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(12) **United States Patent**
Jaster

(10) **Patent No.:** **US 8,982,467 B2**
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- (54) **HIGH ASPECT RATIO DAYLIGHT COLLECTORS**
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- (73) Assignee: **Solatube International, Inc.**, Vista, CA (US)

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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 0 days.

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G02B 27/00 (2006.01)
F21S 11/00 (2006.01)

Primary Examiner — Christ Mahoney

(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

- (52) **U.S. Cl.**
CPC **G02B 17/00** (2013.01); **F21S 11/00** (2013.01)
USPC **359/592**; 359/597

(57) **ABSTRACT**

Lighting devices and methods for providing daylight to the interior of a structure are disclosed. Some embodiments disclosed herein provide a daylighting device including a tube having a sidewall with a reflective interior surface, a light collecting structure, and a light reflector positioned to reflect daylight into the light collector. In some embodiments, the light collector is associated with one or more light-turning and/or light reflecting structures configured to increase the amount of light captured by the daylighting device. Optical elements may allow for the absorption and/or selective transmission of infrared light away from an interior of the daylighting device.

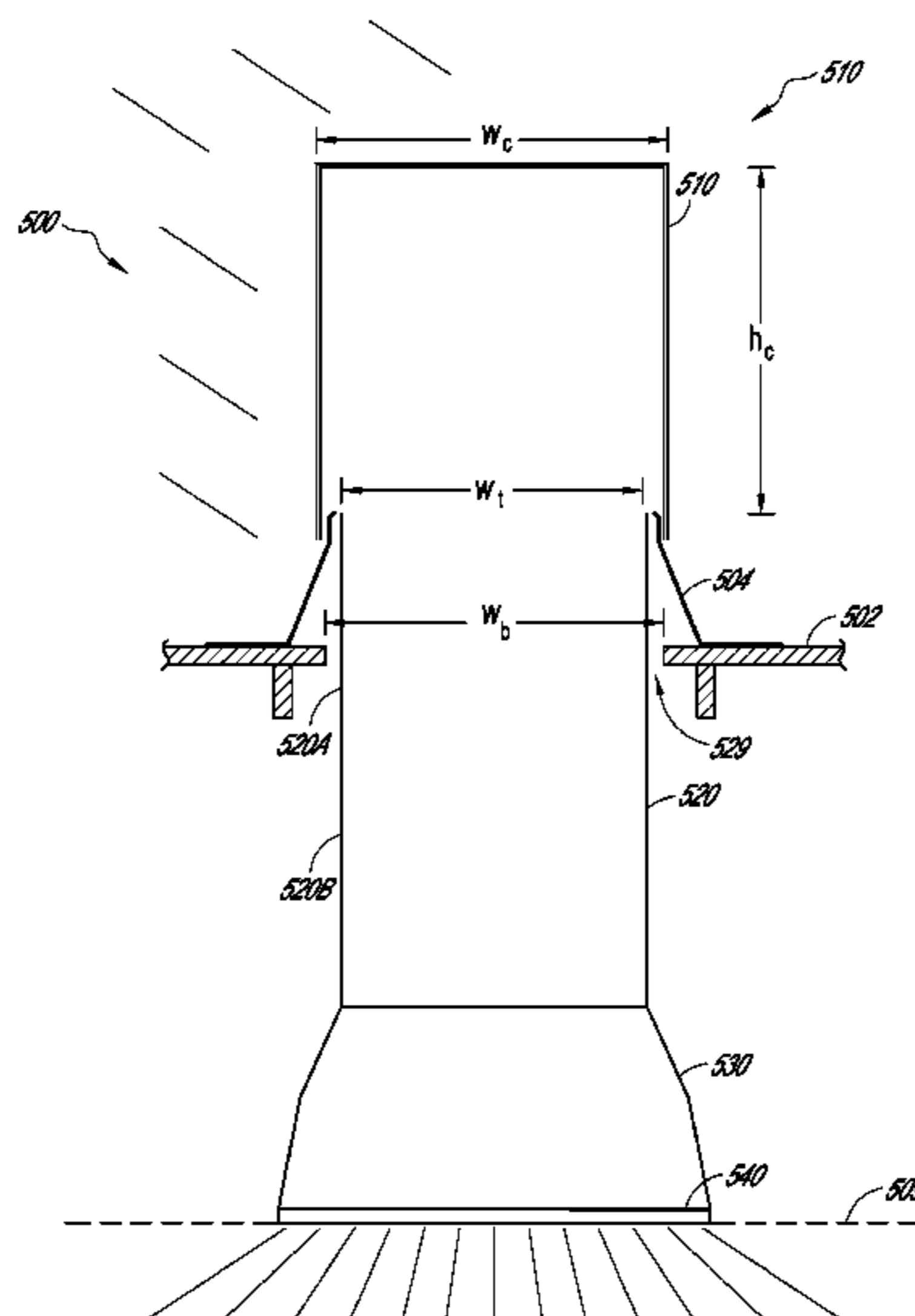
- (58) **Field of Classification Search**
CPC F21S 11/00; F21S 11/002
USPC 359/591–592, 595, 597
See application file for complete search history.

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21 Claims, 22 Drawing Sheets



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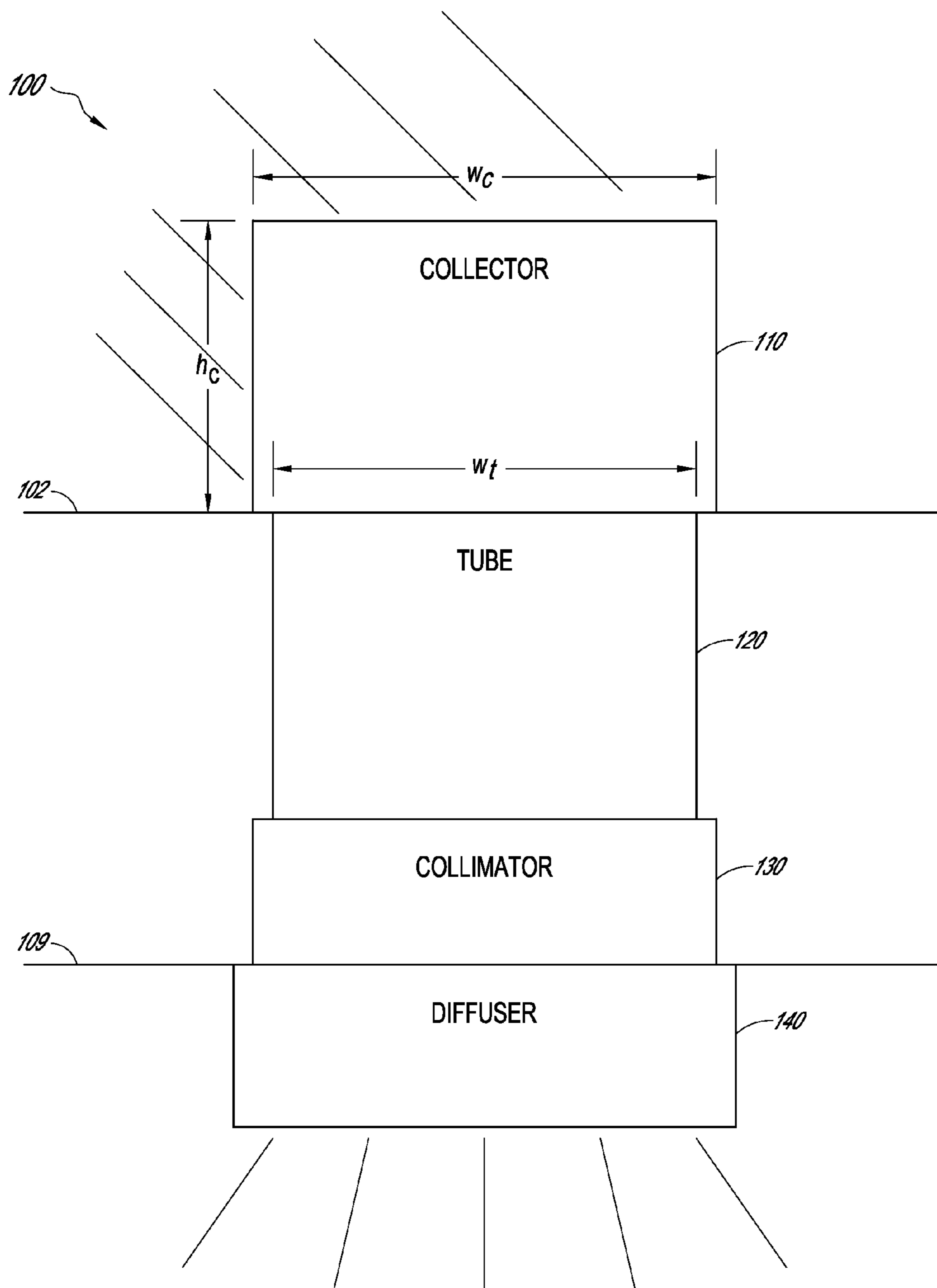


FIG. 1

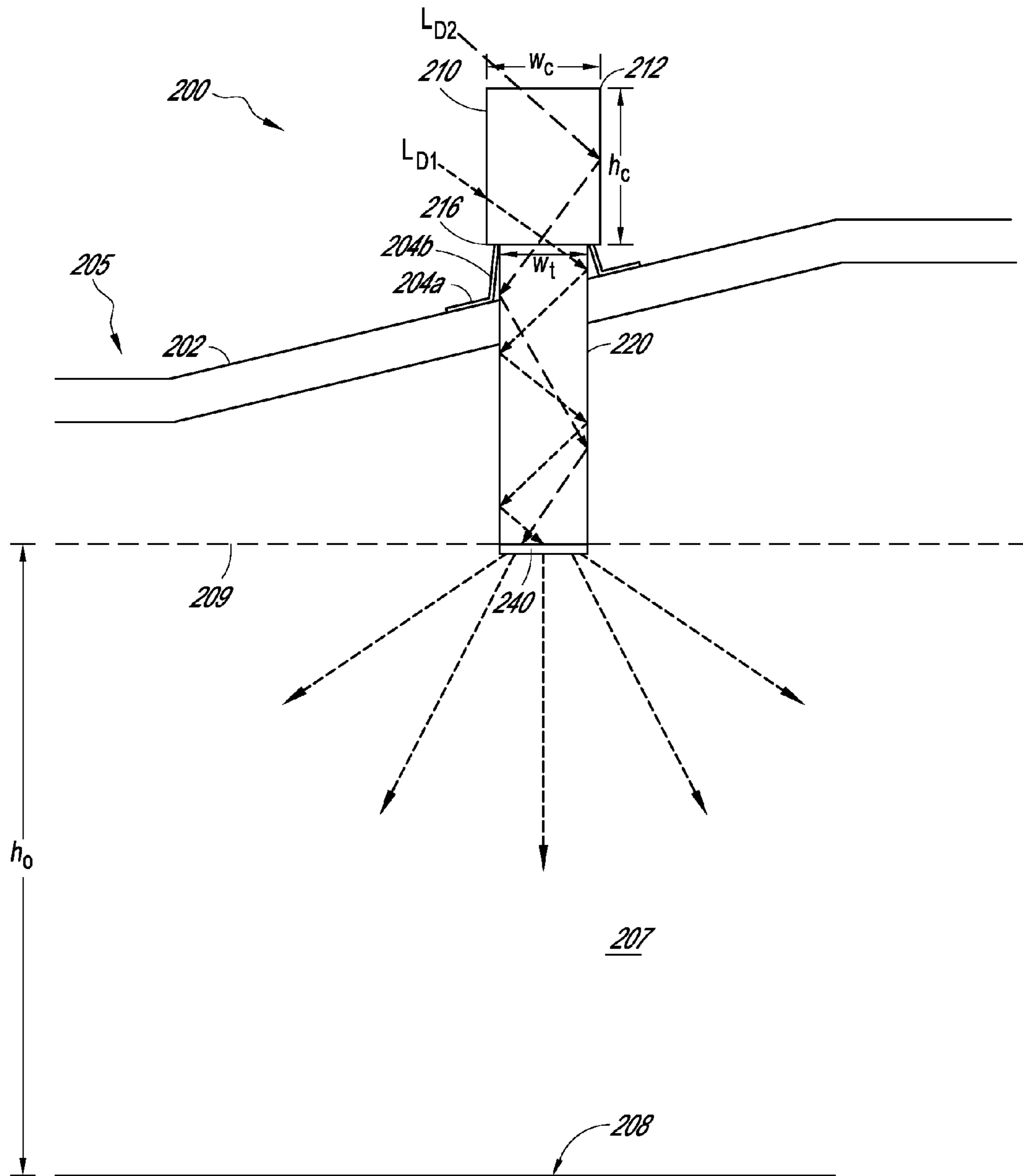


FIG. 2

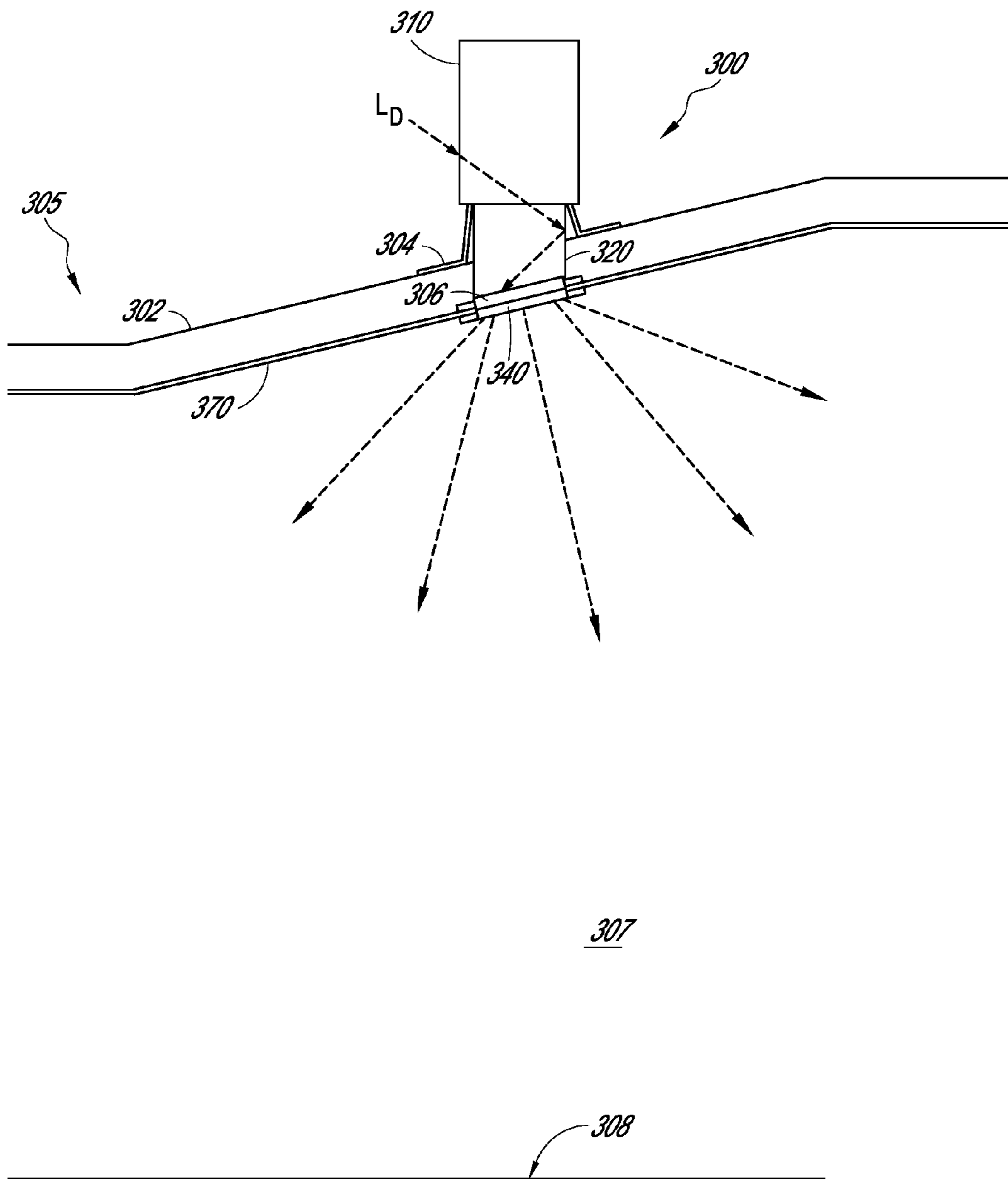


FIG. 3

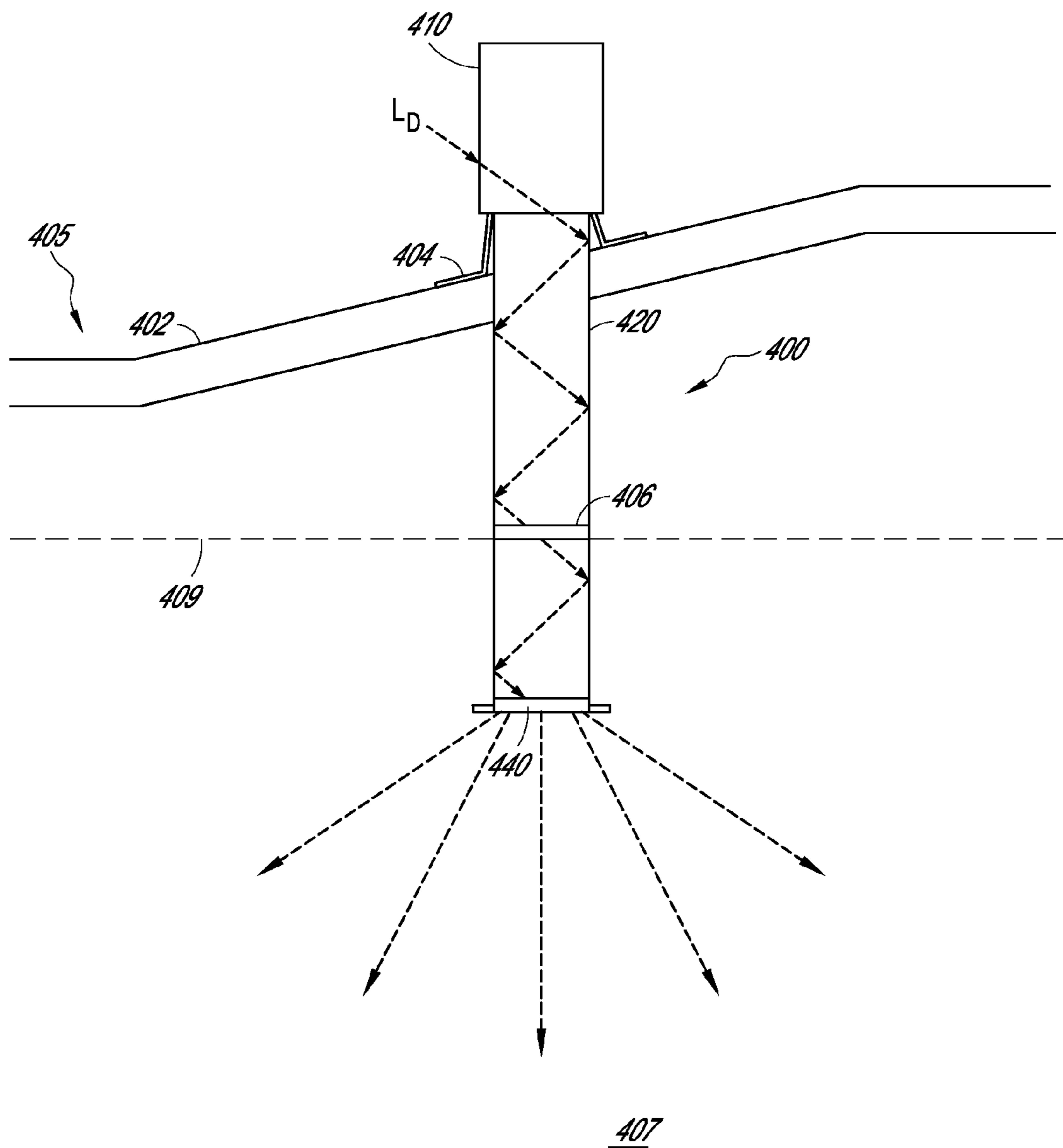


FIG. 4

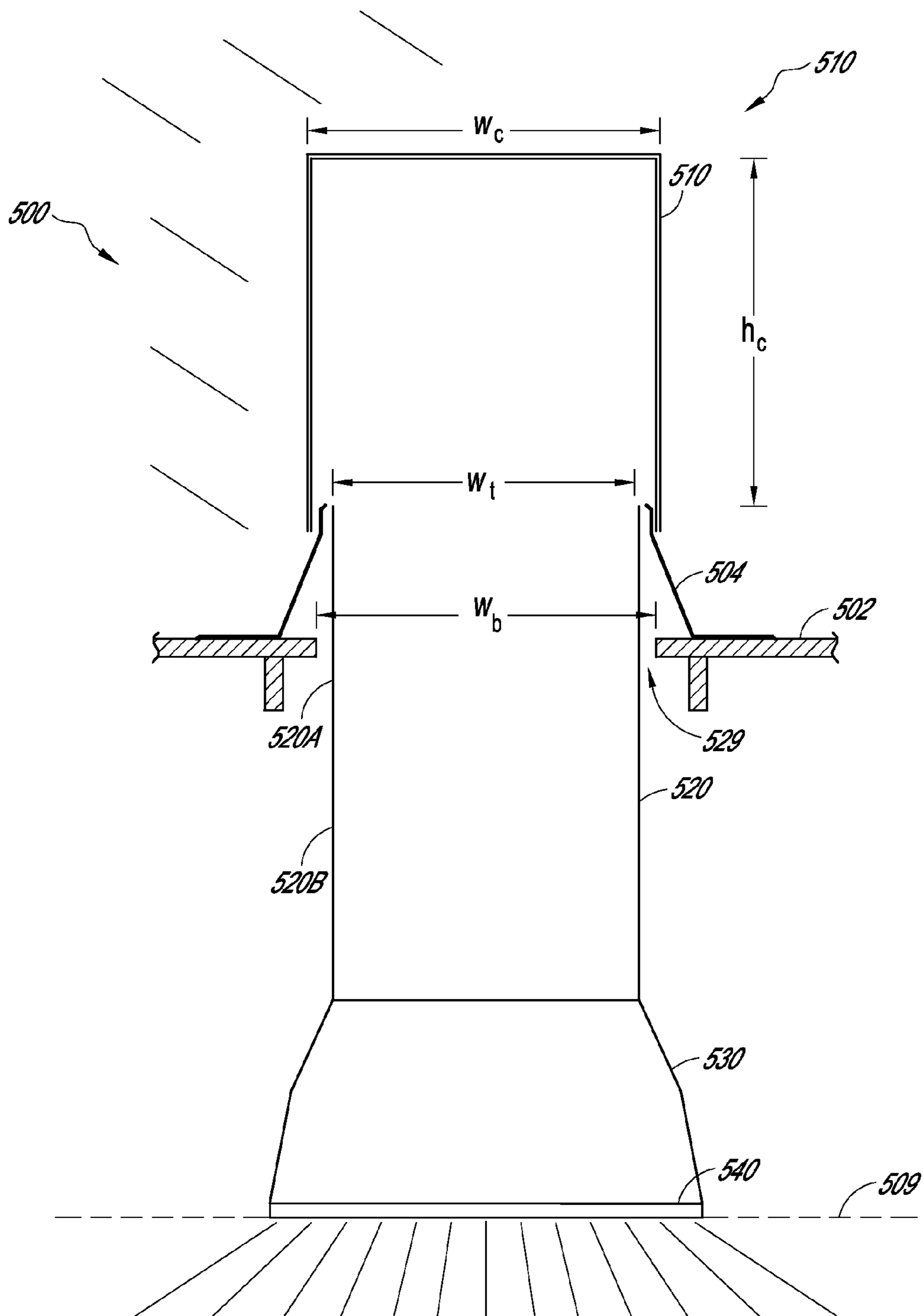


FIG. 5

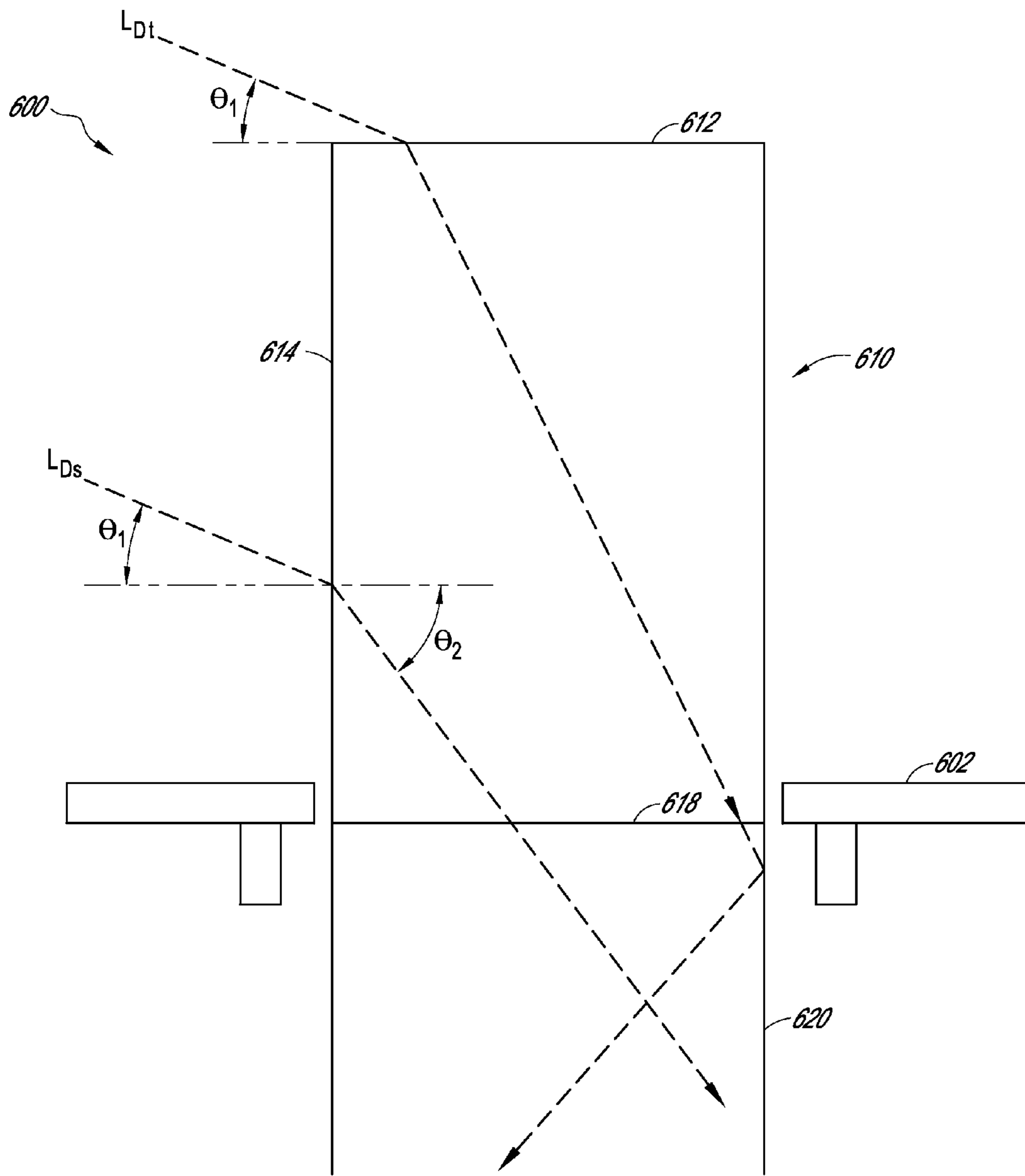


FIG. 6

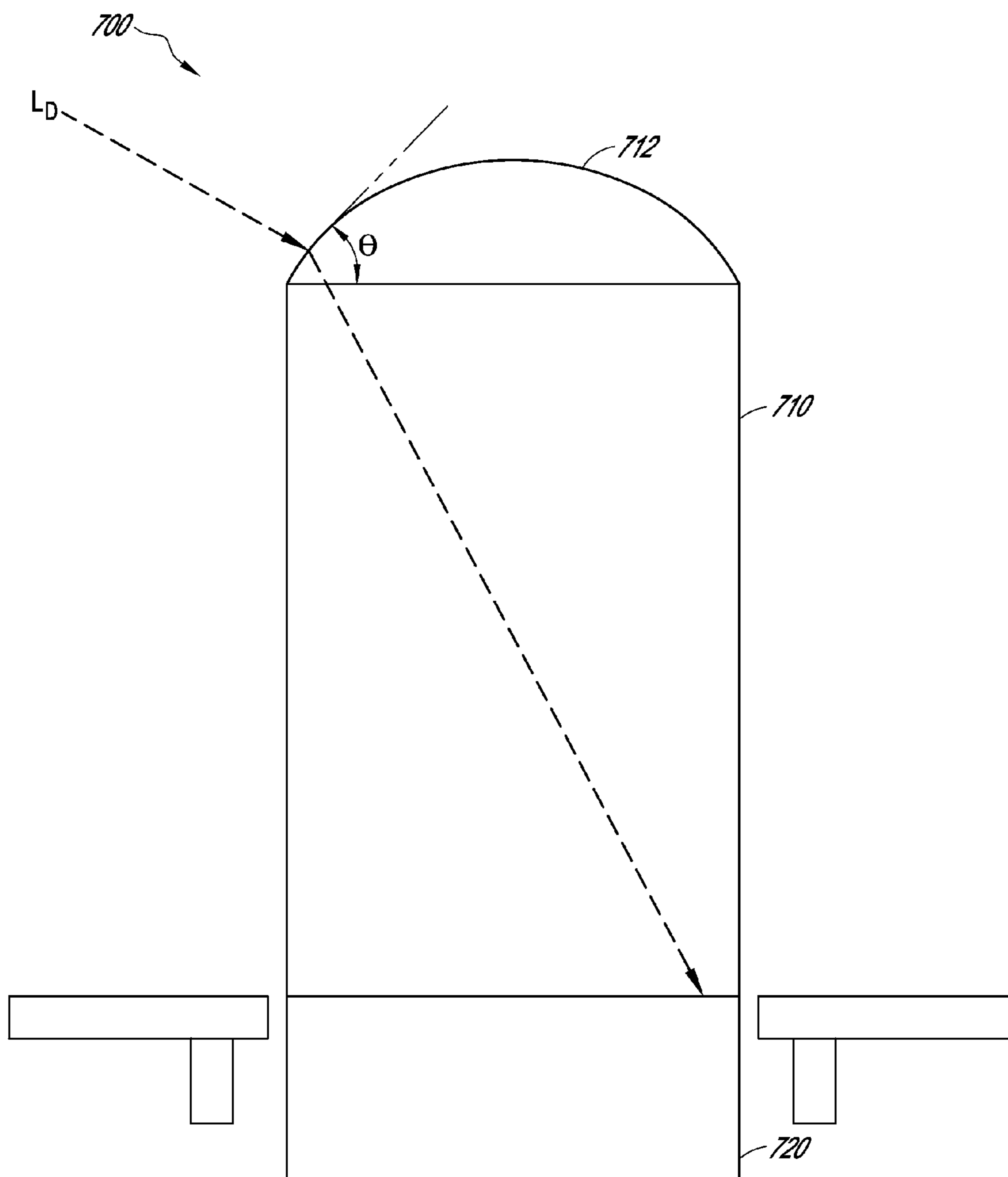


FIG. 7

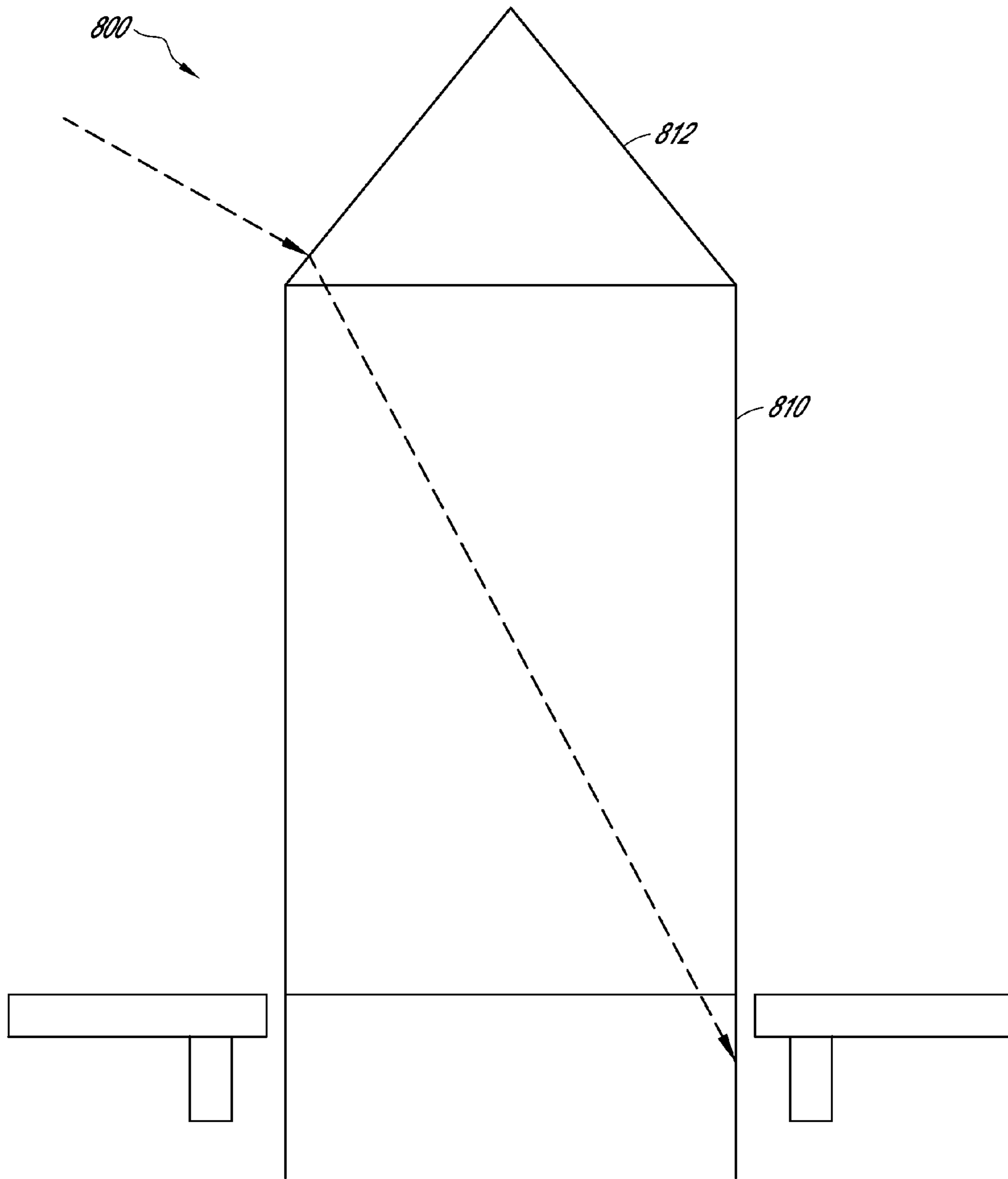


FIG. 8

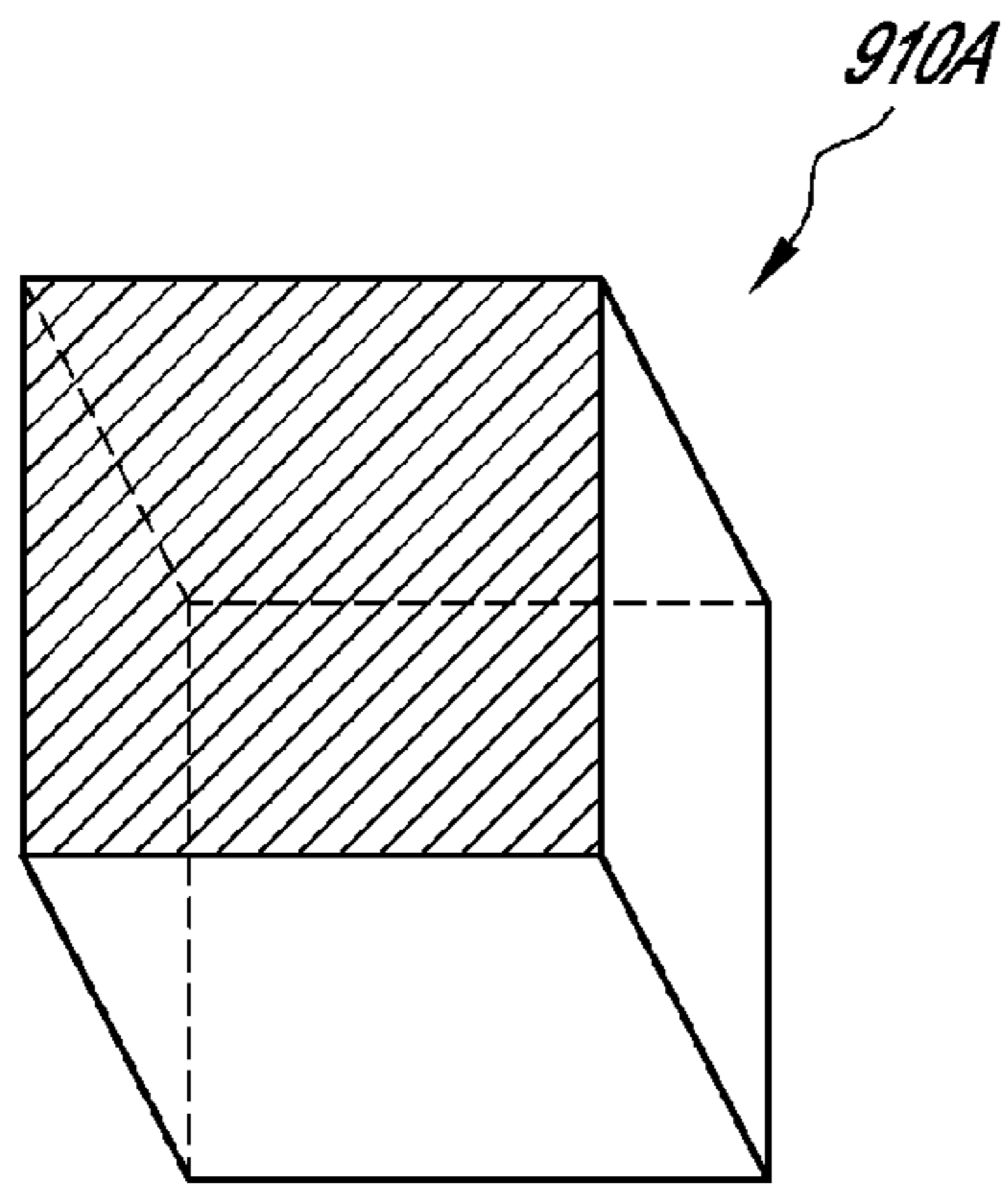


FIG. 9A

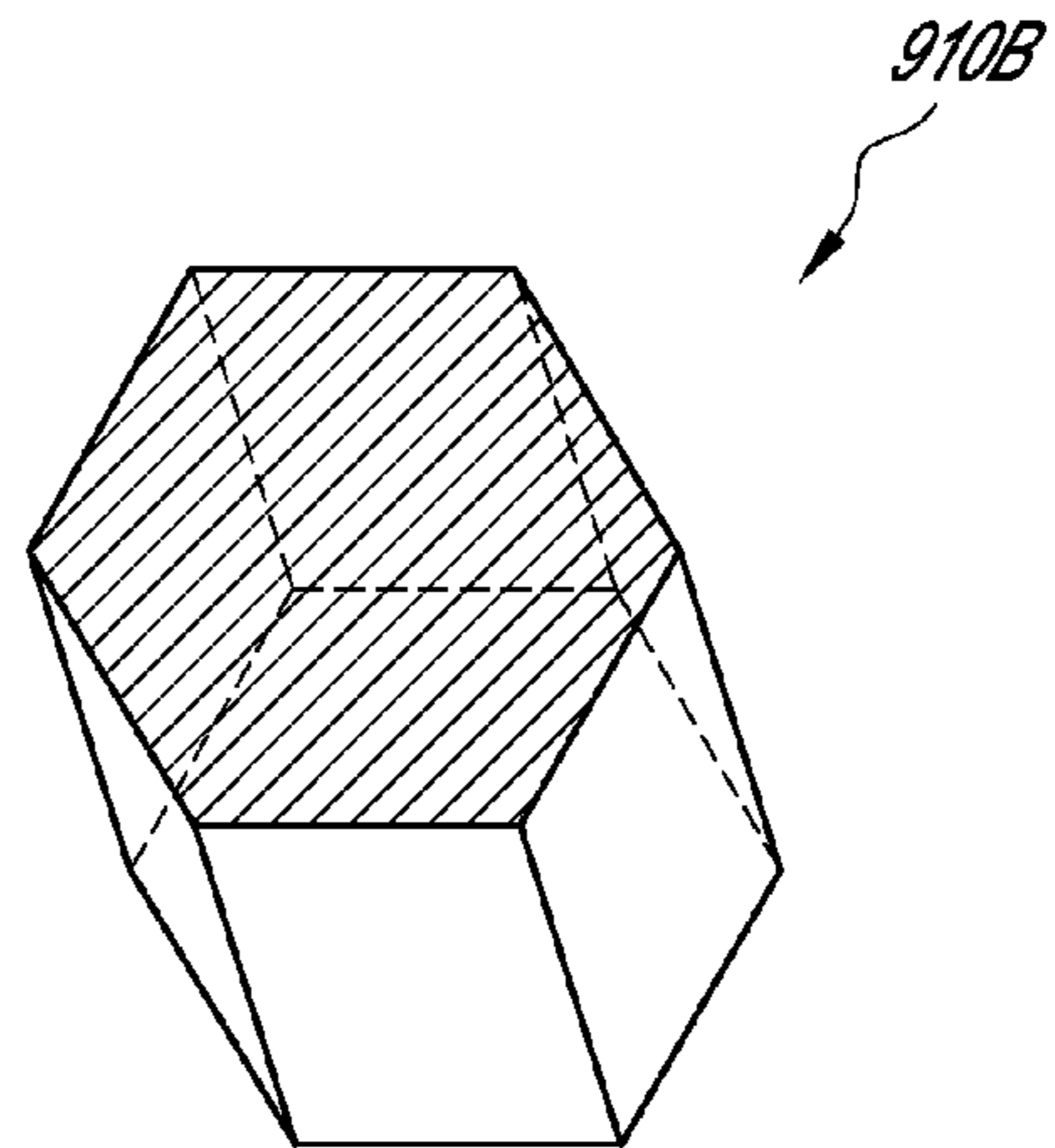


FIG. 9B

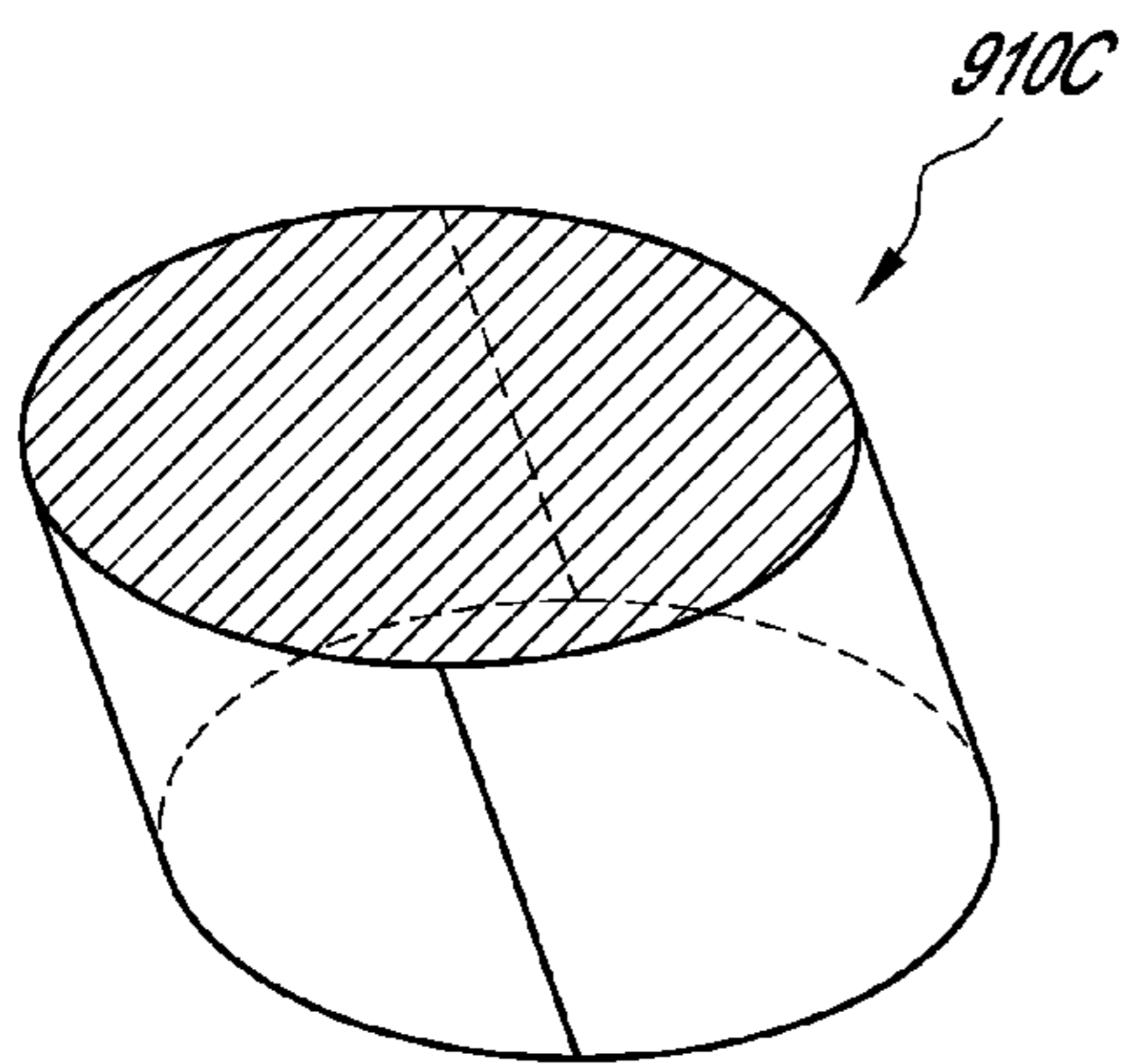


FIG. 9C

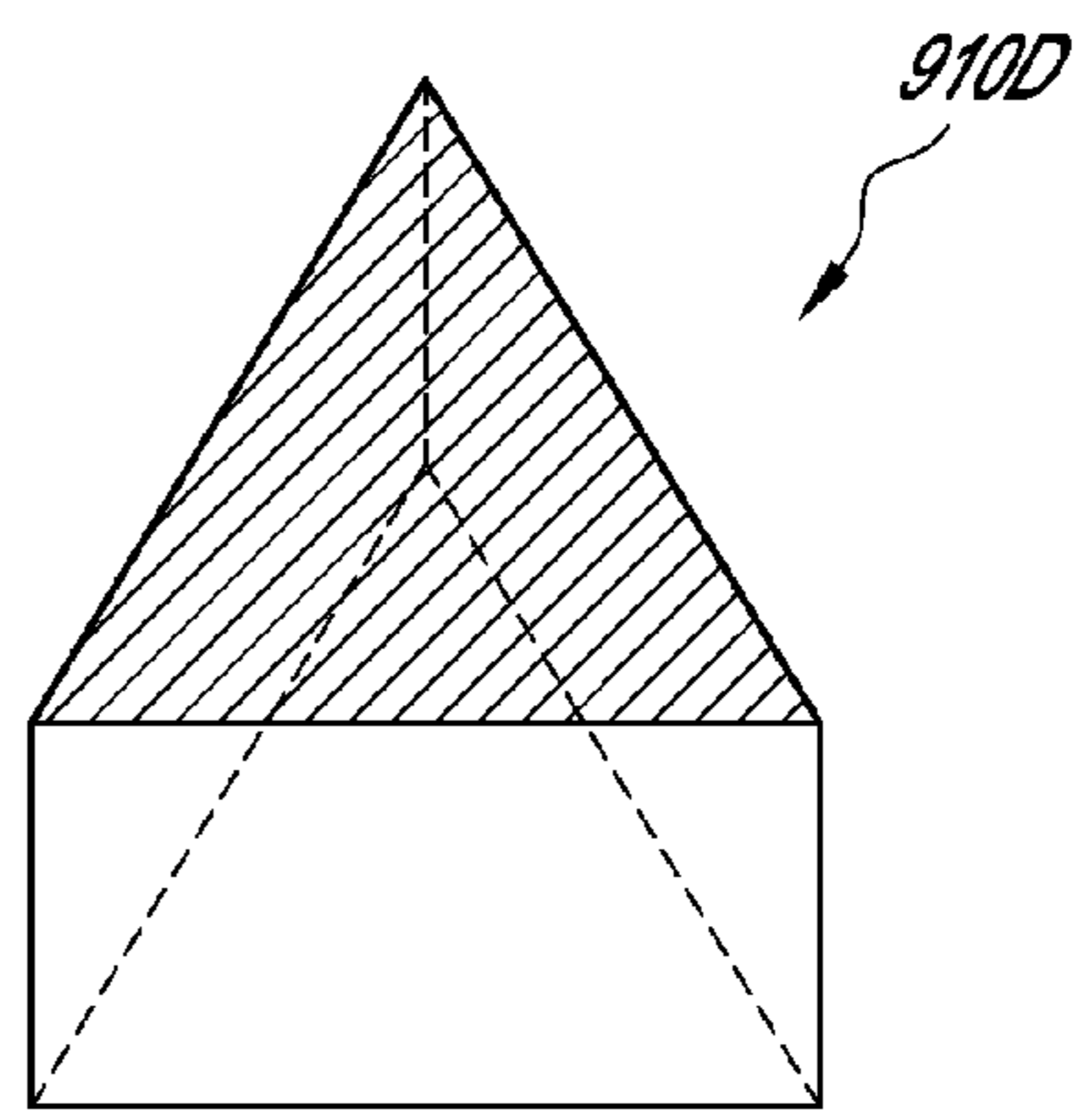


FIG. 9D

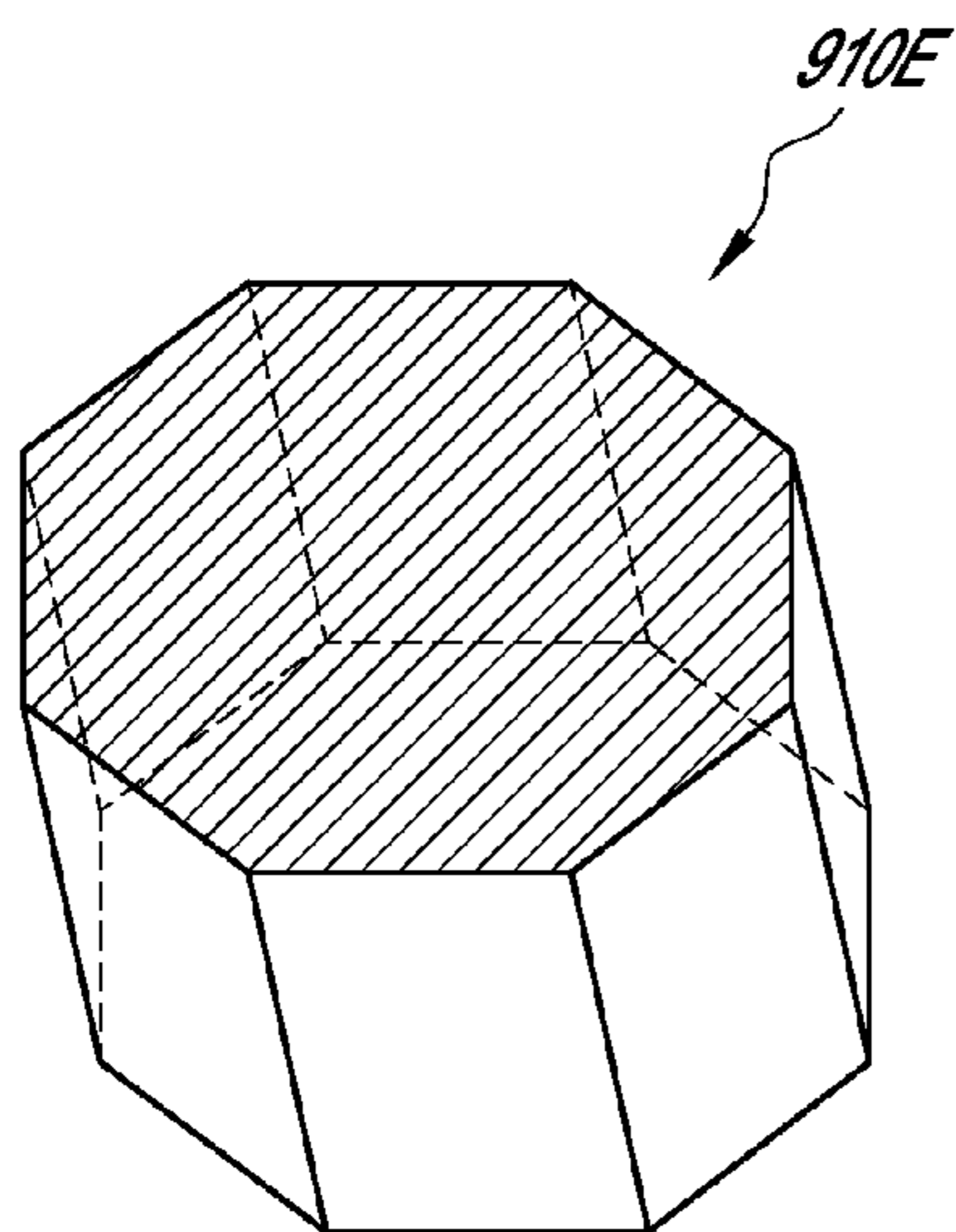


FIG. 9E

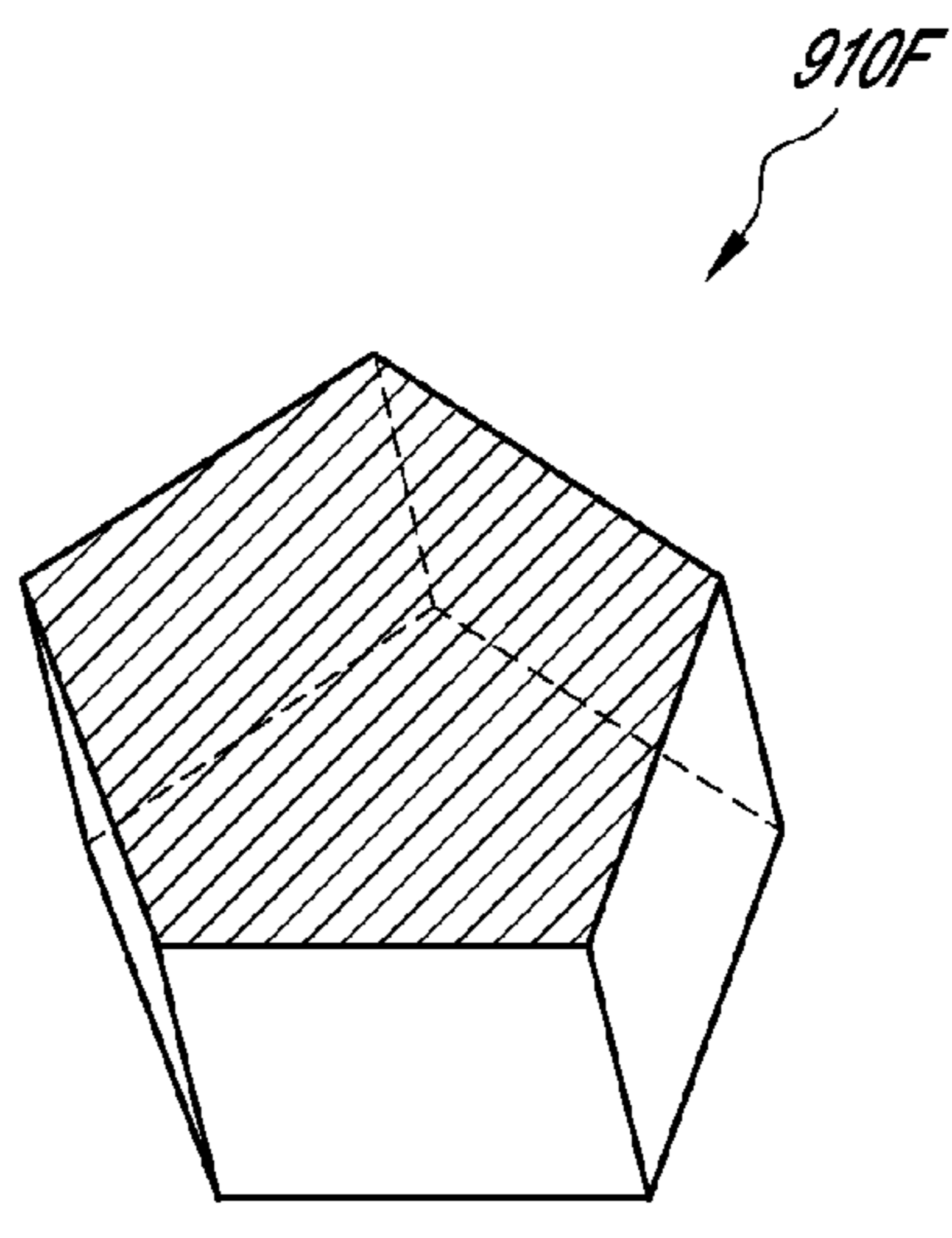


FIG. 9F

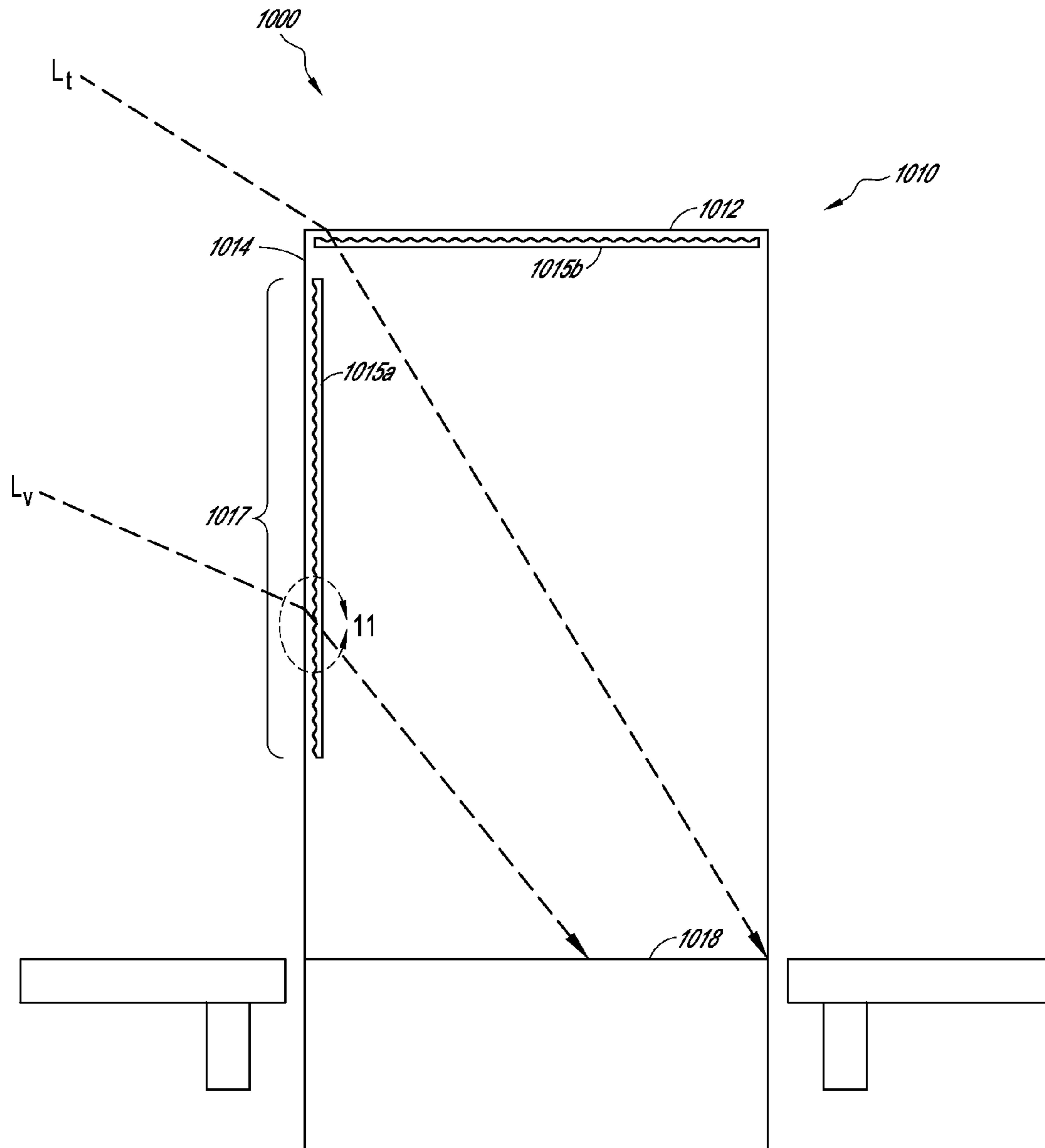


FIG. 10

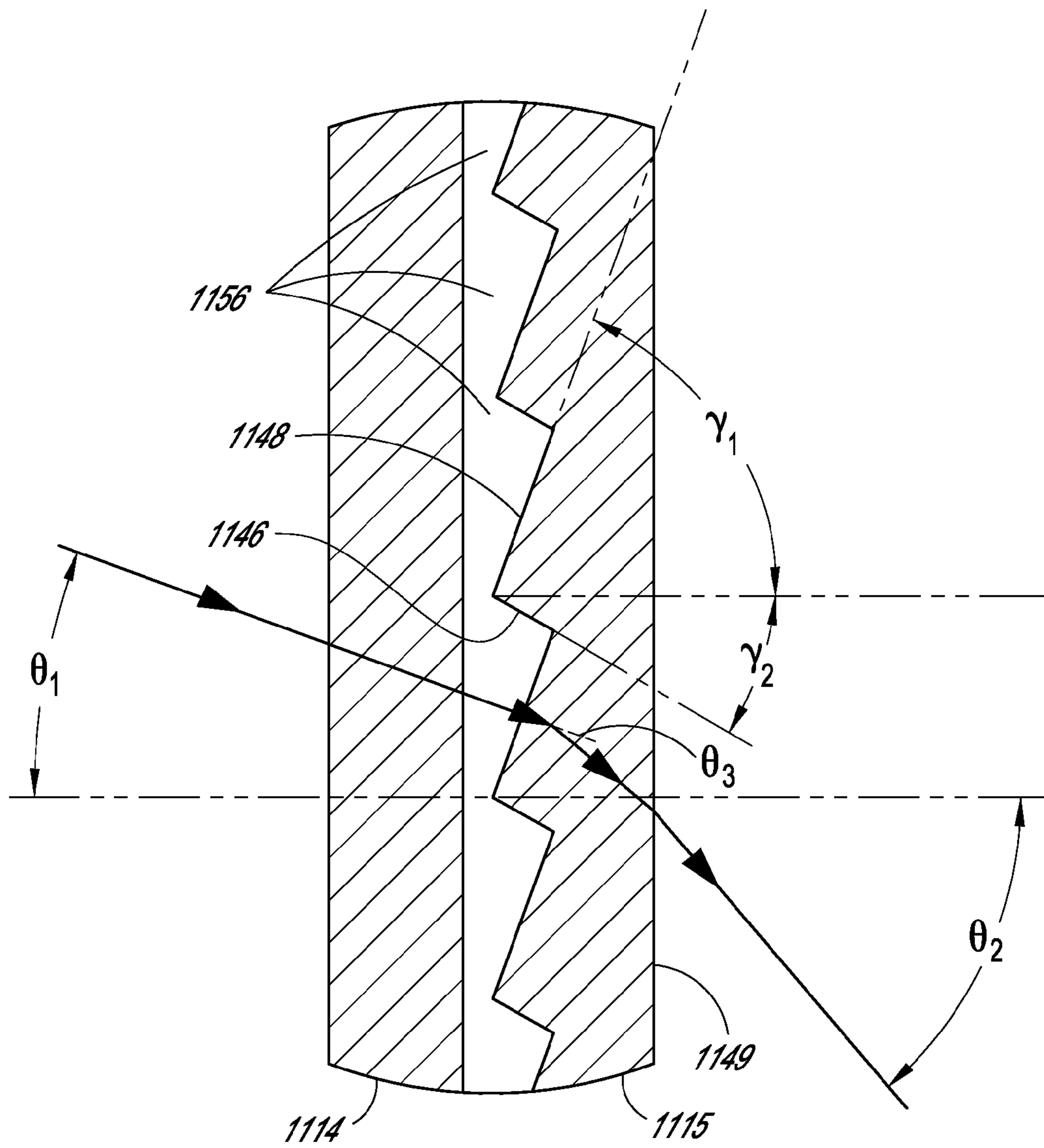


FIG. 11

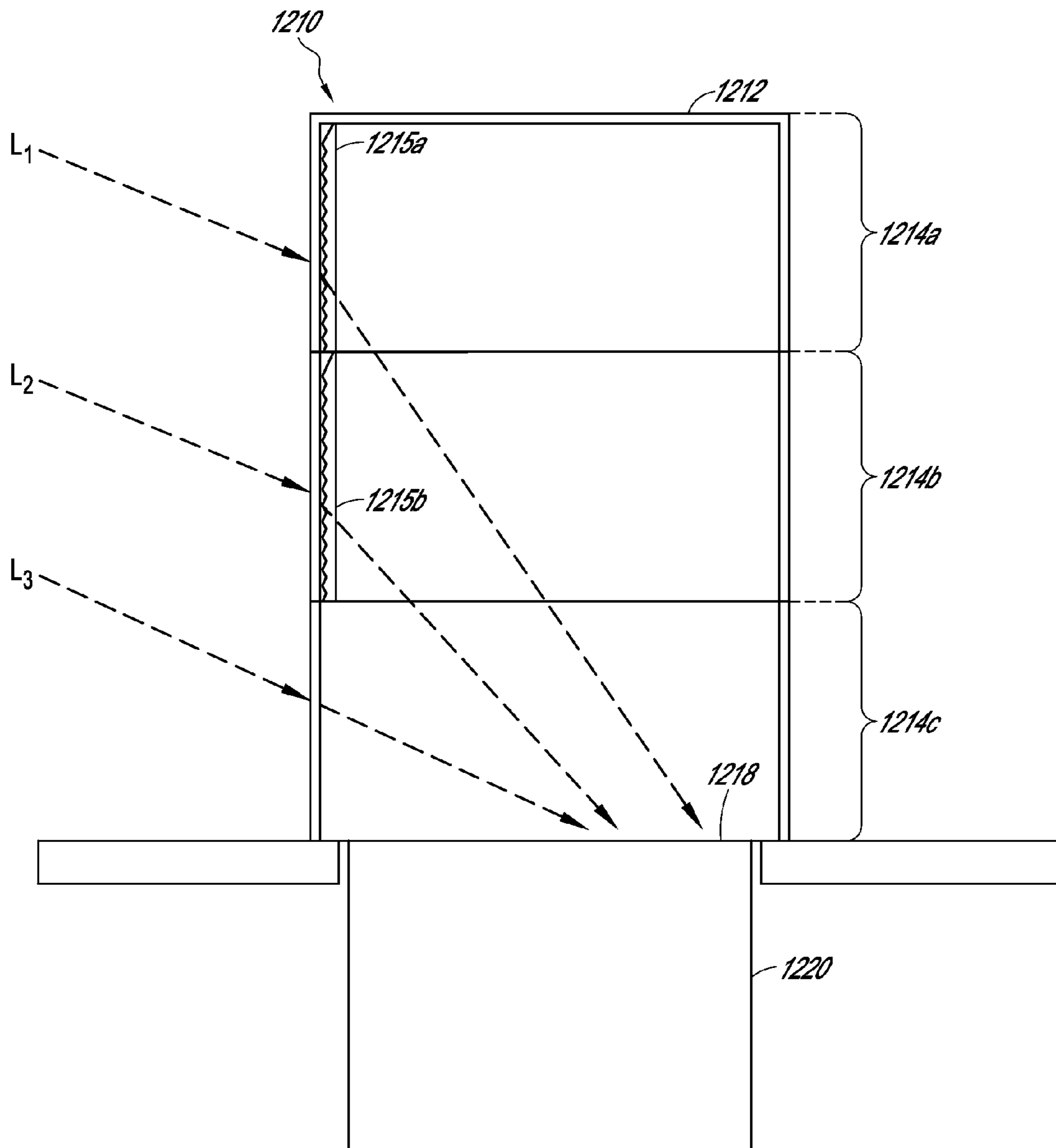


FIG. 12

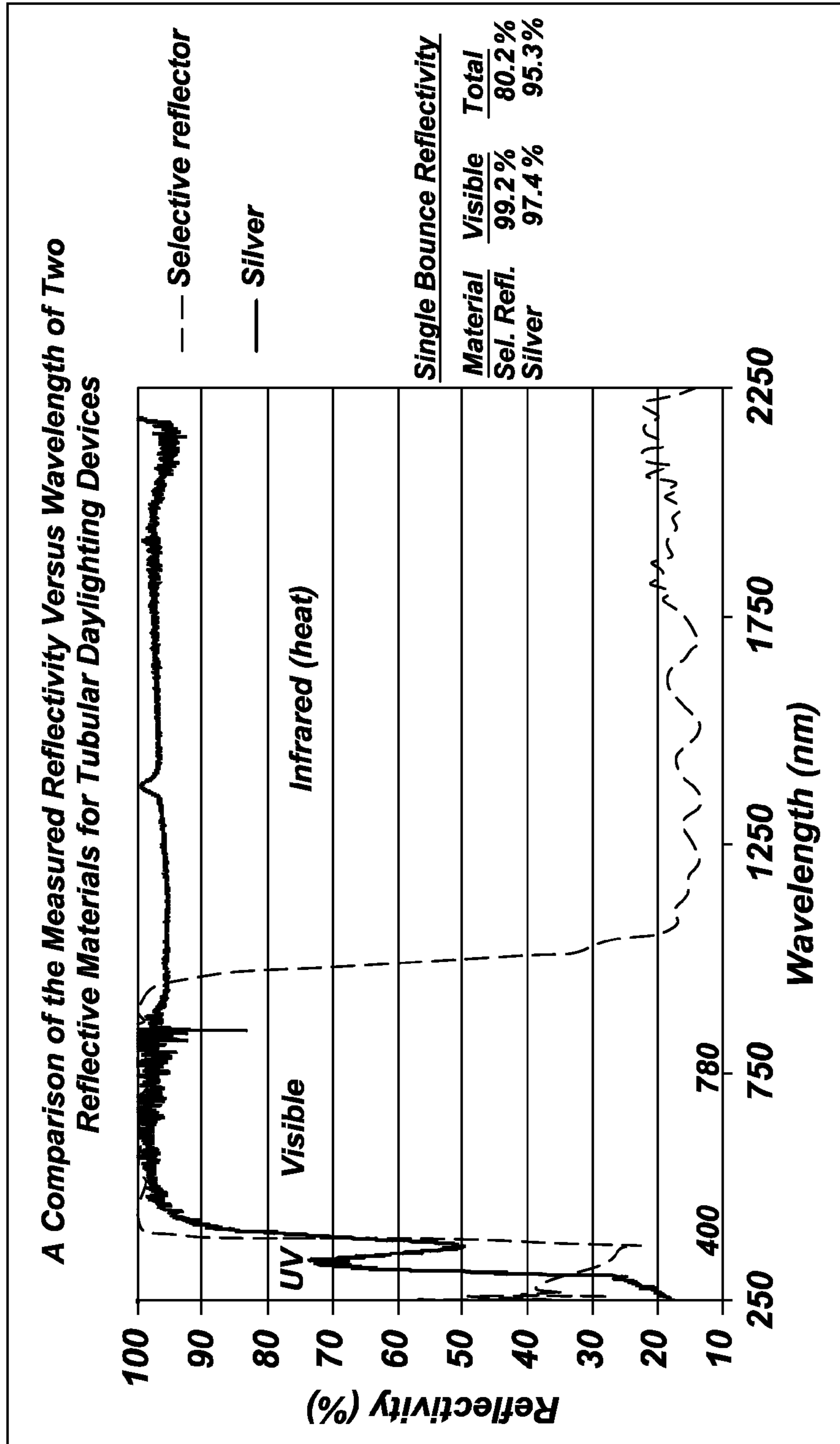


FIG. 13

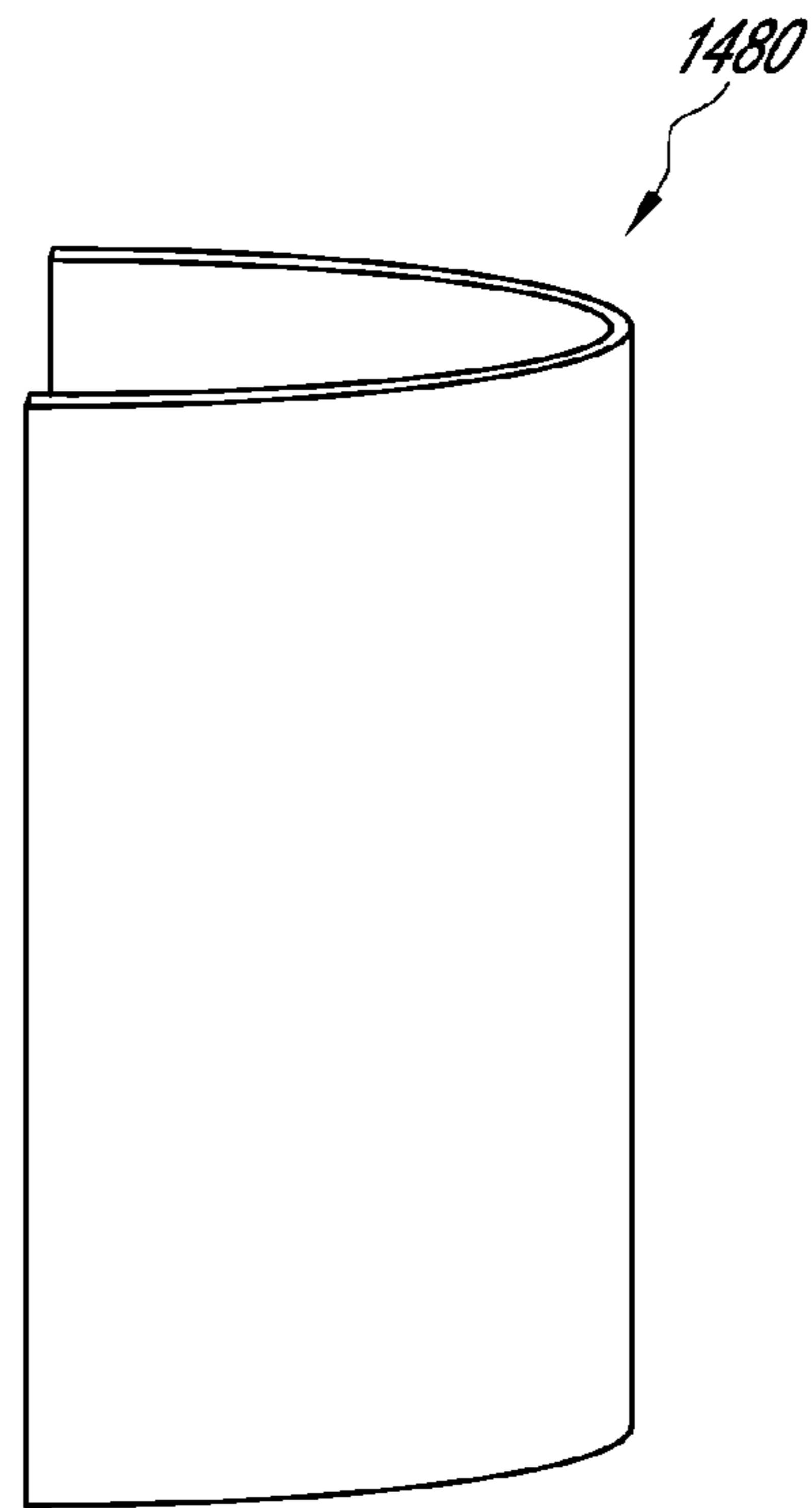


FIG. 14A

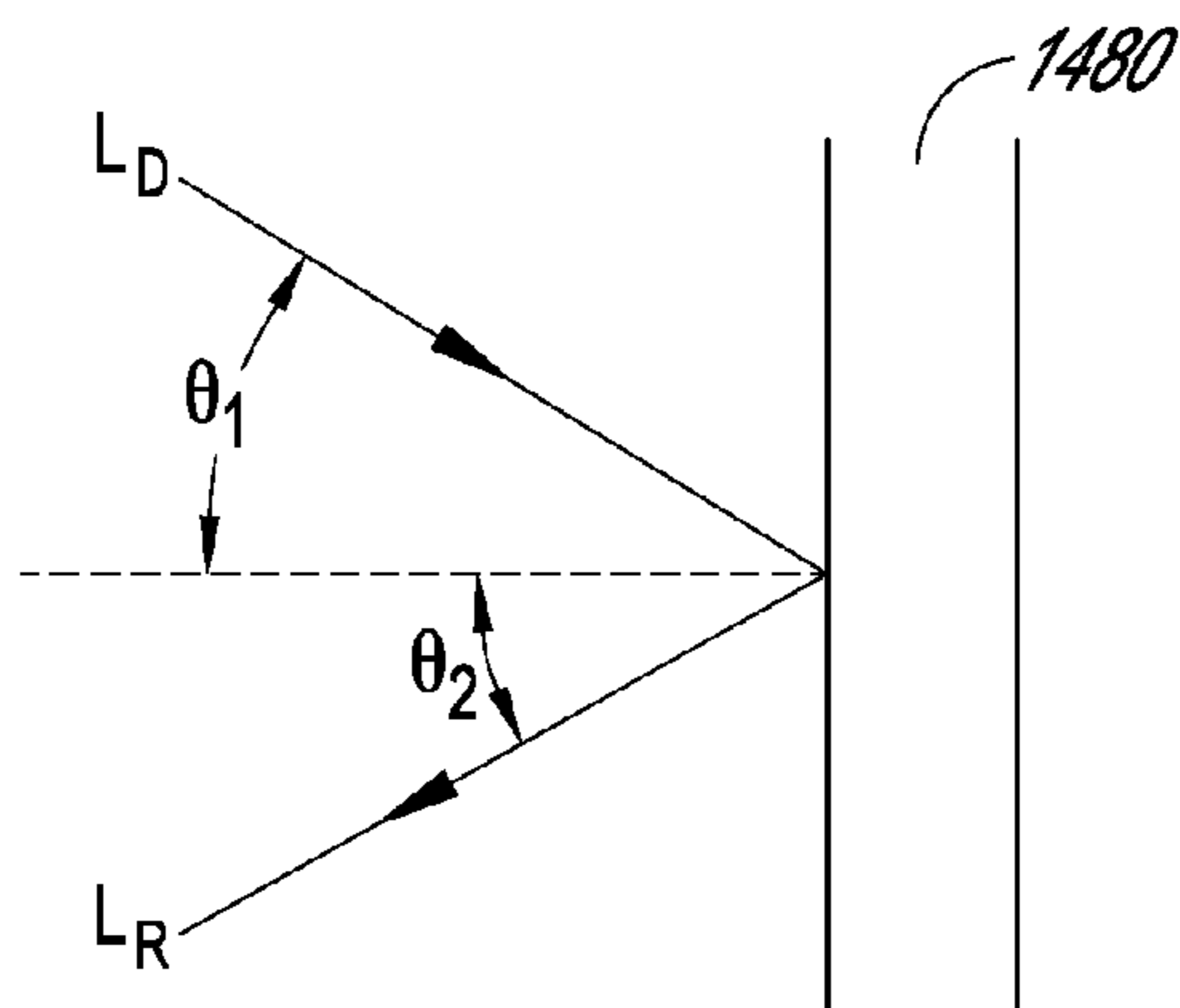


FIG. 14C

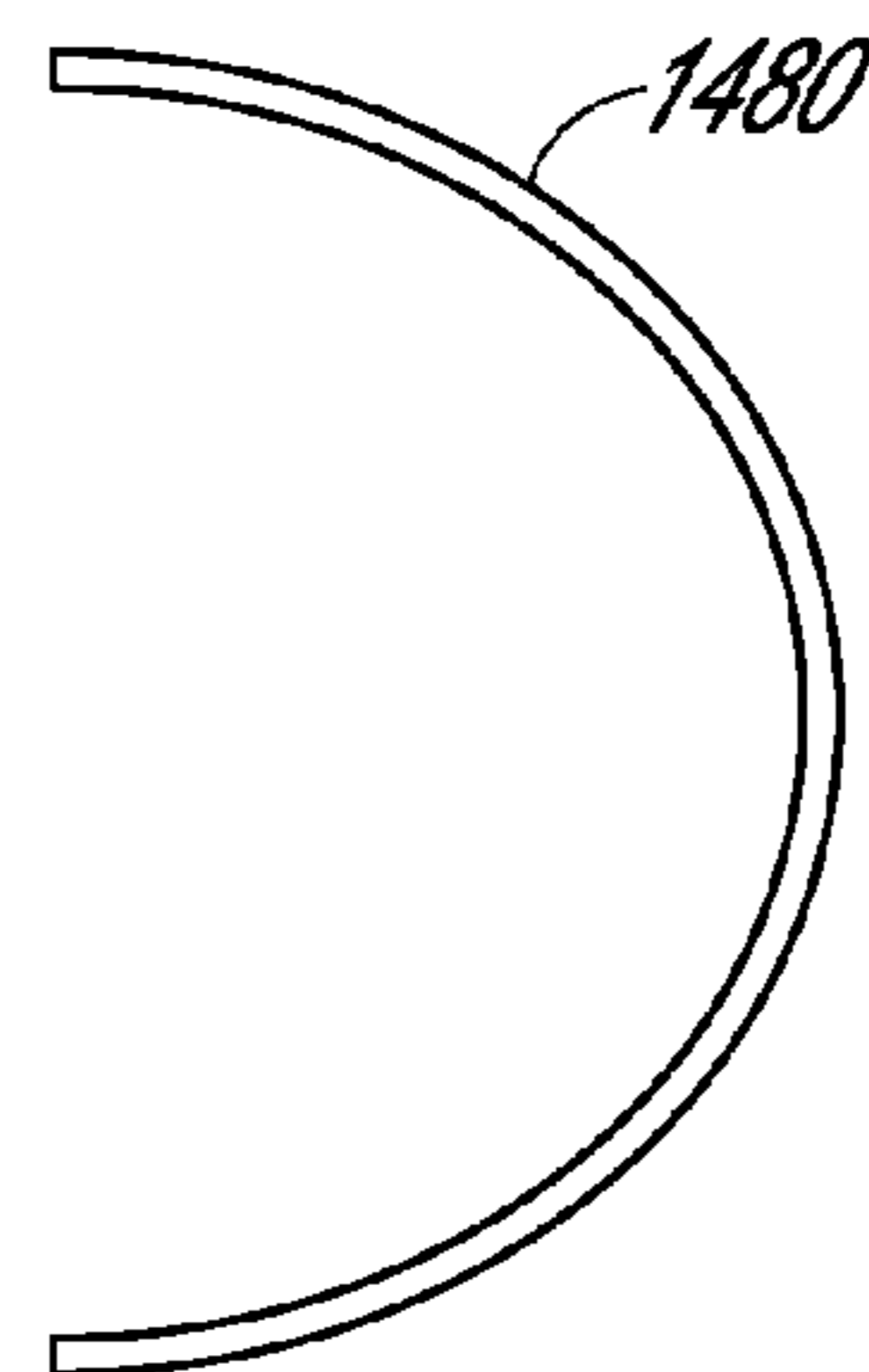


FIG. 14B

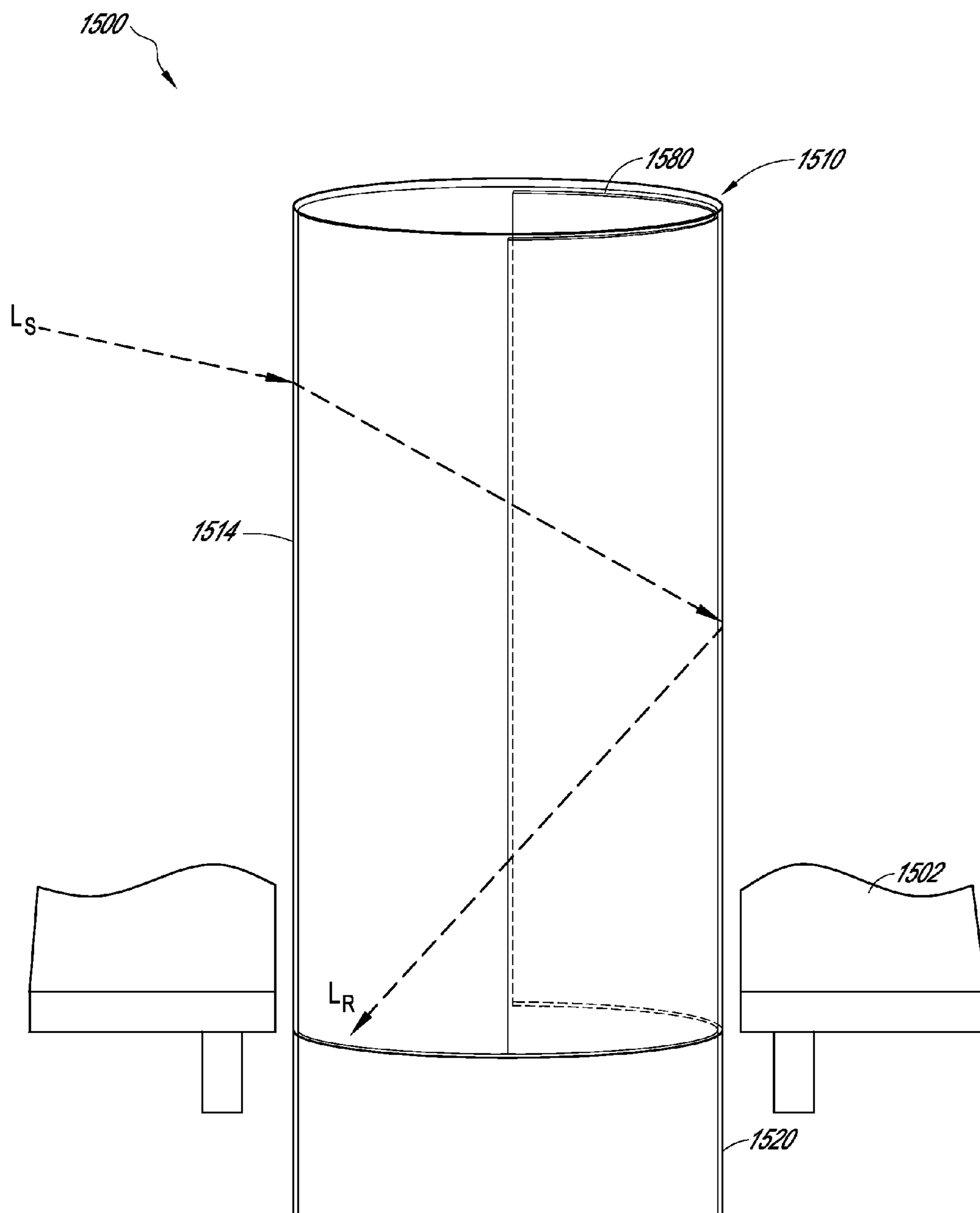


FIG. 15

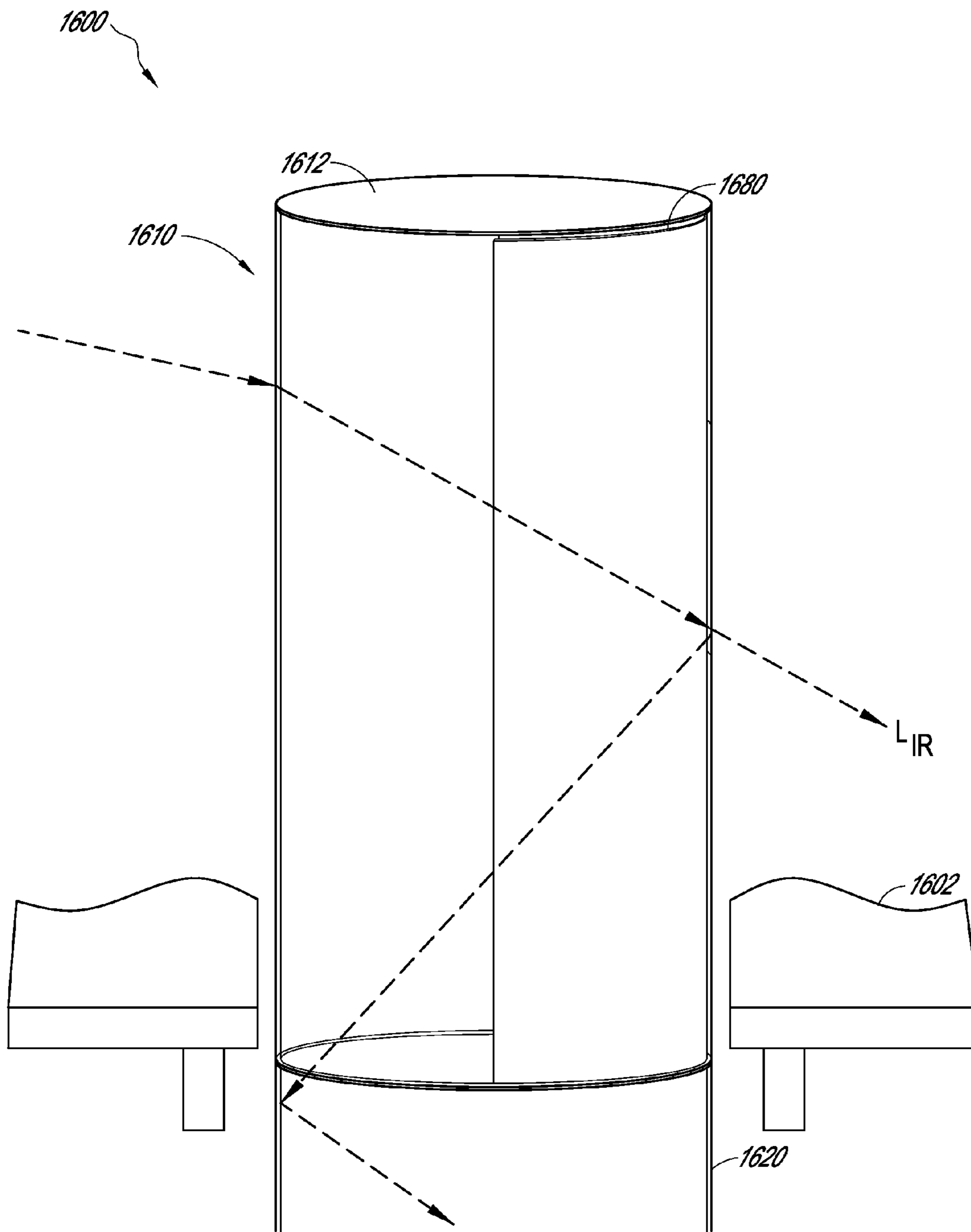


FIG. 16

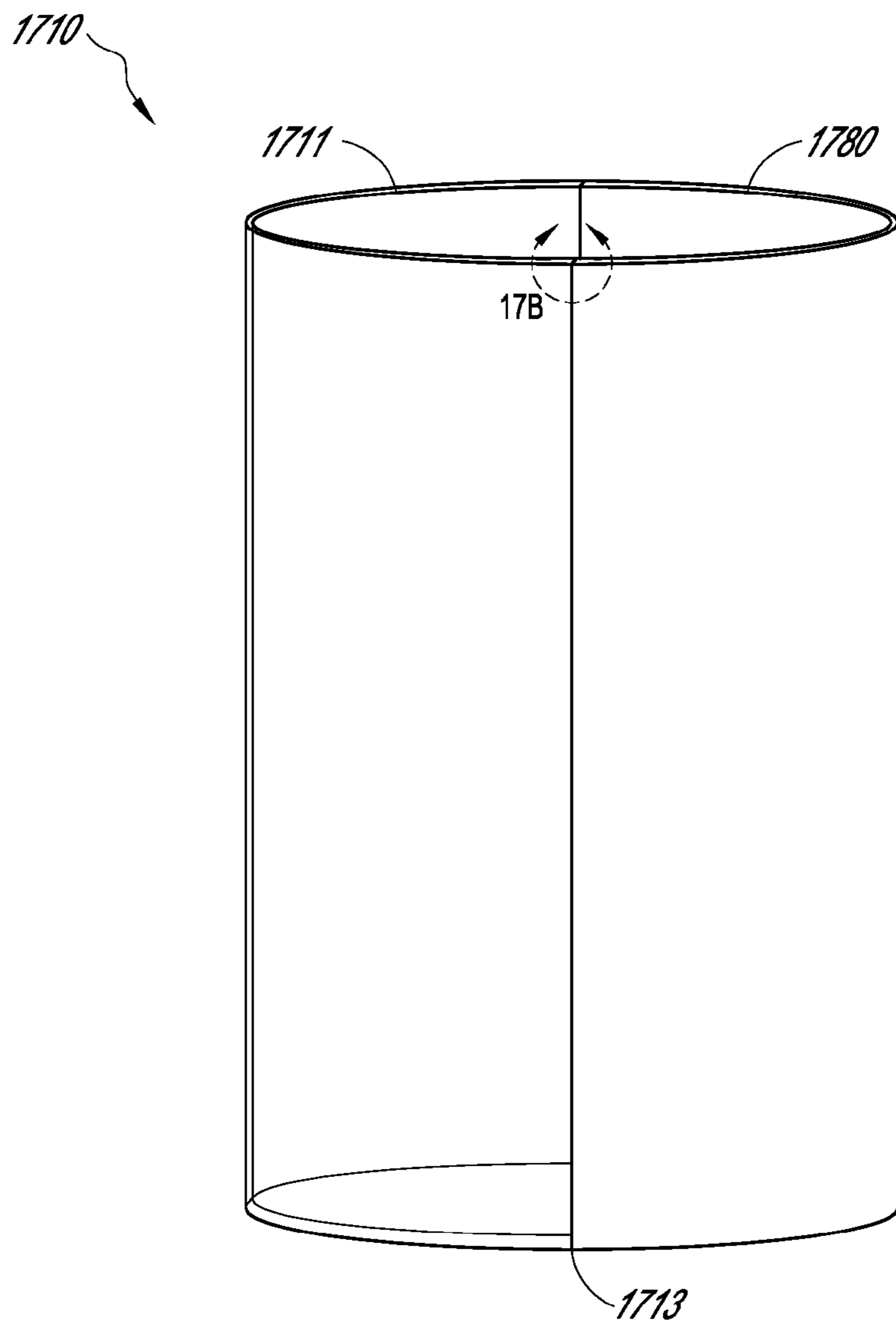


FIG. 17A

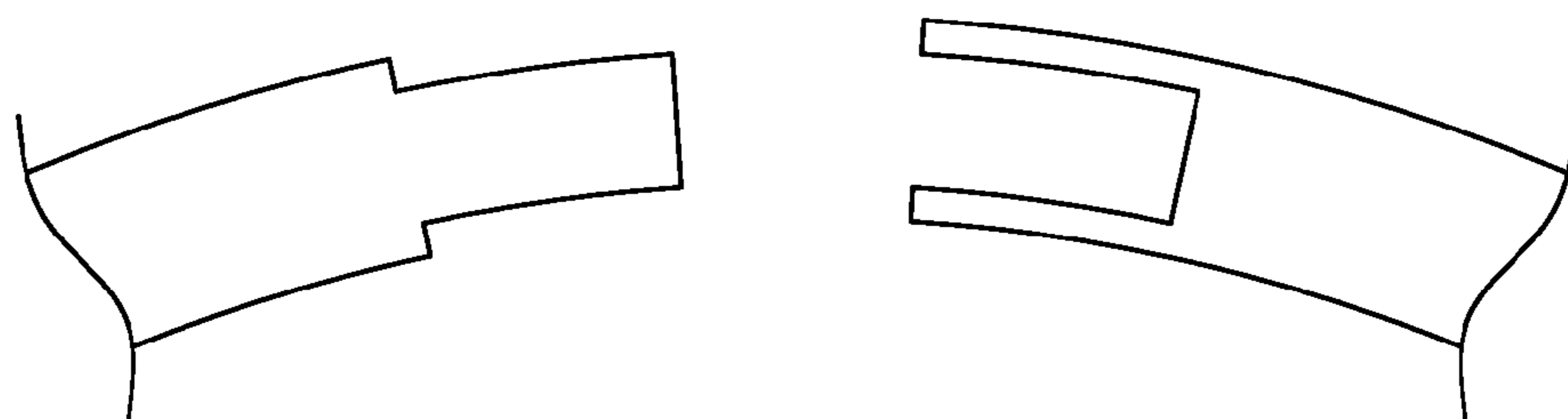


FIG. 17B

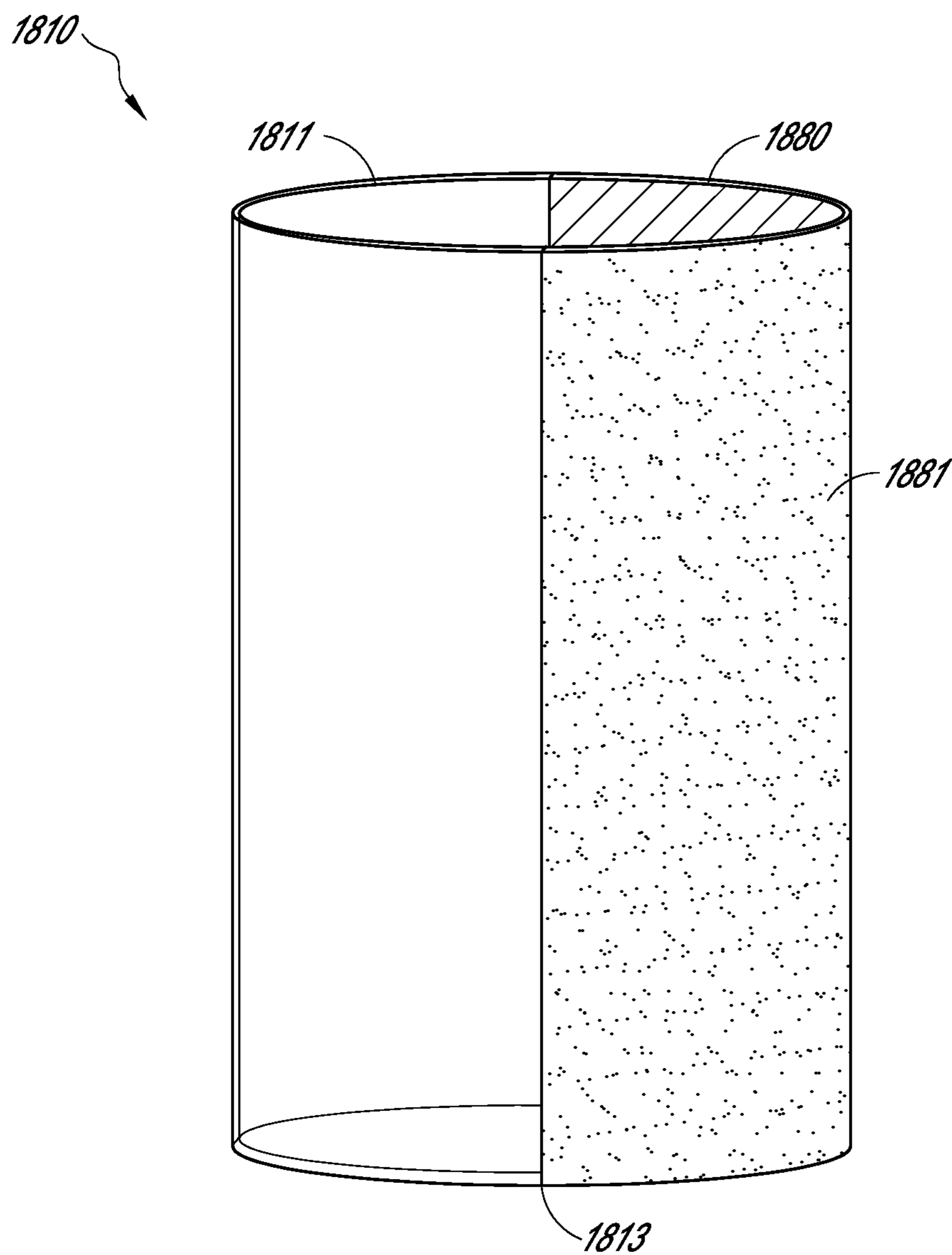


FIG. 18

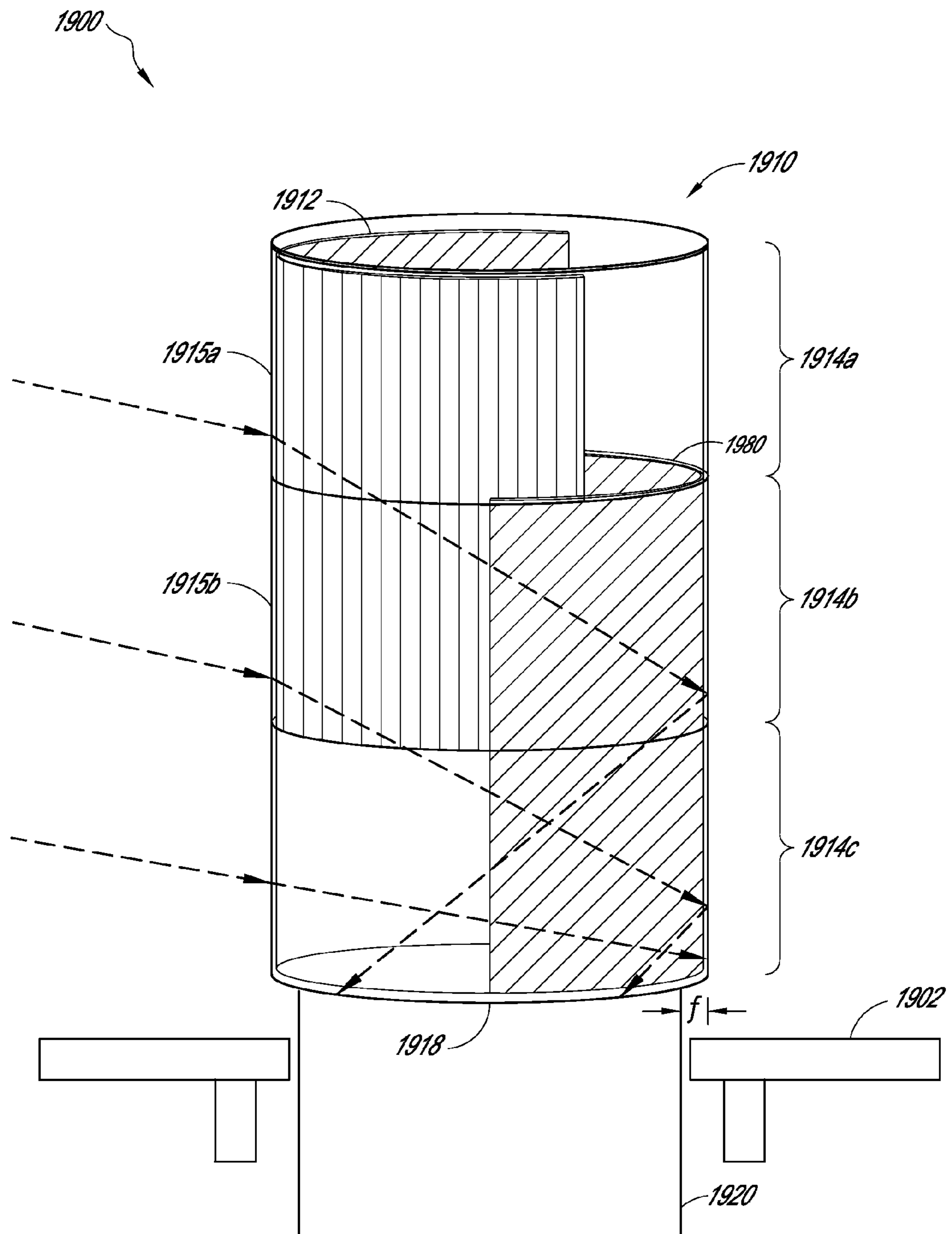


FIG. 19

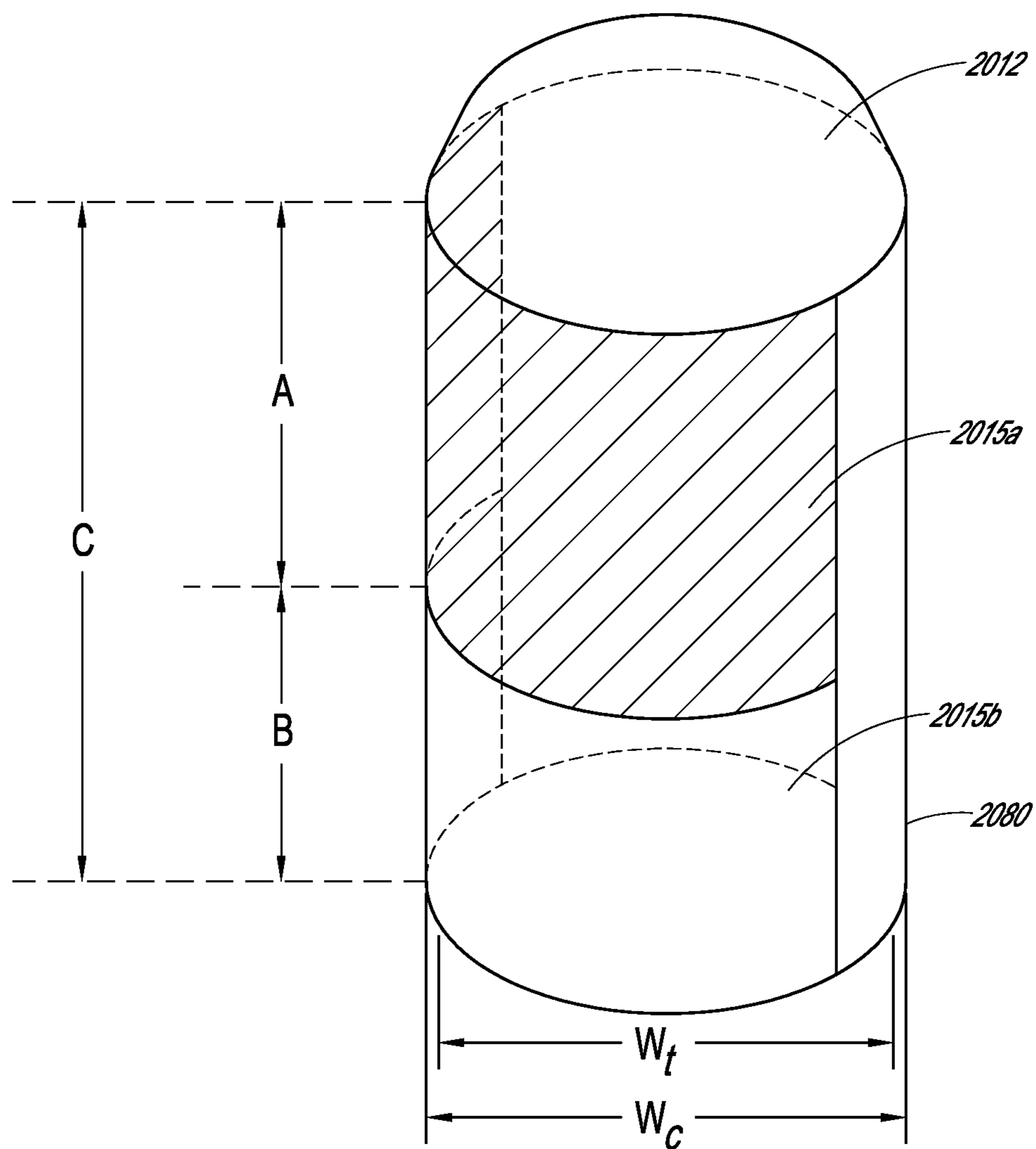


FIG. 20

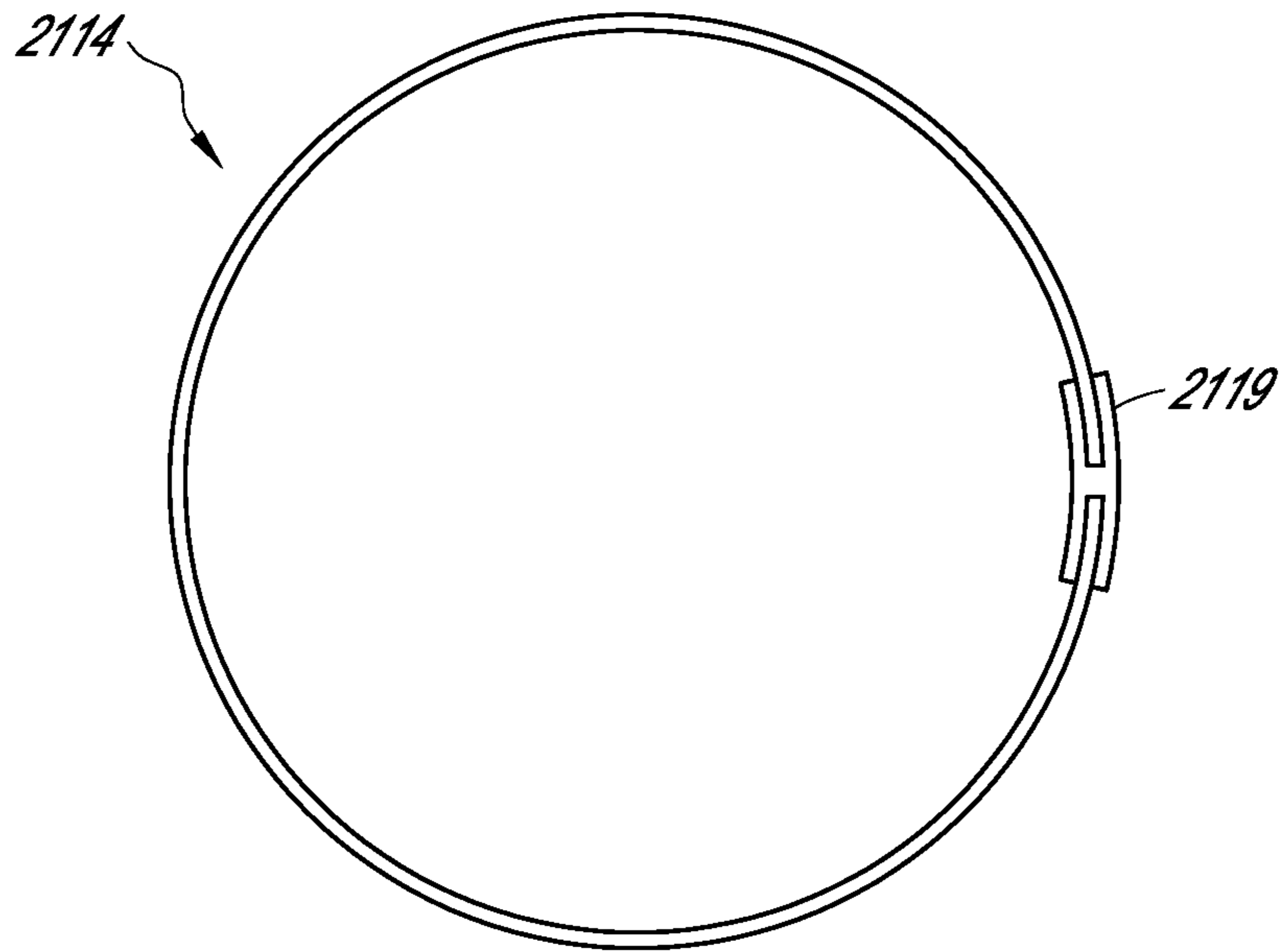


FIG. 21A

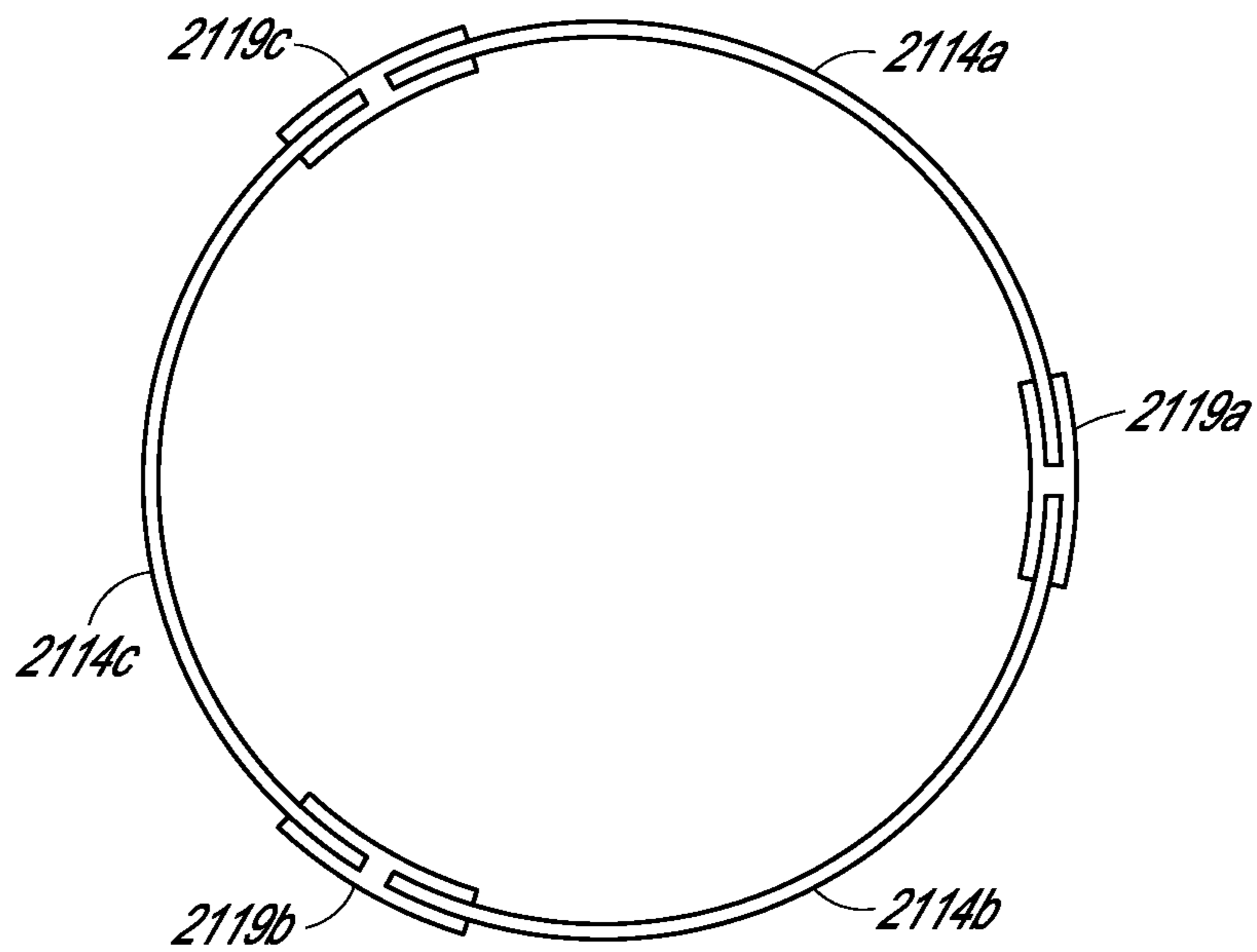


FIG. 21B

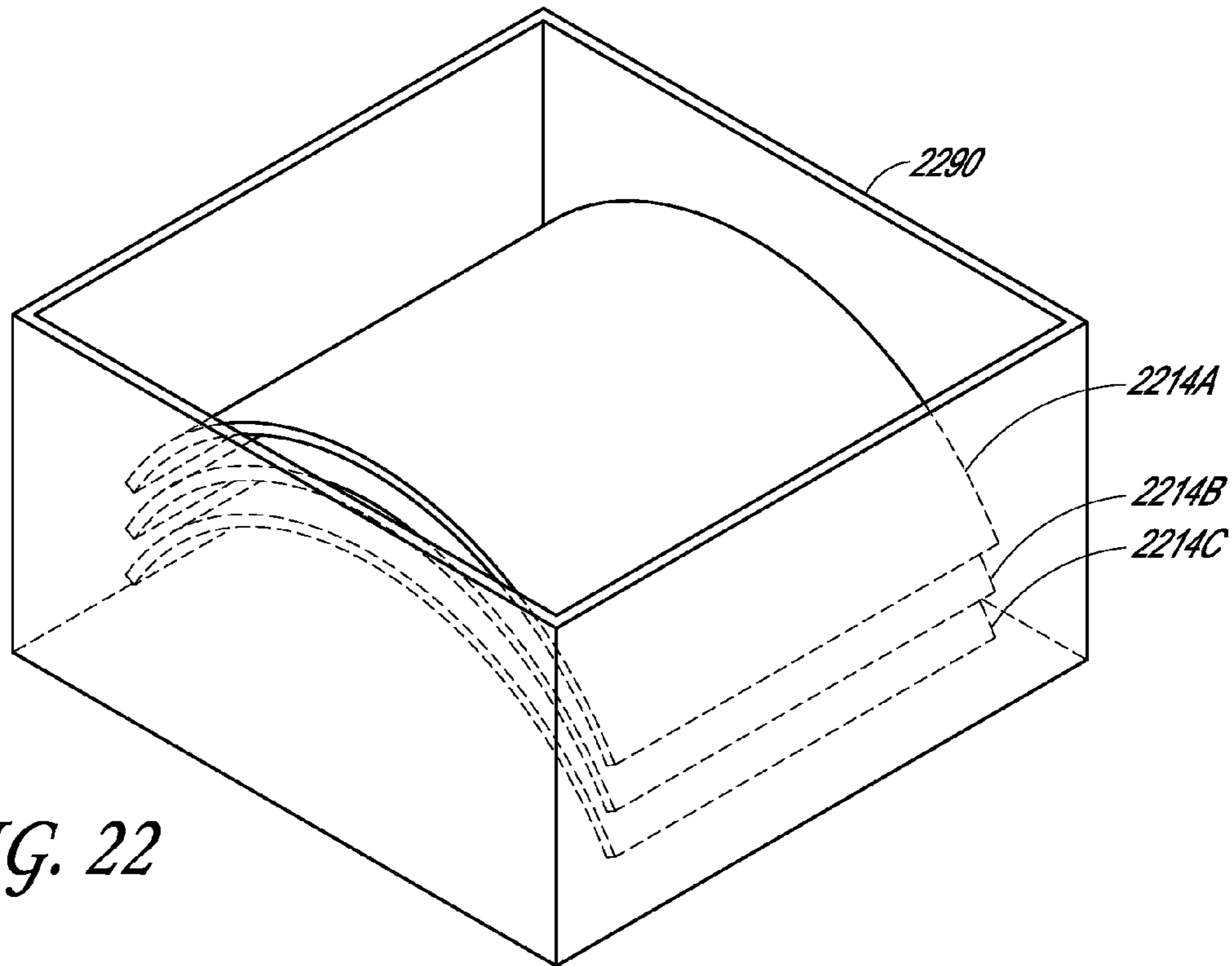


FIG. 22

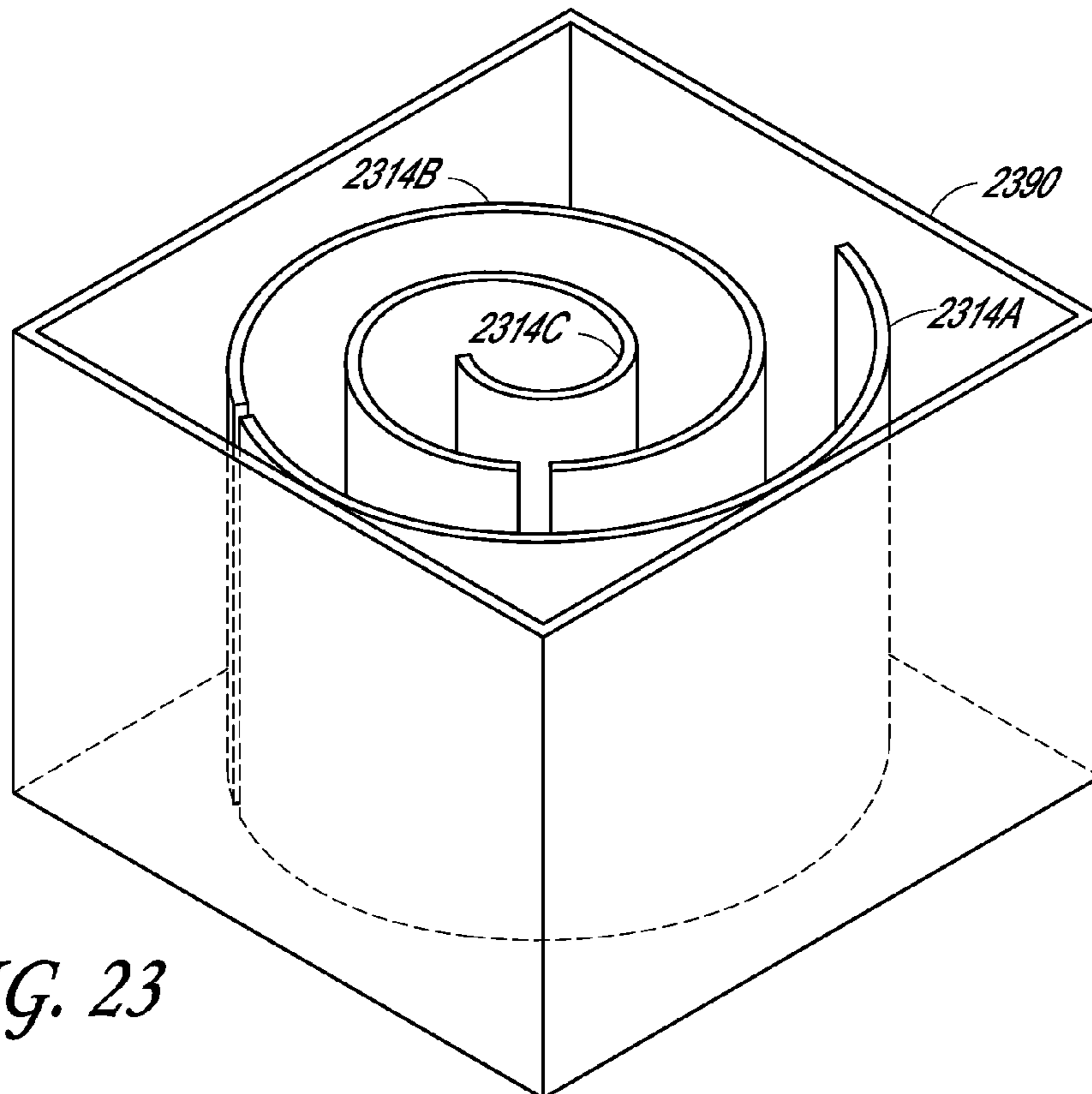


FIG. 23

HIGH ASPECT RATIO DAYLIGHT COLLECTORS

BACKGROUND

1. Field

This disclosure relates generally to daylighting and to light collectors used in daylighting systems.

2. Description of Related Art

Daylighting systems typically include windows, openings, and/or surfaces that provide natural light to the interior of a building. Examples of daylighting systems include skylights and tubular daylighting device installations. Various devices and methods exist for receiving daylight into a daylighting device. Certain currently known devices and methods for receiving daylight into a daylighting device suffer from various drawbacks.

SUMMARY

Lighting devices and methods for providing daylight to the interior of a structure are disclosed. Some embodiments disclosed herein provide a daylighting device including a tube having a sidewall with a reflective interior surface, a light collecting assembly, and a light reflector positioned to reflect daylight into the light collector. In some embodiments, the light collector is associated with one or more refractive and/or reflective elements configured to increase the amount of light captured by the daylighting device.

Some embodiments provide an at least partially transparent light-collecting device for directing daylight into a collector base aperture. The device can include a top cover portion and a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion. In certain embodiments, the substantially vertical portion has a height that extends between the top cover portion and the collector base aperture, and is configured to receive daylight.

The light-collecting device can include a prismatic element associated with the substantially vertical sidewall portion and configured to turn at least a portion of daylight received by the vertical portion towards the collector base aperture, and a reflector associated with the substantially vertical portion configured to reflect the portion of daylight towards the opening. In certain embodiments, the collector base aperture has a width and is configured to be positioned adjacent to an opening of a building when the light-collecting device is installed as part of a tubular daylighting device installation.

Certain embodiments disclosed herein provide an at least partially transparent light-collecting device configured to direct daylight through a collector base aperture and into an interior of a building when the light-collecting device can be installed on a roof of the building. The device can include a top cover portion and a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion, wherein the substantially vertical portion has a height that extends between the top cover portion and the collector base aperture, and wherein the substantially vertical portion can be configured to receive a substantial amount of daylight during midday hours. The device can include a prismatic element associated with the substantially vertical sidewall portion and configured to turn at least a portion of daylight received by the vertical portion towards

the collector base aperture, as well as an infrared control element associated with the substantially vertical sidewall portion configured to absorb or transmit at least a portion of infrared (IR) light of the portion of daylight. The light-collecting device can be configured to be positioned over an opening in a roof of a building and can be configured to direct daylight into the opening in the roof when the light-collecting device is installed as part of a daylighting device installation.

The infrared control element can be configured to absorb the at least a portion of infrared light and reradiate the portion of infrared light away from an interior of the light-collecting device. The infrared control element can include a material having high emissivity characteristics, such as a material having an emissivity value of greater than 0.90. In certain embodiments, the sidewall portion can be configured to absorb the reradiated portion of infrared light. The sidewall portion can be configured to transmit the reradiated portion of infrared light. For example, the sidewall portion can include acrylic.

In certain embodiments, the infrared control element can be at least partially secured to the sidewall portion by an adhesive configured to absorb infrared light incident on a surface of the infrared control element. The height of the vertical portion can be greater than the width of the collector base aperture. In certain embodiments, the top cover portion can be substantially flat. In other embodiments, the top cover portion includes a dome-shaped or cone-shaped surface.

The vertical portion can include a plurality of vertically-arranged segments, including a top segment, a middle segment, and a bottom segment. The top, middle, and bottom segments can be each approximately 5 to 10 inches in height. In certain embodiments, the top, middle, and bottom segments can be each a uniform height.

The infrared control element can be at least partially transparent with respect to infrared light. In certain embodiments, the vertical portion is substantially cylindrically shaped. In such embodiments, the infrared control element can be curved and nestingly disposed along an interior surface of the vertical portion. The vertical portion can include a first semi-circle portion that is at least partially transparent, and a second semi-circle portion that is at least partially reflective. For example, the second semi-circle portion can be configured to absorb a substantial portion of infrared light incident on a surface of the second semi-circle portion. In certain embodiments, the second semi-circle portion includes a surface in thermal communication with a high-emissivity material configured to facilitate radiation of heat away from the second semi-circle portion, such as paint having an emissivity value greater than or equal to about 0.9. In certain embodiments, the vertical portion can be integrated with an internally reflective tube configured to channel light towards an interior space of the building.

Certain embodiments disclosed herein provide a process of illuminating an interior of a building. The process can include receiving daylight on a substantially vertical surface, turning the daylight towards an opening in a building using a prismatic element disposed within a light-collecting device, and transmitting or radiating a portion of infrared light of the daylight out of the light-collecting device.

The process can include radiating the portion of infrared light out of the light-collecting device at least partially by absorbing the portion of infrared light with an adhesive material and reradiating the portion of infrared light using the adhesive material and/or material having high emissivity characteristics.

Certain embodiments provide a process of manufacturing an at least partially transparent light-collecting device for

3

directing daylight into a building interior. The process can include providing a light collecting device configured to receive daylight on a substantially vertical surface when installed on a building having an opening, disposing a prismatic element within the light collecting device, and disposing an infrared control element adjacent to a wall of the light collecting device. The prismatic element can be configured to turn at least a portion of daylight received on the substantially vertical surface towards the opening. The infrared control element can be configured to transmit or absorb infrared light of the portion of daylight.

Certain embodiments disclosed herein provide an at least partially transparent light-collecting device configured to direct daylight through a collector base aperture and into an interior of a building when the light-collecting device can be installed on a roof of the building. The light-collecting device can include a top cover portion and a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion, wherein the substantially vertical portion has a height that extends between the top cover portion and the collector base aperture, and wherein the substantially vertical portion can be configured to receive a substantial amount of daylight during mid-day hours. The light-collecting device can include a prismatic element associated with the substantially vertical sidewall portion and configured to turn at least a portion of daylight received by the vertical portion towards the collector base aperture and a reflector associated with the substantially vertical sidewall portion configured to reflect at least a portion of visible light of the portion of daylight towards the opening and absorb or transmit at least a portion of infrared (IR) light of the portion of daylight. In certain embodiments, the light-collecting device is configured to be positioned over an opening in a roof of a building and can be configured to direct daylight into the opening in the roof when the light-collecting device can be installed as part of a daylighting device installation.

The reflector can be configured to absorb the at least a portion of infrared light and reradiate the portion of infrared light away from an interior of the light-collecting device. The reflector can include a material having high emissivity characteristics, such as a material having an emissivity value of greater than 0.90. The sidewall portion can be configured to absorb the reradiated portion of infrared light. The sidewall portion can be configured to transmit the reradiated portion of infrared light. For example, the sidewall portion can include acrylic.

In certain embodiments, the reflector is at least partially secured to the sidewall portion by an adhesive configured to absorb infrared light incident on a surface of the reflector. The height of the vertical portion can be greater than the width of the collector base aperture. The vertical portion can include a plurality of vertically-arranged segments, including a top segment, a middle segment, and a bottom segment. For example, the top, middle, and bottom segments can be each approximately 5 to 10 inches in height. In certain embodiments, the top, middle, and bottom segments can be each a uniform height. The reflector can be associated with the top segment and the middle segment. In some embodiments, the reflector is not associated with and/or does not extend to the bottom segment. The reflector can be at least partially transparent with respect to infrared light and/or other wavelengths of radiation that do not contribute to desired illumination of a building.

4

The vertical portion can be substantially cylindrically shaped. Furthermore, the reflector can be curved and nestingly disposed along an interior surface of the vertical portion. In certain embodiments, the vertical portion includes a first semi-circle portion that can be at least partially transparent, and a second semi-circle portion that can be at least partially reflective. For example, the second semi-circle portion can be configured to absorb a substantial portion of infrared light incident on a surface of the second semi-circle portion. The second semi-circle portion can include a surface in thermal communication with a high-emissivity material configured to facilitate radiation of heat away from the second semi-circle portion, such as material including paint with an emissivity value greater than or equal to about 0.9. In certain embodiments, the vertical portion is integrated with an internally reflective tube configured to channel light towards an interior space of the building.

Certain embodiments disclosed herein provide a process of illuminating an interior of a building. The process can include receiving daylight on a substantially vertical surface, turning the daylight towards an opening in a building using a prismatic element disposed within a light-collecting device, reflecting a portion of visible light of the daylight towards the opening using a reflector, and transmitting or radiating a portion of infrared light of the daylight out of the light-collecting device. The process can include radiating the portion of infrared light out of the light-collecting device at least partially by absorbing the portion of infrared light with an adhesive material and reradiating the portion of infrared light using the adhesive material, such as by using material having high emissivity characteristics.

Certain embodiments provide a process of manufacturing an at least partially transparent light-collecting device for directing daylight into a building interior. The process can include providing a light collecting device configured to receive daylight on a substantially vertical surface when installed on a building having an opening, disposing a prismatic element within the light collecting device, and disposing a reflector adjacent to a wall of the light collecting device. The prismatic element can be configured to turn at least a portion of daylight received on the substantially vertical surface towards the opening. In addition, the reflector can be configured to reflect visible light of the portion of daylight towards the opening, and transmit or absorb infrared light of the portion of daylight.

Certain embodiments disclosed herein provide an at least partially transparent light-collecting device configured to direct daylight through a collector base aperture and into an interior of a building when the light-collecting device can be installed on a roof of the building. The device can include a top cover portion and a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion, wherein the substantially vertical portion has a height that extends between the top cover portion and the collector base aperture, and wherein the height of the substantially vertical portion can be greater than a width of the collector base aperture. The device can include a prismatic element configured to turn a portion of light that passes through the top cover portion or substantially vertical sidewall portion. The light-collecting device can be configured to be positioned over an opening in a roof of a building and can be configured to direct daylight into the opening in the roof when the light-collecting device is installed as part of a daylighting device installation.

The device can include a reflector associated with the substantially vertical portion configured to reflect the portion of daylight towards the opening. The collector base aperture can be substantially circular in shape, and the width can be equal to a diameter of the collector base aperture. In certain embodiments, an aspect ratio of the height of the vertical portion to the width of the collector base aperture is greater than 1.2 to 1. For example, the aspect ratio can be greater than 1.5 to 1, 1.7 to 1, 2 to 1, or greater. In certain embodiments, the aspect ratio is in the range of 1.2-1.5 to 1, 1.5-1.75 to 1, or 1.75-2.0 to 1.

The top cover portion can be substantially flat, or can be at least partially dome, or cone-shaped. The vertical portion can include a plurality of vertically-arranged segments, including a top segment, a middle segment, and a bottom segment. In some embodiments, the top segment is associated with first optical elements having first light-turning characteristics and the middle portion is associated with second optical elements having second light-turning characteristics. In some embodiments, light transmitting through the bottom segment is not refracted by light-turning optical elements. In certain embodiments, each of the top, middle, and bottom segments has a height that is greater than or equal to about 5 inches and/or less than or equal to about 10 inches. The top, middle, and bottom segments can each be greater than 10 inches in height. For example, the top, middle, and bottom segments can be each approximately 10 to 18 inches in height. In certain embodiments, the top, middle, and bottom segments are each of uniform height.

In certain embodiments, the vertical portion is substantially cylindrically shaped. The vertical portion can be integrated with an internally reflective tube configured to channel light towards an interior space of the building. The height of the vertical portion can be between 18 and 35 inches, or between 35 and 45 inches. In certain embodiments, the width of the collector base aperture is between 8 and 16 inches, or between 16 and 20 inches, or between 20 and 25 inches.

Certain embodiments disclosed herein provide an at least partially transparent light-collecting device for directing daylight into a building interior. The light-collecting device can include a top cover portion, a base aperture having a width and configured to be disposed adjacent to an opening of a building, and a substantially vertical portion having a height, the vertical portion extending between the top portion and the base aperture and configured to receive daylight when installed on a building. The light-collecting device can include a reflector associated with the vertical portion, the reflector configured to reflect at least a portion of daylight received by the vertical portion towards the opening. The vertical portion can be associated with a prismatic element configured to turn the portion of daylight received by the vertical portion towards the opening. Furthermore, the height of the vertical portion can be greater than the width of the opening of the building.

The vertical portion can have a rectangular cross-sectional shape, a substantially elliptical cross-sectional shape, or any other desired cross-sectional shape. The vertical portion can be constructed out of a single planar sheet formed in the shape of an ellipse, wherein two ends of the sheet can be joined to form a singular vertical seam. Alternatively, the vertical portion can include a plurality of horizontally-arranged curved sheets that can be configured to be joined together to form an ellipse. In certain embodiments, the vertical portion has a substantially triangular cross-sectional shape.

Certain embodiments disclosed herein provide a process of illuminating an interior of a building. The process can include receiving daylight on a substantially vertical surface, turning

the daylight towards an aperture lying in a substantially horizontal plane using a prismatic element disposed within a light-collecting device, and reflecting the daylight towards the opening using a reflector. The substantially vertical surface may have a height greater than a width of the aperture.

Certain embodiments disclosed herein provide a process of manufacturing an at least partially transparent light-collecting device for directing daylight into a building interior. The process can include providing a light collecting device configured to receive daylight on a substantially vertical surface when installed on a building having an opening and disposing a reflector adjacent to a wall of the light collecting device. The reflector can be configured to reflect the portion of daylight towards the opening through a base aperture of the light collecting device, the substantially vertical surface having a height that can be greater than a width of the base aperture.

Certain embodiments disclosed herein provide a passive light-collecting device for directing sunlight into a building interior. The light-collecting device can include a top cover portion, a base aperture having a width and configured to be disposed adjacent to an opening of a building, and a substantially vertical portion having a height that extends between the top portion and the base aperture and can be configured to receive sunlight. The light-collecting device can be configured to direct a first luminous flux through the base aperture when the light-collecting device is exposed to sunlight at a solar altitude of approximately 30 degrees, and to direct a second luminous flux through the base aperture when the light-collecting device is exposed to sunlight at a solar altitude of approximately 70 degrees, wherein the first luminous flux is greater than or equal to about 75% of the second luminous flux when the light-collecting device is exposed to substantially only direct sunlight on a clear day.

The light-collecting device can include a prismatic element associated with the vertical portion and configured to turn at least a portion of sunlight received by the vertical portion towards the base aperture. The light-collecting device can include a reflector associated with the vertical portion configured to reflect the portion of sunlight towards the base aperture. In certain embodiments, the height of the vertical portion can be greater than the width of the base aperture.

In certain embodiments, the top cover portion is substantially flat. The top cover portion can include a dome-shaped surface, a cone-shaped surface, a planar surface, a faceted surface, another surface shape, or a combination of surface shapes. The top cover can be associated with a second prismatic element configured to turn sunlight incident on the top cover towards the base aperture. The second luminous flux can be greater than 18,000 lumens.

In certain embodiments, the vertical portion is substantially cylindrically shaped. The vertical portion can include a plurality of vertically-arranged segments, including a top segment, a middle segment, and a bottom segment. For example, the top segment can be associated with a first prismatic element having first light-turning characteristics and the middle portion can be associated with a second prismatic element having second light-turning characteristics. The bottom segment may not be associated with light-turning optical elements. The top, middle, and bottom segments can be each approximately 5 to 10 inches in height, and may each be of uniform height.

The vertical portion can be integrated with an internally reflective tube configured to channel light towards an interior space of the building. The height of the vertical portion can be between 20 and 25 inches, or between 35 and 45 inches. In certain embodiments, the reflector is disposed adjacent to an interior surface of the substantially vertical portion. Alterna-

tively, the reflector can be disposed adjacent to an outer surface of the substantially vertical portion.

Certain embodiments disclosed herein provide a passive light-collecting device for directing sunlight into a building interior. The light-collecting device can include a top cover portion, a base aperture having a width and configured to be disposed adjacent to an opening of a building, and a substantially vertical portion having a height that extends between the top portion and the base aperture and can be configured to receive sunlight. The light-collecting device can be configured to direct a first luminous flux through the base aperture when the light-collecting device is exposed to sunlight at a solar azimuth of approximately 45 degrees and a first solar altitude, and direct a second luminous flux through the base aperture when the light-collecting device can be exposed to sunlight at a solar azimuth of approximately 0 degrees, wherein the first luminous flux can be greater than or equal to about 75% of the second luminous flux when the light-collecting device can be exposed to substantially only direct sunlight on a clear day.

The light-collecting device can include a prismatic element associated with the vertical portion and configured to turn at least a portion of sunlight received by the vertical portion towards the base aperture. The light-collecting device can include a reflector associated with the vertical portion configured to reflect the portion of sunlight towards the base aperture. In certain embodiments, the second luminous flux can be greater than 18,000 lumens.

Certain embodiments disclosed herein provide an at least partially transparent light-collecting device for directing sunlight into a building interior. The light-collecting device can include a top cover portion, a base aperture having a width and configured to be disposed adjacent to an opening of a building, and a substantially vertical portion having a height that extends between the top portion and the base aperture and can be configured to receive sunlight. The light-collecting device can be configured to direct a first luminous flux through the base aperture when the light-collecting device can be exposed to sunlight at a solar altitude of approximately 30 degrees and a solar azimuth of approximately 45 degrees, and direct a second amount of light through the base aperture when exposed to sunlight at a solar altitude of approximately 70 degrees and a solar azimuth of approximately 0 degrees, wherein the first luminous flux can be greater than or equal to about 75% of the second luminous flux when the light-collecting device can be exposed to substantially only direct sunlight on a clear day.

The light-collecting device can include a prismatic element configured to turn at least a first portion of sunlight received by the vertical portion towards the base aperture. The light-collecting device can include a reflector associated with the vertical portion, the reflector configured to reflect at least a second portion of the sunlight received by the vertical portion towards the base aperture.

In certain embodiments, the top cover can be associated with a second prismatic element configured to turn sunlight incident on the top cover towards the base aperture, and can be substantially flat. The vertical portion may have a substantially rectangular, elliptical, triangular, hexagonal, pentagonal, or octagonal cross-sectional shape.

Certain embodiments disclosed herein provide a process of illuminating an interior of a building. The process can include receiving first sunlight having a solar altitude of approximately 30 degrees on a vertical surface, directing the first sunlight into an opening in a building, receiving second sunlight having a solar altitude of approximately 70 degrees on the vertical surface, and directing the second sunlight into the

opening in the building. The first sunlight and the second sunlight can include direct sunlight, and the first sunlight can include a luminous flux that is greater than or equal to about 75% of a luminous flux of the second sunlight when said receiving the first sunlight and receiving the second sunlight are performed on a clear day.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments are depicted in the accompanying drawings for illustrative purposes, and should in no way be interpreted as limiting the scope of the inventions. In addition, various features of different disclosed embodiments can be combined to form additional embodiments, which are part of this disclosure. Any feature or structure can be removed or omitted. Throughout the drawings, reference numbers can be reused to indicate correspondence between reference elements.

FIG. 1 illustrates a block diagram representing an embodiment of a daylighting device.

FIG. 2 illustrates a cutaway view of an example of a daylighting device installed in a building for illuminating an interior room of the building.

FIG. 3 illustrates a cutaway view of an example of a daylighting device installed in a building for illuminating an interior room of the building.

FIG. 4 illustrates a cutaway view of an example of a daylighting device installed in a building.

FIG. 5 illustrates an embodiment of a daylighting device incorporating a collimator at a terminal portion of the daylighting device.

FIG. 6 illustrates an embodiment of the light collector shown in FIG. 1.

FIG. 7 illustrates an embodiment of a daylighting device including a light collector with a dome-shaped top portion.

FIG. 8 illustrates an embodiment of a daylighting device with a top portion having a triangular cross-section.

FIGS. 9A-9F illustrate embodiments of light collectors having various cross-sectional shapes.

FIG. 10 illustrates a cross-sectional view of a light collector including both a side portion, and a top portion.

FIG. 11 illustrates a cross-sectional view of a portion of the prismatic element shown in FIG. 10.

FIG. 12 illustrates a cross-sectional view of a light collector including a side portion that includes a plurality of vertically arranged optical zones.

FIG. 13 is a graph showing reflectivity profiles of two different reflective materials.

FIG. 14A illustrates a perspective view of an embodiment of a light reflector for disposing within, adjacent to, or in integration with, a light collecting assembly.

FIG. 14B, illustrates a top view of an embodiment of the reflector shown in FIG. 14A.

FIG. 14C illustrates a cross-sectional view of a vertically-oriented planar reflector.

FIG. 15 illustrates a perspective view of an embodiment of a daylighting device including a light collector incorporating a reflector.

FIG. 16 illustrates a perspective view of an embodiment of a daylighting device including a light collector incorporating a reflector.

FIG. 17A illustrates an embodiment of a light collector having a transparent portion and a reflector assembly.

FIG. 17B illustrates a top view of an embodiment of a connecting structure of a light collector.

FIG. 18 illustrates an embodiment of a light collector having a reflector assembly with a high-emissivity coating.

FIG. 19 illustrates an embodiment of a daylighting device including a light collector having prismatic and reflective optical elements.

FIG. 20 illustrates a perspective view of an embodiment of a light collector.

FIG. 21A illustrates an embodiment of a light collector formed from a singular panel.

FIG. 21B illustrates a top view of an embodiment of a portion of a light collector having a circumference that includes multiple curved panels.

FIG. 22 illustrates a packaging configuration for an embodiment of one or more curved light collector panels.

FIG. 23 illustrates a packaging configuration for an embodiment of one or more curved light collector panels.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

Although certain embodiments and examples are disclosed herein, inventive subject matter extends beyond the examples in the specifically disclosed embodiments to other alternative embodiments and/or uses, and to modifications and equivalents thereof. Thus, the scope of the claims appended hereto is not limited by any of the particular embodiments described below. For example, in any method or process disclosed herein, the acts or operations of the method or process can be performed in any suitable sequence and are not necessarily limited to any particular disclosed sequence. Various operations can be described as multiple discrete operations in a manner or order that can be helpful in understanding certain embodiments; however, the order of description should not be construed to imply that these operations are order-dependent. Additionally, the structures, systems, and/or devices described herein can be embodied as integrated components or as separate components. For purposes of comparing various embodiments, certain aspects and advantages of these embodiments are described. Not necessarily all such aspects or advantages are achieved by any particular embodiment. Thus, for example, various embodiments can be carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other aspects or advantages as can be taught or suggested herein.

FIG. 1 depicts a block diagram representing an embodiment of a daylighting device 100. The daylighting device 100 can be a passive light-collection and distribution system for providing daylight to an interior of a building or other structure. The daylighting device 100 includes a light collector 110 which is exposed, either directly or indirectly to a source of light, such as, for example, the Sun. Light enters the light collector and propagates into a tube 120. For example, the light may enter the light collector 110 through a substantially vertical daylight-collection surface and/or top cover portion of the light collector. The tube 120 provides a channel, or pathway, between the light collector 110 and a light-aligning structure 130. The interior surface of the tube 120 is at least partially reflective. In some embodiments, at least a portion of the interior surface of the tube 120 is specularly reflective.

As used herein, the terms “substantially vertical” and “vertical” are used in their broad and ordinary sense and include, for example, surfaces that are generally perpendicular to the ground, surfaces that are generally perpendicular to a horizontal plane, and/or surfaces that deviate by less than about 10° from a plane perpendicular to the ground and/or a horizontal plane. Such surfaces can be planar, curved, or irregularly shaped while still being substantially vertical so long as an elongate dimension of a surface is generally vertical. The

terms “substantially horizontal” and “horizontal” are used in their broad and ordinary sense and include, for example, surfaces that are generally parallel to the ground, surfaces that are generally parallel to the roof of a building, and/or surfaces that deviate by less than or equal to about 10° from a plane parallel to the ground and/or a roof. Such surfaces can be planar, curved, or irregularly shaped while still being substantially horizontal so long as an elongate dimension of a surface is generally horizontal.

The light collector permits exterior light, such as natural light, to enter the interior of the reflective tube 120. The light collector 110 can have one or more components. For example, the light collector 110 can include a transparent dome, a prismatic dome, other prismatic elements, one or more light turning structures or elements, a durable cover, one or more reflective surfaces (e.g., positioned inside or outside of a portion of the collector 110), other optical elements, other components, or a combination of components. At least some components of the light collector can be configured to be positioned on the roof 102 of the building or in another suitable area outside the building. The light collector 110 can include a transparent cover installed on the roof 102 of the building or in another suitable location. The transparent cover can be cylindrically shaped, dome-shaped, or can include any other suitable shape or combination of shapes, and can be configured to capture sunlight during certain periods of the day. In certain embodiments, the cover keeps environmental moisture and other material from entering the tube. The cover can allow exterior light, such as daylight, to enter the system.

In the example embodiments disclosed, the measure h_c represents a height of a substantially vertical sidewall portion of the light collector 110. In certain embodiments, the sidewall portion presents a substantially vertical daylight-collection surface through which daylight may enter the daylighting device 100. The measure w_c represents a width of a portion of the collector, such as the width of the base or top portions of the collector 110. In certain embodiments, the width of the collector is substantially uniform over its height h_c . The width w_c of the collector at its base can be greater than the width of the tube 120 at a point near the collector base. In some embodiments, a daylight device is configured such that a width of the tube into which daylight is directed, at least in a region disposed in proximity to the collector base, is less than the height h_c of the collector. The width of the tube w_t may represent a width of a target area to which the light collector 110 is configured to direct daylight entering the collector. The term “target area” is used herein according to its broad and ordinary meaning and can be used to refer to an area through which a daylight collector is configured to direct daylight in order for the daylight to enter an internally-reflective tube between a roof structure and interior room of a building.

The relationship between the height of the collector and the width of the tube or width of the target area of the collector can be characterized using a ratio between the quantities that will be referred to herein as the aspect ratio. In general, the aspect ratio refers to the ratio between the height of the collector and the width of the tube with which the collector is configured to be used. For example, in some embodiments, the height h_c of the collector, as compared to the width w_t of the tube/target area 120, or width w_c of the collector 110, can have an aspect ratio of approximately 1.2 to 1, or greater. The term “collector” is used herein according to its broad and ordinary meaning and includes, for example, a cover, window, or other component or collection of components, configured to direct daylight into an opening of a building. A collector can include optical elements that refract and/or reflect daylight such that the luminous flux of natural light

entering a building is greater than if an opening in the building included a fenestration apparatus without optical elements.

In some embodiments, the cover includes a light collection system configured to enhance or increase the daylight entering the tube **120**. The collector **110** can include one or more optical elements, either integrated or non-integrated with respect to the cover, configured to turn light entering one or more portions of the collector **110** generally in the direction of the tube **120**, or opening in the building. The light collector **110** can include a top cover. For example, the top cover can be clear or include prisms for refracting daylight toward the collector base aperture. The prisms can be fabricated into the cover material or can be formed in a separate prismatic element placed beneath or above a clear dome. As used herein, prismatic element is used in its broad and ordinary sense and includes, for example, prismatic films, molded prismatic assemblies, extruded prismatic materials, another prismatic material, or a combination of materials.

The daylighting device **100** can be configured such that light enters the collector **110** and proceeds through the tube **120**, which can be internally reflective, thereby allowing light to propagate through the tube to a targeted area of the building. An auxiliary lighting system (not shown) can be installed in the daylighting device **100** to provide light from the tube to the targeted area when daylight is not available in sufficient quantity to provide a desired level of interior lighting.

The collimator **130** can be configured such that light that would otherwise enter the diffuser at undesirable angles is turned to a more desirable angle. For example, the collimator **130** can ensure that light passing through the daylighting device will exit the daylighting device at an exit angle of less than or equal to about 45 degrees from vertical, or at a substantially vertical orientation, when the diffuser **140** is in a horizontal arrangement. In some embodiments, the collimator **130** may ensure that light passing through the daylighting device will exit the daylighting device at an exit angle of less than or equal to about 45 degrees from a longitudinal axis of the daylighting device or a portion of the daylighting device. In certain embodiments, the collimator **130** is configured to reduce or prevent light from exiting the daylighting device **100** at an angle of between about 45 degrees and about 60 degrees from vertical. In this manner, the collimator **130** may reduce or eliminate glare and visibility issues that light exiting a lighting fixture between those angles can cause.

The daylighting device **100** includes a light-diffusing structure, or diffuser **140**. The diffuser **140** spreads light from the tube into the room or area in which it is situated. The diffuser **140** can be configured to distribute or disperse the light generally throughout a room or area inside the building. Various diffuser designs are possible.

When the daylighting device **100** is installed, the tube **120** can be physically connected to, or disposed in proximity to, the light-aligning structure, or collimator **130**, which is configured to turn light propagating through the daylighting device such that, when light exits the daylighting device **100** and/or enters a diffuser **140**, the light has increased alignment characteristics, as compared to a device without a collimator. In some embodiments, a substantial portion of light propagating through the daylighting device **100** may propagate within the daylighting device at relatively low angles of elevation from a horizontal plane of reference. Such angles of propagation may, in some situations, cause the light to have undesirable properties when it exits the daylighting device. For example, the optical efficiency of a diffuser substantially positioned within a horizontal plane can be substantially reduced when light is incident on the diffuser at low angles of elevation from the horizontal plane. As another example, light

that is incident on a diffuser at low angles of elevation can result in light exiting the daylighting device at an exit angle of greater than or equal to about 45 degrees from vertical. Light exiting a daylighting device at such angles can create glare and visibility issues in the area or room being illuminated.

Though the embodiment depicted in FIG. 1 is described with reference to one or more features or components, any of the described features or components can be omitted in certain embodiments. Furthermore, additional features or components not described can be included in certain embodiments in accordance with the device shown in FIG. 1.

FIG. 2 shows a cutaway view of an example of a daylighting device **200** installed in a building **205** for illuminating, with natural light, an interior room **207** of the building. The daylighting device **200** can be suited for use in commercial, high-bay applications, such as in structures or buildings having ceilings above twenty feet high. For example the distance h_0 between the floor **208** and a ceiling plane **209** can be in the range of approximately 20-28 feet. The daylighting device **200** can be configured to improve the performance of a light collection system through the use of a light collector **210**, wherein the light collector **210** incorporates, or is associated with, one or more passive optical elements. The daylighting device **200** can be particularly configured for applications that operate within an approximately six-hour window during which daylight is most intense. For example, depending on geographical location of the building **202**, among possibly other things, the daylighting device **200** can be configured to capture desirable amounts of daylight between the hours of 9:00 am and 3:00 pm.

The light collector **210** can be mounted on a roof **202** of the building and may facilitate the transmission of natural light into a tube **220**. In certain embodiments, the collector **210** is disposed on a pitched roof. In order to compensate for the pitch in the roof, the collector **210** can be mounted to the roof **202** using a flashing **204**. The flashing can include a flange **204a** that is attached to the roof **202**, and a curb **204b** that rises upwardly from the flange **204a** and is angled as appropriate for the cant of the roof **202** to engage and hold the collector **210** in a generally vertically upright orientation. Other orientations are also possible. In certain embodiments, at least a portion of the roof **202** is substantially flat.

The light collector **210** has a height h_c and is disposed adjacent to a tube opening having a width, or diameter, w_t . The tube opening may provide a target area into which the light collector **210** is configured to direct daylight. As used herein, the height h_c may refer to the height of a substantially vertical sidewall portion of the collector **210**, or may refer to the height of the collector **210** including the height of a cover portion disposed above the vertical portion. In certain embodiments, the substantially vertical sidewall portion may provide a vertical daylight-collection surface for daylight incident on certain portions of the collector **210**. In certain embodiments, the height h_c is approximately 20-26 inches. In other embodiments, the height h_c can be approximately 35-45 inches. In addition, the width w_t of the tube opening can be between 15-30 inches. For example, in an embodiment, the height h_c of the collector **210** is approximately 42 inches and the width w_t of the tube opening is approximately 25 inches. The collector **210** may have a width w_c slightly greater than the width w_t of the tube opening such that when the light collector is disposed above the tube opening, a lip of the collector **210** extends beyond the width of the tube opening. For example, the collector **210** may have a 1-inch lip around a circumference or perimeter of the tube opening, such that the width w_c of the collector **210** is approximately 2 inches greater than the width of the tube opening w_t . The height h_c of

the collector **210** and the width w_r of the tube opening can be configured to obtain a desirable aspect ratio that provides satisfactory performance characteristics. In certain embodiments, the aspect ratio of height h_c to width w_r is approximately 1.7:1. In some embodiments, the aspect ratio is greater than or equal to about 1.2:1 and/or less than or equal to about 2:1. Such aspect ratios, in connection with daylighting device features described herein, may provide improved daylight capturing characteristics.

The tube **220** can be connected to the flashing **204** and can extend from about a level of the roof **202** through a ceiling level **209** of the interior room **207**. The tube **220** can direct light L_{D2} that enters the tube **220** downwardly to a light diffuser **240**, which disperses the light in the room **207**. The interior surface of the tube **220** can be reflective. In some embodiments, the tube **220** has at least a section with substantially parallel sidewalls (e.g., a generally cylindrical inside surface). Many other tube shapes and configurations are possible. The tube **220** can be made of metal, fiber, plastic, other rigid materials, an alloy, another appropriate material, or a combination of materials. For example, the body of the tube **220** can be constructed from type **1150** alloy aluminum. The shape, position, configuration, and materials of the tube **220** can be selected to increase or maximize the portion of daylight L_{D1} , L_{D2} or other types of light entering the tube **220** that propagates into the room **207**.

The tube **220** can terminate at, or be functionally coupled to, a light diffuser **240**. The light diffuser **240** can include one or more devices that spread out or scatter light in a suitable manner across a larger area than would result without the diffuser **240** or a similar device. In some embodiments, the diffuser **240** permits most or substantially all visible light traveling down the tube **220** to propagate into the room **207**. The diffuser can include one or more lenses, ground glass, holographic diffusers, other diffusive materials, or a combination of materials. The diffuser **240** can be connected to the tube **220**, or other component of the daylighting device **200**, using any suitable connection technique. In some embodiments, the diffuser **240** is located in the same general plane as a ceiling level **209** of the building, generally parallel to the plane of the ceiling level **209**, or near the plane of the ceiling level **209**. In certain embodiments, the building **205** has an open ceiling, exposing structure associated with the roof **202**. For example, certain high-bay buildings may have open-ceiling configurations, exposing structural I-beams and/or the like. In an open ceiling configuration, the diffuser **240** can be disposed adjacent to a ceiling-level plane **209**, rather than a physical ceiling structure.

In certain embodiments, the diameter of the diffuser **240** is substantially equal to the diameter of the tube **220**, slightly greater than the diameter of the tube **220**, slightly less than the diameter of the tube **220**, or substantially greater than the diameter of the tube **220**. The diffuser **240** can distribute light incident on it toward a lower surface below the diffuser (e.g., the floor **208**) and, in some room configurations, toward an upper surface of the room **207**. In some embodiments, a diffuser **240** provides substantial amounts of both direct diffusion and indirect diffusion. In some embodiments, the diffuser **240** reduces the light intensity in one or more regions of the room interior **207**.

One or more daylighting devices configured according to the embodiment described with respect to FIG. **2** may increase illumination of a building, or decrease the number of devices required to achieve a desired amount of light infusion into the building. For example, certain embodiments described herein may improve performance and/or reduce the number of required devices by 20-30%.

The daylighting device **200** can be configured to sustain significant physical stress without substantial structural damage. For example, in certain embodiments, the daylighting device **200** is configured to withstand a drop test, wherein a bag of sand having particular weight/size characteristics is dropped onto the top of the device from a minimum height. To pass such test, the device can be required to withstand the fall test without allowing the bag to fall through the opening in the building. In some embodiments, a daylighting system is configured to meet standards and/or regulations promulgated by standards organizations and/or government agencies that are designed to improve the safety of rooftop environments containing daylighting fixtures. For example, certain embodiments are configured to meet the Federal Occupational Safety and Health Administration (OSHA) regulations, which provide, for example, that skylight screens shall be of such construction and mounting that they are capable of withstanding a load of at least 200 pounds applied perpendicularly to a surface. Daylighting devices can be constructed to meet regulatory standards. In certain embodiments, one or more portions of the flashing **204**, and/or collector **210** can be constructed and/or mounted such that the collector **210** is not damaged to the extent that an opening or aperture providing an ingress into the building interior **207** is created therein, when a 267-lb. sand bag, having an approximately 5.5" bull nose, is dropped generally perpendicularly to a plane of the roof and/or to a top surface of the collector **210** from a height of about 36" above the roof onto the center of the top portion of the daylight collector.

FIG. **3** shows a cutaway view of an example of a daylighting device **300** installed in a building **305** for illuminating, with natural light, an interior room **307** of the building. The daylighting device **300** includes a light collector **310** mounted on a roof structure **302** of the building **305** that allows natural light to enter a tube **320**. In the depicted embodiment, the daylighting device **300** includes an insulation structure, or layer, **306** disposed adjacent to, or within, the tube **320**. The insulation structure **306** can be configured to reduce a rate of thermal energy transfer between the interior of the daylighting device **300** and the room **307**. For example, the insulation structure **306** can be disposed adjacent to a diffuser **340**, such as between the diffuser **340** and the interior of the tube **320**. The insulation structure **306** can be disposed at any other suitable position, such as near the top of the tube **320**, near the level of a ceiling, or near the level of the collector **310**. In some embodiments, the insulation structure **306** can be positioned at the same level as an insulation layer found in the building, and can be positioned to provide a substantially contiguous layer of insulation together with the building insulation layer. The daylighting device **300** can also include insulation structures disposed in various positions or locations. The position(s) of the insulation structure(s) **306** can be selected to produce any desired thermal energy transfer characteristics.

In the embodiment depicted in FIG. **3**, the diffuser **340** is disposed adjacent to, and in a substantially parallel alignment with, a surface **370** of the roof structure **302**. As shown, the tube **320** may extend from the light collector **310** and through at least a portion of the roof structure **302**, without extending substantially into the interior room space **307**. In certain embodiments, the daylighting device **300** can include a light collector configured to provide light to the interior room **307** without the use of a tube **320**. For example, the light collector **310** may extend through the roof structure **302**, and connect directly with the diffuser **340**.

FIG. **4** shows a cutaway view of an example of a daylighting device **400** installed in a building **405**. The daylighting

device **400** includes a light collector **410** mounted on a roof **402** of the building **405** that allows natural light to enter a tube **420**. In certain building applications, such as high-bay building applications, light provided by a daylighting system can be at least partially blocked or undesirably redirected by one or more obstructions disposed in the vicinity of the system's lower perimeter, or along the path of light between the system and a desired area of illumination. The daylighting device **400** can be configured to extend below one or more possible obstructions, or low enough to reduce the effects of one or more obstructions on lighting performance. In certain embodiments, the effect of obstructions on lighting performance is reduced by incorporating a daylighting device that maintains a substantial portion of its transmitted light within a cone half angle of less than approximately 40-45°. In the depicted embodiment, the tube extends through the roof **402**, and a distance d below a ceiling level **409**. The ceiling level **409** can be a physical ceiling structure, or may represent a ceiling level in an open-ceiling building configuration. The ceiling level can be, for example, at approximately the same level as one or more I-beam structures, or other building structure. In an embodiment including a physical ceiling structure **409**, the daylighting device **400** can include an insulation structure disposed adjacent to the ceiling level **409**.

In certain embodiments, the daylighting device **400** includes a thermal insulation subsystem, or portion **406**, that substantially inhibits thermal communication between the interior **407** of a structure and the outside environment. The thermal insulation subsystem can have any suitable configuration, such as, for example, one of the configurations disclosed in U.S. Patent Application Publication No. 2011/0289869, entitled "Thermally Insulating Fenestration Devices and Methods," the entire contents of which are incorporated by reference and made a part of this specification.

The tubular daylighting device can include a thermal break in any materials or components of the daylight device that have high thermal conductivity. For example, a spacer or gap in the sidewall of the tube can be positioned near a thermal insulating portion and the thermal insulating portion and thermal break can be configured to form a substantially continuous layer between the building interior and the exterior environment. In certain embodiments, the insulating portion and thermal break are disposed in the same plane as other building insulation material, such as fiberglass or the like.

FIG. **5** illustrates an embodiment of a daylighting device **500** incorporating a collimator **530** at a bottom, or terminal portion of the daylighting device **500**. The bottom portion of the daylighting device **500** can include one or more light diffusing or spreading devices **540**, thermal insulation devices, or combination of devices referenced herein. Collimator **530** represents an embodiment of the collimator **130** shown in FIG. **1**. The collimator **530** serves to generally align rays of light propagating through the daylighting device **500** so that light reaches the diffuser **540** at greater angles with respect to the base of the diffuser **540** than it would without a collimator. The collimator **530** can be a multi-segment, or multi-stage, collimator. In some embodiments, the collimator **530** is a single-stage collimator. In certain embodiments, sunlight entering the tube will have a solar altitude (angle from the horizon) that will remain substantially the same as it reflects down the tube when the tube sides are vertical and parallel. Installation of a collimator, such as a flared out reflective tube, at or near the base of a tube **520** with the diffuser attached to the base may substantially reduce the incident angle of light to the diffuser, which may increase the diffuser optical efficiency and other system performance characteristics.

The daylighting device **500** includes a light collector **510** having a height h_c . As used herein, the height h_c may refer to the height of a substantially vertical sidewall portion of the collector **510**. For example, the substantially vertical sidewall portion may provide a vertical daylight-collection surface for daylight incident on certain portions of the collector **510**. The light collector **510** can be disposed about, or adjacent to, the tube **520**, which extends through an opening **529** in a building. The opening **529** has a width w_o ; the tube **520** has a width w_t . The opening of the tube or the opening **529** of the building may provide a target area into which light can be directed by the light collector **510** or otherwise received into the daylighting system **500**. In certain embodiments, the height h_c of the light collector **510** is greater than the width w_o of the opening **529**, and/or width w_t of the tube/target area. For example, the daylighting installation **500** can include, a light collector **510** configured such that the height of the light collector h_c is approximately 1.2 to 2.5 times greater than the width w_t . That is, the height of the light collector h_c has an aspect ratio of approximately 1.1-2.1, or 1.2:1 to 2.1:1 with respect to the width w_o of the opening **529**. In certain embodiments, the aspect ratio is greater than 2.5:1. In certain embodiments, the width w_t of the tube **520** is approximately 21 inches, and the width w_o of the opening **529** is greater than, or approximately equal to, the width w_t of the tube **520**. In certain embodiments, the light collector **510** has a width w_c of approximately 23 inches, a height h_c of approximately 36 inches, and a collimator **530** terminating in a base having a width of approximately 31 inches.

FIG. **6** illustrates an embodiment of the light collector **110** shown in FIG. **1**. In certain embodiments, the light collector is configured to turn at least a portion of the light L_D striking one of its surfaces such that the light is directed downwardly toward a horizontal aperture of a tube **620**. Various features and characteristics of the light collector **610** affect the light turning properties of the collector. As disclosed in U.S. Pat. No. 7,546,709, the entire contents of which are incorporated by reference and made a part of this specification, a transparent cover including a smooth outside surface in combination with an internal prismatic element may produce desirable light-turning effects. In certain embodiments, such a configuration provides a double refraction of the sunlight incident on an outside surface of the collector **610**. The collector **610** can be configured to have a continuous curved shape with respect to one or more dimensions, or may have a series of curved and/or flat surfaces.

The light collector **610** illustrated in FIG. **6** includes a top surface **612** and one or more side surfaces **614**. The top surface **612** can be substantially flat, as shown, or have a slope substantially near zero. Such a configuration may increase an incident angle of light striking the top portion **612**, which may contribute to higher refraction and/or transmission values. In certain embodiments, both the top surface **612** and one or more side surfaces are associated with light turning characteristics. The sidewall portion **614** of the collector **610** may present a vertical daylight-collection surface through which daylight may enter the daylighting device **600**. As shown, daylight L_{Ds} may enter the collector **610** through sidewall **614** at a solar altitude θ_1 . Light turning characteristics associated with the sidewall **614** may turn light L_{Ds} in a direction towards a target area **618**, such as an opening in the tube **620**, or other building opening. Turning can be achieved through prismatic characteristics of the collector wall or prismatic element or sheet, or other optical element, in association with the sidewall **614**. In certain embodiments, the resultant solar altitude θ_2 of L_{Ds} is greater than that of θ_1 . In certain embodiments, an

aspect ratio between the height of the collector **610** and the width or diameter of the relevant target area is optimized to improve performance.

Light turning features of the light collector **610** can include prismatic patterns formed on a surface of the collector **610**. Such a pattern can be, for example, molded into the inside and/or outside surface of the collector **610**. The pattern can be formed by any suitable method, such as by using a casting, or injection molding technique. In certain embodiments, a prismatic element, or other prismatic structure, is adhered to, connected to, or otherwise associated with the collector **610**. In certain embodiments, the prisms can be established by horizontal grooves that are defined by opposed faces that may have a flat or curved cross-sectional shape. Furthermore, as disclosed further below, grooves can vary in depth and pitch and/or in other respects. Prisms may circumscribe the entire circumference of the collector **610**, and can be substantially uniform throughout the height or circumference, or perimeter, of a portion of the collector **610**. In certain embodiments, prisms/grooves vary with respect to one or more parameters at different heights or points along the circumference of the collector **610**. For example, prisms can include faces of varying angles, shapes, and/or widths, depending on height and/or position. In certain embodiments, portions of the collector **610** are not associated with prismatic structure.

The top portion **612** of the collector **610** can be associated with light turning characteristics. For example, as shown, light L_{DT} entering the collector **610** through top portion **612** can be turned in a direction towards the tube opening **618**, or opening in a building, such that a resulting solar altitude of the light L_{DT} has a solar altitude of θ_3 . In certain embodiments including optical turning elements associated with both the top portion **612** and the sidewall portion **614**, θ_3 is greater than θ_2 . That is, light L_{DT} striking the top portion **612** can be turned to a greater degree than light L_{DS} striking the side portion **614**. In certain embodiments, the top portion **612** does not include prismatic structure or light-turning characteristics. For example, the top portion can include a clear acrylic surface that is substantially optically transparent. In certain embodiments, the top portion is at least partially optically opaque, or reflective. Such qualities can be desirable in order to reduce the amount of light transferred through the collector **610** into the tube **620** at various points during the day, such as during the middle of the day when sunlight levels are relatively intense.

The tube **620** can be a separate component of the daylighting device **600** than the light collector **610**. For example, the tube can be an internally reflective channel of rigid construction, such as having a construction of aluminum and/or other material that is disposed adjacent to, or connected to, the light collector **610**. In certain embodiments, the tube **620** and the collector **610** are integrated such that the two components are substantially combined into a single structure.

FIG. 7 illustrates an embodiment of a daylighting system **700** including a light collector with a dome-shaped top portion **712**. The dome-shaped top portion **712** may present a surface that is angled (θ) at various points with respect to a horizontal plane. Such an angle θ may affect the refractive characteristics of the top portion **712**, and may vary along the surface of the top portion **712**.

The top portion **712** can include any suitable shape. For example, FIG. 8 illustrates an embodiment of a daylighting system **800** with a top portion **812** having a triangular cross-section. The cross-section of FIG. 8 may, for example, correspond to a light collector having a top portion **812** that is conical or pyramidal in shape. The shape, and/or size of the light collector **810** and/or top portion **812** may depend on

various system considerations, such as ease of manufacturing/installation, refractive characteristics, aesthetics, and/or other considerations. Any suitable shape or size of the top portion (e.g., **712**, **812**) can be used in daylighting devices constructed or configured according to one or more embodiments disclosed herein.

Though generally illustrated herein as having a cylindrical, or oval-shaped cross-section in certain embodiments, a light collector in accordance with the present disclosure may have any suitable cross-sectional shape. Furthermore, the cross-sectional shape of a light collector may vary at different points along a vertical axis of the light collector. FIGS. 9A-9F illustrate embodiments of light collectors having various cross-sectional shapes. The various shapes shown in FIGS. 9A-9F include square or rectangular **910A**, hexagonal **910B**, elliptical or oval-shaped **910C**, triangular **910D**, octagonal **910E**, and pentagonal **910F** light collectors. However, the embodiments depicted are provided as examples only, and a light collector for use in a daylighting system as described herein can be any suitable or feasible shape and/or size. Various shaped light collectors can be configured to correspond to a shape of a building opening through which a daylighting device transmits light.

FIG. 10 shows a cross-sectional view of a light collector **1010** including both a side portion **1014**, and a top portion **1012**. The collector **1010** can include a transparent acrylic material, or other material that is at least partially transparent. In certain embodiments, the collector **1010** can be manufactured at least partially of transparent acrylic having a thickness of approximately 100-125 mm. In certain embodiments, a prismatic element is disposed within or without the side portion **1014**, which may provide double refraction of light. For example, as illustrated in FIG. 10, the prismatic element **1015a** can include prisms facing outward to provide a first refraction of light and a planar surface of the sheet providing a second refraction. In certain embodiments, this prismatic pattern is molded into a thin polymer sheet that can be placed inside a protective transparent collector structure. The top portion **1012** can include a variable prism dome. Alternatively, or in addition to, the incorporation of the prismatic element **1015**, one or more walls or surfaces of the collector **1010** can include prismatic features formed therein. While such formed prismatic features can be used, in certain embodiments, a prismatic element may provide desirable light turning characteristics relatively more efficiently, with respect to cost, ease of manufacture, and/or other considerations.

In certain embodiments, the side portion **1014** is cylindrically shaped, providing a 360-degree sunlight capture zone. The effective light capture area of the side portion **1014** can be an area of a cylinder in direct exposure to rays of sunlight, as well as a portion of the top cover **1012** that is directly exposed to the sunlight. In certain embodiments, in the presence of unobstructed, substantially collimated light, the effective capture area of the side portion **1014** can be approximately 90 degrees of the 360 degree circumference of the side portion **1014**, or approximately 25% of the total surface area of the side portion **1014**.

In certain embodiments, the prismatic element **1015a**, with either outwardly-facing or inwardly-facing prisms, extends along the inside of at least a portion **1017** of the side portion **1014** of the collector **1010**. In certain embodiments, sunlight may refract down into the tube if the sunlight is within approximately ± 45 degrees incident angle to the surface of the side portion **1014** of the collector. The side portion **1014**

can be hollow, and may extend from the top portion **1012** down, terminating in an open lower end **1018**, through which light can pass.

In certain embodiments, the light collector **1012** can be configured such that optical elements associated with the side portion **1014** capture sunlight having elevations ranging from 20°-40°, while optical elements associated with the top portion **1012** capture incident light at solar elevations greater than approximately 45°. By capturing sunlight incident at a wide range of solar altitudes, the optical elements of the light collector **1012** can substantially enhance the light collection performance of the daylighting device **1000** over a wide range of latitudes and seasons. As shown in FIG. **10**, the light collector **1010** can include one or more prismatic elements **1015a**, which extend across at least a segment **1017** of a perimeter of the side portion **1014**. The prismatic element **1015a** can be a single unitary member, or can include multiple distinct segments. In certain embodiments that include a prismatic element **1015a**, the prismatic element **1015a** can span the entire side portion **114** of the light collector **1010**. Alternatively, as shown in FIG. **10**, the prismatic element **1015a** can span a segment **1017** of the perimeter of the side portion **1014**, but not span a remaining perimeter segment that is contiguous to the spanned segment **1017**.

In certain embodiments, a prismatic element **1015a** can include prisms configured to refract light. Prisms can include prism grooves on an outer surface of the prismatic element, and can be linear when the sheet is in a flat configuration and, thus, form circles when the sheet **1015a** is formed into a cylindrical configuration. The outer surface of the prismatic element can be positioned against, or proximate to, an inner surface of the side portion of the collector. The prism grooves can be outwardly facing, as shown in FIG. **10**, or otherwise configured. In certain embodiments, similar prisms are present in both the top portion and the side portion, both serving to increase light throughput. The various prism elements included in the light collector **1010** can have different prism angles, depending on what portion of the collector **1010** they are associated with. In certain embodiments, the prism elements in the light collector **1010** have uniform prism angles throughout the collector **1010**. In certain embodiments, prisms within a single region of the collector **1010** have varying prism angles. For example, it can be desirable for adjacent prisms, or adjacent groups of prisms, to include different prism angles in order to mix the light that propagates through a portion of the light collector **1010**. For example, if substantially collimated light enters a prismatic portion of a light collecting assembly that includes prisms with equal prism angles, light entering the tube can be concentrated in certain regions. Such light concentration may cause undesirable "hot spots" in the destination area. By varying the prism angles, the effect of such hot spots can be reduced.

The top portion **1012** can be made integrally with the side portion **1014** and may extend from an open base **1018** to a closed top portion **1012**, forming a continuous wall. Alternatively, the top portion **1012** can be an at least partially separate physical component from the side portion **1014**. In the depicted embodiment, the top portion **1012** is substantially flat, and can be associated with one or more optical components, such as a prismatic element **1015b**. However, as discussed above, the top portion **1012**, or any other portion of the light collector **1010**, can be shaped in any suitable manner.

In certain embodiments, the top portion **1012** is at least partially constructed of transparent acrylic. The top portion **1012** can be formed with prismatic elements, which can be prism lines that are etched in, molded in, or otherwise integrated with or attached to the top portion **1012**. In certain

embodiments, the prism elements increase light throughput by capturing light originating outside the collector **110** and turning it downward through the open base portion **1018**, and into a tube assembly. Prismatic elements associated with the top portion **1012** may differ from those associated with the side portion **1014**. For example, the prismatic element **1015b** can include prismatic grooves having opposing faces that lie at angles of approximately 45° and 18°, respectively, with respect to a vertical plane. Prisms including faces that lie at other angles are also contemplated with respect to embodiments of top, side, and/or other portions of light collecting assemblies disclosed herein.

FIG. **11** provides a cross-sectional view of a portion of the prismatic element **1015a** shown in FIG. **10**. The portion of the prismatic element **1015a** shown in FIG. **11** includes a plurality of prisms **1156**. The structure shown in FIG. **11** includes an outer transparent side portion **1114** of the light-collecting assembly **1010** of FIG. **10**. The prisms **1156** can be positioned along the interior surface of the side portion **1114**, and may face the direction of sunlight L_S penetrating the side portion **1114**. In certain embodiments, prisms **1156** are inwardly facing, with back surface **1149** of the prisms facing the side portion **1114**. In certain embodiments, prismatic element **1115** contains prisms on more than one of its sides. The prisms can be configured to turn at least a portion of sunlight that strikes the cylinder portion of the light collecting assembly downward towards a horizontal aperture of a tube.

In certain embodiments, prisms **1156** include two faces **1146**, **1148**. In the embodiment of FIG. **11**, face **1148** has a prism angle γ_1 with respect to horizontal, while face **1146** has a prism angle γ_2 below horizontal. The prism angles γ_1 and γ_2 can be equal, or may vary, depending on the configuration of the prismatic element **1115**. Furthermore, adjacent prisms **1156**, or groups of prisms, may have varying prism angles. Such varying prism angles may promote mixing of light propagating through a light collector. In certain embodiments the prismatic element **1115** includes prisms having uniform prism angles. In certain embodiments, the prism angles γ_1 and γ_2 have angles of approximately 70° and 30°, respectively.

With further reference to FIG. **10**, prism angles associated with the top portion **1012** and the side portion **1014** can be selected to provide an angle of refraction that increases the range of solar altitudes at which radiation that can be captured and turned towards the daylighting aperture **1018** at the base of the light collector **1010**. In certain embodiments, the light collector **1010** and prismatic element are made of the same material or materials, or materials having substantially similar indexes of refraction. In some embodiments, the prismatic element(s) can include a material or materials with higher index of refraction than a sidewall of the light collector.

The top portion **1012** can be configured to reduce the effective capture area of the light collector **1010** at solar altitudes higher than a certain value to prevent over illumination and/or heating during midday hours (such as, for example, between 10 am and 3 pm, between 11 am and 2 pm, or during a time when the solar altitude is greater than or equal to about 30 degrees). In certain embodiments, at least a portion of the top portion **1012** can be configured to reflect some or all of the light striking such portion at solar altitudes above a certain angle. For example, at least some of the top portion **1012** can be configured to reflect at least a portion of overhead sunlight in order to reduce light and/or heat during midday hours. Embodiments of the light collector **1010** with a prismatic element **1015b** positioned to receive daylight transmitted through the top portion **1012** can be beneficial in sunny and high solar altitude conditions. A prismatic element **1015b** in the top portion **1012** can direct a substantial portion, most,

or substantially all daylight incident on the top portion **1012** towards a reflector, such as, for example, the reflector **1980** shown in FIG. **19**. The reflector can be configured to reject wavelengths of daylight that transmit thermal energy but provide little or no visible illumination.

In certain embodiments, the top portion **1012** of the light collector **1010** can be constructed at least partially from clear acrylic, transparent plastic, another suitable material, or a combination of materials. Embodiments of the light collector **1010** with a clear top portion can be beneficial in diffuse daylight conditions due to relatively high transmission of overhead sunlight.

The walls of the side portion **1014** can be substantially vertical, or may have any desirable inward or outward slope. In certain embodiments, the walls of side portion **1014** are sloped to allow for nesting of multiple such components to allow for tighter packaging.

In certain embodiments, the side portion **1014** provides a substantially vertical daylight-collection surface for sunlight collection, which may provide higher aspect ratios for light collection. Prismatic elements can be integrated with at least a portion of the wall of the side portion **1014**. In alternative to, or in addition to, prisms integrated in the side portion **1014**, the above-described prismatic element can be used to refract light downward. The planar back side **1149** of the prismatic element **1115**, shown in FIG. **11**, may provide good downward refraction due to a high to low index of refraction interface. Certain light collector embodiments include a plastic polymer with an index of refraction in the range of approximately 1.49-1.65.

FIG. **12** shows a cross-sectional view of a light collector **1210** including a side portion that includes a plurality of vertically arranged optical zones, or segments **1214a**, **1214b**, and **1214c**. In certain embodiments, various segments are associated with prismatic elements having different prism angles or characteristics. For example, a top segment, such as segment **1214a**, can be associated with light turning structure **1213a** configured to turn light at a relatively high angle towards the base **1218** of the light collector **1210**. This can be desirable in order to increase the percentage of light L_1 entering the top segment **1214a** that is directed through the base **1218** of the light collector **1210** and into a tube **1220**. As light entering the top segment **1214a** has a relatively farther distance to travel in order to reach the base **1218**, it can be necessary or desirable to turn such light to a relatively high angle. Relative to the prismatic structure **1215a**, the prismatic structure **1215b** that is associated with the second segment **1214b** can include prismatic angles that turn light L_2 to a lesser degree than L_1 is turned. This can be desirable due to the prismatic structure **1215b** being disposed generally closer to the base **1218**. Therefore, it may not be necessary to turn light L_2 as much to facilitate the propagation of light entering the light collector **1210** through the second segment **1214b** to a desirable degree.

The light collector can include one or more portions or segments, such as segment **1214c**, that are not associated with prismatic structures. For example, a segment, such as segment **1214c**, disposed relatively near to the base **1218** may require relatively less turning of light, or no turning of light to achieve desirable levels of light collection. Therefore, as shown, light L_3 entering the bottom segment **1214c** may enter the tube **1220** substantially without being refracted toward the tube by the light collector **1210**.

Although the light collector illustrates three segments, a light collector in accordance with certain embodiments disclosed herein may contain any number of segments or regions. Furthermore, different segments can be associated

with optical elements having varying characteristics, or can be uniform through one or more segments.

As shown in FIG. **12**, the width w_c of the collector base **1218** can be greater than the width w_d of the tube **1220** at a horizontal aperture. For example, the diameter of the collector base **1218** may range from 100% to 150% or more of the width of the tube **1220**.

In certain embodiments, a flat or curved reflective panel is associated with a light collector that reflects at least a portion of sunlight that would otherwise exit the light collector through a portion generally opposite to a region of the light collector through which daylight is received. FIG. **14A** provides a perspective view of an embodiment of a light reflector **1480** for disposing within, adjacent to, or in integration with, a light collecting assembly. The reflector can be made of material having high luminous reflectance. For example, the luminous reflectance of the reflector **1480** can be greater than or equal to about 0.9, greater than or equal to about 0.95, greater than or equal to about 0.98, or greater than or equal to about 0.99, when measured with respect to CIE Illuminant D_{65} . The reflector **1480** can be curved, as shown, or can be any shape configurable to reflect light propagating within or near a light collecting assembly.

As is shown in FIG. **14B**, which provides a top view of the reflector **1480** of FIG. **14A**, the reflector **1480** can be semi-circular in shape, such that it can be nested within a cylindrically-shaped light collector. The reflector **1480** may conform to the shape of a back portion of a light collecting assembly, and can be disposed behind a refractive lens, thereby increasing the effecting light capture area of the light collector. The reflector **1480** may provide increased transmission of captured sunlight into an optical guide tube.

The use of a curved reflector **1280** may allow for sunlight capture from a greater range of circumferential angles about the light collector **1220**. This increase in angular reflection of sunlight may provide a number of benefits, such as increased light mixing. For example, in embodiments in which sunlight enter a tube opening from a wide range of circumferential angles, the distribution of light exiting the tube can be more uniform and may reduce the presence of hot spots on a diffuser at the base of the tube. Such light mixing can prevent collimated light from reaching the diffuser prisms in such a way as to cause rainbows to appear in the building interior.

With respect to certain embodiments in which light is directed into a central feeder tube, and dispersed into multiple branch tubes, light mixing can be important in promoting the dispersion of sunlight into the various branch tubes. In certain embodiments, branch tubes each receive approximately equal amounts of light from the central feeder tube.

The collection and redirection of sunlight using a light reflector, such as the curved reflector **1480**, may substantially increase the performance of a conventional tubular daylighting device. A number of parameters may contribute to increased performance of certain embodiments of sunlight-collection systems. For example, the sunlight collection area of a light collector may affect the performance of such a system. In certain embodiments, the height and width of the collector in relation to the diameter of a tube opening into which light is directed can be determined by the refractive turning power of optical elements (e.g., integrated prisms, prismatic element or lens film, etc.) within, or associated with, the light collector. This aspect ratio of cylinder height to tube opening width, or diameter, may depend on the solar altitude range that is desired to capture and refract into the tube. This range can be from approximately 20 to 70 degrees for most locations in the United States. For example, using lower-end solar altitude of approximately 20 degrees as the

design point for refracting light into the tube from the optical elements associated with a light collector having vertical side walls, the cylinder height can be designed to an approximate range of 1.2 to 2.5 times the tube diameter. These values may vary based on material index of refraction and prism angles, among other things. As an example, a system can include a collector height of approximately 35-45 inches and a tube diameter of approximately 20-25 inches. The diameter of the collector can be approximately equal to the diameter of the tube opening, or can be larger or smaller than the diameter of the tube. The actual effective front light-capture area of the cylinder is associated with the direct non-reflected sun, which, in certain embodiments, can be limited to an exposure angle of approximately 90 degrees due to the off axis curvature limitation of the optics in the collector prisms.

FIG. 14C provides a cross-sectional view of the vertically-oriented planar reflector 1480. As is shown in the figure, the angle θ_1 of direct light L_D with respect to a horizontal plane is generally equal to the angle θ_2 of reflected light L_R . In certain embodiments, it can be desirable for the reflector surface to be tilted with respect to a vertical axis to increase the reflected angle θ_2 with respect to horizontal. Furthermore, in certain embodiments, the reflector 1480 is associated with one or more prismatic surfaces that further increase the angle of reflected light. Such prisms may vary over different portions of the reflector in order to increase the amount of light received into a tube opening.

FIG. 15 illustrates a perspective view of an embodiment of daylighting device 1500 including a light collector 1510 incorporating a reflector 1580. The daylighting device 1500 includes a light-reflecting tube 1520 disposed adjacent to the light collector 1510. As shown, daylight L_S enters the light collector 1510 through a side portion 1514. The light L_S is refracted by one or more optical elements associated with the side portion 1514 and turned towards an opening in the tube 1520. In certain embodiments, the side portion 1514 is not associated with light turning characteristics, and light L_S entering the light collector 1510 propagates within the light collector at an angle substantially equal to the angle of the light L_S prior to entering the light collector 1510. The presence of the reflector 1580 may increase the effective area of collection of one or more refractive lenses associated with the light collector and configured to turn light towards the tube 1520.

The reflector 1580 is disposed along an inside or outside surface of the light collector 1510, such as along a surface that is positioned substantially opposite to a direction at which light L_S may enter the light collector 1510 at one or more points during the day. For example, the reflector 1580 may generally face in a southern direction in an embodiment located at a point in the northern hemisphere. As shown, daylight L_S may enter the light collector 1510 and strike a point on the reflector 1580. The reflector may reflect at least a portion of the daylight in the visible spectrum towards the tube opening 1528. If not for the reflector, a substantial portions of the light L_R may instead propagate out of the tube or be absorbed by materials associated with the light collector 1510. Therefore, inclusion of a reflector 1580 in a daylighting system 1500 may increase the amount of light transmitted through the light collector 1510 into the tube 1520.

FIG. 16 illustrates a perspective view of an embodiment of daylighting system 1600 including a light collector 1610 incorporating a reflector 1680. The reflector 1680 can include characteristics allowing for pass-through transmission of certain amounts of light of certain wavelengths. For example, in certain embodiments, the reflector 1680 is at least partially transparent with respect to light in the infrared spectrum.

Sunlight includes infrared light and visible light. In general, infrared light transfers thermal energy but provides little or no advantage when the goal is illumination. A daylighting device that directs infrared light into a building can substantially increase temperatures within the building without providing any measurable illumination benefit. In some embodiments, a light collector includes a reflector that allows at least a portion of infrared light that is incident on its surface to pass through the reflector and out of the light collector 1610, rather than reflecting such light in the direction of the tube 1620. In certain embodiments, a light collector 1610 is configured to capture and remove at least a portion of infrared light incident on the collector and/or other spectral wavelengths that do not contribute to visible illumination. In such embodiments, the light collector 1610 can simultaneously turn a substantial portion of visible light, such as, for example, greater than or equal to 95%, greater than or equal to 98%, or greater than or equal to 99% of visible light, towards a daylighting aperture formed in the base of the collector 1610.

The dashed line in FIG. 16 shows a possible path of sunlight that is captured by the light collector 1610. When incident on an outside surface of the collector 1610, the sunlight includes visible and infrared light. At least a portion of the light incident on the surface of the at least partially transparent light collector 1610 passes into the interior of the light collector 1610. The light propagates within the light collector 1610 until it strikes a reflector 1680 positioned to receive at least a portion of the light entering the light collector 1610. In certain embodiments, the reflector 1680 is disposed along an inner or outer surface of a substantially vertical sidewall the light collector 1610. In some embodiments, the light transmits through a second transparent sidewall of the light collector before propagating to a surface of the reflector 1680. The reflector 1680 is configured to turn at least a portion of the light in a direction generally towards an opening of a tube 1620 positioned to receive light that exits the daylight collector 1610 through a daylighting aperture in the base of the collector. In some embodiments, the reflector 1680 is at least partially transparent to infrared light L_{IR} . In such embodiments, a portion of the infrared light L_{IR} transmits through the reflector 1680 and exits the light collector 1610, propagating away from the opening of the tube 1620.

In certain embodiments, the reflector 1680 is configured to transmit wavelengths other than infrared. For example, the reflector 1680 can partially reflect and partially transmit visible light. As another example, the reflector 1680 can reflect most or substantially all visible light while transmitting and/or absorbing at least a portion of ultraviolet light.

FIG. 17A illustrates an embodiment of a light collector 1710 having a transparent assembly and a reflective assembly. The light collector 1710 includes a transparent assembly 1711 that is at least partially transparent to daylight incident on its surface. For example, the transparent assembly 1711 can include a sheet of substantially clear acrylic in a semi-circular, curved, planar, and/or segmented configuration. The reflective assembly 1780 can include material for reflecting at least a portion of light incident on one or more of its surfaces. For example, the reflective assembly 1780 can be a semi-circular, curved, planar, and/or segmented reflector. In certain embodiments, the reflective assembly 1780 includes aluminum, reflective film, a metallic reflector, other reflective materials, other optical elements, or a combination of optical elements.

The transparent portion 1711 and the reflector assembly 1780 can be connected at a seam 1730 to form a combined structure, such as an enclosed cylinder or other shape. The structures can be combined in any suitable manner. For

example, the structures can be adhered together through the use of an adhesive substance, or by welding or other technique. In certain embodiments, the structures **1711**, **1780** are connected using one or more physical connection structures, such as clips, slots, staples, and the like. For example, as shown in FIG. **17B**, which provides a top view of a portion of the light collector **1710**, one or more end portions of the respective structures can include male/female slot connecting members for connecting two or more structures. Such a configuration may allow for connection of structures without the need of additional separate connecting devices or materials.

FIG. **18** illustrates an embodiment of a light collector **1810** having a transparent portion and a reflector assembly. Depending on material characteristics of the reflector assembly **1880**, portions of the reflector assembly, or any other component of the light collector **1810**, may absorb thermal energy from light (e.g., infrared light) coming in contact therewith. For example, in certain embodiments, the reflector assembly can include aluminum. Heat absorbed by such a structure may contribute to undesirable heating within a light collector, daylighting system and/or interior of a building.

In certain embodiments, an outside surface **1881** of at least a portion of the light collector **1810** is coated or covered with a layer of material having a relatively high thermal emissivity factor, serving to aid in the transfer of thermal energy away from the light collector **1810**. The emissivity factor is related to the ratio of absorbed thermal energy to reflected and/or transmitted thermal energy. In certain embodiments, the outside surface **1881** is in thermal communication with a material having an emissivity factor of greater than about 0.9. Furthermore, high-emissivity material(s) used in connection with a light collector such as that depicted in FIG. **18** may have varying emissivity characteristics for different wavelengths of light. For example, a material can be configured to transmit a relatively high percentage of energy in the infrared spectrum. Material in thermal communication with outer surface **1881** can be in the form of paint or other coating, or can be a sheet or film disposed in the surface **1881**. Other components of the daylighting system, such as a daylight-reflective tube, can be coated or lined with high-emissivity materials in order to draw heat away from the interior of the daylighting system, thereby reducing unwanted heating. Examples of types of high-emissivity materials that can be used in connection with a daylighting apparatus include various types of glass (e.g., frosted glass), plastic, sheet metal, paint, powders (e.g., graphite powder), lacquer, or tape (e.g., electrical tape) having high-emissivity characteristics, and can be black or white in color. High-emissivity material can be used in connection with various embodiments of light collecting assemblies as disclosed herein, including light collectors of having any suitable shape or including any suitable material or combination of materials.

FIG. **19** illustrates an embodiment of a light collector **1910** in a daylighting system **1900**. The light collector includes three vertically-arranged optical zones, or segments **1914a**, **1914b** and **1914c**. The segments **1914a**, **1914b** and **1914c** can be of uniform height, or the heights of different segments may vary. In certain embodiments, each segment is approximately 10-15 inches tall. For example, the segments **1914a**, **1914b** and **1914c** can be approximately 12 inches in height. In certain embodiments, a bottom segment, such as segment **1914c**, has a greater height than other segments to accommodate attachment of the light collector **1910** to a flashing. For example, the bottom segment **1914c** may have a height of about 14 inches. Furthermore, the light collector can include a lip, or fringe **f** that extends beyond the opening of the tube **1920**.

Although three segments are shown, a light collector can include any suitable number of segments or portions. In certain embodiments, different segments can be associated with different optical refraction, transmission and/or reflection characteristics. For example, in some embodiments, at least a portion of the top segment **1914a** is associated with a prismatic element **1915a**, or other optical element or elements. As shown in FIG. **19**, the prismatic element **1915a** may extend around more than half the circumference of a generally cylindrically-shaped light collector **1900**. In certain embodiments, the prismatic element **1915a** extends around approximately 270° of the cylindrically shaped collector **1910**, and may generally face a direction from which daylight enters the collector **1910**, as shown. Providing prismatic element that extends beyond 180° of the perimeter of the light collector may allow for capture of a wider spectrum of light. In certain embodiments, the prismatic element **1915a** circumscribes the entire perimeter of the light collector **1910**, at least with respect to the top segment **1914a**.

In the depicted embodiment, the middle segment **1914b** is also associated with light turning structure **1915b**, such as prismatic element. A prismatic element **1915b** can extend along approximately 50%, or 180°, of the perimeter of the light collector **1910**, as shown, and can generally face a direction from which daylight enters the collector **1910**. The prismatic elements **1915a** and **1915b** can be a unitary structure, or can be separate sheets or films. The prismatic elements **1915a** and **1915b** can include prisms having similar or different light-turning characteristics. In certain embodiments, one prismatic element **1915a** is configured to turn daylight to a greater degree than another prismatic element **1915b**.

Collector segment **1914c** can be associated with light-turning prismatic structure, or may not, depending on collector **1910** characteristics. For example, as shown, the segment **1914c** may allow for daylight to pass into the collector **1910** without substantially altering an angle of the daylight with respect to a horizontal plane. Therefore, the segment **1915c** may present a substantially clear acrylic material without additional optical elements to daylight entering therein.

In addition to, or in place of, a light turning structure **1915a**, **1915b**, one or more portions or segments of the light collector **1910** can be associated with a reflector assembly **1980**. In the embodiment shown in FIG. **19**, a reflector **1980** is disposed in proximity to an inside surface of the sidewall of the light collector **1910** along portions of light collector segments **1914b** and **1914c**. It can be desirable to include one or more reflectors in at least a lower portion of the light collector **1910** because light striking a reflector in a lower portion of the light collector **1910** can be more likely to reflect into the tube **1920** rather than exiting out the front side of the collector. For example, in an embodiment including a reflector in the top segment **1914a**, light striking the reflector at a point in segment **1914a** may have a further distance to travel in order to reach the tube **1920**. Therefore, the angle of trajectory may carry the light out of the collector before it reaches the tube **1920**. In certain embodiments, the top segment **1914a** of the collector **1920** is not associated with the reflector assembly **1980**. In some embodiments, a light collector **1910** having a reflector **1980** can have a height that is greater than or equal to about twice the height of a light collector that does not have a reflector. In some embodiments, a light collector **1910** having a reflector **1980** limits the collection of light at sun azimuthal angles greater than 60 to 90 degrees when the reflector **1980** is facing south.

Reflective characteristics of the reflector **1980** may vary in different portions or segments of the reflector. Furthermore, while FIG. **19** shows the reflector as a singular piece, the

reflector can include distinct pieces or structures. The reflector **1980**, or portions of the thereof may span any suitable portion of the circumference, or perimeter, of the light collector **1910**. In certain embodiments, the reflector **1980** spans approximately 180° of the light collector's perimeter, as shown. The reflector can be positioned generally at a back portion of the light collector with respect to a direction from which daylight enters the light collector **1910**. In certain embodiments, and under certain daylight conditions, the light collector **1910** and reflector **1980** can be configured such that approximately 85% or more of the light entering the collector will be directed to the reflector **1980**, and can allow for the removal of infrared light from daylight before the daylight enters the tube **1920**.

The reflector **1980** can be constructed from a material system that has high luminous reflectance and high transmittance of infrared light. The finish of the reflector **1980** can be specular or have any desired level of specularity. Wavelength-selective light reflectance can be achieved using any suitable materials. Examples of wavelength-selective material systems include dielectric coatings and/or multi-layer films that use small differences in refractive index between many layers of the film to achieve desired optical properties. Multi-layer films can include coextruded stacks of two or more polymers having different refractive indices. FIG. 13 shows the reflectivity profile of a multi-layer film, 3M Daylighting Film DF2000MA, which is available from the 3M Company of Maplewood, Minn., USA. This polymeric film is an example of a multi-layer film that can be part of the material system of the reflector **1980** or as the reflector **1980**. The reflectivity profile of an enhanced silver coating is also shown. The multi layer film provides very high reflectivity in the visible region, having a luminous reflectance greater than 99% when measured with respect to CIE Illuminant D₆₅. The film has substantially lower reflectivity of infrared light; the reflectivity of infrared light is less than or equal to about 20%. The reflectivity of ultraviolet light is also substantially lower than the reflectivity of visible light. In comparison, the enhanced silver coating has lower luminous reflectance and infrared light reflectivity greater than 90%.

After infrared light is transmitted through a wavelength-selective reflector **1980**, the infrared light can transmit through an infrared transmissive material, such as, for example, acrylic or PET. In some embodiments, the sidewall of the collector **1910** is made from an infrared transmissive material. In some embodiments, the infrared light is absorbed after transmitting through a wavelength-selective reflector **1980**. In such embodiments, the infrared light can be absorbed by an infrared absorbing paint or adhesive positioned to receive the infrared light after it transmits through the reflector **1980**. In some embodiments, the infrared paint or adhesive is adhered to a metal substrate. The metal substrate can form a portion of the sidewall of the collector that is not transparent (e.g., a portion of the sidewall configured to face away from direct sunlight). The metal substrate can be heated by the paint or adhesive when it absorbs infrared light, and the infrared light can then be reemitted in a direction generally away from the daylighting aperture **1918** and the tube **1920**.

In some embodiments, an exterior surface of the portion of the sidewall of the collector **1910** that absorbs infrared light has high emissivity. High emissivity can be obtained by applying a high emissivity material, such as paint, to the surface, or by performing another type of surface treatment, such as anodization. At least some anodized metals exhibit high emissivity, and such metals can form at least a portion of the exterior surface of the light collector **1910**. A high emissivity surface can also be provided on the outside surface of

the tube **1920**, which can permit the tube **1920** to readily reemit infrared radiation absorbed by the tube **1920** out of the daylighting device **1900**.

In certain embodiments, the daylighting device **1900** is configured to reject heat during summer months, when the solar altitude is higher, and to direct heat into the building being illuminated by the daylighting device during winter months, when the solar altitude is lower.

A daylighting device incorporating a light collector in accordance with the embodiments described above can be configured to maintain an illumination level within a range of about +/-20% of a given value throughout a period of interest, such as the hours from around 9:00 am to 3:00 pm. Furthermore, such a device may provide around 20,000 lumens of light, or more, at a given time, depending on, among other things, external daylight conditions.

Table A lists potential illumination performance values of two daylight collectors in accordance with one or more embodiments disclosed herein. The performance can be measured by total daylight transmission (in lumens) through the daylighting device into an interior space of a building or structure. In some embodiments, the illumination performance of a daylight collector can be determined by measuring the luminous flux of daylight through the daylighting aperture of a daylight collector. Table A provides potential results with respect to a range of daylight conditions/solar altitudes. In some embodiments, a daylighting collector is configured to direct greater than or equal to about 30,000 lumens and/or greater than or equal to about 40,000 lumens of daylight into a daylighting aperture when the daylighting collector is exposed to sunlight at a solar altitude of 40°.

TABLE A

Solar altitude (degrees from horizontal)	Light Transmitted - 23" cylinder with 45°/10° prismatic element at top (lumens)	Light Transmitted - 27" cylinder with 45°/10° prismatic element at top (lumens)
20	18,284	24,900
30	27,799	36,857
40	30,318	40,730
50	28,575	38,219
60	24,523	33,928
70	23,155	32,558
80	10,394	16,494

FIG. 20 illustrates an embodiment of a light collector **2010**. The figure shows two vertically-arranged zones, or segments, 'A' and 'B.' The segments A and B can be of uniform height, or the heights of different segments may vary. In certain embodiments, the segment A represents a portion of a vertical side portion of the light collector **2010** that is associated with prismatic structure **2015a**, at least over some portion of the circumference or perimeter of the side portion. Furthermore, the segment B may represent a portion of the vertical side portion of the light collector **2010** that is not associated with prismatic structure. The light collector **2010** can include a back half-cylinder portion, which can include reflective properties. For example, at least a portion of the back portion **2080** can include or be associated with aluminum, or other reflective material. In certain embodiments, the vertical walls of the light collector **2010** can be configured to capture daylight having a solar altitude of approximately 20°-50°.

The light collector **2010** can include a substantially clear dome-shaped cover portion **2012**. The cover portion **2012** can be configured to capture daylight having a solar altitude of approximately 30°-90°. The combination of vertical sidewall

and dome-shaped cover portions may provide improved performance during both clear and cloudy weather conditions.

In general, with respect to a light collector embodiments in accordance with FIG. 20, greater performance a lower solar elevations (e.g., 20°-40°) can be achievable with higher aspect ratios (i.e., height of vertical cylinder portion C vs. width of tube opening w_t). With respect to daylight at solar altitudes greater than 40°, the horizontal daylight-collection surface provided by the cover 2012 may provide the majority of daylight capture. In certain embodiments, an aspect ratio of approximately 1.9 will produce approximately 40% or more improvement in captured light at 20° and/or 30° when compared to an aspect ratio of approximately 1.3 or less. However, performance at 40°-90° may remain approximately steady for both configurations.

Design considerations in manufacturing daylight collectors in accordance with one or more embodiments disclosed herein may take into consideration various cost-related and/or other factors. For example, different materials that can be selected for incorporation in a daylight collector can be available at different prices. Furthermore, different materials may have different physical properties contributing to the performance and/or ease of manufacturing of various components of the collector. Therefore, certain information about the physical dimensions of a light collector can be useful in making design or other decisions. Table B provides example physical specifications for a number of possible embodiments of daylight collectors. The dimensions provided in Table B correspond to the areas and dimensions called out in FIG. 20. Table B provides size and area information that can be helpful in assessing cost/performance issues associated with the respective embodiments, as well as other embodiments.

TABLE B

Collector Type	High Aspect Ratio	Scaled-Up High Aspect Ratio	Low Aspect Ratio	Scaled-Up Low Aspect Ratio
Cylinder Diameter (W_c)	23"	27.3"	23"	27.3"
Tube Diameter (W_t)	21"	25.3"	21"	25.3"
A	23.6"	28.2"	10.4"	12.5"
B	18.0"	21.1"	18.0"	21.1"
C	41.6"	49.3"	28.4"	33.6"
Cover (2012) Surface Area	2.88 ft ²	4.09 ft ²	2.88 ft ²	4.09 ft ²
Front Prismatic Portion (2015a) Area	5.9 ft ²	8.40 ft ²	2.6 ft ²	3.7 ft ²
Front Prismatic Portion (2015a) Size	23/6" × 36.1"	28.2" × 42.8"	10.4" × 36.1"	12.5" × 42.8"
Back Portion (2080) Area	10.4 ft ²	14.7 ft ²	7.2 ft ²	10.0 ft ²
Back Portion (2080) Size	41.6" × 36.1"	49.3" × 42.8"	28.4" × 36.1"	33.6" × 42.8"

The values provided in Table B are approximations of various possible daylight collector dimensions, and are not limiting on the scope of the disclosure in any way. Furthermore, although certain values are provided in the table, the respective collector dimensions need not conform in any way to such values, and can be configured to be any suitable dimensions. As shown in the table, construction of a daylight collector may demand more than 8 ft² of prismatic material, as well as more than 14 ft² of reflective back portion material. Therefore, costs associated at least with such materials/areas may represent a significant factor in daylight collector design.

In certain embodiments, a light collector in accordance with one or more embodiments described herein can be configured such that fabrication and/or installation of the collector are simplified. For example, the side portion of a light collector 2014 can be formed from a substantially flat or

curved sheet that can be formed into a cylinder, as shown by the top view of FIG. 21A. Such a configuration, as installed, may have a singular vertical seam that can be, for example, secured by an attaching member 2019, or in any other suitable way.

FIG. 21B shows top view of an embodiment of a portion of a light collector, wherein the circumference of the light collector is made up of multiple segments 2114a, 2114b and 2114c, that can be attached in any suitable manner, such as by using attaching members 2119a, 2119b, and/or 2119c. With respect to the embodiments depicted in both FIGS. 21A and 21, a flat, slightly curved, or otherwise shaped top cover can be placed on the cylinder top.

FIG. 22 illustrates a packaging configuration for one or more curved light collector portions. For example, with respect to the embodiments of FIGS. 20 and 21, which can include one or more curved panels that can be formed into a cylinder or other shape, such panels can be disposed in a stacked configuration in a package 2290 for shipping, transporting, storing, or for other purposes. FIG. 23 illustrates a packaging configuration in which one or more curved panels 2314a, 2314b, 2314c are concentrically arranged in a package 2390. The packages shown can allow space for prismatic and/or reflective components, or any other components, associated with a daylighting device. Such packaging configurations may reduce cost and/or effort associated with the manufacture, transportation, and/or installation of one or more components of a daylighting device.

At least some of the embodiments disclosed herein may provide one or more advantages over existing lighting systems. For example, certain embodiments effectively allow increased daylight capture through the use of a light collector

50

incorporating one or more prismatic elements and/or reflective elements. As another example, some embodiments provide techniques for directing light to a building interior using a light collector having a height greater than the width of an opening in the building, or of a base aperture of the collector, through which light is transmitted. The height of the collector may provide an increased target light capture area. Certain embodiments may provide additional benefits, including reducing the incident angle at the diffuser of light propagating through the daylighting device, which can result in the diffuser operating with higher optical efficiency.

Other Embodiments

The following list has example embodiments that are within the scope of this disclosure. The example embodiments that are listed should in no way be interpreted as lim-

65

iting the scope of the disclosure. Various features of the example embodiments that are listed can be removed, added, or combined to form additional embodiments, which are part of this disclosure:

1. An at least partially transparent light-collecting device configured to direct daylight through a collector base aperture and into an interior of a building when the light-collecting device is installed on a roof of the building, the device comprising:

a top cover portion;

a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion, wherein the substantially vertical portion has a height that extends between the top cover portion and the collector base aperture, and wherein the substantially vertical portion is configured to receive a substantial amount of daylight during mid-day hours;

a prismatic element associated with the substantially vertical sidewall portion and configured to turn at least a portion of daylight received by the vertical portion towards the collector base aperture; and

a reflector associated with the substantially vertical portion configured to reflect the portion of daylight towards the opening;

wherein the light-collecting device is configured to be positioned over an opening in a roof of a building and is configured to direct daylight into the opening in the roof when the light-collecting device is installed as part of a daylighting device installation.

2. The device of embodiment 1, wherein the height of the vertical portion is greater than the width of the collector base aperture.

3. The device of embodiment 2, wherein an aspect ratio of the height of the vertical portion to the width of the collector base aperture is greater than 1.2 to 1.

4. The device of any of embodiments 1-3, wherein the top cover portion is substantially flat.

5. The device of any of embodiments 1-4, wherein the top cover portion comprises a dome-shaped surface.

6. The device of any of embodiments 1-5, wherein the top cover portion comprises a cone-shaped surface.

7. The device of any of embodiments 1-6, wherein the vertical portion comprises a plurality of vertically-arranged segments, including a top segment, a middle segment, and a bottom segment.

8. The device of embodiment 7, wherein the top segment is associated with first optical elements having first light-turning characteristics and the middle portion is associated with second optical elements having second light-turning characteristics.

9. The device of any of embodiments 7-8, wherein the bottom segment is not associated with light-turning optical elements.

10. The device of any of embodiments 7-9, wherein the top, middle, and bottom segments are each approximately 5 to 10 inches in height.

11. The device of any of embodiments 7-10, wherein the top, middle, and bottom segments are each a uniform height.

12. The device of any of embodiments 7-11, wherein the reflector is at least partially transparent with respect to infrared light.

13. The device of any of embodiments 7-12, wherein the vertical portion is substantially cylindrically shaped.

14. The device of embodiment 13, wherein the vertical portion comprises a first semi-circle portion that is at least partially transparent, and a second semi-circle portion that is at least partially reflective.

15. The device of embodiment 14, wherein the second semi-circle portion comprises a surface in thermal communication with a high-emissivity material configured to facilitate radiation of heat away from the second semi-circle portion.

16. The device of embodiment 14, wherein the high-emissivity material comprises paint with an emissivity value greater than or equal to about 0.9.

17. The device of any of embodiments 7-16, wherein the vertical portion is integrated with an internally reflective tube configured to channel light towards an interior space of the building.

18. The device of any of embodiments 7-17, wherein the height of the vertical portion is between 35 and 45 inches.

19. The device of any of embodiments 7-18, wherein the width of the collector base aperture is between 20 and 25 inches.

20. An at least partially transparent light-collecting device for directing daylight into a building interior, the device comprising:

a top cover portion;

a base aperture having a width and configured to be disposed adjacent to an opening of a building;

a substantially vertical portion having a height, the vertical portion extending between the top portion and the base aperture and configured to receive daylight when installed on a building; and

a reflector associated with the vertical portion, the reflector configured to reflect at least a portion of daylight received by the vertical portion towards the opening;

wherein the vertical portion is associated with a prismatic element configured to turn the portion of daylight received by the vertical portion towards the opening; and wherein the height of the vertical portion is greater than the width of the opening of the building.

21. The device of embodiment 20, wherein the vertical portion has a rectangular cross-sectional shape.

22. The device of any of embodiments 20-21, wherein the vertical portion has a substantially elliptical cross-sectional shape.

23. The device of embodiment 22, wherein the vertical portion is constructed out of a single sheet, wherein two ends of the sheet are joined to form a single vertical seam.

24. The device of embodiment 22, wherein the vertical portion comprises a plurality of curved sheets that are configured to be joined together to form a shape having a substantially elliptical cross section.

25. The device of any of embodiments 20-24, wherein the vertical portion has a cross-sectional perimeter comprising one or more curved portions and one or more straight portions.

26. A method of illuminating an interior of a building, the method comprising:

receiving daylight on a substantially vertical surface;

refracting the received daylight towards an opening in a building using a prismatic element disposed within a light-collecting device; and

reflecting the daylight towards the opening using a reflector.

27. The method of embodiment 26, wherein reflecting the daylight comprising reflecting the daylight after it is refracted using the prismatic element.

28. A method of manufacturing an at least partially transparent light-collecting device for directing daylight into a building interior, the method comprising:

- providing a light collecting device configured to receive daylight on a substantially vertical surface when installed on a building having an opening;
 - disposing a prismatic element within the light collecting device; and
 - disposing a reflector adjacent to a wall of the light collecting device;
- wherein the prismatic element is configured to turn at least a portion of daylight received on the substantially vertical surface towards the opening, and the reflector is configured to reflect the portion of daylight towards the opening.

Discussion of the various embodiments disclosed herein has generally followed the embodiments illustrated in the figures. However, it is contemplated that the particular features, structures, or characteristics of any embodiments discussed herein can be combined in any suitable manner in one or more separate embodiments not expressly illustrated or described. It is understood that the fixtures disclosed herein can be used in at least some systems and/or other lighting installations besides daylighting systems.

It should be appreciated that in the above description of embodiments, various features are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that any claim require more features than are expressly recited in that claim. Moreover, any components, features, or steps illustrated and/or described in a particular embodiment herein can be applied to or used with any other embodiment(s). Thus, it is intended that the scope of the inventions herein disclosed should not be limited by the particular embodiments described above, but should be determined only by a fair reading of the claims that follow.

What is claimed is:

1. An at least partially transparent light-collecting device configured to direct daylight through a collector base aperture and into an interior of a building when the light-collecting device is installed on a roof of the building, the device comprising:

- a top cover portion;
 - a substantially vertical sidewall portion configured to support the top cover portion above an upper end of the substantially vertical sidewall portion and to define a collector base aperture at a lower end of the substantially vertical sidewall portion, wherein the substantially vertical sidewall portion has a height that extends between the top cover portion and the collector base aperture, and wherein the height of the substantially vertical portion is greater than a width of the collector base aperture;
 - a prismatic element configured to refract a portion of light that passes through the substantially vertical sidewall portion; and
 - a reflector configured to turn at least a portion of the refracted light towards the collector base aperture, wherein the reflector has a luminous reflectance greater than or equal to about 0.95 when measured with respect to CIE Illuminant D₆₅;
- wherein the light-collecting device is configured to be positioned over an opening in a roof of a building and is configured to direct daylight into the opening in the roof

when the light-collecting device is installed as part of a daylighting device installation.

2. The device of claim 1, wherein the reflector is associated with the substantially vertical portion.

3. The device of claim 1, wherein the collector base aperture is substantially circular in shape, and the width is equal to a diameter of the collector base aperture.

4. The device of claim 1, wherein an aspect ratio of the height of the vertical portion to the width of the collector base aperture is greater than 1.2 to 1.

5. The device of claim 4, wherein the aspect ratio is greater than 1.5 to 1.

6. The device of claim 4, wherein the aspect ratio is greater than 2 to 1.

7. The device of claim 1, wherein the top cover portion is clear, and wherein the top cover portion is substantially flat or at least partially dome-shaped.

8. The device of claim 1, wherein the top cover portion includes a second prismatic element configured to refract daylight passing through the top cover portion.

9. The device of claim 8, wherein the second prismatic element comprises a prismatic film with prisms having a riser angle and a draft angle, and wherein the riser angle is different from the draft angle.

10. The device of claim 1, wherein the vertical portion comprises a plurality of vertically-arranged segments, including at least an upper segment and a lower segment.

11. The device of claim 10, wherein the upper segment is associated with first optical elements having first light-turning characteristics and the lower segment is clear.

12. The device of claim 10, wherein the upper and lower segments are each approximately 5 to 30 inches in height.

13. The device of claim 10, wherein the upper and lower segments are each greater than or equal to about 10 inches in height.

14. The device of claim 1, wherein the height of the vertical portion is between approximately 35 and 45 inches.

15. The device of claim 1, wherein the height of the vertical portion is between approximately 18 and 35 inches.

16. The device of claim 1, wherein the width of the collector base aperture is between approximately 20 and 30 inches.

17. The device of claim 1, wherein the width of the collector base aperture is between approximately 8 and 16 inches.

18. The device of claim 1, wherein the vertical portion is constructed out of a single planar sheet formed in the shape of an ellipse, wherein two ends of the sheet are joined to form a singular vertical seam.

19. The device of claim 1, wherein the vertical portion comprises a plurality of curved sheets that are configured to be joined together to form an ellipse.

20. The device of claim 1, wherein the vertical portion comprises one or more sheets that are configured to be joined together to form an angular portion, a curved portion, or a combination of at least one angular portion and at least one curved portion.

21. A method of illuminating an interior of a building, the method comprising:

- receiving daylight on a substantially vertical surface;
 - turning the daylight towards an aperture lying in a substantially horizontal plane using a prismatic film disposed within a light-collecting device; and
 - reflecting the daylight towards the aperture using a reflector;
- wherein the substantially vertical surface has a height greater than a width of the aperture.