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(54) **SYSTEM AND METHOD FOR GENERATING TREATMENT PATTERNS**

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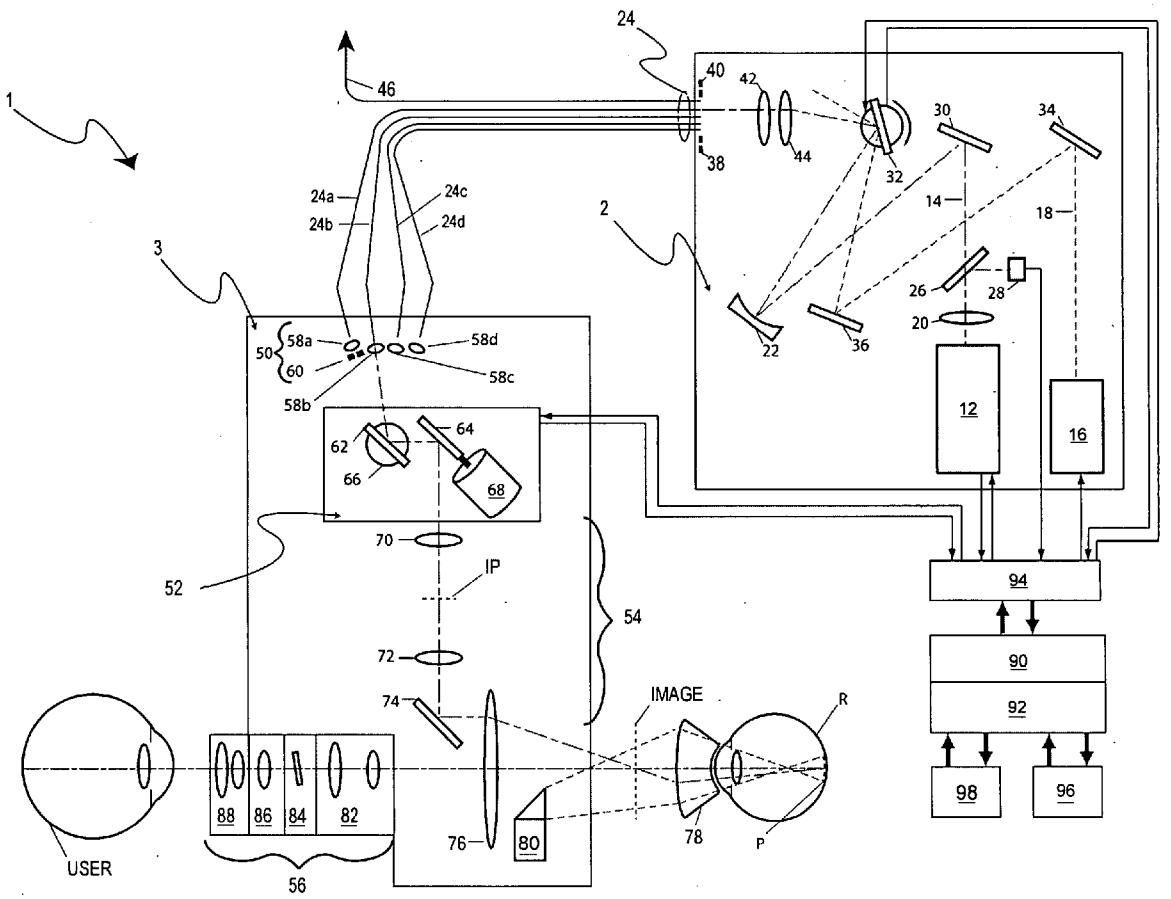
(52) **U.S. Cl.** **607/88**; 606/4

(57) **ABSTRACT**

System and method for generating patterns P of aiming and treatment light on target eye tissue (e.g. the retina) of a patient's eye. The system includes light sources for treatment and aiming light, a scanner for generating patterns of spots of the generated light, a controller, and a graphic user interface that allows the user to select one of several possible spot patterns, adjust the spot density and/or spot size, and apply patterns with fixed or varied density. The patterns can be formed of interlaced sub-patterns and/or scanned without adjacent spots being consecutively formed to reduce localized heating. Partially or fully enclosed exclusion zones within the patterns protect sensitive target tissue from exposure to the light.



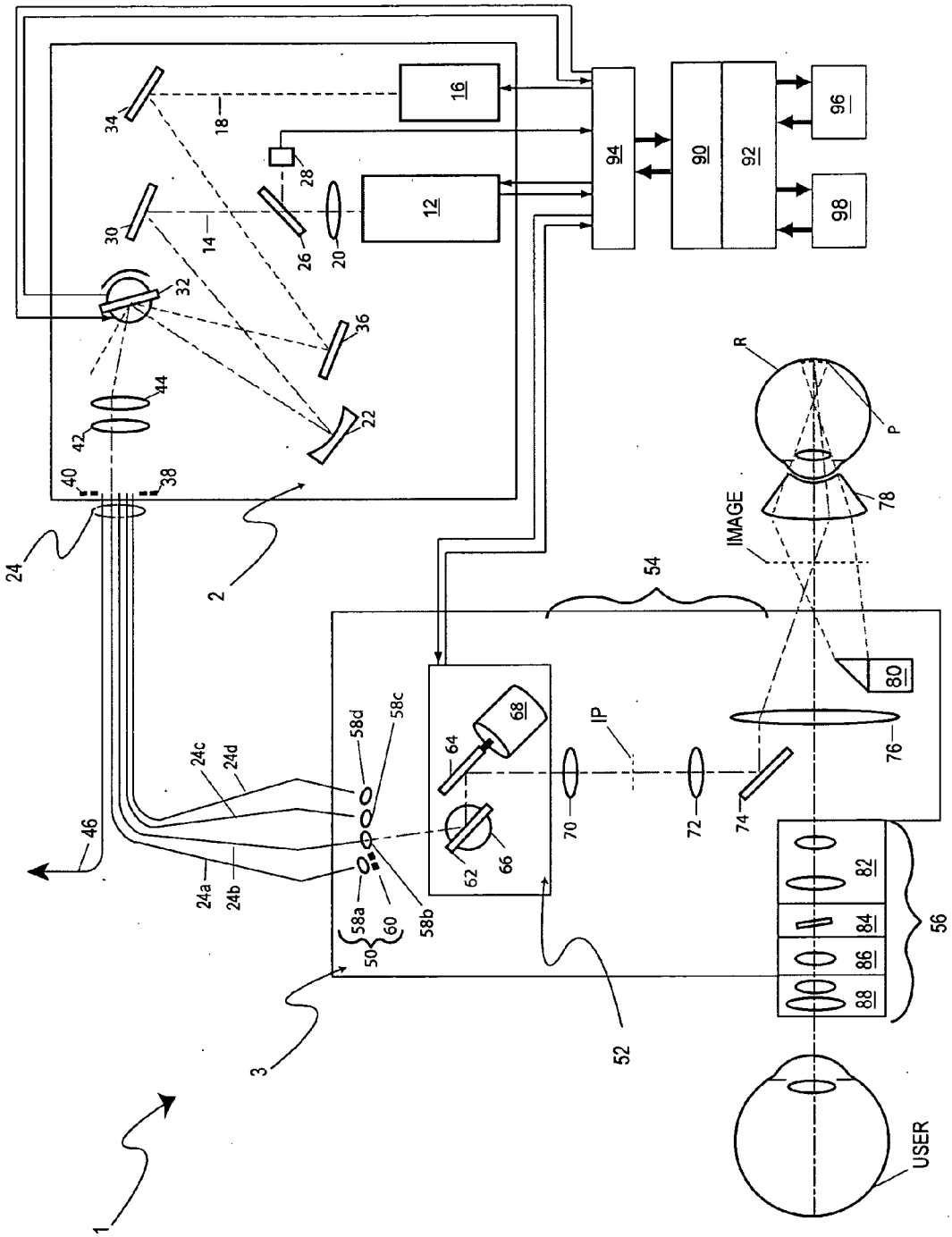

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Fig. 1

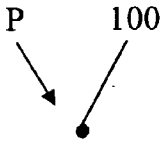


Fig. 2

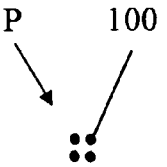


Fig. 3A

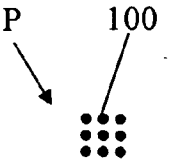


Fig. 3B

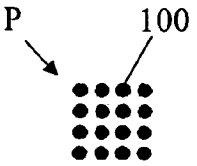


Fig. 3C

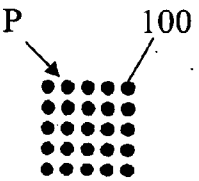


Fig. 3D

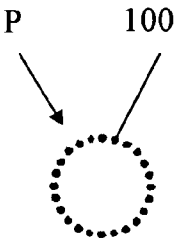


Fig. 3E

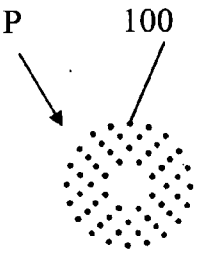


Fig. 3F

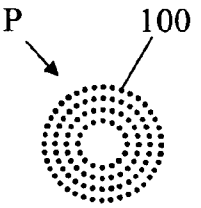
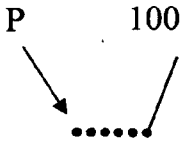


Fig. 3G



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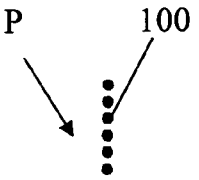

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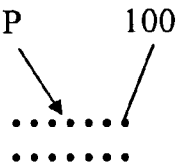

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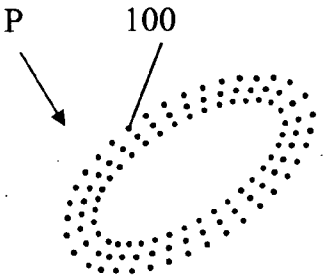

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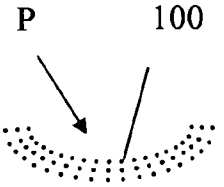

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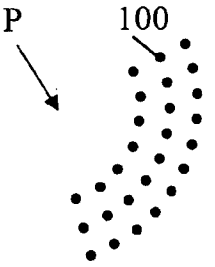

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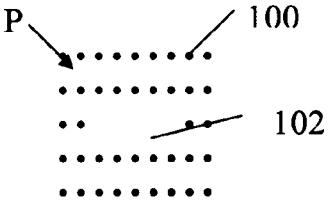

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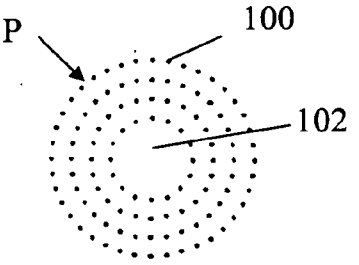

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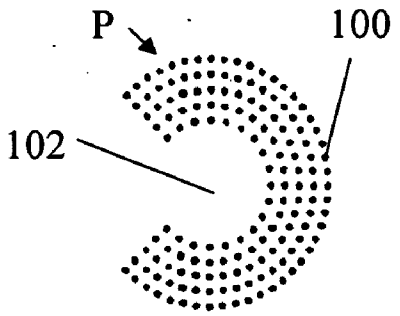

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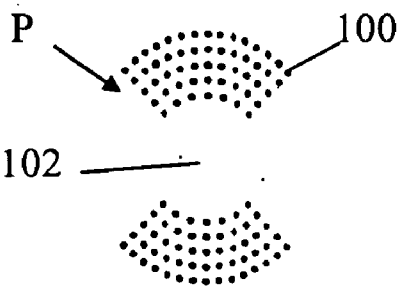

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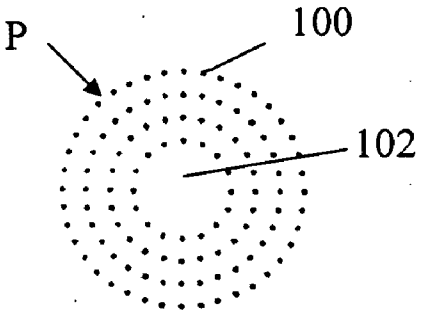

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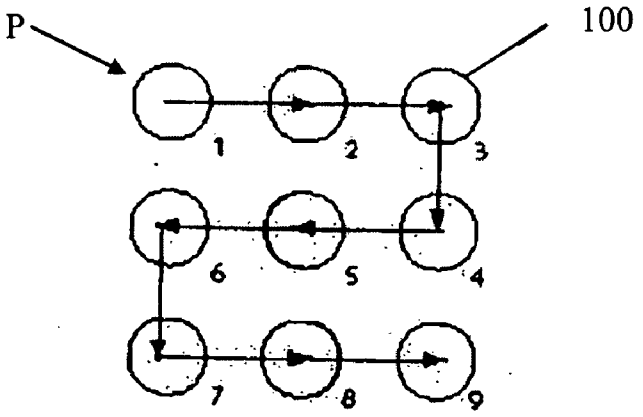

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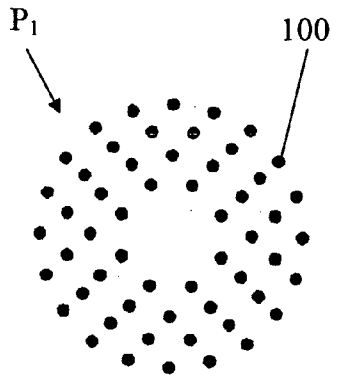

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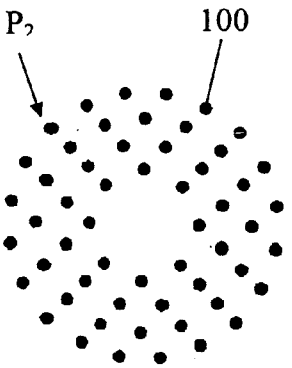

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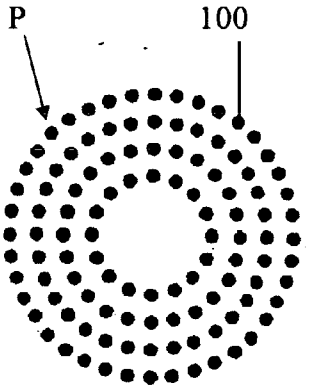

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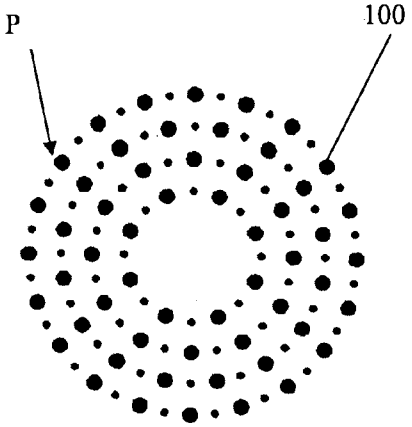

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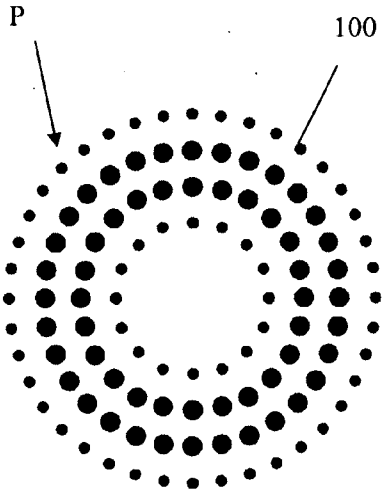

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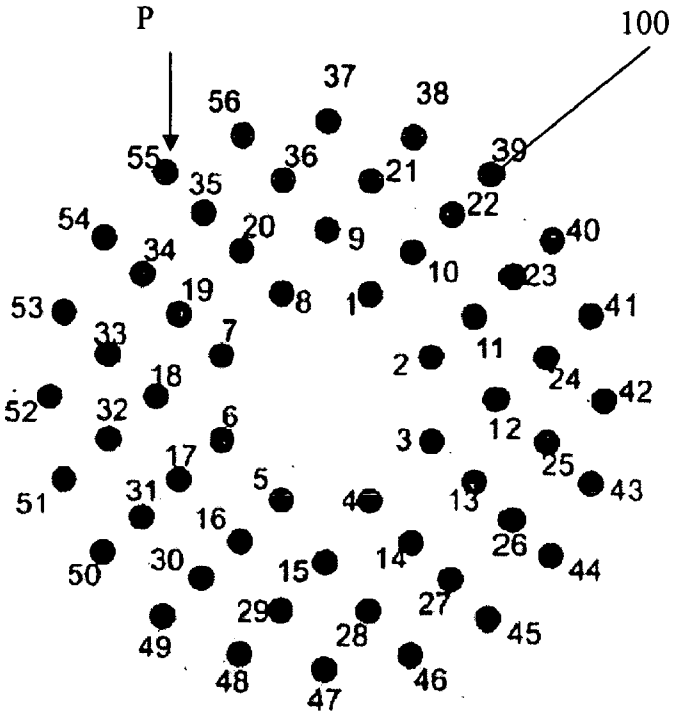

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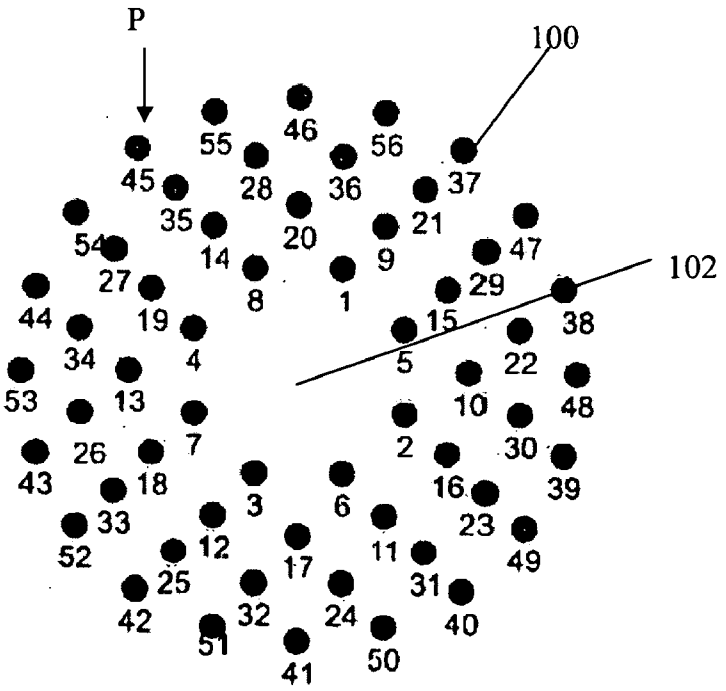

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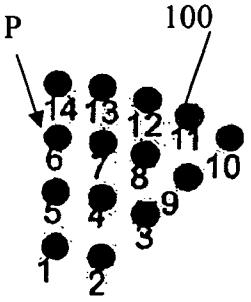

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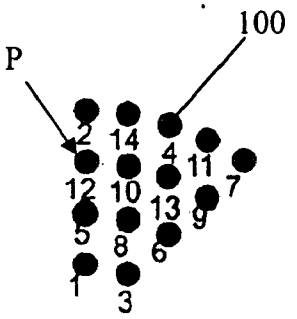

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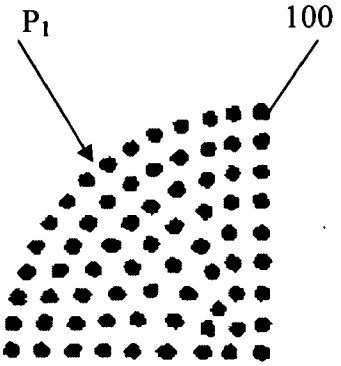

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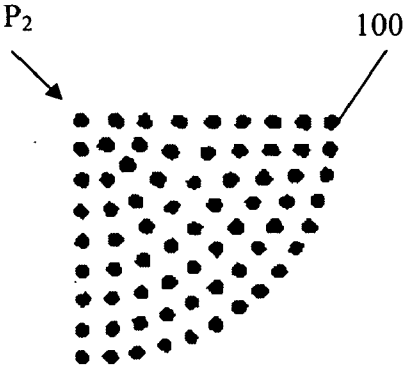

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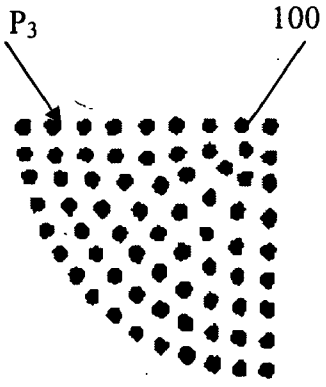
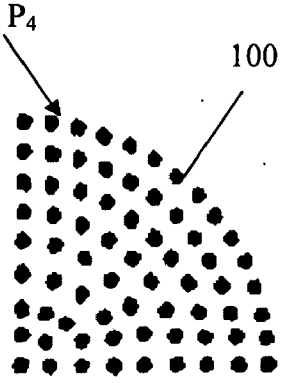


Fig. 13C



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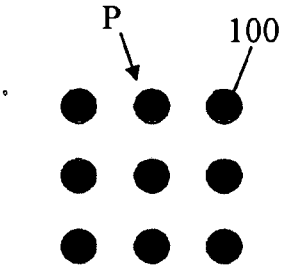

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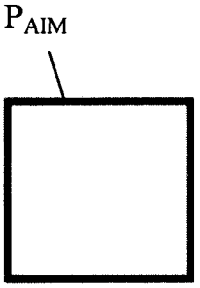

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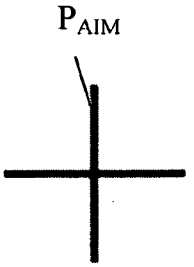

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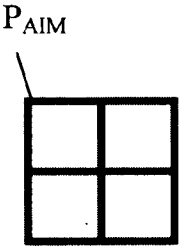


Fig. 14D

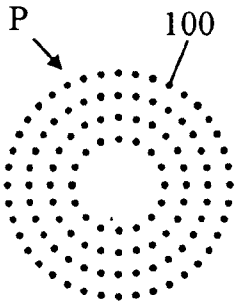
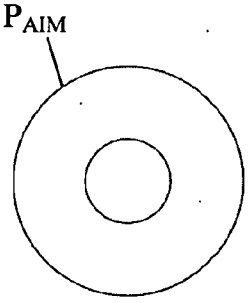


Fig. 15A



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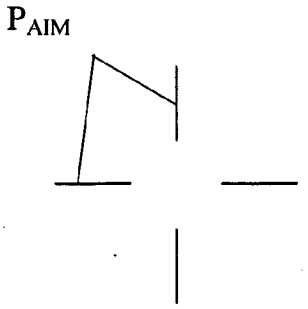

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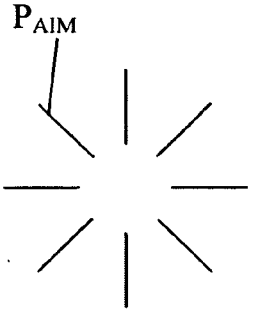

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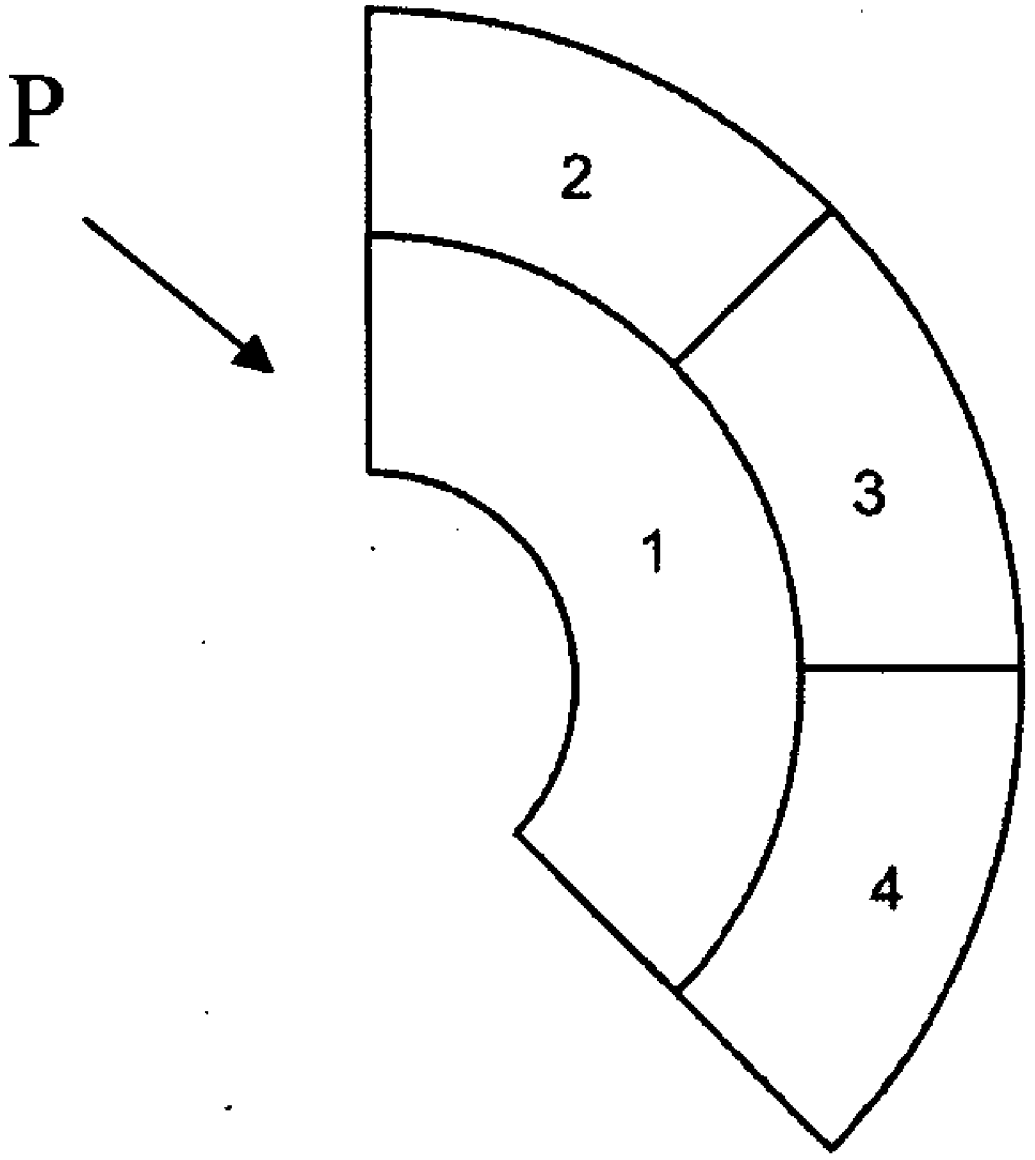
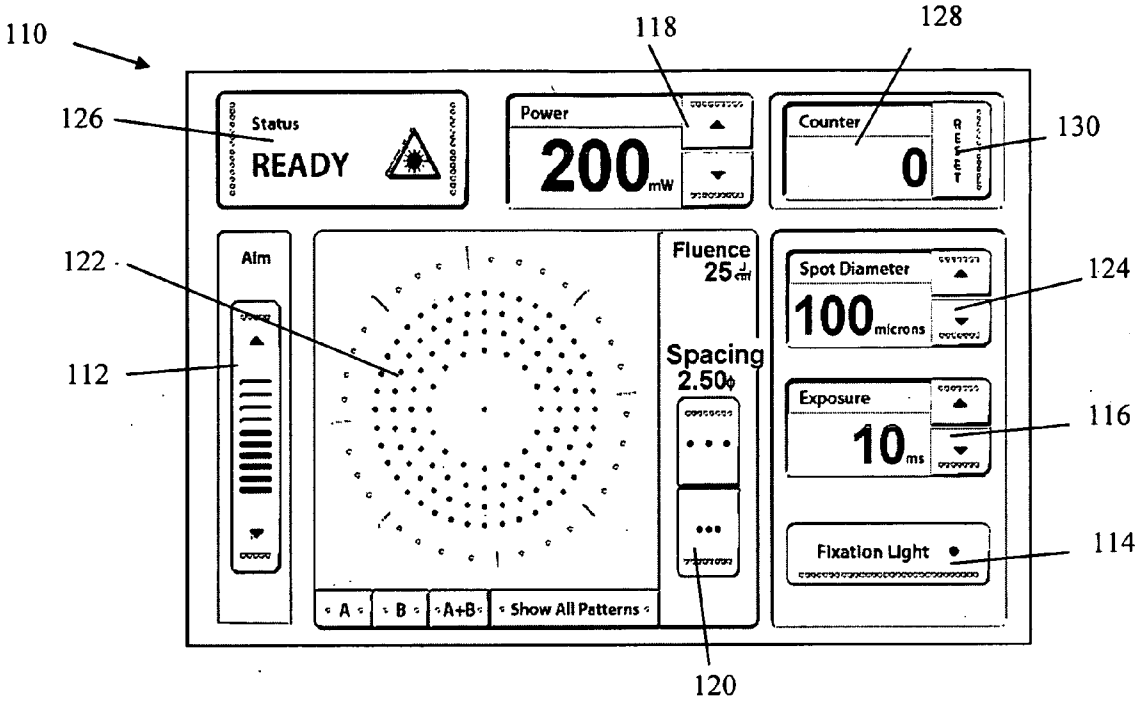


Fig. 16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Fixation Light
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A
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A+B
Show All Patterns
120

Fig. 17

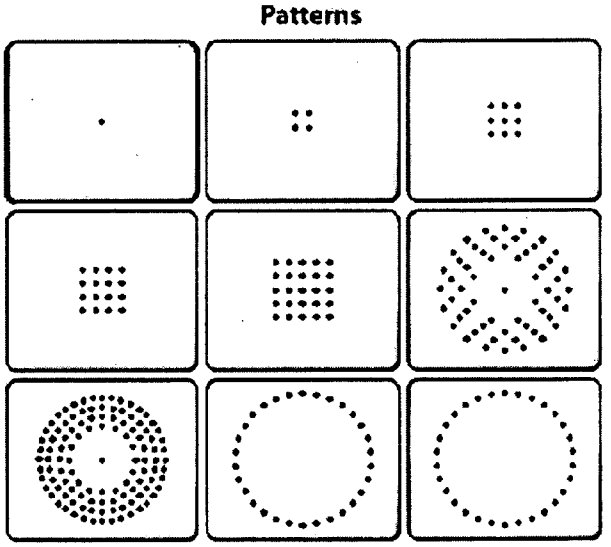
Patterns

Fig. 18

SYSTEM AND METHOD FOR GENERATING TREATMENT PATTERNS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/718,762, filed Sep. 19, 2005, and of U.S. Provisional Application No. 60/758,169, filed Jan. 10, 2006, both of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to retinal photocoagulation, and more particularly to a system and method for patterned optical ophthalmic treatment.

BACKGROUND OF THE INVENTION

[0003] Presently, conditions such as diabetic retinopathy and age-related macular degeneration are subject to photocoagulative treatment with visible laser light. While this type of visible laser light treatment halts the progress of the underlying disease, it can be problematic. For example, because the treatment entails exposing the eye to visible laser light for a long period of time (typically on the order of 100 ms), damage can be caused to the patient's sensory retina from the heat that is generated. During the treatment, heat is generated predominantly in the retinal pigmented epithelium (RPE), which is the melanin-containing layer of the retina directly beneath the photoreceptors of the sensory retina. Although light is absorbed in the RPE, this type of treatment irreversibly damages the overlying sensory retina and negatively affects the patient's vision.

[0004] Another problem is that some treatments require the application of a large number of laser doses to the retina, which can be tedious and time consuming. Such treatments call for the application of each dose in the form of a laser beam spot applied to the target tissue for a predetermined amount of time. The physician is responsible for ensuring that each laser beam spot is properly positioned away from sensitive areas of the eye that could result in permanent damage. Since some treatments can require hundreds of laser beam spots to evenly treat the target tissue, the overall treatment time can be quite long and require great physician skill to ensure an even and adequate treatment of the entire target tissue area.

[0005] To reduce the treatment time needed for retinal photocoagulation, a system and method has been proposed for applying multiple laser spots automatically in the form of a pattern of spots, so that an area of target tissue is efficiently treated by multiple spots pre-positioned on the tissue in the form of the pattern. See for example U.S. Patent Publication US2006/0100677. However, rapid delivery of multiple beam spots in patterns raises new issues. For example, localized heating can occur with the rapid and consecutive delivery of adjacent beam spots within a pattern. Moreover, variations in the patterns are needed to provide better exclusion zone and beam spot density control (both for even density and variable density), as well as better system control through a graphic user interface.

SUMMARY OF THE INVENTION

[0006] The present invention solves the aforementioned problems by providing a system and method of automatic projection of spot patterns onto the target tissue. More particularly, a photomedical system for treating target tissue includes a light source for generating a beam of light, a scanner assembly for translating the beam to form a pattern of spots of the light, a focusing element for focusing the pattern of spots on the target tissue, a controller for controlling the scanner assembly, and a graphic user interface connected to the controller that includes a display for displaying a configuration of the pattern of spots and for displaying a plurality of different pattern configurations to choose from for the pattern of spots in response to an activation of the display.

[0007] A method of treating target tissue includes selecting a pattern of spots from a plurality of different pattern configurations displayed on a display of a graphic user interface by activating the display, generating a beam of light, translating the beam to form the selected pattern of spots of the light, and focusing the pattern of spots of the light on the target tissue.

[0008] Other objects and features of the present invention will become apparent by a review of the specification, claims and appended figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a schematic diagram of the scanning coagulation system.

[0010] FIG. **2** is a diagram of a pattern P of a single spot.

[0011] FIGS. **3**A-**3**G are diagrams of symmetrical patterns P of spots.

[0012] FIGS. **4**A-**4**F are diagrams of non-symmetrical patterns P of spots.

[0013] FIGS. **5**A-**5**B are diagrams of patterns P of spots with fully enclosed exclusion zones.

[0014] FIGS. **6**A-**6**B are diagrams of patterns P of spots with partially open exclusion zones.

[0015] FIG. **7** is a diagram of a circular pattern P of spots having a generally uniform spot density.

[0016] FIG. **8** is a diagram illustrating the scanning order of a pattern P of spots with adjacent spots scanned consecutively.

[0017] FIGS. **9**A and **9**B are diagrams illustrating adjacent spots from a single pattern P separated into two different spot patterns.

[0018] FIG. **9**C is a diagram illustrating the pattern P of spots resulting from the combination of patterns in FIGS. **9**A and **9**B.

[0019] FIGS. **10**A-**10**B are diagrams of a pattern P of spots with adjacent spots having different sizes.

[0020] FIGS. **11**A and **11**B are diagrams illustrating two different scanning orders of a round pattern P of spots.

[0021] FIGS. **12**A and **12**B are diagrams illustrating two different scanning orders of a wedge shaped pattern P of spots.

[0022] FIGS. **13**A and **13**D are diagrams illustrating four separately scanned sub-patterns that together form scanned pattern P.

[0023] FIGS. **14**A-**14**D are diagrams illustrating aiming patterns that either enclose the area in which the treatment pattern P of spots of will be positioned or identify the center and outer extent of the treatment pattern P.

[0024] FIGS. **15**A-**15**D are diagrams illustrating aiming patterns that either enclose the area in which the treatment pattern P of spots of will be positioned or identify the center and outer extent of the treatment pattern P.

[0025] FIG. **16** is a diagram illustrating automatic generation of arc patterns.

[0026] FIG. **17** is a front view of a graphic user interface screen for operating the photocoagulation system.

[0027] FIG. **18** is a front view of the graphic user interface screen displaying multiple possible pattern configurations from which to choose from.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] The present invention is a system and method for generating patterns P of aiming and treatment light on target eye tissue (e.g. the retina) of a patient's eye. FIG. **1** depicts an ophthalmic slit lamp based scanning photocoagulator **1**, which is a non-limiting example of a photocoagulation system for creating and projecting aiming and/or treatment patterns of spots onto a patient's retina R. System **1** includes a light source assembly **2** and a slit lamp assembly **3**.

[0029] The light source assembly **2** includes a treatment light source **12** for generating an optical beam of treatment light **14**, and an aiming light source **16** for generating an optical beam of aiming light **18**. Treatment beam **14** from treatment light source **12** is first conditioned by lens **20**, which is used in conjunction with a curved mirror **22** to prepare treatment beam **14** for input into an optical fiber bundle **24**. After encountering lens **20**, treatment beam **14** is sampled by partially reflecting mirror **26**. The light reflected from mirror **26** is used as an input for a photodiode **28** that monitors the output power of treatment beam **14**, assuring that the light source **12** is operating at the desired power. A mirror **30** is used to steer treatment beam **14** onto mirror **22**, which in turn directs treatment beam **14** onto moving mirror **32**. Aiming beam **18** from aiming light source **16** is directed onto moving mirror **32** via mirrors **34** and **36**.

[0030] Moving mirror **32** is preferably mounted on a galvanometric scanner (but could also be moved by piezo actuators or other well know optic moving devices), and moves to selectively direct treatment and aiming beams **14**, **18** to one of the optical fibers **24***a*, **24***b*, **24***c*, **24***d* of optical fiber bundle **24** at any given time, where lenses **42**, **44** focus the treatment and aiming beams **14**, **18** into the selected optical fiber(s). Preferably, moving mirror **32** is spaced one focal length away from lens **20** to provide for a telecentric scan condition (thus allowing for the injection of treatment beam **14** into all the optical fibers **24***a*-**24***d* on parallel paths, which preserves the launch numerical aperture across the optical fiber bundle **24**). Adjacent to the optical fibers **24***a*-**24***d* are beam dumps **38**, **40**, which provide convenient locations to "park" the treatment beam **14**. Optical fibers **24***a*-**24***d* are used to deliver the treatment and aiming beams **14**, **18** from the light source assembly **2** to the slit lamp assembly **3**. An additional optical fiber **46** may be used to direct the treatment and/or aiming beams **14**, **18** to the patient via other means such as an endoprobe or laser indirect ophthalmoscope (not shown).

[0031] Slit lamp assembly **3** includes an optical fiber input **50** (for receiving optical fibers **24***a*-**24***d*), a scanner assembly **52**, a delivery assembly **54**, and a binocular viewing assembly **56**. The optical fiber input **50** preferably includes a unique optical conditioning system for each of the optical fibers **24***a*-**24***d*, so that each optical fiber can produce a specific (and preferably unique) spot size at the image plane IP of the slit lamp assembly **3**. For example, light from optical fiber **24***a* first encounters a lens **58***a* that collimates the light, followed by an aperture **60** that serves to reduce the effective numerical aperture by obscuring all but the central portion of the light beam. Light from optical fibers **24***b* through **24***d* first encounter lenses **58***b* through **58***d*, respectively. Lenses **58***b*-**58***d* are preferably configured to create different spot sizes at the image plane IP, and subsequently at the target tissue (retina R). In the illustrated example, optical fibers **24***a* and **24***b* have the same core diameter, but are made to create different spot sizes by using different lenses **58***a* and **58***b*. Optical fibers **24***c* and **24***d* have different core diameters. It is preferable (but not necessary) that all optical fibers deliver light with the same numerical aperture. Therefore, to keep the operating numerical apertures identical for these different channels, aperture **60** is used to counteract the change in optical power of lens **58***a* relative to lenses **58***b*, **58***c*, **58***d*.

[0032] The optical output of each optical fiber **24***a*-**24***d* after conditioning by the associated optical systems (e.g. lenses **58***a*-**58***d*, aperture **60**, etc.) is directed to the scanner assembly **52**, which includes two movable mirrors **62**, **64** mounted to two galvanometers **66**, **68** (although any well known optic moving device such as piezo actuators could be used). Mirrors **62**, **64** are configured to rotate in two orthogonal axes to scan (i.e. translate) the incoming light to form any desired pattern P. Mirror **62** may be rotated to redirect the light from any given one of the fibers **24***a*-**24***d* into the remainder of slit lamp assembly **3**, thus acting to "select" the output from that optical fiber while prohibiting any light from the other optical fibers to continue through the entire slit lamp assembly **3**. Because the output ends of optical fibers **24***a*-**24***d* are not coincident, mirror **62** must be rotated into position to intercept the light from the desired optical fiber and transmit that light to mirror **64**, which can further move the light in an orthogonal axis. This configuration has the added benefit of preventing any stray light that may be delivered by the non-selected optical fibers from exiting the system. In FIG. **1**, optical fiber **24***b* is shown as the selected fiber, where the output of this fiber is scanned by mirrors **62**, **64** to create a scanned pattern of light that travels through the rest of the system.

[0033] The scanned pattern of light P (which originates from treatment light source **12** and/or aiming light source **14**) leaving the scanner assembly **52** passes through the delivery assembly **54**, which includes lens **70** (for creating the intermediate scanned pattern at image plane IP), lens **72** (for conditioning the light pattern for focusing into the eye), mirror **74** (for directing the light pattern toward the target eye tissue), lens **76** (preferably an infinity-corrected microscope objective lens) and lens **78** (preferably a contact lens that provides final focusing of the pattern of light P onto the target eye tissue such as the retina R). Illumination source **80** (such as a halogen light bulb) is used to illuminate the target eye tissue R so that the physician can visualize the target eye tissue.

[0034] The user (i.e. physician) views the target eye tissue R directly via the binocular viewing assembly **56**, which includes magnification optics **82** (e.g. one or more lenses used to magnify the image of the target eye tissue, and preferably in an adjustable manner), an eye safety filter **84** (which prevents potentially harmful levels of light from reaching the user's eye, and which may be color-balanced to provide for a photopically neutral transmission), optics **86**, and eyepieces **88**.

[0035] Pattern P of light is ultimately created on the retina of a patient R using optical beams **14**, **18** from treatment light source **12** and aiming light source **16** under the control of control electronics **90** and central processing unit (CPU) **92**. Control electronics **90** (e.g. field programmable gate array, etc.) and CPU **92** (e.g. a dedicated microprocessor, a stand-alone computer, etc.) are connected to various components of the system by an input/output device **94** for monitoring and/or controlling those components. For example, control electronics **90** and/or CPU **92** monitor photodiode **28** (to ensure treatment beam **14** is generated at the desired power level), operate the light sources **12**, **16** (turn on/off, set power output level, etc.), operate mirror **32** (to select which optical fiber will be used for treatment and/or aiming beams **14**, **18**), and control the orientations of galvanometric scanners **66**, **68** to produce the desired pattern P on the target eye tissue. CPU **92** preferably serves to support control electronics **90**, and serves as input for a graphical user interface (GUI) **96** and an alternate user input device **98**. GUI **96** allows the user to command various aspects of the system, such as the delivered spot size and pattern, pulse duration and optical power output from treatment light source **12** and aiming light source **16**. In addition to the user physically moving slit lamp assembly **3** for gross alignment, the ultimate fine alignment of the light pattern P on the target tissue may be further controlled by use of the input device **98** (which can be a joystick, a touchpad, etc.), which causes mirrors **62**, **64** alter their rotations when scanning the light beam thus translating the entire pattern P on the target tissue. This approach yields very fine control of the disposition of the scanned beam. Additional input devices **98** can be included, such as knobs to adjust the output power of the light sources **12**, **16**, a footswitch or other type of activation device to activate the application of the aiming pattern and/or treatment pattern, etc. The ultimate disposition of the optical output of light sources **12**, **16** is intended to be the pattern P contained in the patient's retina R.

[0036] The most basic types of patterns P are those formed of discrete, uniformly sized and uniformly spaced fixed spots. The user can use GUI **96** to select, modify, and/or define a number of pattern variables, such as: spot size, spot spacing (i.e. spot density), total number of spots, pattern size and shape, power level, pulse duration, etc. In response, the CPU **92** and control electronics **90** control the treatment light source **12** (assuming it is a pulsed light source) or additionally a shuttering mechanism (not shown) somewhere along the beam **14** to create pulsed treatment light. Mirrors **62**, **64** move between pulses to direct each pulse to a discrete location to form a stationary spot. FIG. **2** shows a pattern P having a single spot **100**. FIGS. **3**A-**3**G show fully symmetrical (i.e. symmetrical in both the vertical and horizontal axes) square or circular patterns P of spots **100**. FIGS. **4**A-**4**D show non-symmetrical patterns P of spots **100** such as lines, rectangles and ellipses. FIGS. **5**A-**5**B show patterns P of spots **100** with completely enclosed exclusion zones **102**, which are zones within the pattern P that are free of spots-**100**. FIGS. **6**A-**6**B show patterns P of spots **100** with partially open exclusion zones **102**, where the exclusion zone **102** is not completely surrounded by the spots **100**. Different patterns are ideal for different treatments. For example, a single spot pattern is ideal for titrating the power for treatment, performing touchups to space between pattern spots, and sealing individual micro-aneurysms. Rectangle, square and line patterns are ideal for PRP (panretinal photocoagulation). Elliptical and circular patterns are ideal for treating the macula, and sealing tears. Arc patterns (i.e. circular or elliptical wedge patterns but without a radially center portion as shown in FIG. **4**F) are ideal for partially surrounding and treating a tear, as well as for PRP treatment for periphery and lattice degeneration. Patterns with enclosed exclusion zones are ideal for treating around sensitive areas such as the fovea where it is important that the sensitive area not receive any treatment light. Patterns with partially open exclusion zones are ideal for treating sensitive areas that are connected to other sensitive areas, such as avoiding treatment of both the fovea and the optic nerve that extends from the fovea—see especially pattern P in FIG. **6**A)

[0037] FIG. **7** illustrates a circular pattern P with a substantially uniform spot density. With rectangular shaped patterns, uniform spot density over the entire pattern P is easily achieved by making the rows and columns equally spaced apart and spots **100** all the same size. However, with a circular pattern, uniformity is not easily achieved. Forming concentric circles of spots with the same number of spots in each circle will result in a reduced spot density as the radius increases. Therefore, the following criteria has been developed to maximize the uniformity of the spot density of a circular pattern P of spots **100** (where the following calculations are preferably performed by the CPU **92**):

[0038] 1) Spots **100** are positioned in N circles of different radii all concentrically positioned around a single central point.

[0039] 2) The diameter D(n) of the nth circle of pattern P (where n=1, 2, . . . N, and n=1 is the circle closest to the center) is:

$$D(n)=EZ+S_D+(n-1)\times S_D(1+\text{Round}(DF)) \quad (1)$$

[0040] where EZ is the diameter of the desired exclusion zone if any (i.e. desired diameter of most inner circle), S_D is the diameter of the spots, and Round(DF) is the density factor DF rounded (up or down) to the nearest whole number. The density factor DF is a number preferably selected or adjusted by the user via the system GUI **96**. Typical density factors for eye surgery can be in the low single digits. If no exclusion zone is desired, then n=2, 3, . . . N, and n=2 is the circle closest to the center

[0041] 3) The number of spots **100** in the nth circle of pattern P is:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\right] \quad (2)$$

[0042] where Round here is rounding (up or down) to the nearest whole number.

[0043] 4) If there is no exclusion zone EZ, then n=2, 3 . . . N, with n=2 corresponding to the circle closest to the center.

[0044] These same equations can be utilized to form constant density concentric arcs of equal angular extent A along N concentric circles (e.g. see FIGS. **4**F, **6**A, **6**B). For calculating the diameter of the circle on which the arcs lie, equation (1) is the same, where A is the angular extent of the arcs and is between 0 and 2π. The number of spots in each concentric arc is (i.e. equation (2) becomes):

$$\text{Number}(n) = 8 \times \text{Round}\left[\pi \times D(n) \times \frac{1}{8} \times \frac{1}{S_D} \times \frac{1}{DF} \times \frac{A}{2\pi}\right] \quad (3)$$

[0045] The most straight forward technique for scanning spots **100** in a pattern P is sequentially where adjacent spots are scanned consecutively from one end of the pattern to the other to minimize the amount of scanning mirror movement between spots (as illustrated in FIG. **8**). However, exposing two adjacent spots consecutively (one just after the other) may result in undesirable localized heating. Thus, interlaced patterns can be used to minimize localized heating. Interlaced patterns are patterns that overlap each other in an alternating manner, so that the patterns themselves overlap each other, but the spots of one pattern do not overlap the spots of the other pattern (i.e. spots of one pattern are positioned among the spots of the other in an alternating or intermixed manner). FIGS. **9**A and **9**B represent how a pattern P (illustrated in FIG. **9**C) can be split up into two separate patterns P_1 and P_2 of alternating spots, so that spots immediately adjacent to each other in the pattern P are scanned onto the target tissue in two separate patterns (and thus more separated in time). In the particular example of FIGS. **9**A-**9**C, pattern P_1 represents half of the total spots in pattern P, and pattern P_2 represents the same pattern as pattern P_1 except it is rotated by a small angle (e.g. 11.25 degrees). Thus pattern P_1 of FIG. **9**A is scanned in its entirety, then pattern P_2 of FIG. **9**B is scanned in its entirety in an interlaced fashion relative to pattern P_1, thus resulting in pattern P of FIG. **9**C that induces less localized heating during its scan onto the target tissue.

[0046] FIG. **10**A illustrates a variation of the interlacing of the two patterns P_1 and P_2 to result in pattern P. In this configuration, the size of spots **100** forming pattern P_2 is smaller than that of the spots **100** forming pattern P_1. Thus, in the combined pattern P, adjacent spots have different sizes. This has the advantage of preserving more of the untreated retina and maintaining open space for subsequent follow-up treatment(s) (i.e. variable dosing). FIG. **10**B is a variation on FIG. **10**A, in which the spot size is consistent within the same ring, but spot sizes from one ring to the next can vary.

[0047] FIGS. **11**A-**11**B illustrate how varying the spot sequencing can be used to balance control of localized heating with other considerations. In FIG. **11**A, the sequence in which each spot is scanned is numbered. Thus, the first eight pulses are used to consecutively scan the eight spots that form the innermost circle. Then, the next most innermost circle is consecutively scanned, and so on. Each circle is scanned in a single direction with adjacent spots being scanned in consecutive order. The advantage of this pattern sequence is that the innermost circle closest to the exclusion zone **102** is scanned first, so that if the patient's eye moves later on while the pattern is still being scanned, the beam at that point in the treatment will be further away from the sensitive eye tissue in the exclusion zone and thus will minimize the risk of inadvertent exposure to this tissue (e.g. the fovea). It should be noted that this spot sequence results in adjacent spots in each circle being scanned consecutively, which may result in undesirable localized heating. In FIG. **11**B, the spot sequence is modified so that each circle is scanned one at a time starting with the innermost circle, but within each circle adjacent spots are not scanned consecutively (i.e. adjacent pulses in the beam are not used to scan adjacent spots in the final pattern). This can entail either a random ordering, or a more orderly sequence such as scanning every other spot as the beam traverses around the circle (as shown in FIG. **11**B).

[0048] FIGS. **12**A and **12**B show pulse sequencing similar to that of FIGS. **11**A and **11**B, except as applied to a wedge shaped pattern P. Specifically, in FIG. **12**A, arcs of different radii are scanned one arc at a time, in order, starting from the innermost circle. In FIG. **12**B, the spots **100** of the wedge shaped pattern P are scanned randomly both within as well as among the different arcs.

[0049] FIGS. **13**A-**13**D show how a larger pattern P can be broken up into sub-patterns. Specifically, instead of scanning the entire pattern P (in this example a circular pattern), it may be preferable to break up the pattern P into sub-patterns (in this example wedge-shaped quadrants), and scan each sub-pattern P_1, P_2, P_3, P_4 in its entirety before moving on to the next sub-pattern. Within each sub-pattern, the spots may be scanned out of order to minimize localized heating as discussed above. The advantage of this technique is that if the scanning were interrupted during one sub-pattern (e.g. due to excessive eye movement), the system can better recover by simply moving on to the next sub-pattern. Trying to resume a partially completed scan of a pattern may not be feasible in some applications once registration between the scanner and the target tissue is lost. In other words, it is easier to register the location of an entire sub-pattern and continue rather than try to register the location of the remaining spots within a partially completed scanned pattern. By scanning the spots using sub-patterns to form an overall pattern P, and each sub-pattern is scanned without scanning adjacent spots consecutively, there is a good balance between small pattern local working areas and avoidance of excessive localized heating.

[0050] There are various relationships that the aiming beam can take relative to the treatment beam. For example, the aiming light can be projected onto the target tissue in a pattern that generally matches that of the treatment light (i.e. the system projects a pattern P of spots with the aiming light, followed by the projection of the pattern P of spots with the treatment light overlapping the positions of the spots projected by the aiming light). In this manner, the physician can align the pattern P of treatment light spots knowing they will be positioned where the pattern P of alignment light spots are seen on the target tissue. Alternately, the aiming light can be scanned in a pattern P_{AIM} of enclosed shape (e.g. circle, rectangle, ellipse, etc.), where the treatment light pattern P of spots will be inside that enclosed shape (i.e. the pattern P_{AIM} of aiming light outlines the target tissue that will receive the treatment light pattern P). Thus, P_{AIM} of FIG. **14**B outlines the pattern P of FIG. **14**A, and P_{AIM} of FIG. **15**B outlines the pattern P of FIG. **15**A. In yet another example, the alignment pattern P_{AIM} can identify the center of the

treatment light pattern P of spots, and possibly indicate the extent of the treatment light pattern P of spots (e.g. alignment pattern P_{AIM} is cross hairs showing the center of the treatment light pattern P, with the outer ends of the cross hairs indicating the outer perimeter of the treatment light pattern P. Thus, P_{AIM} of FIGS. **14**C and **14**D identify the center and extent of the pattern P of FIG. **14**A, and P_{AIM} of FIGS. **15**C and **15**D identify the center and extent of the pattern P of FIG. **15**A.

[**0051**] FIG. **16** illustrates how the system can automatically generate pattern sizes that exceed the scan size capabilities of the system. In FIG. **16**, the desired pattern P is in the shape of a circular arc, with four sub-arc patterns **1**-**4**. The system can be set to allow the user to define the innermost sub-arc pattern **1** as a first scan, where the system will proceed to scan sub-arc pattern **1**, and then automatically identify and scan in sequential order sub-arc patterns **2**, **3**, **4** which are disposed radially outwardly from the sub-arc pattern **1**. With this configuration, a user can define an arc shaped pattern that approaches the scan limits of the system, and the system will automatically scan additional sub-patterns disposed radially outwardly from the pattern identified by the user.

[**0052**] FIG. **17** illustrates an exemplary graphic user interface (GUI) **96** for selecting and implementing the above described photocoagulation patterns. The illustrated GUI **96** comprises a touch screen display **110**, which defines soft keys on the screen can be used to change the operating conditions of the system. For example, the display **110** defines soft keys for adjusting aim beam power **112**, fixation light power **114**, exposure time **116**, treatment power **118**, spot density **120**, pattern **122**, and spot diameter **124**. Touching these soft keys allows the user to adjust the selected parameter(s). Some soft keys are in the form of up/down arrows, which allow the user to directly adjust the numeric value. Other soft keys provide multiple options (e.g. spot density **120**) from which the user can select the desired option. Still other soft keys illustrate an operating parameter, and when activated open new menus from which to manipulate that operating parameter (e.g. the pattern soft key **122** illustrates the configuration of the selected pattern such as spot spacing and pattern shape and layout, and when activated such as being touched opens a menu for selecting from a plurality of predefined patterns as illustrated in FIG. **18**, or for defining a new pattern; the spot diameter soft key **124** indicates the size of the spots and when touched opens a menu for adjusting the spot size). Status indicators are also provided on display **110** (e.g. status indicator **126** indicates whether the system is in a standby mode, an aiming light mode, or a treatment light mode; counter indicator **128** keeps track of the number of treatment applications and can be reset by touching the reset soft key **130**). Soft keys can also be tailored to the specific data being input. For example, by dragging the user's finger around pattern soft key **122** allows the user to select how many quadrants, octants, etc. that will be included in a circular pattern (e.g. dragging around the pattern key **122** for approximately **310** degrees will select a pattern with seven octants—i.e. one octant will be left out of an otherwise complete circular pattern).

[**0053**] As used herein, the terms "comprises,""comprising,""includes,""including,""has,""having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[**0054**] It is to be understood that the present invention is not limited to the embodiment(s) described above and illustrated herein, but encompasses any and all variations falling within the scope of the appended claims. For example, while many of the patterns P described above and illustrated in the figures have a uniform spot density configuration, the present invention is not so limited. The spot density can be varied in the same pattern P in various ways. For example, the sizes and/or separation of spots **100** in one portion of the pattern P can be different than that in another portion of the same pattern P. Treatment density can also be varied in the same pattern P, by varying the power and/or pulse duration that form spots in one portion of the pattern P relative to the power and/or pulse duration that spots in another portion of pattern P. Pattern P can not only be formed of discrete stationary spots as described above, but also by one or more moving spots that form scanned lines or other scanned images. The aiming light source (or another light source) can be used to project a fixation pattern on the eye along with the aiming pattern P and/or the treatment pattern P to give the patient a reference point to keep the eye still during treatment. The above system is ideal for, but not limited to, photocoagulation diagnosis/treatment. Lastly, as is apparent from the claims and specification, not all method steps necessarily need be performed in the exact order illustrated or claimed, but rather in any order that allows for the proper alignment and projection of the treatment pattern P.

What is claimed is:

1. A photomedical system for treating target tissue, comprising:

a light source for generating a beam of light;

a scanner assembly for translating the beam to form a pattern of spots of the light;

a focusing element for focusing the pattern of spots on the target tissue;

a controller for controlling the scanner assembly; and

a graphic user interface connected to the controller that includes a display for displaying a configuration of the pattern of spots and for displaying a plurality of different pattern configurations to choose from for the pattern of spots in response to an activation of the display.

2. The photomedical system of claim 1, wherein the display of the graphic user interface is a touch sensitive screen.

3. The photomedical system of claim 1, wherein the pattern of spots comprises at least first and second sub-patterns of the spots which are interlaced together to form the pattern of spots.

4. The photomedical system of claim 3, wherein the spots in the first sub-pattern have a diameter that is greater than that of the spots in the second sub-pattern.

5. The photomedical system of claim 3, wherein the controller causes the scanner assembly to entirely form the first sub-pattern before entirely forming the second sub-pattern.

6. The photomedical system of claim 5, wherein the first and second sub-patterns of the spots are the same.

7. The photomedical system of claim 6, wherein the first sub-pattern is positionally shifted relative to the second sub-pattern.

8. The photomedical system of claim 6, wherein the second sub-pattern is positionally rotated by a predetermined angle relative to the first sub-pattern.

9. The photomedical system of claim 1, wherein the scanner assembly forms the spots of light sequentially and in an order that avoids spots adjacent to each other in the pattern from being formed consecutively.

10. The photomedical system of claim 1, wherein the pattern is generally round in shape and has a generally constant density of the spots.

11. The photomedical system of claim 1, wherein the spots in the pattern are positioned in N concentric circles each having a diameter D defined as:

$$D(n)=EZ+S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=1, 2, . . . N,

EZ is a diameter of an exclusion zone in a center of the pattern,

S_D is a diameter of the spots, and

Round (DF) is a density factor DF rounded up or down to the nearest whole number.

12. The photomedical system of claim 11, wherein each of the n=1, 2, . . . N concentric circles includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

13. The photomedical system of claim 1, wherein the spots in the pattern are positioned in N concentric circles each having a diameter D defined as:

$$D(n)=S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=2, 3, . . . N,

S_D is a diameter of the spots, and

Round(DF) is a density factor DF rounded up or down to the nearest whole number.

14. The photomedical system of claim 13, wherein each of the n=2, 3, . . . N concentric circles includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

15. The photomedical system of claim 1, wherein the spots in the pattern are positioned in arcs of equal angular extent A along N concentric circles each having a diameter D defined as:

$$D(n)=EZ+S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=1, 2, . . . N,

EZ is a diameter of an exclusion zone in a center of the pattern,

S_D is a diameter of the spots,

Round (DF) is a density factor DF rounded up or down to the nearest whole number, and

A is the angular extent of the arcs and is between 0 and 2π.

16. The photomedical system of claim 15, wherein each of the n=1, 2, . . . N concentric arcs includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\times\frac{A}{2\pi}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

17. The photomedical system of claim 1, wherein the spots in the pattern are positioned in arcs of equal angular extent A along N concentric circles each having a diameter D defined as:

$$D(n)=S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=2, 3, . . . N,

S_D is a diameter of the spots,

Round(DF) is a density factor DF rounded up or down to the nearest whole number, and

A is the angular extent of the arcs and is between 0 and 2π.

18. The photomedical system of claim 17, wherein each of the n=2, 3, . . . N concentric arcs includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\times\frac{A}{2\pi}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

19. The photomedical system of claim 1, wherein the pattern has a density of the spots with the pattern that varies.

20. The photomedical system of claim 1, wherein the pattern is an arc pattern, and wherein the controller causes the scanner to automatically scan the arc pattern and additional arc patterns radially outward from the arc pattern.

21. The photomedical system of claim 1, wherein the spots have varying diameters in the pattern.

22. The photomedical system of claim 1, further comprising:

an aiming light source for generating an aiming beam of aiming light, wherein the scanner assembly is configured for translating the aiming beam to form an enclosed aiming pattern of the aiming light on the target tissue in which the pattern of spots is to be confined.

23. The photomedical system of claim 1, further comprising:

an aiming light source for generating an aiming beam of aiming light, wherein the scanner assembly is configured for translating the aiming beam to form an aiming pattern of the aiming light on the target tissue that indicates a center position of the pattern of spots.

24. The photomedical system of claim 23, wherein the aiming pattern further indicates an outer boundary in which the pattern of spots is to be confined.

25. The photomedical system of claim 24, wherein the aiming pattern comprises two or more crossed lines.

26. The photomedical system of claim 1, wherein the pattern of spots defines a partially enclosed exclusion zone on the target tissue in which the spots are not incident.

27. The photomedical system of claim 1, wherein the pattern of spots comprises a plurality of arc patterns separated from each other.

28. A method of treating target tissue, comprising:

selecting a pattern of spots from a plurality of different pattern configurations displayed on a display of a graphic user interface by activating the display;

generating a beam of light;

translating the beam to form the selected pattern of spots of the light; and

focusing the pattern of spots of the light on the target tissue.

29. The method of claim 28, wherein the display of the graphic user interface is a touch sensitive screen.

30. The method of claim 28, wherein the pattern of spots comprises at least first and second sub-patterns of the spots which are interlaced together to form the pattern of spots.

31. The method of claim 30, wherein the spots in the first sub-pattern have a diameter that is greater than that of the spots in the second sub-pattern.

32. The method of claim 30, wherein the translating of the beam comprises:

forming the first sub-pattern; and

forming the second sub-pattern only after the forming of the first sub-pattern.

33. The method of claim 32, wherein the first and second sub-patterns of the spots are the same.

34. The method of claim 33, wherein the first sub-pattern is positionally shifted relative to the second sub-pattern.

35. The method of claim 33, wherein the second sub-pattern is positionally rotated by a predetermined angle relative to the first sub-pattern.

36. The method of claim 28, wherein the translating of the beam results in forming the spots of the light sequentially and in an order that avoids spots adjacent to each other in the pattern from being formed consecutively.

37. The method of claim 28, wherein the pattern is generally round in shape and has a generally constant density of the spots.

38. The method of claim 28, wherein the spots in the pattern are positioned in N concentric circles each having a diameter D defined as:

$$D(n)=EZ+S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=1, 2, . . . N,

EZ is a diameter of an exclusion zone in a center of the pattern,

S_D is a diameter of the spots, and

Round (DF) is a density factor DF rounded up or down to the nearest whole number.

39. The method of claim 38, wherein each of the n=1, 2, . . . N concentric circles includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

40. The method of claim 28, wherein the spots in the pattern are positioned in N concentric circles each having a diameter D defined as:

$$D(n)=S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=2, 3, . . . N,

S_D is a diameter of the spots, and

Round(DF) is a density factor DF rounded up or down to the nearest whole number.

41. The method of claim 40, wherein each of the n=2, 3, . . . N concentric circles includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8\times\text{Round}\left[\pi\times D(n)\times\frac{1}{8}\times\frac{1}{S_D}\times\frac{1}{DF}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

42. The method of claim 28, wherein the spots in the pattern are positioned in concentric arcs of equal angular extent A along N concentric circles each having a diameter D defined as:

$$D(n)=EZ+S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=1, 2, . . . N,

EZ is a diameter of an exclusion zone in a center of the pattern,

S_D is a diameter of the spots,

Round (DF) is a density factor DF rounded up or down to the nearest whole number, and

A is the angular extent of the arcs and is between 0 and 2π.

43. The method of claim 42, wherein each of the n=1, 2, . . . N concentric arcs includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8 \times \text{Round}\left[\pi \times D(n) \times \frac{1}{8} \times \frac{1}{S_D} \times \frac{1}{DF} \times \frac{A}{2\pi}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

44. The method of claim 28, wherein the spots in the pattern are positioned in concentric arcs of equal angular extent A along N concentric circles each having a diameter D defined as:

$$D(n)=S_D+(n-1)\times S_D(1+\text{Round}(DF))$$

wherein:

D(n) is the diameter of the nth concentric circle of the pattern with n=2, 3, . . . N,

S_D is a diameter of the spots,

Round(DF) is a density factor DF rounded up or down to the nearest whole number, and

A is the angular extent of the arcs and is between 0 and 2π.

45. The method of claim 44, wherein each of the n=2, 3, . . . N concentric arcs includes a predetermined number(n) of the spots according to:

$$\text{Number}(n) = 8 \times \text{Round}\left[\pi \times D(n) \times \frac{1}{8} \times \frac{1}{S_D} \times \frac{1}{DF} \times \frac{A}{2\pi}\right]$$

wherein Round[] means rounding up or down to the nearest whole number.

46. The method of claim 28, wherein the pattern has a density of the spots within the pattern that varies.

47. The method of claim 28, wherein the pattern is an arc pattern, and wherein the method further comprises:

translating the beam to form additional arc patterns radially outward from the arc pattern; and

focusing the additional arc patterns of spots of the light on the target tissue.

48. The method of claim 28, wherein the spots have varying diameters in the pattern.

49. The method of claim 28, further comprising:

generating an aiming beam of aiming light;

translating the aiming beam to form an enclosed aiming pattern of the aiming light on the target tissue in which the pattern of spots is to be confined.

50. The method of claim 28, further comprising:

generating an aiming beam of aiming light; and

translating the aiming beam to form an aiming pattern of the aiming light on the target tissue that indicates a center position of the pattern of spots.

51. The method of claim 50, wherein the aiming pattern further indicates an outer boundary in which the pattern of spots is to be confined.

52. The method of claim 50, wherein the aiming pattern comprises two or more crossed lines.

53. The method of claim 28, wherein the pattern of spots defines a partially enclosed exclusion zone on the target tissue in which the spots are not incident.

54. The method of claim 28, wherein the pattern of spots comprises a plurality of arc patterns separated from each other.

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