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(54) **Title**: LASER SYSTEM AND METHOD FOR PERFORMING AND SEALING CORNEAL INCISIONS IN THE EYE

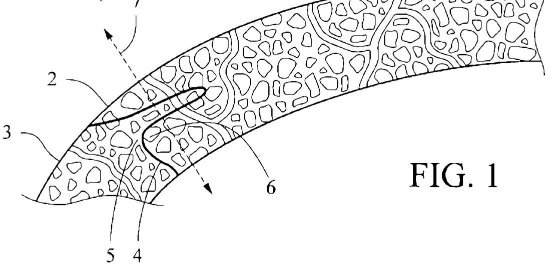

FIG. 1

(57) **Abstract**: There is provided a system, apparatus and methods for developing laser systems that can create precise predetermined self-sealing incisions in the cornea. The systems, apparatus and methods further provide laser systems that can provide these incisions in conjunction with the removal and replacement of the natural human crystalline lens.

WO 2011/011202 A1

LASER SYSTEM AND METHOD FOR PERFORMING AND SEALING CORNEAL INCISIONS IN THE EYE

[0001] Applicants claim, under 35 U.S.C. § 119(e), the benefit of priority of the filing date of July 24, 2009 of U.S. provisional patent application serial number 61/228,484, filed on the aforementioned date, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to methods and systems for improving procedures that address cataracts, opacifications in the lens, clear lens extraction, removal of natural lens material, use of lens replacement materials and combinations of these. Specifically, the present invention relates to systems and methods that provide predetermined, precise and reproducible laser shot patterns for creating incisions in the cornea and for sealing such incisions, and which are made in predetermined and precise shapes that are reproducible from patient to patient and surgeon to surgeon.

Discussion of Related Art

[0003] The established treatment for cataracts is the removal of the opacified human crystalline lens and its replacement with an intraocular lens ("IOL"). In general, IOLs consist of a small plastic lens with plastic side struts, called haptics, to hold the lens in place within the capsular bag inside the eye. Exemplary types of IOLs include monofocal lenses, multifocal IOLs, which provide the patient with multiple-focused vision at far and reading distance, and accommodative IOLs, which provide the patient with visual accommodation. The flexible nature of many IOLs enables them to be rolled and/or folded up for insertion into the capsule. Examples of IOL are found in U.S. Patent Nos. 7,188,949, 6,849,091, 5,699,142 and 5,607,472, the entire disclosures of each of which are incorporated herein by reference. Commercially available IOLs that, by way of example, may benefit from the present invention are CRYSTALENS and ACRYSOF RESTOR.

[0004] The CRYSTALENS IOL was developed by Eyeonics and is presently provided by Bausch & Lomb, and it is at least in part believed to be disclosed in U.S. Patent No. 6,849,091. Further information regarding its structure and efficacy is provided by Food and Drug Administration (FDA) PMA P030002 and related documents to that PMA file. The FDA approved indicated use for CRYSTALENS was in part: "The crystalens™ Model AT-45 Accommodating IOL is intended for primary implantation in the capsular bar of the eye for visual correction of apkakia in adult patients in whom a cataractous lens has been removed and is intended to provide near, intermediate, and distance vision without spectacles. The crystalens™ IOL provides approximately one diopter of monocular accommodation." (November 14, 2003 PMA P030002 at Part 2, Summary of Safety and Effectiveness Data, ¶ INDICATIONS FOR USE).

[0005] Thus, the CRYSTALENS is an example of an FDA approved accommodating IOL. The term "FDA approved accommodating IOL" refers to any IOL that has obtained FDA approval having an indicated use that provides for accommodation, regardless of whether such IOL is actually being employed for such an approved use.

[0006] The ACRYSOF RESTOR IOL is provided by Alcon, and it is at least in part believed to be disclosed in U.S. Patent No. 5,669,142. Further information regarding its structure and efficacy is provided by FDA PMA P040020 and related documents to that PMA file. The FDA approved use for RESTOR was in part: "AcrySOF® ReSTOR® IOLs are indicated for the visual correction of aphakia secondary to removal of a cataractous lens in adult patients with and without presbyopia, who desire near, intermediate and distance vision with increased spectacle independence. The lens is intended to be placed in the capsular bag." (April 24, 2004, PMA P040020, at Part 2, Summary of Safety and Effectiveness Data, ¶ INDICATIONS).

[0007] Thus, the RESTOR is an example of an FDA approved IOL for near, intermediate and distance vision. The term "FDA approved IOL for near, intermediate and distance vision" refers to any IOL that has obtained FDA approval having an indicated use that provides for near, intermediate and distance vision, regardless of whether such IOL is actually being employed for such an approved use. The CRYSTALENS would also be an example of an FDA approved IOL for near, intermediate and distance vision. Moreover, the RESTOR and CRYSTALENS are examples of an FDA approved IOLs that reduce and/or eliminate the need for spectacles.

[0008] The removal of the natural crystalline lens and replacement with a lens replacement material employs the use of small initial incision or incisions in the limbal area of the eye, which is the transition area between the cornea and sclera. This initial incision is typically made with a small triangular blade that is pushed into the limbal area of the eye. It is through this initial incision that other instruments for use in the removal and replacement of natural lens material are inserted and also it is through this incision that the natural lens material is removed from the eye and replacement lens material inserted into the eye.

[0009] Once the initial incision has been made the removal of the opacified natural crystalline lens and replacement with a lens replacement material, such as an FDA approved IOL, presently employs a capsulorhexis and/or a capsulotomy. A capsulorhexis generally consists of the removal of a part of the anterior lens capsule and the creation of a hole or opening in the lens capsule, that results from at least in part a tearing action. A capsulotomy generally consists of a cutting of the lens capsule, without or with minimum tearing of the capsule. Thus, to remove the opacified natural lens material, the lens capsule is opened. There are several known techniques for performing a capsulorhexis and a capsulotomy. These would include the technique known as a can opener approach, a Continuous Curvilinear Capsulorhexis (CCC) and the use of a Fugo plasma blade.

[0010] To date is it believed that all prior techniques and apparatus and in particular all prior FDA approved apparatus for creating the initial incision into the cornea of the eye have to varying degrees given rise to surgeon-to-surgeon and patient-to-patient irregularities. These irregularities have given rise to slower or less desirable wound healing and results. Moreover, it is believed that all of these prior techniques and apparatus, which are performed by hand, in general can only produce cuts or holes that are essentially simple and planar in nature. Further, because these are hand held devices the shape of these cuts may vary from patient-to-patient and surgeon-to-surgeon. Thus, it is not believed that these hand held devices and non-automated techniques can provide the precise predetermined techniques and cuts of the present invention.

SUMMARY

[0011] It is desirable to develop systems that would reduce, eliminate or correct these undesirable features, provide greater control in the creation of the incisions and make these improvements patient and surgeon independent, or at least, reduce the variability from patient-to-patient and surgeon-to-surgeon, associated with the formation of these undesirable features that is found with the use of present techniques and tools.

[0012] The novel and improved methods and systems for the performance of incisions in the sclera, limbus and cornea, which comprise aspects of the present inventions and which are set forth in detail in the present patent specification, may provide for better implementation of other methods and systems for delivering laser beams to the lens of the eye, such as those disclosed in published applications US 2007/173794A1, US 2007/173795A1, US 2007/185475A1, WO 2007/084694 A2, and WO 2007/084627A2 the entire disclosures of each of which are incorporated herein by reference.

[0013] The present invention, among other things, solves this need by providing greater control in the creation of precise and predetermined incision to the sclera, limbus and cornea. Thus, there is provided herein a system and method to perform as disclosed and claimed here in.

[0014] One of ordinary skill in the art will recognize, based on the teachings set forth in these specifications and drawings, that there are various embodiments and implementations of these teachings to practice the present invention. Accordingly, the embodiments in this summary are not meant to limit these teachings in any way.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 is a schematic diagram of a first embodiment of a limbal area pattern and resultant cut in accordance with the present invention.

[0016] FIG. 2 is a schematic diagram of a second embodiment of a limbal area pattern and resultant cut in accordance with the present invention.

[0017] FIG. 3 is a schematic diagram of a third embodiment of a limbal area pattern and resultant cut in accordance with the present invention.

[0018] FIG. 4 is a schematic diagram of an embodiment of a system for delivering a laser beam to the lens of an eye in accordance with the present invention to produce the limbal area patterns and cuts shown in FIGS. 1-3.

DESCRIPTION OF THE DRAWINGS AND THE PREFERRED EMBODIMENTS

[0019] In general, the present inventions relate to methods and systems for providing a laser to the cornea of the eye to address, improve and procedures relating to the removal of the natural crystalline lens and replacement of that lens with lens replacement material, and more specifically to improvements in systems and methods related to cataract surgery. In particular, the present inventions relate to methods and systems for providing self sealing incisions to the eye which incisions may be used as a way to insert instruments into the eye and to remove material from the eye, and to provide increased healing of these particular incisions, as well as, other types of corneal incisions.

[0020] The present methods and systems described herein can be used with the novel and innovative laser system techniques that are the subject of the co-pending patent applications that are cited herein and which have been incorporated herein by reference, and the present methods and systems may possibly be used with other laser delivery systems for the removal of lens material to the extent such systems may be developed in the future. Preferably, the present methods and systems can be incorporated into and used in conjunction with the systems of the co-pending applications that have been incorporated herein by reference. In this way a single system, with a single therapeutic laser, can function as a start to finish device for performing the cuts necessary to remove and replace the natural lens.

[0021] Novel and pioneering laser systems and methods for the removal and replace of lens material are disclosed in regular and provisional U.S. patent applications: serial number 61/228,506; serial number 61/228,529; serial number 61/228,514; serial number 12/509,412; and serial number 12/509,211, the entire contents of each of which are incorporated herein by reference.

[0022] Thus, in general the present invention provides for a laser system, i.e., a laser device for delivering a laser to the cornea of the eye. In general, the laser system has a treatment or therapeutic laser, optics for delivering the laser beam from the treatment laser to the eye, and a particular pattern which provides for the placement of treatment laser shots in the cornea to create precise and predetermined incisions in that material, which incisions are for the purpose of inserting instruments and material into and from the eye. The patterns and resultant incisions are made in general by creating a single cut having an anterior point or opening located at or near the limbus and a posterior point or opening located at or near Descement's membrane, which results in two sides or side pieces. It is theorized that each piece is shaped in a manner that provides for physical interaction between the pieces, creating a locking and/or tongue and groove effect. Additionally, because the incisions of the present invention have a total length that is greater then a straight incision along the same general path, i.e., from posterior opening to anterior opening, and thus have greater surface area between the two sides, it is theorized that this increased surface area promotes quicker healing. In this way after the incision is physically opened with instruments for the insertion and removal of material from the eye and in particular the natural lens of the eye, upon removal of the instrument the incision will close and the physical shape of the sides of the incision will result in the self-sealing of the incision.

[0023] Referring now to FIG. 1 there is provided an example of a self-sealing pattern and resultant incision of the present invention. Accordingly, there is shown in a schematic representation the cornea 1, the limbus 2 and sclera 3. A shot pattern 4 is provided, which when delivered to the eye results in an incision of the same shape. The incision has two sides 5 and 6. When viewed along the anterior to posterior axis of the incision, axis arrow 7, it is seen that the incision loops back on top of itself. Thus the incision crosses its anterior to posterior axis at least twice. This would be an example of a tongue and groove type of pattern. Further, the angle of the cut with respect to the surface of the eye at the anterior point or opening of the cut resulting from pattern 4 is very shallow, i.e., it is less than 90 degrees, preferably less than about 45 degrees and more preferably less than about 30 degrees. The angle of the cut with respect to the posterior surface of the cornea, and in particular Descement's membrane, at the posterior point or opening of the cut resulting from pattern 4 is about 90 degrees and more preferably about 75 degrees to about 105 degrees.

[0024] Referring now to FIG. 2 there is provided an example of a self-sealing pattern and resultant incision of the present invention. Accordingly, there is shown in a schematic representation the cornea 1, the limbus 2 and sclera 3. A shot pattern 8 is provided, which when delivered to the eye results in an incision of the same shape. The incision has two sides 9 and 10. When viewed along the anterior to posterior axis of the incision, axis arrow 7, it is seen that the incision loops back on top of itself. Thus the incision crosses its anterior to posterior axis at least three times. This would be an example of a tongue and groove type of pattern. If can further be seen that the side 10 has a finger section 11 extending into side 9. This finger section 11 has a narrow portion 12 and a wide portion 13. It can further be seen that the portion 13 is wider than the narrow portion 12, thus providing added locking force to this tongue and groove configuration.

[0025] Referring now to FIG. 3 there is provided an example of a self-sealing pattern and resultant incision of the present invention. Accordingly, there is shown in a schematic representation the cornea 1, the limbus 2 and sclera 3. A shot pattern 14 is provided, which when delivered to the eye results in an incision of the same shape. The shot pattern has an anterior start point 19 and a posterior end point 20, which is located in Descement's membrane. The length of the incision is substantially greater than the length of a straight line drawn between points 19 and 20. The use of the terms "start" and "end" are solely for special identification purposes and are not intend to require that the cut be made from the anterior to the posterior. The incision has two sides 15 and 16. When viewed along the anterior to posterior axis of the incision, axis arrow 7, it is seen that the incision loops back on top of itself. Thus the incision crosses its anterior to posterior axis at least three times. This would be an example of a tongue and groove type of pattern. If can further be seen that side 15 has finger section 17 and side 16 has finger section 18 and 16 have finger section 11 extending into side 9. Unlike finger section 11, finger sections 17, 18 do not have narrow and wide portions.

[0026] In general a preferred laser system, *i.e.,* a laser device, for treating patients is provided as shown by way of example in FIG. 4. In this system there is provided a treatment laser 101; optics 102 for delivering the laser beam 104; a control system 103 for delivering the laser beam to the lens in a particular pattern, which control system 103 is associated with and/or interfaces with the other components of the system, as shown for example by dashed lines in FIG. 4, and/or other control systems not shown in FIG. 4.

[0027] In general, a laser system for providing the pattern and creating the resultant cuts in the cornea has by way of example and referring to FIG. 4 a treatment laser 101 which should provide a beam 104. The beam should be of a short pulse width, together with the energy and beam size, to produce photodisruption. Thus, as used herein, the term laser shot or shot refers to a laser beam pulse delivered to a location that results in photodisruption. As used herein, the term photodisruption essentially refers to the conversion of matter to a gas by the laser. The term photodisruption has also been generally refered to as Laser Induced Optical Breakdown (LIOB). In particular, wavelengths of about 300 nm to 2500 nm may be employed. Pulse widths from about 1 femtosecond to 100 picoseconds may be employed. Energies from about a 1 nanojoule to 1 millijoule may be employed. The pulse rate (also referred to as pulse repetition frequency (PRF) and pulses per second measured in Hertz) may be from about 1 KHz to several GHz. Generally, lower pulse rates correspond to higher pulse energy in commercial laser devices. A wide variety of laser types may be used to cause photodisruption of ocular tissues, dependent upon pulse width and energy density. Thus, examples of such lasers are disclosed in 2007/084694 A2 and WO 2007/084627A2, which are incorporated herein by reference. These and other similar lasers may be used a therapeutic lasers. For procedures on the cornea, limbus and area where the cornea and sclera join the same type of therapeutic laser as described herein may be used, with the energy and focal point being selected to perform the desired procedure.

[0028] In general, the optics 102 for delivering the laser beam 104 to the structures of the eye including the cornea and the natural lens of the eye should be capable of providing a series of shots in a precise and predetermined pattern in the x, y and z dimension. The z dimensions as used herein refers to that dimension which has an axis that corresponds to, or is essentially parallel with the A-P axis of the eye. The optics should also provide a predetermined beam spot size to cause photodisruption with the laser energy reaching the structure of the eye intended to be cut.

[0029] In general, the control system 103 for delivering the laser beam 104 may be any computer, controller, and/or software hardware combination that is capable of selecting and controlling x-y-z scanning parameters and laser firing. These components may typically be associated at least in part with circuit boards that interface to the x-y scanner, the z focusing device and/or the laser. The control system may also, but does not necessarily, have the further capabilities of controlling the other components of the system, as well as, maintaining data, obtaining data and performing calculations. Thus, the control system may contain the programs that direct the laser through one or more laser shot patterns. Similarly, the control system may be capable of processing data from the slit scanned laser and/or from a separate controller for the slit scanned laser system.

[0030] The laser optics 102 for delivering the laser beam 104 includes a beam expander telescope 105, a z focus mechanism 106, a beam combiner 107, an x-y scanner 108, and focusing optics 109. There is further provided relay optics 110, camera optics 111, which include a zoom, and a first ccd camera 112.

[0031] Optical images 113 of the eye 114 and in particular optical images of the natural lens 115 of the eye 114 are conveyed along a path 113. This path 113 follows the same path as the laser beam 104 from the natural lens 115 through the laser patient interface 116, the focusing optics 109, the x-y scanner 108 and the beam combiner 107. There is further provided a laser patient interface 116, and a structured light source 117 and a structured light camera 118, including a lens. Examples of patient interface and related apparatus that are useful with the present system are provided in provisional and regular U.S. patent applications serial number 12/509,021, and serial number 61/228,457, wherein the entire disclosures of each of which are incorporated herein by reference.

[0032] The structured light source 117 may be a slit illumination having focusing and structured light projection optics, such as a Schafter+Kirchhoff Laser Macro Line Generator Model 13LTM+90CM, (Type 13LTM-250S-41 + 90CM-M60-780-5-Y03-C-6) or a StockerYale Model SNF-501L-660-20-5, which is also referred to as a slit scanned laser. In this embodiment the structured illumination source 117 also includes slit scanning means 119.

[0033] When using a scanned slit illumination the operation includes positioning the slit on one side of the lens, taking an image then moving the slit approximately one slit width, then taking another image, and then repeating this sequence until the entire lens is observed. For example, a 100 µm slit width can scan a nominal 9 mm dilated pupil diameter in 90 images, which takes approximately 3 seconds using a 30 Hz frame rate camera. To obtain images of the anterior surface in a single image without overlap, the slit should be at an angle to the AP axis, i.e., it should not be parallel to that axis. The nominal slit angle can be approximately 15 to 30 degrees from the AP axis. Any visible or near IR wavelength source within the sensitivity of the camera may be used. Low coherence length sources are preferable to reduce speckle noise.

[0034] The structured light illumination source 117 and the structured light camera 118 are arranged in an angled relationship. The angled relationship may be but is not required to be in the so-called Scheimpflug configuration, which is well-known. The structured light source 117, in conjunction with the slit scanning means 119, projects a line and or a plurality of lines onto the eye lens 115 at an angle or plurality of angles. The light scattered at the eye lens 115 forms the object to be imaged by the lens and focused onto the camera system 118. Since the slit illuminated image in the eye lens 115 may be at a large angle with respect to the camera 118, this presents a large depth of field to the camera and the entire slit image may not be in sharp focus at the camera. By tilting the camera at an angle or plurality of angles the image along the illuminated plane can be in sharper focus. To the extent that a shaper focus is not obtained, arithmetic data evaluation means are further provided herein to determine a more precise location of the illuminated structures with respect to the laser device.

[0035] The images from the camera 118 may be conveyed to the controller 103 for processing and further use in the operation of the system. They may also be sent to a separate processor and/or controller, which in turn communicates with the controller 103. The structured light source 117, the camera 118 and the slit scanning means 119 includes a means for determining the position and apex of the lens in relation to the laser system.

[0036] The delivery of laser shot patterns and cuts per FIGS. 1-3 for the removal of lens material is provided. Thus, there are provided methods and systems for producing cuts, *i.e.*, incisions in the anterior lens capsule. These cuts are created by the therapeutic laser beam 104 being delivered to the anterior lens capsule in precise predetermined and highly reproducible patterns, delivery results in precise predetermined and highly reproducible shaped cuts in patterns as described and taught herein, or as may be called for by the use of a particular IOL or other device or material to be inserted within the lens capsule. As used herein geometric shaped patterns or cuts referrer to circular and elliptical shaped patterns or cuts. As used herein non-geometric shaped patterns or cuts refers to all other shapes that are not circular or elliptical.

[0037] The methods and systems to create these cuts in the anterior capsule provide superior results to the handheld methods and apparatus previously known for performing capsulorhexus and capsulotomy, and thus, the methods *and* systems disclosed herein are considered to be a substantial advancement in these techniques. In addition the delivery of the laser beam shots in a manner that greatly reduces the risk of a missed cut, which depending upon the particular application may be very significant is provided. Moreover, as provided in the following examples, anterior capsule cuts are envisioned and provided that may be a continuous cuts, cuts and lands (uncut capsule portions between cuts) and perforations. Thus, as used herein the terms "missed cut" or "missed cuts" refer to a cut that was intended to be carried out by the delivery of a particular laser shot pattern, but which did not occur because the laser beam missed the lens capsule or targeted lens material. Thus, in a cut and land pattern the lands would not be considered missed cuts, if they were intended to be left uncut by the laser pattern.

[0038] The cuts in the lens anterior surface are for the purpose of creating an opening in the lens capsule for the remove of the interior structures of the lens. To facilitate this removal there are provided various laser shot patterns that cut the interior structure of the lens into small volumes, which volumes can then be removed from the lens capsule. These small volumes can range from about 1 mm^2 to about 16 mm^2 and more preferably from about 2.5 mm^2 to about 4 mm^2. Thus a grid laser shot pattern within the interior structures of the lens, which creates cube shaped volumes of interior lens material, can be employed. These cubes can range in size from a side having a length of about 100 μm to about 4 mm, with about 500 μm to 2 mm being a preferred size. Additionally, this invention is not limited to the formation of cubes and other volumetric shapes of similar general size may be employed. For example arrangement of other shapes such as triangles and pie sliced volumes may be employed.

[0039] The laser cut in the anterior capsule is used to create a small opening in the lens anterior surface of the lens capsule for removal of the sectioned volumes of interior material. Thus, this procedure may be used to treat cataracts. This procedure may also be used to remove a lens having opacification that has not progressed to the point of being cataractous. This procedure may further be used to remove a natural lens that is clear, but which has lost its ability to accommodate. In all of the above scenarios, it being understood that upon removal of the lens material the lens capsule would subsequently house a suitable replacement, such as an IOL, accommodative IOL, or synthetic lens refilling materials. Moreover, the size and the shape of the opening is variable and precisely controlled and preferably for presently know lens refilling materials and IOLs is 2 mm or less diameter for lens refilling applications and about 5 mm for IOLs.

[0040] The order in which these activities are performed may depend upon the particular characteristics of the internal lens structure, the density of the cataract, the position of the cataract, the type of device used to remove the internal lens material once it has been sectioned into small volumes, the type and power of the laser used, the amount and size of gas bubbles that are produced by the laser, and other factors. Thus, although the examples herein provide for an order of performing the activity of cutting the anterior surface of the lens and sectioning the interior structures of the lens, it should be recognized that this order can be changed, as well as, performed essentially simultaneously or simultaneously.

[0041] The preferred laser system for treating patients is capable of making precise and predetermined cuts in the capsule of the lens thus giving rise to capsulotomies that are of precise and predetermined shapes. Thus, there is provided the method of obtaining and analyzing the shape and structure of an IOL, and in particular obtaining and analyzing the shape and structure of an accommodating IOL, an IOL that reduces and/or eliminates the need for spectacles, and/or an IOL for near, intermediate and distance vision, including but limited to FDA approved versions of the IOLs. Based upon this analysis an optimized shape and position for the capsulotomy for use with a particular IOL, or grouping of similarly shaped IOLs, is determined. A predetermined shot pattern for making this optimized shaped capsulotomy is then provided to the laser system, preferably by providing the shot pattern to the control system 103. The laser system can then be used for an one or all of the following procedures, determining the shape and position of the anterior surface of the lens, and in particular the anterior surface of the lens capsule, determining the apex of the lens capsule in relation to the laser system, performing a laser capsulotomy having the precise and predetermined shape selected for a particular type of IOL, and removal of the natural lens material.

[0042] Thus, there is provided techniques, systems and apparatus to deliver laser beam in a shot pattern to the lens of the eye and in particular to the capsule of the lens of the eye in a precise and predetermined manner to provided for a precise predetermined capsulotomy. The shape of these patterns may be delivered using either the jigsaw or ring delivery sequences.

[0043] When performing laser assisted cataract surgery the process of cutting the nucleus with a photodisruption laser can cause a buildup of gas bubbles sufficiently near the soft cortex to allow the gas bubbles to propagate toward the capsule. In those situations where bubbles collect in close proximity to the anterior capsule, when the laser attempts to cut the capsulotomy, the sudden release of bubbles my change the position of the anterior capsule during the delivery of the laser shot pattern causing the laser to miss the capsule resulting in missed cuts, at least partially around the circumference of the capsulotomy. To solve this problem, there is provided herein a special cutting pattern that is less dependent of capsule position versus time and provides cutting of the capsule despite position changes of the capsule during the laser capsulotomy procedure. Thus, resulting in substantially reduced or no missed cuts.

[0044] There is further provided herein the use of laser shot patterns having a large range of Z swept at a high rate of speed, while the X-Y position is moved in a circular, or elliptical or other pattern or desired shape, more slowly so that the laser cutting action occurs multiple times over essentially the same X-Y position. Thus, it could be envisioned that the laser beam is operating like the tip of a jigsaw blade moving up and down rapidly compared to the X-Y positioning to create the cut shape. In this way, if the anterior capsule shifts during the cut, due to gas bubble propagation or any other reason, the cut will still be made to the capsule, albeit perhaps outside the center region of the z direction up-down distribution of shots, and more to the anterior or posterior ends of that distribution. For laser cutting of the nucleus where a great deal of bubble buildup is created, a Z range, or up-down range of the cut should be approximately 1mm in extent, nominally centered on the anterior capsule which would allow approximately +/- 475 μm of capsule movement and still provide cutting of a 25 μm thick capsule.

[0045] In addition to enabling cutting of a capsule that moves during the procedure, this procedure can be used to compensate for static errors in capsule position due to for example measurement errors. In this way the extent of the Z range may be increased by the known error of the system.

[0046] In addition to the large Z range sweeps disclosed herein, there is also contemplated the use of a smaller Z range of cut motion for the case where the uncertainty in capsule position from both static measurement error and anticipated change in position might be smaller, perhaps in the range of hundreds of μm or in the case of highly precise measurement data and near zero movement of the capsule during surgery. In such a case the Z range could be tens of μm -- enough range to cut through the capsule thickness.

[0047] Further methods and systems to define a high accuracy position measurement of structures of the eye and in particular the anterior capsule, so as to provide in general greater accuracy, precisions and reproducibility from patient to patient for procedures on the eye and in particular capsulotomies, is provided in regular U.S. patent application serial number 12/509,412, wherein, the entire disclosure of which is incorporated herein by reference.

[0048] In the laser shot patterns provided herein it is preferred that the placement of individual shots with respect to adjacent shots in the pattern are sufficiently close enough to each other, such that when the pattern is complete a sufficiently continuous layer and/or line and/or volume of material has been removed. Shot spacing of lesser or greater distances are contemplated herein and including overlap as necessary to obtain the desired results. Shot spacing considerations include gas bubble dissipation, volume removal efficiency, sequencing efficiency, scanner performance, and cleaving efficiency among others. For example, by way of illustration, for a 5 μm size spot with an energy sufficient to cause photodisruption, a spacing of 20 μm or greater results in individual gas bubbles, which are not coalesced and dissipate more quickly, than with close shot spaces with the same energy, which result in gas bubble coalescence. As the shot spacing gets closer together volume efficiency increases. As shot spacing gets closer together bubble coalescence also increases. Further, there comes a point where the shot spacing becomes so close that volume efficiency dramatically decreases. Moreover, the forgoing shot spacing considerations are interrelated to a lesser or greater extent and one of skill in the art will know how to evaluate these conditions based upon the teachings of the present disclosure to accomplish the objectives herein. Finally, it is contemplated that the placement of individual shots with respect to adjacent shots in the pattern may in general be such that they are as close as possible, typically limited by the size and time frame of photodisruption physics, which would include among other things gas bubble expansion of the previous shot. As used herein, the time frame of photodisruptive physics referrers to the effects that take place surrounding photodisruption, such as plasma formation and expansion, shock waive propagation, and gas bubble expansion and contraction. Thus, the timing of sequential pulses such that they are timed faster than some of, elements of, or all of those effects, can increase volumetric removal and/or cleaving efficiency. Accordingly, it is proposed to use pulse repetition frequencies from 50 MHz to 5 GHz, which could be accomplished by a laser with the following parameters: a mode lock laser of cavity length from 3 meters to 3 cm. Such high PRF lasers can more easily produce multiple pulses overlapping a location allowing for a lower energy per pulse to achieve photodisruption.

[0049] The terms first, second, third, etc. as used herein are relative terms and must be viewed in the context in which they are used. They do not relate to timing, unless specifically referred to as such. Thus, a first cut may be made after a second cut. In general, it is preferred to fire laser shots in general from posterior points in the laser pattern to anterior points, to avoid and/or minimize the effect of the gas bubbles resulting from prior laser shots. However, because of the varied laser shot patterns that are provided herein, it is not a requirement that a strict posterior to anterior shot sequence be followed. Moreover, in the case of cataracts it may be advantageous to shoot from anterior to posterior, because of the inability of the laser to penetrate substantially beyond the cataract.

[0050] An additional benefit from this type of laser system may be obtained. Shots or pulses from this laser can be distributed throughout the cornea in a plane or series of planes that are perpendicular to the A-P axis of the eye. These planes will cause a wound healing effect, creating myacin. Additionally, the creation of myacin will cause a cross linking of the cornea collagen which will have the tendency to shrink the area treated with the plane of shots, which in turn tends to flatten the curvature of the cornea providing the added benefit of correcting low levels of myopia.

[0051] From the foregoing description, one skilled in the art can readily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and/or modifications of the invention to adapt it to various usages and conditions.

What is claimed:

1. A system for providing laser shot patterns to an eye, the system comprising:

a therapeutic laser for producing a laser beam; and

optics for receiving the laser beam and directing the laser beam to an eye so that: 1) a laser shot pattern for performing a capsulotomy is generated on the eye, 2) a laser shot pattern for sectioning a lens of an eye is generated on the eye; and 3) a laser shot pattern for providing an incision in a cornea of the eye, the incision having an anterior start point and a posterior end point, and a length of the incision being substantially greater than a distance between the anterior start point and the posterior end point.

2. The system of claim 1 wherein the laser shot pattern for providing an incision in the cornea of the eye is a tongue and groove pattern.

3. The system of claim 1 wherein the laser shot pattern for providing an incision in the cornea of the eye is a locking tongue and groove pattern.

4. The system of claim 1 wherein the laser shot pattern for providing an incision in the cornea of the eye comprises an anterior posterior axis and crosses the anterior posterior axis at least twice.

5. The system of claim 1 wherein the laser shot pattern for providing an incision in the cornea of the eye corneal pattern comprises an anterior posterior axis and crosses the anterior posterior axis at least three times.

6. The system of claim 1 wherein the poster end point is in Descement's membrane of the eye.

7. The system of claim 1 wherein an angle of the incision in the cornea of the eye at the anterior start point with respect to an anterior surface of the cornea is shallow.

8. The system of claim 1 wherein an angle of the incision in the cornea of the eye at the posterior end point with respect to a posterior surface of the cornea is about 90 degrees.

9. A system for providing a laser beam shot pattern to an eye, the system comprising:

a laser for providing a laser beam;

a controller in communication with the laser and controlling the laser beam so as that a shot pattern is generated on an eye, wherein the shot pattern comprises a pattern for providing an incision in a cornea of the eye, the incision having an anterior start point and a posterior end point, the posterior end point positioned in Descement's membrane of the eye and a length of the incision being greater than a distance between the anterior start point and the posterior end point.

10. A system for providing a laser beam shot pattern to an eye, the system comprising:

a laser for providing a laser beam;

a controller in communication with the laser and controlling the laser beam so that a shot pattern is generated on an eye, wherein the shot pattern comprises a pattern for providing an incision in a cornea of the eye, the incision having a locking tongue and groove pattern.

11. A system for providing a self-sealing incision to an eye, the system comprising:

a laser for providing a laser beam;

a controller in communication with the laser and controlling the laser beam so that a shot pattern is generated on an eye, wherein the shot pattern comprises a pattern for providing a self-sealing incision in a cornea of the eye.

12. The system of claim 11 wherein the pattern for providing a self-sealing incision is a tongue and groove pattern.

13. The system of claim 11 wherein the pattern for providing a self-sealing incision is a locking tongue and groove pattern.

14. The system of claim 11 wherein the pattern for providing a self-sealing incision comprises an anterior posterior axis and crosses the anterior posterior axis at least twice.

15. The system of claim 11 wherein the pattern for providing a self-sealing incision comprises an anterior posterior axis and crosses the anterior posterior axis at least three times.

16. A method for performing cataract surgery stimulating corneal wound healing, using a laser system, the method comprising:

positioning an eye of a patient with respect to a laser system;

directing the laser system to create an incision in a cornea of the eye;

directing the laser system to perform a capsulotomy on the eye; and

directing the laser system to deliver a planer shot pattern to an area of the incision in the cornea of the eye, thereby promoting wound healing.

17. A method for performing cataract surgery stimulating corneal wound healing, using a laser system, the method comprising:

positioning an eye of a patient with respect to a laser system;

creating an incision through a cornea of the eye having a posterior end point in Descement's membrane of the eye;

directing the laser system to perform a capsulotomy on the eye; and

directing the laser system to deliver a planer shot pattern to an area of the incision of the eye, thereby promoting wound healing.

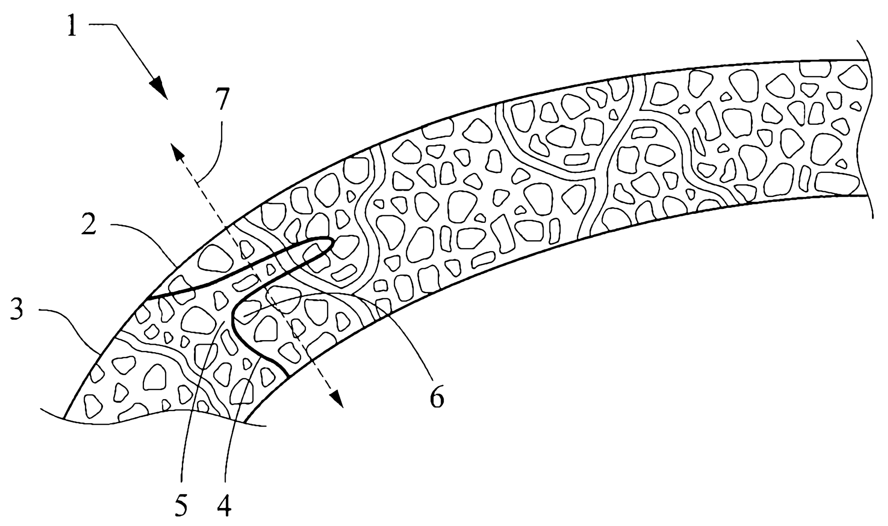

FIG. 1

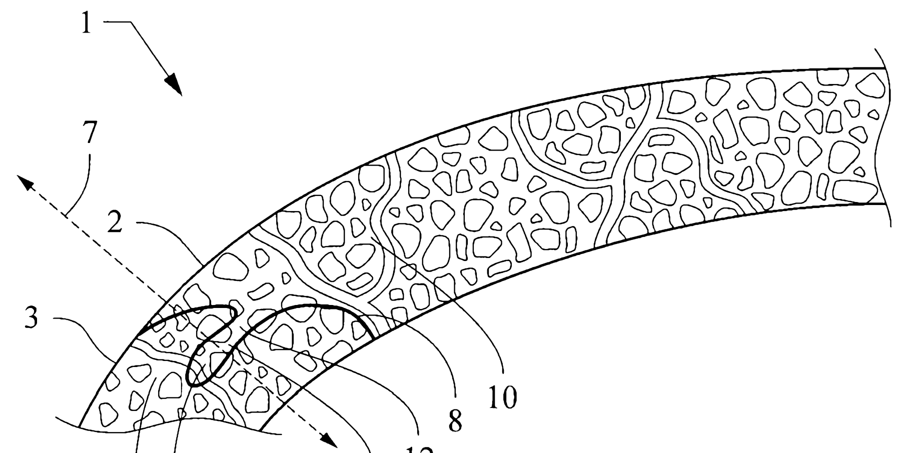

FIG. 2

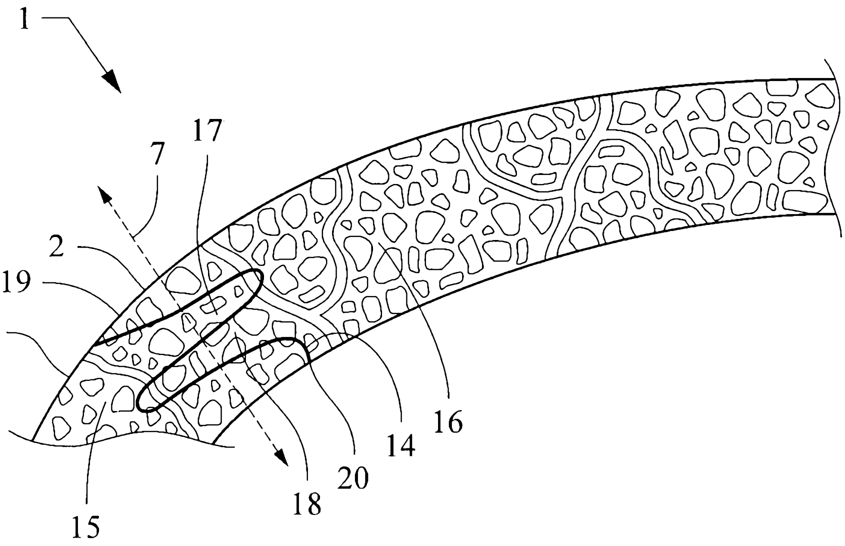

FIG. 3

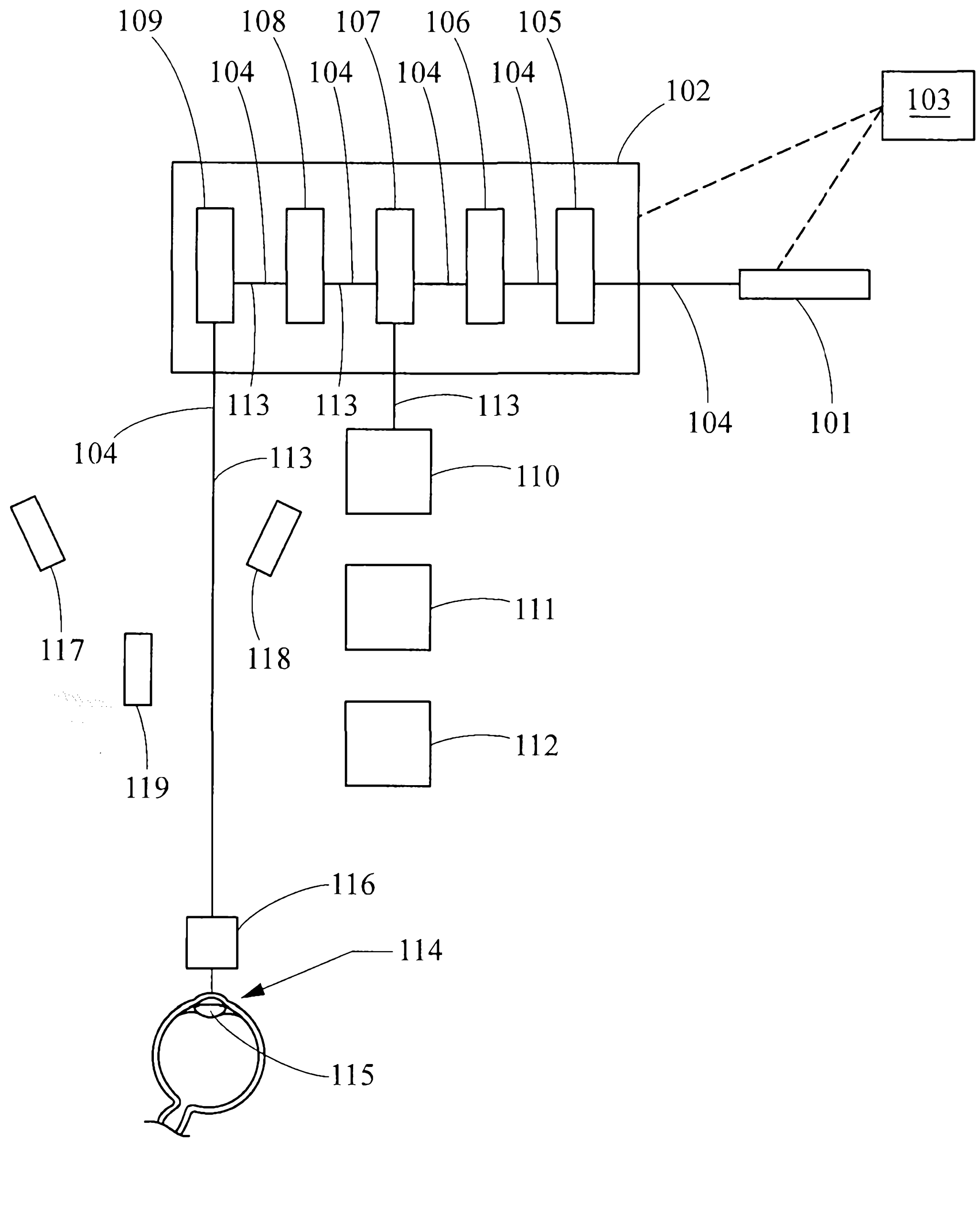
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FIG. 4