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**An optical lens and a miner's helmet lamp**

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**Abstract**

The embodiments of the present invention provide a kind of optical lens and a kind of miner's helmet lamp. A kind of optical lens, comprising a reflective surface and a light exit surface; wherein, in a circle with the central position of the said reflective surface as its center, at least a light distribution camber and a reflective camber are set up along the radius direction of the said reflective surface; in a circle with the central position of the said light exit surface as its center, at least a Fresnel annular surface and a surface are set up along the radius direction of the said light exit surface; the said light distribution camber is used for refracting the light incident on the said reflective surface to the said Fresnel annular surface and the said surface; the said reflective camber is used for reflecting the light incident on the said reflective camber to the said surface in collimation; the said Fresnel annular surface is used for reflecting the light incident on the said Fresnel annular surface through the said light distribution camber from the said light exit surface in collimation; the said surface is used for wholly reflecting the incident light through the said light distribution camber to the said reflective camber and for reflecting incident light through the said reflective camber from the said light exit surface in collimation.

## AN OPTICAL LENS AND A MINER'S HELMET LAMP

The application specified herein was submitted to the China Patent Office on July 13, 2012 with application number as 20120243822.3 and invention title as "A Kind of Optical Lends and A Kind of Miner's Helmet Lamp". The entire content of the China patent application priority is incorporated in this application through reference. The present application is a divisional application of Australian Patent Application No. 2013228036, the contents of which are incorporated in its entirety.

### **Technical Field**

The present invention involves the field of optical device technology, in particular a kind of optical lens and a kind of miner's helmet lamp.

### **Background Art**

Most condensing components currently used in miner's helmet LED lamps adopt parabola-shaped reflectors or total-reflection secondary optical lens to converge light emitted from LED.

For miner's helmet LED lamps using total-reflection secondary optical lens, as shown in Figure 1, when a current lens with a diameter of 20mm-30mm is fitted with a 1-3W LED with a 1mm x 1mm chip, usually the minimal beam angle that can be obtained is about  $8^{\circ}$ - $10^{\circ}$ , which makes it impossible to produce an illuminance of 4,000-6,000 Lux at a distance of 1-3 meters. In order to meet the said illuminance requirement, usually at least 3 to 4 LEDs are needed, which makes it fast for batteries to be used up when the lamps operate for a long period of time. For a single LED, to meet the said illuminance requirement, its beam angle has to be kept below  $5^{\circ}$ . Nevertheless, to realize a beam angle below  $5^{\circ}$ , the diameter of the lens has to be increased to more than 50mm-60mm. If the total-reflection lens structure as shown in Figure 1 is adopted, the thickness of the lens will have to be greatly increased. In such a case, the lens will have a large shrinkage during the process of injection molding, making injection molding very difficult to realize. Moreover, with the increase of the thickness of the lens, the weight of the lens will be increased greatly as well.

Therefore, at present, a kind of optical lens that can output beams at a narrow angle is urgently needed.

**Summary of Invention**

The embodiments of the present invention provide a kind of optical lens and a kind of miner's helmet lamp, which can output beams at a narrow angle.

To solve the aforesaid technical problems, the following technical solutions are adopted in the embodiments of the present invention:

A kind of optical lens, comprising a reflective surface and a light exit surface; wherein, in a circle with the central position of the said reflective surface as its center, at least a light distribution camber and a reflective camber are set up along the radius direction of the said reflective surface; in a circle with the central position of the said light exit surface as its

center, at least a Fresnel annular surface and a surface are set up along the radius direction of the said light exit surface;

The said light distribution camber is used for refracting the light incident on the said reflective surface to the said Fresnel annular surface and the said surface;

The said reflective camber is used for reflecting the light incident on the said reflective camber to the said surface in collimation;

The said Fresnel annular surface is used for reflecting the light incident on the said Fresnel annular surface through the said light distribution camber from the said light exit surface in collimation;

The said surface is used for wholly reflecting the incident light through the said light distribution camber to the said reflective camber and for reflecting incident light through the said reflective camber from the said light exit surface in collimation.

Further, there is a first convex surface in the central position of the said reflective surface and a second convex surface in the central position of the said light exit surface; the said first convex surface and the said second convex surface meet the conditions for Kohler illumination.

Further, the distribution of the light incident on the said light distribution camber by the said light distribution camber meets the following tangent conditions:

$$\theta_2 = \tan^{-1} \left( \frac{\theta_1}{90} \cdot \tan \theta \right)$$

Wherein,  $\theta_1$  is the angle between the light incident on the said light distribution camber and the central optical axis of the said optical lens;  $\theta_2$  is the angle between the light incident on the said light distribution camber refracted from the said light distribution camber and the central optical axis of the said optical lens;  $\theta$  is the angle between the periphery of the said surface to the central position of the reflective surface of the said optical lens and the central optical axis of the said optical lens.

Further, the said  $\theta$  is  $65^\circ$ .

Further, there is a roof prisms array on the said reflective camber; the said roof prisms array is centered on the central position of the said reflective surface and arranged rotationally in a 360 degree; the said roof prisms array is used for reflecting the light incident on the said reflective camber to the said surface in collimation.

Further, the said roof prisms are of a right-angled V-shaped groove structure; the light incident on the said roof prisms is wholly reflected to the two sides of the said right-angled V-shaped groove structure and then incident on the said surface in collimation; the cross section of the said right-angled V-shaped groove structure is a right-angled triangle; the vertex of the right angle is located at the said reflective camber and the two edges of the right angle are located on the two sides of the said right-angled V-shaped groove structure.

Further, the angular spacing between the two adjacent roof prisms is  $0.5^\circ$ - $10^\circ$ .

Optimally, the angular spacing between the two adjacent roof prisms is  $1^\circ$ .

A kind of miner's helmet lamp, comprising any optical lens described above and a light source component.

Further, the said light source component is a single LED lamp.

The optical lens in the embodiments of the present invention as set up above can shoot out the light emitted from the light source component in collimation and form focusing faculae, thus realizing the output of beams at a narrow angle. Moreover, this optical lens is thin and light with a large diameter.

### **Description of Attached Drawings**

To describe the technical solutions adopted in the embodiments of the present invention or the prior art more clearly, the following is a brief introduction to the drawings needed in the description of the embodiments or the prior art. Obviously, the drawings described below are only some embodiments of the present invention, and persons of ordinary skill in the art are able to obtain other drawings based on these drawings without creative work.

Figure 1 is a structure diagram of a miner's helmet LED lamp in prior art;

Figure 2 is a sectional drawing of a kind of optical lens in an embodiment of the present invention;

Figure 3a is a sectional drawing of a kind of optical lens in an embodiment of the present invention;

Figure 3b is a bottom view of the optical lens in the embodiment shown in Figure 3a;

Figure 3c is a vertical view of the optical lens in the embodiment shown in Figure 3a;

Figure 3d is an equiaxial side view of the optical lens in the embodiment shown in Figure 3a;

Figure 4 is a light path drawing of the first convex surface and the second convex surface in the embodiment shown in Figure 3a;

Figure 5 is a light distribution diagram of the light distribution camber in the embodiment shown in Figure 3a;

Figure 6 is a diagram of relationship between  $\theta_2$  and  $\theta_1$  of the light distribution camber in the embodiment shown in Figure 3a;

Figure 7 is a diagram of light path through the Fresnel annular surface and the surface in the embodiment shown in Figure 3a;

Figures 8a-8b are diagrams of total reflection of light in roof prisms in the embodiment shown in Figure 3a;

Figure 9 shows images of faculae at 1m away from a miner's helmet lamp equipped with an optical lens in an embodiment of the present invention;

Figure 10 is a ray tracing diagram of an optical lens in an embodiment of the present invention;

Figure 11 is an illuminance distribution diagram at 1m away from an optical lens in an embodiment of the present invention;

Figure 12 is a diagram of far-field angular distribution of light intensity in an embodiment of the present invention;

Figure 13 is a diagram of actually tested light distribution curve of a miner's helmet lamp equipped with an optical lens in an embodiment of the present invention.

### **Specific Embodiments**

To enable technical personnel in this art to further understand the characteristics and technical contents of the present invention, please refer to the description of the present invention and drawings below. The drawings are for reference and description only and should not be used for confining the present invention.

Below is a description of the technical solutions adopted in the present invention in light of the drawings and embodiments.

Refer to Figure 2, which a sectional drawing of a kind of optical lens in an embodiment of the present invention.

This optical lens comprises reflective surface 21 and light exit surface 22; wherein, in a circle with the central position of the reflective surface 21 as its center, at least a light distribution camber 211 and a reflective camber 212 are set up along the radius direction of the reflective surface 21; in a circle with the central position of the light exit surface 22 as its center, at least a Fresnel annular surface 221 and a surface 222 are set up along the radius direction of the light exit surface 22.

The light distribution camber 211 is used for refracting the light incident on the reflective surface 21 to the Fresnel annular surface 221 and the surface 222; the reflective camber 212 is used for reflecting the light incident on the reflective camber 212 to the surface 222 in collimation; the Fresnel annular surface 221 is used for reflecting the light incident on the Fresnel annular surface 221 from the light exit surface 22 in collimation; the surface 222 is used for wholly reflecting the incident light through the light distribution camber 211 to the reflective camber 212 and for reflecting incident light through the reflective camber 212 from the light exit surface 22 in collimation. Because the light undergoes folded total reflection (from the surface 222 and the reflective camber 212) in the lens twice, a relatively long focus can be realized within a relatively thin space, so that the faculae reflected from the lens can be produced at a narrow angle.

The light emitted from the light source component passes through the light distribution camber 211 on the reflective surface 21 of the optical lens first. After being reflected from the light distribution camber 211, it is incident on the Fresnel annular surface 221 and the surface 222. The light incident on the Fresnel annular surface 221 and the surface 222 is reflected from the light exit surface 22 in collimation; the light incident on the surface 222 meets the requirements for total reflection [from the surface 222] and therefore is wholly reflected to the reflective camber 212. The light incident on the reflective camber 212 is reflected [from the reflective camber 212] in collimation and then is reflected through the surface 222 from the light exit surface 22.

The optical lens in the embodiment of the present invention as set up above enables the light to undergo folded reflection inside the lens twice. It folds a long optical path in a relatively thin space, and can produce the light emitted from the light source component in collimation forming focusing faculae. Because the focus of the optical lens in the embodiment of the present invention is longer than the focus of the lens adopting prior art (only one total reflection) as shown in Figure 1, according to the law that size of the beam

angle (full angle  $2\theta$ ) produced by this optical lens is  $2\theta = 2 \cdot \tan^{-1}\left(\frac{D}{2f'}\right)$ , it delivers beams at a narrow angle. This optical lens is thin and light with a large diameter. In the formula,  $D$  is the length of the diagonal line of the light-emitting surface of the chip and  $f$  is the focus of the lens. Assuming that the length of the diagonal line of the light-emitting surface of the LED chip is  $\sqrt{2}$  mm, when the focus  $f$  is longer than 16.2mm, the angle of the emitted beam is smaller than  $5^\circ$ .

Refer to Figure 3a, which is a sectional drawing of a kind of optical lens in an embodiment of the present invention; Figure 3b is a bottom view of the optical lens; Figure 3c is a vertical view of the optical lens; Figure 3d is an equiaxial side view of the optical lens.

In this embodiment, the optical lens is a circular lens and comprises reflective surface 31 and light exit surface 32. As shown in Figures 3a and 3b, the reflective surface comprises the first convex surface 311, light distribution camber 312, transition camber 313 and reflective camber 314. As shown in Figures 3a, 3c and 3d, the light exit surface comprises the second convex surface 321, Fresnel annular surface 322 and surface 323. Flange 33, which is used for fixing other devices, can be set up at the periphery of the reflective surface and the light exit surface. It has no impact on optics and may assume any shape.

The first convex surface 311 is located in the central position of the reflective surface 31 of the optical lens, and is used for collecting the light emitted from LED chip and converging the light onto the vertex of the second convex surface 321. The light distribution camber 312 is a rotary cambered surface centered at the central position of the reflective surface 31 and revolving round the first convex surface 311, and is used for evenly distributing the light emitted from LED chip to the Fresnel annular surface 322 and the surface 323. The transition camber 313 is a non-optical surface and a rotary cambered surface revolving round the light distribution camber 312 or a camber or conical surface of other kinds. The reflective camber 314 is a rotary cambered surface centered at the central position of the reflective surface 31 and revolving round the transition camber 314, and is used for reflecting the light incident on the reflective camber 314 to the surface 323 in collimation.

The second convex surface 321 is located at the central position of the light exit surface 32 and opposite to the first convex surface 311. It is used for reflecting the light converged at the vertex of the second convex surface 321. The Fresnel annular surface 322 is centered at the central position of the light distribution surface 32. It revolves round the second convex surface 321 and is used for reflecting the incident light distributed by the light distribution camber 312 in collimation. The surface 323 is centered at the central position of the light distribution surface 32. It revolves round the Fresnel annular surface

322 and is used for wholly reflecting the incident light distributed by the light distribution camber 312 to the reflective camber 314.

Wherein, the first convex surface 311 is right in the center of the reflective surface. The first convex surface 311 coincides with the focal plane of the second convex surface 321 on the light exit surface. The first convex surface 311 and the second convex surface 321 meet the conditions for Kohler illumination, that is, the first convex surface 311 forms the image of the light-emitting surface of LED chip at the vertex H of the second convex surface 321, and the shape of the optical pupil of the first convex surface 311 is projected to a distant place through the second convex surface 321. As shown in Figure 4, the light emitted from the central position O of the light-emitting surface of LED chip at a smaller angle with the optical axis OZ of the optical lens (the optimal maximum angle between the light and the optical axis OZ is  $\pm 15^\circ$  in the present invention) is collected by the first convex surface 311. It is then refracted and focused at the vertex H of the second convex surface 321 before being projected outward. The shape of the faculae reflected from the second convex surface 321 is that of the aperture of the first convex surface 311, which is round. The setup of the said first convex surface 311 and the second convex surface 321 avoids square faculae reflected due to the shape of the chip. As for the faculae reflected from the second convex surface 321, the tangent value of the semi-angle of their beams is equal to the ratio of the half of the aperture of the convex surface 11 to the focus of the convex surface 321, which is within the range of  $\pm 10^\circ$ - $20^\circ$ . The optimal beam angle here is  $\pm 15^\circ$ . The beams reflected from the first convex surface 311 and the second convex surface 321 are used as ambient light.

The light distribution camber 312 distributes the part of light emitted from the central position O of the light-emitting surface of LED chip and forming a big angle with the optical axis OZ of the optical lens (the optimal maximum angle between this part of light and the optical axis OZ is  $\pm 15^\circ$ - $\pm 90^\circ$  in the present invention), and the distributed beams are incident on the Fresnel annular surface 322 and the surface 323 at the vertex of the optical lens. As shown in Figure 5, to facilitating the explanation of the light distribution principle of the light distribution camber 312, assuming that the light distribution camber 312 extends to OZ axis, i.e. the first convex surface 311 in the middle is ignored, the angle between the light emitted from LED and the optical axis OZ is  $\theta_1$ , and after light distribution by the light distribution camber 312, the angle between the refracted light and the optical axis OZ is  $\theta_2$  (light distribution angle), then when  $\theta_1$  varies between  $0^\circ$  and  $90^\circ$ , the light distribution at  $\theta_2$  meets the following tangent conditions:

$$\theta_2 = \tan^{-1}\left(\frac{\theta_1}{90} \cdot \tan \theta\right)$$

Of which,  $\theta$  is the angle between the periphery of the surface 323 to the center O of the light-emitting surface of LED chip (or the central position of the reflective surface) and OZ axis.

The main purpose of satisfaction of the said tangent conditions is to relatively evenly distribute  $0$ - $90^\circ$  beams emitted from LED at the aperture occupied by the surface 323.

In this embodiment, if the angle between the periphery of the surface 323 to the center O of the light-emitting surface of LED chip (or the central position of the reflective surface) and OZ axis is about  $65^\circ$ , the light distribution at  $\theta_2$  meets the following tangent conditions:

$$\theta_2 = \tan^{-1}\left(\frac{\theta_1}{90^\circ} \cdot \tan 65^\circ\right)$$

As shown in Figure 6, when the light reflected from LED varies between  $0^\circ$  and  $90^\circ$ , the refracted light after light distribution by the light distribution camber 312 will be wholly distributed between  $0^\circ$  and  $65^\circ$  according to the aforesaid tangent conditions.

After light distribution by the light distribution camber 312, the beams are incident on the Fresnel annular surface 322 and the surface 323 on the light exit surface of the optical lens. Of which, the Fresnel annular surface 322 will directly reflect the light with a small incident angle in collimation, as shown in Figure 7.

Since the remaining beams have a relatively big incident angle, the light that meets the conditions for total reflection will be wholly reflected by the surface 323, and then be incident on the reflective camber 314 at the bottom of the optical lens, and then be reflected by the reflective camber 314 and finally be reflected from the surface 323, as shown in Figure 7. In another embodiment, a reflective coating can be put on the surface 323, to reflect the incident light to the reflective camber 314.

Of which, because the light incident on the reflective camber 314 has a relatively small incident angle and does not meet the conditions for total reflection, the reflective camber 314 needs to undergo certain technical process so that it can reflect the light to the surface 323.

In the implementation of the embodiment, the reflective camber 314 may be plated with the reflective coating, so that this part of light will be reflected again and then be reflected from the surface 323 in collimation. However, the adoption of the plating process will increase the cost of production; in addition, the reflective coating is easily to come off in the adverse environment with strong alkaline and acid at mining areas.

Of course, other processes may be adopted to realize total reflection of the incident light by the reflective camber 314. For example, a micro-roof prisms array is set up at the reflective camber 314. These micro-roof prisms of the same structure are centered on the center O of the light-emitting surface of LED chip (or the central position of the reflective surface 31) and arranged rotationally in a 360 degree. The said roof prisms array is used for reflecting the light incident on the reflective camber 314 to the surface 323 in collimation. All the micro-roof prisms are of the same right-angled V-shaped groove structure. The light incident on the roof prisms is wholly reflected to the two sides of the right-angled V-shaped groove structure, then is incident on the surface 323 in collimation, and then is reflected from the surface 323 in collimation.

Refer to Figures 8a-8b for the principle of total reflection of the light in the micro-roof prisms. Take the example of a roof prism, the cross section of the right-angled V-shaped groove structure is a right-angled triangle; the vertex of the right angle is located at the reflective camber 314 and the two edges of the right angle are located on the two sides of the right-angled V-shaped groove structure. The contour of the section Q1P1R1 perpendicular to the V-shaped groove structure is a right-angled triangle, the included angle  $\angle Q1P1R1$  at the bottom is a  $90^\circ$  right angle. Therefore, the light BC1 incident on the reflective camber 314 can undergo twice total reflections inside the roof prism of the right-angled V-shaped groove structure; first, the light will be wholly reflected by the first side P1Q1Q2P2 of the roof prism (the reflected light is C1C2); then, the light will be wholly reflected by the second side P1R1R2P2 of the roof prism (the reflected light is C2D); finally, this reflected light will be reflected from the surface 323 in collimation.

This roof prisms array can realize 100% total reflection in theory, without loss of optical energy. The angular spacing between the two adjacent micro-roof prisms may be  $0.5^{\circ}$ - $10^{\circ}$ . The angular spacing is that when the micro-roof prisms are arranged rotationally centered around the optical axis OZ, the angle formed between the ridge lines of two adjacent roof prisms revolving round the optical axis OZ. Optimally, the angular spacing between the two adjacent micro-roof prisms is  $1^{\circ}$  in the present invention.

Figure 9 shows the image of faculae at 1m away from a miner's helmet lamp equipped with an optical lens in an embodiment of the present invention. It can be seen from the Figure that the faculae are very clean and transited gently and do not have any stray light. The faculae comprise a very bright round facula in the center and a relatively dark round facula around the periphery of the bright facula. Of which, the very bright facula in the center is produced by the reflective camber 314 in which a micro-roof prisms array is set up. The relatively dark round facula around the periphery of the bright facula is produced by the first convex surface 311, the second convex surface 321 and the Fresnel annular surface 322 on the optical lens.

Below is the computer simulation of an optical lens in an embodiment of the present invention. Supposing LED is Philips's Luxeon Rebel DS56 LED and the flux of the single LED is 90 Lumen. Figure 10 is a ray tracing diagram of an optical lens in an embodiment of the present invention. Figure 11 is an illuminance distribution diagram at 1m away. It can be seen from the diagrams that the faculae are round, about  $\phi 100\text{mm}$ . The maximum illuminance on the screen is 16100.2187 Lux and the flux collected on the screen is 77.2796469135825820 Lumen. That is, the optical efficiency of the lens is:

$$\eta = 77.2796469135825820 / 90 \cdot 100\% = 85.8662743484250911111111111111\%.$$

Figure 12 is a diagram of far-field angular distribution of light intensity in an embodiment of the present invention, i.e. light distribution curve. The width of the beam angle at the half of the peak light intensity is about  $\pm 1.7^{\circ}$ . Figure 13 is a diagram of actually tested light distribution curve of a miner's helmet lamp equipped with an optical lens in an embodiment of the present invention. The regulated electric current is 105mA. The full beam angle of the faculae measured at the half of the peak light intensity is about  $3.3^{\circ}$ .

By the adoption of the aforesaid structure, the optical lens in the embodiments of the present invention realizes output of beams at a narrow angle, and the lens is thin and light with a large diameter. A single LED lamp is good enough to meet the illuminance requirement and support long periods of operation. This optical lens does not need a reflective coating, as the reflective coating may easily come off, get rusty or corrode in the adverse environment with strong alkaline and acid.

The embodiments of the present invention also provide a kind of miner's helmet, which comprises a light source component and an optical lens fixed outside the light source component. The said light source component may be LED. The said optical lens may be any optical lens described in the aforesaid embodiments. Please refer to the aforesaid embodiments for details.

The embodiments of the present invention described above shall in no way confine the scope of protection for the present invention. Any modification or equivalent replacement or improvement made in the spirit and principle of the present invention shall be included in the scope of protection for the claims regarding the present invention.

**Claims**

1. A kind of optical lens, characterized by the fact that it comprises a reflective surface and a light exit surface; wherein, in a circle with the central position of the said reflective surface as its center, at least a light distribution camber and a reflective camber are set up along the radius direction of the said reflective surface; in a circle with the central position of the said light exit surface as its center, at least a Fresnel annular surface and a surface are set up along the radius direction of the said light exit surface;

the said light distribution camber is used for refracting the light incident on the said reflective surface to the said Fresnel annular surface and the said surface;

the said reflective camber is used for reflecting the light incident on the said reflective camber to the said surface in collimation;

the said Fresnel annular surface is used for reflecting the light incident on the said Fresnel annular surface through the said light distribution camber from the said light exit surface in collimation;

the said surface is used for wholly reflecting the incident light through the said light distribution camber to the said reflective camber and for reflecting incident light through the said reflective camber from the said light exit surface in collimation.

2. The optical lens described in Claim 1, characterized by the fact that there is a first convex surface in the central position of the said reflective surface and a second convex surface in the central position of the said light exit surface; the said first convex surface and the said second convex surface meet the conditions for Kohler illumination.
3. The optical lens described in Claim 1, characterized by the fact that the distribution of the light incident on the said light distribution camber by the said light distribution camber meets the following tangent conditions:

$$\theta_2 = \tan^{-1} \left( \frac{\theta_1}{90} \cdot \tan \theta \right)$$

wherein,  $\theta_1$  is the angle between the light incident on the said light distribution camber and the central optical axis of the said optical lens;  $\theta_2$  is the angle between the light incident on the said light distribution camber refracted from the said light distribution camber and the central optical axis of the said optical lens;  $\theta$  is the angle between the periphery of the said surface to the central position of the reflective surface of the said optical lens and the central optical axis of the said optical lens.

4. The optical lens described in Claim 3, characterized by the fact that the said  $\theta$  is  $65^\circ$ .
5. The optical lens described in Claim 1, characterized by the fact that there is a roof prisms array on the said reflective camber; the said roof prisms array is centered on the central position of the said reflective surface and arranged rotationally at 360 degree; the said roof prisms array is used for reflecting the light incident on the said reflective camber to the said surface in collimation.

6. The optical lens described in Claim 5, characterized by the fact that the said roof prisms are of a right-angled V-shaped groove structure; the light incident on the said roof prisms is wholly reflected to the two sides of the said right-angled V-shaped groove structure and then incident on the said surface in collimation; the cross section of the said right-angled V-shaped groove structure is a right-angled triangle; the vertex of the right angle is located at the said reflective camber and the two edges of the right angle are located on the two sides of the said right-angled V-shaped groove structure.
7. The optical lens described in Claim 5, characterized by the fact that the angular spacing between the two adjacent roof prisms is  $0.5^{\circ}$ - $10^{\circ}$ .
8. The optical lens described in Claim 7, characterized by the fact that the angular spacing between the two adjacent roof prisms is  $1^{\circ}$ .
9. A kind of miner's helmet lamp, characterized by the fact that it comprises any optical lens described in Claims 1 through 8 and a light source component.
10. The miner's helmet lamp described in Claim 9, characterized by the fact that the said light source component is a single LED lamp.

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Patent Attorneys for the Applicant/Nominated Person  
SPRUSON & FERGUSON

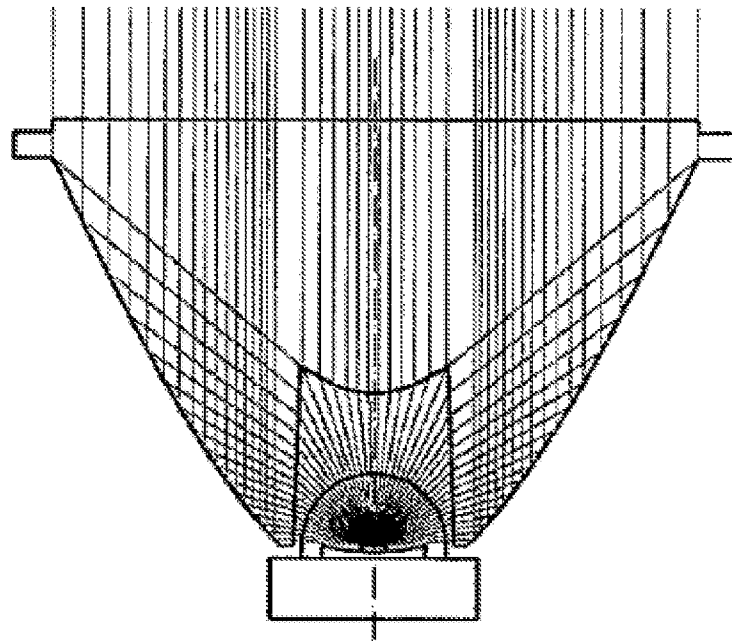


FIGURE 1

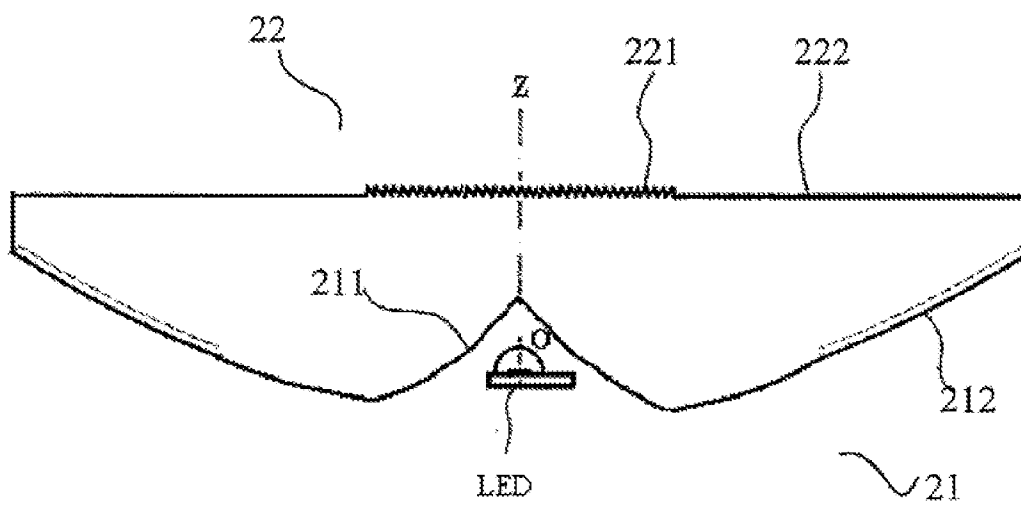


FIGURE 2

-2/9-

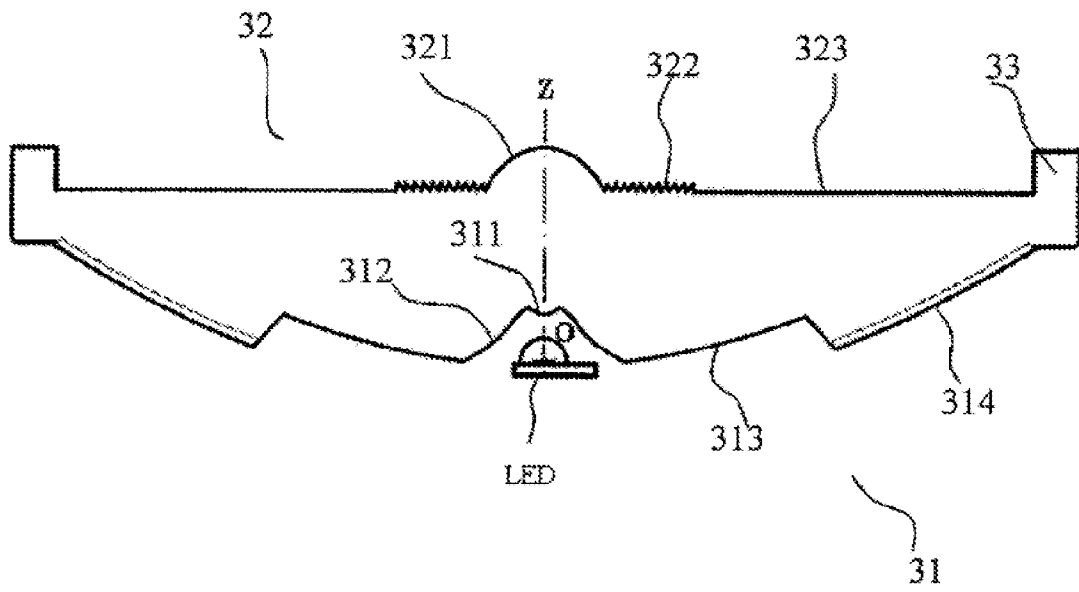


FIGURE 3A

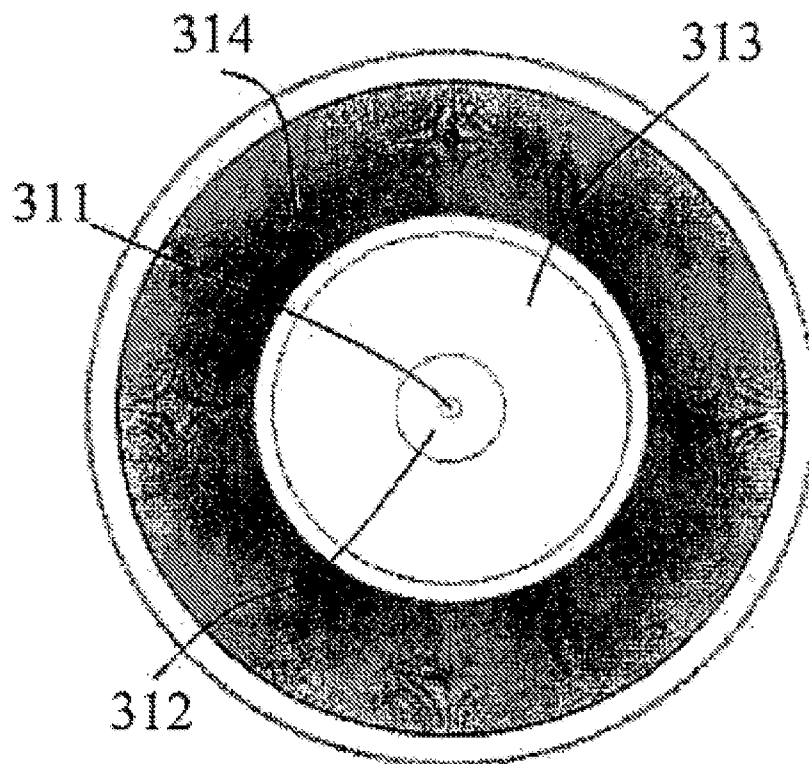


FIGURE 3B

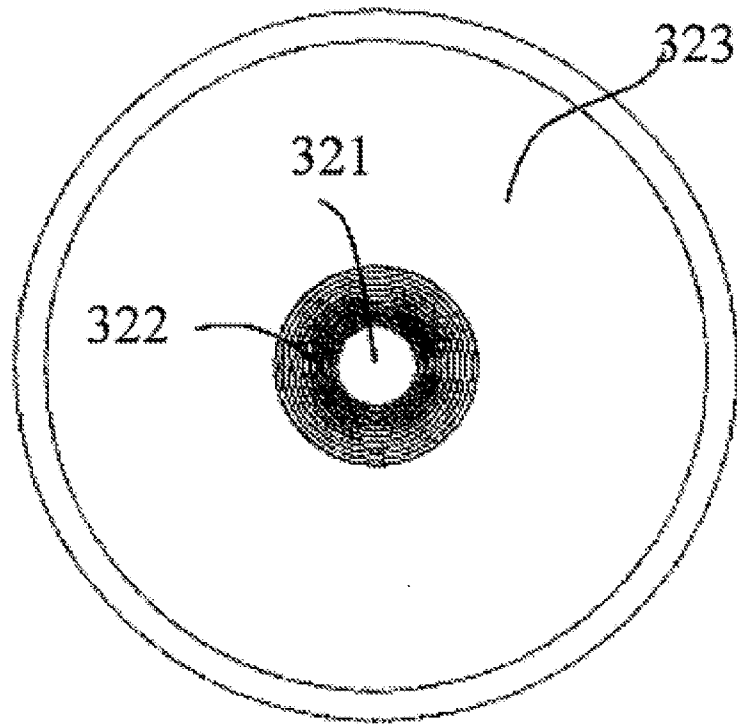


FIGURE 3C

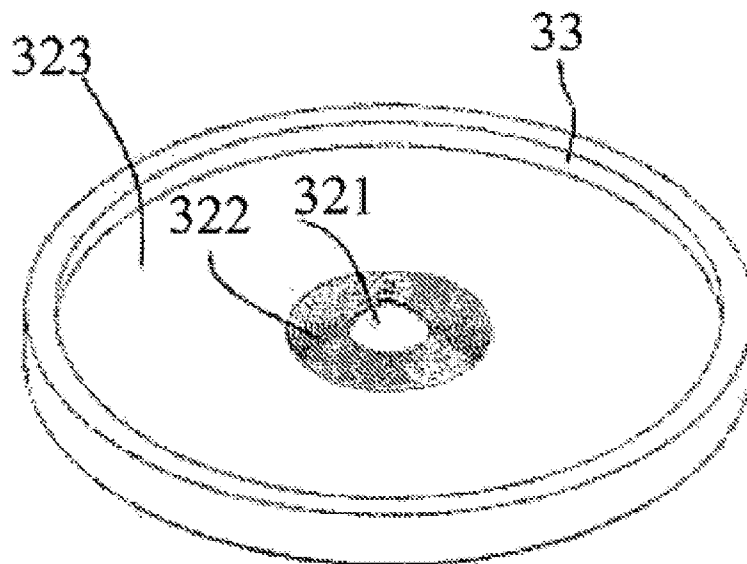


FIGURE 3D

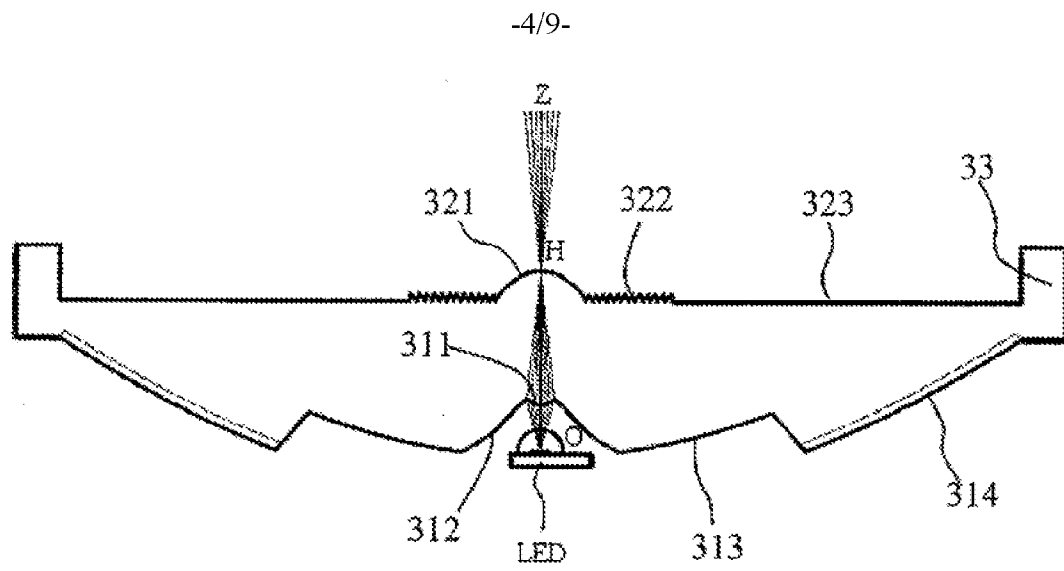


FIGURE 4

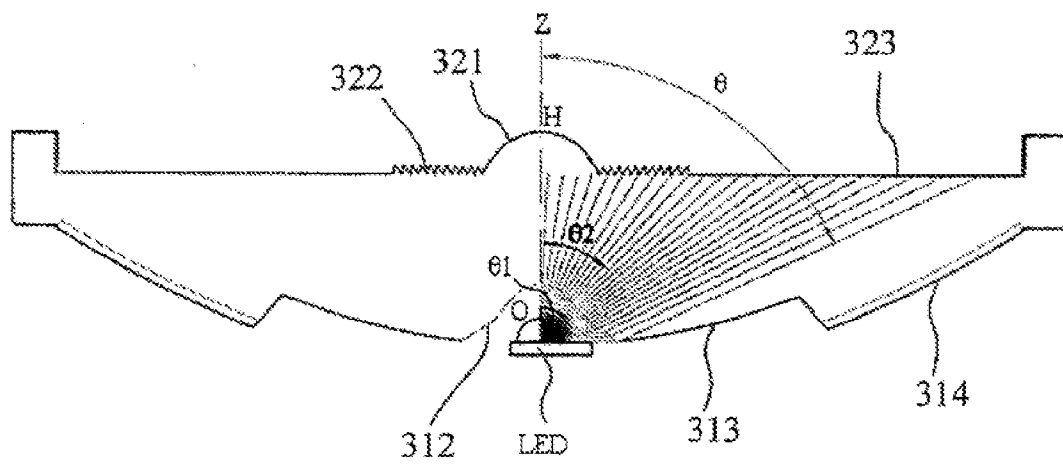


FIGURE 5

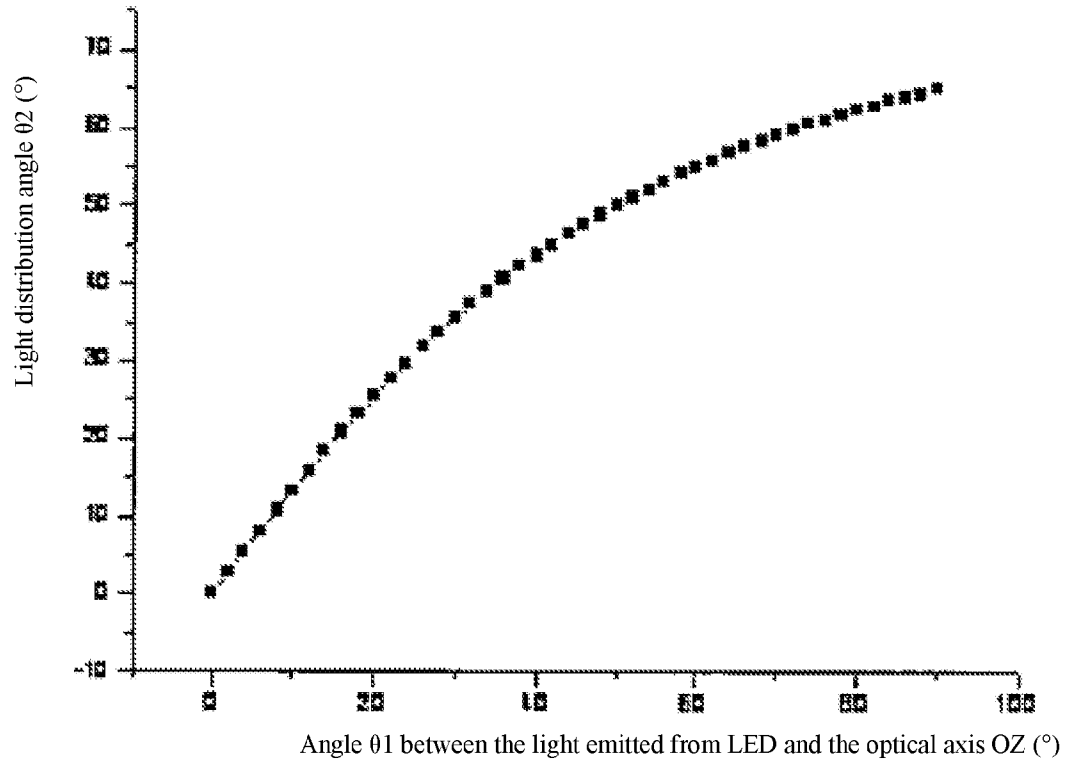


FIGURE 6

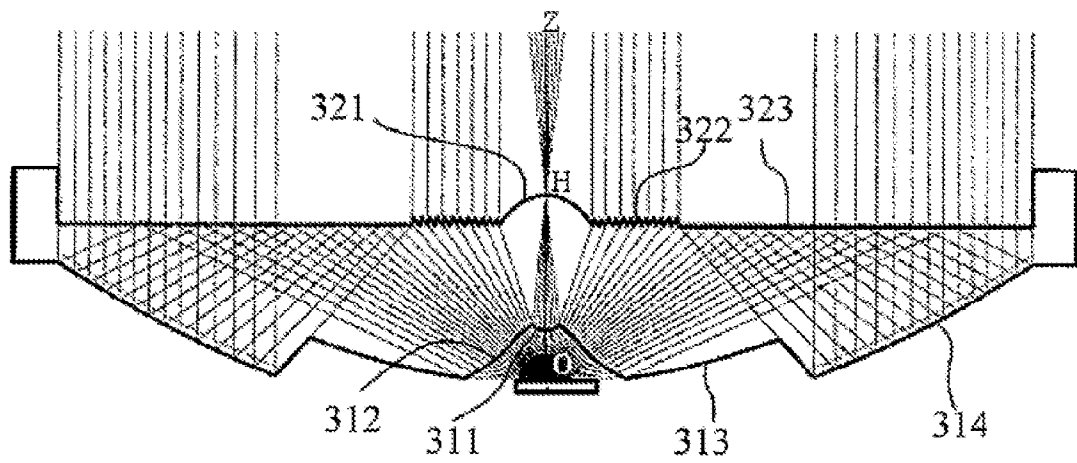


FIGURE 7



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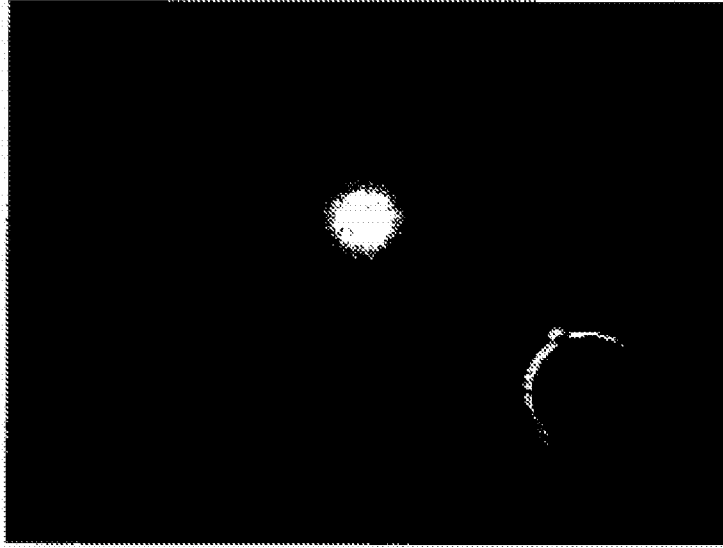


FIGURE 9

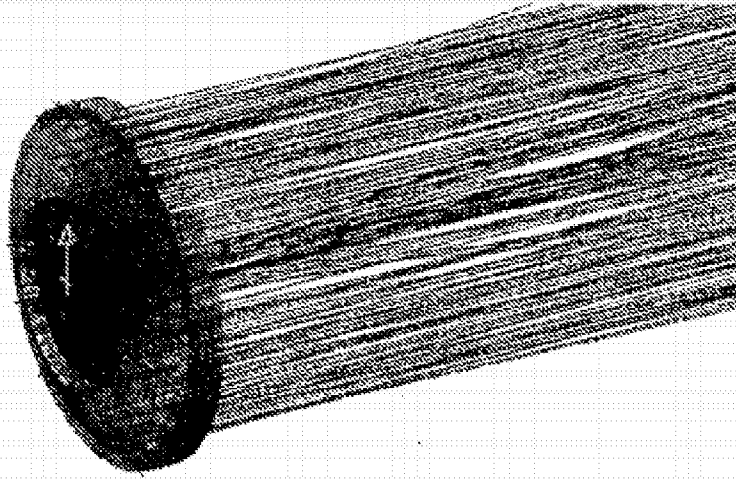


FIGURE 10

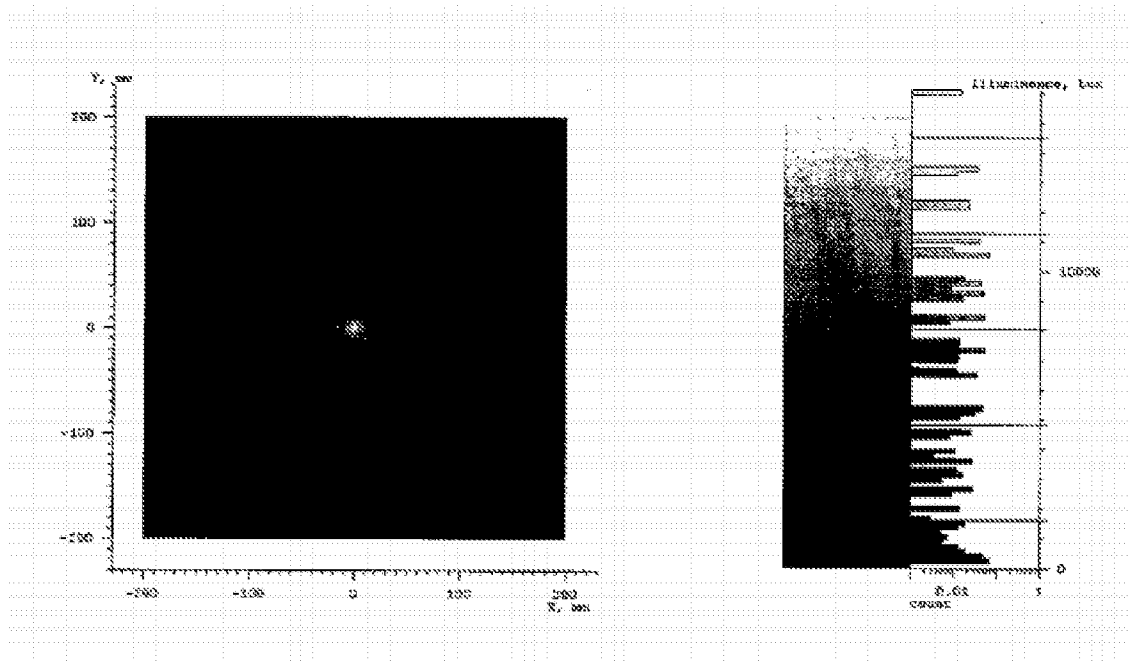


FIGURE 11

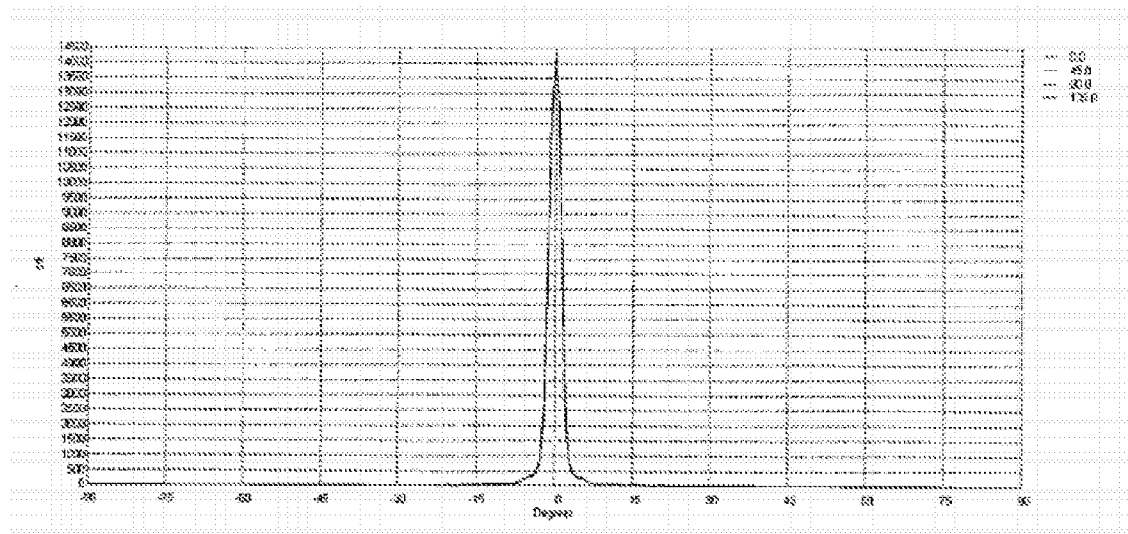


FIGURE 12

Testing results of far-field angular distribution (March 23, 2012); maximum light intensity: 6,635cd; beam angle: 3.3°

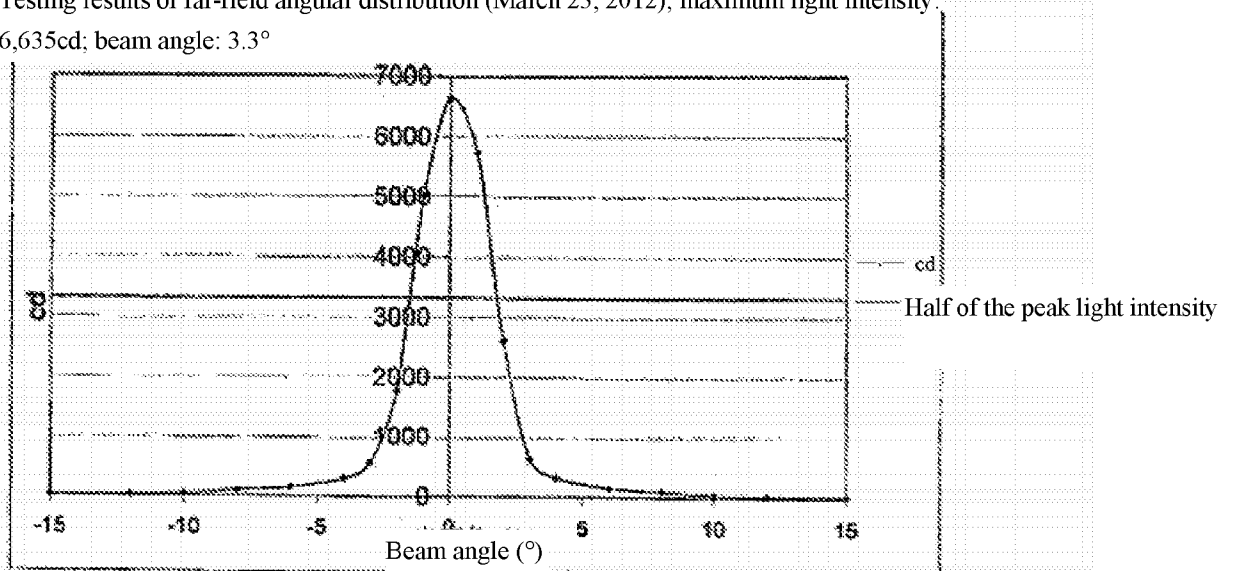


FIGURE 13