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(54) MULTIPURPOSE DIODE LASER SYSTEM FOR OPHTHALMIC LASER TREATMENTS

(75) Inventors: **Wolfgang Neuberger**, F.T. Labuan (MY); **Detlev Berndt**, Koln (DE); **Julian Maughan**, Salisbury (GB)

Correspondence Address:
BOLESH J. SKUTNIK PhD, JD
515 Shaker Road
East Longmeadow, MA 01028 (US)

(73) Assignee: **CeramOptec Industries Inc.**

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(57) **ABSTRACT**

A laser device and method for treating ophthalmic diseases is enclosed. The device comprises a system for irradiating the eye with electromagnetic irradiation with a wavelength in the range of 654-681 nm. The system preferably comprises a laser source and ancillary equipment to direct and regulate the radiation. The use of this wavelength range makes the device effective for a wide variety of ophthalmic indications. It is capable of providing photocoagulation treatments for diseases such as glaucoma, diabetic retinopathy and age-related macular degeneration. The system is also useful for photodynamic therapy. Also disclosed are laser diodes with high beam quality and slit lamp adaptors to further enhance the versatility of the system.

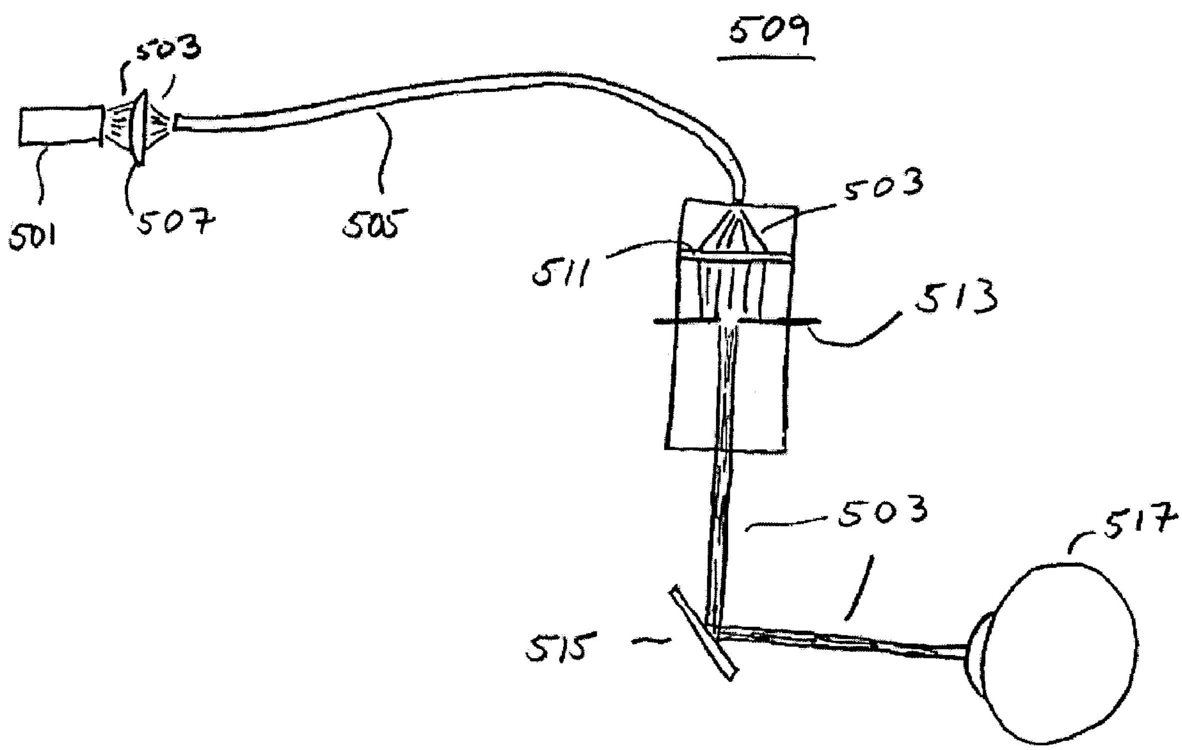


FIGURE 1

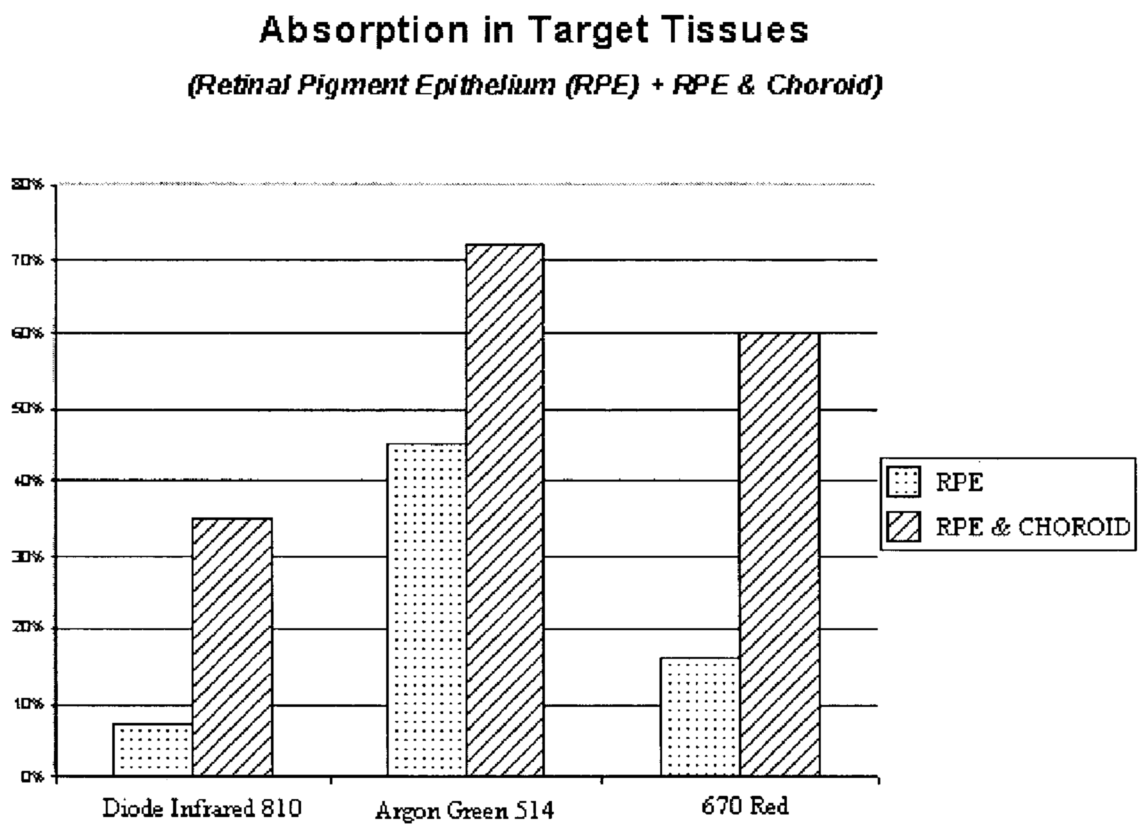

Absorption in Target Tissues
(Retinal Pigment Epithelium (RPE) + RPE & Choroid)
80%
70%
60%
50%
40%
30%
20%
10%
0%
Diode Infrared 810
Argon Green 514
670 Red
RPE
RPE & CHOROID

FIGURE 2

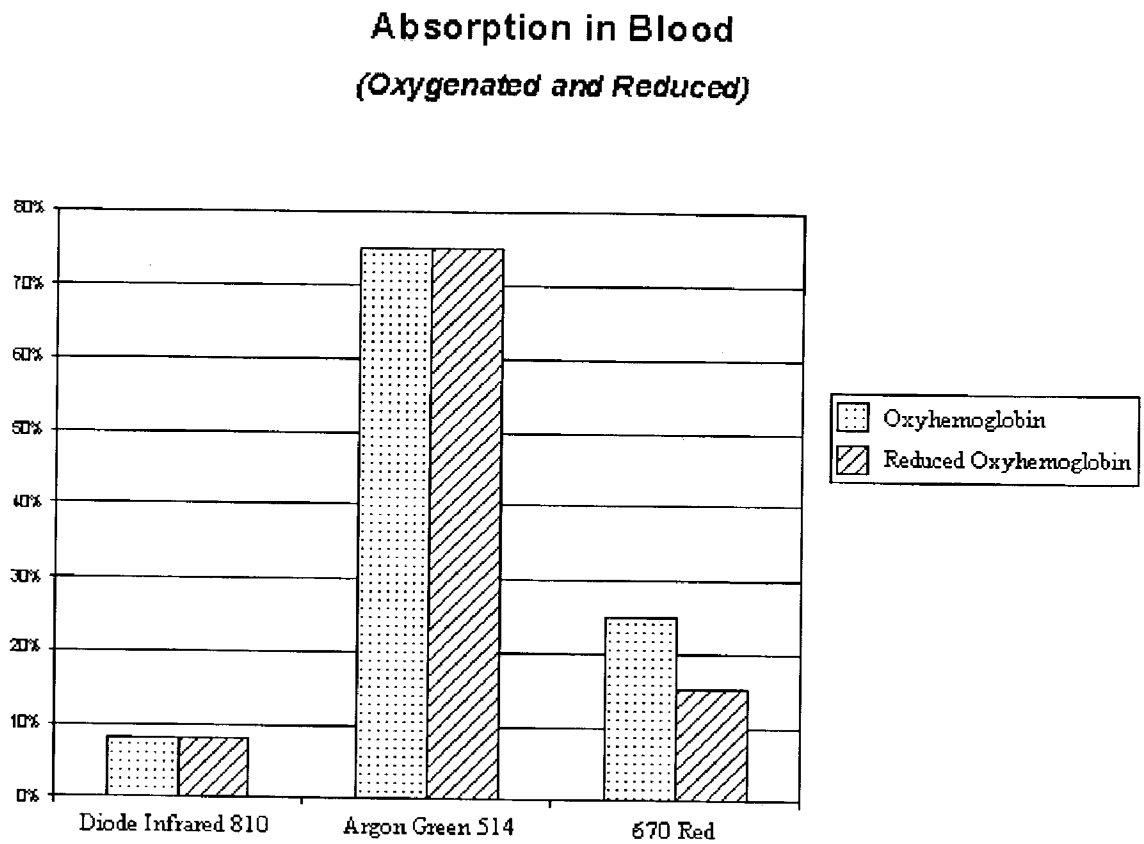

Absorption in Blood
(Oxygenated and Reduced)
80%
70%
60%
50%
40%
30%
20%
10%
0%
Diode Infrared 810
Argon Green 514
670 Red
Oxyhemoglobin
Reduced Oxyhemoglobin

FIGURE 3

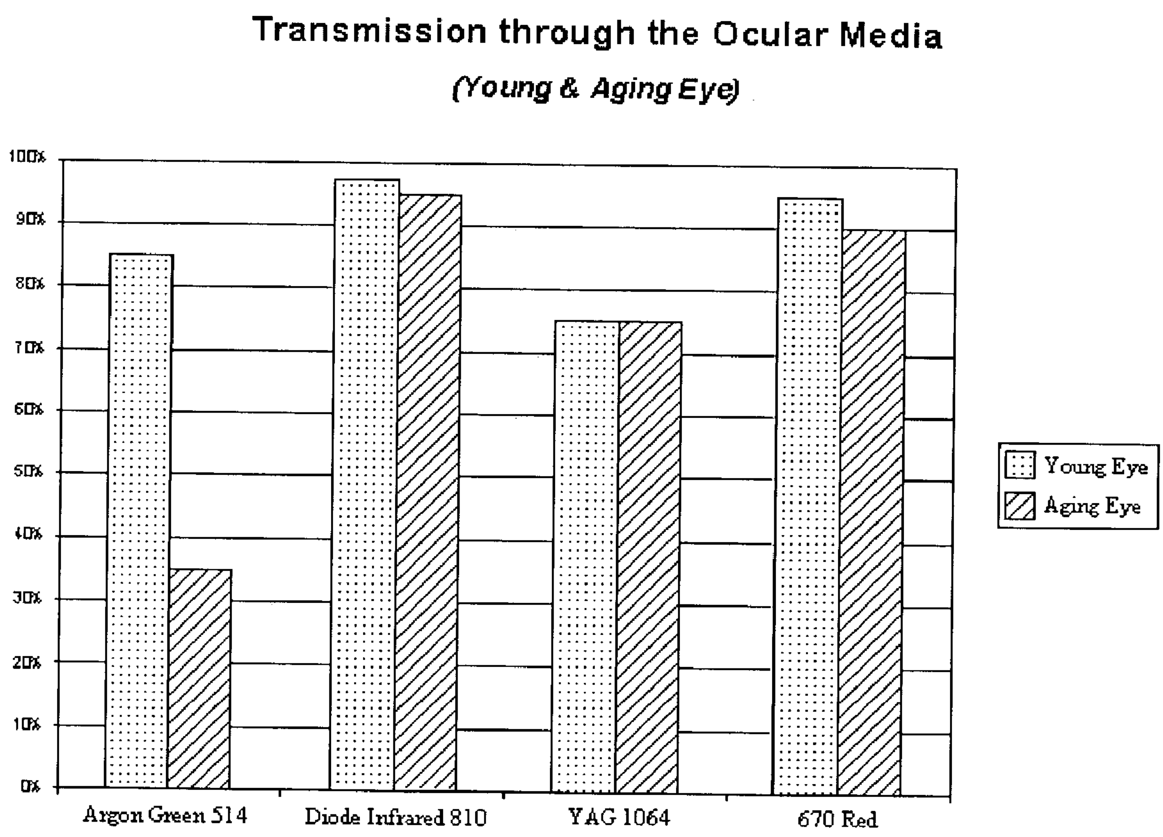

Transmission through the Ocular Media
(Young & Aging Eye)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Argon Green 514
Diode Infrared 810
YAG 1064
670 Red
Young Eye
Aging Eye

FIGURE 4

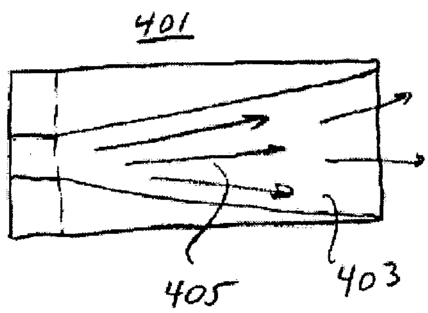
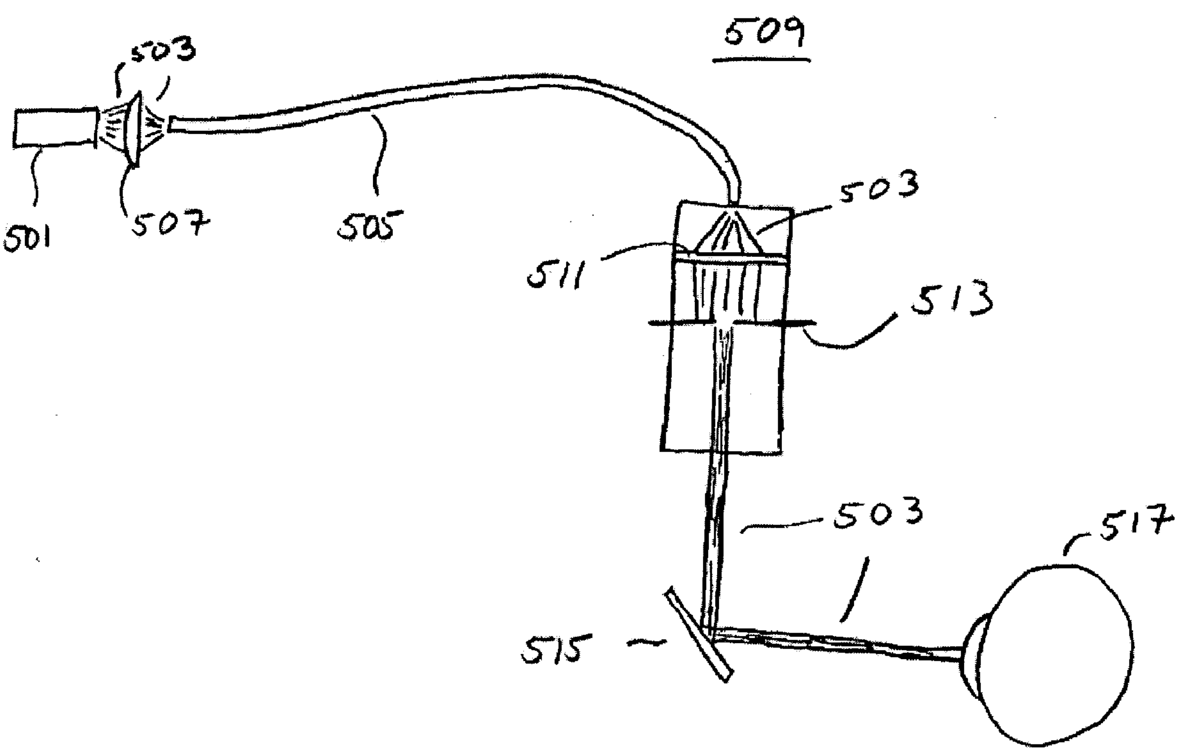


FIGURE 5



MULTIPURPOSE DIODE LASER SYSTEM FOR OPHTHALMIC LASER TREATMENTS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The invention relates to ophthalmic laser treatments, particularly to devices and systems capable of performing multiple ophthalmic photocoagulation treatments.

[0003] 2. Information Disclosure Statement

[0004] Ophthalmic laser treatments comprise a variety of modalities to combat different diseases or indications. Ion or dye lasers, such as Argon and Krypton lasers, have been preferred because the wavelengths they produce (488 or 514 nm for Argon, 648 nm for Krypton) are effective in various photocoagulation procedures. For example, wavelengths produced by Argon lasers are well absorbed in hemoglobin and thus are effective for coagulating hyperproliferating or leaking blood vessels that can occur in diabetic patients, among others. (see U.S. Pat. No. 5,147,349) Retinal photocoagulation has also been performed with the Nd:YAG laser (1064 nm) and the 810 nm diode laser. (see U.S. Pat. No. 5,688,264)

[0005] U.S. Pat. No. 5,295,989 describes a light cable in an apparatus for ophthalmic treatment consisting of a plurality of optical fibers. A preferred embodiment utilizes an Argon laser beam as a treatment light source.

[0006] Many of the current photocoagulators are of an inconveniently and inefficiently high cost, size and complexity. For example, conventional Krypton and Argon lasers are capable of emitting sufficient power levels for photocoagulation but are bulky, technically complex, and are inefficient "(below 0.1%) requiring up to 40 kW of three phase power and associated water cooling" to remove excess heat. (see U.S. Pat. No. 4,917,486) Thus, these setups are expensive and often require fixed installations.

[0007] The advantages of using a laser diode over other laser sources are espoused in U.S. Pat. No. 4,917,486, which describes the laser diode as having a relatively low cost (around 10-20%) compared to an Argon laser, high efficiency of around 30% providing sufficient output power with a low amount of electrical input, lack of need for water cooling and smaller size. U.S. Pat. No. 4,917,486 uses infrared light preferably at a wavelength of substantially 800 nm, which is longer than Kr or Ar wavelengths, and preferably emitted by a laser diode.

[0008] U.S. Pat. No. 5,442,487 also discloses a photocoagulation apparatus that focuses emission radiation from a high power laser diode for use in ophthalmic photocoagulation procedures. Preferred diodes are GaAlAs laser diodes emitting radiation with a wavelength of approximately 800 nm. An additional He—Ne laser emitting visible radiation having a wavelength of 633 nm is also provided for aiming purposes.

[0009] Other photocoagulation treatment methods include the use of probes for insertion into the eye prior to irradiation, the use of photosensitive substances in conjunction with radiation (photodynamic therapy), and the use of two or more radiation sources simultaneously or during a single treatment to enhance treatment efficacy. Examples of these are described below.

[0010] U.S. Pat. No. 5,147,349 discloses a device and method for retinal transcutaneous laser photocoagulation using a diode laser coupled to an optical fiber. The method involves creating an incision in the eye and inserting an endoprobe for irradiation. One embodiment utilizes a diode laser with a wavelength in the range of 700-840 nm. Another embodiment utilizes radiation with a wavelength in the range of 600-700 nm, typically 685 nm or less. This patent is limited to transcutaneous photocoagulation procedures, wherein radiation is applied after insertion of an endoprobe.

[0011] U.S. Pat. No. 6,110,165 discloses an apparatus that combines a wavelength longer than 600 nm and a wavelength shorter than 600 nm. An example of a longer wavelength is a semiconductor laser of 670 nm. In one embodiment, a Krypton laser emits the longer wavelength, and an Argon laser emits the shorter wavelength. This patent purports to provide an improved method of treating a retinal separation by coagulation through the intraretinal layer, retinal pigment epithelium and choroidal layer by using a plurality of wavelengths to coagulate different depths with a single device. The use of the 670 nm laser is provided only in conjunction with another beam wavelength. The invention does not disclose the use of this wavelength individually to treat ophthalmic diseases, and appears to be primarily for treating retinal detachment.

[0012] U.S. Pat. No. 6,471,691 discloses photodynamic therapy for treatment of neovascularization. Among the preferred radiation wavelengths is 670 nm for procuring an image of the fundus and for activating a photosensitive substance. This invention is limited to the use of photosensitive substances in conjunction with laser light, and thus does not disclose devices or methods for photocoagulation exclusively with radiation.

[0013] U.S. Pat. No. 5,300,062 describes a photocoagulation device featuring two semiconductor laser sources that are combined and delivered to the eye for performing treatments such as transcleral cyclophotocoagulation for glaucoma. Each semiconductor source, in one embodiment, emits a wavelength of 845 nm. In another embodiment, a main beam of 810 nm and a guide beam of 632.8 nm are guided through an optical fiber to a treatment site.

[0014] Another device is described in U.S. Pat. No. 5,892, 569, which features a scanning laser ophthalmoscope equipped with external laser sources for retinal microphotocoagulation. By selecting certain wavelengths and pulse durations, selective targeting of the photoreceptor layer or the retinal pigment epithelium layer can be achieved. In one embodiment, light consisting of a merger of 633 nm light, emitted by a He—Ne laser, and 792 nm light, emitted by a diode, is focused onto the eye. In another embodiment, a first therapeutic laser beam, such as an Argon or diode laser emitting such wavelengths as 488, 514, 532, 810 and 1064 nm, is coupled with a 630-670 nm laser for aiming purposes.

[0015] U.S. Pat. No. 5,688,264 provides an optical fiber probe and method of photocoagulation for producing chorioretinal adhesion to treat retinal detachment. Two or more laser sources are connected to a fiber optic probe. A third laser beam of a visible wavelength such as 670 nm may be used to facilitate aiming during surgery. This invention is limited to treating retinal detachment and requires insertion of a probe prior to irradiation.

[0016] Ophthalmic treatment systems have been proposed that are capable of performing different types of treatments with a single system or device. However, these systems utilize the ability to apply radiation of different wavelengths to achieve different results. A system that can perform multiple treatment types with a single wavelength range has not been disclosed.

[0017] Recent commercial announcements describe a new multi-laser photocoagulation laser system for treating a range of retinal diseases. The system provides a spectrum of green, yellow and red light in a single device and is claimed to be useful for age-related macular degeneration, diabetic retinopathy, diabetic macular edema and other diseases.

[0018] Likewise, U.S. Pat. No. 5,331,649 discloses a system for producing different wavelengths often needed in ophthalmic treatments. This is a system for generating a plurality of wavelengths of light in a single apparatus

[0019] U.S. Pat. No. 5,423,798 describes a system for performing laser vitrectomy and endophotocoagulation within a single system to avoid the need to change devices between the two treatments. Two wavelengths can be applied through the same fiberoptic delivery apparatus. The first wavelength for photoablation operates at about the 2.94 micron region, and the second wavelength for photocoagulation operates at about 800 nm. The first photoablative laser comprises an Er:YAG crystal and the second photocoagulative laser is a semiconductor laser diode array.

[0020] U.S. Pat. No. 5,144,630 describes a wavelength conversion system for use in ophthalmic surgery. The system switches between a plurality of nonlinear crystals to allow for applying radiation with a wavelength range from ultraviolet to infrared and large enough to replace the need for the use of many traditional laser for a variety of treatments. The ability to switch wavelengths allows one to treat a variety of conditions with one system.

[0021] The above patents illustrate the current state of the art with respect to ophthalmic, and especially photocoagulative, laser surgery. Different wavelengths are known to affect various tissue types differently, and thus different wavelengths are thought to be more effective for different treatments. It would be extremely useful to provide a laser system operating at a wavelength that is effective for a variety of photocoagulative treatments. The present invention addresses this need.

OBJECTIVES AND BRIEF SUMMARY OF THE INVENTION

[0022] It is an object of the present invention to provide a laser device and method for treating a variety of ophthalmic diseases with a single device or system.

[0023] It is another object of the present invention to provide a device and method for photocoagulation of the eye that is capable of treating a larger number of ophthalmic diseases than any singular prior art device or method.

[0024] It is yet another object of the present invention to provide a device and method for treating ophthalmic diseases that is more convenient and economical than prior art devices and methods.

[0025] Briefly stated, the present invention describes a laser device and method for treating a variety of ophthalmic diseases. The invention comprises a system for irradiating the eye with electromagnetic irradiation with a wavelength in the range of 654-681 nm. The system preferably comprises a laser source and ancillary equipment to direct and regulate the radiation. The use of this wavelength range makes the present invention effective for a wide variety of ophthalmic indications. It is capable of providing photocoagulation treatments for diseases such as glaucoma, diabetic retinopathy and age-related macular degeneration. The system is also useful for photodynamic therapy.

[0026] Also disclosed are laser diodes with high beam quality and slit lamp adaptors to further enhance the versatility of the system.

[0027] "The above, and other objects, features and advantages of the present invention will become apparent from the following description read in conjunction with the accompanying drawings, (in which like reference numbers in different drawings designate the same elements.)"

BRIEF DESCRIPTION OF FIGURES

[0028] **FIG. 1**—Graph of absorption characteristics of various wavelengths in ocular tissue.

[0029] **FIG. 2**—Graph of absorption characteristics of various wavelengths in blood.

[0030] **FIG. 3**—Graph of transmission of various wavelengths through the ocular media.

[0031] **FIG. 4**—Illustration of a preferred high power diode laser.

[0032] **FIG. 5**—Illustration of a preferred embodiment of a treatment device utilizing a slit-lamp adaptor.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0033] It has been found that a diode laser operating at a wavelength in the range of 654-681 nm has similar properties in ocular tissues to a number of laser wavelengths that are currently used to treat a variety of ophthalmic diseases.

[0034] The present invention contains many of the treatment properties of various wavelengths used for photocoagulation in the prior art, and has the additional advantage of being able to exhibit these properties with a single wavelength range and consequentially a single device. It can perform a number of different photocoagulation procedures that previously would have required numerous devices or a device capable of emitting various wavelengths, as well as photodynamic therapy for diseases such as age-related macular degeneration. A medical professional can now treat these and other diseases more conveniently and inexpensively than was possible in the prior art. Because the present invention is capable of performing numerous treatments with a single wavelength, a practitioner can now avoid having to buy a number of devices to treat the range of indications that the present invention can treat with a single device.

[0035] The 668 nm laser (which emits at 668 nm+/−20% equaling 654-681, nominally 670 nm) utilized in the present invention emits in the red part of the spectrum. The absorption characteristics of this laser are very similar to those of the 647 nm red krypton laser. Also, the 670 nm laser has transmission qualities that are very similar to those of the near infrared 810 nm diode laser and has an excellent curve that is minimally influenced by opacities and is very similar to the transmission of the near infrared 810 nm diode laser.

[0036] The 670 nm laser has excellent properties for laser photocoagulation of the fundus. It is sufficiently absorbed by the melanin of the retina and choroid and it is relatively minimally absorbed by blood and media opacities. Therefore, retinal whitening is obtained very easily and no learning curve is needed as for the near infrared diode laser, and irradiation can pass through cataracts, vitreous opacities and hemorrhages.

[0037] The similar properties of the 670 nm diode laser and 810 nm diode laser are illustrated in the accompanying figures. **FIG. 1** shows similar absorption properties of both the 670 nm and 810 nm lasers in the retinal pigment epithelium and choroid. **FIG. 2** illustrates that, like the 810 nm laser, 670 nm radiation of the present invention is relatively minimally absorbed in blood. Finally, **FIG. 3** demonstrates similar transmission properties of the 670 nm and 810 nm lasers in the ocular media.

[0038] The present invention is useful for a number of ophthalmic indications that previously would have required different wavelengths and thus numerous laser devices or much more complex multi-laser devices. It is especially effective for those procedures that have previously utilized a Krypton, Argon, or 810 nm diode laser. The following is a brief description of many of the ophthalmic diseases that the present invention can effectively treat and the treatment modalities for which the present invention is effective.

[0039] Diabetic retinopathy is characterized by retinal dot and blot hemorrhages, microaneurysms and exudates in early stages. Proliferative diabetic retinopathy, a late stage of the disease, is characterized by neovascularization and vitreous or pre-retinal hemorrhages. Photocoagulative treatments can successfully treat the problem. In particular, pan-retinal photocoagulation is effective for causing regression of neovascular tissues.

[0040] Glaucoma has recently been treated with a procedure known as transscleral cyclophotocoagulation, which consists of treating the ciliary body of the eye to decrease production of aqueous fluid which reduces pressure in the eye. Nd:YAG and thalmium:YAG lasers have been used with this procedure. 810 nm diode lasers have also been recognized as an effective laser for this procedure. The 810 nm diode laser is characterized by good penetration and selective absorption by the pigmented tissues of the ciliary body, which makes it an effective wavelength for this procedure. The present invention can be successfully utilized with this procedure.

[0041] The present invention can also be utilized as a photocoagulator for treating retinal vein occlusion, rhegmatogenous peripheral retinal lesions and retinal breaks and for prophylactic peripheral retinopexy prior to silicone oil removal.

[0042] The 670 nm diode laser is effective for laser treatments requiring endo-probe delivery via an incision in the eye, transcleral delivery and transpupillary delivery.

[0043] Other retinal photocoagulation treatments include transpupillary retinal photocoagulation, retinal endophotocoagulation and cyclophotocoagulation. It is generally accepted that retinal photocoagulation treatments are effective with the use of laser radiation near 800 nm.

[0044] The present invention is also useful as a tool in treatments such as photodynamic therapy for age-related macular degeneration (AMD), transpupillary thermotherapy (TTT) for AMD and choroidal melanomas, and for ophthalmic veterinary applications.

[0045] The procedures and wavelength specifications described above have been employed in the prior art for the described indications. Because the 670 nm wavelength of the present invention features the superior penetration qualities of the near infrared wavelengths, and the absorption characteristics of red wavelengths, particularly the 647 nm wavelength, the present invention can be used to effectively treat the indications described above with a single treatment system, thus greatly reducing the complexity and expense of procuring the capability to treat such a variety of indications.

[0046] Additional benefits of the present invention, apart from its evident versatility, include power on demand (true delivery of the called-for energy upon activation), delivery of a true square pulse of energy without spikes or peaks occurring throughout the pulse cycle, and the benefits inherent in a diode system. As described above, these benefits include high efficiency and thus lower power requirements, and longer life due to reduced need for maintenance.

[0047] In a preferred embodiment, the present invention incorporates a device comprising a laser source emitting in the wavelength range of 668 nm+/−20%, nominally 670 nm, suitable optics to focus and direct a treatment beam into a treatment area, an illuminator such as a slit lamp, and means for observing the treatment area. Many optical treatment devices known in the art may be used. The source for providing the above radiation is preferably a diode laser or diode laser array.

[0048] A further object of the present invention includes new diode laser designs providing high beam quality and thus the ability to couple with very thin optical fibers (such as 50 um core or even 20 um core, with 0.1 N.A.), which can be coupled to slit lamp adaptors to provide superior quality beams that can have a long focal length. The ability to produce such small and high quality beams allows for even greater versatility of the present invention. Treatments for which such beam would be useful include micro photocoagulation in the region of the macula and optic disc and minimally destructive procedures in the region of the ciliary body for glaucoma treatments. This aspect of the present invention would also be advantageous for transpupillary applications in small pupils where beam clipping of larger spot sizes can decrease power density to ineffective levels. A smaller spot diameter would also be desirable in the treatment of Retinopathy of Prematurity (RoP), which is an increasing condition owing to improved mortality rates of premature babies and if left untreated always leads to blindness.

[0049] In a preferred embodiment, "bow-tie" or trapezoidal diode lasers emitting near single mode radiation with a wavelength of 670 nm are used to produce a high quality beam. The diode lasers have a flared, highly diverging region that is in the shape of a trapezoid or a "bow-tie". The beam is then coupled to an oligimode optical fiber with suitable optics such as step-mirrors so as to preserve beam quality during coupling. For delivery of the treatment radiation to the eye, the optical fiber is coupled to a slit lamp adaptor. The slit lamp adaptor determines the spot sizes and includes attenuation means that effectively attenuate the power received from the laser source. Thus a monotonic relationship between the spot diameter and the laser power administered is easily achieved. Preferably the attenuation means is chosen such that the intensity of the beam is independent of the spot size. In a preferred embodiment, the attenuation means is in the form of an iris whose aperture is varied in accordance with the movement of a selection ring to select a beam spot size. In another embodiment, the attenuation means is an attenuator disc rotated in accordance with selection ring at a suitable point in the optical path. In this manner the laser unit itself can be simplified to only produce a constant power output, and if this is desirable, only the time of irradiation needs to be varied to achieve different treatment dosages. Other embodiments may include adaptors to indirect opthalmoscopes or may include a slit lamp that has already included in its structure the spot size selection mechanism as described above.

[0050] FIGS. **4-5** illustrate a preferred embodiment of a treatment system according to the present invention. The system consists of a diode laser emitting 670 nm radiation, which is shown in **FIG. 4**. Diode laser **401** has tapered gain region **403** for producing a high quality beam from radiation **405**. As shown in **FIG. 5**, radiation **503** emitted from diode laser **501** is coupled into low-mode optical fiber **505** by means of focusing optics **507**. Optical fiber **505** delivers radiation **503** to slit-lamp **509** for delivery of a beam of radiation **503** with a spot size that is controllable without changing power density. Slit-lamp **509** consists of collimating optics **511** for collimating beam **503**, adjustable iris **513** for adjusting beam spot size, and mirror **515** to direct beam **503** to eye **517**.

[0051] Having described preferred embodiments of the invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to the precise embodiments, and that various changes and modifications may be effected therein by those skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

What is claimed is:

1. An ophthalmic laser treatment device comprising:

a radiation source emitting radiation having a wavelength of 668 nm+/−20%;

means to direct said radiation to a treatment area in an eye; and

means to couple said radiation to said directing means.

2. The ophthalmic laser treatment device according to claim 1, wherein said radiation source is a high power diode laser.

3. The ophthalmic laser treatment device according to claim 2, wherein said diode laser contains a light diverging gain region selected from a group consisting of a trapezoidal shaped region and a "bow-tie" shaped region.

4. The ophthalmic laser treatment device according to claim 1, wherein said coupling means is an optical fiber.

5. The ophthalmic laser treatment device according to claim 4, wherein said optical fiber is an oligimode fiber.

6. The ophthalmic laser treatment device according to claim 4, wherein a core of said optical fiber has a diameter not greater than 50 microns.

7. The ophthalmic laser treatment device according to claim 1, wherein said directing means is selected from a group consisting of a focusing lens system, a handpiece, and a slit lamp adaptor.

8. A method for ophthalmic laser treatment comprising the steps of

determining treatment parameters;

directing radiation having a wavelength of 668 nm+/−20% to a treatment area of an eye using said determined treatment parameters; and

irradiating said treatment area of an eye with said radiation.

9. The method according to claim 8, wherein said step of directing said radiation is accomplished by providing entry of said radiation to said treatment area transsclerally or transpupillarily.

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