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Rizkin et al.

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(54) **HIGHLY EFFICIENT LED ARRAY MODULE WITH PRE-CALCULATED NON-CIRCULAR ASYMMETRICAL LIGHT DISTRIBUTION**

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(22) Filed: **Apr. 8, 2011**

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Related U.S. Application Data

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(51) **Int. Cl.**
F21V 7/00 (2006.01)

(52) **U.S. Cl.**
USPC **362/346**; 362/237; 362/298

(58) **Field of Classification Search**
USPC 362/235, 237, 241, 296.01, 297, 362/298, 346
See application file for complete search history.

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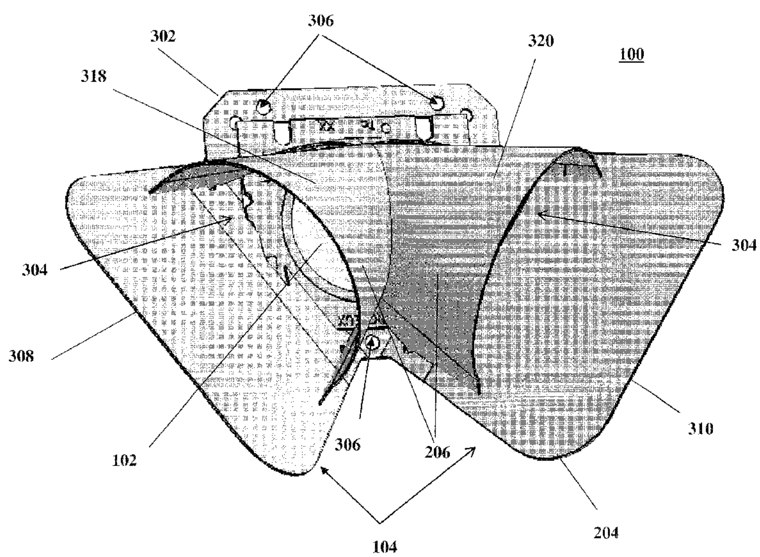
(57) **ABSTRACT**

A light module includes a light emitting diode (LED) array and a double-reflective assembly coupled to the LED array. The double-reflective assembly includes a lower member having a frame. The frame has an opening corresponding to the LED array. The frame and LED array are located in the same plane. The light module further includes a left bottom reflector and a right bottom reflector. The light module further includes an upper member which includes a left top reflector; and a right top reflector, wherein the left top reflector is attached to the left bottom reflector, and right top reflector is attached to the right bottom reflector, each forming an arbitrary left and right double-reflective assembly. A shape geometry and profile of each double-reflective assembly provides a pre-calculated combined non-circular asymmetrical intensity distribution pattern. The intensity distribution pattern is a superposition of light reflected from the bottom reflectors, light reflected from the top reflectors, light doubly reflected from both the top and bottom reflectors, and light directed into the intensity distribution pattern directly from the LED array.

16 Claims, 12 Drawing Sheets



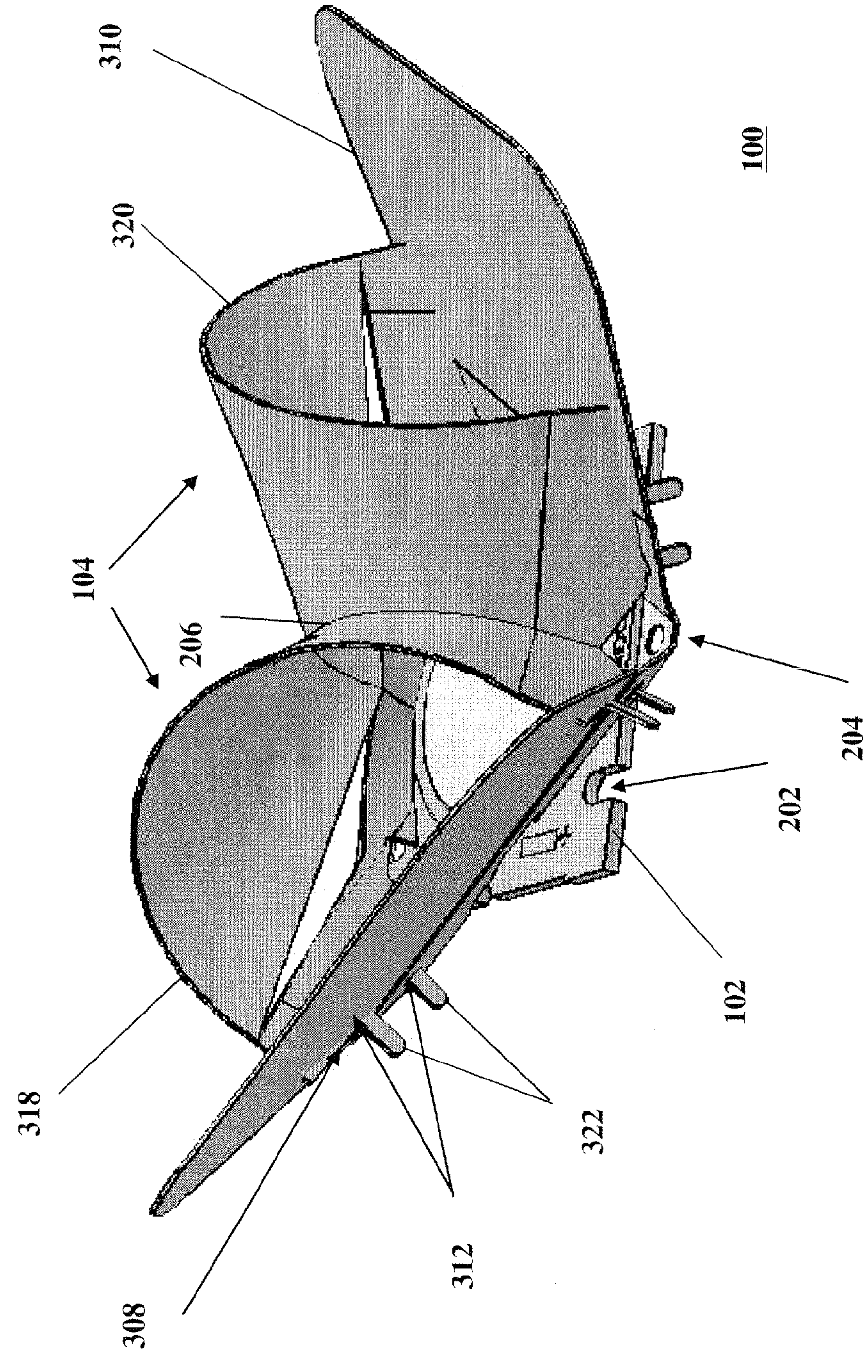


FIG. 1A

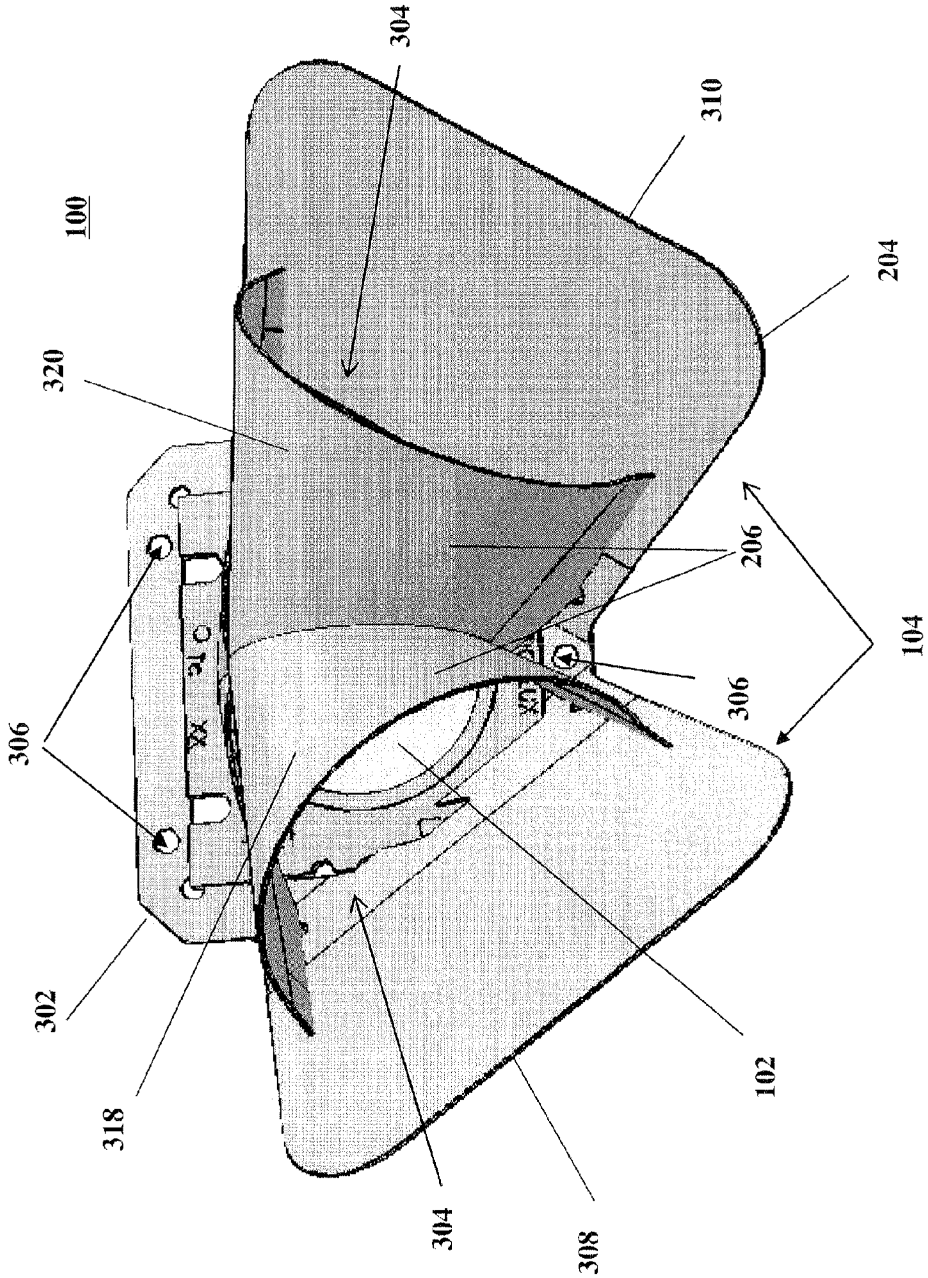


FIG. 1B

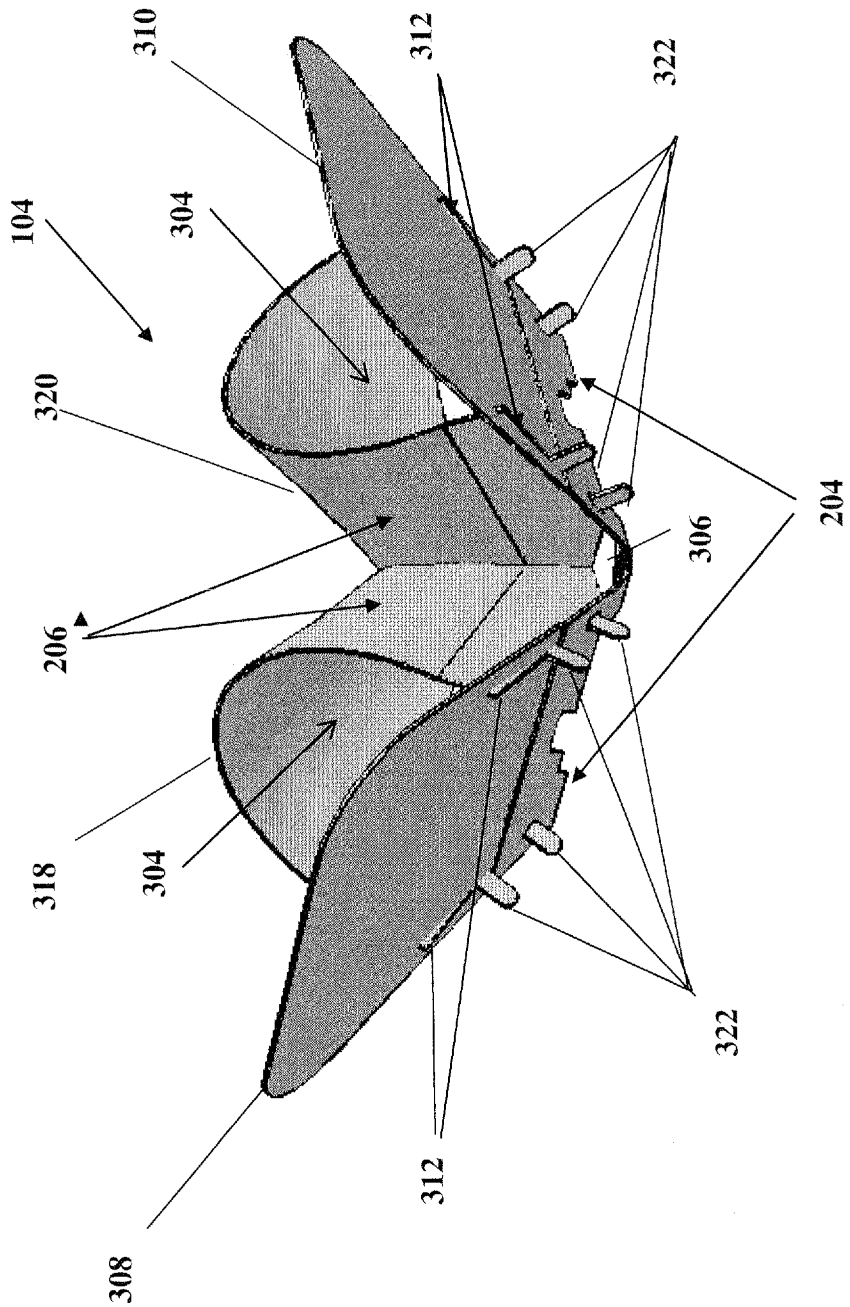


FIG. 2A

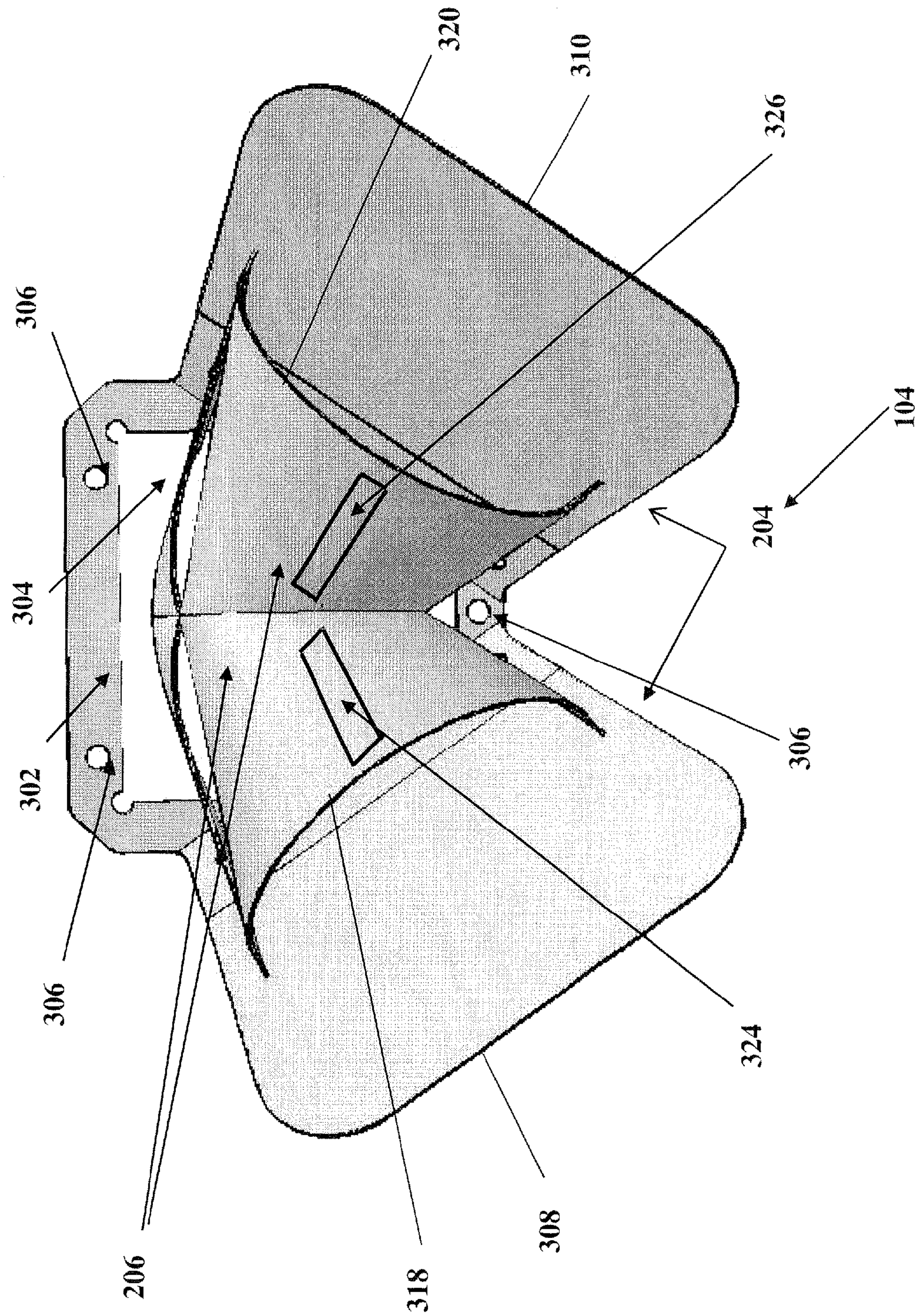


FIG. 2B

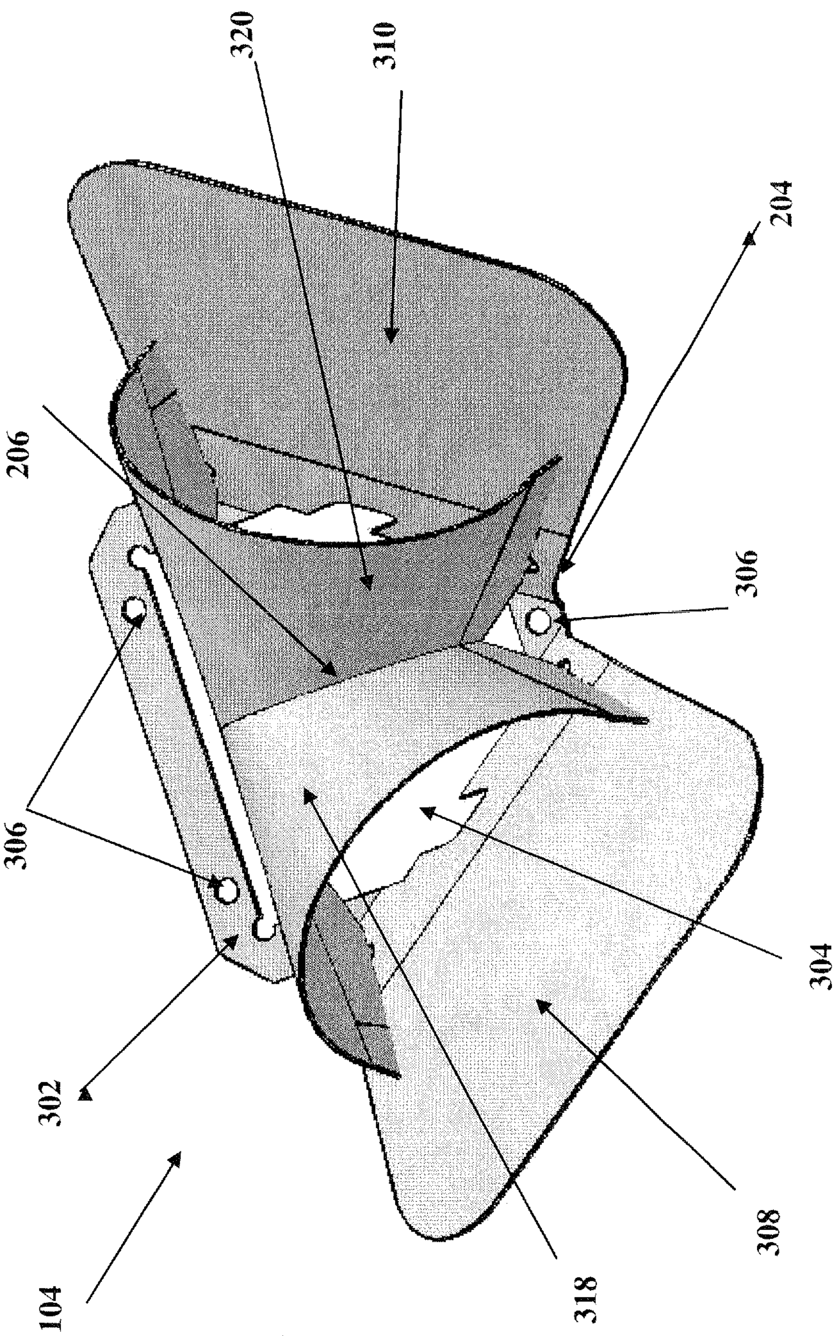


FIG. 3

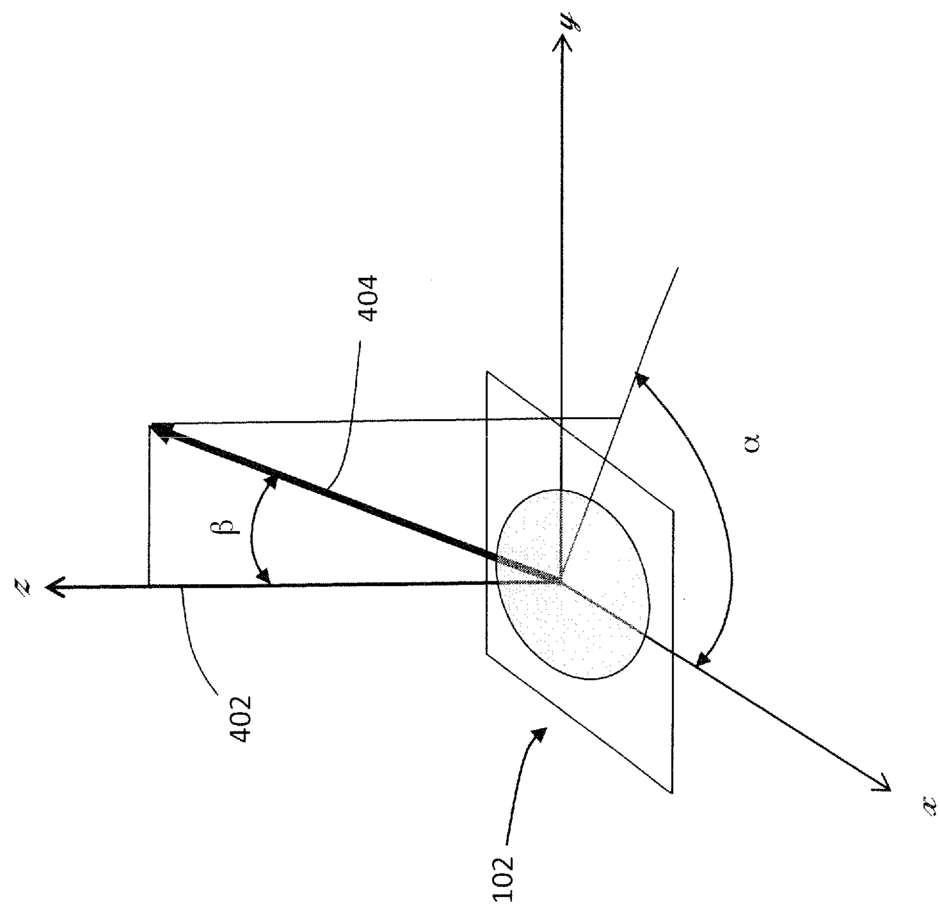


FIG. 4

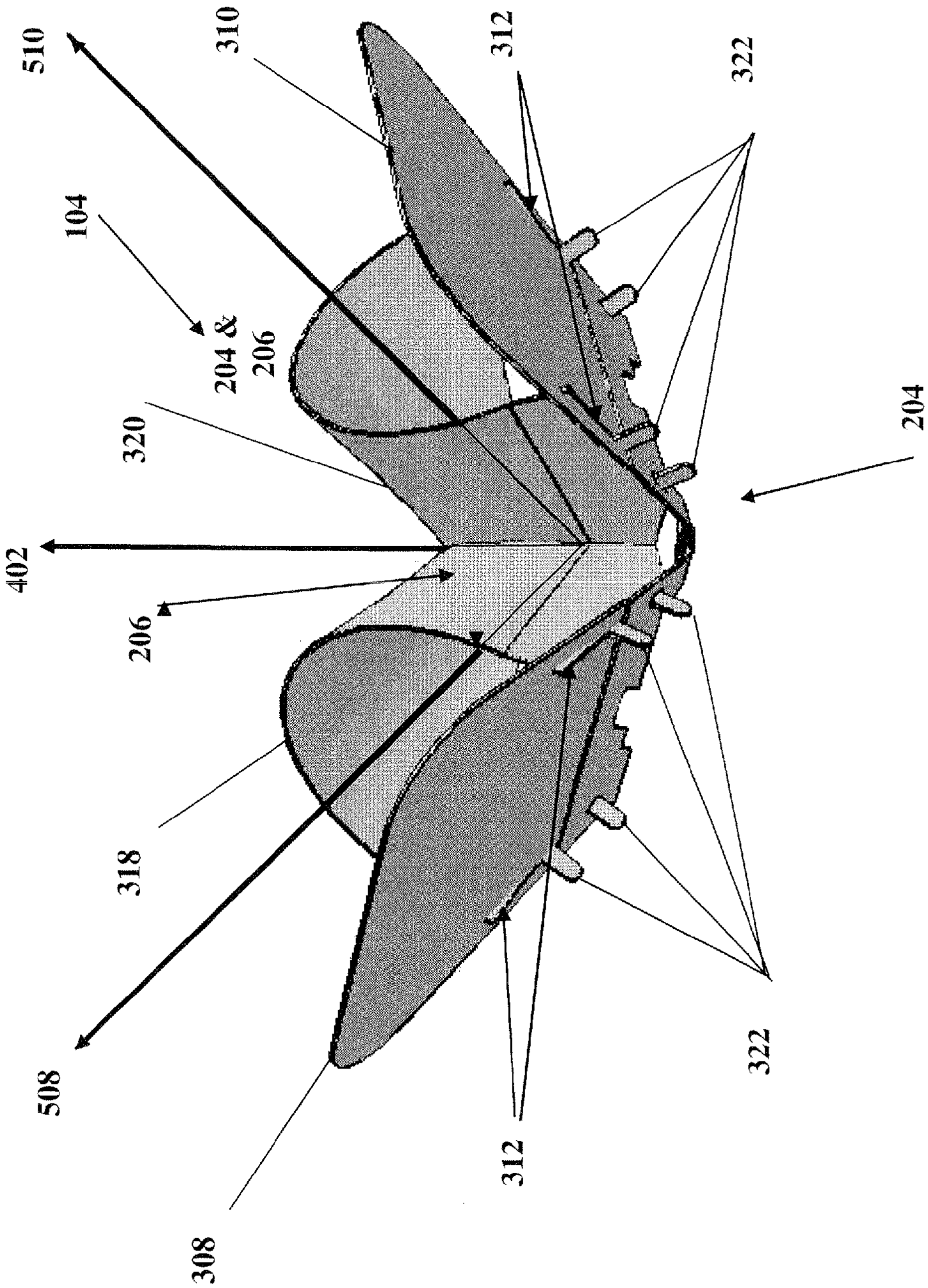


FIG. 5A

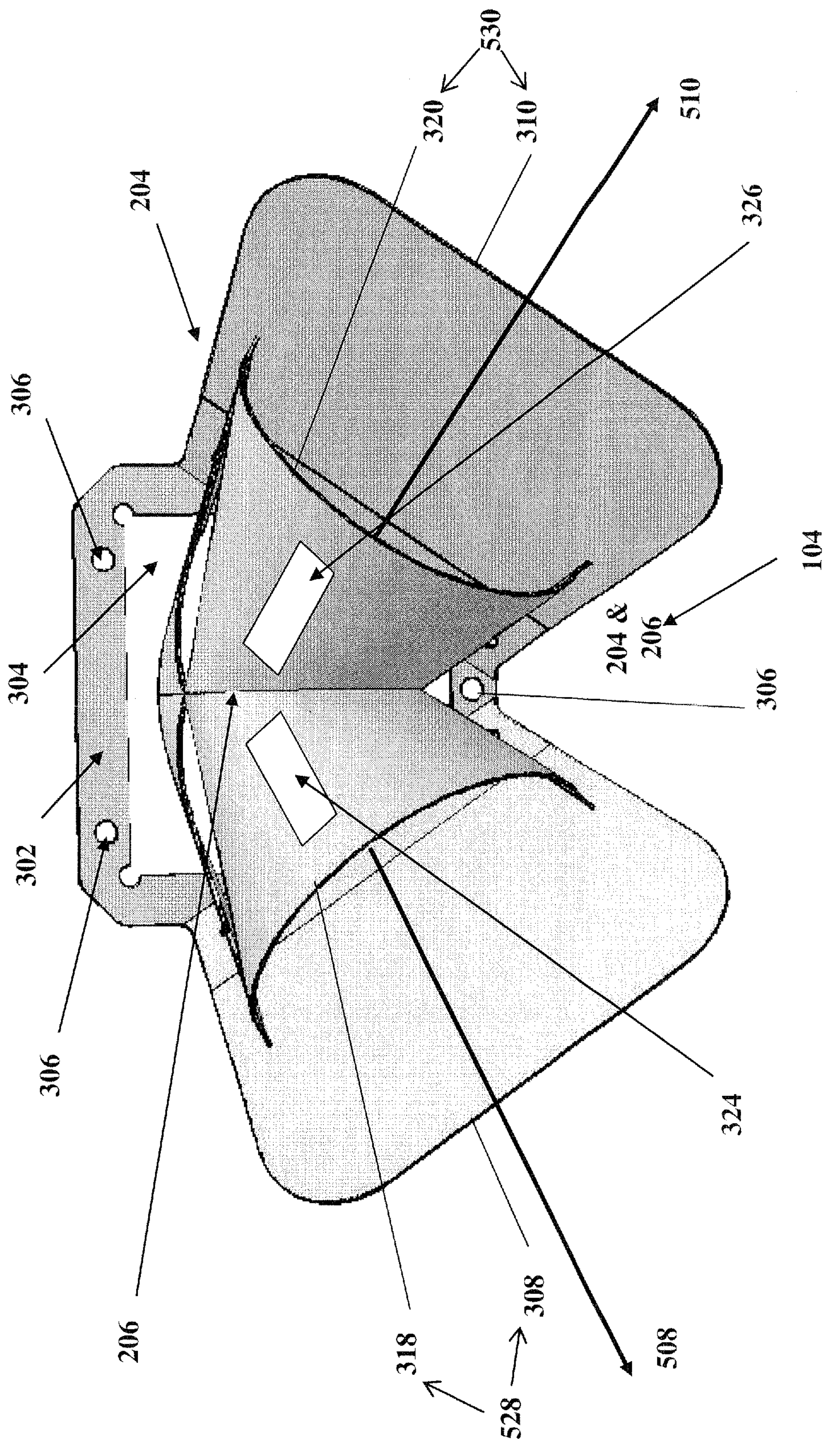
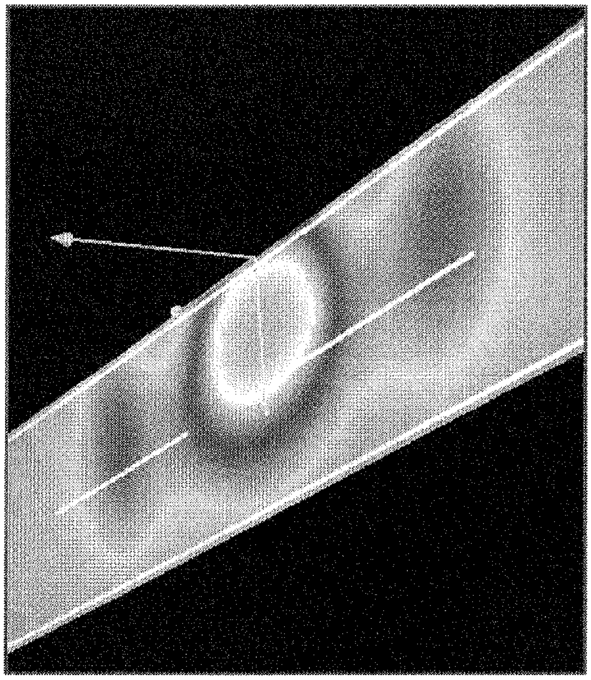

530
320
310
510
204
326
306
304
104
204 &
206
306
302
306
324
206
318
308
508
528

FIG. 5B



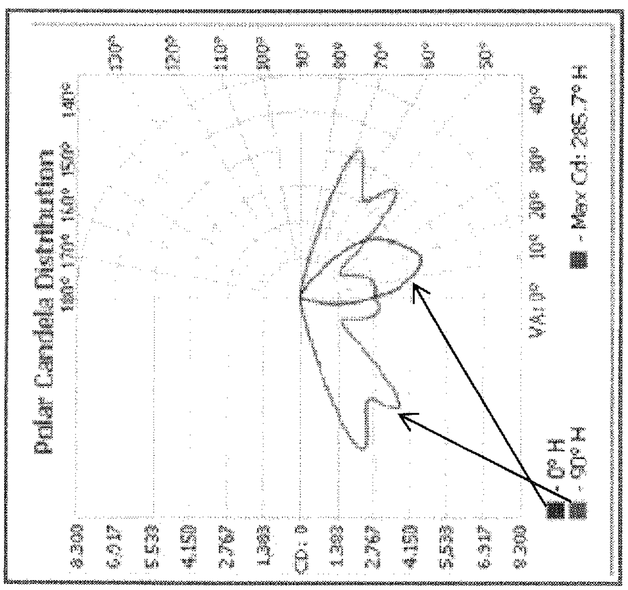


FIG. 6

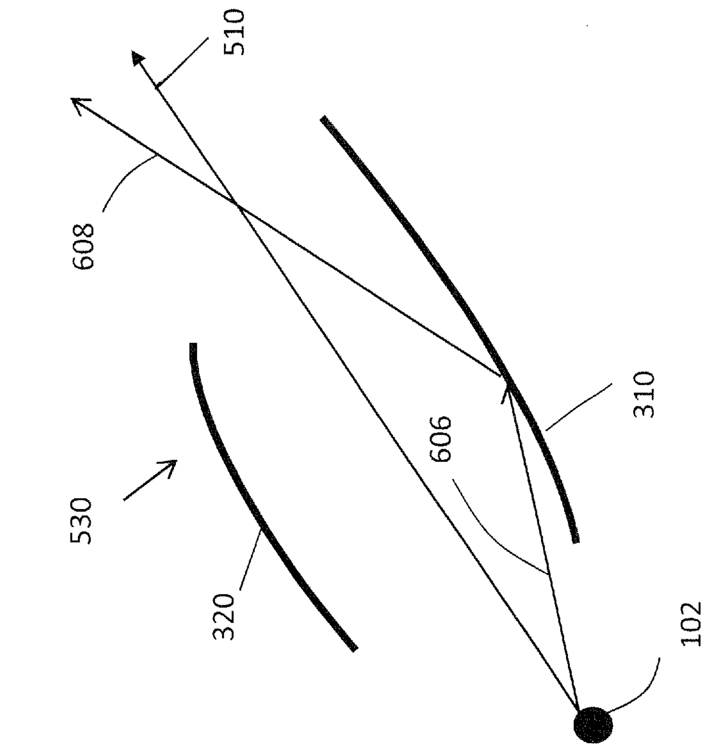


FIG. 7B

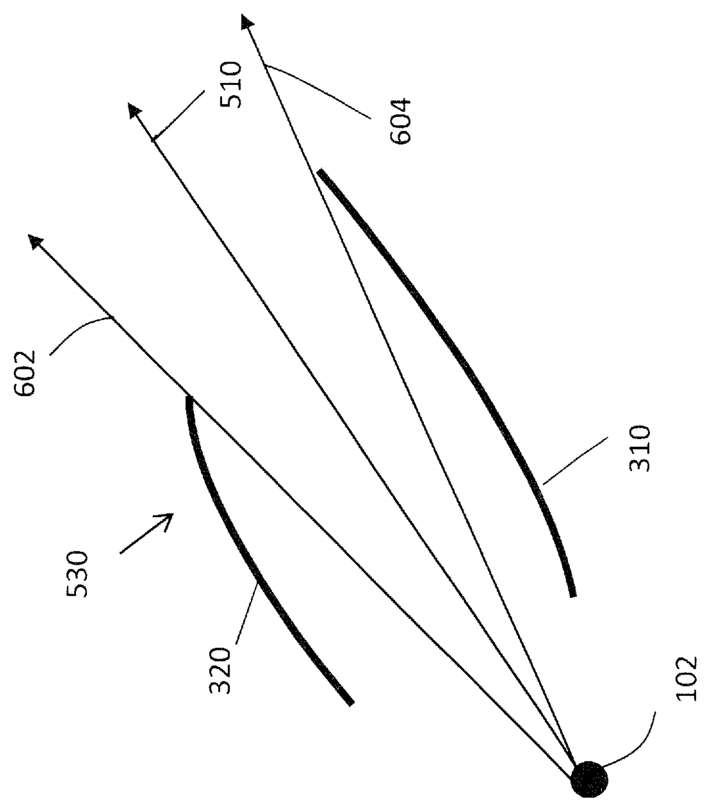


FIG. 7A

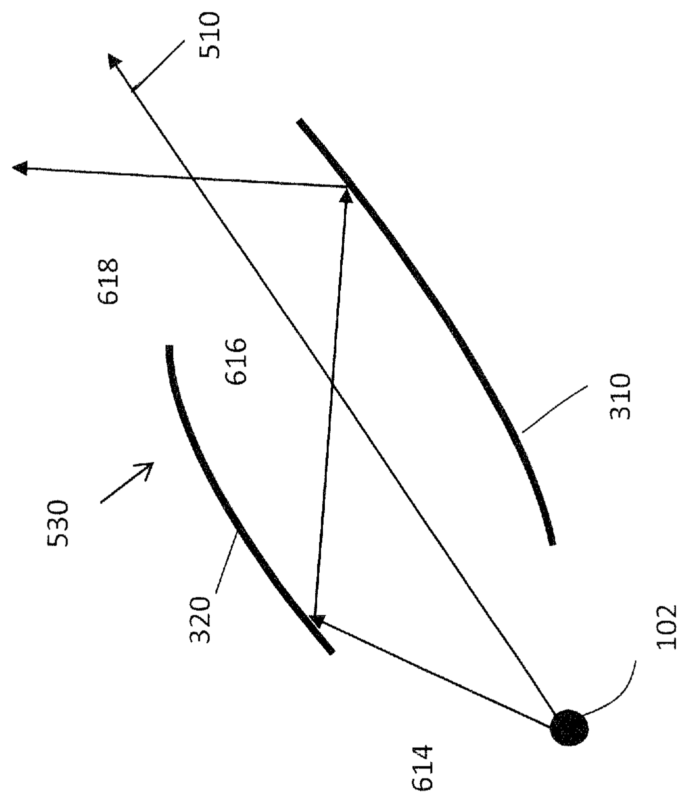


FIG. 7D

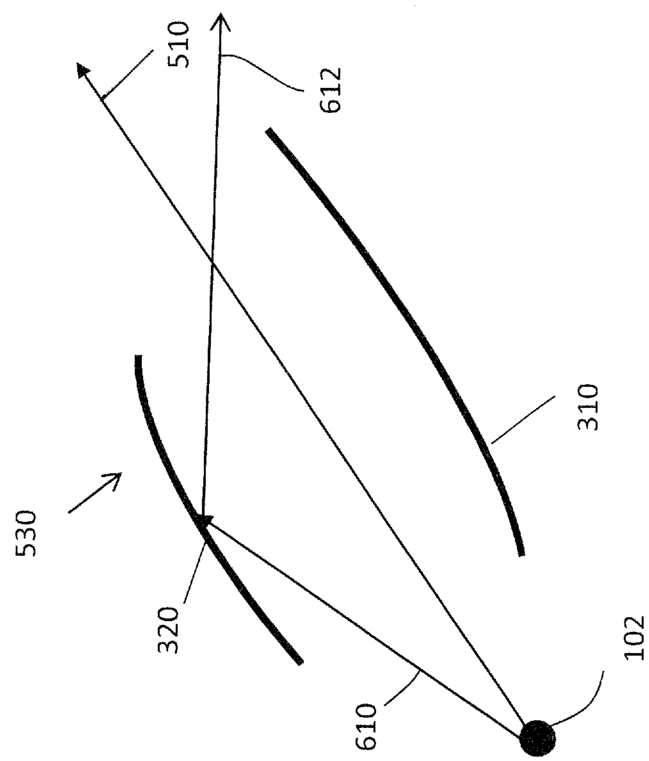


FIG. 7C

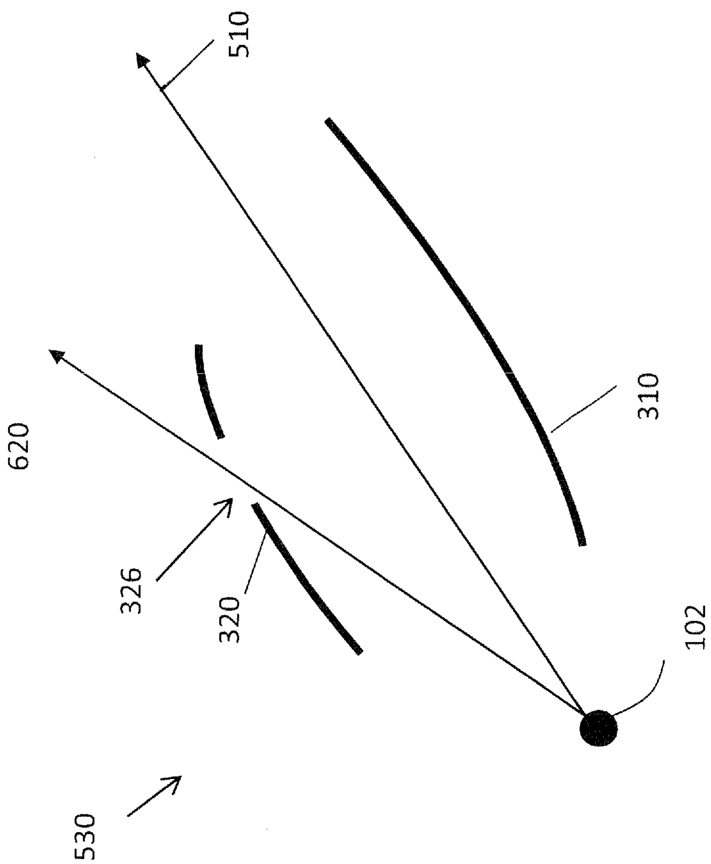


FIG. 7E

HIGHLY EFFICIENT LED ARRAY MODULE WITH PRE-CALCULATED NON-CIRCULAR ASYMMETRICAL LIGHT DISTRIBUTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 61/322,756, titled "HIGHLY EFFICIENT LED ARRAY MODULE WITH PRE-CALCULATED NON-CIRCULAR ASYMMETRICAL LIGHT DISTRIBUTION," filed Apr. 9, 2010, which is hereby incorporated by reference its entirety.

BACKGROUND

1. Field

The present disclosure relates to a light module and, more particularly, to a light emitting diode (LED) array optical module based on a double-reflective element concept.

2. Description of Related Art

Light modules have been developed for various applications, but most of them have been addressed to a single source reflective module, which creates a roughly circular pattern but provide an uneven light distribution pattern.

SUMMARY

In an aspect of the disclosure set forth herein, a light module includes a LED array, a double-reflective assembly coupled to the LED array, where the double-reflective assembly includes a lower member having a frame, wherein the frame has an opening corresponding to the LED array. The frame and LED array are located in the same plane. The light module further includes a left bottom reflector and a right bottom reflector. The light module further includes an upper member which includes a left top reflector; and a right top reflector, wherein the left top reflector is attached to the left bottom reflector, and right top reflector is attached to the right bottom reflector, each forming an arbitrary left and right double-reflective assembly, wherein a shape geometry and profile of each double-reflective assembly providing a pre-calculated combined non-circular asymmetrical intensity distribution pattern, wherein the intensity distribution pattern is a superposition of light reflected from the bottom reflectors, light reflected from the top reflectors, light doubly reflected from both the top and bottom reflectors, and light directed into the intensity distribution pattern directly from the LED array.

In yet another aspect of the disclosure set forth herein, a method of forming a pre-determined non-circular asymmetrical light distribution pattern in a plane of illumination, includes emitting light from a LED array, and reflecting a portion of the emitted light from a double-reflective array assembly, wherein the double-reflective assembly includes a lower member comprising a frame, the frame having an opening corresponding to the LED array, wherein the frame and LED array are located in the same plane, wherein the lower member further includes a left bottom reflector and a right bottom reflector; wherein the double-reflective assembly further includes an upper member comprising a left top reflector and a right top reflector, wherein the left top reflector is attached to the left bottom reflector, and right top reflector is attached to the right bottom reflector, each forming an arbitrary left and right double-reflective assembly, wherein a shape geometry and profile of each double-reflective assembly providing a pre-calculated combined non-circular asymmetrical intensity distribution pattern, wherein the intensity distribution pattern is a superposition of light reflected from the bottom reflectors, light reflected from the top reflectors, light doubly reflected from both the top and bottom reflectors, and light directed into the intensity distribution pattern directly from the LED array.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure relates to a light emitting module that utilizes an array of light emitting devices including, for example, light emitting diodes (LEDs) as a light source and can create non-circular asymmetrical patterns with pre-calculated intensity distribution.

FIGS. **1**A-**1**B are perspective views of an exemplary light emitting module configured in accordance with one aspect of the light emitting device module disclosed herein. The light emitting module includes a double-reflective assembly shaped and arranged to produce the pre-calculated illumination pattern.

FIGS. **2**A-**2**B are side and front views, respectively, of the double-reflective assembly configured in accordance with one aspect of the light emitting device module disclosed herein.

FIG. **3** is a perspective view of the double-reflective assembly configured in accordance with one aspect of the light emitting device module disclosed herein.

FIG. **4** is a graphic representation of the relationship between orthogonal and polar coordinates in a light emitting device array module domain.

FIGS. **5**A-**5**B are another side and front views, respectively, of the double-reflective assembly that shows spatial orientation of optical axes.

FIG. **6** are charts illustrating a light dispersal pattern with non-circular asymmetrical light distribution.

FIGS. **7**A-**7**E are cross-sectional views of a right double-reflective component in a plane containing the optical z axis located perpendicular to x-y plane containing the light emitting device array module domain.

DETAILED DESCRIPTION

The present invention is described more fully hereinafter with reference to the accompanying drawings, in which various aspects of the present invention are shown. This invention, however, may be embodied in many different forms and should not be construed as limited to the various aspects of the present invention presented throughout this disclosure. Rather, these aspects are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. The various aspects of the present invention illustrated in the drawings may not be drawn to scale. Rather, the dimensions of the various features may be expanded or reduced for clarity. In addition, some of the drawings may be simplified for clarity. Thus, the drawings may not depict all of the components of a given apparatus (e.g., device) or method.

Various aspects of the present invention will be described herein with reference to drawings that are schematic illustrations of idealized configurations of the present invention. As such, variations from the shapes of the illustrations as a result, for example, manufacturing techniques and/or tolerances, are to be expected. Thus, the various aspects of the present invention presented throughout this disclosure should not be construed as limited to the particular shapes of elements (e.g., regions, layers, sections, substrates, etc.) illustrated and described herein but are to include deviations in shapes that result, for example, from manufacturing. By way of example, an element illustrated or described as a rectangle may have rounded or curved features and/or a gradient concentration at its edges rather than a discrete change from one element to another. Thus, the elements illustrated in the drawings are schematic in nature and their shapes are not intended to illustrate the precise shape of an element and are not intended to limit the scope of the present invention.

It will be understood that when an element such as a region, layer, section, substrate, or the like, is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present. It will be further understood that when an element is referred to as being "fainted" on another element, it can be grown, deposited, etched, attached, connected, coupled, or otherwise prepared or fabricated on the other element or an intervening element.

Furthermore, relative terms, such as "lower" or "bottom" and "upper" or "top," may be used herein to describe one element's relationship to another element as illustrated in the drawings. It will be understood that relative terms are intended to encompass different orientations of an apparatus in addition to the orientation depicted in the drawings. By way of example, if an apparatus in the drawings is turned over, elements described as being on the "lower" side of other elements would then be oriented on the "upper" side of the other elements. The term "lower", can therefore, encompass both an orientation of "lower" and "upper," depending of the particular orientation of the apparatus. Similarly, if an apparatus in the drawing is turned over, elements described as "below" or "beneath" other elements would then be oriented "above" the other elements. The terms "below" or "beneath" can, therefore, encompass both an orientation of above and below.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and this disclosure.

As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The term "and/or" includes any and all combinations of one or more of the associated listed items.

Whereas the embodiments presented below are described in terms of an array of LEDs for a light source, any other light sources that may be approximately represented as point light sources may be contemplated as well within the scope and intent of the disclosure, including lasers, miniature bulbs, and the like.

FIGS. **1**A and **1**B are perspective views of an exemplary light array module **100**. The light module **100** includes LED array **102** and double-reflective assembly **104**. FIGS. **2**A and **2**B are, respectively, side and front views of double-reflective assembly **104**, and FIG. **3** is a perspective view of double-reflective assembly **104**. In an aspect of the LED array module set forth herein, slots **202** provide for fasteners such as screws to affix the light emitting device array **102** to a heat sink (not shown).

As shown in FIGS. **1**A, **1**B, **2**A, **2**B and **3**, double-reflective assembly **104** comprises lower member **204** and upper member **206** attached to each other by way of pins **322** on the upper member **206** and slots **312** on the lower member **204**. The interior surfaces of the double-reflective assembly **104** are highly reflective surfaces.

In FIG. **2**A, lower member **204** includes a frame **302**, an LED array opening **304**, holes for affixing to heat sink **306**, a left bottom reflector **308**, a right bottom reflector **310**, and slots **312**.

In FIG. **2**B, upper member **206** includes a left top reflector **318**, a right top reflector **320**, and pins **322** (visible in FIG. **2**A) corresponding to slots **312**.

The lower member **204** of double-reflective assembly **104** includes left bottom reflector **308**, right bottom reflector **310** and frame **302** (shown in FIG. **1**B) with a light emitting device array opening **304** in which the LED array **102** is located and positioned. Frame **302** has holes **306** for screws to fix double-reflective assembly **103** on a heat sink (not shown).

The upper member **206** of double-reflective assembly **104** comprises a left top reflector **318** and a right top reflector **320**. In another aspect, as shown in FIG. **2**B, the left top reflector **318** and the right top reflector **320** may have one or more additional openings **324** and **326** respectively, to provide additional control to direct light into the pattern directly from the LED array **102** without first reflecting from any surfaces.

In an aspect of the disclosure, an optical axis of left bottom reflector **308** is coincident with an optical axis of the left top reflector **318**, and an optical axis of right bottom reflector **310** is coincident with an optical axis of the right top reflector **320**.

FIG. **4** presents a relationship between orthogonal coordinates (x, y, z) and polar coordinates [$P(\alpha, \beta)$] in a light module **100** reference domain. As shown in FIG. **4**, the center of coordinates is located in a geometrical center of the LED array **102**. The LED array **102** is located in a plane of orthogonal x-y coordinates, and a z axis, orthogonal to the x-y plane, defines a LED array optical axis **402**.

Any arbitrary direction **404** in x, y, z coordinates can be presented by polar coordinates α and β, where α is an angle in the x-y coordinate plane relative to axis x and a plane in which direction **404** and axis z are located, and β is an azimuth angle in this plane between the axis z and direction **404**.

Both orthogonal and polar coordinates can be mutually transferred using simple equations.

FIGS. **5**A and **5**B are, respectively, another side and front views showing double-reflective assembly optical axes.

As shown in FIGS. **5**A and **5**B, assembled left bottom reflector **308** and left top reflector **318** form a left double reflective component **528** of a double reflective assembly **104**.

Left double-reflective component **528** has an optical axis **508** with a spatial orientation that can be described as a direction $\rho_l(\alpha_l, \beta_l)$ in polar coordinates.

Accordingly, assembled right bottom reflector **310** and right optic reflector **320** that form right double reflective component **530**, have an optical axis **510** with a spatial orientation that can be described as a direction $\rho_r(\alpha_r, \beta_r)$ in polar coordinates.

In general, $\alpha_l \neq \alpha_r$ and $\beta_l \neq \beta_r$ which means that spatial orientation of left double reflective component and right double reflective component are arbitrary to each other. In other words, the spatial orientations and resulting light patterns may be asymmetrical.

In the case where $\alpha_l=\alpha_r$ and $\beta_l=\beta$, axes **508** and **510** have mirror symmetry relative to plane x-z in orthogonal coordinates.

In operation the LED array **102** emits light with a complicated spatial intensity distribution I(α, β).

In general, an LED array spatial intensity distribution can be described using the following functional:

$$I(\alpha,\beta)=F\{n;(x_i,y_i);\Sigma^n I_i;\sigma;p\},$$

where:

n is the number of single emitters in array;

x_i, y_i, are coordinate of single emitter in x-y plane;

I_i is intensity of single emitter;

σ is an area parameter including the active array surface; and

p is the function, related to light wavelength transformation (e.g., from blue to white).

The LED array spatial intensity distribution I(α, β) may be represented in a number of ways: as a system of analytical equations, as a graphics, as a ray tracing file, etc.

In a plane to be illuminated, such as a parking lot surface, a required intensity distribution across the planar surface emitted by the light module **100** may also be given as a function of spatial intensity distribution in a pattern domain in the surface plane to be illuminated.

FIG. **6** is an example of a light pattern with non-circular asymmetrical light distribution that may be produced by the light module **100**.

One goal is to transform a given LED array spatial intensity distribution I(α, β) with high efficiency into a pre-calculated (given, e.g., pre-determined) intensity distribution across the illuminated planar pattern domain by the use of a double-reflective assembly.

Light distribution across the pattern forms as a superposition of constituents, including light directed into the pattern directly from the light source (LED array **102**), light reflected from the bottom reflectors, light reflected from the top reflectors, light double-reflected from both top and bottom reflectors.

FIGS. **7A**-**7E** are cross-sectional views of right double-reflective component **530** in a plane of optical axis **510**, located perpendicular to the x-y plane in LED array module domain. For simplicity, the LED array **102** is shown as a point source, just to demonstrate conceptual difference between the constituents, listed above.

As shown in FIG. **7A**, all rays emitted by the LED array **102** and located between ray **602** (passing without reflection from top reflector **320**) and ray **604** (passing without reflection from bottom reflector **310**) are directed into the pattern in a direction around optical axis **510** directly from the LED array **102**.

FIG. **7B** is an exemplary view of ray **606** emitted by the LED array **102** and reflected by the right bottom reflector **310** into ray **608** directed into the pattern.

FIG. **7C** is an exemplary view of ray **610** emitted by the LED array **102** and reflected by the right top reflector **320** into ray **612** directed into the pattern.

FIG. **7D** is an exemplary view of ray **614** emitted by the LED array **102**, reflected by the right top reflector **320** as a ray **616**, and then reflected by right bottom reflector **310** as a ray **618** into the pattern.

FIG. **7E** is an exemplary view of ray **620** emitted by the LED array **102** and emerging through opening **326** into the pattern.

With a given LED array **102** spatial intensity distribution I(α, β) each of the constituents listed above can be calculated as a function of following parameters: the direction of optical axes **508** and **510**, the location and orientation of bottom reflectors **308** and **310**, and top reflectors **318** and **320**, the shape and geometrical dimensions of reflectors **308**, **310**, **318**, **320**, and the reflectors **308**, **310**, **318**, **320** profiles.

The superposition of all four constituents creates a final intensity distribution across the plane of the pattern, and can be presented by equation:

$$I_p(\alpha,\Theta)=I_d+I_c+I_tI_{tc}$$

where:

$I_p(\alpha,\Theta)$ is the final intensity distribution in the pattern;

α,Θ are polar coordinates in the pattern domain;

I_d is intensity distribution in the pattern directly from LED array **102**, including intensity distribution in the pattern from the portion of light emitted by LED array **102** emerging through openings **324** and **326** of top reflectors **318** and **320**, respectively;

I_c is intensity distribution in the pattern from the portion of light emitted by LED array **102** and reflected from bottom reflectors **308** and **310**;

I_t is intensity distribution in the pattern from the portion of light emitted by LED array **102** and reflected from top reflectors **318** and **320**; and

I_{tc} is intensity distribution in the pattern from the portion of light emitted by LED array **102**, reflected from top reflectors **318** and **320**, and double-reflected from bottom reflectors **308** and **310** respectively.

In the case where required intensity distribution in the outgoing pattern is given (predetermined), a procedure such as may be implemented in software may be created to determine the optimal combination of components I_d, I_c, I_t and I_{tc} by way of calculation of reflectors **308**, **310**, **318** and **320** profiles, dimensions, geometries, shape, orientation and direction optical axes **508** and **510**.

In operation, outgoing light comprises four components: (1) light directed into the pattern immediately from the LED array **102**, including the portion of light emitted by LED array **102** emerging through optional openings **324** and **326** of top reflectors **318** and **320** respectively (2) light reflected from the bottom reflector, (3) light reflected from the top reflectors and, (4) light double-reflected from both top and bottom reflectors.

Based on given spatial light distribution of the LED array **102**, shapes, geometry and profiles of bottom and top reflectors can be combined to provide a pre-determined required intensity distribution across a non-circular asymmetrical pattern, for example, a street light pattern with required illumination over an asymmetric non-circular area.

The various aspects of this disclosure are provided to enable one of ordinary skill in the art to practice the present invention. The claims are not intended to be limited to the various aspects of this disclosure, but are to be accorded the full scope consistent with the language of the claims. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase “means for” or, in the case of a method claim, the element is recited using the phrase “step for.”

What is claimed is:

1. A light module comprising:
a light emitting diode (LED) array;
a double-reflective assembly coupled to the LED array, the double-reflective assembly comprising:
a lower member comprising:
a frame, the frame having an opening corresponding to the LED array, wherein the frame and LED array are located in the same plane;
a left bottom reflector;
a right bottom reflector;
an upper member comprising:
a left top reflector; and
a right top reflector, wherein the left top reflector is attached to the left bottom reflector, and right top reflector is attached to the right bottom reflector, each forming an arbitrary left and right double-reflective assembly, wherein a shape, geometry and profile of each double-reflective assembly provides a pre-calculated combined non-circular asymmetrical intensity distribution pattern, wherein the intensity distribution pattern is a superposition of light reflected from the bottom reflectors, light reflected from the top reflectors, light doubly reflected from both the top and bottom reflectors, and light directed into the intensity distribution pattern directly from the LED array.

2. The light module of claim **1**, further comprising:
a heat sink coupled to the lower member; and
holes in the lower member for fixing the heat sink to the lower member.

3. The light module of claim **1**, wherein a distribution of light across the illuminated pattern domain comprises a superposition of:
an intensity distribution from light directed into the pattern directly from the LED array;
an intensity distribution from light reflected from the bottom reflectors;
an intensity distribution from light reflected from the top reflectors; and
an intensity distribution from light double-reflected from both top and bottom reflectors.

4. The light module of claim **3** further comprising one or more additional openings in each of the top reflectors.

5. The light module of claim **4**, wherein the distribution of light across the illuminated pattern domain comprises a further superposition comprising an intensity distribution from light emitted through the one or more additional openings in the top reflectors.

6. The light module of claim **1** wherein the double-reflective assembly is fabricated from sheet metal with a high reflective surface coating.

7. The light module of claim **1** wherein the double-reflective assembly is fabricated from a plastic material by the means of injecting molding and a high reflective coating of reflective surfaces.

8. The light module of claim **7** wherein the double-reflective assembly fabricated from a high temperature plastic material.

9. The light module of claim **1** wherein the double-reflective assembly is fabricated from a combination of a sheet metal and a plastic molded components with high reflective coating.

10. The light module of claim **9** wherein the upper member of the double-reflective assembly comprises two or more molded components.

11. A method of forming a pre-determined non-circular asymmetrical light distribution pattern in a plane of illumination, comprising:
emitting light from a light emitting diode (LED) array; and
reflecting a portion of the emitted light from a double-reflective array assembly, the double-reflective assembly comprising:
a lower member comprising:
a frame, the frame having an opening corresponding to the LED array, wherein the frame and LED array are located in the same plane;
a left bottom reflector;
a right bottom reflector;
an upper member comprising:
a left top reflector; and
a right top reflector, wherein the left top reflector is attached to the left bottom reflector, and right top reflector is attached to the right bottom reflector, each forming an arbitrary left and right double-reflective assembly, wherein a shape geometry and profile of each double-reflective assembly provides a pre-calculated combined non-circular asymmetrical intensity distribution pattern, wherein the intensity distribution pattern is a superposition of light reflected from the bottom reflectors, light reflected from the top reflectors, light doubly reflected from both the top and bottom reflectors, and light directed into the intensity distribution pattern directly from the LED array.

12. The method of claim **11**, further comprising:
coupling a heat sink to the lower member; and
providing the lower member with holes for fixing the heat sink to the lower member.

13. The method of claim **11**, further comprising:
determining a spatial light output distribution of the LED array;
determining a combined light output of the LED array and a reflected light from the bottom and top reflectors on the basis of a shape geometry and profile of the bottom and top reflectors of the double-reflective array assembly; and
determining a light distribution pattern in a plane of illumination on the basis of the array of LEDs and a shape and configuration of the double-reflective array assembly.

14. The method of claim **11**, wherein a distribution of light across the illuminated pattern domain comprises a superposition of:
an intensity distribution from light directed into the pattern directly from the LED array;
an intensity distribution from light reflected from the bottom reflectors;
an intensity distribution from light reflected from the top reflectors; and
an intensity distribution from light double-reflected from both top and bottom reflectors.

15. The method of claim **14**, wherein the top reflectors further comprise one or more additional openings.

16. The method of claim **15**, wherein a distribution of light across the illuminated pattern domain comprises a further superpositioning of an intensity distribution from light emitted through the one or more additional openings in the top reflectors.

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