30** is disposed to be spaced apart from a distal end part **11** in the axial direction X of the optical transmission cable **10**.

[0062] A refractive surface **31** is formed on the optical transmission cable **10** side of the refractive member **30**. The refractive surface **31** faces the emission surface **12** and is disposed so as to be inclined with respect to the axial direction X of the optical transmission cable **10**. As shown in FIG. **6**, the refractive surface **31** emits the laser light L emitted from the emission surface **12** at the distal end part **11** of the optical transmission cable **10** to the outside of the holding member **40** in a direction that is inclined at an angle of a predetermined angle or more with respect to the axial direction X of the optical transmission cable **10**.

[0063] The holding member **40** is a cylindrical tube. Both ends of the holding member **40** in the axial direction are sealed in a state in which the optical transmission cable **10**, the covering layer **20**, and the refractive member **30** are housed therein.

[0064] A window (not shown) through which the laser light L passes may be formed on the outer periphery of the holding member **40**. The window of the holding member **40** is formed at a position where the laser light L is emitted on the outer periphery of the holding member **40**. For example, the window may be an opening whose diameter is smaller than the outer diameter d1 of a core **13**, or may be a plurality of small holes. As a result, the peripheral edge part of the laser light L can be cut, and the laser light L having a more flat-topped light intensity distribution can be irradiated.

[0065] The optical transmission cable **10**, the covering layer **20**, and the refractive member **30** are fixed in the holding member **40** by, for example, setting the outer diameters or the widths thereof to be larger than the inner diameter of the holding member **40** and tightening them with a force directed radially inward by the holding member **40** (in a so-called interference fit state). The material of the holding member **40** preferably has a light transmittance of 50% or more. Examples of the material of the holding member **40** include acrylic resin and FEP (fluororesin formed by combining tetrafluoroethylene and hexafluoropropylene).

Fourth Embodiment

[0066] Next, a light diffusion device **1**C according to a fourth embodiment will be described with reference to FIGS. **7** and **8**. FIG. **7** schematically shows the light diffusion device **1**C according to the fourth embodiment, and is a side view of the light diffusion device **1**C that mainly irradiates the laser light L to the side. FIG. **8** schematically shows a light diffusion device **1**C according to the fourth embodiment, and is a side view of the light diffusion device **1**C that mainly irradiates the laser light L rearward. In FIGS. **7** and **8**, a tubular member **40**C is indicated by a two-dot chain line. In the following description of the fourth embodiment, components corresponding to those of the first embodiment are denoted by corresponding reference numerals based on the same conventions.

Their descriptions may be omitted or incorporated.
[0067] The light diffusion device **1**C of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**, a covering layer **20**, a rod-shaped member **30**C as a reflective member, and a tubular member **40**C. The light diffusion device **1**C of the present embodiment mainly differs from that of the first embodiment in that it includes the rod-shaped member **30**C and the tubular member **40**C.
[0068] The tubular member **40**C is a cylindrical tube made of resin. The term "tube made of resin" herein includes both tubes made of resin only and tubes made mainly of resin. The tubular member **40**C houses a part of the optical transmission cable **10**, the covering layer **20**, and the rod-shaped member **30**C therein. The tubular member **40**C is configured to be reducible in diameter. In the present embodiment, the optical transmission cable **10** is inserted into the tubular member **40**C such that at least a distal end part **11** side is located inside the tubular member **40**C. As shown in FIG. **7**, the optical transmission cable **10** is housed in the tubular member **40**C in a state of extending in the axial direction of the tubular member **40**C. The resin forming the tubular member **40**C preferably has a light transmittance of 50% or more. Examples of the resin forming the tubular member **40**C include polyimide, FEP (tetrafluoroethylene-hexafluoropropylene copolymer), and acrylic resin.
[0069] The rod-shaped member **30**C is made of quartz and is housed in the tubular member **40**C. The term "rod-shaped member **30**C made of quartz" herein includes both a rod-shaped member **30**C made of quartz only and a rod-shaped member **30**C mainly made of quartz. Specifically, the rod-shaped member **30**C is housed in the tubular member **40**C, extending in the axial direction of the tubular member **40**C and spaced apart from the optical transmission cable **10**. In the present embodiment, the rod-shaped member **30**C is disposed substantially coaxially with the optical transmission cable **10** in the tubular member **40**C. The rod-shaped member **30**C is entirely housed in the tubular member **40**C and is not exposed to the outside. The optical transmission cable **10** and the rod-shaped member **30**C are fixed in the tubular member **40**C by, for example, setting the outer diameters thereof to be larger than the inner diameter of the tubular member **40**C and tightening them with a force directed radially inward by the tubular member **40**C (in a so-called interference fit state). The rod-shaped member **30**C may be made of silicon. The term "rod-shaped member **30**C made of silicon" herein includes both a rod-shaped member **30**C made of silicon only and a rod-shaped member **30**C mainly made of silicon.
[0070] A refractive surface **31**C is formed at an end part of the rod-shaped member **30**C on the optical transmission cable **10** side. The refractive surface **31**C is an inclined surface made of quartz, formed by cutting the rod-shaped member **30**C obliquely with respect to the axial direction thereof. The term "refractive surface **31**C made of quartz" herein includes both a refractive surface **31**C made of quartz only and a refractive surface **31**C mainly made of quartz. The refractive surface **31**C faces an emission surface **12** in the tubular member **40**C and is disposed so as to be inclined with respect to the axial direction X of the optical transmission cable **10**. The refractive surface **31**C may be made of silicon. The term "refractive surface **31**C made of silicon" herein includes both a refractive surface **31**C made of silicon only and a refractive surface **31**C mainly made of silicon.
[0071] As shown in FIG. **7**, the refractive surface **31**C emits the laser light L emitted from the emission surface **12** at the distal end part **11** of the optical transmission cable **10** to the outside of the tubular member **40**C in a direction that is inclined at a predetermined angle or more with respect to the axial direction X of the optical transmission cable **10**. At this time, the laser light L having a flat-top light intensity distribution is irradiated by the distal end part **21** of the covering layer **20** protruding so as to cut the peripheral edge part of the laser light L in the direction in which the laser light L is emitted. For example, as shown in FIG. **7**, the refractive surface **31**C refracts each laser light L emitted in the axial direction X of the optical transmission cable **10** from a plurality of locations of the emission surface **12**, and emits the laser light L to the side of the

tubular member **40**C. For example, the laser light L having a flat-top light intensity distribution refracted through the refractive surface **31**C passes through the tubular member **40**C, is emitted in a direction inclined with respect to the insertion direction of the optical transmission cable **10**, and is irradiated onto cancer cells or the like present on the surface of an organ. Alternatively, for example, as shown in FIG. **8**, the inclination of the refractive surface **31**C may be set to be closer to the vertical direction with respect to the axial direction X of the optical transmission cable **10** than the refractive surface **31**C shown in FIG. **7**. With this configuration, as shown in FIG. **8**, the laser light L having a flat-top light intensity distribution can be irradiated rearward from the refractive surface **31**C.

[0072] As shown in FIG. **7**, the refractive surface **31**C of the present embodiment is formed in a planar shape as a whole. The unevenness of the refractive surface **31**C on which the laser light L is incident is preferably equal to or less than the wavelength of the laser light L generated from the laser oscillator. For example, by mirror-polishing the refractive surface **31**C, it is possible to realize an unevenness equal to or less than the wavelength of the laser light L. A metal **32** is vapor-deposited on the refractive surface **31**C of the present embodiment. Examples of the metal **32** vapor-deposited on the refractive surface **31**C include gold, silver, and aluminum.

[0073] As shown in FIG. **7**, the outer diameter d6 of the rod-shaped member **30**C is larger than the outer diameter d1 of the core of the optical transmission cable **10**. That is, the outer diameter of the refractive surface **31** viewed from the axial direction X of the optical transmission cable **10** is larger than the outer diameter d1 of the core. With this configuration, since the refractive surface **31**C that receives the laser light L emitted from the optical transmission cable **10** is larger than the emission surface **12**, it is possible to allow for misalignment of the position of the refractive surface **31**C with respect to the optical transmission cable **10**.

[0074] The refractive surface **31**C is disposed at a predetermined distance from the emission surface **12** in the tubular member **40**C. The distance between the emission surface **12** and the refractive surface **31**C is preferably in the range of 0.5 mm to 1 mm. A medium having a refractive index different from those of the emission surface **12** and the refractive surface **31**C exists between the emission surface **12** and the refractive surface **31**C. For example, in the present embodiment, only space **41** exists as the medium having a different refractive index between the emission surface **12** and the refractive surface **31**C. A lens or the like having a refractive index different from those of the emission surface **12** and the refractive surface **31**C and being in contact with both the emission surface **12** and the refractive surface **31**C may be interposed between the emission surface **12** and the refractive surface **31**C so as to fill the space **41**.

[0075] Here, in the photoimmunotherapy and the photodynamic therapy, since laser light having an output of about 0.5 W to 2.0 W is used, the amount of heat generated in the tubular member **40**C through which the laser light L from the optical transmission cable **10** passes is relatively small. Therefore, the heat resistance required for the member is relatively low, and as the material of the tubular member **40**C, a material made of a resin more excellent in biocompatibility can be used instead of metal, quartz, or the like. In the photoimmunotherapy and the photodynamic therapy, the optical transmission cable **10** that is a multimode fiber having a relatively large outer diameter d1 of the core **13** of about 500 μm is mainly used. Thus, even if heat sufficient to deform the resin is applied to the tubular member **40**C, causing a shift of several μm in the relative position between the emission surface **12** and the refractive surface **31**C, optical effects resulting from the shift in the relative position is unlikely to occur. Therefore, the light diffusion device **1** according to the present embodiment uses the tubular member **40**C made of resin suitable for use in photoimmunotherapy or photodynamic therapy.

Fifth Embodiment

[0076] Next, a light diffusion device **1**D according to a fifth embodiment will be described with reference to FIG. **9**. FIG. **9** is a side view schematically showing the light diffusion device according to the fifth embodiment. In FIG. **9**, a tubular member **40**D is indicated by a two-dot chain line. In the following description of the fifth embodiment, components corresponding to those of the fourth embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0077] The light diffusion device **1**D of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**, a covering layer **20**, a rod-shaped member **30**C as a reflective member, and a tubular member **40**D. The light diffusion device **1**D of the present embodiment mainly differs from that of the first embodiment in the configuration of the tubular member **40**D.

[0078] The tubular member **40**D has an opening **42** formed on the outer periphery thereof. Specifically, the opening **42** is formed in a part of the outer periphery of the tubular member **40**D that faces a refractive surface **31**C. With this configuration, since the tubular member **40**D is not present in the optical path of laser light L emitted from an emission surface **12** via the refractive surface **31**C, stronger laser light L can be irradiated to the outside without being transmitted through the tubular member **40**D.

Sixth Embodiment

[0079] Next, a light diffusion device **1**E according to a sixth embodiment will be described with reference to FIG. **10**. FIG. **10** is a side view showing the light diffusion device **1**E according to the sixth embodiment. FIG. **10** is a side view of the distal end part side of the light diffusion device **1**E in which the structure in the tubular member **40**E is also shown. In FIG. **10**, the tubular member **40**E is indicated by a two-dot chain line. In FIG. **10**, some lines are omitted to make the figure easy to see. In the following description of the sixth embodiment, components corresponding to those of the first embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0080] The light diffusion device **1**E of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**, a covering layer **20**, a rod-shaped member **30**E as a reflective member, and a tubular member **40**E. The light diffusion device **1**E of the present embodiment mainly differs from the light diffusion device **1**C of the fourth embodiment in the configuration of the rod-shaped member **30**E.

[0081] The rod-shaped member **30**E has a refractive surface **31**E formed at an end part thereof on the optical transmission cable **10** side. The shape of the refractive surface **31**E differs from that of the refractive surface **31**C of the rod-shaped member **30**C of the fourth embodiment. As shown in FIG. **10**, the refractive surface **31**E is formed in a curved surface shape that is concave with respect to an emission surface **12** of the optical transmission cable **10**. The curvature radius of the refractive surface **31**E is preferably 1200 μm. By adjusting the curvature radius of the refractive surface **31**E, laser light L emitted from the emission surface **12** can be condensed as well as diffused. For example, as shown in FIG. **10**, the laser light L emitted from the emission surface **12** can be uniformly emitted as a whole by the configuration of the curved refractive surface **31**E that is concave with respect to the emission surface **12**.

Seventh Embodiment

[0082] Next, a light diffusion device **1**F according to a seventh embodiment will be described with reference to FIG. **11**. FIG. **11** is a side view schematically showing the light diffusion device **1**F according to the seventh embodiment. FIG. **11** is a side view of the distal end part side of the light diffusion device **1**F in which the structure in a tubular member **40**F is also shown. In FIG. **11**, the tubular member **40**F is indicated by a two-dot chain line. In the following description of the seventh embodiment, components corresponding to those of the fourth embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0083] The light diffusion device **1**F of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**F, a covering layer **20**, a rod-shaped member **30**C, and a tubular member **40**F. The light diffusion device **1**F according to the present embodiment mainly differs from the light diffusion device **1**C according to the fourth embodiment in the configuration of a distal end part **11**F of the optical transmission cable **10**F.

[0084] An emission surface **12**F of the optical transmission cable **10**F of the present embodiment is formed by cutting the distal end part **11**F obliquely with respect to the axial direction X of the optical transmission cable **10**F. That is, the emission surface **12**F is inclined with respect to the axial direction X of the optical transmission cable **10**F. Accordingly, as shown in FIG. **11**, laser light L can be emitted from the emission surface **12**F while being further diffused. In the present embodiment, as shown in FIG. **11**, the emission surface **12**F is inclined with respect to the axial direction X of the optical transmission cable **10**F so as to face a refractive surface **31**C substantially in parallel. Accordingly, the optical transmission cable **10**F can be brought closer to the refractive surface **31**C, and the laser light L transmitted through the refractive surface **31**C without being refracted can be reduced.

Eighth Embodiment

[0085] Next, a light diffusion device **1**G according to an eighth embodiment will be described with reference to FIG. **12**. FIG. **12** is a side view showing an appearance of the distal end part side of the light diffusion device **1**G according to the eighth embodiment. FIG. **12** is a longitudinal sectional view of the distal end part side of the light diffusion device **1**G in which the structure in a tubular member **40**G is also shown. In the following description of the eighth embodiment, components corresponding to those of the fourth embodiment are denoted by corresponding reference numerals based on the same conventions. Their descriptions may be omitted or incorporated.

[0086] The light diffusion device **1**G of the present embodiment includes a laser oscillator (not shown), an optical transmission cable **10**, a covering layer **20**, a rod-shaped member **30**C, a tubular member **40**G, and an intervening member **50**. The light diffusion device **1**G of the present embodiment mainly differs from the light diffusion device **1**C of the fourth embodiment in that it further includes the intervening member **50** and in the configuration of the tubular member **40**G.

[0087] The tubular member **40**G of the present embodiment is a cylindrical tube made of resin. The tubular member **40**G differs from the tubular member **40**C of the fourth embodiment in that the inner diameter thereof is slightly smaller than the outer diameter of the rod-shaped member **30**C and larger than the outer diameter of the covering layer **20** covering the optical transmission cable **10**. The rod-shaped member **30**C is housed in the tubular member **40**G so that the outer peripheral surface thereof and the inner peripheral surface of the tubular member **40**G are in close contact with each other. On the other hand, the covering layer **20** is housed in the tubular member **40**G with a space between the outer peripheral surface of the covering layer **20** and the inner peripheral surface of the tubular member **40**G.

[0088] The intervening member **50** is made of a resin having a low refractive index. The intervening member **50** is disposed along the covering layer **20** in the tubular member **40**G, and fills the gap between the outer peripheral surface of the covering layer **20** and the inner peripheral surface of the tubular member **40**G. Examples of the resin forming the intervening member **50** include an acrylic resin. The intervening member **50** may be a layer that covers the outer peripheral surface of the covering layer **20**, or may be an adhesive that bonds the outer peripheral surface of the covering layer **20** and the inner peripheral surface of the tubular member **40**G.

EXAMPLES

[0089] Next, Examples of the present invention will be described. The present invention is not limited to the Examples.

<Method for Measuring Light Intensity Distribution>

[0090] In the Examples, the light intensity distribution of the laser light L emitted from the distal end part of the light transmission cable of the light diffusion device of each of Examples 1 and 2 and a comparative example was confirmed. The light intensity distribution of the laser light L was measured using a beam profiler (SP928, manufactured by Ophir Optronics). The light intensity distribution of the laser light L was obtained by measuring the intensity of the laser light L in a cross section (hereinafter, referred to as a cross section of the laser light L) obtained by cutting the laser light L along a plane orthogonal to the optical axis.

[0091] As Example 1, a light diffusion device having the same configuration as that of the light diffusion device **1** of the first embodiment was used. As the optical transmission cable of Example 1, an optical transmission cable having a core with an outer diameter of 500 μm and a cladding with a thickness of 25 μm was used. As the covering layer of Example 1, a nylon tube having a thickness of 50 μm was used. The nylon tube was disposed so as to extend 500 μm from the distal end part of the optical transmission cable **10** in the axial direction X of the optical transmission cable **10**.

[0092] In Example 2, a light diffusion device having the same configuration as that of Example 1 except for the type of the covering layer was used. In Example 2, a PTFE/polyimide tube was used instead of the nylon tube as the covering layer. The PTFE/polyimide tube used had a PTFE layer thickness of 25 μm and a polyimide tube layer thickness of 25 μm. The PTFE/polyimide tube was disposed so as to extend 500 μm from the distal end part of the optical transmission cable **10** in the axial direction X of the optical transmission cable **10**.

[0093] As a comparative example, a light diffusion device having the same configuration as that of Example 1 except that a covering layer was not provided was used. Used.

<Evaluation Results of Light Intensity Distribution>

[0094] The evaluation results will be described with reference to FIGS. **13** to **15**. FIG. **13** is a graph showing a light intensity distribution of laser light emitted from the distal end part of the optical transmission cable of the light diffusion device of Example 1. FIG. **14** is a graph showing a light intensity distribution in the case of using laser light emitted from the distal end part of the optical transmission cable of the light diffusion device of Example 2. FIG. **15** is a graph showing a light intensity distribution in the case of using laser light emitted from the distal end part of the optical transmission cable of the light diffusion device of the comparative example. In FIGS. **13** to **15**, the vertical axis indicates the light intensity, and the horizontal axis indicates the cross-sectional distance as the measurement position of the light intensity on the straight line passing through the center of the laser light L in the cross section of the laser light L. The light intensity on the vertical axis in FIGS. **13** to **15** is a standard value in which the maximum value of the measured light intensity is defined as 1, and is a moving average of the measured light intensity, that is, an average value of the light intensity measured within the measurement time. The cross-sectional distance on the horizontal axis in FIGS. **13** to **15** is a standard value in which one end of the measurement position on the straight line is set to 0 and the other end is set to 1. In FIGS. **13** to **15**, a range indicated by a solid-line double-sided arrow is a region in which the core exists on the optical transmission cable side in the optical axis direction of the laser light L (hereinafter, referred to as a core region), and a range indicated by a broken-line double-sided arrow is a region in which the core and the cladding exist on the optical transmission cable side in the optical axis direction of the laser light L.

[0095] As shown in FIG. **15**, in the comparative example, the variation in the light intensity of the laser light L in the core region exceeds 30%. Then, the light intensity gradually decreases and becomes lower as the distance from the center of the laser light L increases. In contrast, as shown in FIGS. **13** and **14**, in Examples 1 and 2, it can be confirmed that the variation in of the laser light L in the core region is suppressed to 20% or less on the distal end part side of the optical transmission cable. In the region where the cladding is present on the optical transmission cable side in the optical axis direction of the laser light L, the light intensity of the laser light L sharply decreases as the distance from the center of the laser light L increases. At the position corresponding to the outer periphery of the cladding, it can be confirmed that the light intensity is decreased by 80% or more compared to the light intensity at the center of the laser light L. That is, as shown in FIGS. **13** and **14**, it can be confirmed that the light intensity distributions of Examples 1 and 2 provided with a covering layer are more flat-topped than that of the comparative example

not provided with a covering layer.
[0096] According to the embodiments described above, the following effects are achieved.
[0097] The light diffusion devices **1** to **1**G for photoimmunotherapy or photodynamic therapy include the optical transmission cables **10**, **10**A, and **10**F configured to transmit the laser light L emitted from a laser oscillator and emit the transmitted light from the emission surfaces **12**, **12**A, and **12**F of the distal end parts **11**, **11**A, and **11**F; and the covering layers **20** and **20**A having at least one of a function of absorbing the laser light L or a function of scattering the light, the covering layers **20** and **20**A covering the optical transmission cables **10**, **10**A, and **10**F. The covering layers **20** and **20**A have distal end parts **21** and **21**A that protrude by a required length for cutting the peripheral edge part of the light, in a direction in which the light is emitted. Accordingly, since the laser light L emitted from the peripheral edge side of the distal end parts **11**, **11**A, and **11**F on the distal end parts **11**, **11**A, and **11**F sides of the optical transmission cables **10**, **10**A, and **10**F is removed by the covering layers **20** and **20**A and is reflected to the center side of the laser light L, it is possible to emit flat-top laser light L in which the center side of the laser light L is more uniform. Therefore, the light diffusion devices **1**A to **1**G that irradiate the laser light L with high therapeutic efficiency can be produced by simple processing of forming layers that cover the optical transmission cables **10**, **10**A, and **10**F.
[0098] In the light diffusion devices **1** to **1**G according to the above embodiments, the optical transmission cables **10**, **10**A, and **10**F each include a core **13** and a cladding **14** formed on the outer periphery of the core **13**. The required length Y is calculated by the following Equation (1):
[00003] $$Y = (1 / \mathrm{NA}^2 - 1)^{1/2} \times d2 \quad \text{Equation(1)}$$
where Y is the required length, NA is an aperture coefficient of the optical transmission cable, and d2 is the thickness of the cladding. As a result, light that spreads at a wider angle with respect to the optical axis of the laser light L than the spread angle θ of the laser light L can be cut, and light having a flat top light intensity distribution can be more reliably irradiated.
[0099] In the light diffusion device **1** according to the above embodiment, the optical transmission cable **10** includes the core **13** and the cladding **14** formed on the outer periphery of the core **13**. The cladding **14** has a thickness d2 of 1/10 or less of the outer diameter d1 of the core **13**. The covering layer **20** has a thickness d4 greater than that of the cladding **14**. Accordingly, it is possible to reduce the diameter of the optical transmission cable **10** while efficiently emitting the laser light L. Even when the cladding mode light leaks to the outside of the cladding **14**, since the cladding mode light is removed by the covering layer **20** and is reflected toward the center of the laser light L, more flat-topped laser light L can be emitted.
[0100] In the light diffusion devices **1**A and **1**F according to the above embodiments, the emission surfaces **12**A and **12**F of the optical transmission cables **10**A and **10**F are inclined with respect to the axial direction X of the optical transmission cables **10**A and **10**F. Accordingly, since the laser light L can be irradiated in a direction inclined with respect to the insertion direction of the optical transmission cables **10**A and **10**F, it is possible to efficiently irradiate the laser light L to cancer cells or the like present on the surface of a long and narrow organ in the human body.
[0101] In the light diffusion device **1** according to the above embodiment, the covering layer **20** has a refractive index equal to or greater than the refractive index of the covering material of the optical transmission cable **10**. Accordingly, the laser light L emitted from the peripheral edge side of the distal end part **11** can be more reliably absorbed or scattered by the covering layer **20** and reflected toward the center of the laser light L.
[0102] In the light diffusion device **1** according to the above embodiment, the covering layer **20** has a refractive index of 1.53 or more. Accordingly, the laser light L emitted from the peripheral edge side of the distal end part **11** can be more reliably absorbed or scattered by the covering layer **20** and reflected toward the center of the laser light L.
[0103] The light diffusion devices **1**B to **1**G according to the above embodiments further include

the refractive member **30** having the refractive surface **31**, **31**C, or **31**E that refracts light emitted from the emission surface **12** or **12**F, or the rod-shaped member **30**C or **30**E, and the holding member **40** or one of the tubular members **40**C to **40**G made of resin into which the optical transmission cable **10** or **10**F, and the refractive member **30** or the rod-shaped member **30**C or **30**E are inserted. The refractive surface **31**, **31**C, or **31**E is disposed at a predetermined distance from the emission surface **12** or **12**F in the holding member **40** or one of the tubular members **40**C to **40**G and is inclined with respect to the axial direction X of the optical transmission cable **10** or **10**F. The light emitted from the emission surface **12** or **12**F is emitted in a direction that is inclined at a predetermined angle or more with respect to the axial direction X of the optical transmission cable **10** or **10**F. Accordingly, flat-top laser light L emitted from the optical transmission cable **10** or **10**F can be efficiently irradiated in a direction inclined with respect to the insertion direction of the optical transmission cable **10** or **10**F via the refractive surface **31**C or **31**E. At the time of treatment by photoimmunotherapy or photodynamic therapy, the distal end part **11** or **11**F of the optical transmission cable **10** or **10**F and the refractive surface **31**C or **31**E located on the distal end part side of the light diffusion device **1** exposed to the outside from the endoscope are disposed in the holding member **40** or one of the tubular members **40**C to **40**G made of resin. Accordingly, since it is possible to prevent the relatively hard optical transmission cable **10** or **10**F and the refractive surface **31**C or **31**E made of quartz from coming into contact with organs in the body, biocompatibility is excellent. Further, in addition to the biocompatibility, the degree of freedom of material selection is excellent to meet the needs of device users in terms of cost, operability, etc.

[0104] In the light diffusion devices **1**B to **1**G according to the above embodiments, the refractive member **30** and the rod-shaped members **30**C and **30**E each are a refractive member **30** or a rod-shaped member **30**C or **30**E made of quartz or silicon and are spaced apart from the optical transmission cable **10** or **10**F in the holding member **40** or one of the tubular members **40**C to **40**G. The refractive surface **31**, **31**C, or **31**E is formed on an end part of the refractive member **30** or the rod-shaped member **30**C or **30**E on a side adjacent to the optical transmission cable **10** or **10**F. This allows the light diffusion device **1** to be produced more easily.

[0105] In the light diffusion devices **1**B to **1**G according to the above embodiments, the refractive surfaces **31**, **31**C, and **31**E include vapor-deposited metals. This allows light to be refracted more efficiently.

[0106] In the light diffusion devices **1**B to **1**G according to the above embodiments, the optical transmission cables **10** and **10**F each are a plastic fiber including the core **13** having an outer diameter of 500 μm or more, and the cladding **14** made of resin and formed on the outer periphery of the core **13**. The outer diameters of the refractive surfaces **31**, **31**C, and **31**E viewed from the axial direction X of the optical transmission cables **10** and **10**F are larger than the outer diameter of the core **13**. Accordingly, since the outer diameters of the refractive surfaces **31**, **31**C, and **31**E are larger than the outer diameter d1 of the core **13**, it is possible to improve the tolerance for misalignment of the relative positions of the refractive surfaces **31**, **31**C, and **31**E with respect to the optical transmission cables **10** and **10**F.

[0107] In the light diffusion devices **1**B to **1**G according to the above embodiments, the unevenness of the refractive surfaces **31**, **31**C, and **31**E on which the light is incident is equal to or less than the wavelength of the light generated from the light source. Accordingly, since the unevenness of the refractive surfaces **31**, **31**C, and **31**E on which the laser light L is incident is small, it is possible to suppress heat generation by the laser light L on the refractive surfaces **31**, **31**C, and **31**E at the time of irradiation.

[0108] In the light diffusion devices **1**B to **1**G according to the above embodiments, the refractive surfaces **31**, **31**C, and **31**E are formed in a curved surface shape that is concave with respect to the emission surfaces **12** and **12**F. Accordingly, since the emission surfaces **12** and **12**F of the optical transmission cables **10** and **10**F are inclined obliquely, the light emitted from the optical transmission cables **10** and **10**F can be further diffused.

[0109] Although the embodiments of the present invention have been described above, the present invention is not limited to the above-described embodiments and can be modified as appropriate.
[0110] In the above embodiments, the optical transmission cables **10** and **10**A include the cladding **14** formed on the outer periphery of the core **13**, however, a configuration without the cladding **14** may also be used.
EXPLANATION OF REFERENCE NUMERALS
[0111] **1**, **1**A, **1**B, **1**C, **1**D, **1**E, **1**F, **1**G light diffusion device [0112] **10**, **10**A, **10**F optical transmission cable [0113] **11**, **11**A, **11**F distal end part [0114] **13** core [0115] **14** cladding [0116] **20**, **20**A covering layer [0117] **21**, **21**A distal end part

Claims

1. A light diffusion device for photoimmunotherapy or photodynamic therapy, the light diffusion device comprising: an optical transmission cable configured to transmit light emitted from a light source and emit the transmitted light from an emission surface of a distal end part; and a covering layer having at least one of a function of absorbing the light or a function of scattering the light, the covering layer covering the optical transmission cable, wherein the covering layer has a distal end part that protrudes by a required length for cutting a peripheral edge part of the light, in a direction in which the light is emitted.
2. The light diffusion device according to claim 1, wherein the optical transmission cable comprises a core and a cladding formed on an outer periphery of the core, and wherein the required length is calculated by the following Equation (1): $Y = (1/\mathrm{NA}^2 - 1)^{1/2} \times d2 \quad \text{Equation(1)}$ wherein Y is the required length, NA is an aperture coefficient of the optical transmission cable, and d2 is a thickness of the cladding.
3. The light diffusion device according to claim 1, wherein the optical transmission cable comprises a core and a cladding formed on an outer periphery of the core, wherein the cladding has a thickness of 1/10 or less of an outer diameter of the core, and wherein the covering layer has a thickness greater than that of the cladding.
4. The light diffusion device according to claim 1, wherein the emission surface of the optical transmission cable is inclined with respect to an axial direction of the optical transmission cable.
5. The light diffusion device according to claim 1, wherein the covering layer has a refractive index equal to or greater than a refractive index of a covering material of the optical transmission cable.
6. The light diffusion device according to claim 1, wherein the covering layer has a refractive index of 1.53 or more.
7. The light diffusion device according to claim 1, further comprising: a reflective member having a refractive surface that refracts the light emitted from the emission surface; and a tubular member made of resin into which the optical transmission cable and the reflective member are inserted, wherein the refractive surface is disposed at a predetermined distance from the emission surface in the tubular member and is inclined with respect to an axial direction of the optical transmission cable, and the light emitted from the emission surface is emitted in a direction that is inclined at a predetermined angle or more with respect to the axial direction of the optical transmission cable.
8. The light diffusion device according to claim 7, wherein the reflective member is a rod-shaped member made of quartz or silicon and is spaced apart from the optical transmission cable in the tubular member, and wherein the refractive surface is formed on an end part of the rod-shaped member on a side adjacent to the optical transmission cable.
9. The light diffusion device according to claim 7, wherein the refractive surface comprises a vapor-deposited metal.
10. The light diffusion device according to claim 7, wherein the optical transmission cable is a plastic fiber comprising a core having an outer diameter of 500 μm or more, and a cladding made

of resin and formed on an outer periphery of the core, and wherein an outer diameter of the refractive surface viewed from the axial direction of the optical transmission cable is larger than the outer diameter of the core.

11. The light diffusion device according to claim 7, wherein an unevenness of the refractive surface on which the light is incident is equal to or less than a wavelength of the light generated from the light source.

12. The light diffusion device according to claim 7, wherein the refractive surface is formed in a curved surface shape that is concave with respect to the emission surface.