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Livesay et al.

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(54) **LED LIGHT RECYCLING CAVITY WITH INTEGRATED OPTICS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 562 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/154,314**

(22) Filed: **May 21, 2008**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Provisional application No. 60/931,094, filed on May 21, 2007, provisional application No. 60/931,256, filed on May 22, 2007.

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

(52) **U.S. Cl.** **362/310**; 362/247; 362/298; 362/341

(58) **Field of Classification Search** 362/247, 362/296.01–296.1, 297–310, 341–350, 555
See application file for complete search history.

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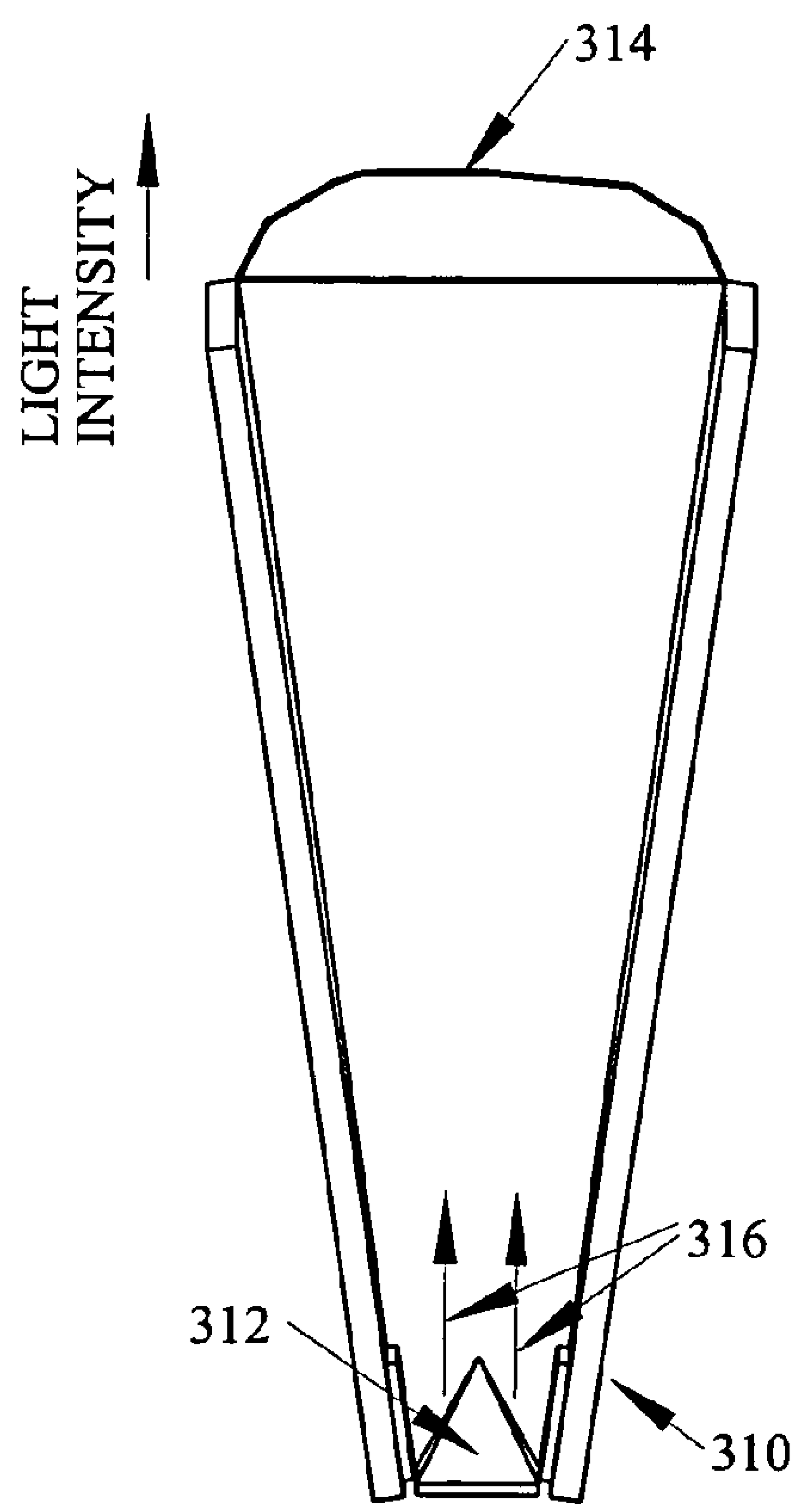
(74) *Attorney, Agent, or Firm* — William Propp, Esq

(57) **ABSTRACT**

A light emitting diode light source with mirrored surfaces is formed on a planar substrate which, when folded, forms both a light recycling cavity and an optical taper at the end of the light recycling cavity.

11 Claims, 7 Drawing Sheets



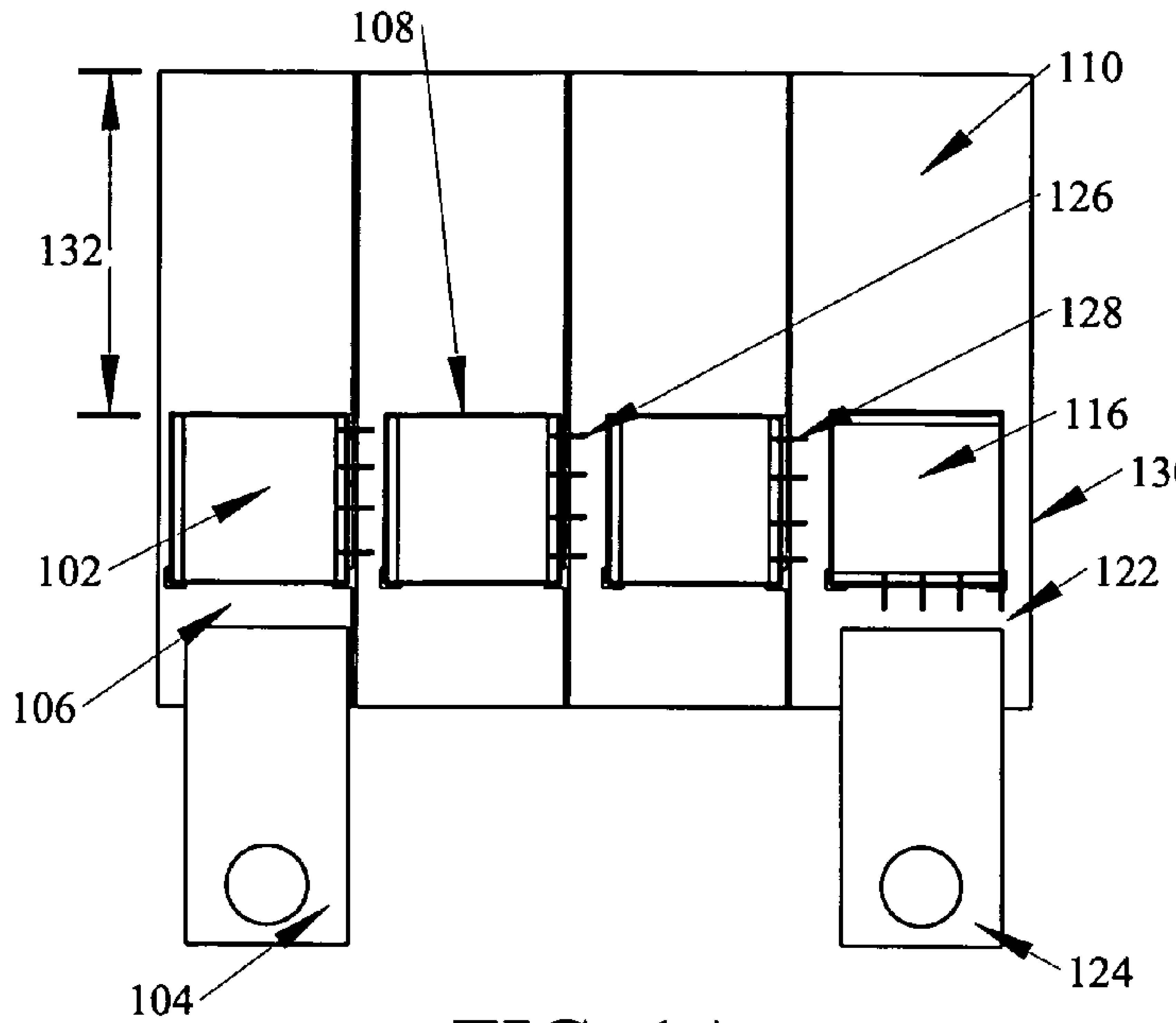


FIG. 1A

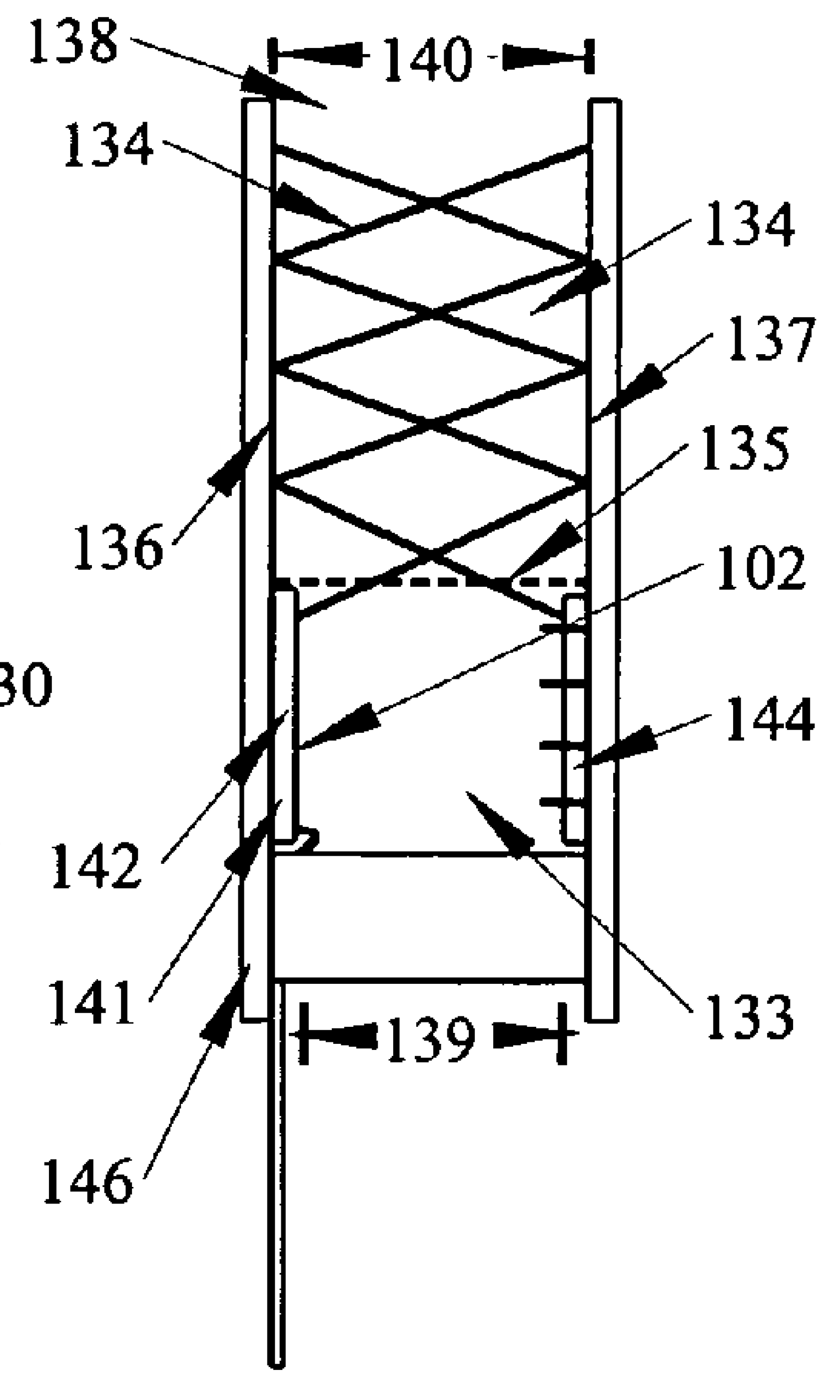


FIG. 1B

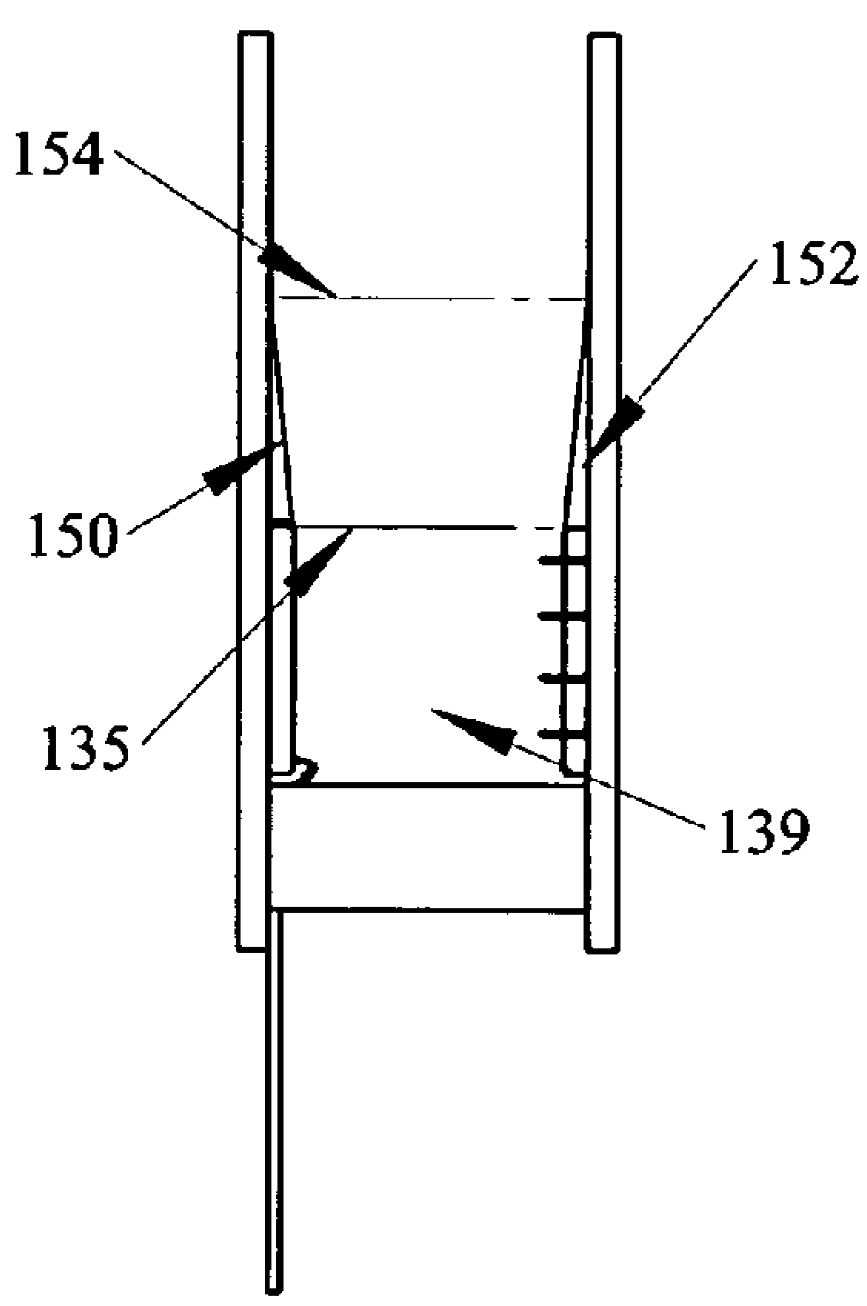


FIG. 1C

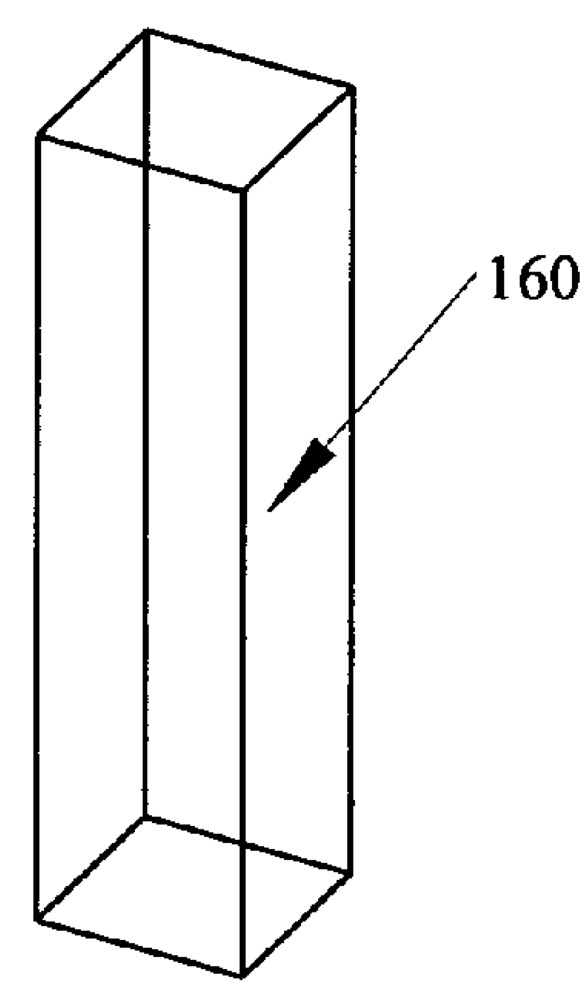


FIG. 1D

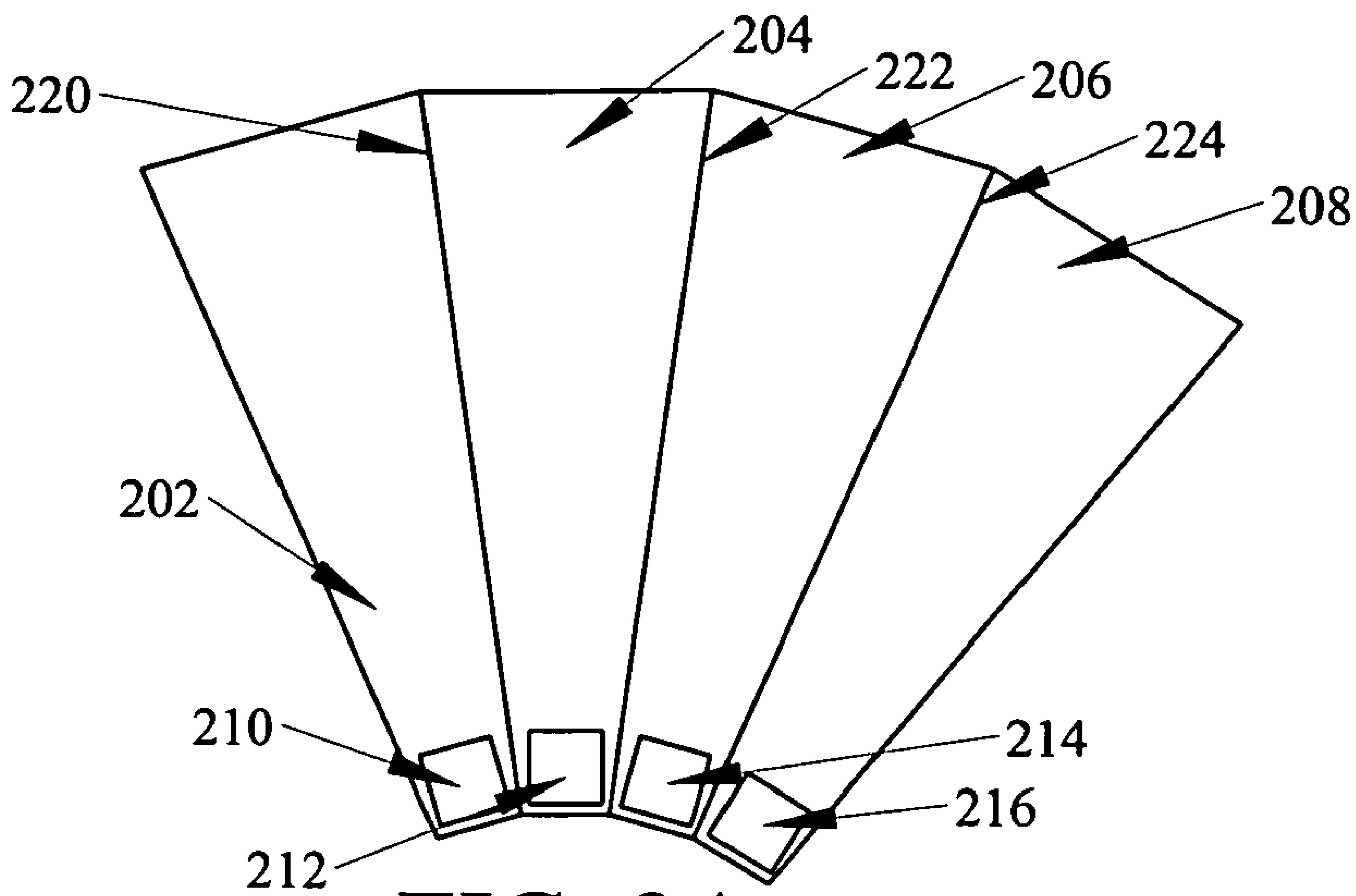


FIG. 2A

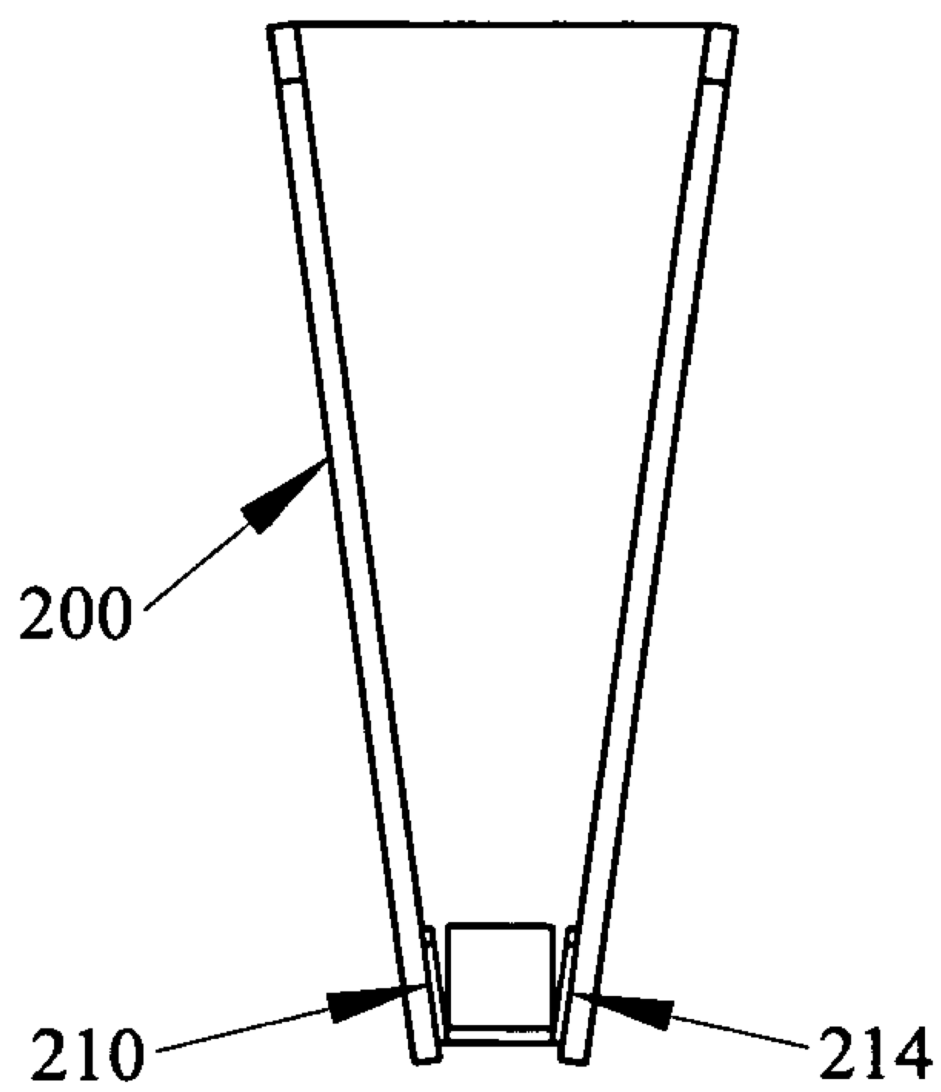


FIG. 2B

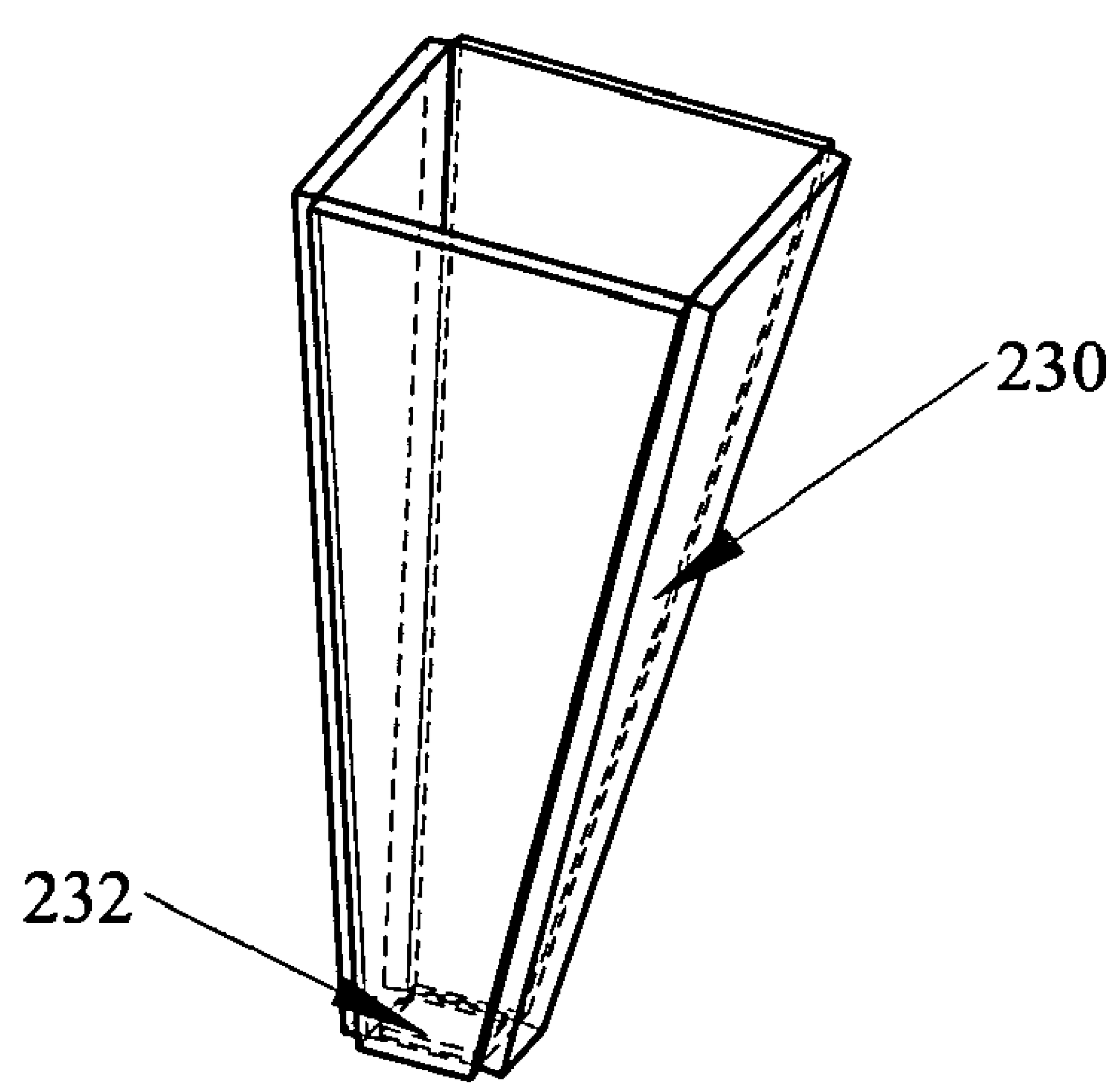


FIG. 2C

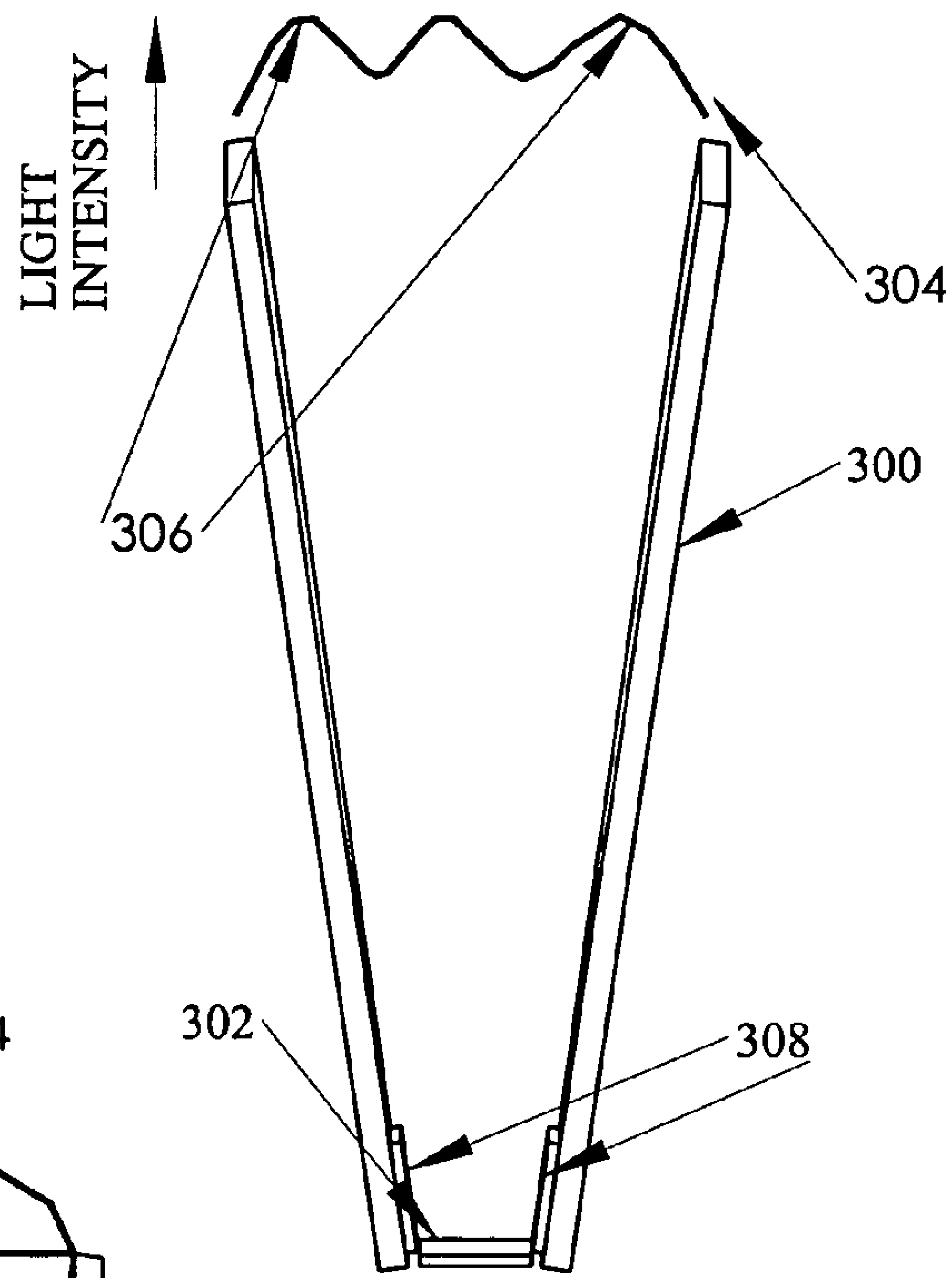


FIG. 3A

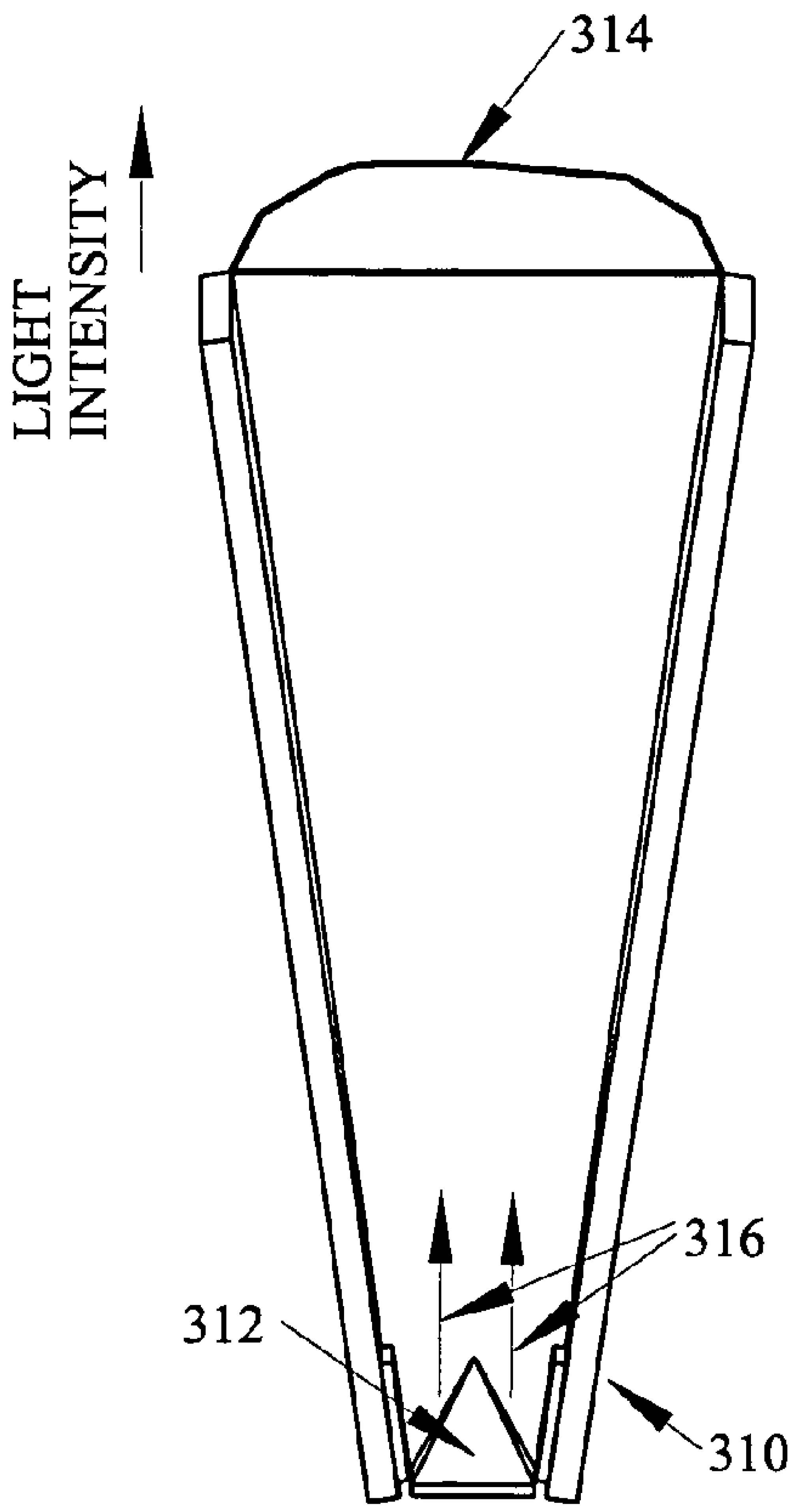


FIG. 3B

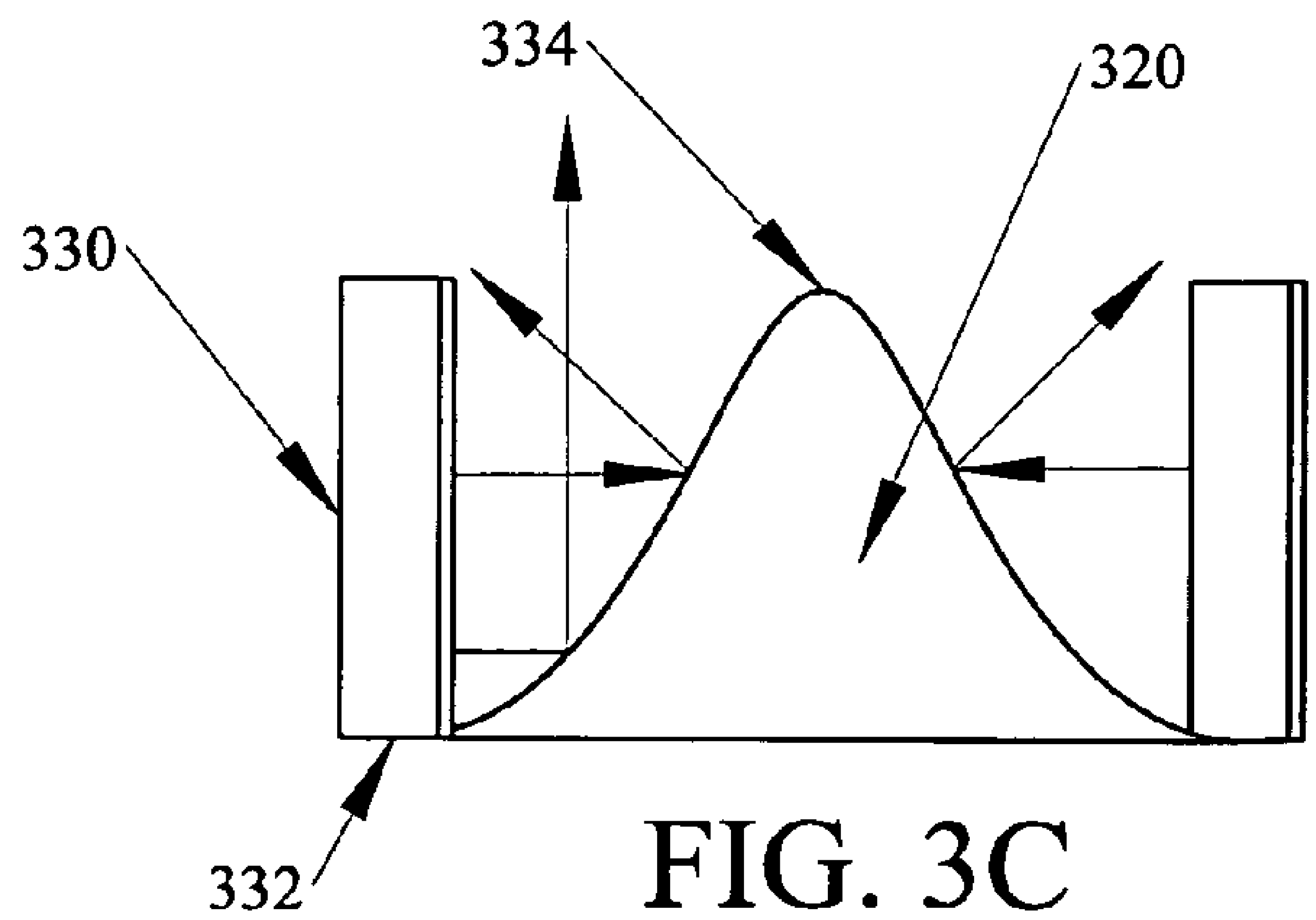


FIG. 3C

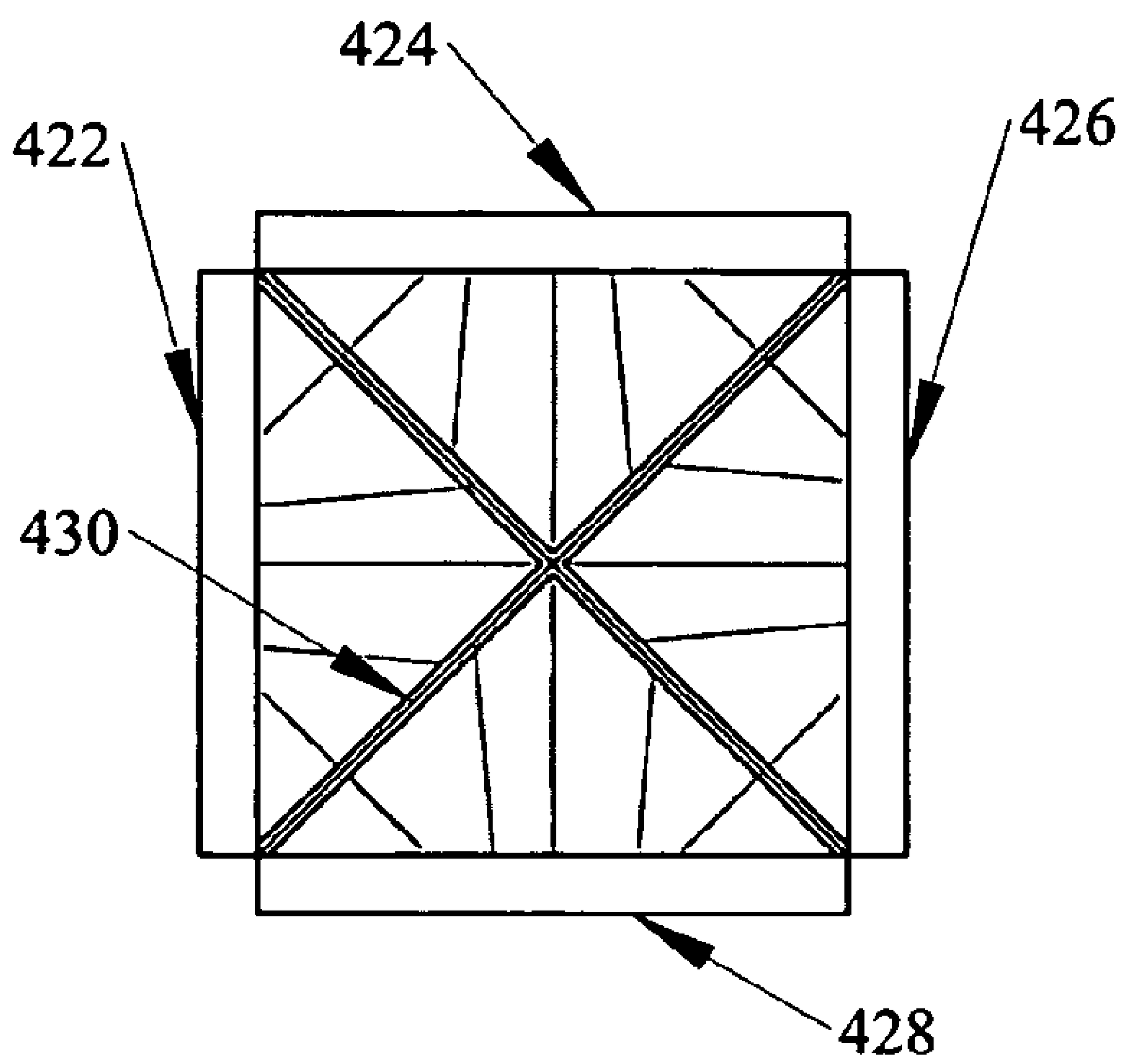


FIG. 4A

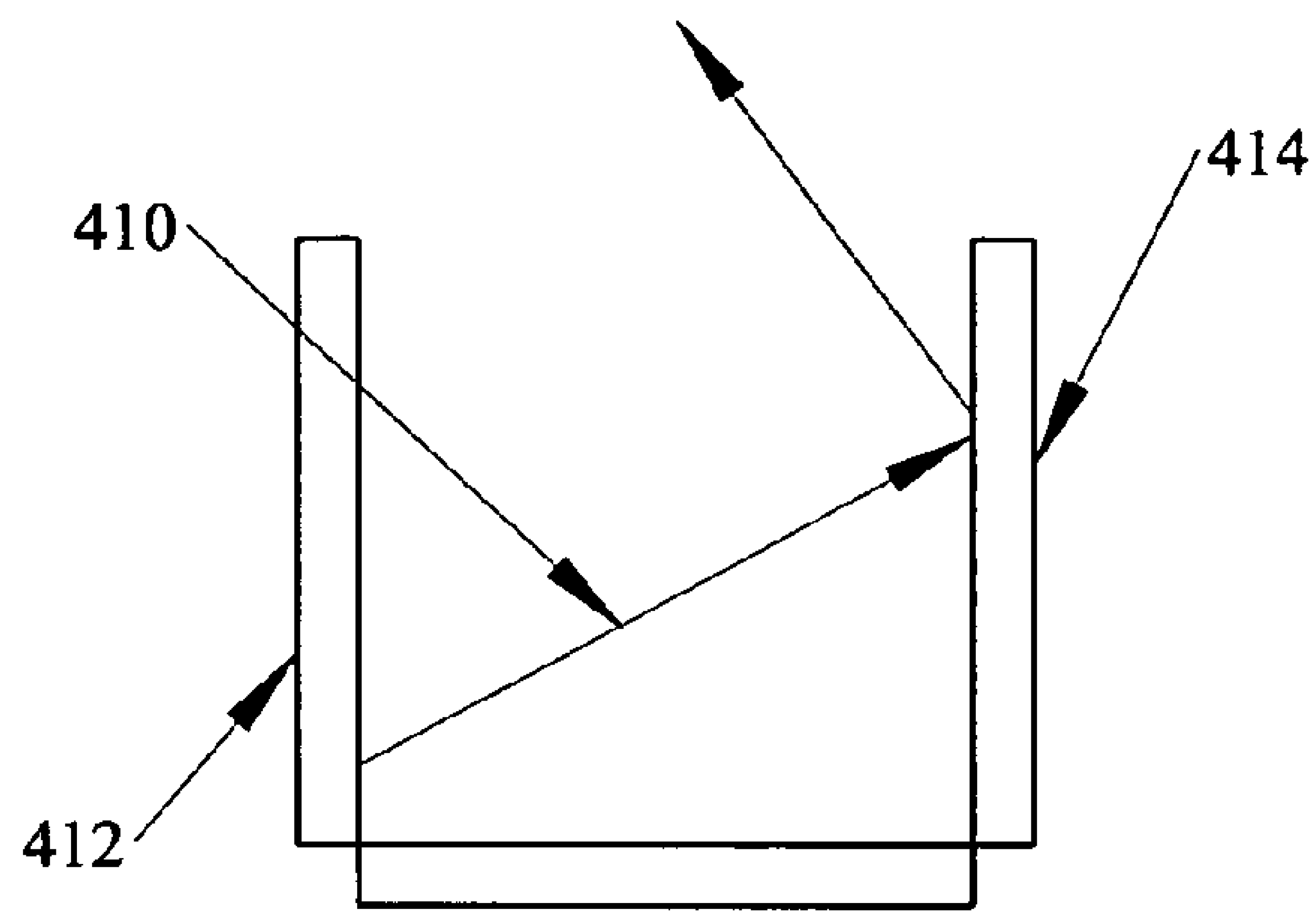


FIG. 4B

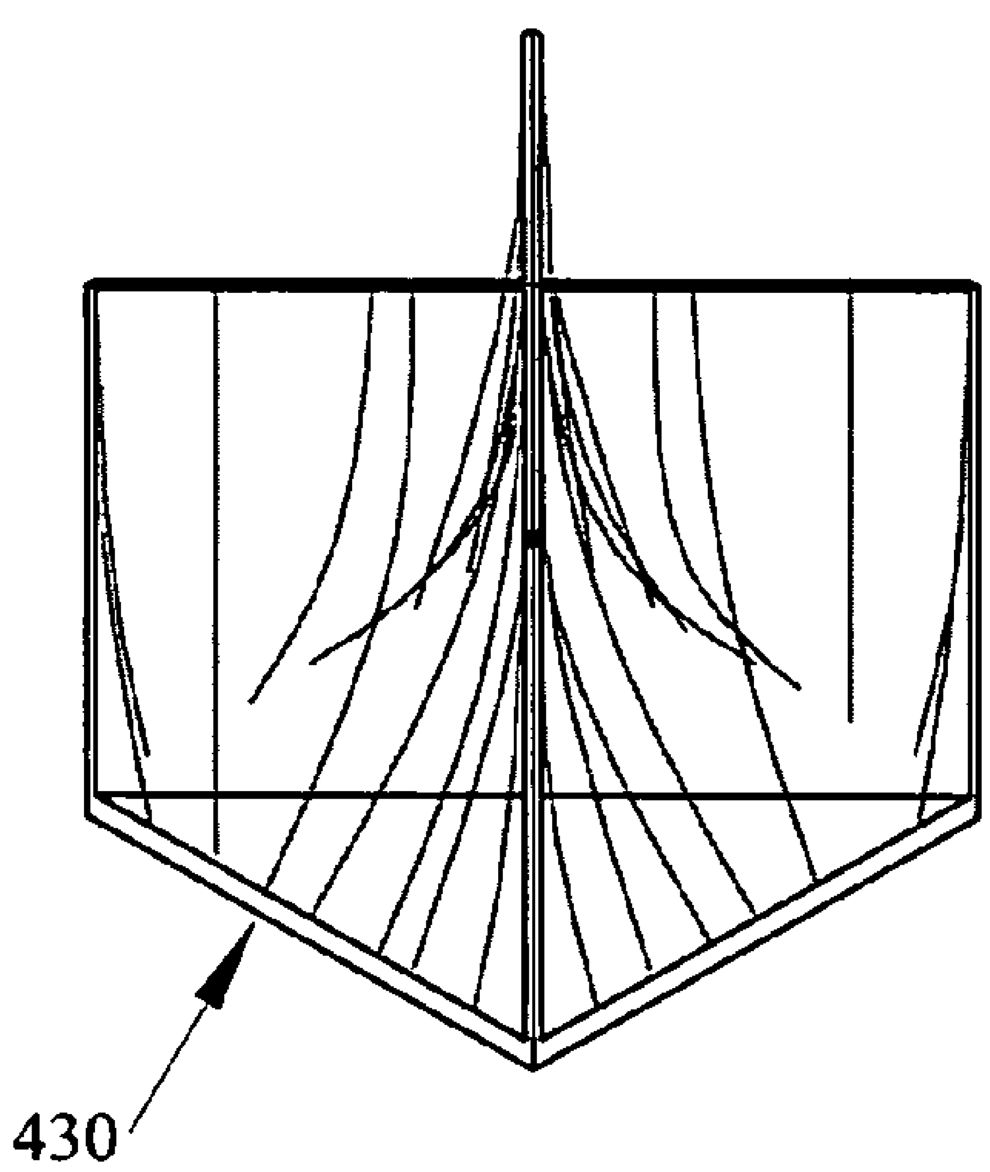


FIG. 4C

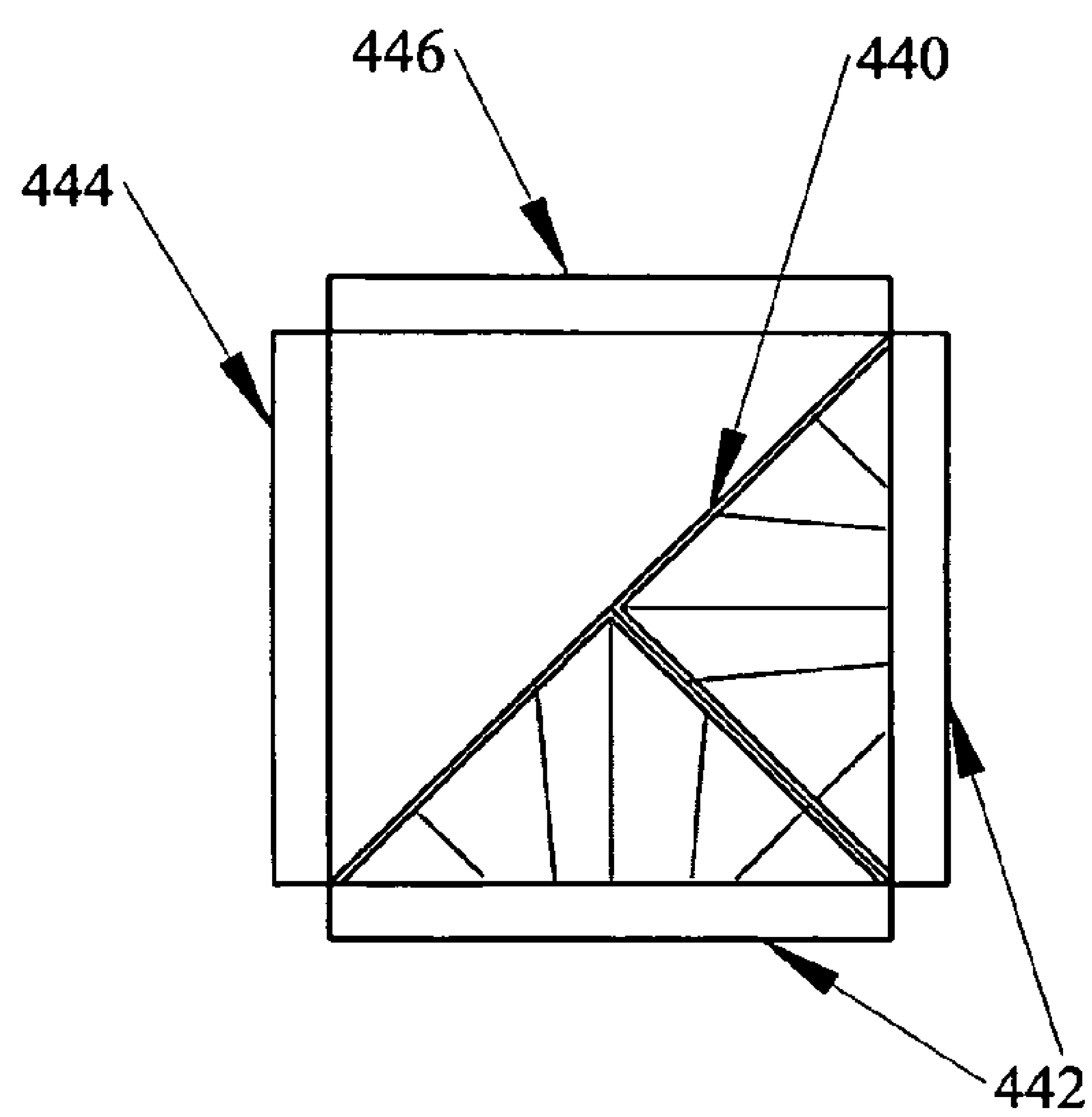


FIG. 4D

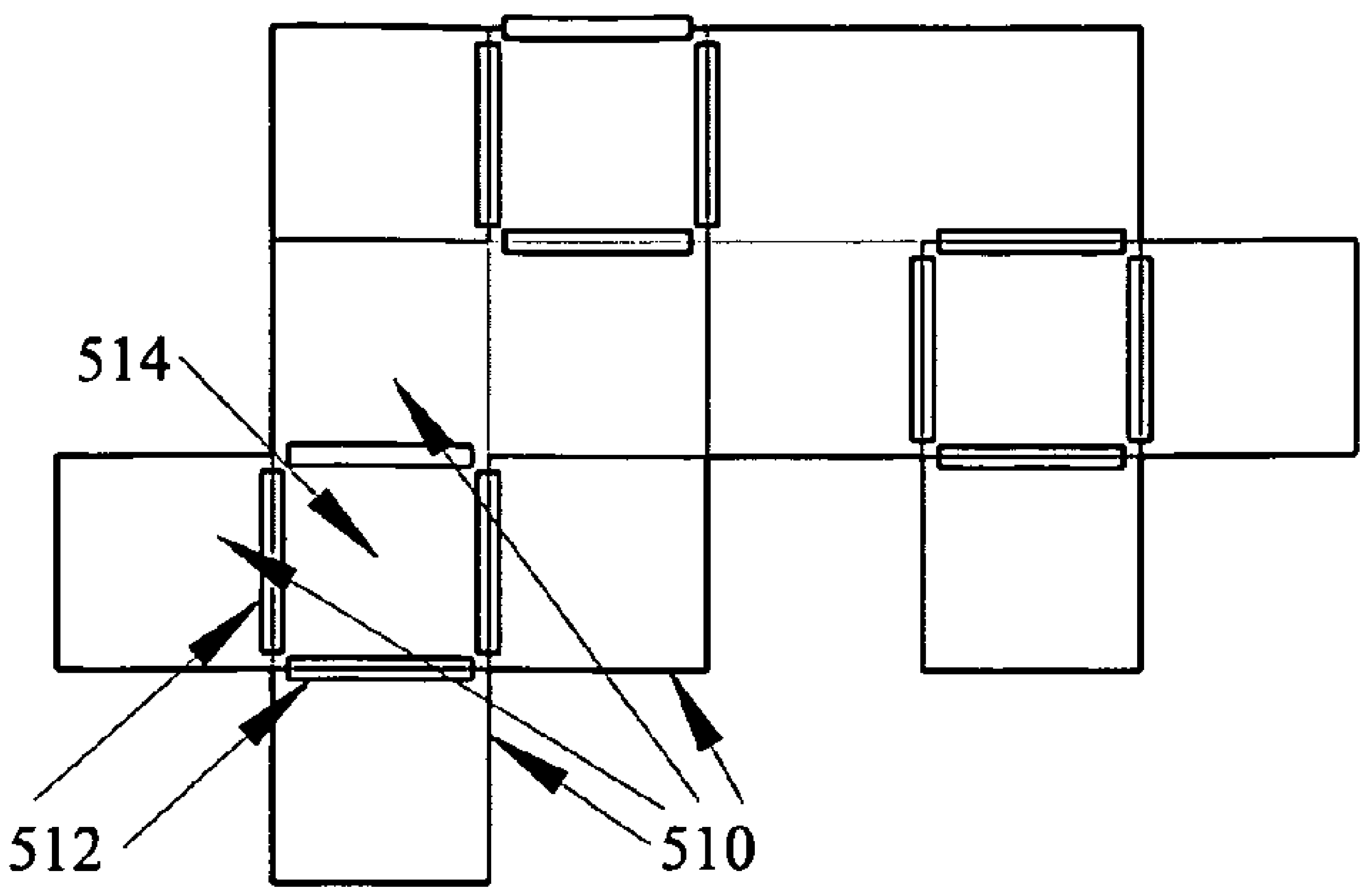


FIG. 5A

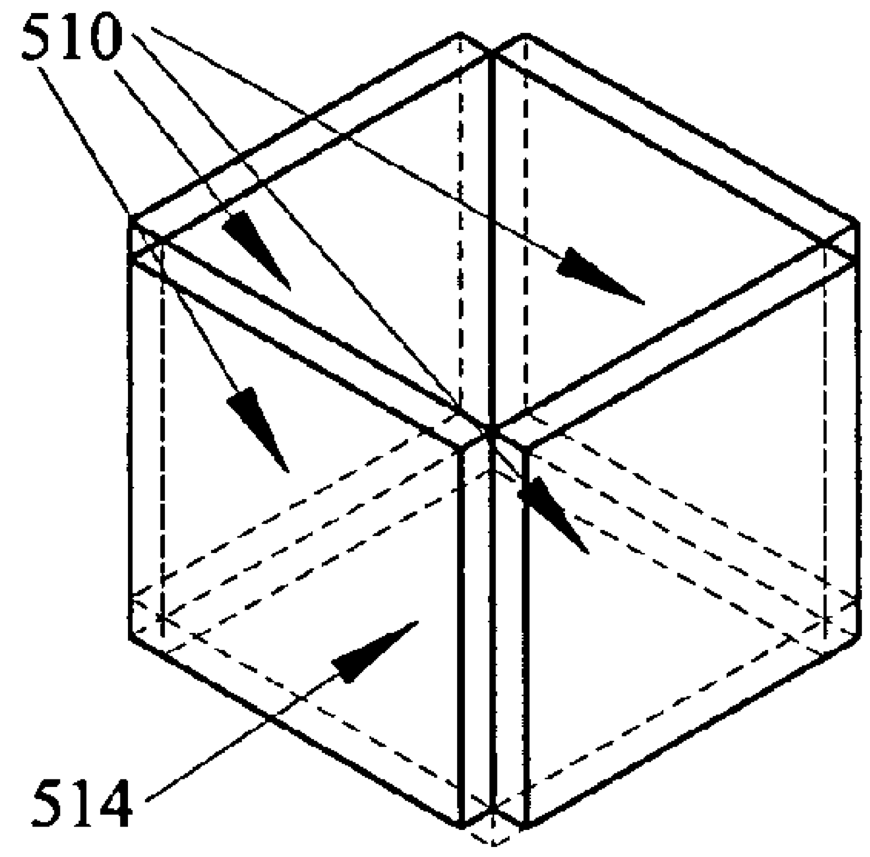


FIG. 5B

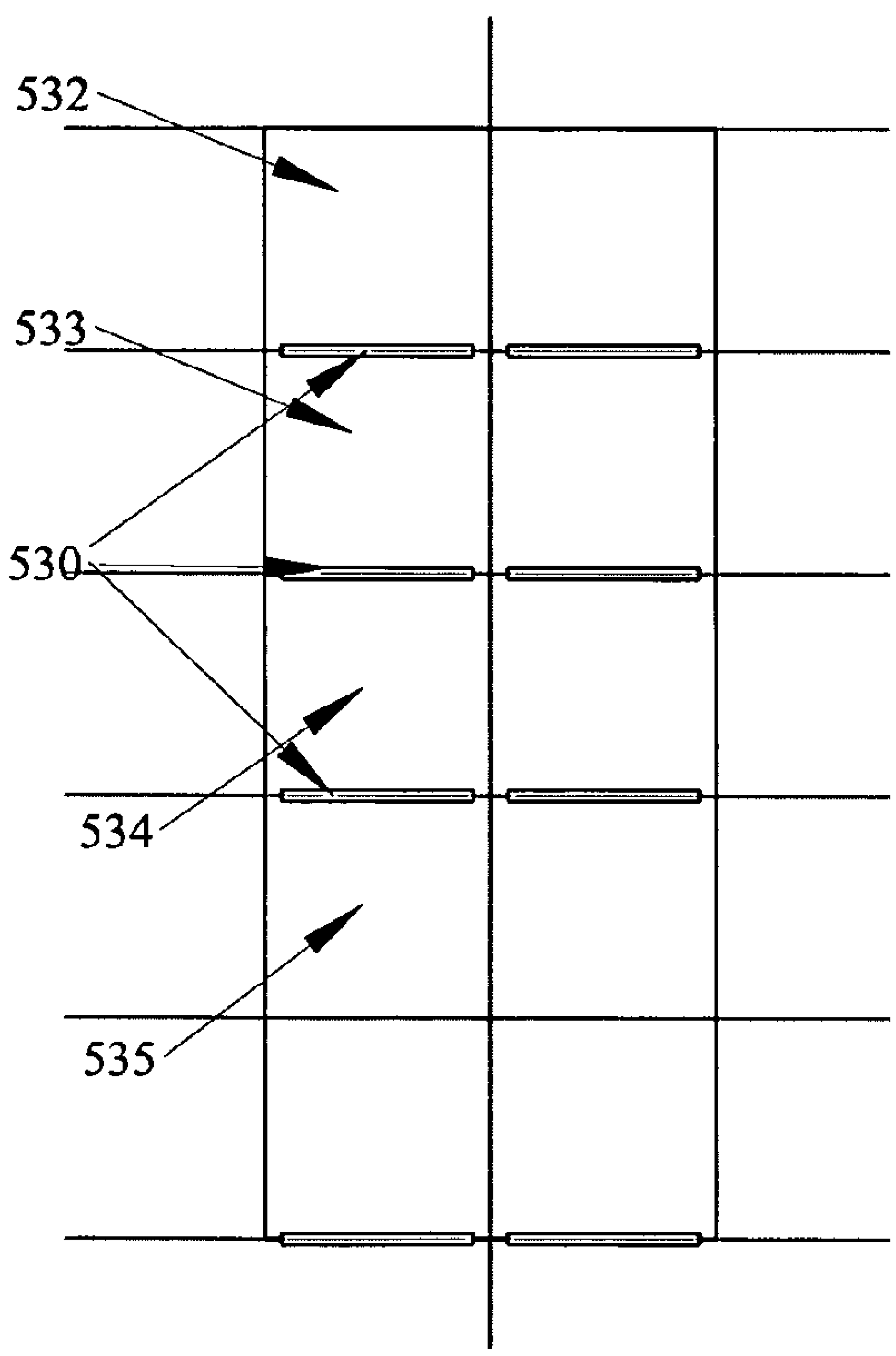


FIG. 5C

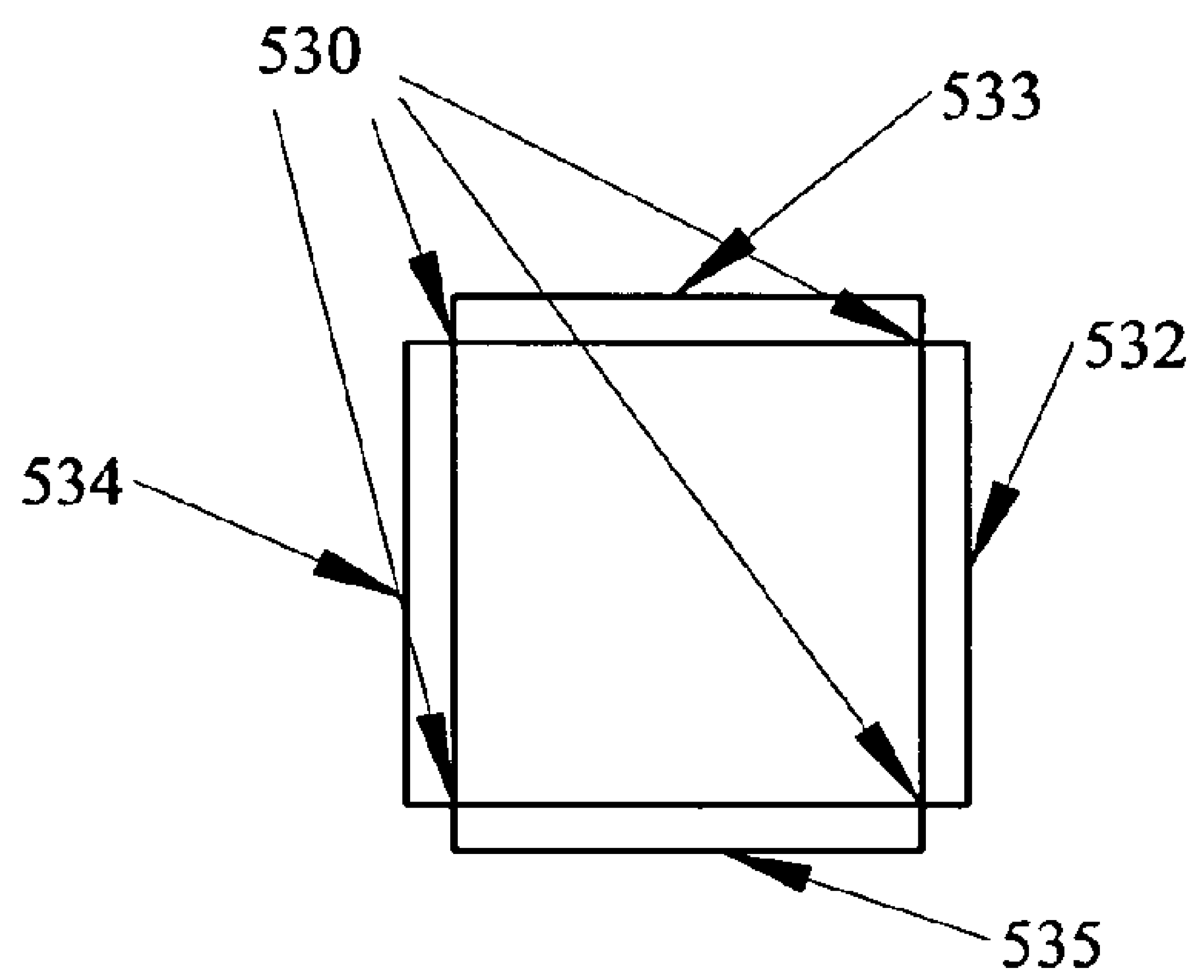


FIG. 5D

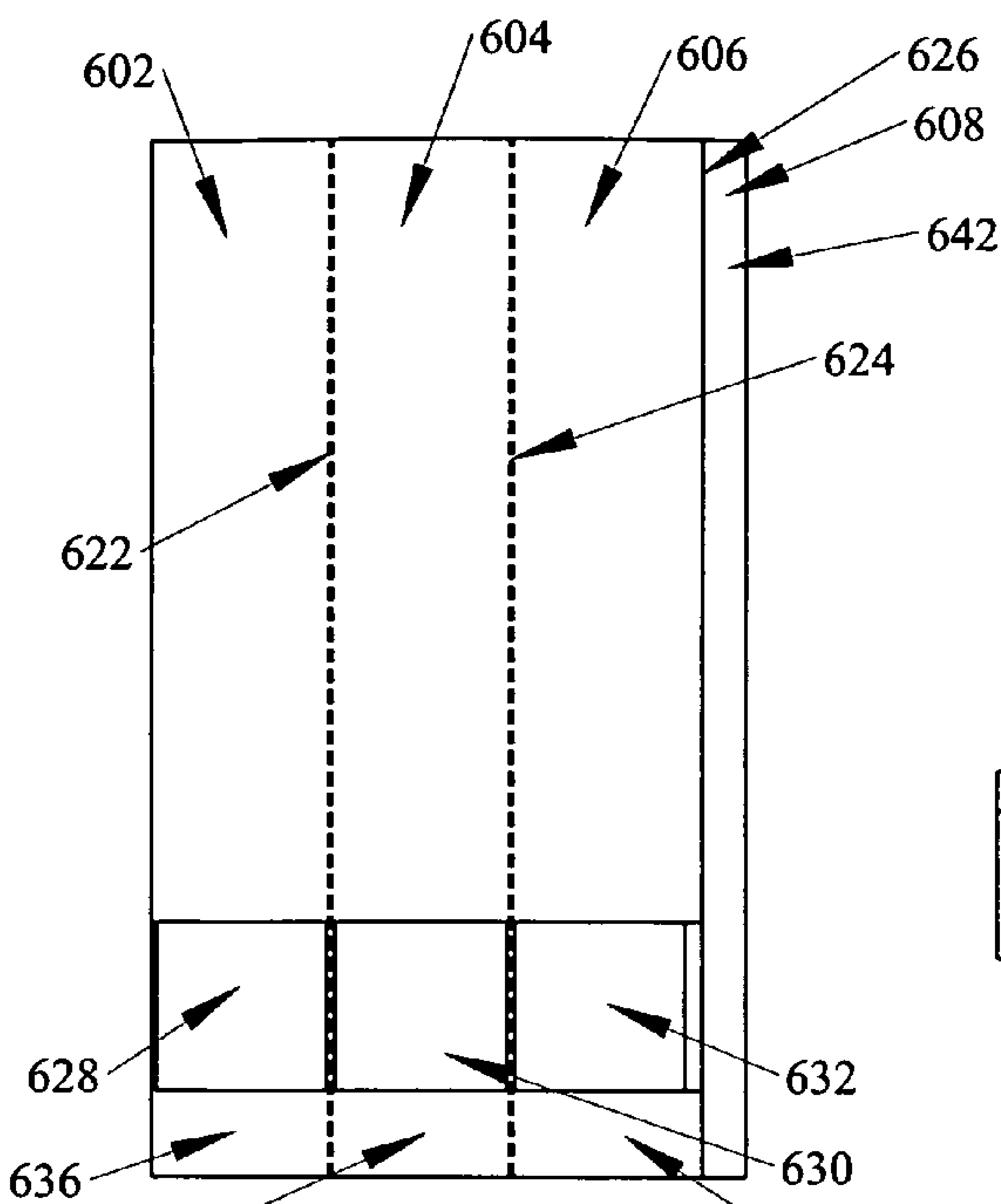


FIG. 6A

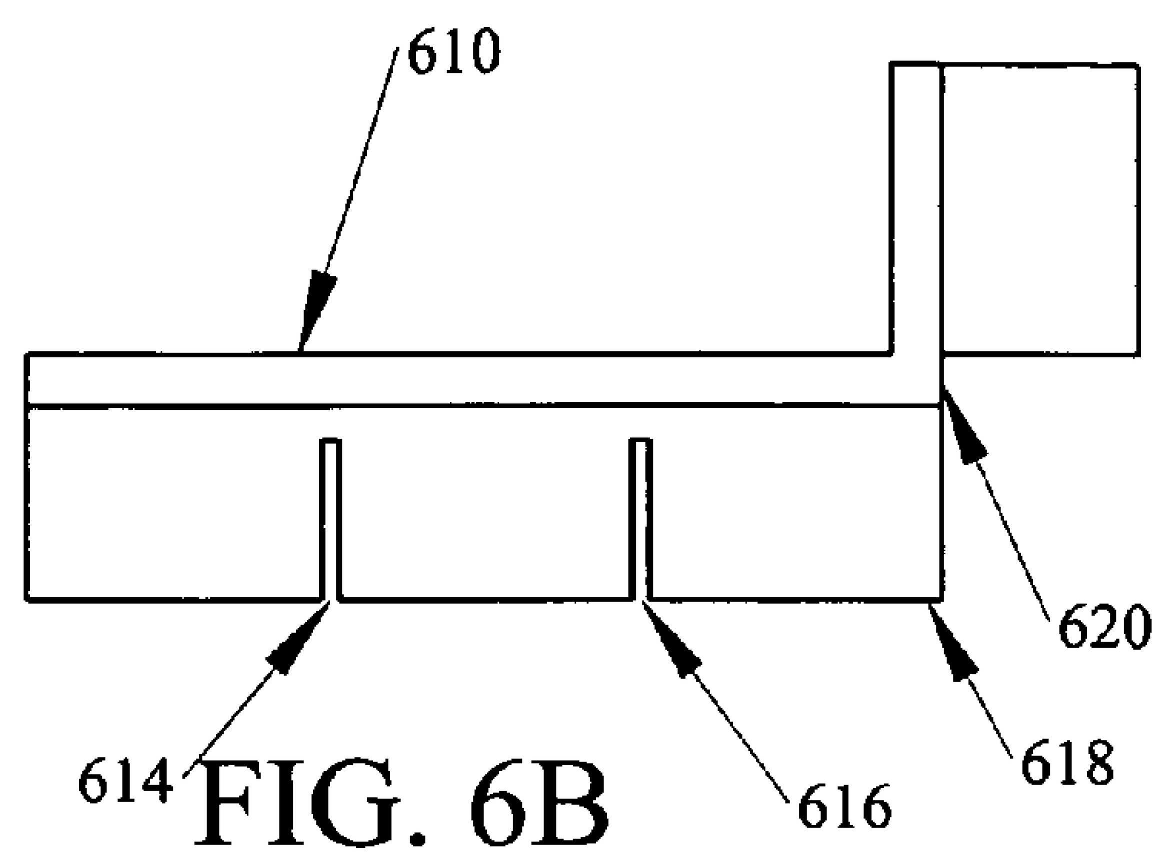


FIG. 6B

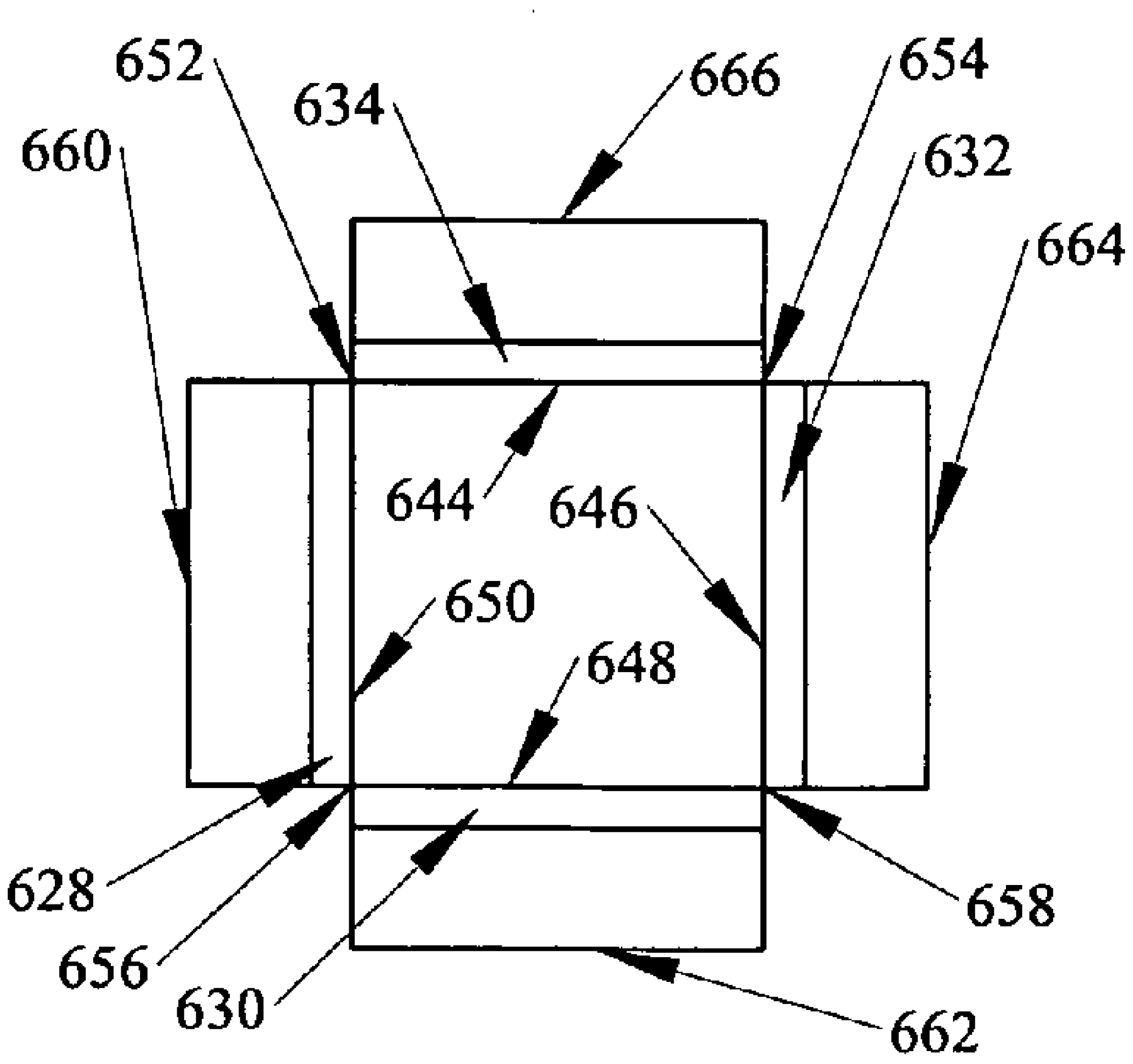


FIG. 6C

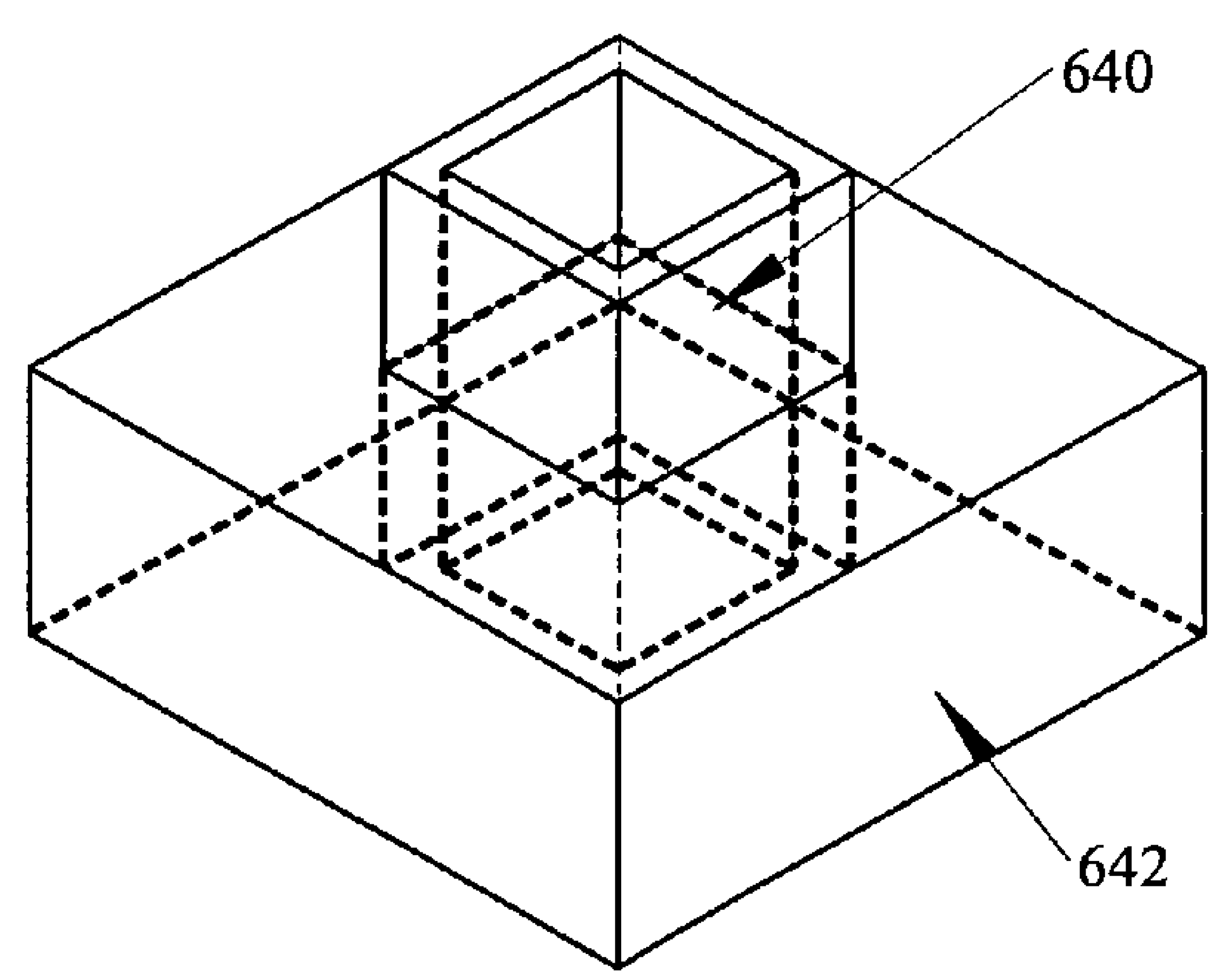


FIG. 6D

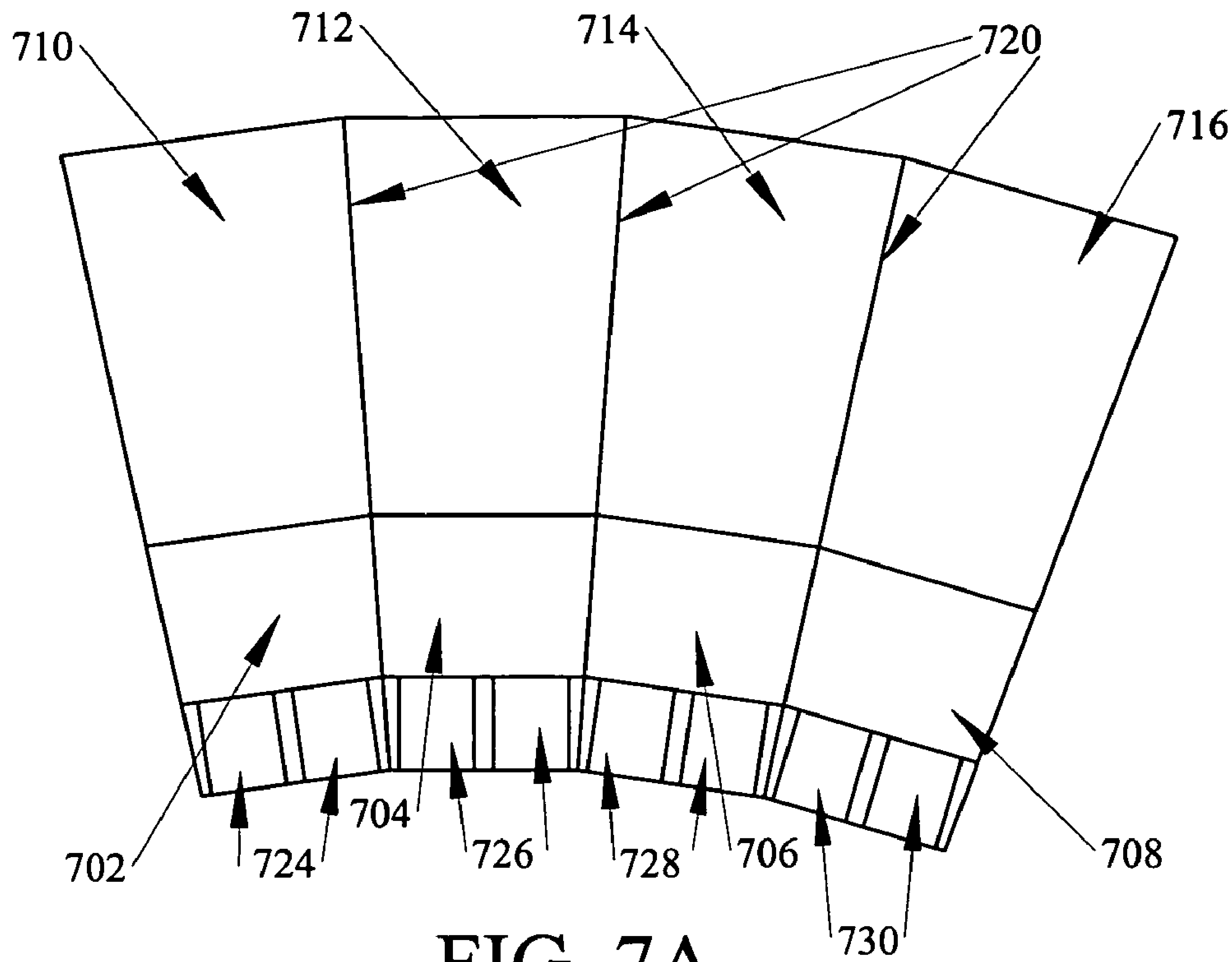


FIG. 7A

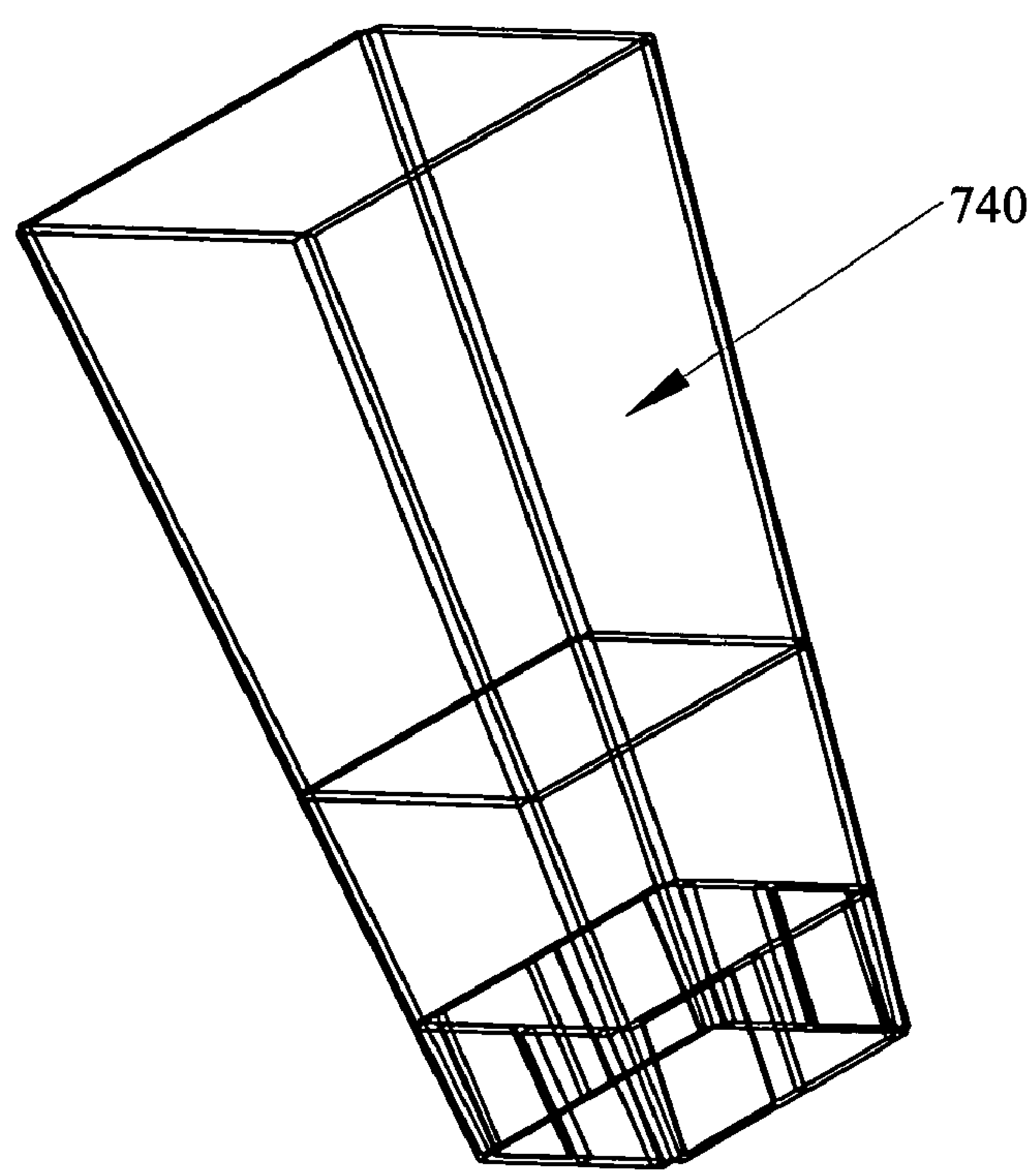


FIG. 7B

LED LIGHT RECYCLING CAVITY WITH INTEGRATED OPTICS

REFERENCE TO PRIOR APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 60/931,094, filed on May 21, 2007, and U.S. Provisional Patent Application Ser. No. 60/931,256, filed on May 22, 2007, which are herein incorporated by reference.

BACKGROUND OF THE INVENTION

A means of generating a high brightness light source using light emitting diodes in a light recycling cavity has been shown in U.S. Pat. Nos. 6,869,206, 6,960,872, and 7,040,774. However, to effectively couple these light sources into optical systems typically requires a means of collecting the light emitting from the light recycling cavity and collimating it to an angle within the acceptance angle of an external optical system.

In the prior art, optical tapers or tunnels are used to provide this collimation of the light exiting the light recycling cavity. These optical tunnels are appended onto the output of the light recycling cavity.

It would be desirable to have a simplified means like a foldable light recycling cavity method to form an integrated optical taper and light recycling cavity. In the prior art, optical tunnels had to be carefully aligned and positioned and somehow attached to the output of the light source or light recycling cavity.

It would be desirable to have a method wherein the light recycling cavity and the optical taper are the same element. This would eliminate subsequent fabrication, alignment and assembly issues in forming a completed high volume manufacturable assembly.

SUMMARY OF THE INVENTION

An integrated optical taper/tunnel and LED light recycling cavity is described wherein the optical tunnel and the light recycling cavity are the same element. In one embodiment of the invention, a foldable LED light recycling cavity forms an optical tunnel at the output aperture of the cavity.

Mirrored surfaces are fabricated in a planar process on the same substrate (LED submount) of a foldable LED light recycling cavity.

The submount is scribed, however, the dimensions of the submount are extended in the direction of the output of the light recycling cavity. The portion of the submount that extends beyond the LED is covered or coated with a mirror or mirror finish. Further, the substrate is scribed to enable folding to form the cavity. For this present invention, the scribe lines are made at slight angles to each other such that when the substrate is folded it forms a tapered optical tunnel extending beyond the output edge of the LED light recycling cavity. This allows for a simple process to form both the optical taper, light recycling cavity and electrical interconnects utilizing a planar process with very few steps. This also provides for self-alignment of the LEDs to each other and to the optical taper when the cavity is folded.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a plan view of a four section (sided) folding recycling light cavity optical tunnel integrator of the present invention.

FIG. 1B is a cross-sectional view of a four sided folding recycling light cavity optical tunnel integrator of the present invention.

FIG. 1C is cross-sectional view with wedge mirrors of the present invention.

FIG. 1D is a perspective view of a four sided folding recycling light cavity optical tunnel integrator of the present invention.

FIG. 2A is a plan view of the optical taper (funnel) recycling light cavity substrate in planar form of the present invention.

FIG. 2B is a cross-sectional view of the folded integrated optical taper (funnel) LED light recycling cavity of the present invention.

FIG. 2C is a perspective view of the folded LED light source and optical taper (funnel) of the present invention.

FIG. 3A is a cross-sectional view of two sides of the optical taper light recycling cavity with a flat reflective bottom of the present invention.

FIG. 3B is a cross-sectional view of two sides of the optical taper light recycling cavity with a reflecting pyramid bottom of the present invention.

FIG. 3C is a cross-sectional view of two sides of the optical taper light recycling cavity with a parabolic cone reflector mounted on the bottom of the cavity of the present invention.

FIG. 4A is plan view of the four quadrant curved reflector mounted on the bottom of the cavity of the present invention.

FIG. 4B is a cross-sectional view of two sides of the optical taper light recycling cavity with a four quadrant curved reflector mounted on the bottom of the cavity of the present invention.

FIG. 4C is a perspective view of the four quadrant curved reflector of the present invention.

FIG. 4D is a plan view of a three quadrant curved reflector mounted on the bottom of the cavity of the present invention.

FIG. 5A is a plan view of an unfolded five sided recycling LED light cavity prior to wafer dicing of the present invention.

FIG. 5B is a perspective view of a five sided recycling LED light cavity of the present invention.

FIG. 5C is a plan view of a four sided recycling light cavity on a gallium nitride wafer prior to dicing of the present invention.

FIG. 5D is a cross-sectional top view of the four sided recycling light cavity of the present invention.

FIG. 6A is a plan view of an unfolded light recycling cavity with integrated reflectors of the present invention.

FIG. 6B is a cross-sectional view of foldable optical taper face up with one quadrant folded of the present invention.

FIG. 6C is a top view cross-section of the folded four sided cavity and optical integrator of the present invention.

FIG. 6D is a perspective view of the folded optical recycling light cavity with optical integrator mounted in a heatsink of the present invention.

FIG. 7A is a plan view of an unfolded integrated optical funnel and recycling light cavity made entirely on gallium nitride epichips of the present invention.

FIG. 7B is a perspective view of a complete integrated optical funnel and recycling light cavity made entirely with substrate-less gallium nitride ready to be placed into a receptacle heatsink of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention uniquely combines an optical tunnel taper and light recycling cavity and light extraction means thereof into a one piece integrated assembly. Additional embodiments of the invention are shown that provide improved light extraction and homogenization of light generated with a light recycling cavity.

This invention discloses a means of forming a light recycling cavity with integrated optical taper such that the light recycling cavity and optical taper are fabricated on one contiguous planar substrate which, when folded, forms both the light recycling cavity and optical taper.

FIG. **1**A shows a plan view of the planar metal coated substrate with four sections for forming both the light recycling cavity and an optical tunnel integrator. The metal coating on the substrate forms both the electrical connection to the LEDs and also acts as a hinge to form the foldable cavity. In this invention, the metal also acts as a mirrored surface to form the reflecting interior faces of the optical tunnel taper at one end. The metal is patterned to form a series or parallel interconnect arrangement between LEDs mounted onto the substrate at the other end. The substrate is made significantly longer in dimension at the output side of the recycling light cavity **110**. In this extended area **110**, a dielectric mirror or protected metal mirror is coated. This mirror coating may be added to the metal coating, which forms the electrical interconnect and hinge, by physical vapor deposition, sputtering, electroplating, etc.

Alternatively, a single metal may be used to form the mirror, electrical interconnect, and hinge. Preferably this mirror coating is silver. Silver has a very high reflectivity. Silver has been demonstrated to be a reliable metal for wirebonding or soldering electrical interconnects. In the areas where there are no electrical interconnects, the silver is preferably coated with a thin insulating material such as silicon dioxide, silicon monoxide, calcium fluoride, magnesium fluoride, etc. These materials are deposited at preferably a quarter of the wavelength thickness to the wavelength of the light of interest to protect the reflecting metal, such as silver, aluminum, etc., from oxidation or tarnishing.

The positive lead or electrical connection to the first LED **102** in FIG. **1**A in the cavity is made with a wire or electrical conducting tab **104** that is soldered to metal island **106**. Metal island **106** makes contact to the anode (bottom) of LED **102**. The top (cathode) of LED **102** makes contact to metal island **108** via the wirebonds **110**. This interconnect method is continued for LEDs **112**, **114**, and **116** using metal islands **118**, **120**, and **122** and wirebonds **126**, **128**, and **130** with the external negative polarity connection to the array of LEDs made through tab **124** which is been soldered to metal island **122**.

The substrate is preferably an insulator with high thermal conductivity such as aluminum nitride. The substrate protrudes beyond the upper edge of LEDs **102**, **112**, **114**, and **116** and with its mirrored surface forms an optical tunnel when folded of sufficient length **132** to homogenize the light exiting the cavity.

FIG. **1**B shows how light rays **134** that exit the light recycling cavity are reflected with multiple bounces off the mirrored surfaces **136** until when they exit **138** the cavity they are fully spatially mixed. The exit of the optical tunnel will have a Lambertian (180°) light distribution identical to the exit aperture of the LED light recycling cavity **135** since the mirrored surfaces **136** and **137** are parallel to each other. Further, the angular non-uniformities in the light beam are not altered either. This method of construction forms a fully aligned optical tunnel integrator and light recycling cavity using one piece construction and very few processing steps.

It should be noted that some etendue is not preserved due to the construction shown in FIG. **1**B. The exit aperture **135** with width **139** is smaller than the width **140** of the exit of the optical tunnel **138**. This is due to the thickness **141** of the LEDs **142** and **144** mounted on the inside walls of the reflecting folded substrate **146**. This loss of etendue is non-trivial. For example, even with a thin LED that has a thickness of 0.1 mm for a 1 mm square exit aperture, the increase in etendue will be 21%. The increase in etendue is merely the ratio of the are of the exit aperture **138** of the optical tunnel to the area of the exit aperture **139** of the light recycling cavity.

In an additional embodiment of this invention, the etendue in the above example can be preserved. The light recycling cavity and optical tunnel in FIG. **1**C have two wedge mirrored surfaces **150** and **152** mounted just outside and adjacent to the exit aperture **135** of the light recycling cavity **139**. These two wedge mirrors **150** and **152** have a thickness equal to the LED thickness at the plane of the exit aperture **135** of the cavity. For ease of viewing, FIG. **1**C only shows two wedge mirrors instead of the four wedge mirrors to cover all four sides of the cavity.

At a distance of approximately 0.73 times the width of the exit aperture of the cavity, the mirror surface **150** and **152** will meet the mirrored surface of the optical tunnel substrate. With this arrangement, the etendue at the output plane **154** is identical to the etendue of the exit aperture of the cavity **135**. This is due to any light that is reflected off of the tapered mirrored surfaces is slightly collimated. Therefore, the light angular distribution is narrowed at image plane **154** to within a 120° solid angle (60° half angle). This example assumes an LED thickness of 0.1 mm, a wedge length of 0.73 mm, and a cavity exit aperture width of 1 mm. This novel integrated one piece optical light recycling cavity and optical taper provides a very short form factor with a collimated light output. If the mirrored surfaces **150** and **152** have reflectivities of greater than 98%, then the light exiting the image plane at **154** will be greater than 98% of the light exiting the recycling light cavity. These wedge mirrors are easily fabricated using casting or molding techniques and are applied while the substrate is in planar form. A perspective view of the folded cavity is shown in FIG. **1**D.

The aforementioned embodiments create an integrated light recycling cavity in FIG. **1**D, and optical tunnel integrator wherein the angular distribution of light emitted from the output of the light recycling cavity is preserved at the output of the optical tunnel integrator. And, a slight collimation of the light in FIG. **1**C is provided when exiting the light recycling cavity. However, it is many times desirable to further collimate the light that is emitted by the light recycling cavity to more efficiently couple it into an optical system.

A foldable light recycling cavity and integrated optical taper in FIG. **2**A can be formed that collimates the light exiting the light recycling cavity to any desired angle. A planar four section array substrate prior to folding. LEDs **210**, **212**, **214** and **216** are mounted on metallized substrates **202**, **204**, **206** and **208**. These separate substrates are formed by scribing a singular substrate from its backside along the dotted lines indicated by **220**, **222**, and **224**. A suitable metal, such as silver, gold, copper, etc., is coated over the entire substrate before scribing. The metal coating is isolated utilizing photolithography and/or a laser to form interconnects to each LED mounted on the substrate. However, the metal is not scribed or patterned where it crosses the scribe lines **220**, **222**, and **224**. The metal, therefore, acts as a hinge so that the four sections can be folded up into a tapered optical tunnel and integrated light recycling cavity.

Shown in FIG. **2**B is a cross-sectional view of the folded integrated light recycling cavity and optical taper **200**. The LEDs **210** and **214** are angled relative to each other, therefore, forming a mini-optical taper collimator within the light recycling cavity. Since the etendue of the light recycling cavity is determined by the area of the output aperture, it would appear that the etendue of the light recycling cavity depicted in FIG. **2** is larger than the light recycling cavity depicted in FIG. **1**. However, since the light emitted within the light recycling cavity is altered and collimated by the optical tunnel (taper), this offsets the increase in area, therefore, preserving the etendue, which would be attained with a rectilinear light recycling cavity as depicted in FIG. **1**. The degree of collimation is determined by the angle of the LED faces to a normal of the bottom of the cavity and the amount of specular reflectivity of the LEDs. If the LEDs only have diffused reflectivity, then there is no collimation of the light within the light recycling cavity. Further, light emitted from the LEDs that does not strike or reflect off other LEDs or other tilted surfaces within the cavity undergoes no partial collimation, therefore, the amount of collimation within the cavity is relatively small.

There is, however, compensation for opening the output aperture of the light recycling cavity. Typically, if the output aperture is increased on a light recycling cavity, the gain of the cavity is reduced, the gain being defined as the ratio of the brightness of the LEDs to the brightness of the cavity. However, although the gain is reduced, the efficiency of the cavity improves, the efficiency being defined as the total amount of light emitted by the cavity divided by the total amount of light emitted by all of the LEDs within the cavity. The integrated optical taper light recycling cavity has many advantages including ease of assembly and eliminating the requirement of mounting, positioning, and aligning an optical tunnel or taper to the output of the light recycling cavity.

To complete the folded optical tunnel and integrated light recycling cavity **230** in FIG. **2**C, an additional LED **232** may be mounted on the bottom of the light recycling cavity. Alternatively a high reflectivity material such as Spectralon, barium sulfide, or specular mirrored surface may be mounted as a base plate on the bottom of the light recycling cavity.

One problem with this arrangement is that the emission pattern from the cavity may not be totally lambertian and may have peaked side lobes. A representative light intensity graph **304** is shown in FIG. **3**A across the output of the taper of the integrated tapered cavity **300** with a flat highly reflective bottom **302**. By placing a pyramid with highly reflecting sides, such as silver with SiO_2 coating, on the bottom of the cavity a uniform light output can be achieved eliminating the side lobes **306** created by the LEDs **308** placed around the inside vertical walls of the cavity.

An integrated tapered light recycling cavity **310** with a reflecting pyramid **312** and a light intensity graph **314** output from such an arrangement is shown in FIG. **3**B. The pyramid **312** also improves the extraction efficiency of the cavity. Typically, the LEDs **316** do not have as high a reflectivity as the other optical elements inside the cavity. By placing the pyramid **312** at the bottom of the cavity, light rays **316** that would be emitted from LEDs on one side of the cavity and directed at LEDs on the other side of the cavity are intercepted by the pyramid **312** which can have reflectivity of greater than 98% and then specularly reflected and collimated toward the output of the cavity.

A parabolic pyramid **320** in FIG. **3**C directs light out of the cavity. This parabolic curve has a surface, which is normal to the bottom LED **330** at the bottom of the pyramid **332**, and gradually slopes up to the top of the pyramid **334**. The pyramid can be made of quartz, glass, sapphire, molded plastic, metal, etc. and coated with a highly reflecting material such as silver. Alternatively, the pyramid may be coated with a multilayer dielectric reflector as well known in the art.

It is sometimes advantageous to combine multiple colors in a light recycling cavity, as in U.S. Pat. No. 7,048,385. A light recycling cavity can have two green LEDs **422** and **424**, one red LED **426** and one blue LED **428** as shown in FIG. **4**A. However, to achieve a high efficiency of light output from the light recycling cavity, high reflectivity on all interior surfaces of the cavity is required. This high reflectivity is a problem when mixing LEDs of different colors. For example, light emitted by red LEDs have reflectivities of around 30 to 40% of light emitted by the blue and green LEDs. As depicted in FIG. **4**B, a light ray **410** emitted by a green LED **412** is incident on the red LED **414**, however, only about 35% of the light incident on the red LED is reflected back into or out of the cavity. This low red light reflectivity can significantly impact the light output efficiency of the cavity.

To overcome this low red light reflectivity, a multifaceted reflector keeps all of the light within the cavity restricted to each respective LED and facilitates mixing and homogenizing all of the colors. The multifaceted reflector is a four quadrant compound parabolic reflector **430** as depicted in FIG. **4**C. This reflector, which is fabricated by molding or electroforming, has a reflective surface similar to the one depicted in FIG. **3**C in that the reflective surface that meets the bottom of the LED is perpendicular to the emitting surface of the LED. This surface then is curved upward and slopes to the top edge of this four quadrant reflector. The top edges are coplanar with the top edges of the LEDs making up the light recycling cavity.

This multifaceted reflector is shown dividing up the cavity into quadrants **430** in FIG. **4**A. Therefore, no light emitted by any individual LED inside the cavity can reach any of the other LEDs inside the cavity. This compound reflector, however, not only separates the light but it also partially collimates the light directing it toward the output of the cavity. This compound parabolic four quadrant reflector can be utilized in a rectilinear light recycling cavity or an integrated optical taper light recycling cavity as previously described.

In addition to the configuration of a multi-colored light recycling cavity depicted in FIG. **4**A which contains the colors red, green, and blue, one of the green LEDs can be exchanged for a blue LED with a wavelength conversion material, as described in U.S. Pat. No. 7,285,791, on its output face to produce yellow, cyan, etc. This configuration would provide a four color light recycling cavity, all with high reflectivity.

Another alternative embodiment is to modify the four quadrant compound parabolic reflector to create a three quadrant compound parabolic reflector **440**. This is depicted in FIG. **4**D wherein the two green LEDs are placed adjacent to each other. The compound parabolic reflector, therefore, separates the red LED **444** and the blue LED **446** from the others, but the two green LEDs **442** are mixed with each other.

A further embodiment of this invention greatly simplifies construction of the light recycling cavity. As shown in FIG. **5**A, the LEDs **510**, which are to be used inside the light recycling cavity are metallized, at the wafer level, interconnecting adjacent LEDs with a thin metal hinge **512** on top of the output face of the LED. The hinge pattern shown in FIG. **5**A would form a five sided recycling light cavity when folded as shown in FIG. **5**B, with LED **514** on the bottom of the cavity. The wafer is scribed from the backside with a scribe or wafer saw or preferably with an excimer laser, but not all the way through to the topside metal. The patterned metal forming the hinges can be made using conventional wafer lithography and etching processes.

To form a four sided cavity, open bottom metal hinges can be located as shown in FIG. **5**C. Four hinges **530** are located in line connecting LEDs **532**, **533**, **534**, and **535** in FIG. **5**D. In U.S. patent application Ser. No. 12/148,888 and U.S. provisional application 61/067,935, a method is shown to produce substrate-less LEDs. This method can be combined with the aforementioned embodiments to form a substrate-less integrated recycling light cavity.

Another method for forming an integrated light recycling cavity with integrated optical taper is shown in FIG. **6**A. A foldable glass taper has three segments **602**, **604**, **606** unfolded and one segment **608** folded. The glass taper consists of a glass substrate with a reflective metal film **610** coated on the top surface of a glass or ceramic substrate **612**. The reflective metal film **610** can be silver, aluminum, etc. The substrate is scribed or cut on the backside **614 616**, **618** with a laser or a saw. The substrate is only partially scribed or broken so as to keep the metal film intact such that it can act as a hinge **620** and the assembly to be folded into an optical tunnel. The mirrored faces **602**, **604**, **606** can be folded along the dotted lines **622**, **624**, **626**. LEDs **628**, **630**, **632**, **634** are attached to a metal coated, thermally conducting submount **636**, **638**, **640**, **642**. The metal coated submount can be aluminum nitride, copper, etc.

FIG. **6**B shows the mirrored surfaces of the foldable optical taper face up with one quadrant folded. Another mirrored substrate made out of glass, plastic, flexible circuit, or metal clad PCB, and preferably having the same thickness as the LEDs, is bonded to the extended portion of the thermally conductive submount. The mirrored substrate is scribed from the backside and then can be folded on the silver reflective film or underlying metal film making up the reflective front surface as discussed previously.

LEDs **610**, **612**, **614**, and **616** are mounted onto a thermally conductive substrate **618** of aluminum nitride, alumina, copper tungsten, beryllium oxide, or diamond. The foldable mirrored substrate, which will form the optical tunnel, is also mounted onto the substrate. The substrate is then scribed and broken along the same lines as the mirrored substrate hinges. The taper is then folded into a combination light recycling cavity and optical tunnel. The LEDs are then coincident with the surface of the reflective portion of the optical tunnel. Since the optical tunnel is folded on the front side of the LEDs, no gap occurs between the LEDs. Therefore, the LEDs, when placed on the substrate, can be mounted in close proximity further improving the efficiency of the light recycling cavity.

FIG. **6**C shows the integrated optical tunnel light recycling cavity folded in a cross-sectional view looking down into the cavity. The LEDs **628**, **630**, **632**, **634** are coincident with the reflective surface of the optical tunnel since the reflective surface **644**, **646**, **648**, **650** is fabricated with a thin metal film that can be hinged on this thin metal film **652**, **654**, **656**, **658**. To complete the assembly, the folded cavity is inserted into a heatsink wherein the backside surfaces of the thermally conductive substrate **660**, **662**, **664**, **666** are bonded or eutectically soldered to the inside surfaces of the heatsink or head spreader, which is fabricated from copper, aluminum, or some other suitable highly thermally conductive material.

The integrated optical taper light recycling cavity **640** in FIG. **6**D is mounted in the heatsink **642**.

By combining techniques shown in FIG. **2**, FIG. **5** and FIG. **6**, a tapered optical light pipe can be fabricated where the hinges or folds are made on the top of the LEDs and reflective surfaces of the optical taper. Shown in FIG. **7**A is a method utilizing epichips as described in U.S. patent application Ser. No. 12/148,888 and U.S. provisional application 61/067,935, which further simplifies the process of making an integrated light recycling cavity and optical light funnel or taper. On a thick (greater than 10 microns) gallium nitride wafer, LEDs are formed in the areas **702**, **704**, **706** and **708**. Areas **710**, **712**, **714** and **716** are coated with a multilayer dielectric reflective film or a protected metal reflective film. Since the emitting surface of the LEDs **702**, **704**, **706** and **708** lie on the same surface as the reflecting surfaces **710**, **712**, **714** and **716**, very efficient optical coupling is achieved when folded into an optical funnel or taper. Metal hinges are deposited underneath the reflective film along the lines separating the four quadrants of the epichip integrated optical funnel and recycling light cavity. Connections to the LEDs are simplified by utilizing extended area below the LED **724**, **726**, **728**, and **730**. This eliminates the wirebonds that normally would be required to interconnect the LEDs from interfering with the reflective bottom that is placed in the folded optical cavity. A perspective view of the folded optical cavity and light funnel **740** is shown in FIG. **7**B ready to be placed into a receptacle heatsink.

While the invention has been described in conjunction with specific embodiments and examples, it is evident to those skilled in the art that many alternatives, modifications and variations will be apparent in light of the foregoing description. Accordingly, the invention is intended to embrace all such alternatives, modifications and variations as fall within the spirit and scope of the appended claims.

What is claimed is:

1. A light recycling cavity with integral light taper comprises

a planar substrate having a first side and an opposite second side;

a metal layer on said first side of said planar substrate, said metal layer having a mirrored surface, said metal layer having a first end and a second end, said metal layer having at least two bond pads at said first end, said metal layer having at least four isolation islands at said first end;

at least three cut channels in said second side of said planar substrate; said at least three cut channels forming at least three fold lines on said first side of said planar substrate, at least one of said isolated islands extending across at least one fold line;

at least four light emitting diodes mounted on said at least four isolated islands; said at least one of said isolated islands extending across at least one fold line being an electrical connection between said at least two light emitting diodes;

at least two contacts on said at least two bond pads; and

wherein folding said planar substrate along said there fold lines forms a four sided light recycling cavity at said first end and a light taper at said second end, said metal layer acts as a hinge during folding said planar substrate and said metal layer forms the walls of said light recycling cavity and said light taper, light emitted by said at least four light emitting diodes exiting at said second end.

2. The light recycling cavity with integral light taper of claim **1** wherein light emitted by said light emitting diodes is fully spatially mixed when exiting from the light taper at said second end.

3. The light recycling cavity with integral light taper of claim **1** wherein said planar substrate is aluminum nitride.

4. The light recycling cavity with integral light taper of claim **1** wherein said metal layer is silver.

5. The light recycling cavity with integral light taper of claim **1** further comprising at least four wedge mirrors, each wedge mirror on one mirrored surface of said light taper adjacent to said light recycling cavity.

6. The light recycling cavity with integral light taper of claim **1** wherein said light taper is tapered outward from said light recycling cavity to collimate the light emitted by said light emitting diodes when exiting at said second end.

7. The light recycling cavity with integral light taper of claim **1** further comprising a fifth light emitting diode covers the open end at said first end of said light reflective cavity away from said light taper.

8. The light recycling cavity with integral light taper of claim **1** further comprising a reflective base plate covers the open end at said first of said light reflective recycling cavity away from said light taper to reflect light towards said second end.

9. The light recycling cavity with integral light taper of claim **1** further comprising

a reflective pyramid covers the open end at said first end of said light reflective recycling cavity, said reflective pyramid reflecting light from said at least one light emitting diode to said second end.

10. The light recycling cavity with integral light taper of claim **9** wherein said reflective pyramid is a parabolic pyramid.

11. The light recycling cavity with integral light taper of claim **9** wherein said reflective pyramid is a four quadrant compound parabolic reflector, said parabolic reflector partially collimates reflected light towards said second end.

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