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(54) **MEDICAL HEADLAMP OPTICS**

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- (71) Applicant: **River Point, LLC**, Portland, OR (US)
- (72) Inventor: **John Thomas Ferguson**, Portland, OR (US)
- (73) Assignee: **River Point, LLC**, Portland, OR (US)
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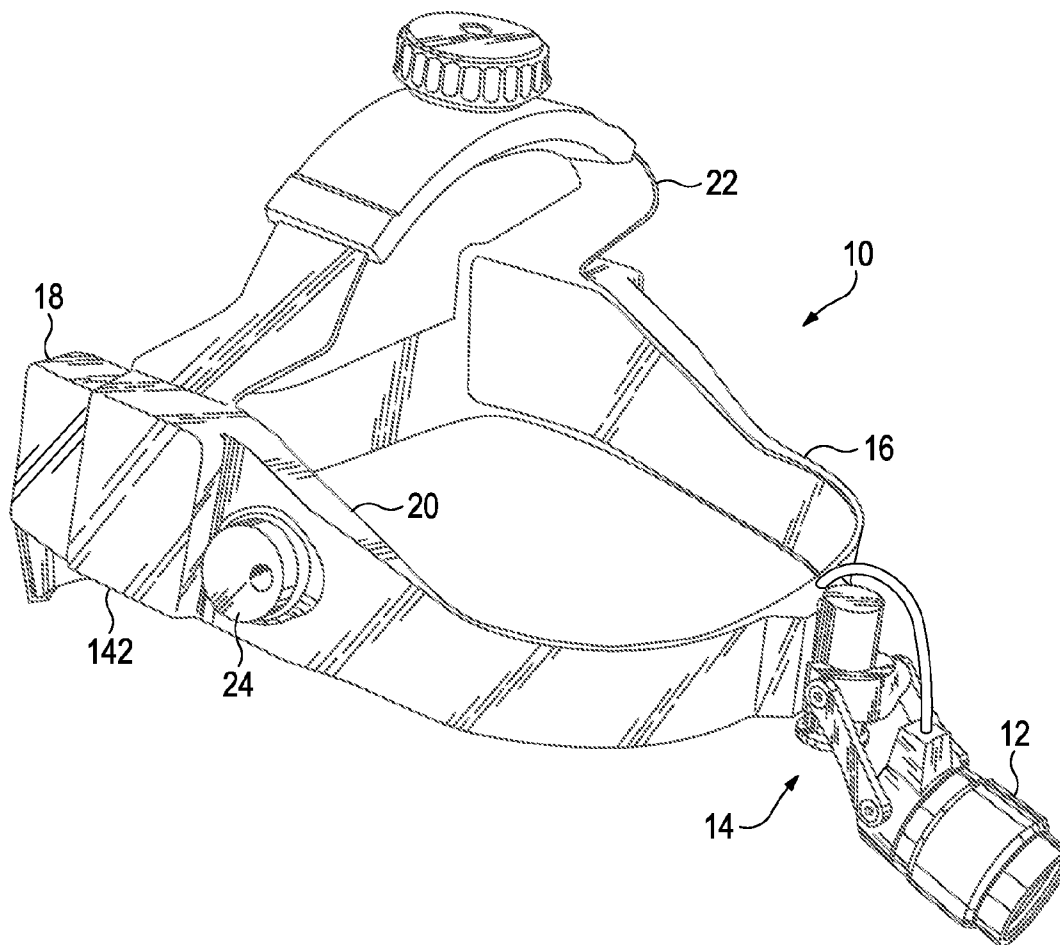
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(57) **ABSTRACT**

A lamp having a front surface from which a beam of light is emitted and that includes a housing. An optical assembly is supported and partially enclosed by the housing, and includes an LED assembly, a prime lens and an exit lens, with light emitted from the LED assembly passing through the aspheric prime lens and exiting through the exit lens. Also, the exit lens defines a front surface and a rear surface and the rear surface has a convex shape different from the shape of the front surface.

Related U.S. Application Data

- (60) Provisional application No. 61/822,493, filed on May 13, 2013.



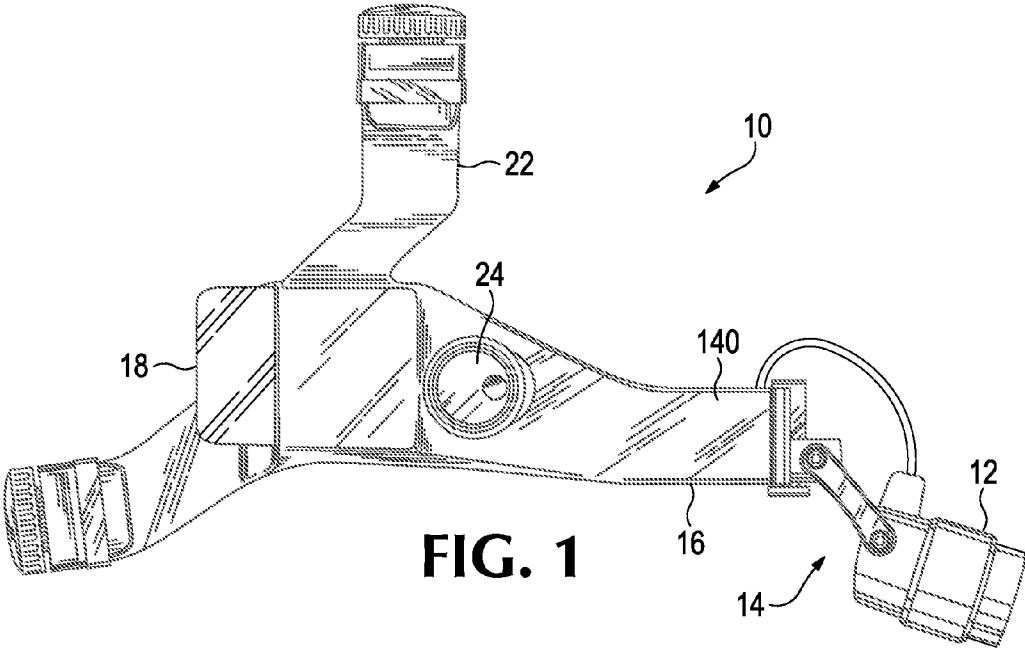


FIG. 1

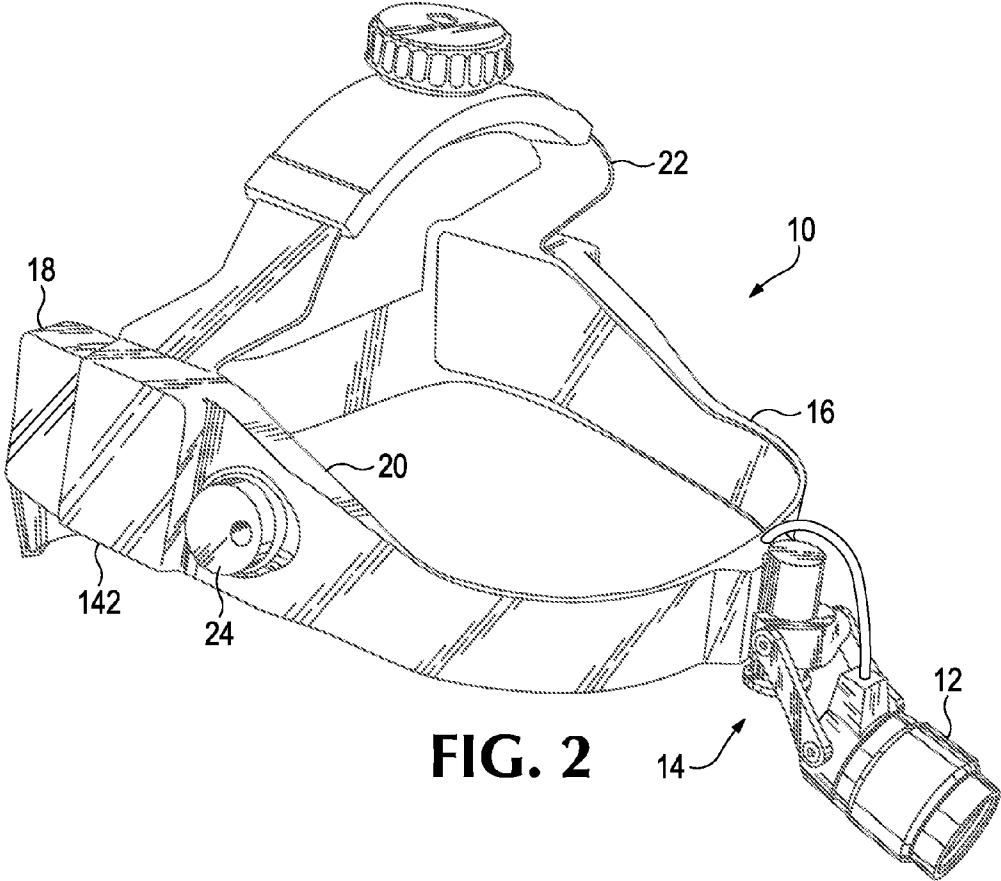
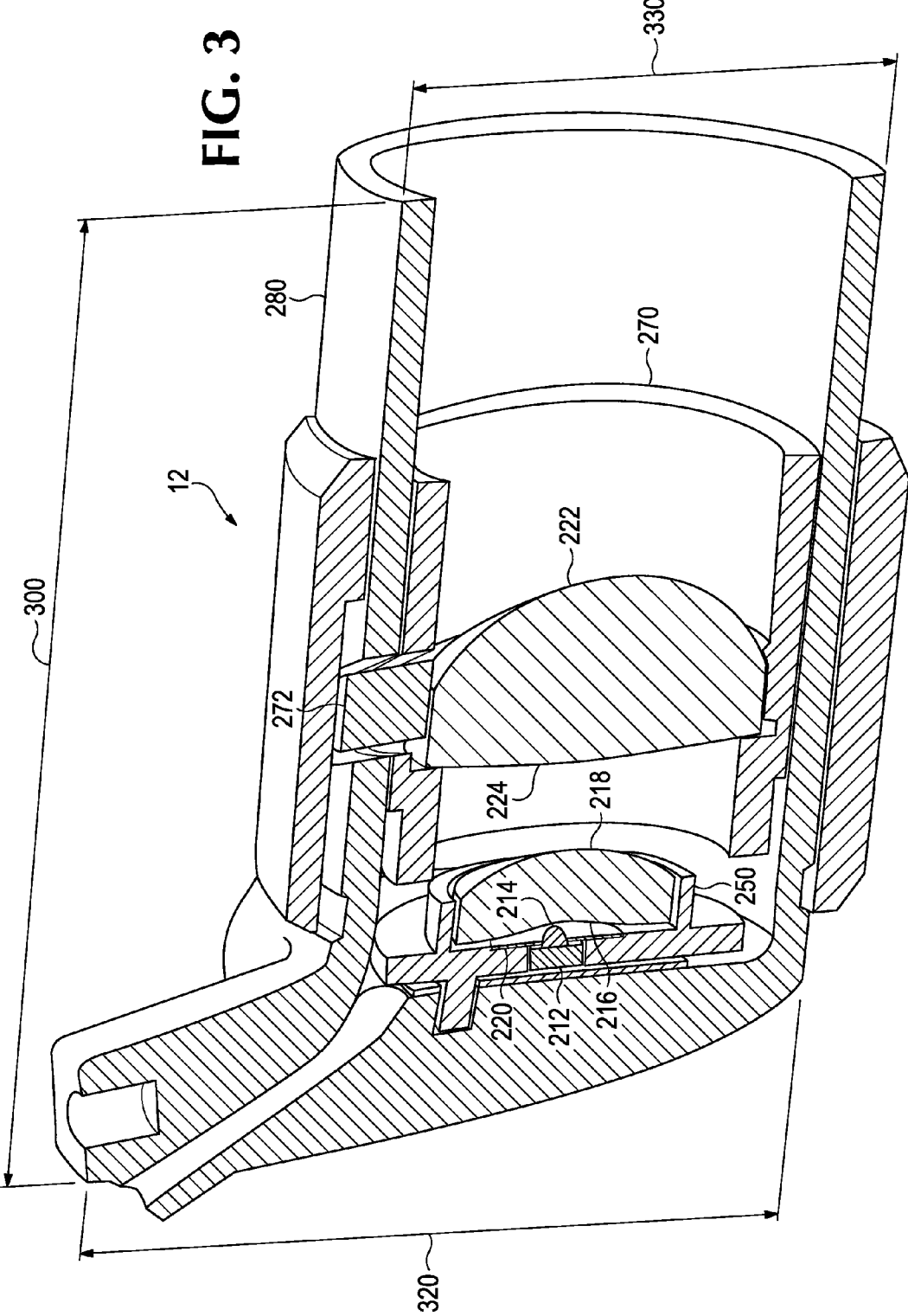


FIG. 2



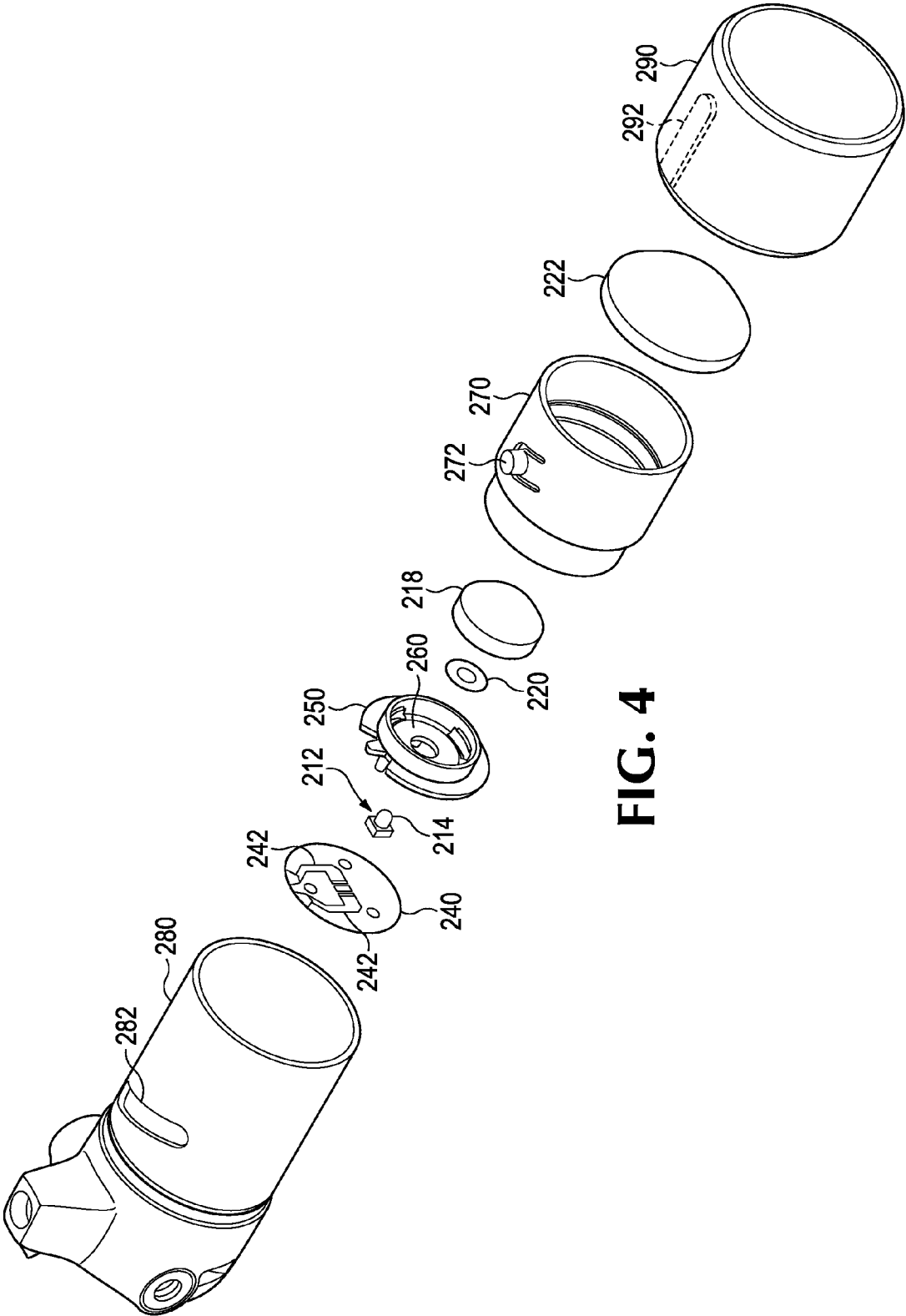


FIG. 4

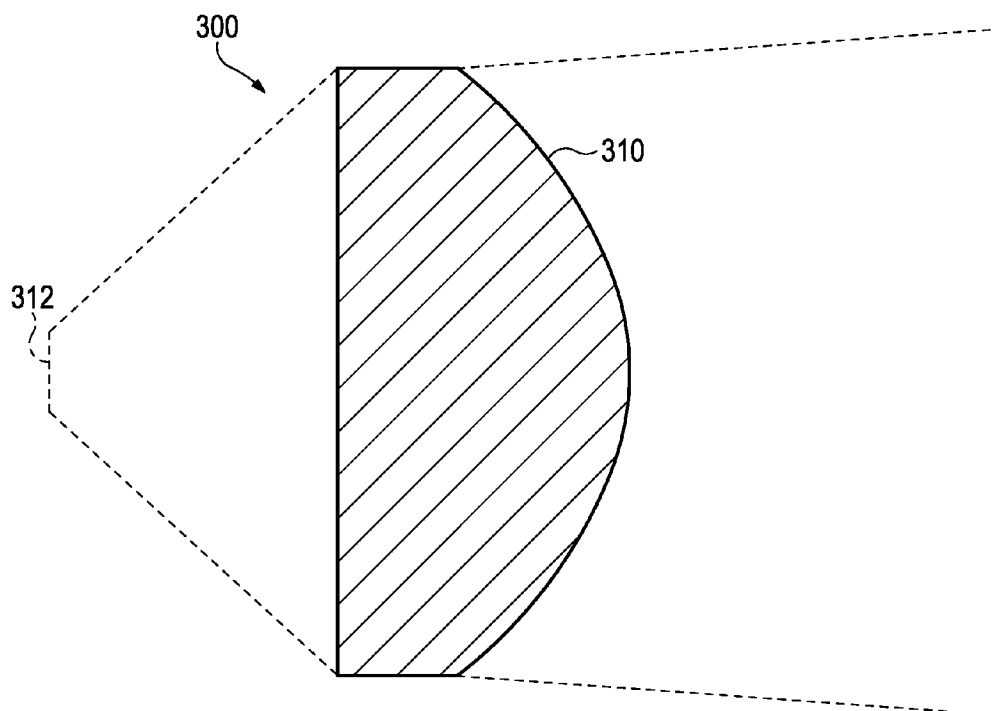


FIG. 5
Prior Art

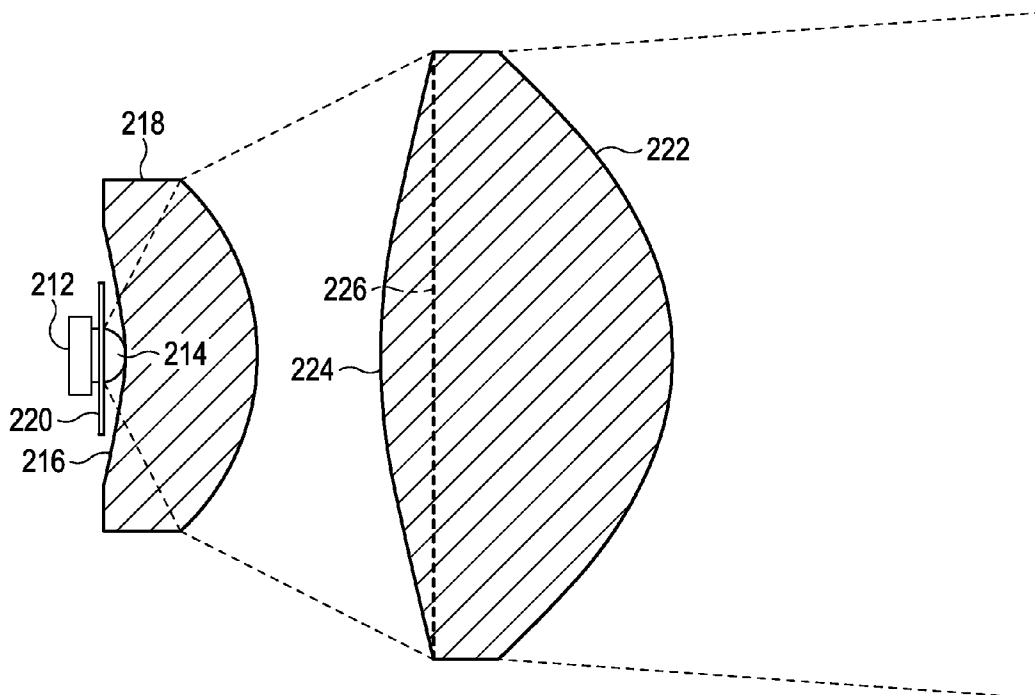


FIG. 6

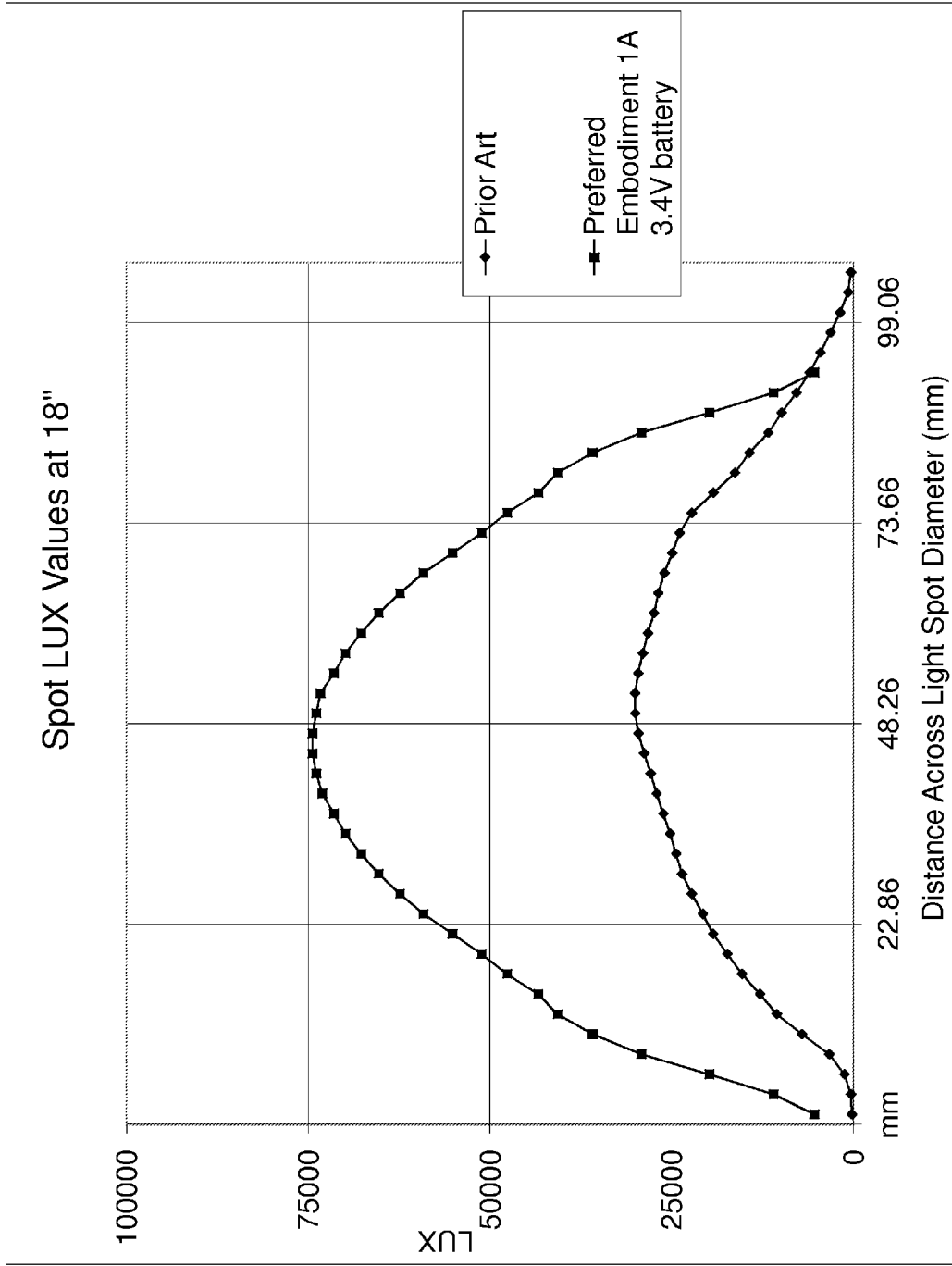


FIG. 7

MEDICAL HEADLAMP OPTICS

RELATED APPLICATIONS

[0001] This application claims priority from provisional application Ser. No. 61/822,493, filed May 13, 2013, which is incorporated by reference as if fully set forth herein.

BACKGROUND

[0002] A medical headlamp assembly is a critical part of the surgeon’s suite of tools, as it is of great importance that a surgeon can clearly see in the operating theater. The ideal headlamp would be easily portable, light and comfortable to wear for at least four hours. Further, it would have battery power, mounted on the headstrap, sufficient to last four hours off one charge, thereby eliminating the necessity of waist mounted battery pack and cables connecting this pack to the lamp, which are uncomfortable and complicate antiseptic protocol. Further the ideal headlamp assembly would create a bright beam of light that was homogenous and uniform in brightness and color, from edge-to-edge, directly along the surgeon’s line of sight, without obscuring his or her line of sight. Also, it would be entirely silent, easily adjustable in position and would not be susceptible to infection by mold or any other sort of organism.

[0003] Unfortunately, these criteria are not only difficult to meet, but are also frequently at odds with each other. For example, although it is better to have a bright light, this creates more heat, which must be safely expressed from the lamp. It is helpful in the elimination of heat to make the lamp bigger, but doing so is likely to cause it to obscure the surgeon’s line of sight and add unbearable weight. Another option for expressing heat would be to provide a fan, but this creates a sound which may be difficult for the surgeon to tolerate. To permit longer battery life it would be helpful to have higher capacity batteries, but doing so makes the assembly heavier and more difficult for the surgeon to tolerate for a long period of time. The batteries could be placed in a waist pack, but doing so requires an electrical line extending from an aseptic area, about the waist underneath the scrubs (anything under the neck is a “sterile” area), to a nonsterile area, on the surgeon’s head. This arrangement complicates aseptic protocol.

[0004] There is a currently available headlamp assembly that mounts batteries on the headband and that has batteries that can be swapped out, one at a time, for extended surgical periods. The light produced by this headlamp is on the order of 166 lumens in intensity. For many types of surgery, for example where a deep cavity that has been opened up inside a patient requires illumination, a higher intensity lamp is desirable.

SUMMARY

[0005] The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods which are meant to be exemplary and illustrative, not limiting in scope. In various embodiments, one or more of the above-described problems have been reduced or eliminated, while other embodiments are directed to other improvements.

[0006] In a first separate aspect, the present invention takes the form of a lamp having a front surface from which a beam of light is emitted and that includes a housing. An optical assembly is supported and partially enclosed by the housing,

and includes an LED assembly, a prime lens and an exit lens, with light emitted from the LED assembly passing through the aspheric prime lens and exiting through the exit lens. Also, the exit lens defines a front surface and a rear surface and the rear surface has a convex shape different from the shape of the front surface.

[0007] In a second separate aspect, the present invention takes the form of a medical headlamp assembly that includes a headstrap assembly and batteries mounted on the headstrap assembly. Further, a lamp is operatively mounted on the headstrap assembly and powered by the batteries and has a high-efficiency light source that emits light and an optical assembly structured and positioned so as to accept and emit most of the light from the high-efficiency light source. Finally, the lamp produces a beam of light from the optical assembly that at a distance of 46 cm, on a white surface perpendicular to the beam, creates a spot of light that is greater than 40 mm in diameter and that is all illuminated to an intensity of greater than 50,000 lux.

[0008] In a third separate aspect, the present invention takes the form of a medical headlamp assembly, comprising a headstrap assembly, a source of electric power and a lamp, operatively mounted on the headstrap assembly and powered by the source of electric power. The lamp has a high-efficiency light source that emits light and an optical assembly structured and positioned so as to accept and emit most of the light from the high-efficiency light source; and wherein at an ambient temperature of 30 degrees Celsius, the lamp can operate at maximum power without forced fluid cooling it and without causing damage to itself, and produces a beam of light that at a distance of 46 cm, on a white surface perpendicular to the beam, creates a spot of light that is greater than 40 mm in diameter and that is all illuminated to a brightness of greater than 50,000 lux.

[0009] In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following detailed descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Exemplary embodiments are illustrated in referenced drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

[0011] FIG. 1 shows a side view of a medical headlamp assembly, according to the present invention.

[0012] FIG. 2 shows an isometric view of the medical headlamp assembly of FIG. 1.

[0013] FIG. 3 is a cross-sectional view of a lamp for use in a medical headlamp assembly such as that of FIG. 1.

[0014] FIG. 4 is an exploded view of the lamp of FIG. 3.

[0015] FIG. 5 is a diagram of the lens system of a prior art headlamp, showing the outer light rays when the system is in operation.

[0016] FIG. 6 is a diagram of the lamp of FIG. 3, showing the outer light rays when the system is in operation.

[0017] FIG. 7 is a graph of light intensity values from a spot formed on a white background formed 45.7 cm (18 inches) in front of the front surface of the headlamp, according to a preferred embodiment, using 1 Amp of current and a 3.4 Volt, from battery, voltage drop. The intensity values are taken along a diameter of the light spot.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Definitions

[0018] For the purposes of this application, a “high efficiency light source” is an electrically powered light source having a light emitting surface area of less than 50 mm² that produces light at a rate of greater than 50 lumens per watt of input power and at a rate greater than 30 lumens per square millimeter of light emitting area. This term does not include packaging or a lens. If these items are included the phrase used is “high efficiency light source assembly”.

[0019] A light emitting diode (LED), as used in the application, refers to a solid state electrical device and does not include any lens or packaging. This element is sometimes referred to as a “die,” by others. A light emitting diode assembly, includes packaging and a lens.

[0020] The term “most” as used in this application, means more than 50%.

[0021] The term “light” as used in this application refers to visible light.

[0022] The “front” of the medical lamp is the side from which light is emitted. The “longitudinal dimension” extends from front to back.

[0023] Referring to FIGS. 1 and 2, in a preferred embodiment of the present invention is a medical headlamp assembly 10, having a headlamp optical assembly (bezel) 12, an adjustable headlamp bezel support assembly 14, a headstrap assembly 16, supporting a pair of batteries 18, each in contact to a circuit board (not shown) in a circuit board repository 20. A head-top strap 22 and brightness control knob 24 also are supported by headstrap assembly 16. Assembly 10 includes a headlamp bezel 12 that has a slightly larger diameter than generally found in the prior art. This permits a brighter light beam since it can support more power intake (drive current), as the greater surface area permits more heat to be radiated away. But it also necessitates a better degree of positioning control and ease of positioning control.

[0024] It is highly desirable, but very difficult, to produce a large, clear, sharp round light spot for a surgeon, using LED technology that is powered by head-mounted batteries. To do this it would be beneficial to use an LED assembly that produces a cone of light having a 3 dB beam width of greater than 90°, but there is no such LED assembly available that produces a beam that has a sharp edge while still being efficient enough to provide the brightness necessary to do a deep cavity surgery. The Oslon Square™ LED assembly provides a beam width of 120°, and although bright enough was considered unusable in this application due to the slow tapering off of the beam edges, which if not corrected would create a spot of light having a fuzzy boundary, when an aspheric lens system is used, as is typical. This detracts from the tight focus on a specific area that the medical light is intended to provide and can cause distracting reflections of the metal instruments used in surgery.

[0025] Referring to FIGS. 3, 4 and 6, in a preferred embodiment, of an optical assembly 12, an LED assembly 212, including a domed silicone lens 214, and producing a light beam having a 3 dB beamwidth of 120°, has a 25μ (1 mil) thick annular light block 220 fitted around LED assembly 212, with the domed silicone lens 214 extending through the annulus of the light block 220. The beam exiting light block 220 has a beamwidth of 120° but with a much sharper edge than the beam from LED assembly 212. This contrasts with

prior art systems in which an adjustable iris light block is placed entirely in front of the light source, resulting in a greater portion of the light being blocked and lost to beneficial use. Because this permits the use of the otherwise unusable 120° beam width assembly, this assembly permits a larger spot of light for the surgeon using the optical assembly 12. The placement of the light block 220 together with its 25μ thickness, creates a sharp boundary about the light, and ultimately creating a sharp spot of light, at the typical 80-100 mm (16-18 in) working distance. Lens 214 is fit into a concavity 216 formed in the back of an aspheric prime optic lens 218. Table 1 shows the LED assembly 212 characteristics for four differing embodiments. In an alternative preferred embodiment an LED assembly is used that is similar to the Oslon Square LED assembly, but includes more than one LED die, and in another preferred embodiment more than one LED assembly is used.

[0026] In front of prime optic lens 218, an exit lens 222 has a convex rear surface 224, thereby better directing the captured light back to create a beam of constant illumination over area. The equation for the surface is:

$$Z=(CR^2)/(1+\text{SQRT}(1-(1+K)C^2R^2));$$

[0027] Where Z is the distance of the surface away from the apex of the rear surface 224 of the exit lens 222, in the longitudinal dimension, toward plane 226 (see FIG. 6), where:

[0028] R=radial distance from center in mm; and where C=0.05479 mm⁻¹, and K=-14.954 (unitless).

[0029] More generally, the curve described by the above equation has the characteristic that for every 0.5 mm chord connecting two points along the curve the perpendicular distance (“sagitta” or “sag”) from the chord to the curve, at the chord midpoint, is at least 0.025 mm.

[0030] As noted in the background, prior art systems included an adjustable iris aperture in front of the light source to permit adjustment of light spot size and create a sharply defined edge and homogeneous brightness and color from edge to edge. Although this permitted flexibility with respect to spot size, the movable elements of the iris required the iris aperture to be positioned further in front, the light source resulting in more light being blocked. Also, the need to have moveable leaf elements that fit together could impart a non-circular shape to the beam and the spot of light produced by the beam. Even when an iris was not used, as illustrated by FIG. 5, prior art systems, such as optical arrangement 300, would lose light by placement of the prime lens 310 far ahead of the light source 312. By contrast, a preferred embodiment has a set aperture size created by the 25 micron—100 micron (1 to 4 mils) thick annular light block 220. This novel arrangement creates a far sharper light-spot boundary, due to the extremely thin circular aperture wall, resulting in virtually no light reflecting from the inner surface of annulus. This light block 220 is positioned around dome 214 of LED assembly 212, thereby blocking a smaller portion of the light produced by assembly 212.

[0031] The LED assembly 212 is driven by a 750 milliamp or greater current. A one (1) amp current at a typical battery voltage of 3.45 Volts results in a voltage drop through the LED assembly of about 3.15 Volts, due to some voltage drop through a rheostat, which is used to adjust light intensity, in the headstrap 16. This creates about 3.15 Watts of power that must be dissipated as heat from the LED assembly 212. The LED assembly 212 is driven by traces 242 that extend through

a sheet of flex circuit **240** that is mounted behind prime lens holder **250** (FIGS. **3** and **4**). Annular light block **220** fits into a round recess **260** in the center of holder **250**. A layer of the flex circuit **240** is made of copper (except for channels where the copper has been removed to separate the traces **242** from the rest of the copper covering), which efficiently conducts heat away from assembly **212**. Light is reflected from this conductive layer, which is close to the front, and at most covered with a transparent coating. This light is re-reflected back by the annular light block, preventing this yellowish light from entering the beam of light produced by assembly **10**.

[0032] As illustrated in FIGS. **3** and **4**, the exit lens **222** is held in a lens holder **270** that has a slot-follower **272** which is fitted into a curved slot **282** in an aft barrel **280**. An outer ring **290** includes a straight internal longitudinal slot **292**, and is mounted about aft barrel **280**, so that when outer ring **290** is rotated, lens holder **270** is also rotated as slot-follower **272** is forced to stay in straight slot **292**. This rotation forces slot-follower **272** to rotate within curved slot **282**, which in turn causes slot-follower **272** and lens holder **270** to be moved either forward or backward in aft barrel **280**. This either focuses or defocuses the light beam, creating a larger or smaller spot of light. The aft barrel **280** is made of aluminum and has a high thermal conductivity, whereas lens holder **270** and outer tube **290** are made of hard, black acrylonitrile butadiene styrene (ABS) polymer. Aft barrel **280** has a length **300** of 49.36 mm, and a height **320** of 38.61 mm. The front of aft barrel **280** has an outer diameter **330** of 27.26 mm. The other parts shown in FIGS. **3** and **4** are shown at the same scale as the aft barrel. The optical assembly **12** has a mass of 43 grams. The entire assembly **10**, including batteries **18**, has a mass of 340 grams.

TABLE 1

LED Assemblies Used in Various Embodiments				
	Manufacturer Designation	Further Designation Class (Color)	LED Beam Angle	
LED Assembly of Emb. 1	Oslon Square	PC	120	
LED Assembly of Emb. 2	Oslon Square	EC	120	
LED Assembly of Emb. 3	Oslon Square	CC	120	
LED Assembly of Emb. 4	Oslon Square	EQW	120	
Current Applied	750 mA	1 A	1.2 A	1.5 A
Lumen Output				
LED Assembly of Emb. 1	252-346	312-429	372-511	408-561
LED Assembly of Emb. 2	220-294	273-364	325-434	357-476
LED Assembly of Emb. 3	189-271	234-336	279-401	306-440
LED Assembly of Emb. 4	294-409	364-507	434-604	476-663
Voltage				
LED Assembly of Emb. 1	3.08	3.15	3.2	3.28
LED Assembly of Emb. 2	3.08	3.15	3.2	3.28
LED Assembly of Emb. 3	3.08	3.15	3.2	3.28
LED Assembly of Emb. 4	3.08	3.15	3.2	3.28
Wattage				
LED Assembly of Emb. 1	2.31	3.15	3.84	4.92
LED Assembly of Emb. 2	2.31	3.15	3.84	4.92
LED Assembly of Emb. 3	2.31	3.15	3.84	4.92
LED Assembly of Emb. 4	2.31	3.15	3.84	4.92

TABLE 1-continued

LED Assemblies Used in Various Embodiments				
	Lm/Watt @ max lm			
LED Assembly of Emb. 1	150	136	133	114
LED Assembly of Emb. 2	127	116	113	97
LED Assembly of Emb. 3	117	107	104	89
LED Assembly of Emb. 4	177	161	157	135

[0033] The effect of the above detailed design is a medical headlamp assembly **10** with batteries **18** mounted on the headstrap assembly **16**, and without a fan to provide forced air cooling, but which produces a brighter beam than previously available headlamp assemblies of this sort. The beam produced, in one preferred embodiment, has a light volume of 413 lumens with a color rendering index of at least 65. The beam is emitted relatively evenly from the 23 mm diameter front surfaces of the exit lens **222**, and spreads out by 4.19 degrees in all directions as the beam advances. Referring to FIG. **7**, a one (1) Amp lamp, as described above, where the voltage drop from the batteries is 3.4 Volts, produces a spot of light at 45.7 cm (18 inches) as shown. With a bright central area, about 52 mm wide at all above 50,000 lux at a color rendering index (CRI) of greater than 65. This is surrounded by a ring of about 10 mm width, where the light intensity declines from 50,000 lux to 25,000 lux. At the edges of the light beam, the brightness drops off by 20 dB in 0.5°. The lamp is operable in an ambient temperature of up to 30° Celsius, with no fan to cool the lamp.

[0034] This brightness is achieved by two improvements, with respect to prior art assemblies. First, the electric power applied to the LED assembly **212** is greater than in the prior art.

[0035] Second, the proportion of light produced by the LED that is emitted in the beam is greater. The greater electric power of 2.5875 Watts creates a problem of successfully expressing the heat produced. It is highly advantageous to do this without the use of a fan, which would drive up electric power usage and create an unwanted noise. Accordingly, no fan is used in the preferred embodiment. The need to express the heat produced, is addressed by a longer aft barrel **280** which is made of aluminum and acts as a heat radiator, without blocking the surgeon's view. Also, the copper surface of flex circuit **240** conducts heat away from the LED assembly **212** and toward the bezel housing. A greater proportion of light produced by the LED is emitted in the light beam because: 1) the distance between the LED assembly **212** and the prime lens is shortened to virtually nothing, as the LED assembly **212** protrudes into a concavity **216** in the prime lens **218**; 2) the adjustable iris, present in many prior art systems has been eliminated; 3) the annular light block **220** sits on the lens of the LED assembly **212**, so that it is so far back that it blocks only a small proportion of the light. In one preferred embodiment 70% of the light produced by LED assembly **212** is emitted from the exit lens **222** as a light beam. Alternative preferred embodiments emit anywhere from 50% to 70% of the light produced by the led assembly **212** out of exit lens **222**. This compares favorably with prior art systems where less than 45% of the light produced by the light source is emitted in the beam. In a preferred embodiment the light beam produced from exit lens **222** has a volume of 114 to 161 lumens for every watt of power applied to LED assembly 212.

In one alternative preferred embodiment this figure ranges from 90 lumens of output light per watt to 161 lumens of output light per watt.

[0036] This device greatly eases the task of the surgeon, who may now have an adequately bright and wide spot for deep cavity surgery, without the need for the distracting noise and cumbersome extra weight of a fan and without the need of any power cable traversing from a sterile to a nonsterile zone.

[0037] While a number of exemplary aspects and embodiments have been discussed above, those possessed of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit and scope.

1. A lamp having a front surface from which a beam of light is emitted, comprising:

- (a) a housing
- (b) an optical assembly supported and partially enclosed by said housing, including an LED assembly, a prime lens and an exit lens, with light emitted from the LED assembly passing through the aspheric prime lens and exiting through the exit lens; and
- (c) wherein said exit lens defines a front surface and a rear surface and said rear surface has a convex shape different from the shape of said front surface.

2. The lamp of claim 1 wherein said rear surface defines a curve across its diameter having the characteristic that for every 0.5 mm chord connecting two points along the curve the perpendicular distance ("sagitta" or "sag") from the chord to the curve, at the chord midpoint, is at least 0.025 mm.

3. The lamp of claim 1 wherein the rear surface defines a curve, across its diameter, fitting the equation: $Z=(CR^2)/(1+\text{SQRT}(1-(1+K)C^2R^2))$, where Z is forward displacement from the peak of the rear surface in mm, R is distance from the center in mm, C is a constant of between 0.05 and 0.06 mm⁻¹ and K is a unitless constant of between 14 and 16.

- 4. A medical headlamp assembly, comprising:
 - (a) a headstrap assembly;
 - (b) batteries mounted on said headstrap assembly;
 - (c) a lamp, operatively mounted on said headstrap assembly and powered by said batteries and having:
 - (i) a high-efficiency light source that emits light; and
 - (ii) an optical assembly structured and positioned so as to accept and emit most of said light from said high-efficiency light source; and
 - (d) wherein said lamp produces a beam of light from said optical assembly that at a distance of 46 cm, on a white surface perpendicular to said beam, creates a spot of light that is greater than 40 mm in diameter and that is all illuminated to an intensity of greater than 50,000 lux.

5. The medical headlamp assembly of claim 4, wherein said spot of light has a color rendering index of greater than 60.

6. The medical headlamp assembly of claim 4, wherein said spot of light is all illuminated to an intensity of greater than 58,000 lux.

7. The medical headlamp assembly of claim 4, wherein said spot of light has a maximum intensity of greater than 70,000 lux.

8. The medical headlamp assembly of claim 4, having a mass of less than 300 grams.

9. The medical headlamp assembly of claim 4, wherein said optical assembly includes a prime lens adjacent to said light source and an exit lens.

10. The medical headlamp assembly of claim 9, wherein said prim lens defines a concavity in its rear surface and said light source protrudes into said concavity, thereby permitting said optical assembly to capture more light from said light source.

- 11. A medical headlamp assembly, comprising:
 - (a) a headstrap assembly;
 - (b) a source of electric power;
 - (c) a lamp, operatively mounted on said headstrap assembly and powered by said source of electric power and having:
 - (i) a high-efficiency light source that emits light; and
 - (ii) an optical assembly structured and positioned so as to accept and emit most of said light from said high-efficiency light source; and

(d) wherein at an ambient temperature of 30 degrees Celsius, said lamp can operate at maximum power without forced fluid cooling and without causing damage to itself, and produces a beam of light that at a distance of 46 cm, on a white surface perpendicular to said beam, creates a spot of light that is greater than 40 mm in diameter and that is all illuminated to a brightness of greater than 50,000 lux.

12. The medical headlamp assembly of claim 11, wherein said beam has a light intensity of more than 90 lumens per watt of power delivered to said lamp.

13. The medical headlamp assembly of claim 11, wherein said beam has a light intensity of more than 100 lumens per watt of power delivered to said lamp.

14. The medical headlamp assembly of claim 11, wherein said beam has a light intensity of more than 110 lumens per watt of power delivered to said lamp.

15. The medical headlamp assembly of claim 11, wherein said source of electric power is a battery assembly supported by said headstrap assembly.

16. The medical headlamp assembly of claim 11, having a mass of less than 300 grams.

17. The medical headlamp assembly of claim 11, wherein said light assembly is an LED assembly.

18. The medical headlamp assembly of claim 17, wherein said LED assembly includes an LED supported by a substrate and covered by a silicone dome lens.

19. The medical headlamp assembly of claim 18, wherein an annular light block is seated on said silicone dome lens.

20. The medical headlamp assembly of claim 11, wherein said spot of light has a color rendering index of greater than 60.

21. The medical headlamp assembly of claim 11, wherein said spot of light has a color rendering index of about 65.

* * * * *