A system/method allowing hydrophilicity alteration of a polymeric material (PM) is disclosed. The PM hydrophilicity alteration changes the PM characteristics by decreasing the PM refractive index, increasing the PM electrical conductivity, and increasing the PM weight. The system/method incorporates a laser radiation source that generates tightly focused laser pulses within a three-dimensional portion of the PM to affect these changes in PM properties. The system/method may be applied to the formation of customized intraocular lenses comprising material (PLM) wherein the lens created using the system/method is surgically positioned within the eye of the patient. The implanted lens refractive index may then be optionally altered in situ with laser pulses to change the optical properties of the implanted lens and thus achieve optimal corrected patient vision. This system/method permits numerous in situ modifications of an implanted lens as the patient’s vision changes with age.
FIG. 1

Prior Art
FIG. 4

Prior Art
FIG. 5

- Laser Source 0511
- Acousto-Optic Modulator (AOM) 0512
- Laser Scanner 0513
- Microscope Objective 0514
- Polymeric Lens Material (PLM) 0501
- Sample Staging/Positioning 0516
- Computer Control System 0520
- GUI 0523
- Operator 0524
- Computer 0521
- Hard Drive 0522

Flow of light: 0500 → 0511 → 0512 → 0513 → 0514 → 0501 → 0516
FIG. 6

Lens Formation System
Laser Source
Laser Scanner
Microscope Objective

Operator

Patient Eye Examination

Map of Optical Correction Necessary

Laser pulse/position control to change refractive index of PLM within in situ patient lens to fully correct vision
FIG. 7

0701 Laser
0702 Dispersion Compensator
0703 Beam Shaping I
0704 AOM
0705 Beam Shaping II
0706 Diagnostics
0707 Laser Microscope Coupling (Mirror Arm)
0708 Camera System
0709 Scanner
0710 Z Module
0711 Objective
0712 Objective and Sample Interface
0713 Sample
0714 Positioning System

0720 Computer & I/O System

0722
Prior Art
(using convex lens for optical convergence)

Present Invention
(using concave lens for optical convergence)
FIG. 9

Polymer 0913
Hydrophilic Region 0912

Hydrophilic 0923
Polymer 0922
FIG. 10

Convex Lens 1001

Biconvex Lens 1002
FIG. 12

Phase Wrapping Convex Lens

Phase Wrapping Concave Lens

Phase Wrapping Lens Stack Example

Phase Wrapping Lens Concept
FIG. 13

Refractive Index Gradient Lens
1301

Refractive Index Gradient Lens (Side View)
1302
FIG. 14

1400 PLM Hydrophilicity Alteration Method

1401 Generate pulsed laser radiation from a laser radiation source

1402 Distribute the focused laser light output across an input area of a microscope objective

1403 Accept the distributed pulsed laser radiation into a numerical aperture within the microscope objective to produce focused laser radiation

1404 Transmit the focused laser radiation into a polymeric lens material (PLM) to modify the hydrophilicity within the PLM
FIG. 15

1500  Lens Shaping/Formation Method

1501  Execute lens calculations to determine the form and structure of lens

1502  Select laser wavelength suitable for hydrophilicity change

1503  Shutter and/or power regulate laser using AOM or equivalent modulator

1504  Scan laser across microscope objective

1505  Form laser spot size and precisely position using microscope objective

1506  Retain/hold sample for hydrophilicity alteration

1507  Optionally position target sample using X/Y/Z positioning system

1508  End
FIG. 16

1600 - Lens Calculation Method

1601 - Measure required lens properties

1602 - Select lens material

1603 - Calculate lens curvature

1604 - Calculate phase wrapping lens information

1605 - Create output images

1606 - Treatment Area > Field Size?
   Yes → 1607 - Chop images according to field size
   No

1608 - Does patient require additional lens properties?
   Yes

1609 - End
FIG. 17

1700

1.33mm

14.35mm

1.91mm
FIG. 18

Weight Gain Due to Water Absorption

<table>
<thead>
<tr>
<th>Sample Condition</th>
<th>Weight [mg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Weight</td>
<td>37</td>
</tr>
<tr>
<td>Soaked</td>
<td>37.5</td>
</tr>
<tr>
<td>1st Shaping</td>
<td>38</td>
</tr>
<tr>
<td>2nd Shaping</td>
<td>38.5</td>
</tr>
<tr>
<td>3rd Shaping</td>
<td>39</td>
</tr>
</tbody>
</table>
FIG. 21

Efficiency vs. Scan Speed

![Graph showing efficiency vs. scan speed](image-url)
FIG. 30

Air Vs. Water Storage

Days After Shaping

Lens Diopter [D]

Initially Shaped in Water
Air Dried
Placed in Water
FIG. 33

3300
In-Vivo Lens Shaping Method

3391
Preparation

3392
Lens Data Creation

3393
Patient Interface

3394
Start Initialization

3395
Diagnostics

3396
Lens Shaping

3397
Verification

FIG. 34 (3400)
FIG. 35 (3500)
FIG. 36 (3600)
FIG. 37 (3700)
FIG. 38 (3800)
FIG. 39 (3900)
FIG. 40 (4000)
FIG. 34

3400 Preparation

3401 Patient existing lens material determination

3402 Patient aberration measurement

3403 Patient selects which aberrations need treatment

FIG. 35 (3500)
FIG. 35

3500 - Lens Data Creation

3504 - Doctor selects needed lens information and lens material

3505 - Lens information exists?

3506 - Calculate curvature

3507 - Determine phase weighting height

3508 - Phase wrapping lens creation

3509 - Data output file creation

3510 - Data loading to system

FIG. 36

(3600)
FIG. 36

3600 Patient Interface

3611 Patient is positioned towards the system

3612 Doctor positions the objective towards the patient's iris

FIG. 37 (3700)
FIG. 37

3700 - Start Initialization

3713 - Doctor enters the Patient ID in the system

3714 - Doctor verifies information and selects START

FIG. 38 (3800)
FIG. 38

3800 — Diagnostics

3815 — System checks if laser wavelength is correct

3816 — System checks if energy stable

3817 — System checks if pulse width stable

FIG. 39
(3900)
FIG. 39

3900 Lens Shaping

3918 Z module is used for the Z positioning of the focus spot

3919 Scanner is used for the focus spot position

3920 AOM is used for the energy distribution

FIG. 40 (4000)
FIG. 40

4000 Verification

4021 New lens diopter is verified

FIG. 33
(3300)
FIG. 41

- Manufacturing Custom Lens Shaping Method
- Preparation
- Lens Data Creation
- Positioning
- Start Initialization
- Diagnostics
- Lens Shaping
- Verification / shipping
FIG. 42

4200 Preparation

4201 Patient selects lens material

4202 Patient aberration measurement

4203 Patient selects which aberrations need treatment

FIG. 43 (4300)
FIG. 43

4300 Lens Data Creation

4304 Doctor selects needed lens information and lens material

4305 Lens information exists? No

4306 Calculate curvature

4307 Determine phase weighting height

4308 Phase wrapping lens creation

4309 Data output file creation

4310 Data loading to system

FIG. 44
(4400)
FIG. 44

4400 Positioning

4411 Lens/blank is positioned in the manufacturing system

FIG. 45 (4500)
FIG. 45

4500  Start Initialization

4512  Technician enters the Customer ID

4513  Technician verifies information and selects START

FIG. 46 (4600)
FIG. 46

4600  Diagnostics

4614  System checks if laser wavelength is correct

4615  System checks if energy stable

4616  System checks if pulse width stable

FIG. 47 (4700)
FIG. 47

4700  Lens Shaping

4717  Z module is used for the Z positioning of the focus spot

4718  Scanner is used for the focus spot position

4719  AOM is used for the energy distribution

4720  A X and Y stage system is used to support a larger treatment area

4721  A Z stage is used to allow the movement between layers

FIG. 48 (4800)
FIG. 48

4800 Verification and shipping

4822 New lens diopter is verified

4823 Lens is packaged and shipped to doctor

FIG. 41 (4100)
HYDROPHILICITY ALTERATION SYSTEM AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS


PARTIAL WAIVER OF COPYRIGHT

[0002] All of the material in this patent application is subject to copyright protection under the copyright laws of the United States and of other countries. As of the first effective filing date of the present application, this material is protected as unpublished material.

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STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0004] Not Applicable

REFERENCE TO A MICROFICHE APPENDIX

[0005] Not Applicable

FIELD OF THE INVENTION

[0006] The present invention relates to the modification of the hydrophilicity of a material. The hydrophilicity of the material is changed by exposing the material to targeted laser pulses. The laser pulses are absorbed and alter chemical bonds of the molecules within the material. The material (if hydrophobic) then either absorbs water because of the altered molecular structure or rejects water (if the material is hydrophilic). By way of example only, the present invention teaches a laser system and a method for modifying the hydrophilicity of an optical lens in a predetermined region inside of the lens bulk body with or without a hydrophilicity change on the lens surfaces. The material used in the experiments described herein as applied to the present invention is a polymeric acrylic lens material (PLM) but this material selection is exemplary and should not be treated as a limitation of the present invention.

PRIOR ART AND BACKGROUND OF THE INVENTION

Background (0100)-(0400)

[0007] Conventionally, intraocular lenses are manufactured using cutting or molding techniques to fabricate polymer-based lenses which may need a tumbling step to acquire optical grade quality. Optical lenses can be surface modified by physical and chemical methods.

[0008] Physical methods include, but are not limited to plasma, corona discharge, and microwave processes. This treatment can change the hydrophilicity of the lens surface. For example, U.S. Pat. No. 5,260,093 issued on Nov. 9, 1993 to Ihab Kamel and David B. Soll for METHOD OF MAKING BIOCOSMUTE, SURFACE MODIFIED MATERIALS disclosed a method for permanently modifying the surface of a substrate material by radio frequency plasma. One of the substrates in disclosed in this patent is an intraocular lens.

[0009] Chemical modification of optical lenses is also well known. The chemical modification of optical lenses can change the chemical composition on the surface, thus this not only changes the hydrophilicity of the lens surface, but also the physical and chemical properties of the surface as well. For example, U.S. Pat. No. 6,011,082 issued on Jan. 4, 2000 to Yading Wang, Robert van Boxtel, and Stephen Q. Zhou for PROCESS FOR THE MODIFICATION OF ELASTOMERS WITH SURFACE INTERPRETING POLYMER NETWORKS AND ELASTOMERS FORMED THEREFROM disclosed a chemical modification method which allows a polymeric silicone intraocular lens to be chemically modified into a hydrophilic surface by heparin as well as other hydrophilic agents.

[0010] However, the above prior art methods can only be used to treat the lens surfaces. They cannot be used to modify the hydrophilicity of the lens bulk body below the surface. In other words, they cannot be used to treat a predetermined region inside a lens material.

[0011] In contrast, recent laser technology has made it possible to selectively target a predetermined region inside a material, including optical lens materials without changing the lens surface. For example, United States Patent Application Publication US2002/0117624A1 for PLASTIC OBJECT published on Aug. 29, 2002 having inventors Shigeru Katayama and Mika Horiike disclosed a general method using a laser to fabricate a plastic object which has been structurally modified in one part of its internal body by a laser light of ultrashort pulse duration of 10^-12 second or shorter. Examples of internal structures created using this prior art technique are generally illustrated in FIG. 1 (0100) and FIG. 2 (0200).

[0012] A more recent application in United States Patent Application Publication US2008/0001320A1 for OPTICAL MATERIAL AND METHOD FOR MODIFYING THE REFRACTIVE INDEX published on Jan. 3, 2008 having inventors Wayne H. Knox, Li Ding, Jay Friedrich Kunzler, and Dharmendra M. Jani disclosed a method for modifying the refractive index of an optical polymeric material comprising irradiating the selected region by femtosecond laser pulses (using a system configuration as generally illustrated in FIG. 3 (0300)) resulting in the formation of refractive optical structure of the laser treated region which is characterized by a positive change in refractive index. This patent application publication also disclosed calculating the refractive index change (Δn) as positive in the range of 0.03 to 0.06. This prior art teaches that if the selected treatment region is a convex-planar shape, it will create a positive lens while if the treated region is a biconvex shape, then it will be a negative lens. This is described in drawings of the US2008/0001320A1 patent application publication and is reproduced as FIG. 4 (0400) herein.
The prior art does not address the modification of the hydrophilicity of an internal region of a material.

Deficiencies in the Prior Art

While the prior art as detailed above can theoretically be used to form optical lenses, it suffers from the following deficiencies:

Prior art limits the lens formed within the lens material to 2.65 diopter in change for a lens with a 200 micron thickness and 6 mm diameter while the present invention creates a up to 20 diopter lens with the same lens diameter.

Prior art requires several hours to create a 2.65 diopter lens while the present invention would produce the same lens in a few minutes. Prior art paper publication show a shaping speed of 0.4 um/s for the high refractive index change. The following parameters have been used: a spot size of 1 um in XY and 2.5 um in Z and a convex lens diameter with 6 mm and a lens depth of 200 um. Source: Li Ding, Richard Blackwell, Jay E. Künzler and Wayne H. Knox “LARGE REFRACTIVE INDEX CHANGE IN SILICONE-BASED AND NON-SILICONE-BASED HYDROGEL POLYMERS INDUCED BY FEMTOSECOND LASER MICRO-MACHINING”.

Prior art can only produce a positive diopter change assuming a convex lens while the present invention can only produce a negative diopter change using a convex lens.

Prior art is limited to one lens within the material while the invention can stack multiple lenses to increase the diopter change or alter asphericity, toxicity or other lens properties.

Prior art discloses no relationship between hydrophilicity change and UV absorption while the instant invention relies on UV absorption to effect the change in hydrophilicity.

Prior art makes no change in hydrophilicity and the instant invention relies upon a change in hydrophilicity to effect the change in the material.

To date the prior art has not fully addressed these deficiencies.

OBJECTIVES OF THE INVENTION

Accordingly, the objectives of the present invention are (among others) to circumvent the deficiencies in the prior art and affect the following objectives:

1. provide for a system and method that permits the modification of the hydrophilicity of the interior of a material with or without a change in the hydrophilicity of the surface of the material;
2. provide for a system and method that alters the hydrophilicity of an entire predetermined three dimensional region within a polymeric material;
3. provide a system and method of manufacturing an optical lens;
4. provide a system and method for altering the hydrophilicity of a predetermined internal region of an implanted intraocular lens thus altering the refractive properties of the implanted intraocular lens according to the individual patient’s need for a desirable vision outcome.

While these objectives should not be understood to limit the teachings of the present invention, in general these objectives are achieved in part or in whole by the disclosed invention that is discussed in the following sections. One skilled in the art will no doubt be able to select aspects of the present invention as disclosed to affect any combination of the objectives described above.

BRIEF SUMMARY OF THE INVENTION

The present invention pertains to a system, method, and product-by-process wherein a pulsed laser system is used to modify the hydrophilicity of a polymeric material (the material used in all referenced experiments was a polymeric acrylic polymer (“PLM”) however that material is used as an example and is not limitation of the present invention scope). The change in hydrophilicity may be used to:

- form an optical lens having predetermined refractive properties;
- create hydrophilic areas in an otherwise hydrophobic material; or
- create hydrophilic areas in an otherwise hydrophobic material.

The present invention is particularly, but not exclusively, useful as describing the procedure to create a very thin, multi-layered, micro-structured customized intraocular lens inside a PLM. This technique could be used, but is not limited to modifications of an existing lens which is currently implanted within a human eye. The modifications can adjust diopter and/or add additional properties like toxicity and asphericity. The instant invention is capable of creating new lenses which are thinner than existing products and can be injected through a small incision. In particular, a system and method for the shaping of a refractive index within lenses based on the modification of the hydrophilicity of the material is disclosed.

The present invention describes a laser system and a method for modifying the hydrophilicity for a predetermined internal region of PLM which may be used as an optical lens. The present invention can be utilized to modify the optical properties of an optical lens by adding (or reducing) its optical power, or altering its asphericity, multifocality, toxicity and other optical properties. Typical application for this invention may include correcting the post-operative residual refractive error of an intraocular lens which has already been implanted in a patient’s eye.

In spite of the best effort by surgeons, residual refractive error is inevitable in many cases due to deviations in lens power selection, patient’s history of past eye surgeries such as LASIK procedure, surgery induced astigmatism, and progressive change in vision of a patient. Currently, surgeons use LASIK, a procedure to reshape a patient’s cornea by destroying a portion of the cornea by laser beams, to correct residual refractive error after cataract surgery. Alternatively, patients may need to wear eye glasses to correct post-operative refractive errors. The present invention promotes a scenario in which these optical non-idealities may be corrected in situ after the cataract surgery is completed.

Within the scope of the present invention a customized intraocular lens may be manufactured using either all optical processes or a combination of the traditional manufacturing in combination with optical processes to reduce the lens thickness and the needed incision size. The optical process is typically employed by using a femtosecond laser with pulse energies of 0.17 to 500 nanjoules and a megahertz repetition rate of 1 to 100.
The focus spot of the laser beam is moved inside the lens material to create a pattern of changes in the material, creating a three-dimensional lens. Different patterns will provide different lens properties, for example a toric or aspheric lenses.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the advantages provided by the invention, reference should be made to the following detailed description together with the accompanying drawings wherein:

FIG. 1 illustrates a prior art methodology of internal plastic modification as taught by United States Patent Application Publication US2002/0117624A;

FIG. 2 illustrates a prior art methodology of internal plastic modification as taught by United States Patent Application Publication US2002/0117624A;

FIG. 3 illustrates a prior art system for lens formation as taught by United States Patent Application Publication US2008/0001320A1;

FIG. 4 illustrates a prior art lens form as taught by United States Patent Application Publication US2008/0001320A1;

FIG. 5 illustrates an exemplary system block diagram depicting a preferred exemplary system embodiment of the present invention;

FIG. 6 illustrates an exemplary system block diagram of a preferred exemplary system embodiment of the present invention depicting a typical invention application setup context;

FIG. 7 illustrates a detail system block diagram illustrating system components that may be used to implement some preferred invention embodiments;

FIG. 8 illustrates a comparison of prior art lens configurations using a convex lens for optical convergence and present invention lens configurations using a concave lens for optical convergence;

FIG. 9 illustrates the use of the present invention to modify the hydrophilicity of a PLM in single and multiple layer configurations;

FIG. 10 illustrates an exemplary convex/biconvex lens structure as taught by the present invention;

FIG. 11 illustrates an exemplary concave/biconcave lens structure as taught by the present invention;

FIG. 12 illustrates exemplary phase wrapping lens structures that may be formed using the teachings of the present invention;

FIG. 13 illustrates the refractive index patterns associated with exemplary phase wrapping lens structures that may be formed using the teachings of the present invention;

FIG. 14 illustrates an exemplary PLM hydrophilicity alteration method flowchart used in some preferred embodiments of the present invention;

FIG. 15 illustrates an exemplary lens shaping/formation method flowchart used in some preferred embodiments of the present invention;

FIG. 16 illustrates an exemplary lens calculation method flowchart used in some preferred embodiments of the present invention;

FIG. 17 illustrates an exemplary experimental sample PLM structure as taught by the present invention;

FIG. 18 illustrates a graph of experimentally measured PLM water absorption measurements;

FIG. 19 illustrates an exemplary diffraction grid pattern as taught by the present invention;

FIG. 20 illustrates an exemplary experimental refractive index measurement setup as taught by the present invention;

FIG. 21 illustrates an exemplary experimental refractive index pattern as taught by the present invention;

FIG. 22 illustrates an exemplary experimentally measured diffraction grating power measurement over time as taught by the present invention;

FIG. 23 illustrates an exemplary experimentally measured diffraction grating 0 order power measurement as taught by the present invention;

FIG. 24 illustrates an exemplary experimentally measured water de-absorption curve as taught by the present invention;

FIG. 25 illustrates an exemplary experimentally constructed convex phase wrapping DIC and theoretical side view as taught by the present invention;

FIG. 26 illustrates a NIMO dioptr reading of an exemplary experimentally constructed convex phase wrapping DIC and theoretical side view as taught by the present invention;

FIG. 27 illustrates an exemplary experimentally constructed concave phase wrapping DIC and theoretical side view as taught by the present invention;

FIG. 28 illustrates a NIMO dioptr reading of an exemplary experimentally constructed concave phase wrapping DIC and theoretical side view as taught by the present invention;

FIG. 29 illustrates an exemplary experimental 3 mm convex phase wrapping lens top view as constructed;

FIG. 30 illustrates an exemplary experimentally measured dioptr reading as it relates to water absorption comparison as taught by the present invention, depicting the difference between air drying and water hydration on measured lens dioptr readings;

FIG. 31 illustrates an exemplary experimentally measured water absorption curve for water as taught by the present invention and its variation based on time and ambient temperature;

FIG. 32 illustrates an exemplary experimentally measured water absorption dioptr dependency graph as taught by the present invention;

FIG. 33 illustrates an exemplary method flowchart depicting a generalized in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 34 illustrates an exemplary method flowchart depicting preparation details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 35 illustrates an exemplary method flowchart depicting lens data creation details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 36 illustrates an exemplary method flowchart depicting patient interface details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 37 illustrates an exemplary method flowchart depicting start initialization details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;
FIG. 38 illustrates an exemplary method flowchart depicting diagnostics details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 39 illustrates an exemplary method flowchart depicting lens shaping details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 40 illustrates an exemplary method flowchart depicting verification details of an in-vivo lens shaping method as implemented by a preferred invention embodiment;

FIG. 41 illustrates an exemplary method flowchart depicting a generalized manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 42 illustrates an exemplary method flowchart depicting preparation details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 43 illustrates an exemplary method flowchart depicting lens data creation details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 44 illustrates an exemplary method flowchart depicting positioning details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 45 illustrates an exemplary method flowchart depicting start initialization details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 46 illustrates an exemplary method flowchart depicting diagnostics details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 47 illustrates an exemplary method flowchart depicting lens shaping details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment;

FIG. 48 illustrates an exemplary method flowchart depicting verification/shipping details of a manufacturing custom lens shaping method as implemented by a preferred invention embodiment.

DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detailed preferred embodiment of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiment illustrated.

The numerous innovative teachings of the present application will be described with particular reference to the presently preferred embodiment, wherein these innovative teachings are advantageously applied to the particular problems of a HYDROPHILICITY ALTERATION SYSTEM AND METHOD. However, it should be understood that this embodiment is only one example of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Moreover, some statements may apply to some inventive features but not to others.

Hydrophilicity not Limitive

Within the context of the present invention the term “hydrophilicity” will be defined as the characteristic of a material to “have a strong affinity for water or tend to dissolve in, mix with, or be wetted by water.”

Material (PLM) not Limitive

The present invention may incorporate a wide range of materials, including the PLM but not limited to the PLM, within the scope of anticipated embodiments, many of which may be application specific. PLM may in many preferred embodiments incorporate the use of an ultraviolet (UV) (generally 300-400 nm wavelength) absorbing material to augment the absorption of pulsed laser energy by the PLM and thus affect a change in hydrophilicity of the PLM. PLM as used herein should not be constrained as limiting its use to materials that form optical lenses. Specifically, the term “polymeric material (PM)” may be used herein to denote applications of the invention system/method/product that are not necessarily limited to the production of optical lenses. Thus, “PM” may cover a broader application of the invention concepts than “PLM”, although the materials may be identical. Therefore, the term “polymeric lens material (PLM)”, “polymeric material (PM)” and their equivalents should be given the broadest possible meaning within this context.

UV Absorbers not Limitive

The PLM may incorporate a number of chemicals which may enhance the UV absorption of the PLM and thus enhance the change in the PLM’s hydrophilicity when irradiated with pulsed laser radiation. The present invention makes no limitation on the types and quantities of chemicals used to affect this behavior, and the recitation of these chemicals within this document is only exemplary of those anticipated.

Laser Radiation not Limitive

The present invention may incorporate a wide variety of laser radiation to affect changes in hydrophilicity within the PLM described herein to form a lens. Therefore, the term “laser radiation” and its equivalents should be given the broadest possible meaning within this context, and not limited to near infrared light laser radiation.

Laser Source not Limitive

The present invention may incorporate a wide variety of laser radiation sources provide the required pulsed laser radiation used within the disclosed invention. Within this context, the term “laser source” may also incorporate an Acousto-Optic Modulator (AOM) (also called a Bragg cell) that uses the acousto-optic effect to diffract and shift the frequency of laser light generated using sound waves (usually at radio-frequency). Within this context, the “laser source” may be globally defined as comprising a laser radiation source and optionally an AOM, whether or not the AOM is physically incorporated into the laser radiation source hard-
ware. Therefore, the term “laser source” and its equivalents should be given the broadest possible meaning within this context.

Acousto-Optic Modulator (AOM) not Limitive

[0092] Various invention embodiments may make use of an Acousto-Optic Modulator (AOM) to act as a switch to enable/disable or moderate the quantity of laser radiation pulse stream as directed to the laser scanner within the context of the invention. Within this context the AOM may incorporate “greyscale” modulation wherein the switching function serves to switch a portion of the laser radiation pulse train to the laser scanner and therefore permit reductions in effective laser power as applied to the targeted PLM to which the hydrophilicity is to be modified. Thus, the utilization of “greyscale AOM” components to modulate laser radiation intensity is specifically anticipated within the scope of the invention.

[0093] The AOM as depicted in the present invention is used as a shutter and as variable attenuator and as such could therefore be replaced with another equivalent component which simulates the same functionality as described above.

Laser Scanner not Limitive

[0094] The use of a laser scanner within the preferred invention embodiments described herein may incorporate many different varieties of scanner, including but not limited to flying spot scanners (generally vector-based modes) and raster scanners (generally raster-based modes). The scanner is used to distribute the laser pulse to the correct location within the objectives field size. The present invention makes no limitation on the type of laser scanner that may be used in this context.

Microscope Objective not Limitive

[0095] References herein to a “microscope objective” may equivalently utilize a “microscope objective or other focusing device” to achieve these functions. Thus, the term “microscope objective” should be given its broadest possible interpretation within this application context.

Patient not Limitive

[0096] The present invention may be applied to situations where a lens placed in a living creature is modified in situ to correct/modify the refractive properties of the lens without removal from the eye of the creature. Within this context, the term “patient” shall be broadly construed and should not be limited to application only on human beings.

Lens Form not Limitive

[0097] The present invention may incorporate a wide variety of lenses formed to affect optical light bending and thus the construction of an overall lens formation. While exemplary embodiments of the present invention are described herein as being used to construct convex, biconvex, concave, biconcave, and plano lens structures, these structures are only exemplary of a plethora of lens forms that may be constructed with the present invention. Therefore, the term “lens formation” and its equivalents should be given the broadest possible meaning within this context.

Two-Dimensional not Limitive

[0098] The present invention may incorporate the use of two-dimensional pattern structures within the PLM to form diffraction gratings and other thin planar structures which while technically three-dimensional, will be termed herein as two-dimensional. While no modification of the PLM hydrophilicity can occur strictly in a zero-thickness plane, the term “two-dimensional” will refer to the creation of structures which occur within the PLM that do not require Z-axis focus repositioning across the X-Y plane perpendicular to the optical axis. Thus, a two-dimensional modification of the PLM refractive index could occur along a non-planar boundary that comprises a singular Z-axis focal distance for the laser pulses. Therefore, the term “two-dimensional” and its equivalents should be given the broadest possible meaning within this context.

Three-Dimensional not Limitive

[0099] The present invention may incorporate the use of three-dimensional pattern structures within the PLM to form complex optical structures. These three-dimensional pattern structures and their associated volumes may comprise multiple layers having interstitial PLM having a hydrophilicity that has not been modified by irradiation with laser pulses. Thus, a three-dimensional structure may incorporate unmodified areas having unmodified or slightly modified layer, or multiple layers comprising differing levels of hydrophilicity and resulting refractive index changes. Therefore, the term “three-dimensional” and its equivalents should be given the broadest possible meaning within this context.

Intraocular Lens not Limitive

[0100] The present invention may be advantageously applied to the construction of dynamically adjustable optical lenses incorporating a wide range of materials. The mechanisms of incorporation of a wide variety of materials within the optical lens are not limited by the present invention. Therefore, the term “intraocular lens” and “optical lens (which would include contact lenses)” and its equivalent construction embodiments should be given the broadest possible meaning within this context.

General System Description

[0101] The present invention may be generally described as utilizing a laser system which consists of a femtosecond laser source, an AOM, a scanner, and an objective which delivers the laser pulses into the predetermined region. The laser source preferably has a pulse duration of approximately 350 fs or shorter, a wavelength in the range of 690 to 1000 nm, and a repetition rate of between approximately 0.1 to 100 MHz. The pulse energy is typically in the range of 0.17 to 500 nJoules. Those who are skilled in the art understand that these laser parameters can be adjusted and rebalanced to be outside above-specified range but still be able to achieve the same level of energy delivered to the targeted regions of the lens material. For example, a tunable laser unit, such as Ti:Sapphire oscillator (Mai Tai By Newport, Irvine, Calif.) can provide a variable wavelength in the range of approximately 690-1040 nm, a pulse width of as low as 70 fs, and a source power up to 2.9 W.
Generalized Hydrophilicity Modification System (0500)

[0102] A preferred exemplary system embodiment of the present invention is generally illustrated in FIG. 5 (0500), wherein a material (0501) is irradiated (0515) to produce a change in hydrophilicity within a selected region (0502) within the PLM (0501). This system (0500) generally incorporates a laser source (0511) that is configured to generate pulses of laser radiation which may be controlled/moderated/modulated/switched by an acousto-optic modulator (AOM) (0512) to produce a predetermined laser pulse train having specified energy and pulse timing characteristics. In some embodiment, the laser source (0511) and AOM (0512) may be integrated into a single laser source module. The pulsed laser radiation generated by the laser source (0511)/AOM (0512) is then transmitted to a laser scanner (0513) that is configured to distribute the laser pulses in an X-Y plane across an input area of a microscope objective (0514). The microscope objective (0514) incorporates a numerical aperture configured to accept the distributed pulsed laser radiation and produce a focused laser radiation output (0515). This focuses laser radiation output (0515) is then transmitted by the microscope objective (0514) to a polymeric lens material (PLM) (0501) region (0502) in which the hydrophilicity of the PLM (0501) is to be changed. The position of the hydrophilic-modified PLM region (0502) may be determined by the laser scanner (0513) as well as a sample staging/positioning system (0516) that mechanically positions the PLM (0501) to allow the focused laser pulses (0515) to be properly localized within the desired interior region (0502) of the PLM (0501).

[0103] This system may optimally operate under control of a computer control system (0520) incorporating a computer (0521) executing software read from a computer readable medium (0522) and providing a graphical user interface (GUI) (0523) from which an operator (0524) may direct the overall operation of the hydrophilicity change (0502) within the PLM (0501).

System/Method Application Context Overview (0600)

[0104] A typical application context for the present invention is generally illustrated in FIG. 6 (0600), wherein the present invention is embodied in a hydrophilicity alteration system (0610) used to configure patient lenses. This hydrophilicity alteration system (0610) typically comprises a laser source (0611) that generates a pulsed laser output that is then distributed in an X-Y plane using a laser scanner (0613) and then focused using a microscope objective (0614) (or other focusing apparatus). This distributed and focused pulsed laser radiation (0615) is transmitted within a lens structure (0601) having some portion of which that is constructed of material (PLM) (0602). This PLM (0602) is irradiated in a two or three-dimensional pattern (0603) within the PLM structure (0602) to modify the hydrophilicity. Any modifications in hydrophilicity will create some change in the refractive index of the internal region of the PLM (0603). This change in refractive index generated by the focused laser pulses (0614) causes the two or three-dimensional pattern (0603) to form an optical lens function within the overall lens structure (0601).

[0105] In conjunction with this general system/method configuration, the lens structure (0601) may be incorporated (0604) within a human eye (0605) and the PLM (0602) modified in situ after the lens structure (0601) has been surgically implanted within the eye of a patient as generally illustrated in the diagram.

[0106] The described hydrophilicity alteration system (0610) is typically operated under control of a computer system (0621) executing instructions from a computer readable medium (0622). This computerized control (0621) optimally incorporates a graphical user interface (0623) permitting the system operator (0624) to interface with the overall system and direct its operation. With respect to the above-mentioned in situ lens formation application, the control software (0622) may incorporate software implementing methods to perform an automated patient eye examination to determine the non-idealities in the patient's vision (0625), from which a map of optical corrections (0626) necessary to improve the patient's vision is generated, followed by automated laser pulse/position control procedures to change in situ the refractive index of PLM within the patient lens to fully correct the patient vision (0627).

System/Method Application Context Detail (0700)

[0107] A more detailed system configuration of a preferred invention application context is provided in FIG. 7 (0700), wherein a computer system (0720) operating under control of software read from a computer readable medium (0721, 0722) is used to control and supervise the overall lens fabrication process. Within this application context, the following components generally comprise the system:

[0108] The laser source (0701) with a wavelength suitable to treat the desired material and an energy-per-pulse sufficient to change the refractive index of the target area provided by the used objective (0710).

[0109] The Dispersion Compensator (0702) is used to pre-compensate the beam to allow a pulse width of around 100 fs. Without the feature the pulse width at the target would be larger because the pulse width gets longer when passing through an optical media like a lens. With a longer pulse with more heat would occur on the treatment area, making the process a little more imprecise and the treatment time a little longer. This feature therefore is optional but part of the RIS optimization.

[0110] The Beam Shaping 1 (0703) unit can be used to modify the laser beam diameter to fit the AOM specifications. This also allows the exchange of the laser source without additional modifications after the beam shaping 1 unit.

[0111] The AOM (0704) is used to modulate the number of pulses and the energy per pulse which will be directed to the treatment area. Depending on the received signal (normally 0 to 5V) the energy will be distributed to the 0 or the 1st order of the AOM. Those orders are two different beams, with an angle between them, coming out from the AOM. The 1st order beam is normally the one going to the target area and the 0 order beam is stopped directly after the AOM. The receiving signal from the AOM driver is maximum (5V) the maximum energy per pulse is in the 1st order beam, when the driver signal is at the minimum the 0th order beam will have 0% energy and everything will be delivered to the 0 order.

[0112] Beam Shaping 2, after the beam has passed through the AOM additional beam shaping is required to fit the system. For example the beam diameter has to be
enlarged to fit the used objective (0710), to allow the use of
the numerical aperture of the objective.
[0113] A Diagnostics (0705) system is used to measure
the wavelength, energy per pulse and the pulse width of
the laser beam. This feature in included to allow the safe
and repeatable use of the system. If one of the variables
is not performing as planned the system will shut down
and
[0114] Laser Microscope Coupling (Mirror Arm) (0706)
is used to redirect the laser beam into the laser micro-
scope head. Depending on the system setup and laser
orientation it can contain between one and multiple mir-
rors to redirect the laser beam to the needed position.
[0115] The Camera System (0707) is used to position the
sample towards the microscope objective. It also is used
to find the correct Z location, depending on the materials
curvature. Additionally the camera can be used for track-
ing purposes.
[0116] The Scanner (0708) is used to distribute the laser
spot on the XY plane. Different scanners can be used for
this purpose. Depending on the scanner type the un-
treated area would still be covered but with no laser
energy per pulse or only the treated areas would be
covered. For this purpose the software controlling will
also control the AOM because the scanner software will
position the spot and the AOM will contribute the energy
per pulse for that spot.
[0117] The Z Module (0709) can be used to allow an
extra focusing element in the system, this for example
can be used for tracking purposes for a plane in a differ-
ent Z location than the shaping plane. It also could be
used to change the Z location during the shaping pro-
cess.
[0118] The Objective (0710) focuses the beam on the
sample and determines the spot size. With a larger spot
size a larger energy per pulse is required it therefore has
to be fitted to the laser source and the required precision
of the process. Additionally it provides the field size of
the shaping process, if the field size of the objective is
smaller than the required lens, this requires additional
hardware for the lens shaping.
[0119] The Objective and Sample Interface (0711) is
depending on the application. For the lens manufactur-
ing the space between the sample and the objective is
filled with water to reduce scattering and allow an addi-
tional cooling element. For other applications different
contact method with other mediums like eye gel could be
used.
[0120] The Sample (0712) can surprise of different opti-
cal mediums and could for example be a hydrophobic
polymer which is placed in front of the objective.
Depending on the application that sample will be
directly after the Objective and Sample interface or
deeper inside an additional medium combination like an
eyeball.
[0121] The Positioning System (0713) can be used to
position the blocks comprising of the objective field
sizes towards each other to allow the shaping of a larger
structure. It can also be used to move the sample in the Z
direction.
[0122] One skilled in the art will recognize that a particular
invention embodiment may include any combination of the
above components and may in some circumstances omit one
or more of the above components in the overall system
implementation.

Comparison of Prior Art/Present Invention (0800)

[0123] A comparison of the prior art and present invention
methodologies for achieving optical convergence within a
lens structure is generally illustrated in FIG. 8 (0800). The
prior art as generally depicted in FIG. 8 (0800, 0810) makes
use of convex lens formation methodologies to generate opti-
cal convergence as illustrated in this example. It is essential
to note that the prior art makes no change in hydrophilicity of the
lens material but simply changes the refractive index of the
material. By contrast, the present invention using changes in
PLM hydrophilicity as generally illustrated in FIG. 8 (0800,
0820) to generate optical convergence. While both techniques
may make use of multiple lens structures, the present inven-
tion relies on negative dioptr material modification (0821) to
create these lens formations (all increases in hydrophilicity
reduce the refractive index of the material while all the prior
art makes changes in the material that create positive dioptr
material modification (0811).

Exemplary Application Context Overview (0900)

[0124] As generally depicted in FIG. 9 (0900), the present
invention uses a femtosecond pulse laser (0911) to enable a
hydrophilicity change (alteration) (0912) inside a PLM
(0913). As generally depicted in FIG. 9 (0900), a three di-
imensional layer (0922) of hydrophilicity change (alteration) can
be shaped in a PLM (0921) using a XYZ stage system. The
depth of the layer is predetermined in the software. The layer
could be positioned at the surface (0923) or intermediate
layers (0924, 0925).
[0125] The present invention also anticipates a system con-
figured to form optical lenses from a PLM, a method by which
lenses may be formed using PLM, and the lenses formed by
the method using the PLM. Any of these invention embedi-
ments may be applied to situations in which a lens implanted
in a human (or other biologic eye) may be modified and/or
corrected in situ without the need for removal of the lens from
the patient.
[0126] The present invention can also be used to create
hydraulic channels within a PLM. Such areas can be used to
facilitate the passage of other chemical substances into our
out of such materials.

Exemplary Lens Formation Structures (1000)-(1300)

[0127] While the present invention may in many contexts
be applied to the formation of a wide variety of lens struc-
tures, several forms are preferred. These include but are not
limited to convex (1001) and biconvex (1002) structures as
depicted in the profiles of FIG. 10 (1000); concave (1101) and
bicongave (1102) structures as depicted in the profiles of FIG.
11 (1100); and phase wrapping convex (1201) and phase
wrapping concave (1202) structures as depicted in the profiles
of FIG. 12 (1200). One skilled in the art will recognize that
these lens structures are only exemplary of a wide variety of
lenses that may be formed using the teachings of the present
invention. Additionally, the layering of PLM modified struc-
tures as depicted in FIG. 9 (0900, 0921) may permit the
layering of a plurality of lens structures within a single PLM.
Phase Wrapping Lens (1200, 1300)

[0128] The present invention may be used to form phase wrapping lens as generally depicted in the phase wrapping convex (1201) and phase wrapping concave (1202) structures depicted in FIG. 12 (1200) and the associated exemplary refractive indexes depicted in FIG. 13 (1300). Phase wrapping lenses use the same theoretical idea as the Fresnel lens (1204). The difference in quality can be summarized in three different factors:

[0129] the original lens curvature is preserved for the Phase Wrapping lens;
[0130] the laser shaping technique allows the preservation of the 90 degree angle at each zone for the Phase Wrapping lens; and
[0131] the micrometer precision to which the Phase Wrapping may be shaped.

In contrast, the limitations for the Fresnel lens (1205) are generally derived from the manufacturing process in which it is created. The main manufacturing difference for a Phase Wrapping Lens and a Fresnel lens are shown in image 1206.

Refractive Index Gradient Lens (1300)

[0132] The present invention may be used to form a refractive index gradient lens as generally depicted in FIG. 13 (1300). The information of the lens curvature is in this concept is stored in a single layer. The grayscale values are used to represent the energy per pulse. Therefore 256 variations of the power between 0% and 100% are possible and allow the precise shaping of a single layer. The top view of a refractive index lens (1301) shows the different zones of an original convex phase wrapping lens. Each original discussed lens type data information can be compressed to one single layer. The side view of the refractive index gradient lens (1302) shows the energy distribution at each spot for one horizontal slice through the center of the lens.

[0133] The modulation of the pulse energy can be accomplished using the AOM or an automatic variable attenuator.

PLM Method (1400)

[0134] The present invention method anticipates a wide variety of variations in the basic theme of implementation, but can be generalized as depicted in FIG. 14 (1400) as a lens formation method using hydrophilicity alteration comprising:

[0135] (1) generating a pulsed laser radiation output from a laser source (1401);
[0136] (2) distributing the pulsed laser radiation output across an input area of a microscope objective (1402);
[0137] (3) accepting the distributed pulsed radiation into a numerical aperture within the microscope objective to produce a focused laser radiation output (1403); and
[0138] (4) transmitting the focused laser radiation output into a PLM to modify the hydrophilicity within the PLM (1404).

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention. These other methods described herein are optimally executed under control of a computer system reading instructions from a computer readable media as described elsewhere herein.

[0139] As generally depicted in FIG. 9 (0900, 0912), this region of hydrophilic alteration may form arbitrary optical lens structures as generally depicted in FIG. 10 (1000)-FIG. 13 (1300) having multiple optical inner layers of hydrophilic alteration as generally depicted in FIG. 9 (0900, 0921).

Lens Shaping/Formation Method (1500)

[0140] The present invention also teaches a lens shaping/formation method wherein a lens of arbitrary complexity may be formed within PLM. The lens shaping consists of different parts. First the lens dioptric and curvature have to be calculated depending on the selected material. The laser wavelength afterward is also adjusted towards this material. The AOM functions as the shutter and also as a variable power attenuator in the setup, allowing (in combination with the scanner) the lens structure to be precisely shaped inside the polymer. The AOM is controlled by the input images of the calculated lens information, providing the laser power information for each area (micrometer) of irradiated area. The scanner afterward distributes the power to the correct location and the microscope objective focuses the pulsed laser beam to the desired focus spot inside the polymer. The PLM sample is kept in a sample holder after the microscope objective and is optionally positioned on a stage system (mechanized X/Y/Z positioning system) to allow the shaping of a larger lens structure. The stage system could also be replaced with a mirrored laser arm which ends with the microscope objective. The mirrored arm in this case would not only replace the stage system but the whole camera and scanner board.

[0141] The present invention method may incorporate an embodiment of this lens shaping/formation method as depicted in FIG. 15 (1500) comprising:

[0142] (1) executing lens calculations to determine the form and structure of lens to create (1501);
[0143] (2) selecting the laser wavelength suitable for the desired hydrophilicity change in the PLM (1502);
[0144] (3) shuttering and/or power regulating a laser using an AOM or equivalent modulator to generate laser pulses (1503);
[0145] (4) scanning the laser pulses across a microscope objective (1504);
[0146] (5) forming a laser spot size and precisely positioning the focused laser within a PLM using a microscope objective (1505);
[0147] (6) retaining/holding the PLM for hydrophilicity alteration by the laser pulse stream (1506); and
[0148] (7) optionally positioning the target PLM sample using X/Y/Z positioning system (1507).

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention.

[0149] This method may be applied to one or more layers within the PLM to achieve formed lens structures of arbitrary complexity. The lens calculations associated with this procedure as identified in step (1) are detailed in FIG. 16 (1600) and described below.
Lens Calculation Method (1600)

[0150] The present invention also teaches a lens calculation method wherein lens parameters are used to determine the internal PLM lens structure that is customized for a particular patient and their unique optical requirements. This method generally involves the following steps:

[0151] Calculating the curvature of the lens to be formed;
[0152] Determining the required lens depth;
[0153] Calculating the number of zones which must be processed via the laser;
[0154] Determining the zone radius for each zone to be processed;
[0155] Create phase wrapping lens data files for the laser; and
[0156] Loading the data files into the RIS mapping system.

These steps will now be discussed in more detail.

[0157] Before the lens parameters for a custom intraocular lens (IOL) can be calculated the patient needs to be examined, the different existing aberrations can be measured and the needed diopter changes can be evaluated. The material (n) for the shaping process has to be known to calculate the lens curvature (C).

\[ C = \frac{Dpt}{(n' - n)} \]  

(1)

Where \( n \) is the refractive index of the original IOL material and \( n' \) is the refractive index after the RIS shaping, and therefore the refractive index of the new lens.

\[ C = \frac{1}{r} \]  

(2)

[0158] The curvature is related to lens radius (r) and the radius can be calculated with the lens diameter \( 2w_{\text{Lens}} \) and the lens depth \( h_{\text{Lens}} \).

\[ r = \frac{h_{\text{Lens}} + w_{\text{Lens}}}{2h_{\text{Lens}}} \]  

(3)

[0159] Afterward the Phase Wrapping Lens Information is calculated for the given information and the output images are created. All required information for the Phase Wrapping Lens already exists in the information of the original lens and its curvature. The Phase Wrapping depth of the lens is determined by the refractive index change amount. Afterward the radius of each zone and for the curvature information of each zone can be easily calculated. Depending on the shaping technique the lens diopter can be larger than the objective field size, in this case a stage system (as described above) is used to align the different areas for the lens shaping. To allow this technique the input images are chopped into their image sizes to represent the block system.

[0160] The lens calculation method described above and generally depicted in FIG. 15 (1500, 1501) may be embodied in many forms, but several preferred embodiments of the present invention method may implement this method as depicted in FIG. 16 (1600) using the following steps:

[0161] (1) measuring or determining required lens properties for desired optical performance (1601);
[0162] (2) selecting a lens material appropriate for lens fabrication (1602);
[0163] (3) calculating the desired lens material (1603);
[0164] (4) calculating phase wrapping lens information necessary to form the lens (1604);
[0165] (5) creating output images that correspond to the desired phase wrapping lens characteristics (1605);
[0166] (6) determining if the lens treatment area is larger than the objective field size, and if not, proceeding to step (8) (1606);
[0167] (7) chopping the output images into segments that fit within the field size (1607);
[0168] (8) determining if the patient (or lens formation) requires additional lens properties, and if so, proceeding to step (1) (1608); and
[0169] (9) terminating the lens calculation method (1609).

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention.

[0170] This method may be applied to the formation of lenses that are retained/held by a staging apparatus, or in some circumstances the lens shaping/forming process may be performed in situ within the eye of a patient. In this situation, the lens PLM may be surgically inserted into the patient while the PLM is in a generally unmodified (or previously modified) state and then “dialed-in” to provide optimal vision for the patient.

Application #1

Optical Lens (1700)-(1800)

[0171] The following experimental application example discusses an internal hydrophilicity change for a polymeric acrylic polymer suitable for making optical lenses.

Step 1—Preparation of Testing Optical Material

[0172] A small sheet of crosslinked polymeric copolymers may be constructed by free radical polymerization of

[0173] (1) 140 grams of mixture of butylacrylate, ethylmethacrylate, N-benzyl-N-isopropylacrylamide, and ethylene glycol dimethacrylate;
[0174] (2) 11.4 grams of 2-[3-(2H-benzotriazol-2-yl)-4-hydroxyphenyl]ethyl methacrylate; and
[0175] (3) a yellow dye less than 0.5%.

under a curing cycle starting at 65°C up to 140°C for a total time of approximately 14 hours in a glass mold sealed with silicone tube. Slightly yellow transparent sheet, about 2 mm thick, obtained this way can be cut into round buttons which can be further lathe machined into intraocular lenses. Alternatively, small chips can also be cut out from the sheet or from the buttons for laser treatment. The refractive index of the yellow sheet or button prepared this way is approximately 1.499.
Step 2—Pre-Soaking

[0176] A small strip (1.91 mm x 1.33 mm x 14.35 mm) of an optically transparent lens material prepared above weighs 38.2 mg. This strip of lens material is soaked in water until no more weight increase, an indication for reaching saturation at room temperature. The saturated strip, after water droplets on its surface are wiped with dry paper tissues, weighs 38.3 mg, indicating water absorption is approximately 0.3%.

Step 3—Laser Treatments

[0177] The water saturated strip was then exposed to laser pulses from a femtosecond laser source (pulse width: 200 fs, repetition rate: 50 MHz, energy per pulse: 5.4 nJ, wavelength: 780 nm). Only a predetermined region (2 mm x 2 mm x 165 μm, 165 μm is the thickness of the treated region) as generally illustrated in FIG. 17 (1700) of the strip was treated. After the treatment the strip was allowed to be saturated with water and then weighed again. The strip was 38.9 mg with an increase of 0.2 mg which represents approximately 30% water absorption by the treated region (0.2 mg x 1.91 x 1.33 = 0.318 - 0.32%).

After the first region was treated, a second region of same dimension was treated, approximately another 0.2 mg increase was observed. This way, a total of 3 regions were treated, final strip weights 38.9 mg. The weight gains after each laser treatment are summarized in the graphs depicted in FIG. 18 (1800).

Application #2

Diffraction Gratings (1900)-(2400)

[0178] The following experimental application example discusses the use of the present invention as applied to Diffraction gratings efficiency dependency on water absorption.

Step 1

[0179] A diffraction grating was shaped inside the acrylic polymeric material as generally depicted in FIG. 19 (1900). The grid size is 3 mm with an X spacing of 18 μm in this example.

Step 2

[0180] The sample is then water saturated.

Step 3

[0181] The efficiency of the refractive index grating was measured (2103) using the setup depicted in FIG. 20 (2000) for different scan speeds. A red (640 nm) laser was placed in front of the sample. The sample is mounted on a set of XY stages to allow positioning of the grating in regards of the laser. At some distance a screen (2101-2103) is positioned and the power of the different orders of the gratings (as depicted in FIG. 21 (2100)) is recorded for different times as depicted in FIG. 22 (2200). The power in the 1st to the 10th order decreases with the water desaturation as illustrated in FIG. 22 (2200), while the energy is going into the zero (0) order as generally depicted in FIG. 23 (2300).

[0182] This can be compared with the water de-absorption curve of the acrylic polymeric material as depicted in FIG. 24 (2400) which shows the material weight loss due to water de-absorption. The graph in FIG. 24 (2400) shows the averaged sample weight measurement in percentage for 10 samples. The important information is shown in the first five (5) hours. The main change is occurring within the first five hours comparing the graphs in FIG. 23 (2300) and FIG. 24 (2400). The diffraction grating starts decrease slower because the grating is shaped inside the material and the water de-absorption takes some time before it will be noticed in the measurement. After the main water amount is de-absorbed the diffraction grating gets very weak.

Application #3

Phase Wrapping Convex Lens (2500)-(2900)

[0183] The following experimental application example discusses a negative refractive index change due to hydrophilicity change.

[0184] Step 1

[0185] A lens shaping of a phase wrapping convex lens is generated as depicted in FIG. 25 (2500). The phase wrapping concave lens shows the negative refractive index change which is induced by the hydrophilicity change inside the material. The NIMO diopter reading for this structure is depicted in FIG. 26 (2600).

[0186] The convex phase wrapping lens shows a negative diopter reading and the concave phase wrapping lens as generally depicted in FIG. 27 (2700) shows a positive diopter reading. The NIMO diopter reading for this structure is depicted in FIG. 28 (2800).

[0187] The image depicted in FIG. 29 (2900) illustrates an exemplary 3 mm convex phase wrapping lens top view as constructed.

Application #4

Water Saturation (3000)-(3100)

[0188] The following experimental application example discusses a full diopter reading only after water saturation of the material.

Step 1

[0189] A concave lens with a positive diopter reading was shaped.

Step 2

[0190] The lens diopter is measured after shaping.

Step 3

[0191] The lens is not stored in water but in air for 18 days and afterward placed in water.

Step 4

[0192] The diopter reading of the lens after placed in water is measured.

[0193] The diopter reading of the lens directly after shaping is minimal. The material still has to be water saturated before the final diopter reading is possible. During the shaping process it already can absorb some water, therefore some diopter reading will be possible after shaping but the full diopter reading will always only be possible after the material is fully water saturated.

[0194] After the lens is placed in water the lens diopter is fully recovered after 24 hours. FIG. 30 (3000) depicts the diopter reading of a 5 diopter 2 mm lens. The first diopter measurement directly after shaping was only 1.5 D.
[0195] For comparison graph in FIG. 31 (3100) depicts the water saturation curve for the polymeric material and its relationship to time.

Application #5

Pre-Soaking

[0196] The following experimental application example discusses the diopter reading of a pre-soaked sample.

[0197] The saturation period can be shortened if the sample was pre-soaked in water before the lens shaping. Directly after shaping the lens shows a larger diopter reading and will recover to the full diopter value much quicker, compared to a non-pre-soaked sample. The pre-water soaking will only shorten the time period of the sample to fully saturate. It will not change the final diopter reading of the lens.

Application #6

Temperature Dependency (3100)

[0198] The following experimental application example discusses the temperature dependency of lens diopter.

[0199] The water absorption of the material is dependent on the surrounding temperature. An incubator can be used to change the sample temperature. After allowing the sample sufficient time to adapt to the temperature change the lens diopter was measured and differences of up to ± 1 D for different temperature settings were observed.

[0200] The water absorption is temperature dependent, therefore the diopter reading of the lens is also temperature dependent. This can be seen from the graph in FIG. 31 (3100), wherein more water is absorbed for 35 degree Celsius than for 22 degree Celsius.

Application #7

Diopter Memory (3200)

[0201] The following experimental application example discusses the temperature dependency of lens diopter.

[0202] The diopter of the treated area is fixed. The sample can be kept in air storage, never allowing it to develop the full lens diopter, but when placed in water the full diopter of the lens will recover to the full, theoretically calculated diopter after saturation.

[0203] Diopter reading of sample increases when hydrated after sample was dehydrated, the lens starts with approximately OD and increases the diopter reading to its full -6 D within 27 hours as depicted in FIG. 32 (3200), which is in accordance with the image in FIG. 31 (3100).

In-Vivo Lens Shaping Method (3300)-(4000)

[0204] The present invention anticipates that lenses may be formed/shaped using the systems/methods described herein in-vivo as generally illustrated in FIG. 33 (3300), comprising the following steps:

[0205] (1) Preparation (3391);
[0206] (2) Lens Data Creation (3392);
[0207] (3) Patient Interfacing (3393);
[0208] (4) Start Initialization (3394);
[0209] (5) Diagnostics (3395);
[0210] (6) Lens Shaping (3396); and
[0211] (7) Verification (3397).

As generally illustrated in FIG. 34 (3400)-FIG. 40 (4000), these generalized steps may be further defined in terms of more detailed steps as follows:

[0212] (1) Patient existing lens material determination (3401) wherein this information is used to determine the laser properties and to calculate the refractive index material change induced by the refractive index shaping.

[0213] (2) Patient aberration measurement (3402) wherein the different patient specific aberrations are determined.

[0214] (3) Patient selects which aberrations need treatment (3403) wherein the selection could be but is not limited to common vision defects like myopia, hyperopia and astigmatism.

[0215] (4) Doctor selects needed lens information and lens material (3504) wherein the selection is depending on the consultation with the patients’ needs and the available options.

[0216] (5) Determining if needed lens information exists, and if the information already exists, proceeds to step (11) (3505). This section is completely software based and not accessible by the doctor or the patient. This step is integrated for the case that a patient has a unique diopter value which is not preloaded to the system.

[0217] (6) Calculating lens curvature (3506) wherein the curvature is depending on the required lens diopter and the refractive index change induced by the refractive index shaping and the surrounding refractive index change of the material.

[0218] (7) Determining phase weighting height (3507) wherein the height is depending on the induced refractive index change difference and therefore also the surrounding material.

[0219] (8) Phase wrapping lens creation (3508) wherein the information of the Phase Wrapping Lens is given by the Phase Wrapping Lens height and the original lens curvature information. For each layer the radii for each zone can be determined using this information.

[0220] (9) Data output file creation (3509), the information for each layer, and possible each block of each layer will be created using the information from the phase wrapping lens (3508).

[0221] (10) Data loading to system (3510) wherein the data files (3509) might need additional time to be loaded into the existing software to be analysed and depending on the material the line pitch can be used to fill the 3 dimensional structure.

[0222] (11) Patient is positioned towards the system (3611) wherein this positioning is the initial step for the patient interface positioning. The patients head is aligned towards the refractive index shaping workstation.

[0223] (12) Doctor positions the objective towards the patient’s iris (3612) The doctor can use the camera module to get a good idea of the position of the objective towards the iris. This is an important step because this position will also be used for the tracking.

[0224] (13) Doctor enters patient ID into the system (3713) wherein the software will display the patient’s information and the pre-selected shaping options.
(0243) (3) Patient selects which aberrations need treatment (4203) wherein depending on patient’s requirement or availability the treatment option is chosen.

(0244) (4) Doctor selects needed lens information and lens material (4304) wherein the patient’s choice for the material and required changes is revised and if needed a new selection is required and will be discussed with the patient.

(0245) (5) Determining if needed lens information exists, and if existing, proceeding to step (11) (4305) wherein the software checks internally if the required aberration code already exists or if new code has to be created for the patient.

(0246) (6) Calculating lens curvature (4306) wherein the curvature is depending on the required lens diopter and the refractive index change induced by the refractive index shaping and the surrounding refractive index change of the material.

(0247) (7) Determining phase wrapping height (4307) wherein the height is depending on the induced refractive index change difference and therefore also the surrounding material.

(0248) (8) Phase wrapping lens creation (4308) wherein the information of the Phase Wrapping Lens is given by the Phase Wrapping Lens height and the original lens curvature information. For each layer the radii for each zone can be determined using this information.

(0249) (9) Data output file creation (4309) wherein the information for each layer, and possible each block of each layer will be created using the information from the phase wrapping lens (3508).

(0250) (10) Data loading to system (4310) wherein the lens/blank is positioned inside the system.

(0251) (11) Lens/blank is positioned in the manufacturing system (4411) wherein the system selects the starting position for the lens shaping.

(0252) (12) Technician enters the Customer ID (4512) wherein the software will display the patient’s information and the pre-selected shaping options.

(0253) (13) Technician verifies information and selects START (4513) wherein the technician verifies in the first step the patient’s identity and afterward the selected treatment options.

(0254) (14) System checks if laser wavelength is correct (4614) wherein the laser wavelength is selected in regards of the original lens material. The diagnostic tool for of the system afterward checks that the displayed wavelength and the real time value of the system are a match.

(0255) (15) System checks if energy is stable (4615) the laser energy is measured. The diagnostic tool of the system afterward checks that the theoretical calculated energy and the real time value of the system are matching.

(0256) (16) System check if pulse width is stable (4616) wherein the diagnostic tool is used to internal check that the pulse width of the system has not changed.

(0257) (17) Z module is used for the Z positioning of the focus spot (4717) wherein the Z module is used to vary the distance between the lens shaping focus spot and the iris tracking focus spot. The IOL inside the patient’s eye can settle differently and also the patients cornea thickness and anterior chamber thickness is variable, there-
fore the Z module is used to find the correct location for the refractive index shaping lens.

(0258) (18) Scanner is used for the focus spot position (4718) wherein the scanner positions the focus spot to the correct shaping location.

(0259) (19) AOM is used for the energy distribution (4719) wherein the AOM provides the correct energy per pulse for the scanner location.

(0260) (20) A X and Y stage system is used to support a larger treatment area (4720) wherein the X and Y stages are used to shape a lens which is larger than the shaping area of the given objective. And

(0261) (21) A Z-stage is used to allow the movement between layers (4721) wherein the Z stage can additionally be used for the Z movement of the different layers of the lens.

(0262) (22) New lens diopter is verified (4822) wherein the IOL’s new diopter reading is measured and verified.

(0263) (23) Lens is packaged and shipped to doctor (4823) wherein the product is packed and shipped.

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention.

PM System Summary

(0264) The present invention system may be broadly generalized as a system for changing the hydrophilicity of an internal region of a polymeric material, said system comprising:

(0265) (a) laser source;
(0266) (b) laser scanner; and
(0267) (c) microscope objective;

(0268) wherein

(0269) the laser source is configured to emit a pulsed laser radiation output;

(0270) the laser scanner is configured to distribute the pulsed laser radiation output across an input area of the microscope objective;

(0271) the microscope objective further comprises a numerical aperture configured to accept the distributed pulsed laser radiation and produce a focused laser radiation output; and

(0272) the focused laser radiation output is transmitted by the microscope objective to an internal region of a polymeric material (PM);

(0273) the focused laser radiation output changes the hydrophilicity within the internal region of the PM.

(0274) This general system summary may be augmented by the various elements described herein to produce a wide variety of invention embodiments consistent with this overall design description.

PLM System Summary

(0275) The present invention system anticipates a wide variety of variations in the basic theme of construction, but can be generalized as a lens formation system comprising:

(0276) (a) laser source;
(0277) (b) laser scanner; and
(0278) (c) microscope objective;

(0279) wherein

(0280) the laser source is configured to emit a pulsed laser radiation output;

(0281) the laser scanner is configured to distribute the pulsed laser radiation output across an input area of the microscope objective;

(0282) the microscope objective further comprises a numerical aperture configured to accept the distributed pulsed laser radiation and produce a focused laser radiation output; and

(0283) the focused laser radiation output is transmitted by the microscope objective to a PLM;

(0284) the focused laser radiation interacts with the polymers within the PLM and results in a change the hydrophilicity within the PLM.

(0285) This general system summary may be augmented by the various elements described herein to produce a wide variety of invention embodiments consistent with this overall design description.

PM Method Summary

(0286) The present invention method may be broadly generalized as a method for changing the hydrophilicity of an internal region of a polymeric material, the system comprising:

(0287) (1) generating a pulsed laser radiation output from a laser source;

(0288) (2) distributing the pulsed laser radiation output across an input area of a microscope objective;

(0289) (3) accepting the distributed pulsed radiation into a numerical aperture within the microscope objective to produce a focused laser radiation output; and

(0290) (4) transmitting the focused laser radiation output to an internal region of polymeric material ("PM") to modify the hydrophilicity within the internal region of the PM.

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention.

PLM Method Summary

(0291) The present invention method anticipates a wide variety of variations in the basic theme of implementation, but can be generalized as a lens formation method comprising:

(0292) (1) generating a pulsed laser radiation output from a laser source;

(0293) (2) distributing the pulsed laser radiation output across an input area of a microscope objective;

(0294) (3) accepting the distributed pulsed radiation into a numerical aperture within the microscope objective to produce a focused laser radiation output; and

(0295) (4) transmitting the focused laser radiation output into a PLM to modify the hydrophilicity within the PLM.

This general method may be modified heavily depending on a number of factors, with rearrangement and/or addition/deletion of steps anticipated by the scope of the present invention. Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of pre-
ferred exemplary embodiment systems described herein is anticipated by the overall scope of the present invention.

PM Product-By-Process

[0296] The present invention is anticipated by the overall scope of the present invention. PM 0306 The present invention anticipates a wide variety of variations in the basic theme of construction. The examples presented previously do not represent the entire scope of possible usages. They are meant to cite a few of the almost limitless possibilities.

[0307] This basic system, method, and product-by-process may be augmented with a variety of ancillary embodiments, including but not limited to:

[0308] An embodiment wherein the distribution of the focused laser radiation output is configured to be larger than the field size of the microscope objective by use of an X-Y stage configured to position the microscope objective.

[0309] An embodiment wherein the laser source further comprises a femtosecond laser source emitting laser pulses with a megahertz repetition rate.

[0310] An embodiment wherein the pulsed laser radiation output has energy in a range of 0.17 to 500 nanojoules.

[0311] An embodiment wherein the pulsed laser radiation output has a repetition rate in the range of 1 MHz to 100 MHz.

[0312] An embodiment wherein the pulsed laser radiation output has a pulse width in the range of 10 fs to 350 fs.

[0313] An embodiment wherein the focused laser radiation output has a spot size in the X-Y directions in the range of 0.5 to 10 micrometers.

[0314] An embodiment wherein the focused laser radiation output has a spot size in the Z direction in the range of 0.01 to 200 micrometers.

[0315] An embodiment wherein the PLM is shaped in the form of a lens.

[0316] An embodiment wherein the PLM is water saturated.

[0317] An embodiment wherein the PLM comprises an intraocular lens contained within an ophthalmic lens material.

[0318] An embodiment wherein the PLM comprises an intraocular lens contained within an ophthalmic lens material, the ophthalmic lens material located within the eye of a patient.

[0319] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a two-dimensional pattern within the PLM.

[0320] An embodiment wherein the PLM comprises an intraocular lens contained within an ophthalmic lens material, the ophthalmic lens material located within the eye of a patient.

[0321] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a three-dimensional pattern within the PLM.

[0322] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a three-dimensional pattern within the PLM, the pattern forming a convex lens within the PLM.

[0323] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a three-dimensional pattern within the PLM, the pattern forming a biconvex lens within the PLM.

[0324] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a three-dimensional pattern within the PLM, the pattern forming a concave lens within the PLM.

[0325] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in
a three-dimensional pattern within the PLM, the pattern forming a biconcave lens within the PLM.

[0326] An embodiment wherein the laser scanner is configured to distribute the focused laser radiation output in a three-dimensional pattern within the PLM; the focused laser radiation creating a hydrophilicity change in the volume associated with the three-dimensional pattern; and the hydrophilicity change resulting in a corresponding change in refractive index of the volume associated with the three-dimensional pattern.

[0327] An embodiment wherein the refractive index change is negative for the PLM having an initial refractive index greater than 1.3.

[0328] An embodiment wherein the refractive index change is greater than 0.005.

[0329] An embodiment wherein the three-dimensional pattern comprises a plurality of layers within the PLM.

[0330] An embodiment wherein the PLM comprises a crosslinked polymeric copolymer.

[0331] An embodiment wherein the PLM comprises a crosslinked polymeric acrylic polymer.

[0332] An embodiment wherein the laser source further comprises an Acousto-Optic Modulator (AOM).

[0333] An embodiment wherein the laser source further comprises a greyscale Acousto-Optic Modulator (AOM).

[0334] An embodiment wherein the PLM has been prosoaked in a liquid solution comprising water.

[0335] An embodiment wherein the PLM comprises an ultraviolet (UV) absorbing material.

[0336] One skilled in the art will recognize that other embodiments are possible based on combinations of elements taught within the above invention description.

Generalized Computer Usable Medium

[0337] In various alternate embodiments, the present invention may be implemented as a computer program product for use with a computerized computing system. Those skilled in the art will readily appreciate that programs defining the functions defined by the present invention can be written in any appropriate programming language and delivered to a computer in many forms, including but not limited to: (a) information permanently stored on non-writable storage media (e.g., read-only memory devices such as ROMs or CD-ROM disks); (b) information alterably stored on writable storage media (e.g., floppy disks and hard drives); and/or (c) information conveyed to a computer through communication media, such as a local area network, a telephone network, or a public network such as the Internet. When carrying computer readable instructions that implement the present invention methods, such computer readable media represent alternate embodiments of the present invention.

[0338] As generally illustrated herein, the present invention system embodiments can incorporate a variety of computer readable media that comprise computer usable medium having computer readable code means embodied therein. One skilled in the art will recognize that the software associated with the various processes described herein can be embodied in a wide variety of computer accessible media from which the software is loaded and activated. Pursuant to In re Beau-regard, 35 USPQ2d 1383 (U.S. Pat. No. 5,710,578), the present invention anticipates and includes this type of computer readable media within the scope of the invention. Pursuant to In re Nuiten, 500 F.3d 1346 (Fed. Cir. 2007) (U.S. patent application Ser. No. 09/211,928), the present invention scope is limited to computer usable media wherein the media is both tangible and non-transitory.

CONCLUSION

[0339] A system/method allowing the modification of the hydrophilicity of a polymeric material (PM) has been disclosed. The modification in hydrophilicity (i) decreases the PM refractive index, (ii) increases the PM electrical conductivity, and (iii) increases the PM weight. The system/method incorporates a laser radiation source that generates focused laser pulses within a three-dimensional portion of the PM to affect these changes in PM properties. The system/method may be applied to the formation of customized intraocular lenses comprising material (PLM) wherein the lens created using the system/method is surgically positioned within the eye of the patient. The implanted lens refractive index may then be optionally altered in situ with laser pulses to change the optical properties of the implanted lens and thus achieve optimal corrected patient vision. This system/method permits numerous in situ modifications of an implanted lens as the patient’s vision changes with age.

[0340] A lens formation system/method that permits dynamic in situ modification of the hydrophilicity of the PLM has also been disclosed. The system/method incorporates a laser that generates focused pulses within a three-dimensional portion of PLM to modify the hydrophilicity and thus the refractive index of the PLM and thus create a customized lens of arbitrary configuration. The system/method may be applied to the formation of customized intraocular lenses wherein an ophthalmic lens material incorporating homogeneous PLM is surgically positioned within the eye of a patient. The patient’s vision is analyzed with the ophthalmic lens installed and the homogeneous PLM is then irradiated in situ with laser pulses to modify the internal refractive characteristics of the PLM to achieve optimal corrected patient vision. This exemplary application may permit in situ modification of intraocular lens characteristics on a dynamic basis as the patient ages.

What is claimed is:

I. A system for changing the hydrophilicity of an internal region of a polymeric material, said system comprising:

(a) laser source;
(b) laser scanner; and
(c) microscope objective;

wherein

said laser source is configured to emit a pulsed laser radiation output;

said laser scanner is configured to distribute said pulsed laser radiation output across an input area of said microscope objective;

said microscope objective further comprises a numerical aperture configured to accept said distributed pulsed laser radiation and produce a focused laser radiation output; and

said focused laser radiation output is transmitted by said microscope objective to an internal region of polymeric material (PM);

said focused laser radiation output interacts with polymers within the treated internal region and results in a change in hydrophilicity within said internal region of said PM.
2. A lens formation system comprising:
(a) laser source;
(b) laser scanner; and
(c) microscope objective;
wherein
said laser source is configured to emit a pulsed laser radiation output;
said laser scanner is configured to distribute said pulsed laser radiation output across an input area of said microscope objective;
said microscope objective further comprises a numerical aperture configured to accept said distributed pulsed laser radiation and produce a focused laser radiation output; and
said focused laser radiation output is transmitted by said microscope objective to a polymeric lens material (PLM);
said focused laser radiation output interacts with polymers within the treated internal region and results in a change in hydrophilicity within said internal region of said PLM.

3. The system of claim 2 wherein said distribution of said focused laser radiation output is configured to be larger than the field size of said microscope objective by use of an X-Y stage configured to position said microscope objective to sequential areas within the material.

4. The system of claim 2 wherein said laser scanner further comprises a femtosecond laser source emitting laser pulses with a megahertz repetition rate.

5. The system of claim 2 wherein said pulsed laser radiation output has energy in a range of 0.17 to 500 nanowatts.

6. The system of claim 2 wherein said pulsed laser radiation output has a repetition rate in the range of 1 MHz to 100 MHz.

7. The system of claim 2 wherein said focused laser radiation output has a pulse width in the range of 10 fs to 350 fs.

8. The system of claim 2 wherein said focused laser radiation output has a spot size in the X-Y directions in the range of 1 to 7 micrometers.

9. The system of claim 2 wherein said focused laser radiation output has a spot size in the Z direction in the range of 0.05 to 10 micrometers.

10. The system of claim 2 wherein said PLM is shaped in the form of a lens.

11. The system of claim 2 wherein said PLM is water saturated.

12. The system of claim 2 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material.

13. The system of claim 2 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

14. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a two-dimensional pattern within said PLM.

15. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM.

16. The system of claim 15 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

17. The system of claim 15 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

18. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM, said pattern forming a convex lens within said PLM.

19. The system of claim 18 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material.

20. The system of claim 18 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

21. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM, said pattern forming a biconvex lens within said PLM.

22. The system of claim 21 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material.

23. The system of claim 21 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

24. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM, said pattern forming a concave lens within said PLM.

25. The system of claim 24 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material.

26. The system of claim 24 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

27. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM, said pattern forming a biconcave lens within said PLM.

28. The system of claim 27 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material.

29. The system of claim 27 wherein said PLM comprises an intraocular lens contained within an ophthalmic lens material, said ophthalmic lens material located within the eye of a patient.

30. The system of claim 2 wherein said laser scanner is configured to distribute said focused laser radiation output in a three-dimensional pattern within said PLM; said focused laser radiation creating a hydrophilicity change in the volume associated with said three-dimensional pattern; and said hydrophilicity change resulting in a corresponding change in refractive index of said volume associated with said three-dimensional pattern.

31. The system of claim 30 wherein said hydrophilicity change results in a negative refractive index change within said PLM having an initial refractive index greater than 1.3.

32. The system of claim 30 wherein said refractive index change is greater than 0.01.

33. The system of claim 29 wherein said three-dimensional pattern comprises a plurality of layers within said PLM.

34. The system of claim 2 wherein said PLM comprises a crosslinked polymeric copolymer.

35. The system of claim 2 wherein said PLM comprises a crosslinked polymeric acrylic polymer.
36. The system of claim 2 wherein said laser source further comprises an Acousto-Optic Modulator (AOM).

37. The system of claim 2 wherein said laser source further comprises a greyscale Acousto-Optic Modulator (AOM).

38. The system of claim 2 wherein said PLM has been presoaked in a liquid solution comprising water.

39. The system of claim 2 wherein said PLM comprises an ultraviolet (UV) absorbing material.

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