(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
03 March 2022 (03.03.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/043318 A1

(51) International Patent Classification:
B29D 11/00 (2006.01) *B29D 11/02* (2006.01)

(21) International Application Number:
PCT/EP2021/073373

(22) International Filing Date:
24 August 2021 (24.08.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/070,180 25 August 2020 (25.08.2020) US

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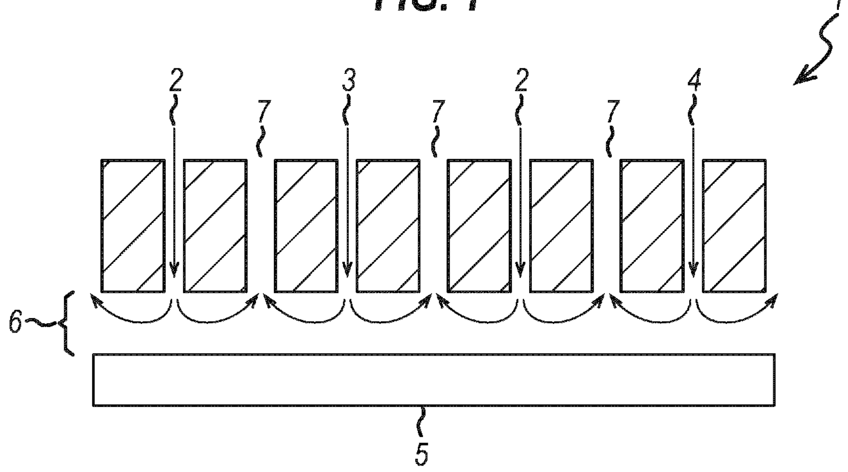
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: PARTIAL COATING OF INTRAOCULAR LENSES USING SPATIAL ALD

FIG. 1



(57) **Abstract:** A system and method for efficiently modifying the surface of an intraocular lenses to reduce tackiness and improve lens unfold time and unfold time consistency, and a product created using the system and method, is disclosed. In some aspects, the system and method utilizes at least part of a lens-forming device as a mask..

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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

PARTIAL COATING OF INTRAOCULAR LENSES USING SPATIAL ATOMIC LAYER DEPOSITION

Field of the Disclosure

This disclosure is directed to the deposition of a thin coating layer on a polymeric material. These coated materials, which have reduced tackiness, improved unfolding time and improved consistency in unfold time, may be used in ophthalmic devices, such as intraocular implants or lenses.

Background of the Disclosure

Cataract surgery is commonly performed to replace the natural lens of an eye that has become opaque. Materials that are used to replace the natural crystalline lens must be soft and have excellent flexibility. They are delicate devices which must be resilient, as they are first rolled tightly, then inserted through very small incisions into the eye. The compression and tensile stresses put on the lens as it is compressed and forced through an insertion tip are not insubstantial. Once inserted, this compressed lens must unfold within a time that is slow enough to allow a surgeon to appropriately position the lens, yet not so long that causes undue delay or patient discomfort. The tackiness of the lens material is one factor which may slow or even inhibit the lens unfolding.

Many of these soft, flexible materials that are used for foldable lenses tend to possess “self-tackiness”. This tackiness leads to longer unfold times once the lenses are implanted into the eye. This is particularly true with regards to the haptics, which are folded over the anterior optic so that they are touching the anterior surface of the lens and each other during insertion into the eye. Tackiness in combination with the forces which encourage the haptics towards the anterior surface of the lens during folding and insertion can lead to unpredictable and often long unfold times. In some instances, the lenses must be manually unfolded once implanted into the eye.

Various approaches are taken to reduce self-tackiness. In some cases, the entire lens may be coated with a hydrophilic coating. This allows for separation of the surfaces in aqueous and thus a more rapid and reliable unfolding of the lens once implanted into the eye.

While hydrophilic lenses do have some benefits, there are still benefits to hydrophobicity in an intraocular lens. One advantage is that hydrophobic surfaces may adhere better to the posterior bag, which will help delay or prevent posterior capsular opacification.

In some instances, a coating may be applied using vacuum or low-pressure chemical vapor deposition. Plasma treatment may be used to facilitate such coatings. Alternatively, as described in US Ap. No. 2009/0076603 (Neal, et al.), atmospheric pressure chemical vapor deposition may be used to apply a partial coating. Chemical vapor deposition describes a process whereby a vaporized material can be used to coat a substrate with a thin film. With this process, the coating molecules are formed in vapor form and settle onto the surface of a substrate. As may be seen from this reference, the process requires the time-consuming step of applying a mask to targeted portions of each lens. The lenses are then each individually placed on a conveyer. These steps require physical manipulation of the lenses. Every time a lens is touched during manufacturing, it increases the potential for damage – by being dropped, by damage to the optical surface, or by other, inadvertent, means. In a best-case scenario, such damage reduces manufacturing yields. In a worst-case scenario, the damage could result in a less than optimal outcome for a patient.

Coating thickness is a concern when using vapor deposition, since care must be taken to ensure that the vapor deposited coating extends over the entire substrate. This concern applies to the upper surfaces of the substrate. It is even more of a concern with regards to non-horizontal surfaces, like edges/sides and bottoms. Attempts to ensure a complete coating can lead to an unduly thick coating being applied.

Furthermore, these processes are suitable for only certain types of situations. Some substrates and uses of substrates have limitations as to the thickness of the coating that may be applied. Other methods are time-consuming, and inefficient.

Accordingly, there is a need for a coating, and an efficient, safe method of applying a thin coating to a lens in a manner which will reduce self-tackiness yet not unduly interfere with the optics of the lens.

Summary of the Disclosure

In one aspect of the present invention, there is a system and method for modifying the surface of an intraocular lens (IOL) using spatial atomic layer deposition. In one aspect of the invention, this surface modification is performed while the lens is contained in a device or portion of a device that is used during the formation of the lens. In one aspect, such device or portion of a device may be a portion of a mold. In another aspect of the invention, such device or portion of a device is a holder that is used during the lathing process. In process, the IOL is delivered to the spatial atomic layer deposition system while still in its device or portion of a device. The spatial atomic layer deposition system then processes the lens through a plurality of coating segments which are used to perform the surface modification. Each coating segment includes a first inert gas source configured to provide inert gas, a precursor injector source configured to provide a precursor gas, a second inert gas source configured to provide inert gas, and a plasma source configured to provide plasma. When the coating segments are activated, and the lenses move through the coating segments, each segment lays down a very thin layer of coating. The plurality of coating segments collectively provides a uniform coating of sufficient thickness to achieve the desired surface modification.

In one aspect of the present invention, there is a system and method for coating an intraocular lens (IOL) using spatial atomic layer deposition. In one aspect of the invention, this coating is performed while the lens is contained in a device or portion of a device that is used during the formation of the lens. In one aspect, such device or portion of a device may be a portion of a mold. In another aspect of the invention, such device or portion of a device is a holder that is used during the lathing process. In process, the IOL is delivered to the spatial atomic layer deposition system while still in its device or portion of a device. The spatial atomic layer deposition system then processes the lens through a plurality of coating segments. Each coating segment includes a first inert gas source configured to provide inert gas, a precursor injector source configured to provide a precursor gas, a second inert gas source configured to provide inert gas, and a plasma source configured to provide plasma. When the coating segments are activated, and the lenses move through the coating segments, each segment lays down a very thin layer of coating. The plurality of coating segments collectively provide a uniform coating of sufficient thickness to achieve the desired result.

In one aspect of the invention, the efficiency is at least partially achieved by using the device or portion of the device that is used to form the lens during both the lens-forming and the lens-coating processes. In another aspect of the invention, the efficiency is achieved by the using device or portion of the device that is used to form the lens during both the lens-forming and the lens-coating processes, and further by using it to at least partially mask the lens body while allowing a portion of the support structure that is located away from the lens body to receive a coating along substantially its entire circumferential surface.

In the above aspects of the invention, when the lens support structure(s) are at least partially removed from the mold and/or the device that is used during lens formation, the coating is applied to the anterior surface of the lens body and a portion of the lens support structure, including substantially all of the circumferential surface of the portion of the lens support structure (s) that is located away from the lens body.

Brief Description of Figures

FIG. 1 shows a repeating unit, or coating segment, which forms part of a processing line;

FIG. 2 shows a substrate holder and substrate in the system under plasma or gas flow;

FIG. 3a and 3b show schematics of different plasma sources;

FIG. 4 shows a schematic of an alternate plasma source;

FIG. 5 shows the Growth Per Cycle of SiO_2 in the system of FIG. 1;

FIG. 6 provides a view of a rotary s-ALD system;

FIG. 7 shows the rotary system of FIG. 6, where the substrates are aligned with the precursor area, purge area, plasma area, respectively; and

FIG. 8 shows a graph demonstrating a change in refractive index of the coating by combining precursor gasses.

FIG. 9 shows a table comprising comparative data for coated lenses that were compressed and passed through a lens insertion system.

Detailed Description of the Disclosure

It is to be understood that the disclosure is not limited to the details of construction or process steps set forth in the following description. The disclosure is capable of other embodiments and of being practiced or being carried out in various ways using the teaching herein.

The present inventors have discovered that the surface of a polymeric material may be modified by applying a thin, uniform coating to the surface of polymeric material. This coating is chemically bound to the surface of the polymeric material.

The coating that is applied as part of the present invention is applied using Spatial Atomic Layer Deposition. Atomic Layer Deposition, or ALD, is a technique used to grow thin films on substrates. It is based on sequential exposure of a substrate to self-limiting surface half-reactions. With ALD, the substrate is exposed to sequential precursors, then a purge step. Spatial ALD, or s-ALD, is a variation of ALD. In s-ALD, precursors are continuously supplied in different locations. These regions are separated by an inert gas region or zone. Film growth is accomplished by exposing the substrate to the locations containing the different precursors. One benefit of s-ALD is that the purge steps used in ALD are not necessary. This allows for substantially faster deposition rates. Additionally, s-ALD can be performed at ambient conditions (atmospheric pressure, no vacuum). Allowing the process to proceed at atmospheric pressure allows the process to proceed in a continual layout. In contrast, use of a vacuum is more consistent with a batch process.

ALD and s-ALD may be distinguished from other coating processes in that the ALD/s-ALD process lays down a thin, uniform coating of a gaseous precursor which is then chemically activated by plasma to form the desired coating. This plasma treatment simultaneously also chemically bonds the coating to the surface of the substrate. From a step-by-step viewpoint, a thin layer of gaseous precursor is first allowed to settle over that portion of the substrate that is open to the gas (i.e., not masked in some form). The precursor gas is then removed from contact with the substrate. Next, plasma is allowed to react with the precursor that is on the substrate. It will be known by one skilled in the art that the plasma should be selected to chemically bond with the chosen precursor to form the desired coating. By way of example, in one aspect of the invention, when the desired coating is an oxide, oxygen plasma may be used. When a nitride is desired, nitrogen plasma may be used. Similarly, when a carbide is desired, CO or CO_2 plasma may be used. In one aspect of the invention, nitric oxide is used.

The plasma encourages the formation of bonds between the plasma molecules and the precursor, as well as between the precursor and unreacted groups in the substrate, which results in a coating over the entire unmasked surface of the substrate. By way of example, when the plasma is oxygen plasma, the plasma encourages the formation of bonds between the oxygen and the precursor, as well as between the precursor and unreacted acrylates in the substrate, which results in a coating over the entire unmasked surface of the substrate that is chemically bonded to the substrate. The chemical bonding of the coating to the substrate results in a chemical modification of the surface; as a result of the ALD/s-ALD treatment, the coated surface of the substrate is less tacky and therefore has a reduced tendency to stick to itself. While reducing unfold times, the coating method as described herein also improves consistency and predictability in unfold times.

When coating an intraocular lens, it is important that the coating thickness be well-controlled. First, this is because thicker coatings (~ >25 nm) have the potential to have an impact on the optical performance of the lens. That is, with a thicker coating, the likelihood that a patient would see a difference in refractive index between the coating and the lens/haptic material as a reflection is increased. A thicker coating may cause crazing of the coating, or may cause chemical reactions when the lens is exposed to other chemicals (e.g., during chemical sterilization of a lens). Thick coatings also have the potential shed particles during an implantation procedure. From a surgical perspective, it is undesirable to leave coating particles loose in the eye after a procedure. Lastly, as lens technology improves, it is becoming increasingly feasible to form intraocular lenses that have a thinner cross-section. As a lens thickness (distance along the optical access) slims, any coating on that lens should also be reduced in thickness to keep the relative thickness between the coating and the lens body consistent. A thinner lens can also fold more tightly, which creates areas of higher stress concentrations. Where a thin coating is desired, a relatively thicker coating can lead to an increased likelihood that a patient have a negative experience or experience detrimental lens performance.

In other applications, a thicker coating may be desired. This may be important, for example, for high refractive lens materials to reduce reflections, in particular when the refractive material is between the refractive index of aqueous and the lens material. Thus, control over the coating thickness is an important aspect of IOL manufacturing.

Use of the ALD/s-ALD process as described herein, where the coating is laid down over the entire unmasked surface of the substrate in a layer-by-layer process, allows for a uniform coating of controlled thickness.

Multiple s-ALD configurations are suitable for use in the method according to the invention, though those in the art which already demonstrate certain efficiencies are preferred. By way of example, US Pat. No. 4,413,022 discloses a method for growing compounds on thin films. The system in this reference is linear, and may reciprocate. US Ap. No. 2004/0052972 discloses a method and apparatus for ALD on a rotary susceptor. EP 2 334 842 describes an ALD apparatus and method which provides improved use of precursor gas, which can be quite costly.

Fig. 1 provides a view of one repeating unit 1 which makes up a portion of the processing line of an s-ALD system. Repeating unit 1 may also be referred to as a coating segment. The repeating unit is comprised of a number of elements: two inert gas sources 2, a precursor source 3, and a plasma source 4. The process gap 6 is shown between the material sources and the conveyor 5. Each element as shown is equipped with two exhausts 7. These exhausts 7 may be shared with the adjacent element, or separately formed. As noted above, an s-ALD system will require a plurality of repeating units to lay down a plurality of molecular layers to achieve a coating of desired thickness.

The shape of the opening in the inert gas source may vary, but is typically oval, round, square, rectangular or slot-like in shape. The shape and size of the opening in the inert gas source is selected to ensure that it provides an effective separation between the environment in the precursor and plasma chambers.

The shape of the opening in the precursor source may vary, but is typically oval, round, square, rectangular or slot-like in shape. The shape and size of the opening in the precursor source is selected to ensure that the precursor may be deposited evenly on the surface of the substrate.

The shape of the opening in the plasma source by which the plasma is delivered may vary, but is typically oval, round, square, rectangular or slot-like in shape. The shape and size of the opening in the plasma source opening should be selected to ensure that plasma is provided in a substantially uniform amount over the full surface of the substrate. This results in a uniform layer conversion from precursor to coating. In one aspect of the invention, the opening in the plasma source takes the shape of a rectangle or slot.

Each element consists of a supply and an exhaust. In one aspect of the invention, each element consists of a supply and more than one exhaust. In one aspect of the invention (shown), each element consists of a supply and two exhausts. In one aspect of the invention, the exhausts are placed towards a side of the conveyor.

As described so far, each element consists of one supply of material. In one aspect of the invention, each element (i.e., an inert gas source 2, a precursor source 3, and a plasma source 4) is made up of a plurality of unit segments. By unit segment it is meant that there are two units of the same element. That is, instead of having only one source with two exhausts, there would be a second source coupled with exhausts immediately following the first. In one aspect of the invention, each element is made up of from 1 to 8 unit segments. In one aspect of the invention, each element is made up of from 1 to 6 unit segments. In one aspect of the invention, each element is made up of from 1 to 4 unit segments. In one aspect of the invention, each element is made up of from 1 to 3 unit segments. In one aspect of the invention, each element is made up of 2 unit segments. In one final aspect of the invention, each purge area/inert gas element would be made up of 2 unit segments.

Intraocular lenses are formed of a central lens portion and at least one support structure, which may be any shape known in the art. In one aspect of the invention, the lens support structure is a haptic. Such lenses may be formed as one piece. Alternatively, the support structure(s) may be joined to the lens after it is formed. In one aspect of the invention, the lenses are molded. The term molded includes lenses that are fully formed in optically accurate form through the molding process as well as lenses that are at least partially formed through a molding process. In one aspect of the invention, where lenses are molded in optically accurate form, the substrate holder may be the one half of the lens mold. In another aspect of the invention, where lenses are lathed prior to receiving the coating, the substrate holder may be the lens holder that is used during the lathing process. This lens holder that is used during the lathing process may or may not be a portion of lens mold. In this aspect of the invention, the lens may or may not be molded.

The molded lenses receive a coating via s-ALD while still at least partially encased in a device that was used during their formation. In one aspect of the invention, this device is one that was used for holding the lens during a lathing process. In another aspect of the invention, this device is a lens mold. In one aspect of the invention, one side of the mold is removed and one side is retained. In one aspect of the invention, the retained side masks substantially all of the posterior side of the lens.

This process is efficient in that the lenses do not have to be first fully removed from the device that is used during their formation, then separately placed in a distinct carrier system and/or masked. This use of the existing device potentially decreases waste and saves time. It also reduces the degree to which each lens is being handled, which lessens the opportunity for inadvertent damage to the lens, hence increasing manufacturing yields of the lenses, and potentially improving patient outcomes. Lastly, when the device is used as a mask, this removes the need for a mask to be separately applied, which again leads to improved efficiency.

When the lens is coated via s-ALD while at least partially encased in its mold or other device that is used during lens formation, it is partially masked by that device. In one aspect, such masking may be accomplished by maintaining the lens in one side of a mold that is used to mold the lens, while removing the other side of the lens-forming mold. In another aspect, such masking may be accomplished by maintaining the lens in the side of the mold that is used to mold the posterior side of the lens, while removing the side of the lens-forming mold that forms the anterior side of the lens. In another aspect of the invention, such masking may be accomplished by maintaining the lens in the side of the mold that is used to mold the bottom side of the lens, while removing the side of the lens-forming mold that forms the top side of the lens. In another aspect of the invention, the lens body may be maintained in one side of the mold that is used to form the lens, while the lens support structure(s)have been released from the mold. In another aspect of the invention, the lens body may be maintained in the side of the mold that is used to form the posterior side of the lens, while the lens support structure(s) have been released from the mold. In another aspect of the invention, the lens body may be maintained in one side of the mold that is used to form the lens, while the lens support structure(s) have been partially released from the mold. In another aspect of the invention, the lens body may be maintained in the side of the mold that is used to form the posterior side of the lens, while the lens support structure(s) have been partially released from the mold. In another aspect of the invention, the lens body may be maintained in the side of the mold that is used to form the posterior side of the lens, while the portion of the mold that is used to form the lens support structure(s) has been removed. In another aspect of the invention, the masking may be accomplished by maintaining the lens in the device that is used during lens formation. In yet another aspect of the invention, the masking may be accomplished by maintaining the lens in the device that is used during lens formation, while a portion of associated lens supporting device(s) are not supported by the device. In another aspect of the invention, where it is desired that the lens support structure(s) have a coating thickness that differs from the coating on the optic, the lens could be masked or oriented so that only the support structure(s) are exposed to the s-ALD.

In some aspects of the invention, discussed above, the lens support structure(s) are partially removed from the mold and/or the device that is used during lens formation. Such partial removal may be accomplished by removing a distal portion of a lens support structure from the device, while allowing the portion of the lens support structure that is closer to the lens to remain in the device. This partial removal allows for substantially full coating of those portions of the lens support structures that engage the anterior face of the lens during insertion.

In the above aspects of the invention, when the lens support structure(s) are at least partially removed from the mold and/or the device that is used during lens formation, the coating is applied to substantially all of the circumferential surface of a portion of the lens support structure(s) that is located away from the lens body as well as to a portion of the remaining lens support structure, and one side of the lens body. In one aspect of the invention, the coating is applied to substantially all of the circumferential surface of more than 75% of the lens support structure. In one aspect of the invention, the coating is applied to substantially all of the circumferential surface of more than 50% of the lens support structure. In one aspect of the invention, the coating is applied to substantially all of the circumferential surface of more than 25% of the lens support structure.

In another aspect of the invention, additional masking may be performed by either chemical or physical means. In one aspect of the invention, this additional masking may be performed using Teflon tape or tape with an adhesive backing. In one aspect of the invention, this additional masking may be performed using a chemical coating or barrier. In one aspect of the invention, this additional masking may be performed using a removable chemical coating or barrier. In one aspect of the invention, additional masking may be performed by placing a mask underneath the precursor source, or by changing the shape of the opening in the precursor source. In one aspect of the invention, this additional masking may be performed by ink jet printing a deposition-resistant block on the substrate. Many other masking methods are known in the art, and all such masking methods could be utilized in association with the present invention.

An apparatus for s-ALD according to one aspect of the invention will include a precursor source. The precursor source will include an opening that is separated from the substrate surface by a deposition space that is defined by the distance between the opening in the precursor source and the substrate surface. The opening in the precursor source is designed to provide a precursor gas from the precursor supply into the deposition space so that the precursor gas may contact the substrate surface. In one aspect of the invention, the precursor supply forms the gas to which the substrate is exposed. In another aspect of the invention, the gas to which the substrate is exposed is formed of a precursor gas and an inert bearing-gas which is distinct from the precursor gas.

The distance between (a) the precursor source and the substrate holder, (b) the inert gas source and the substrate holder, and (c) the plasma source and the substrate holder, are fixed. In one aspect of the invention, these distances are mechanically fixed. In another aspect of the invention, these distances are controlled/fixed using a motorized system. Collectively, these distances will be referred to in terms of spacing away from the injector head.

In one aspect of the invention, one or more of the portion of the precursor source, the inert gas source and the plasma source that provide material to the substrate are circular in configuration. In another aspect of the invention, one or more of the portion of the precursor head, the inert gas inlet and the plasma source that provide material to the substrate have a slit configuration. In another aspect of the invention, one or more of the portion of the precursor head, the inert gas inlet and the plasma source that provide material to the substrate have a slit configuration that has approximately the same width/diameter as a cross-section of the substrate. In another aspect of the invention, one or more of the portion of the precursor head, the inert gas inlet and the plasma source that provide material to the substrate independently have a either a sizing that has approximately the same width/diameter as a cross-section of the substrate or a sizing that has a width/diameter that is smaller than a cross-section of the substrate.

In one aspect of the invention, the injector head is positioned between 100 and 400 microns away from top of the substrate holder. This distance is referred to as the process gap 6. In another aspect of the invention, the injector head is positioned between 150 and 250 microns away from top of the substrate holder. In another aspect of the invention, the distance between the injector head and the substrate holder is 200 microns.

In one aspect of the invention, the substrate holder 10 extends beyond the height of the substrate 11. See Fig. 2, which also shows the flow 12 of precursor or plasma with the curved arrows. In this aspect of the invention, the distance from the injector head 13 to the substrate 11 (the deposition space) is from about 1 mm to about 8 mm. In another aspect of the invention, the distance from the precursor injector head 13 to the substrate 11 is from about 1 mm to about 6 mm. In another aspect of the invention, the distance from the precursor injector head 13 to the substrate 11 is from about 2 mm to about 6 mm. In another aspect of the invention, the distance from the precursor injector head 13 to the substrate 11 is from about 3 mm to about 5 mm. In another aspect of the invention, the distance from the precursor injector 13 head to the substrate 11 is about 4 mm. The holder 14 may also be seen.

Those in the art will appreciate that this deposition space is atypically large for s-ALD. This forgiving distance, when coupled with the comparatively small spacing between the injector head 13 and the top of the substrate holder 10, is what allows the system to work so well with intraocular lenses. When the substrate holder 10 extends beyond the surface of the substrate 11, it allows spacing for a variation in heights for substrate 11. That is, for example, the same system is equally suited to coat curved 34 diopters lenses as virtually flat 5 diopters lenses.

The comparatively small process gap 6 serves almost as a valve to cut off supply of material to the interior 15 of the substrate holder. In one aspect of the invention, this small process gap 6 allows for the inclusion of only one purge station between precursor/plasma, and plasma/precursor. In another aspect of the invention, more than one purge station between precursor/plasma, and plasma/precursor is included.

Exposure time of the substrate to the various portions of the repeating unit (purge, precursor, plasma) may be selected by varying the length of each repeating unit segment and/or the rate of the movement of the substrate through the repeating unit. Typically, the substrate is exposed to the precursor area a plurality of times in order to achieve a sufficient coating. In one aspect of the invention, one exposure of the substrate to the precursor area is for 200-400 ms. In another aspect of the invention, one exposure of the substrate to the precursor area is for 225-350 ms. In another aspect of the invention, one exposure of the substrate to the precursor area is for 250-300 ms. One of skill in the art would also appreciate that exposure time could be reduced if the amount of material at the various portions of the repeating unit (purge, precursor, plasma) could be increased in concentration or flow. The skilled practitioner will be able to determine what the minimum exposure time is for each situation.

An apparatus for s-ALD according to one aspect of the invention will include a source of plasma. In one aspect of the invention, the plasma is oxygen plasma. Oxygen plasma refers to any plasma treatment performed while introducing oxygen to the plasma chamber.

Multiple different plasma generation methods and devices are appropriate for use in the method and system according to the invention. The plasma-generating systems and methods selected for use in association with the present invention should be sufficiently cool such that the generated radicals in the plasma do not heat the substrate beyond the temperature provided by the conveyor. That is, the traditional plasma-generating method, where gasses are heated to extremely high temperatures, is not preferred. By way of example, a plasma may be generated by subjecting a gas to a strong electromagnetic field to the point where the ionized gaseous substance becomes increasingly conductive.

As discussed, the plasma gas may be one gas, or may be a mixture of gasses. In one embodiment of the invention, the mixture is selected to facilitate multiple different reactions with the selected precursor(s). In another aspect of the invention, the mixture may be selected based on other reasons, for example availability, cost and safety. By way of example, when an oxygen plasma species is desired, a combination of oxygen and nitrogen may be used. In one aspect of combination, from 0.5% to 10% oxygen is used in nitrogen. In one aspect of combination, from 0.75% to 7.5% oxygen is used in nitrogen. In one aspect of combination, from 1% to 5% oxygen is used in nitrogen. In one aspect of combination, from 1.5% to 3% oxygen is used in nitrogen.

In one aspect of this invention, the combination of gasses above is generated by using a premix gas. In another aspect of this invention, the combination of gasses above is generated by having two separate gas sources which are combined prior to reaching the opening in the plasma source.

The selection of preferred plasma gas will be made based on the desired chemical reaction and resulting coating to be achieved. The flow rate and pressure of plasma will be determined by the size and shape of the plasma delivery. In one aspect of the invention, the flow rate of the plasma gas out of the plasma source is in the range of from about 0.1 to about 10 slm. In another aspect of the invention, the flow rate of the plasma gas out of the plasma source is in the range of from about 0.5 to about 8 slm. In another aspect of the invention, the flow rate of the plasma gas out of the plasma source is in the range of from about 0.5 to about 6 slm. In another aspect of the invention, the flow rate of the carrier gas with plasma out of the plasma source is in the range of from about 1 to about 4 slm. In another aspect of the invention, the flow rate of the plasma gas out of the plasma source is in the range of from about 1.5 to about 3 slm. It will be appreciated by one of skill in the art that the flow rate will be influenced by the size of the delivery of the plasma. That is, a larger delivery of plasma will allow for a slower flow rate, and a smaller delivery of plasma will typically require a faster flow rate to achieve the same substrate coverage in a given time.

A plasma source which is suitable for an aspect of the present invention is shown in FIG. 3(a), where a plasma jet 30 is generated when gas 32 is passed through a dielectric tube 34. This dielectric tube 34 is surrounded by two ring electrodes 36 which are connected to a power supply 38. To activate the plasma mechanism shown in FIG. 3(a), a high-frequency electric voltage difference is applied between first ring electrodes 36 by a generator.

An alternate plasma source which is suitable for an aspect of the present invention is shown in FIG. 3(b), where a plasma jet 30 is generated when gas 32 is passed through a quartz glass tube 40. This glass tube 40 is surrounded by a high voltage electrode 42 which are connected to a power supply (not shown). The glass tube 40 and electrode 42 are surrounded by a ceramic body 44. Substrate 46 rests on a sample holder 48, which sits on a grounding electrode 49. To activate the plasma mechanism shown in FIG. 3(b), a high-frequency electric voltage difference is applied to high voltage electrode 42 by a generator.

A plasma source which is suitable for another aspect of the present invention is disclosed in US Ap. No. 20170137939, and shown in FIG 4. In FIG. 4, substrate 50 may be moved by transport mechanism 51. 52 denotes fluid/gas inlets which flow between first electrode 53a, 53b and second electrode of electrically conductive material 54. The first and second electrodes are coupled to an electric voltage generator. Electrode 54 may include a dielectric layer 55. By way of example, dielectric layer 55 may be aluminum oxide or silicon carbide.

Aperture 56, through which the generated radicals in the plasma do flow to reach substrate 50 is also shown. First electrode 53 a, b, second electrode 54 and dielectric layer 55 extend at least along the length of aperture 56, which extends perpendicular to the plane of the figure. That is, the aperture 56 takes the form of a slot through which plasma is provided.

To activate the plasma mechanism shown in FIG. 4, a high-frequency electric voltage difference is applied between first electrode 53 a, b and second electrode 54 by the generator (not shown). First electrode 53 a,b may be kept at a constant potential, e.g. ground potential. A higher frequency potential may be applied to second electrode 54. The combination of first and second electrodes 53 a,b, and dielectric layer 55 functions as a dielectric barrier discharge or surface dielectric barrier discharge plasma generator. Gas flows from inlets 52 to aperture 56 through the spaces between the lower surface of dielectric layer 55 and the upper surfaces of the first and second portion 53 a,b of the first electrode.

The high-frequency electric field in these spaces resulting from the voltage differences ionizes the gas, creating plasma. The ionized gas flows into aperture 56 where it forms an atmospheric plasma, i.e. a plasma in a gas of considerable pressure.

In all aspects of the invention, the plasma area is equipped with at least one exhaust through which the generated radicals in the plasma may exit. In one aspect of the invention, the plasma area is equipped with two exhausts, one on one side of the holder 14 that is generally in the path of the movement of the holder 14 and one on the other side of the holder 14 that is generally in the path of the movement of the holder 14. In yet another aspect of the invention, the plasma area is equipped with two exhausts, one on one side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14 and one on the other side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14.

In one aspect of the invention, the distance from the plasma source to the substrate is from about 1 mm to about 8 mm. In another aspect of the invention, the distance from the plasma source to the substrate is from about 1 mm to about 6 mm. In another aspect of the invention, the distance from the plasma source to the substrate is from about 2 mm to about 6 mm. In another aspect of the invention, the distance from the plasma source to the substrate is from about 3 mm to about 5 mm. In another aspect of the invention, the distance from the plasma source to the substrate is about 4 to about 5 mm.

The comparatively large spacing between the (a) opening in the precursor source and the substrate and (b) the plasma source and the substrate was somewhat surprising, as many in the industry believe that the surface of the product would need to be close to the s-ALD heads in order to facilitate an efficient gas separation by the purge area. However, the configuration of the present invention does not significantly adversely impact the gas separation of the slots.

In use, the substrate holder is placed on a conveyor 5 in the s-ALD system. The system is arranged for relative motion between the conveyor and the precursor/purge/plasma sources. This relative motion is achieved without varying the distance between the conveyor and the precursor/purge/plasma sources; the movement is planar. In one aspect of the invention, the conveyor moves past stationary precursor/purge/plasma sources. In another aspect of the invention, the conveyor is stationary and positioned within a system where the precursor/purge/plasma sources are in motion and move past the substrate. In yet another aspect of the invention, both the conveyor and the precursor/purge/plasma sources move with respect to each other. In another aspect of the invention, the conveyor and the precursor/purge/plasma source movement may be characterized as reciprocating.

Movement may be achieved by many different means which will be known to the skilled practitioner. In one aspect of the invention, movement may be achieved through the use of a conveyor belt or a table and a motor to drive the table. In other embodiments the transport mechanism may comprise a motor to move the substrate through the system, or vice versa.

The present invention addresses the problem of self-tackiness and long, unpredictable unfold times by applying a thin anti-tack coating to the anterior surface of the lens using s-ALD. In an aspect of the invention, the thin anti-tack coating is applied to the anterior surface of the lens and the surfaces of the support member(s) using s-ALD. In an aspect of the invention, the anterior side of the lens and all surfaces of the lens support structures are coated with this thin layer of layer. In an aspect of the invention, the anterior side of the lens and substantially all surfaces of the lens support structures are coated with this thin layer of layer. The coating is selected based on its anti-tack properties, its ability to chemically bond to the substrate, and its refractive index. As noted above, while the refractive index of the coating does not have to exactly match the substrate, it should be selected that the difference between refractive index of the coating and the refractive index of the substrate do not unduly cause reflections or negative optical outcomes for a patient.

In one aspect of the invention, the skilled practitioner may desire to design a coating with specifically tailored properties. When the refractive index of the coating matches the refractive index of the lens material there will be no impact to the optical properties. When the refractive index is chosen between the reactive index of the aqueous and the lens material, the angle of total refraction will increase as the difference of the refractive index at every transition is lower. Thus the reflection will be reduced. This is of particular importance for intraocular lenses with a high refractive index and discontinuous features such as diffractive patterns

By way of example, a practitioner may desire to have a non-tack coating with a specific refractive index. In such instances, it may be desirable to provide a coating which is comprised of alternating layers of different compounds. Such alternating does not have to be 1:1; it may be 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, 1:10, 1:1, 1:12, 1:13, 1:14, 1:15 and so forth. In another aspect of the invention, the alternating may be 1:2:1, 1:3:1, etc. In another aspect of the invention, one compound may form the base of the coating while another forms the top layer of the coating. As may be seen, the possible varieties in organization of layers is almost limitless, and all possibilities are considered appropriate for use with this invention. The above anticipates two potential coating compounds. In one aspect of the invention, three different coating compounds are layered into the lens coating. Layering multiple coatings with different refractive indexes to establish a gradient refractive index in the surface coating will further reduce reflection. In one aspect of the invention, four different coating compounds are layered into the lens coating. In one aspect of the invention, five or more different coating compounds are layered into the lens coating.

In another aspect of the invention, the skilled practitioner may design a coating with specifically tailored properties by combining different precursor gasses in different molar ratios so that they are delivered by the same precursor head. In such instances, the relative ratio between the gasses may be, for example, in the range between 1:100 and 100:1. In another aspect of the invention, three or more different precursor gasses are combined in different molar ratios so that they are delivered by the same precursor head. The precursor gasses are combined before they are delivered by the precursor head. By way of example, and not of limitation, such combining may be performed in the channel leading up to the precursor source. In this aspect, the relative ratio among the gasses may be selected by the practitioner based on the desired properties of the resulting coating.

The coating should be applied in a layer that is sufficiently thick to avoid tackiness issues, yet thin enough to avoid unduly interfering with the optics of the lens. In one aspect of the invention, this layer is in the range of about 0.5 nm to about 25 nm. In another aspect of the invention, the layer is in the range of about 0.75 nm to about 20 nm. In another aspect of the invention, the layer is in the range of about 1 nm to about 15 nm. In another aspect of the invention, the layer is in the range of about 1.5 to about 12.5 nm. In another aspect of the invention, the layer is in the range of about 2 to about 11 nm. In another aspect of the invention, the layer is in the range of about 5 to about 11 nm. s-ALD is the only technology that can place an anti-tack coating in these thicknesses, atomic layer by atomic layer.

In one aspect of the invention, the thin anti-tack coating is applied in a layer that is sufficiently thick to avoid tackiness issues, yet thin enough to avoid unduly interfering with the optics of the lens. In one aspect of the invention, this layer is in the range of about 0.5 nm to about 10 nm. In another aspect of the invention, the SiO2 layer is in the range of about 0.75 nm to about 8 nm. In another aspect of the invention, the SiO2 layer is in the range of about 1 nm to about 6 nm. In another aspect of the invention, the SiO2 layer is in the range of about 1.5 to about 2.5 nm. In another aspect of the invention, the SiO2 layer is in the range of about 2 to about 5 nm.

For delivery by the precursor source, the selected precursor is first evaporated, and then the fumes are carried to the precursor source. In one aspect of the invention, the selected precursor is first evaporated, and then the fumes are carried by a neutral carrier gas to the precursor source. It will be appreciated by one of ordinary skill in the art that it is important that the neutral carrier gas not react in an undesired manner with the precursor. The neutral carrier gas should also not contain any impurities that would react in an undesired manner with the precursor. In one aspect of the invention, the carrier gas is nitrogen. In another aspect of the invention, the neutral carrier gas is very pure nitrogen, with only a ppb level of moisture. The vapor pressure of the precursor determines how much precursor vapor can be carried with the carrier gas flow. In one aspect of the invention, the pressure of the carrier gas plus precursor gas is approximately 1 atmosphere.

In one aspect of the invention, the flow rate of the carrier gas with precursor out of the precursor source is in the range of from about 0.5 to about 8 slm. In another aspect of the invention, the flow rate of the carrier gas with precursor out of the precursor source is in the range of from about 0.75 to about 6 slm. In another aspect of the invention, the flow rate of the carrier gas with precursor out of the precursor source is in the range of from about 1 to about 4 slm. It will be appreciated by one of skill in the art that the flow rate will be influenced by the size of the delivery of the precursor. That is, a larger opening will require a slower flow rate, and a smaller opening will typically require a faster flow rate to achieve the same substrate coverage in a given time.

In the aspect of the invention where the anti-tack coating is SiO_2, the precursor may be selected from any of those known in the art. By way of example, and not of limitation, the precursor may be selected from one of the following: bis(diethylamino) silane (CAS No.: 27804-64-4) (BDEAS); tris(dimethylamino) silane (CAS No.: 15112-89-7) (TDMAS, or 3DMAS), di(isopropylamino) silane (CAS No.: 908831-34-5) (DIPAS), tetraethyl orthosilicate (CAS No. 78-10-4) (TEOS), hexamethyldisiloxane (CAS No. 107-46-0) (HMDSO), tri-Chloro-

Silane (CAS No. 2550-06-3) (TCS), or benzyltrimethylsilane (CAS No.: 770-09-2) (BTMAS), or a combination thereof. In one aspect of the invention, the precursor is selected from BDEAS.

In the aspect of the invention where the anti-tack coating is aluminum oxide, the precursor may be selected from any of those known in the art. By way of example, and not of limitation, the precursor may comprise from one of the following: aluminum bromide (CAS No.: 1309-64-4), aluminum trichloride (CAS No.: 7446-70-0), trimethyl-aluminum (CAS No.: 75-24-1), or trimethylamine alane (CAS No. 16842-00-5), aluminum tri-*sec*-butoxide (CAS No. 2269-22-9), or a combination thereof.

In the aspect of the invention where the anti-tack coating is titanium oxide (TiO_2), the precursor may be selected from any of those known in the art. By way of example, and not of limitation, the precursor may comprise one of the following: tetrakis(dimethylamino)titanium(IV) (CAS No. 3275-24-9) (TDMAT), titanium tetrachloride (CAS No.) ($TiCl_4$), and titanium tetraisopropoxide (CAS No. 546-68-9) (TTIP), or a combination thereof.

In some situations, the precursor may be a fluid. In such instances, the fluid may be held in a container. In one aspect of the invention, the container is stainless steel, aluminum, or another material which does not react with the precursor. In another aspect of the invention, the container is glass. In either aspect of the invention, the container may be placed in a temperature-controlled bath, with the temperature selected to generate the appropriate amount of vapor from the fluid precursor. The amount of vapor is the then determined by the temperature of the precursor and the pick-up flow. A further dilution flow of inert gas may be added to the precursor flow if desired.

In an aspect of the invention discussed above, a coating may be designed with specific chemical or physical properties. In such instance, depending on the desired chemical or physical properties, more than one molecule may be used to form the coating. In one aspect of the invention one or more of the coatings described herein are layered together to form a coating. In an alternate aspect of the invention, one or more precursors identified herein are delivered together from one precursor head to provide a coating layer that is composed of more than one molecule.

The concentration of the precursor gas is preferably chosen to be slightly above a minimum concentration needed for atomic layer deposition. This improves efficiency of the system, and reduces the number of cycles which are required to achieve a desired coating thickness.

As described, some of the above precursors are particularly suited to providing an oxide coating when exposed to oxygen plasma. In one aspect of the invention, instead of an oxide coating, a nitride or carbide coating is selected. For nitrides, nitrogen plasma would be used. For carbides, carbon monoxide or carbon dioxide plasma would be used. In one aspect of the invention, nitric oxygen is used. This gas may be used either for its oxygen or nitrogen radicals, depending on precursor reactivity.

Such coating may be used, for example, on an acrylic lens or other lens having a similar refractive index. As one of ordinary skill in the art will appreciate, other coatings and other precursors may also be appropriate – either for acrylic lenses, or lenses made from other materials. One skilled in the art, knowing the chemical makeup of the lens they are seeking to coat, and the properties of the coating they are seeking to generate will be able to select appropriate precursors that may not be included in the list above. Key factors to be considered include the deposition temperature (closer to room temperature is preferred to warmer) and the thickness of the layer which is required to achieve a desired effect. As noted above, a thinner coating is preferred over a thicker coating.

The area where the precursor is applied is equipped with at least one exhaust through which the precursor may exit. In another aspect of the invention, the precursor area is equipped with two exhausts, one on one side of the holder 14 that is in the path of the movement of the holder 14 and one on the other side of the holder 14 that is generally in the path of the movement of the holder 14. In yet another aspect of the invention, the precursor area is equipped with two exhausts, one on one side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14 and one on the other side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14.

As noted above, the area where the precursor is applied is followed by a purge area. This area serves as a flow barrier to halt access of the precursor material to the substrate. In practice, the purge area comprises a source of inert gas. In one aspect of the invention, the purge area comprises a source of nitrogen gas. The purge area is equipped with at least one exhaust through which the nitrogen and any other gasses may exit. In one aspect of the invention, the purge area is equipped with two exhausts, one on one side of the holder 14 that is generally in the path of the movement of the holder 14 and one on the other side of the holder 14 that is generally in the path of the movement of the holder 14. In yet another aspect of the invention, the purge area is equipped with two exhausts, one on one side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14 and one on the other side of the holder 14 that is approximately perpendicular to the relative movement of the holder 14.

As noted above, the area where the plasma is applied is followed by a purge area. This area serves as a flow barrier to halt access of the plasma to the substrate. In practice, the purge area comprises a source of inert gas. In one aspect of the invention, the purge area comprises a source of nitrogen gas.

The number of lenses which may be processed at one time and the length of the tunnel (number of repeating purge, precursor, and plasma units) will be based on the desired thickness of the coating, the flow rate of the precursors, temperature, spacing between the substrate head or the plasma source and the substrate, and potential pre-treatment of the lenses, and the final configuration may be determined by experimentation varying these factors.

In order to encourage the required chemical reactions, heat is required. In one aspect of this invention, this is applied through the conveyor 14. In an alternate aspect, the heat is provided by placing the s-ALD system in a heated chamber. In another aspect of the invention, heat lamps and/or electrical heating rods may be used. Desirable temperatures are in the range of about 25 C to about 90 C. In another aspect of the invention the temperature is in the range of 30 to about 70. In another aspect of the invention the temperature is in the range of 30 to about 55. In another aspect of the invention the temperature is in the range of 32 to about 55. In another aspect of the invention the temperature is in the range of 30 to about 40. This temperature range is beneficial, as the temperature, over the time it is provided, does not have any measurable impact on the chemistry of the substrate.

There should be minimal spacing between the lens holders as they progress through the s-ALD pathway. Smaller gaps between the lens holders reduces the likelihood of leakages and helps to ensure sufficient separation between the gasses. It also reduces the amount of dead volume being processed, which increases throughput.

As may be envisioned, this simplified process to apply a useful coating may be made part of a line of automated molding and demolding, lens inspection, and surface treatment. The footprint of the surface treatment portion of such automated system would be compact. The entire system could fit within one room.

A variety of s-ALD configurations are considered within the range of the present invention. It will be understood that s-ALD apparatuses can be set up in a broad variety of configurations. Some embodiments, which should not be considered limiting, will now be described in detail in the following Examples.

EXAMPLES

Example 1: Tunnel Concept

This Example demonstrates one manner in which surface modification may be accomplished. In this concept, the lenses to be coated travel in holders down a straight path. This may be configured as one column of lenses, or a plurality of columns of lenses in parallel process. In one aspect of the invention, up to 25 lens/lens holders may be processed in parallel process using a tunnel configuration. In an alternate aspect of the invention, from 1-15 lens/lens holders may be processed in parallel process.

Continual processing may be performed where the lenses are arranged in a column, that is, when one lens follows the other. Continual processing may also be arranged in parallel, where multiple lenses proceed through the system concurrently. In one aspect of the system, lenses proceed both in a column and in parallel. This allows for maximum throughput.

As noted above, FIG. 1 is one example of a portion of a s-ALD according to one aspect of the invention. As may be seen, the line is first purged of atmosphere. The substrate then passes through a precursor area, then through a purge area, then through an area where it is exposed to plasma, then through another purge area. The openings in the precursor source, the inert gas source and the plasma source were all slot-like in configuration, with the slot spanning substantially the fill width of the substrate holder. The pathway through precursors and plasma areas, separated by purge areas is repeated until the desired coating thickness is reached. The substrate may then pass through one last purge area. In this example, the plasma is oxygen radicals produced by 2% oxygen in nitrogen the precursor is BDEAS. The vapor pressure of the nitrogen carrier gas and BDEAS precursor was approximately 1 atm. That is, the vapor pressure of BDEAS is lower than 1 atm, but the pressure of the pickup and carrier flow is 1 atm. The flow rate used was 2 slm. All lenses were located 4 mm below the opening in the precursor source, the inert gas source and the plasma source when they were being treated.

FIG. 5 shows the Growth Per Cycle of SiO_2. In this system, the precursor slot length was 70 mm. The average precursor exposure time was 275 ms. For plasma gas a mixture of oxygen and nitrogen, (2 % oxygen), was used. The plasma exposure was 62 mm/s substrate speed. Plasma pressure was approximately 1 atm, and the flow was 2 slm. After 15 cycles (purge/precursor/purge/plasma), a 2 nm coating of SiO_2 was deposited on the lenses.

The coated lenses were compressed and passed through a lens insertion system. Comparative data for coated lenses is shown in Table 1 of FIG. 9. In the table of FIG. 9, lens in cup refers to molded lenses, with haptics, where the top portion of the lens mold has been removed and the lens is retained in the bottom portion of the mold. Lens in cup, haptics pushed refers to molded lenses where the top portion of the lens mold has been removed and the distal ends of the haptics have been pushed out of the mold, and the lens and a portion of the haptics are retained in the bottom portion of the mold. Lathed lenses refer to lenses that are chemically identical to the molded lenses, but which are not formed through an molding process. Instead, the lens is cut and optics are lathed onto the lens surface. Like the molded lenses, these lenses proceeded through the s-ALD system at a distance of 4mm from the openings in the precursor source, the inert gas source and the plasma source.

As may be seen, all three categories of lenses had an average unfold time in the acceptable range of less than 60 seconds. The Lens in cup lenses had an average unfold time of 25.4 seconds, with a yield of 56%. The Lens in cup, haptics pushed lenses had an average unfold time of 31.125 seconds, with an 89% yield. The lathed lenses had an average unfold time of 16.875 seconds, with an 89% yield. Further, as shown by the yields of the three groups of lenses, the consistency of unfold time increased as a larger percentage of the lens and haptic surfaces were coated. In this experiment, a reduced yield means that the lens failed to unfold in less than 60 seconds. By adding a coating of consistent thickness, the inventors were able to improve both unfold time and consistency in unfold time, both of which are key parameters for ophthalmic surgery.

These unfold times may be contrasted with uncoated lenses, which all had unfold times outside of the acceptable range of less than 60 seconds.

Example 2: <u>Circular Concept</u>

This Example demonstrates an alternate manner in which surface modification may be accomplished. In this aspect of the invention, a plurality of substrates to be coated are provided on a circular base. The purge, plasma and precursor areas are spaced around the circle in what can be considered pie wedges which make up the full circle.

FIG. 6 provides a general view of a circular, or rotary, s-ALD system according to one aspect of the invention. Each pie-shaped piece in the top section may be viewed as either a precursor source 62 area, an inert gas source 68 area (also known as a purge area) or a plasma source 66 area. For convenience, this general view shows only one precursor source 62 area and one plasma source 66 area. Circular holder 64 with a plurality of substrate holders 60 are also shown. FIG. 7 shows the rotary system similar to FIG. 6, where some substrate holders 60 on the circular holder 64 are aligned with the precursor source 62 and one purge area 68. One substrate holder 60 is just leaving plasma source 66 area. Relative rotation between the circular conveyor and the top section is shown by arrow A. As shown, this rotation is counterclockwise. It will be understood that the rotation could also be clockwise or oscillating. It will be further understood that movement may come from the circular conveyor or from the top section.

As will be understood, the circular s-ALD system described herein would be suitable for both batch and continuous processing. For continuous processing, an area where substrate holders may be added and removed could be included.

Example 3: Tailored Coating

This Example demonstrates a further manner in which surface modification may be accomplished. In this aspect of the invention, a coating was designed which provided anti-tack properties, but with a higher refractive index. The inventors desired to use a SiO_2 coating for its anti-tack properties but preferred a coating with a slightly higher index. Titanium was incorporated into the SiO_2 by combining the TDMAT precursor with the BDEAS precursor. The TDMAT pressure was 2% of the BDEAS pressure.

FIG. 8 shows that, in this Example, the refractive index of the coating was changed from approximately 1.44 to approximately 1.49 by the addition of about 1.5 to 2% TDMAT to the precursor gas.

Lenses coated in accordance with this Example 3 will have unfold times comparable to the lenses of Example 1.

The above specification, examples and data provide a complete description of the structure and use of exemplary embodiments of the invention as defined in the claims. Although various embodiments of the claimed invention have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of the claimed invention. Other embodiments are therefore contemplated. It is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative only of particular embodiments and not limiting. Changes in detail or structure may be made without departing from the basic elements of the invention as defined in the following claims.

CLAIMS

We claim:

1. A method for coating an intraocular lens, the intraocular lens having a lens surface, the method comprising:

    delivering the intraocular lens to a conveyor,

    activating a processing line, the processing line comprising a plurality of coating segments, each coating segment comprising, in order:

    a first inert gas source configured to provide inert gas,

    a precursor source configured to provide a precursor gas;

    a second inert gas source configured to provide inert gas; and

    a plasma source configured to provide plasma;

    wherein, upon activation, the first inert gas source provides inert gas, the precursor source provides precursor gas, the second inert gas source provides inert gas, and the plasma source provides plasma; and

    passing the intraocular lens from the conveyor through the processing line using relative linear movement between the processing lines and the conveyor, wherein a layer of coating is applied to the intraocular lens each time the intraocular lens passes through a coating segment.
2. The method of claim 1, wherein the intraocular lens is a molded intraocular lens.
3. The method of claim 2, where the molded intraocular lens is fully formed by a molding process.
4. The method of claim 2, wherein the intraocular lens is partially formed through a molding process.
5. The method of any preceding claim, wherein the intraocular lens comprises a lens body and at least one support structure, the method comprising displacing at least a portion of the support structure from a mold half that was used to mold one side of the lens body and the support structure.
6. The method of any preceding claim, wherein the intraocular lens is contained within a substrate holder, the substrate holder formed at least in part by a portion that was used to form the intraocular lens.
7. The method of claim 6, wherein the substrate holder is a mold half.

8. The method of claim 6, wherein the substrate holder is a device for holding the intraocular lens during a lathing process.
9. The method of any preceding claim, wherein the conveyor is configured to receive a plurality of intraocular lenses, and the plurality of intraocular lenses is arranged in a manner selected from in a column, in parallel, and a combination thereof.
10. The method of any preceding claim, wherein one of the first inert gas source and the second inert gas source comprises a plurality of unit segments, each unit segment comprising an inert gas source and an exhaust.
11. The method of any preceding claim, wherein the coating segments are positioned from about 1 mm to about 6 mm apart from the surface of the intraocular lens.
12. The method of any preceding claim, wherein the precursor gas is selected from the group consisting of bis(diethylamino) silane, tris(dimethylamino) silane, di(isopropylamino) silane, benzyltrimethylsilane, tetraethyl orthosilicate, hexamethyldisiloxane, tri-chloro-silane, aluminum bromide, aluminum trichloride, trimethyl-aluminum, trimethylamine alane, aluminum tri-sec-butoxide, Tetrakis(dimethylamino)titanium(IV), titanium tetrachloride, titanium tetraisopropoxide, and combinations thereof.
13. The method of any preceding claim, wherein the apparatus deposits a coating of silicon dioxide on a surface selected from the group consisting of an anterior surface of the intraocular lens, a support structure coupled with the intraocular lens, and combinations thereof.
14. The method of any preceding claim, wherein the source of plasma provides plasma selected from the group consisting of oxygen plasma, nitrogen plasma, carbon monoxide plasma, carbon dioxide plasma, nitric oxide plasma and combinations thereof.
15. The method of any preceding claim, wherein the method is performed at a temperature from about 25 C to about 90 C.

16. An system for atomic layer deposition on a surface of an intraocular lens, the system comprising:

    a station for receiving the intraocular lens, the intraocular lens being contained within a substrate holder,

    a processing line, the processing line comprising a plurality of coating segments, each coating segment comprising, in order:

    - a first inert gas source for providing inert gas;
    - a precursor injector source for providing a precursor gas;
    - a second inert gas source for providing inert gas; and
    - a plasma source for providing plasma;

    wherein the coating segments are positioned from about 1 mm to about 6 mm above the surface of the intraocular lens, and further wherein the system is arranged for relative motion between the substrate holder and the coating segments so that the surface of the intraocular lens is exposed to the plurality of coating segments.

17. The system of claim 16, wherein the intraocular lens is a molded intraocular lens.
18. The system of claim 16 or claim 17 wherein the intraocular lens further comprises at least one support structure, the support structure being at least partially displaced from the portion that was used to form the intraocular lens.
19. The system of any one of claims 16 to 18, wherein the substrate holder comprises a portion that was used to form the intraocular lens.
20. The system of any one of claims 16 to 19, wherein the substrate holder is a mold half.
21. The system of any one of claims 16 to 19, wherein the substrate holder is a device for holding the intraocular lens during a lathing process.
22. The system of any one of claims 16 to 21, wherein the coating segments are positioned from about 2 mm to about 6 mm apart from the surface of the intraocular lens.
23. The system of any one of claims 16 to 21, wherein the station for receiving the intraocular lens is configured to receive a plurality of intraocular lenses.
24. The system of claim 23, where the plurality of intraocular lenses is arranged in a manner selected from in a column, in parallel, and a combination thereof.

25. The system of any one of claims 16 to 24, wherein one of the first inert gas source and the second inert gas source comprises a plurality of unit segments, each unit segment comprising an inert gas source and an exhaust.
26. The system of any one of claims 16 to 25, wherein the precursor gas is selected from the group consisting of bis(diethylamino) silane, tris(dimethylamino) silane, di(isopropylamino) silane, benzyltrimethylsilane, tetraethyl orthosilicate, hexamethyldisiloxane, tri-chloro-silane, aluminum bromide, aluminum trichloride, trimethyl-aluminum, trimethylamine alane, aluminum tri-sec-butoxide, Tetrakis(dimethylamino)titanium(IV), titanium tetrachloride, titanium tetraisopropoxide, and combinations thereof.
27. The system of any one of claims 16 to 26, wherein the apparatus deposits a coating of silicon dioxide on a surface selected from the group consisting of an anterior surface of the intraocular lens, a portion of a support structure coupled to the intraocular lens, and combinations thereof.
28. The system of any one of claims 16 to 27, wherein the source of plasma provides plasma selected from the group consisting of oxygen plasma, nitrogen plasma, carbon monoxide plasma, carbon dioxide plasma, nitric oxide plasma and combinations thereof.
29. The system of any one of claims 16 to 28, wherein the system is heated to a temperature from about 25 C to about 90 C.

FIG. 1

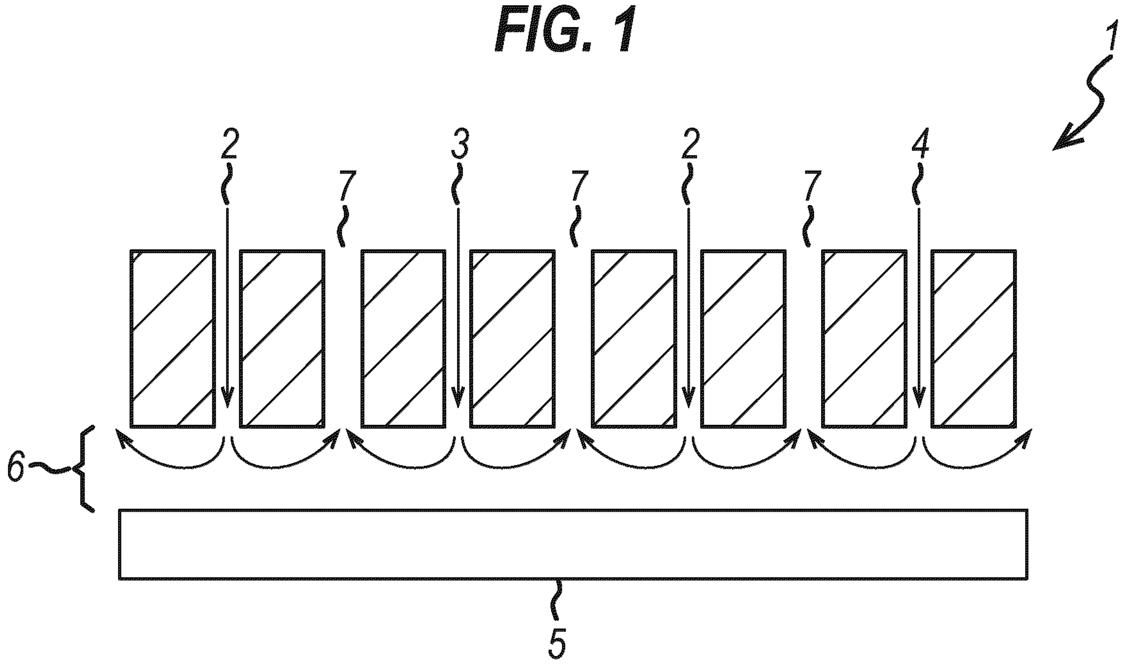


FIG. 2

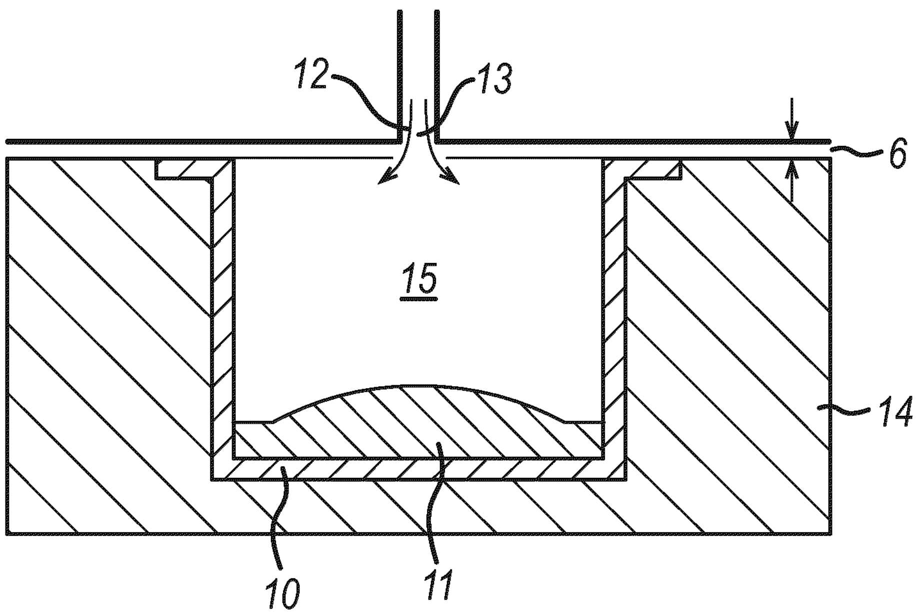


FIG. 3a

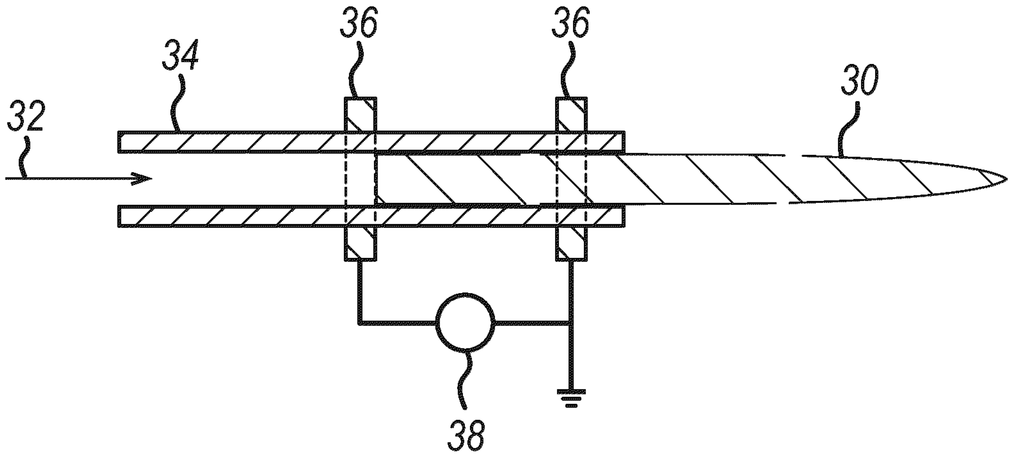


FIG. 3b

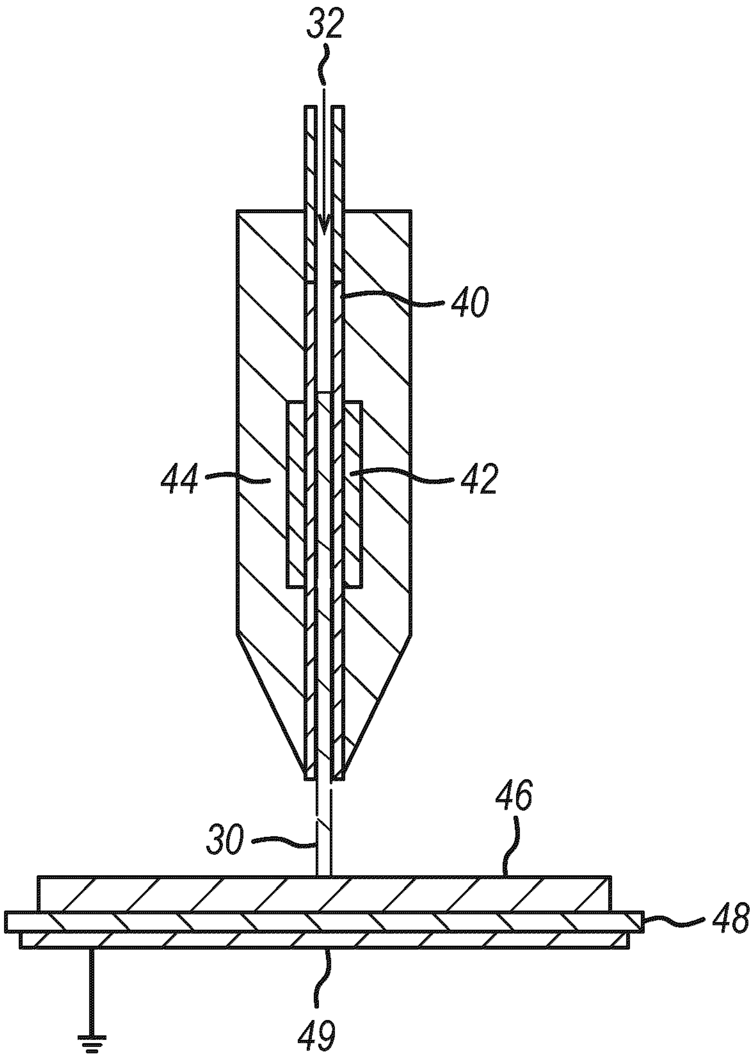


FIG. 4

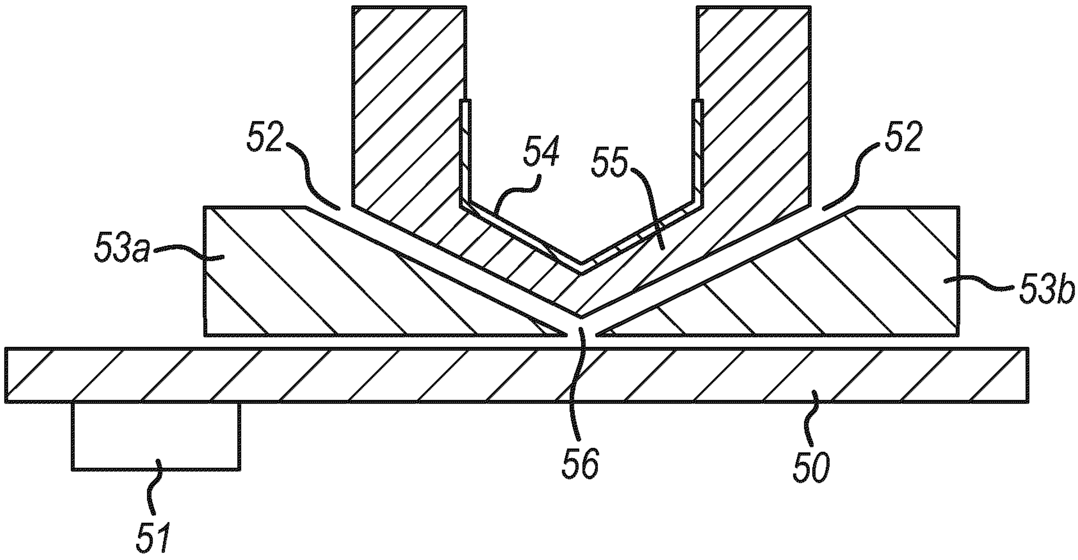

52
54
55
52
53a
53b
56
50
51

FIG. 5

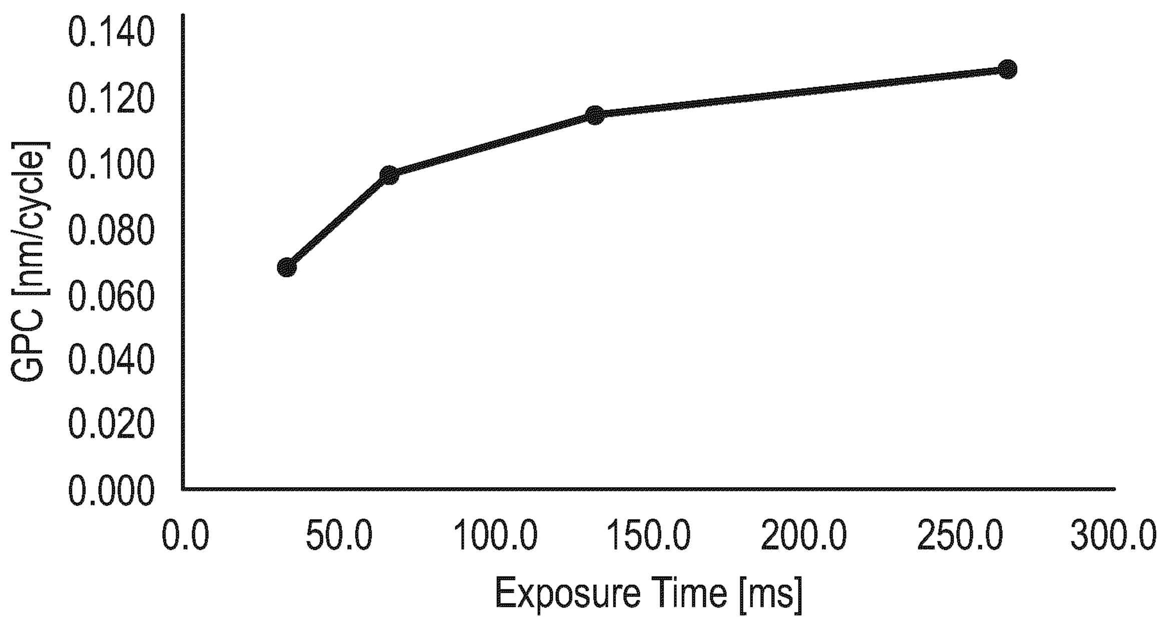

0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
GPC [nm/cycle]
0.0
50.0
100.0
150.0
200.0
250.0
300.0
Exposure Time [ms]

FIG. 6

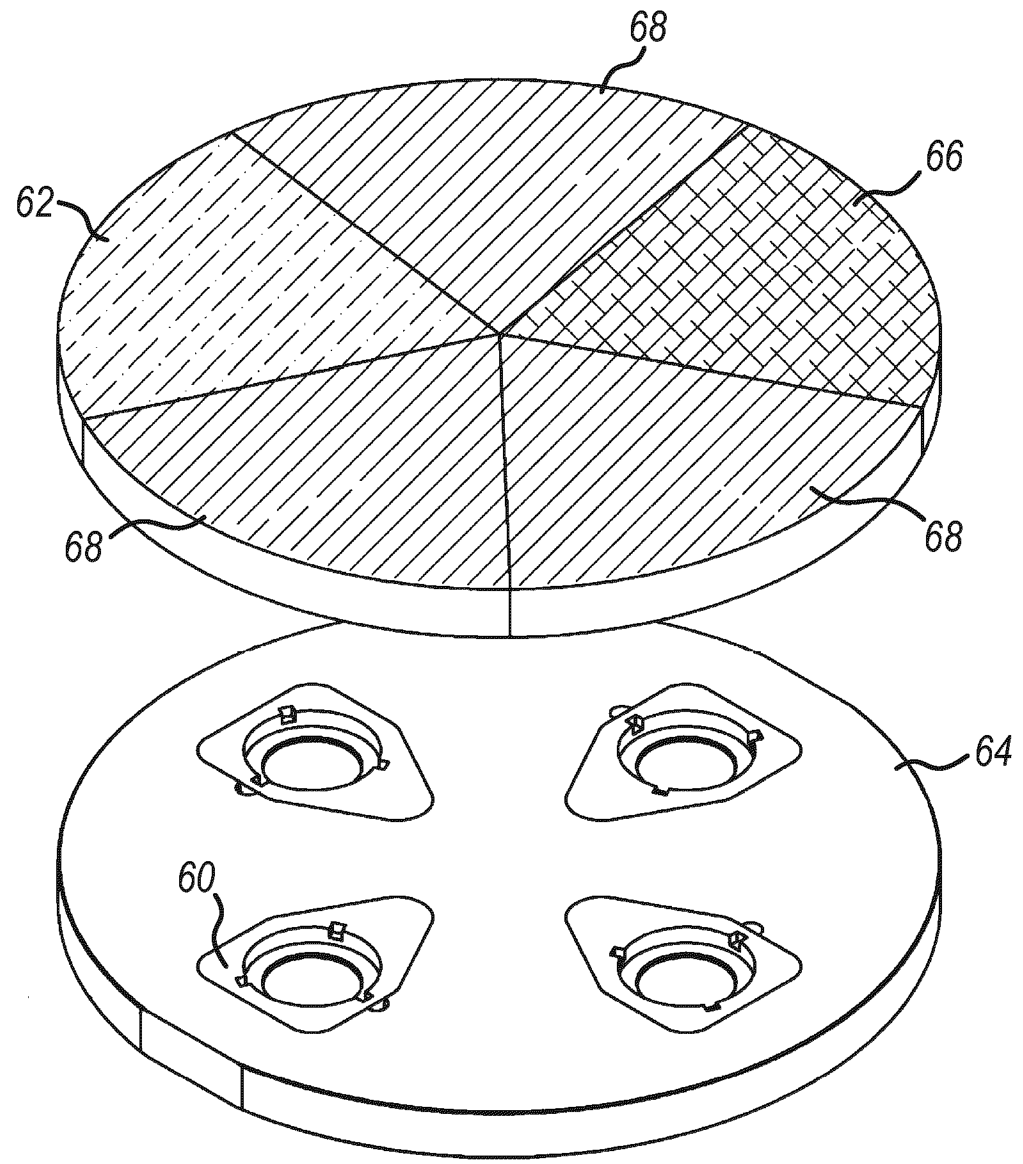


FIG. 7

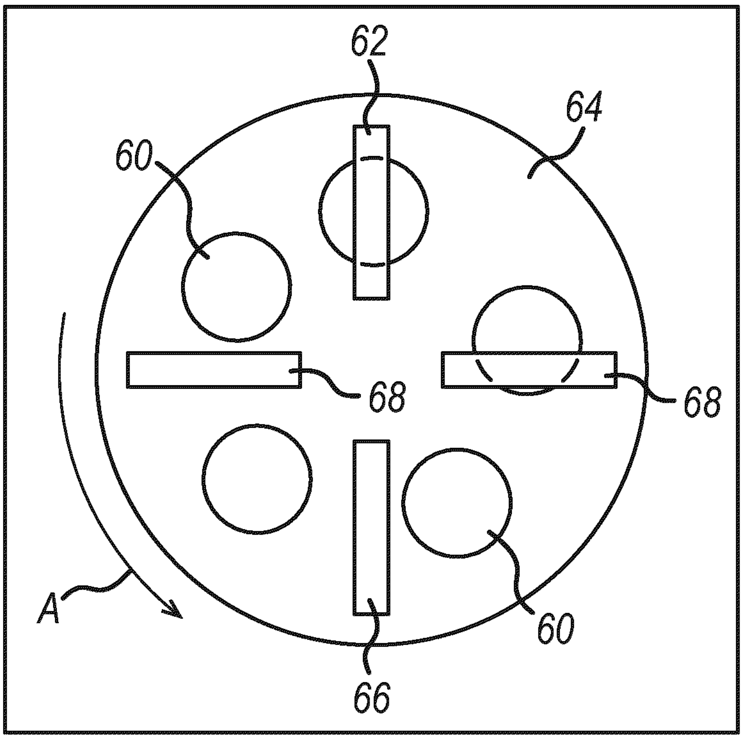
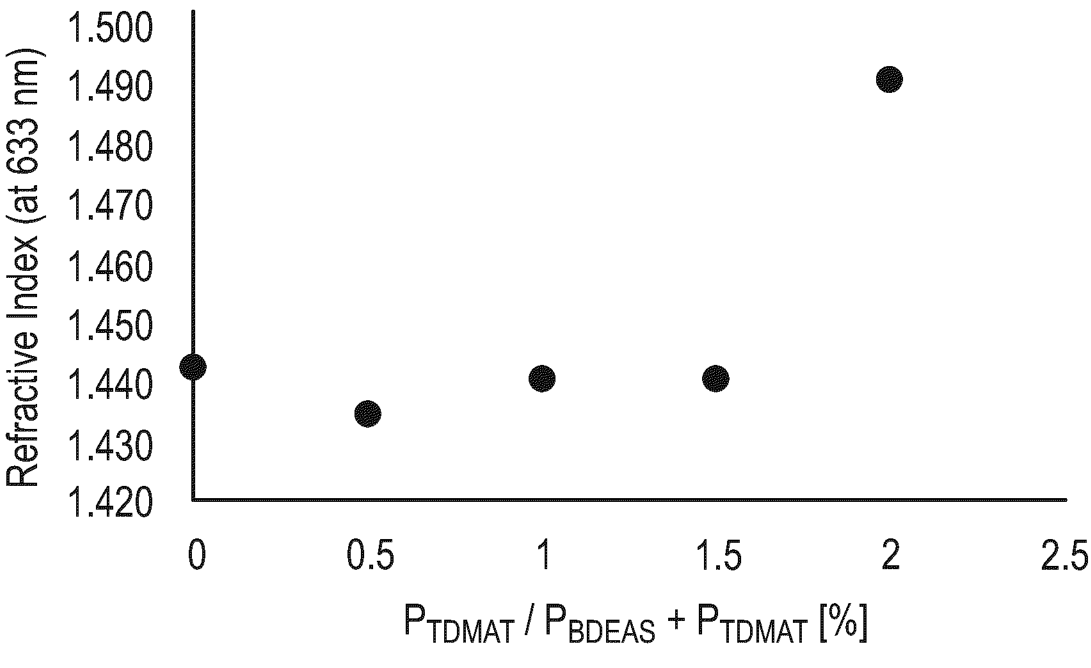

62
64
60
68
68
A
60
66

FIG. 8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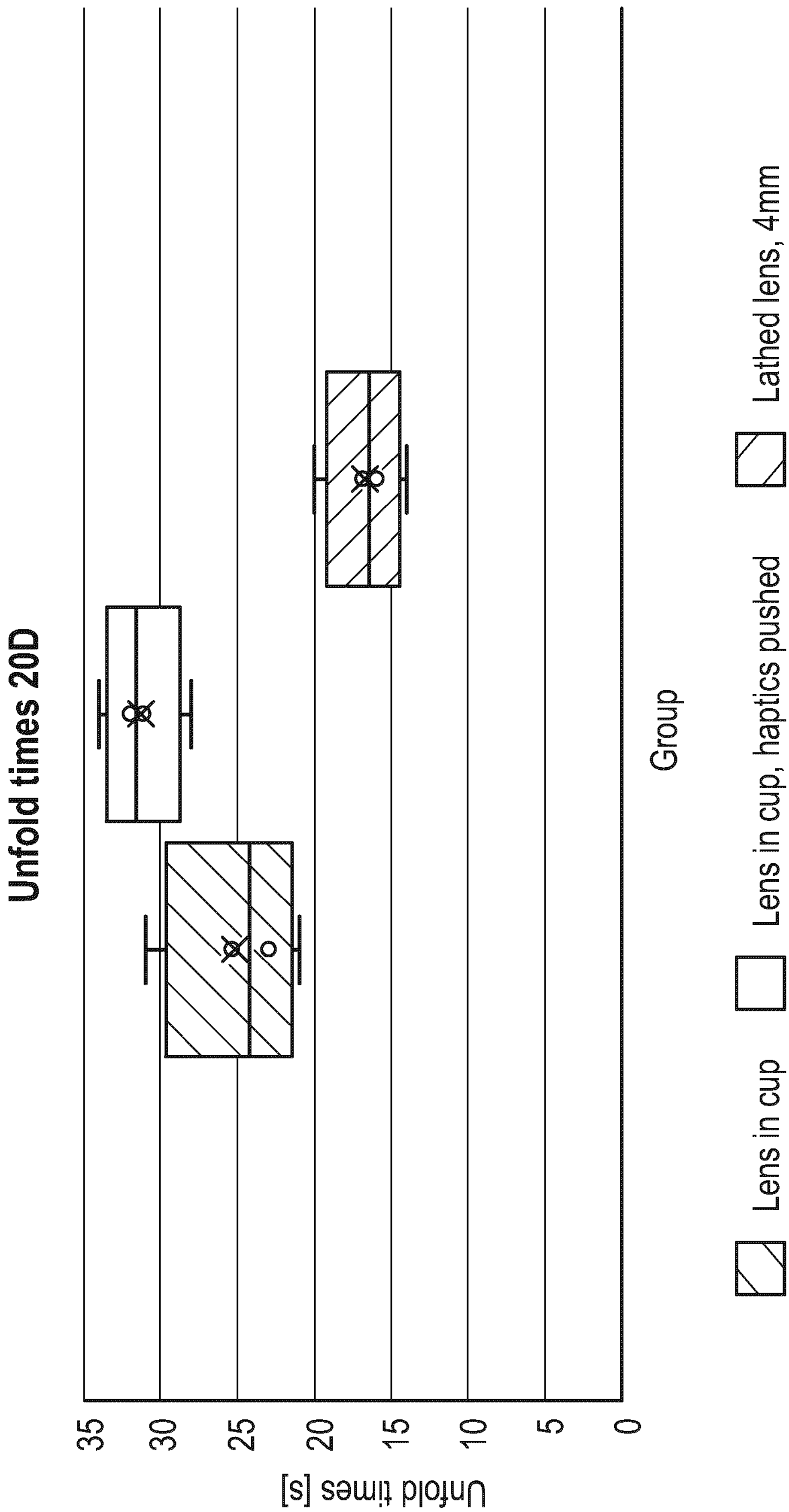
1.490
1.480
1.470
1.460
1.450
1.440
1.430
1.420
0
0.5
1
1.5
2
2.5
PTDMAT / PBDEAS + PTDMAT [%]

FIG. 9


Unfold times 20D
Unfold times [s]
0
5
10
15
20
25
30
35
Group
Lens in cup
Lens in cup, haptics pushed
Lathed lens, 4mm

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/073373

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29D11/00 B29D11/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/238311 A1 (LEVY DAVID H [US]) 11 October 2007 (2007-10-11)	1,10-12, 14,16, 22,25, 26,28
Y	paragraphs [0004], [0007], [0088], [0112], [0160]; figures	2-9,13, 15, 17-21, 23,24, 27,29
Y	US 2003/116873 A1 (AYYAGARI MADHU [US] ET AL) 26 June 2003 (2003-06-26) paragraphs [0013], [0038] - [0043]; claim 12; figures	2-8,15, 17-21,29
Y	US 5 837 156 A (CUMMING J STUART [US]) 17 November 1998 (1998-11-17) paragraph [0088]; figures	9,23,24

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 December 2021	21/12/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Klinger, Thierry

1

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/076603 A1 (AVERY NEAL H [US] ET AL) 19 March 2009 (2009-03-19) cited in the application paragraphs [0040] - [0047]; figures -----	13,27

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/073373

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