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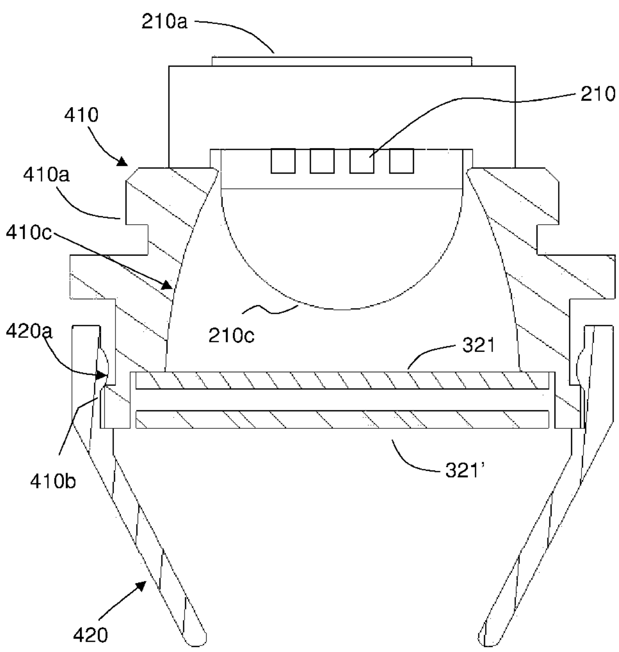
(54) Title: LED CURING LIGHT HAVING FRESNEL LENSES



(57) Abstract: Disclosed is a LED curing light device for curing of photo-polymerization materials. The device comprises of a plurality of LED source and a plurality of Fresnel lenses. The said LED source is powered and controlled by a drive board and batteries providing high power curing light in the range of 300 to 500 nm and optical power in the range of 100 to 800 mW. The said Fresnel lenses comprising a pair of Fresnel lenses couple said curing light efficiently to a focused spot on a curing object.

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INVENTION TITLE

LED Curing Light Having Fresnel Lenses

DESCRIPTION

CROSS-REFERENCE TO RELATED APPLICATIONS

[Para 1] This application claims priority to US patent application Ser. Nr. 11/307,813, filed February 24, 2006 and US provisional patent application Ser. Nr. 60/593,954, filed 2005 February 26.

Field of the invention

[Para 2] The invention relates generally to the field of light curing device, and more particularly to medical curing device and methods for irradiating and curing photosensitive curing compounds/

BACKGROUND OF THE INVENTION

[Para 3] Photosensitive compounds or adhesives are commonly used in bonding object surfaces together or for filling openings and cavities in an object surface. They are cured by exposure to radiation energy, such as UV with a wavelength between 300 to 400 nm or blue light with a wavelength between 400 to 500 nm. Medical curing light device are commonly used in dentistry, endoscopies, and plastic surgeries. In the field of dentistry, curable adhesives and dental curing apparatus are common practice in restoration and cosmetic procedures using restorative materials, dental sealants and orthodontic adhesives to bond brackets to the surfaces of teeth. Curing light is also widely used in device, component and circuit board packaging using photo-initiator activated composites to bond two different surfaces or protect components.

[Para 4] Traditionally, curing light apparatus are implemented with bulk lamps such as tungsten-halogen lamps coupled into fiber optic waveguide that delivers light to expose area of adhesives need to be cured. Recent advances in light emitting diodes (LEDs) technologies have enabled a new class of curing light apparatus with smaller size, longer lifetime and lower cost by semiconductor light emitting chips.

[Para 5] LEDs emit light at selected wavelengths of absorption band of photo-initiators that start the curing process of curable adhesives. Typical wavelength for dental curing is in the range of 400-500nm. It is highly desirable to have high optical density impinged on the curable adhesives to activate the photo-initiators that allow a quick curing time of between 2 to 10 seconds and a deeper curing depth of between 2 to 6 millimeters. Typical ranges of optical density for a desirable 4 to 5 millimeters curing depth and less than 10 seconds curing time are above 1000 mW/cm^2. In dental applications, such intensity is exposed to the curing area, typically in the range of 2 to 6 mm dimension, limited by the cavity and bracket size.

[Para 6] There have been two approaches in the selection of LEDs to achieve such high intensity, namely single high power LEDs or multiple standard single diode LEDs. High power LEDs integrates multiple LED chips in a single package such as LEDs made by Lumiled's Luxeon product lines that generate optical power as high as 800mW. Standard single chip LEDs generate optical power below 150 mW. Typical arrangements of more than five LEDs are required to deliver equivalent power at the curing site. Other critical elements of efficient curing are the light delivering system and working distance of the curing apparatus from the curing object for efficient cure.

[Para 7] U.S. Pat. No. 6,611,110 describes an apparatus using light guides to deliver curing light from a single LED to the curing site. The light guide reduces the deliverable curing light efficiency due to optic coupling, transmission, and diffraction losses from light guide with a typical total efficiency of below 30%. A higher power LED can compensate the loss. Additional use of lens such as total internal reflection (TIR) lens as described in U.S. Pat. No. 6,692,251 can improve the power density. However, they introduce higher cost and more cumbersome system. Additionally, it has been shown that autoclaving the light guide to sterilize the apparatus can reduce the transmission performance of the light guide making them costly to replace.

[Para 8] U.S.Pat No.7,106,523 describes an apparatus using a bulk aspheric lens to directly focus curing light from a single LED to the curing site. The aspheric lens is molded glass or plastic lens. The benefit of such implementation is a reduced size and cost compared to using of light guide. However, a high power LED is highly non-directional typically following a Lambertian radiation pattern with radiation angles above 120 degrees at half of its maximum intensity. Combined with a source chip size of typically 3 millimeter, the LED radiation incurs collection loss through the aspheric lens and diffracts quickly to lose its intensity due to limited collection angles that aspheric lens offer, which is typically less than 70 degrees. Aspheric lenses with short focal length to collect light from LED source are also thick with aspect ratio of diameter to thickness close to one enlarging the size of the apparatus as well. Working distances of such devices are typically limited to a short distance within a few millimeters. In addition, sterilizing tubes to protect the lens entrance will significantly reduce radiation due to optical diffractions.

[Para 9] A need exists, therefore, for improved LED curing apparatus that provide efficient light delivery to the curing site at high optical intensity with low cost particularly in the dental applications.

SUMMARY OF THE INVENTION

[Para 10] Accordingly, it is a principal object of the present invention to overcome the disadvantages of prior art methods of dental curing light system. The present invention comprises a method, and resulting apparatus, for highly efficient curing system for curable materials, in particular for dental curing.

[Para 11] In one embodiment, the optical device of the invention includes a high power LED source and a single Fresnel lens placed at a distance larger than its focal length to the LED source to collect radiation up to 160 degrees and focus the radiation into a curing spot.

[Para 12] In another embodiment, the optical device of the invention includes a high power LED source. The LED illumination is captured by a Fresnel lens with collection angles approximately between 100 to 160 degrees into diffraction limited collimating beam and then focused into a spot diameter approximately less than 5 millimeters by a second Fresnel lens placed in close proximity to the first lens. The pair of Fresnel lenses is bonded together into an efficient lens with two flat surfaces on the outside and lens grooves bonded in-between with a total thickness approximately between 0.5 to 2 millimeters. The exit window of the lens pair is shielded and protected by a sterilizable and disposable cone -shaped plastic cap.

[Para 13] In yet another embodiment, the optical device of the invention includes a high power LED source and an additional Fresnel lens mounted on the cone shaped plastic cap combined with a pair of Fresnel lenses to collect radiation up to 160 degrees and focus the curing light into a curing spot with longer working distance.

[Para 14] It is to be understood that both the foregoing general descriptions and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. Additional features and advantages of the invention will become apparent from the following drawings and description. The drawings illustrate various embodiments of the invention and together with the description serve to explain the principles and operations of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[Para 15] The above and further advantages of this invention may be better understood by referring to the following description taken in conjunction with the accompanying drawings in which like numerals designate corresponding elements or sections throughout, and in which:

[Para 16] Fig.1 shows a prior dental LED curing method using bulk aspheric lens;

[Para 17] Fig. 2 shows an embodiment of the optical device using current invention;

[Para 18] Fig. 3 shows another embodiment of the optical device using current invention;

[Para 19] Fig. 4 shows an embodiment in implementing the optical device using current invention;

[Para 20] Fig. 5 shows the differences in collection angle using the current invention compared to prior art.

[Para 21] Fig. 6 illustrates curing light intensity as a function of the distance from the curing apparatus to the curing object using current invention compared to prior art;

[Para 22] Fig. 7 shows an embodiment of a cordless dental LED curing device using the current invention;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Para 23] Fig. 1 shows a prior art dental LED curing light device 100 consisting of a LED 130, an aspheric lens 110, and a transparent shield 120 all attached to an extension arm

160. The aspheric lens 110 comprises of a first end 140, which is substantially flat, and a second end 141 that has an aspheric curvature. The transparent shield has an apex 121 to ease use for insertion into a dental cavity and clips 150 to wrap around and secure the lens 110 in place. The aspheric lens is preferably composed of a transparent material such as glass, aluminum dioxide, sapphire, quartz, acrylic, polyacrylic, polypropylene, and silicone. Apparatus using standard aspheric lenses as described are limited by the performances of the optical parameters of such lens with collection angle typically less than 70 degrees and thickness of more than 3 millimeters due to high curvature required to have short focal length. As a result, they are not efficient in focusing curing light.

[Para 24] Fig. 2 illustrates an embodiment of the present invention for LED curing source comprising a single high power LED 210 and a Fresnel lens 220 that focuses the illuminating light from the LED to a diffraction limited spot 230. The high power LED 210 preferably has an optical output power approximately between 400 - 800 mW, such as that Luxeon V produced by Lumiled at a wavelength in range of 400-500 nm. Higher powers are preferred since they provide faster and deeper curing time. The illumination rays 240, 240', and 240'' illustrate the function of the lens in collecting radiation and focus to a curing spot.

[Para 25] The Fresnel lens consists of a groove side 231 and a flat side 230. The grooves are circular cylindrical portions intersected by conical portions manufactured by standard machine processes such as diamond turning, injection and compression molding. They maintain the contour of the refracting surface of a conventional lens while removing the bulk of material between the refracting surfaces. The groove side of the Fresnel lens is preferably in the receiving direction of the optical illumination and the flat side in the outward direction to avoid surface damage in an assembly. Constant groove spacing or constant groove heights can be used in the design of the Frensnel lens. Compared to aspheric lens, Fresnel lens can be 10 times thinner which is critical to the application for close distance focus. Depending on the shapes of the grooves, a circular, square or narrow line focused spot can be realized at the focus spot 230 using circular or cylindrical lens.

[Para 26] Fig. 3 illustrates another preferred embodiment of the present invention for LED curing source consisting of a single high power LED 210 and a Fresnel lens pair **320** that focuses the illuminating light to a spot **330**. Compared with a single Frensnel lens in Fig. 2, the Fresnel lens pair **320** is more efficient in which it acts as a condenser lens consisting of a collimating lens **321** and a focusing lens **321'**. The collimating lens 321 is placed at a focal distance from the LED source 310 preferably between 2 to 5 millimeters to collimate the source light to diffraction limited collimation beam. While closer distance from the lens to the LED source chip reduces the size of the lens required, typical LED chips are packaged with glass dome lens with a size in the range of 1 to 3 millimeters limiting the proximity of the lens to the source. Additionally, avoidance of heat dissipated directly from the chip will limit the proximity of the lens to the LED as well.

[Para 27] The Fresnel lens 321 should maximize collection efficiency while balancing the size limitation of the instrument. A good parameter of the lens performance is described by optical F numbers as defined in:

$$\text{F number} = f/D$$

where the F number is the ratio of the focal length of the lens divided by the beam diameter of the lens. Smaller F number provides higher collection efficiency in angular distributed radiations. The use of Fresnel lens enables a much faster lens with F number below 0.3 that can collect the Lambertian illumination from the LED up to 120 to 160 degrees as compared with typical aspheric lens with F number above 0.5 which collects radiation below 70 degrees. This minimizes loss during coupling as is often encountered in the fiber waveguide coupling and aspheric lens coupling.

[Para 28] The focus lens 321' is placed in close proximity parallel to the collimating lens 321 with a focal length determined by working distance of a particular application. For dental curing applications, the focal length of the focusing lens 321' is preferably between 2 to 20 millimeters optimizing the efficiency at a working distance of 2 to 20 millimeters. The Fresnel lens pair also effectively works as a single lens with very short focal length of below 2 millimeters and very thin thickness as small as 0.5 millimeters, which are critical to both minimizing diffraction loss and making compact devices.

[Para 29] The Fresnel lens pair 320 is preferably formed by a groove out Fresnel lens 321 and a groove in Fresnel lens 321' bonded together to form a thin sheet lens 320 with flat outside surfaces. Such arrangement eases mounting of the Fresnel lens pair 320 into a lens cell that attaches to the LED mount in addition to improve scratch resistance to the active Fresnel groove surface.

[Para 30] Fig. 4 illustrates a proposed implementation of the present invention for LED curing source consisting of a high power LED 210 with multiple diode chips packaged in a single diode, directional collimating hyper-spherical lens 210c, diode heat sink 210a, a Fresnel lens pair 321 and 321', a mounting parabolic reflector 410, and a disposable curing cap 420. The light emitted from LED 210 typically has a divergence angle of over 80 degrees after co-packaged lens 210c.

[Para 31] The parabolic reflector 410 redirects the high divergence angle beam to a near collimated beam. The reflector 410 is consisted of a mounting thread 410a, a high reflectance inner surface 410c, and a cap stopper 410b. The mounting threads 410a mounts the LED illumination optic module to a handpiece head as will be discussed in detail in Figure 7. The high reflectance surface 410c provides reflectivity of over 95%, for example 98%, at the LED emitted wavelength range. Example materials for 410 are copper, aluminum and plastics. Electroplating of copper with chromium, zinc, aluminum, and silver offers the best reflectivity. Alternatively, high reflective thin films such as multiplayer metal oxide or polymer films can be evaporated or coated and post mounted at the inner surface **410c** to achieve the desired results.

[Para 32] The proposed lens 321 and 321' are thin disks of Fresnel lenses. The embodiment of the current invention enables collimation of LED illumination with minimum coupling loss, focus of the beam to a desired spot size limited by diffraction from source chip size and a minimum thickness in the lens assembly. The Fresnel lens consists of circular grooves that refract light with different angle at different radial position to form the function of a lens. They can be formed by either constant grooves spacing or constant groove height. Constant groove height is preferred for the Fresnel lens in curing applications to allow bonding of the two lenses forming the condenser lens into a single lens sheet with grooves facing each other as shown in Fig. 3 and flat surface on their outside.

[Para 33] The Fresnel lens can be made of transparent materials such as polycarbonate, acrylic, silicone, rigid vinyl and others that are low cost through compression or injection molding of large piece of materials enabling wafer level productions that make them low cost. The lens pair can be assembled together through standard packaging procedures such as bonding at individual on wafer level. Single lens can be also used in the case of highly collimating beam from the hyper-spherical lens **210c** and parabolic reflector **410c**.

[Para 34] The disposable and sterilizable curing cap **420** provides isolation of curing tip from patients or objects under treatment. It is conveniently snapped on the surface of the mounting reflector **410** and stopped by a mechanical edge stopper **410b**. The length of the lens cap **420** is shorter than the focal length of the second Fresnel lens **321'**. The lens cap **420** provides stray light shield with proper doping of the cap materials to absorb the wavelength of the illuminated light from the LED. It can also be attached with a third Fresnel lens at the exit window to further improve the working distance of the curing light. The lens cap is preferably made of materials that are disposable such as acrylic, polycarbonate and other plastics through standard manufacturing processes such as injection molding. It further provides a means to sterilize or dispose the cap at a minimum cost.

[Para 35] Fig. 5 compares theoretical performance of the current invention with the prior art dental curing device using a single aspheric lens. The calculation shows the radiation intensity as a function of radiation angle relative to the axis normal to the LED mounting surface. The prior art aspheric lens typically limit collection angle below +/-35 degrees at collection efficiency of 50% indicated by 510 while the current invention can increase the collection angle of the radiation above +/-60 degrees indicated by **520** with collection efficiency up to 90%.

[Para 36] Fig. 6 shows the curing light intensity (power density) as a function of the distance from the output window of the curing units to the object. Compared with conventional curing units using fiber optic guide **630** and bulk aspheric lens **620**, the current invention 610 maintains and optimizes curing intensity between 2 to10 mm through minimized diffraction and optimized beam focusing. The light intensity at 10mm of the current invention is more than two times that of the prior art approaches ensuring optimum and reliable curing at desired locations.

[Para 37] Fig. 7 illustrates an embodiment of the current invention in a high efficiency dental LED curing light consisting of an LED mounting head 710, a high power LED 210, a lens mounting reflector **410**, Fresnel lenses 321, a curing cap **420**, a handpiece housing consisting of a control board housing **730**, a rechargeable battery housing **760** and a thread link ring **760b**. The mounting head 710 and the handpiece portion are preferably made of highly heat conductive materials such as aluminum and copper to enhance heat dissipation speed.

[Para 38] The LED head mount **710** provides heat dissipation to the LED generated powers through thermal interface **711** bonded by thermal epoxy between the back side of the LED **210** and the surface **711**. The head mount **710** is attached to the handpiece body through threaded retainer **720** that clamps the two together at the interface **730a**. The head mount **710** tip preferably has an angle from the handpiece to allow an angle of illumination, approximately between 5 to 45 degrees, for ease of access to mouth.

[Para 39] The LED **210** is powered by a control circuit board **740** by two wire leads **710c** feed through a hole inside the head mount **710**. The circuit board **740** resides in the main control housing **730**. It is activated by an on-off switch button through a touch button **740c** and powered by a high energy density rechargeable battery **770**. It performs DC-DC conversion to the desired current for the LED **210** in addition to preset exposure timing sequence, thermal protection of LED against high temperatures through a thermal sensor **710b** placed in close proximity to the LED through two lead wires **710a**, low battery indicator LED **740b** and automatic shut off.

[Para 40] A high energy density rechargeable battery **770** is housed in the battery compartment **760**. The battery interfaces with two circular boards **780a** and **780b** via a pair of contact pins **780c** and is hold tight into the compartment **760** by a ring **760b** via thread **760a**. The circuit board **780a** interfaces with the main control board **740** when the battery compartment **760** is linked with the main control housing **730** through built-in thread **730b**. The interface is through a connecting circular board **750** via contact pins **750a** and **740d**. The circuit board **780b** interfaces an external power adapter through a small molded pin connector **790**. The combined circuit board of **740**, **750**, **780a**, and **780b** also performs the smart charging circuit to safely charge the rechargeable battery **770**.

[Para 41] The rechargeable battery is preferably lithium ion battery that has 3.7-4.2V per battery. A single battery with sufficient energy capacity is typically sufficient for dental curing light operation although multiple batteries can extend the standalone operation time.

[Para 42] The proposed high efficiency LED curing device enables low cost and efficient curing of photosensitive materials. The device is particularly useful for portable handheld dental curing light. It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

[Claim 1] A curing light apparatus for curing light activated composite comprising:

a plurality of LED source;

means of powering up said LED source to emit curing light;

a plurality of Fresnel lenses to deliver said emitted light directly to a curing composite, wherein said Fresnel lenses is configured adjacent to both said LED source and curing composite;

means for holding said Fresnel lenses adjacent to the LED source and curing composite;

wherein the means for holding and protecting the lenses comprise a lens mounting reflector consisting of a mounting thread and a high reflectance parabolic inner surface made of materials comprising plated, coated and bonded aluminum, chromium, zinc, silver and high reflective thin films made of materials comprising multiplayer metal oxide films and polymer films.

[Claim 2] The apparatus of claim 1 further including

a handheld body for portable control;

a mounting head for said LED source;

a lens cap for shielding emitted curing light.

[Claim 3] The apparatus of claim 1, wherein said LED source is a high power semiconductor diode and emit curing light with optical power approximately between 100 mW to 800 mW at a wavelength approximately between 300 to 500 nm.

[Claim 4] The apparatus of claim 1, wherein said LED source mounted inside said mounting head and projecting at an angle approximately between 5 to 45 degrees from the main axis of said handheld body.

[Claim 5] The apparatus of claim 1, wherein said Fresnel lenses comprising

a collimating lens with a focal length approximately between 2 to 10 millimeters to collect and collimate the curing light;

a plurality of Fresnel lenses that focus said collimated curing light to said curing composite.

[Claim 6] The optical apparatus of claim 1, wherein said Fresnel lens is circular cylindrical and has a first flat side and a second circular groove side.

[Claim 7] The optical apparatus of claim 1, wherein said Fresnel lenses have thickness approximately between 0.1 to 5 millimeters and F number of approximately between 0.1 and 2.

[Claim 8] The apparatus of claim 1, wherein said Fresnel lenses are made from materials selected from the group consisting of polycarbonate, acrylic, rigid vinyl, and polyacrylic.

[Claim 9] The apparatus of claim 2, wherein said handheld body comprising

a rechargeable battery;

a plurality of circuit boards;

means of activating said circuit boards.

[Claim 10] The apparatus of claim 10, wherein said handheld body is shaped from the selected group of cylindrical tube and elongated sphere with a main axis along a longitudinal handheld direction.

[Claim 11] The apparatus of claim 2, wherein said circuit board comprising

a constant current circuit to drive said LED;

a timing circuit to control timing sequence of curing exposure;

a protection circuit to prevent overheating of said LED and over discharging of said rechargeable battery.

[Claim 12] The apparatus of claim 10, wherein said means of activating said circuit board comprising mechanical switches and liquid crystal control panels.

[Claim 13] A method of making a dental LED curing light apparatus comprising the step of:

supplying a plurality of LED source;

supplying means of powering up said LED source to emit curing light;

supplying a plurality of Fresnel lenses to collimate and focus said curing light, wherein said Fresnel lenses is configured adjacent to both said LED source and curing composite;

means for holding said Fresnel lenses adjacent to the LED source and curing composite;

wherein the means for holding and protecting the lenses comprise a lens mounting reflector consisting of a mounting thread and a high reflectance parabolic inner surface made of materials comprising plated, coated and bonded aluminum, chromium, zinc, silver and high reflective thin films made of materials comprising multiplayer metal oxide films and polymer films.

[Claim 14] The method of claim 14, wherein said LED source is a high power semiconductor diode and emit curing light with optical power approximately between 100 to 800 mW at a wavelength approximately between 300 to 500 nm.

[Claim 15] The method of claim 14, wherein said means of powering up said LED source comprising the steps of:

supplying a plurality of rechargeable batteries;

supplying a plurality of circuit boards;

supplying means of activating said circuit boards.

[Claim 16] The method of claim 14, wherein said Fresnel lenses comprising a collimating lens with a focal length approximately between 2 to 10 millimeters to collect and collimate said curing light;

a plurality of Fresnel lenses that focus said collimated curing light to said curing composite.

[Claim 17] The method of claim 14, wherein said Fresnel lenses are made from materials selected from the group consisting of polycarbonate, acrylic, rigid vinyl, and polyacrylic.

[Claim 18] The method of claim 14, wherein said said circuit board comprising

a constant current circuit to drive said LED;

a timing circuit to control timing sequence of curing exposure;

a protection circuit to prevent overheating of said LED and over discharging of said rechargeable battery.

[Claim 19] An optical device for focusing light emitted from a high power LED source, the optical device comprising:

a first Fresnel lens having a first end that is substantially flat and a second end comprising circular grooves, wherein the substantially flat first end is configured for receiving light from the LED source, wherein the circular grooved second end is configured for refracting the light received from the first end into a diffraction limited collimation beam;

a second Fresnel lens having a first end comprising circular grooves and a second end that is substantially flat, wherein the first circular grooved end is configured for refracting the light received from the first Fresnel lens into a focused beam and the second flat end is configured for transmitting the light received from the first end into a diffraction limited focused spot adjacent to a curing composite;

means for holding the first Fresnel lens adjacent to the LED source; and means for holding the first and the second Fresnel lenses adjacent immediately to each other; wherein the means for holding and protecting the lenses comprise a lens mounting reflector consisting of a mounting thread and a high reflectance parabolic inner surface made of materials comprising plated, coated and bonded aluminum, chromium, zinc, silver and high reflective thin films made of materials comprising multiplayer metal oxide films and polymer films.

[Claim 20] The apparatus of claim 20, wherein said first and second Fresnel lenses comprising circular grooves of constant height and constant spacing made of transparent materials comprising polycarbonate, acrylic, silicone, rigid vinyl using processes comprising compression and injection molding.

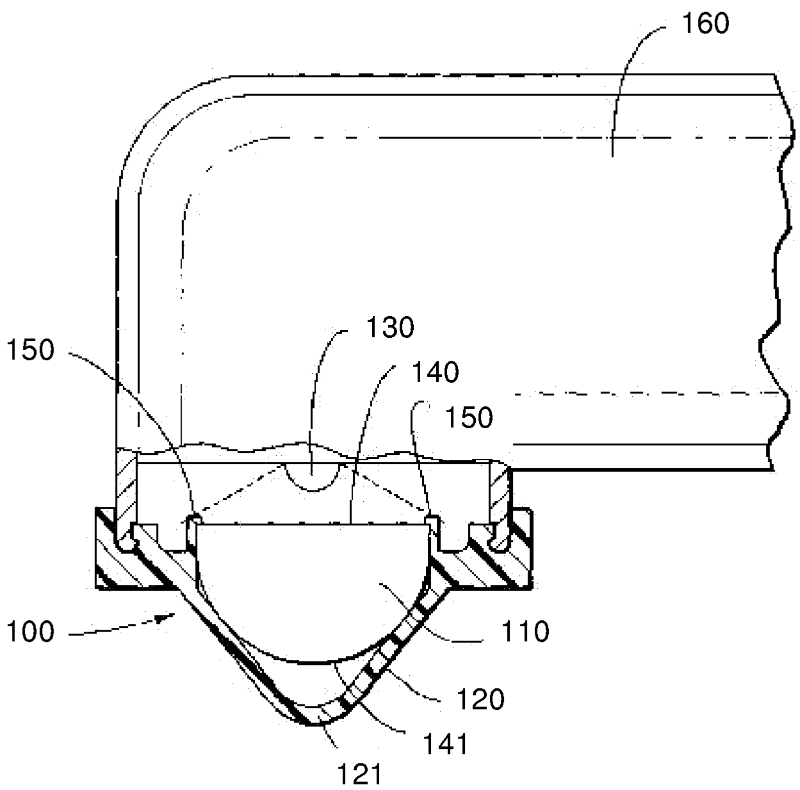


FIG1 (Prior Art)

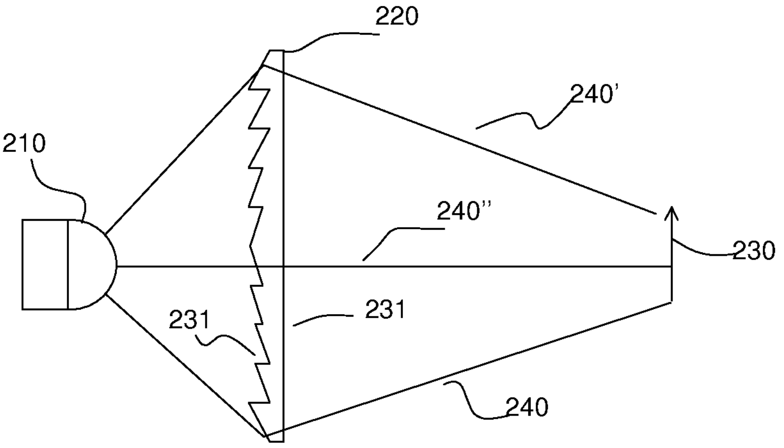


FIG2

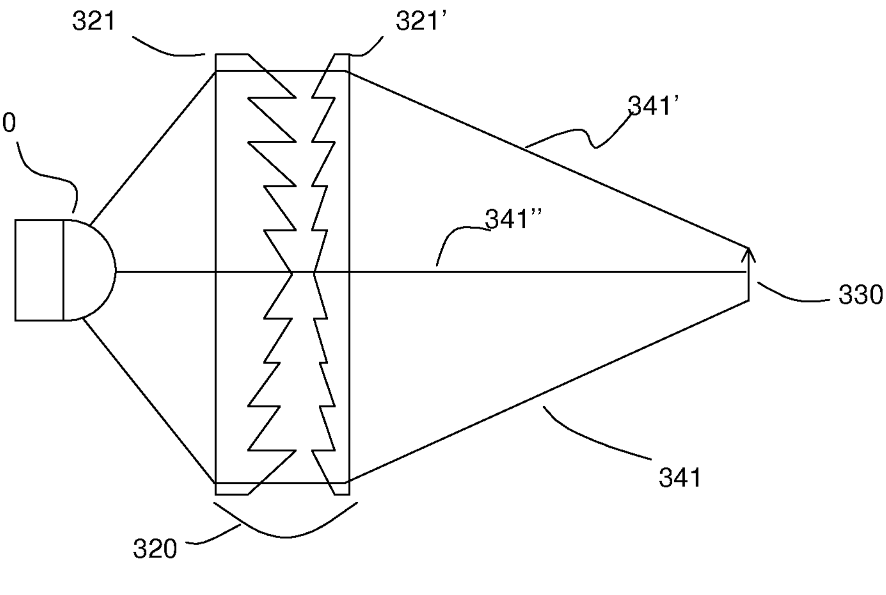


FIG3

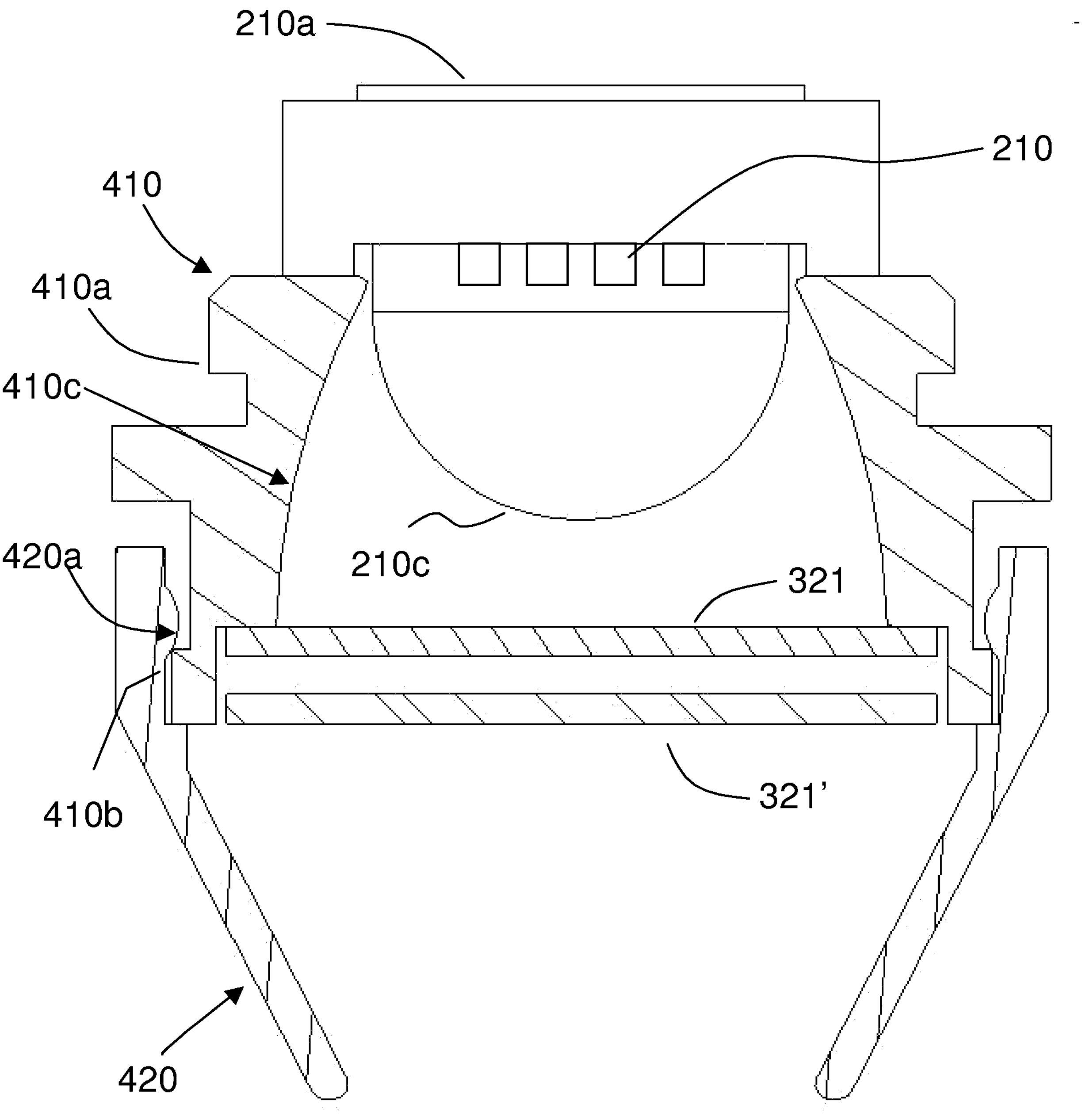
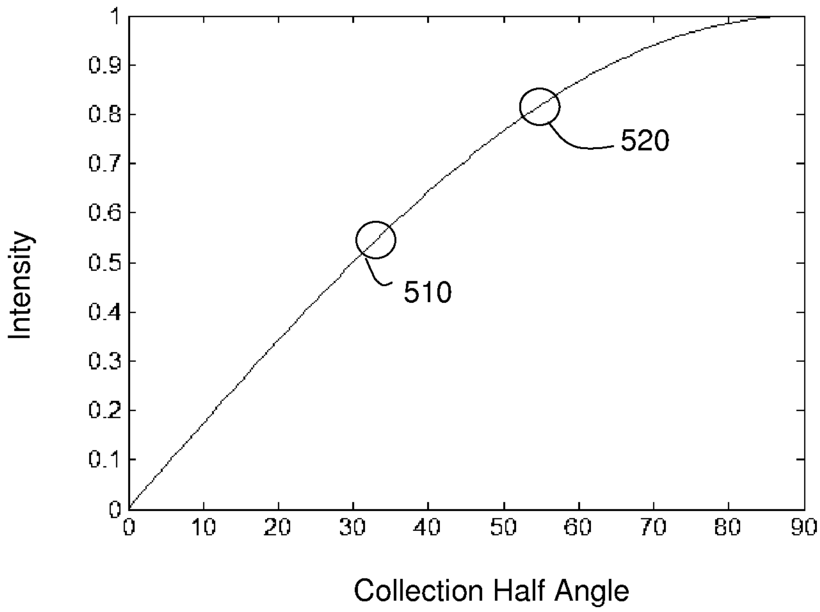


FIG4


Intensity
Collection Half Angle
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
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10
20
30
40
50
60
70
80
90
510
520

FIG5

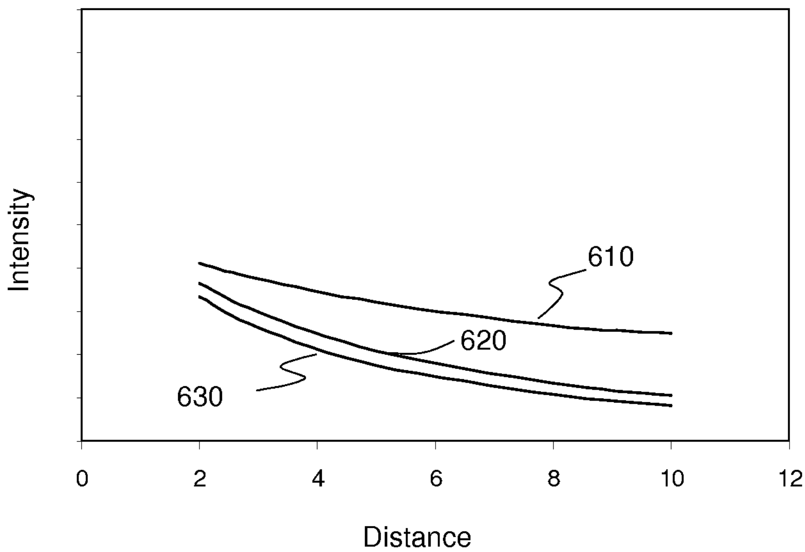
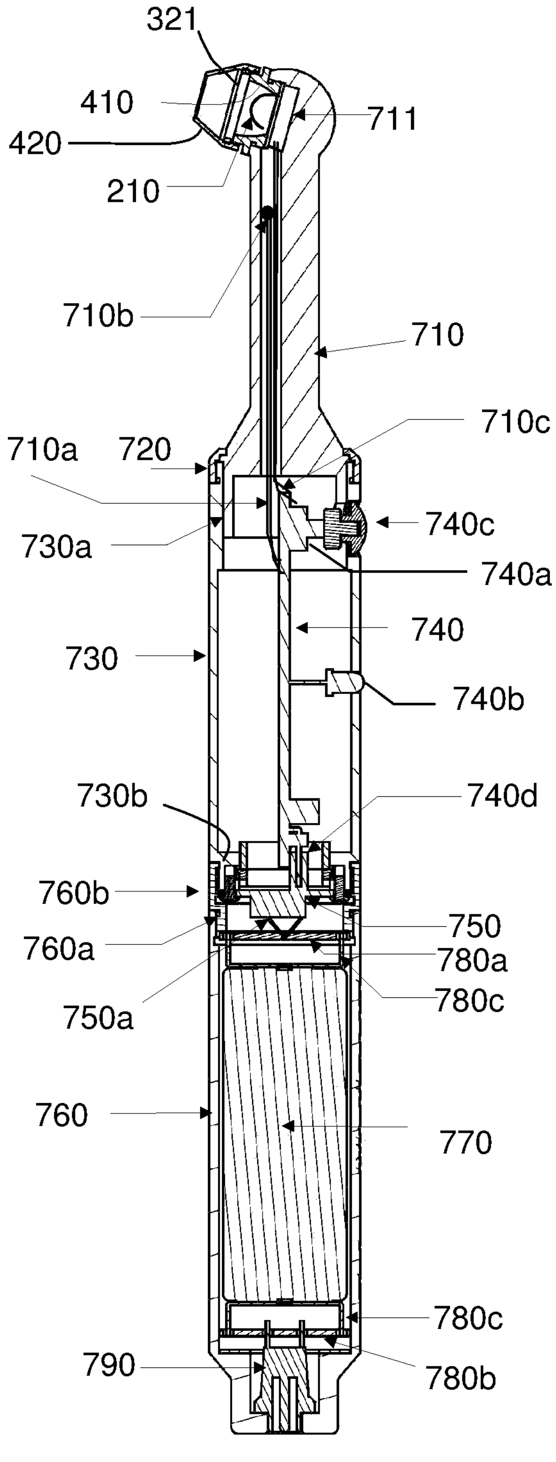

Intensity
Distance
0
2
4
6
8
10
12
610
620
630

FIG6


321
410
711
420
210
710b
710
710c
710a
720
740c
730a
740a
740
730
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730b
740d
760b
750
760a
780a
780c
750a
760
770
780c
790
780b

FIG7