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(54) **Title:** OPTICAL FERRULE HAVING COMPOUND STOPS

(57) **Abstract:** An optical ferrule comprises first and second compound stop features respectively disposed at opposing sides of the optical ferrule. Each compound stop feature has upper and lower contact surfaces. The lower contact surface is offset below the mating surface of the optical ferrule along a thickness axis perpendicular to the mating surface. The upper contact surface is offset above the mating surface along the thickness axis. The lower contact surface is offset forward from the upper stop surface along a mating direction of the optical ferrule. A connecting surface connects the upper contact surface and the lower contact surface.

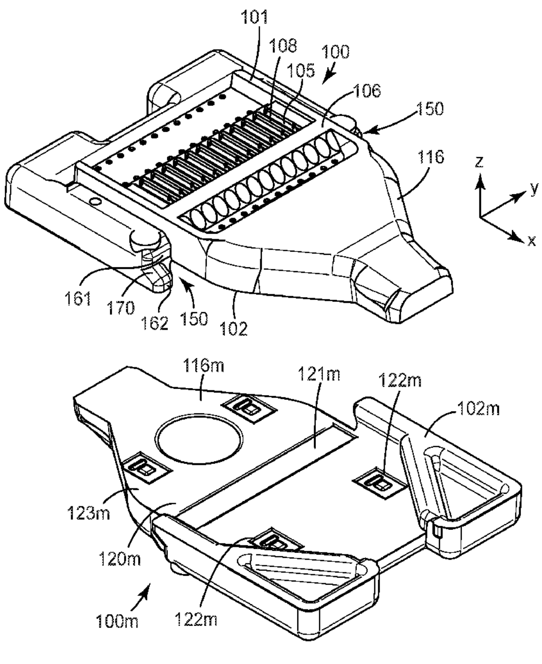

FIG. 1A

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[Continued on next page]

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OPTICAL FERRULE HAVING COMPOUND STOPS

TECHNICAL FIELD

This disclosure relates generally to optical ferrules, optical assemblies, and optical connectors that include optical ferrules.

BACKGROUND

Optical connectors can be used for optical communications in a variety of applications including telecommunications networks, local area networks, data center links, and internal links in computer devices. There is interest in extending optical communication to applications inside smaller consumer electronic appliances such as laptops and even cell phones. Expanded optical beams may be used in connectors for these systems to provide an optical connection that is less sensitive to dust and other forms of contamination and so that alignment tolerances may be relaxed. Generally, an expanded beam is a beam that is larger in diameter than the core of an associated optical waveguide (usually an optical fiber, e.g., a multi-mode fiber for a multi-mode communication system). The connector is generally considered an expanded beam connector if there is an expanded beam at a connection point. The expanded beam is typically obtained by diverging a light beam from a source or optical fiber. In many cases, the diverging beam is processed by optical elements such as a lens or mirror into an expanded beam that is approximately collimated. The expanded beam is then received by focusing of the beam via another lens or mirror.

BRIEF SUMMARY

Embodiments are directed to an optical ferrule having compound stops disposed on opposite sides of the optical ferrule. The optical ferrule comprises a first surface that has one or more substantially parallel grooves oriented for receiving one or more optical waveguides and a plurality of light redirecting members configured to be optically coupled to the optical waveguides. The optical ferrule has an opposing second surface comprising a mating surface that defines a mating plane. The mating surface includes an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule. The first and second compound stop features respectively disposed at opposing sides of the optical ferrule. Each compound stop feature comprises upper and lower contact surfaces. The lower contact surface has an offset below the mating plane along a thickness axis perpendicular to the mating surface. The upper contact surface has an offset above the mating plane along the thickness axis. The lower contact surface has an offset forward from the upper contact surface along a mating direction of the optical ferrule. A connecting surface connects the upper contact surface and the lower contact surface.

According to some embodiments an optical ferrule comprises a first surface comprising one or more substantially parallel grooves oriented for receiving one or more optical waveguides and a plurality of light redirecting members configured to be optically coupled to the optical waveguides. An opposing second surface of the optical ferrule comprises a mating surface that defines a mating plane. The mating surface includes an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule.

First and second compound stop features are respectively disposed at opposing sides of the optical ferrule. Each compound stop feature comprises an upper stop surface and a lower stop surface. The lower stop surface is offset from the upper stop surface along a mating axis of the optical ferrule and along a thickness axis perpendicular to the mating surface. A ramp surface connects the upper stop surface and the lower stop surface. The ramp surface is inclined at an angle with respect to the mating surface over a majority of a length of the ramp surface.

According to some aspects, each compound stop feature includes upper and lower stop surfaces, the lower stop surface offset from the upper stop surface along a mating axis of the optical ferrule and along a thickness axis perpendicular to the mating surface. A connecting surface connects the lower stop surface and the upper stop surface. A slope of the connecting surface relative to the mating axis is greater than zero over a majority of a length of the connecting surface.

In accordance with some aspects, the connecting surface has a length between the upper stop surface and the lower stop surface in a range of about 10 % to about 50 % of a thickness of the optical ferrule taken along the thickness axis perpendicular to the mating surface.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. 1A through 1F show various views of an optical ferrule in accordance with some embodiments;

FIG. 2 is a cutaway view of a portion of optical ferrule of FIG. 1 focusing on the light redirecting member and attachment area;

FIG. 3 illustrates a bend that develops in the optical waveguides between the first and second attachment areas that provides a predetermined mating spring force at a predetermined angle and location of an optical ferrule;

FIG. 4, depicts a portion of an optical connector that can include one or more optical ferrules according to some embodiments; and

FIGS. 5A and 5B are simplified diagrams that respectively show an optical ferrule and a mating optical ferrule prior to and after mating in accordance with some embodiments.

The figures are not necessarily to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Embodiments described herein involve optical ferrules, optical ferrule assemblies and optical connectors that include such optical ferrules. Optical ferrules used in many applications may be optically coupled to one waveguide or arrays of multiple parallel waveguides (typically 4, 8 or 12 or more parallel waveguides). The individual waveguides are typically made of glass with a protective buffer coating, and the parallel waveguides are enclosed by a jacket. Optical ferrules are useful for connecting optical waveguides to other optical waveguides or to optoelectronic components for in-line interconnects and/or printed circuit board (PCB) connections, e.g., backplane connections.

One type of connector is an expanded beam connector, in which light is coupled between waveguides in a beam that is larger in diameter than the core of an associated optical waveguide and typically somewhat less than the waveguide-to-waveguide pitch. The waveguides may comprise optical fibers, e.g., multi-mode fibers for a multi-mode communication system. These expanded beam optical connectors can have non-contact optical coupling and can require reduced mechanical precision when compared with conventional optical connectors.

Optical ferrules may include mechanical stop features that halt relative motion between two mating optical ferrules as the mating surfaces of the optical ferrules slide together to make an optical connection during mating. Under some conditions, the stop features can make contact before the mating surfaces make contact. Static friction at the stop features can be strong enough to cause misalignment of the optical ferrules during mating. Embodiments discussed herein involve compound stop features that provide for reduced misalignment of optical ferrules during mating.

FIG. 1A shows an optical ferrule **100** and identical mating optical ferrule **100m** prior to mating in accordance with some embodiments. The optical ferrule **100** comprises a first surface **101** that includes one or more substantially parallel grooves **105** oriented for receiving one or more optical waveguides **110** (shown in FIG. 2). The first surface **101** also includes a light redirecting member **106** configured to be optically coupled to the optical waveguides **110**. The term “optical waveguide” is used herein to refer to an optical element that propagates signal light. An optical waveguide comprises at least one core with a cladding, wherein the core and cladding are configured propagate light within the core, e.g., by total internal reflection. An optical waveguide may be, for example, a single or multi-mode waveguide, a single core fiber, a multi-core optical fiber, or a polymeric waveguide. A waveguide may have any suitable cross sectional shape, e.g., circular, square, rectangular etc.

Each groove **105** is configured to receive a different optical waveguide **110** of the optical waveguides. The optical waveguides **110** received by the grooves **105** can be permanently attached, e.g., using an adhesive, to the optical ferrule **100** at the grooves **105** which provide an attachment area **108** for the optical waveguides **110**.

The optical ferrule **100** is configured to mate, e.g., hermaphroditically, with another optical ferrule **100m**, which may be identical to the optical ferrule **100**. The optical ferrules **100, 100m** illustrated in FIGS. 1A – 1F include a mechanical mating tongue **116, 116m**. In some embodiments, the mechanical mating tongue **116** can have a tapering width along at least a portion of a length of the tongue portion as shown in the illustrations. The mechanical mating tongue **116** can extend outwardly from a front of an optical connector housing (e.g., see FIG. 4).

FIG. 2 is a cutaway view of a portion **100-1** of optical ferrule **100** focusing on the light redirecting member **106** and attachment area **108**. FIG. 2 illustrates the attachment of several optical waveguides **110** to optical ferrule **100**. Optical waveguides (optical fibers) **110** are aligned in grooves

105 to which they are permanently attached. The exit end of optical waveguides **110** is situated so as to be able to direct light emanating from the optical waveguide **110** into the input side or face of light redirecting member **106**. Light redirecting member **106** includes an array of light redirecting elements **107**, at least one for each the optical waveguides (optical fibers) **110** attached to optical ferrule **100**. For example, in various embodiments each light redirecting element **107** comprises one or more of a prism, a lens, and a reflecting surface.

At the point of attachment, the fiber buffer coating and protective jacket (if any) of the optical waveguide may be stripped away to allow only the bare optical fiber to lie aligned and permanently affixed to groove **105**. Light redirecting element **107** includes light input side **109** for receiving input light from first optical waveguide **110** disposed in and aligned by the groove **105**. Light redirecting element **107** also includes light redirecting side **111** that may include a curved surface for receiving light from the input side **109** along an input direction and redirecting the received light along a different redirected direction. The light redirecting element **107** also includes output side **112** that receives light from light redirecting side **111** of light redirecting element **107** and transmits the received light as output light along an output direction toward a light redirecting member of a mating light coupling unit.

Although FIGS. 1A and 2 show an optical ferrule **100** that includes multiple light redirecting elements **107** that can be optically coupled to multiple optical waveguides **110**, it is also possible that an optical ferrule includes just one light redirecting element that can be optically coupled to a single optical waveguide.

As illustrated in FIGS. 1A and 1B, the optical ferrule **100** has an opposing second surface **102** that includes a mating surface **120**. The second surface **102** of the optical ferrule **100** is best seen in FIG. 1B. The mating surface **120** includes an optically transmitting window **121** for propagating an optical signal therethrough to an optically transmitting window **120m** of a mating optical ferrule **100m**. In some embodiments, the mating surface **120** of the optical ferrule **110** may comprise a main portion **123** that is substantially parallel to a mating plane **199** of the optical ferrule **100** (see FIG. 1F). The mating plane is parallel to the mating axis of the ferrule, and when the ferrule is perfectly aligned in the mated configuration with a mating ferrule, the mating planes of the two ferrules are coincident. There is an axis of rotation shared by two mated ferrules. That axis lies in the mating plane near the window 121. The mating surface **120** may further comprise one or more pads **122** that extend away from the main portion **123** along the thickness axis (z-axis). For example, in some configurations, the pads **122** may extend below a main portion **123** of the mating surface **120** by about 5 μm to about 10 μm. The second surface **102m** of the mating optical ferrule **100m** also includes a mating surface **120m** comprising a main portion **123m**, an optical transmitting window **121m**, and pads **122m** as shown in FIG. 1A.

In some embodiments, the mating surface may not include pads. When present, the one or more pads **122** may collectively occupy less than a majority, e.g., less than 50%, less than 25%, or less than 10% of the surface area of the mating surface **120**. Alternatively, the pads **122** may individually or collectively occupy a substantial portion of the surface area of the mating surface, e.g., more than 10%, more than 25%, or even more than 50% of the surface area of the mating surface **120**.

In some embodiments, after mating, the pads **122** of the optical ferrule **100** rest on corresponding pads **122m** of the mating optical ferrule **100m**, providing a small gap between the main portions **123**, **123m** of the mating surfaces **120, 120m** of the optical ferrule **100** and the mating optical ferrule **100m**. The small gap accommodates dust and/or other irregularities may be present between the main portions **123**, **123m** of the mating surfaces **120**, **120m**.

In other embodiments, after mating, the pads **122** of the optical ferrule **100** rest on the main portion of the mating surface of the mating optical ferrule **100m**, providing a small gap between the main portions **123**, **123m** of the mating surfaces **120, 120m** of the optical ferrule **100** and the mating optical ferrule **100m**.

In some embodiments, when the mating surfaces **120**, **120m** of the optical ferrules **100**, **100m** do not include pads, the main portions **123**, **123m** of the mating surfaces **120**, **120m** may be in contact after the optical ferrules are mated.

In some embodiments, interaction of the compound stop features **150**, **150m** of the optical ferrule **100** and the mating optical ferrule **100m** may provide for a small gap between the main portions **123**, **123m** and/or the pads **122**, **122m** of the mating surfaces **120**, **120m**.

Additional information regarding features and operation of light coupling units, optical cable subassemblies and optical connectors is discussed in commonly owned U.S. Patent 9,482,827 which is incorporated herein by reference in its entirety.

As shown in FIG. 4, an optical connector **400** can include one or more optical ferrules, such as optical ferrule **100**, having optical waveguides **110** attached thereto and disposed within a housing **401**. The optical waveguides **110** are attached to the attachment area **108** of the optical ferrule **100** and to a second attachment area **408** within the housing **401**.

As illustrated by the diagram of FIG. 3, the length of the optical waveguides **110** between the attachment area **108** of the optical ferrule **100**, **100m**, and the second attachment area **408** is configured to allow a bend **300**, **300m** to develop in the optical waveguides **110**, **110m** that provides a predetermined mating spring force at a predetermined angle and location of the optical ferrule **100**, **100m**. In some embodiments, the second attachment area **408**may comprise a cable retainer **350, 350m** attached to the waveguides **110**, **110m** wherein the cable retainer **350**, **350m** is configured to be received and secured by a retainer mount within the optical connector housing **400**. Additional information regarding optical cable assemblies and housings that include cable retainers and mounts is described in commonly owned U.S. Patent Application S/N 62/240,008 filed October 12, 2015 having the title "Optical Assembly with Cable Retainer," identified by Attorney Docket Number 76662US002 which is incorporated herein by reference.

Referring again to FIGS. 1A through 1F, the optical ferrule **100, 100m** includes first and second compound stops **150, 150m** respectively disposed at opposite lateral sides of the optical ferrule **100, 100m**. FIG. 1C shows a side view of the compound forward stops **150**, **150m** as the optical ferrule **100** is mating with the mating optical ferrule **100m**. FIG. 1D shows a side view of the compound forward stops **150**, **150m** after the optical ferrule **100** is in the mated position with respect to the mating optical ferrule

100m. FIG. 1E shows a perspective view of a compound stop **150**. FIG. 1F shows another side view of the compound stop **150**.

Each compound stop **150**, **150m** has an upper stop surface **161**, **161m**, a lower stop surface **162**, **162m** and a connecting surface **170**, **170m**. The main portion **123** of the mating surface **120**, or the lower surface of the pads **122**, if pads are present, define a mating plane **199** for the optical ferrule **100** as indicated in FIG. 1F. As best seen in FIG. 1F, there is an offset **196** along the z axis (perpendicular to the mating plane **199)** between the upper contact surface **161** and the lower contact surface **162**. In the orientation of the ferrule shown in FIG. 1F, the offset **196** comprises an upper offset **197** above the mating plane **199** and a lower offset **198** below the mating plane. The upper offset **197** is between the bottom edge **161a** of the upper contact surface **161** and the mating plane **199**. The lower offset **198** is between mating plane **199** and the top edge **162a** of the lower contact surface **162**.

In some embodiments the offset **197** between the mating plane **199** and the bottom edge **161a** of the upper contact surface **161** may be more than about 50 μm along the thickness axis (z-axis). The offset **198** between the mating plane **199** and the upper edge **162a** of the lower contact surface **162** may be more than about 50 μm along the thickness axis. The lower contact surface **162** can be offset forward from the upper contact surface along the mating direction (x-axis) of the optical ferrule **100**. The compound forward stop **150** includes a connecting surface **170** that connects the upper and lower contact surfaces **161**, **162**, e.g., the connecting surface **170** connects the lower edge **161a** of the upper contact surface **161** to the upper edge **162a** of the lower contact surface **162**.

Notably, the terms "upper," "lower," "above," "below," "bottom," "top," and the like are used herein to identify different features and/or relative orientations between the features. The use of these terms is not intended to indicate specific positions of the features because the optical ferrules may be oriented in various positions.

As illustrated in FIGS. 1C and 1D, as the optical ferrule **100** mates with the mating optical ferrule **100m**, the mating surface **120** of the optical ferrule **100** slidably engages with the mating surface **120m** of the mating optical ferrule **100m** and the connecting surface **170** of the optical ferrule **100** slidably engages with the connecting surface **170m** on the mating optical ferrule **100m**. After the optical ferrules 100, 100m are mated, as show in FIG. 1D, the upper **161** and lower **162** contact surfaces of the optical ferrule **100** contact the lower **162m** and upper **161m** contact surfaces of the mating optical ferrule **100m**, restricting further relative motion between the optical ferrules **100**, **100m** along the mating axis (x-axis). Referring again to FIG. 3, the bend **300, 300m** in the optical waveguides **110, 110m** provides a spring force that holds the stop surfaces **161**, **162** of the optical ferrule **100** in contact with the corresponding stop surfaces **162m**, **161m** of the mating optical ferrule **100m**.

The connecting surfaces **170**, **170m** of the optical ferrules **100**, **100m** are configured to limit a separation between the mating surface **120** of the optical ferrule **100** and the mating surface **120m** of the mating optical ferrule **100m** after mating. When pads **122, 122m** are present in the mating surface **120**, **120**m the connecting surfaces **170**, **170m** may limit the separation between the pads **122** of the optical ferrule **100** and the corresponding pads **122m** of the mating optical ferrule **100m**. For example, the connecting surfaces **170**, **170m** may limit the separation between the pads **122**, **122m** of the optical ferrule **100** and the mating optical ferrule **100m** to less than about 4 μm.

According to some embodiments in which pads configured to contact the main portion **123m** of the mating surfaces **120m** of the mating optical ferrule **100m**, the connecting surfaces **170, 170m** may be configured to limit the separation between the pads and the main portions **123m** of the mating surface **120m** of the optical ferrule **100m** to less than about 4 μm.

According to some embodiments in which pads are not present in either of the mating surfaces **120**, **120m** of the optical ferrule **100** and the mating optical ferrule **100m**, the connecting surfaces **170, 170m** may be configured to limit the separation between the main portions **123**, **123m** of the mating surfaces **120**, **120m** of the optical ferrule **100** and the mating optical ferrule **100m** to less than about 4 μm.

In some embodiments, as shown in FIGS. 1A through 1F, the connecting surface **170** is a ramp surface that is inclined at a constant angle with respect to the mating surface over a majority of a length, L, of the connecting surface **170**. The angle at which the ramp surface **170** is inclined is sufficiently small to allow the ramp surface **170** to slidably engage with a ramp surface **170m** of the mating optical ferrule **100m** during mating. For example, the angle can be between about 15 degrees and about 65 degrees, or between about 25 degrees and about 55 degrees or may be about 30 degrees or about 45 degrees. In some embodiments, the ramp surface **170** may have a length, L, that is greater than the offset **196** (as measured along the thickness axis (z-axis)) between the upper and lower contact surfaces **161**, **162**.

After the optical ferrule **100** is mated with the mating optical ferrule **100m**, the stop surfaces **161**, **162** of the optical ferrule **100** make contact with corresponding stop surfaces **162m**, **161m** of the mating optical ferrule **100m** as shown in FIG. 1D. Connecting surfaces **170** of the optical ferrule may be configured to make contact with corresponding connecting surfaces **170m** of the mating optical ferrule **100m** after mating. Alternatively, the connecting surfaces **170**, **170m** of the optical ferrule **100** and the mating optical ferrule **100m** may be configured to be spaced apart after mating, e.g., by a distance of less than about 5 μm, or less than about 2 μm.

One or both of the first and second stop surfaces **161**, **162** can be oriented substantially perpendicular to the mating plane **199** and parallel to the thickness axis (z-axis) as indicated by dashed lines **191**, **192** in FIG. 1C. In some embodiments, one or both of the first and second stop surfaces **161**, **162** can be disposed at a non-perpendicular angle with respect to mating plane **199** as indicated by dashed lines **193** and **194**. The angle that the upper and/or lower surfaces **161**, **162** make with respect to the mating plane **199** is steep enough not to allow sliding which would result in overshooting the mating position of the optical ferrules. In general, the angle that the upper and/or lower surfaces 161, 162 make with respect to the mating plane **199** is greater than the angle that the ramp connecting portion **170** makes with respect to the mating plane **199**. For example, at least one of the upper stop surface and the lower stop surface can be disposed at an angle greater than about 80° with respect to the mating plane 199.

According to various embodiments, the length, L, of the connecting portion **170** (measured between the bottom edge **161a** of the upper contact surface **161** and the top edge **162a** of the lower contact surface **162**) can be greater than about 10 % of a thickness of the optical ferrule **100** (as measured along the thickness axis (z-axis) and/or can be greater than about 20 % of a length of the optical ferrule **100** (as measured along the mating axis (x-axis)).

The thickness and modulus of elasticity of the optical ferrule **100** can be selected to allow the optical ferrule to flex during mating. Some amount of flexing during mating may facilitate proper seating and/or optical alignment of the optical ferrule **100** and the mating optical ferrule **100m**. For example, the optical ferrule **100** may have a flexural modulus in a range of about 2000 to about 4000 MPa. The optical ferrule **100** may have a thickness as measured along the thickness axis (z-axis) in a range of about 500 to about 2000 μm. After mating, the mating surface **120** of the optical ferrule **100** can be substantially parallel with the mating surface **120m** of the mating optical ferrule **100m**. In some embodiments, the mating surface **120** of the optical ferrule **100** may be disposed at an angle of less than about 2 milliradians with respect to the mating surface **120m** of the mating optical ferrule **100m** after mating.

FIGS. 5A and 5B provide simplified side views optical ferrules **500, 500m** having compound stops **550, 550m** in accordance with some embodiments. FIGS. 5A and 5B respectively show an optical ferrule **500** and a mating optical ferrule **500m** prior to and after mating. The features of the first **501, 501m** and second **502, 502m** surfaces of optical ferrules **500, 500m** are the same as those previously described in conjunction with FIGS. 1A through 1D and are not repeated in detail in the simplified drawings of FIGS. 5A and 5B. As previously discussed, the optical ferrule **500, 500m** includes a first surface **501, 501m** having one or more substantially parallel grooves oriented for receiving one or more optical waveguides and a light redirecting member configured to be optically coupled to the optical waveguides. The opposing second surface **502** of the optical ferrule **500** comprises a mating surface that includes an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule **500m**. As indicated in FIGS. 5A and 5B, the second surface **502, 502m** may comprise pads **522, 522m**.

The optical ferrules **500, 500m** include first and second compound stop features **550, 550m** respectively disposed at opposing sides of the optical ferrule **500, 500m**. Each compound stop feature **550, 550m** comprises an upper stop surface **561, 561m** and a lower stop surface **562, 562m**. The lower stop surface **562, 562m** is offset from the upper stop surface **561, 561m** along a mating axis (x-axis) of the optical ferrule **500, 500m**. The lower stop surface **562, 562m** is also offset from the upper stop surface **561, 561m** along the _thickness axis (z-axis) perpendicular to the mating surface.

For example, the upper stop surface **561, 561m** may be offset from the lower stop surface **562, 562m** along the mating axis (x-axis) by about 50 μm to about 500 μm. The upper stop surface **561, 561m** may be offset from the lower stop surface **562, 562m** along the thickness axis (z-axis) perpendicular to the mating surface by about 100 μm to about 400 μm, e.g., 200 μm to about 400 μm.

The connecting surface **570, 570m** connects the lower stop surface **562, 562m** and the upper stop surface **561, 561m**. The connecting surface **570** may have a length, L, between the upper stop surface **561** and the lower stop surface **562** in a range of about 10 % to about 50 % of a thickness of the optical ferrule **500** taken along the thickness axis (z-axis) perpendicular to the mating surface.

The connecting surface **570**, **570m** may have any suitable shape, e.g., may be linear, piece-wise linear, or may be curved as shown in FIGS. 5A and 5B. The slope (tangent) of the connecting surface **570**, **570m** measured relative to the mating axis (x-axis) is greater than zero over a majority of a length, L, of the connecting surface **570**, **570m**. The slope of the connecting surface **570, 570m** is shallow enough to allow sliding.

After mating, the connecting surfaces **570**, **570m** may not be in contact after mating along all of the length, L. In some embodiments, only a portion of the connecting surfaces **570**, **570m** may be in contact, e.g., in a central portion of the connecting surfaces **570**, **570m** as illustrated in FIG. 5B. As previously discussed, but not shown here, in some embodiments, the connecting surfaces may be spaced apart from each other over the length, L. The pads **522** of the optical ferrule **500** may contact the pads **522m** of the mating optical ferrule **500m** as shown, or the pads **522** may be spaced apart from pads **522m** by a small distance, e.g., about 4 μm, after mating. If no pads are present in the second surface **502**, **502m**, then the mating surfaces may be in contact or may be spaced apart as previously discussed. After mating, the mating surface of the optical ferrule **500** may be substantially parallel or disposed at a small angle, e.g., about 2 milliradians with respect to the mating surface of the mating optical ferrule **500m**. It is preferable to mold both contact surface of the stops in the same side of the mold as the grooves and the light redirecting elements.

A discussion of molds for optical ferrules which is applicable to the present disclosure is provided in commonly owned U.S. Patent Application 62/239,996, filed October 12, 2015 having the title "Optical Ferrules and Optical Ferrule Molds," which is incorporated herein by reference.

Additional information regarding optical ferrules, optical assemblies, and optical connectors that may be used in conjunction with the approaches described herein is provided in the following commonly owned U.S. Patent Applications which are incorporated herein by reference: U.S. Patent Application S/N 62/240,000, filed October 12, 2015; U.S. Patent Application S/N 62/240,069, filed October 12, 2015; U.S. Patent Application S/N 62/240,066, filed October 12, 2015; and U.S. Patent Application S/N 62/240,008, filed October 12, 2015..

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein. The use of numerical ranges by endpoints includes all numbers within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range.

Various modifications and alterations of the embodiments discussed above will be apparent to those skilled in the art, and it should be understood that this disclosure is not limited to the illustrative embodiments set forth herein. The reader should assume that features of one disclosed embodiment can also be applied to all other disclosed embodiments unless otherwise indicated. It should also be understood that all U.S. patents, patent applications, patent application publications, and other patent and non-patent documents referred to herein are incorporated by reference, to the extent they do not contradict the foregoing disclosure.

CLAIMS

1. An optical ferrule, comprising:

a first surface comprising:

one or more substantially parallel grooves oriented for receiving one or more optical waveguides, and;

a plurality of light redirecting members configured to be optically coupled to the optical waveguides;

an opposing second surface comprising a mating surface that defines a mating plane, the mating surface comprising an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule; and

first and second compound stop features respectively disposed at opposing sides of the optical ferrule, each compound stop feature comprising upper and lower contact surfaces, the lower contact surface having an offset below the mating plane along a thickness axis perpendicular to the mating surface, the upper contact surface having an offset above the mating plane along the thickness axis, and the lower contact surface having an offset forward from the upper contact surface along a mating direction of the optical ferrule; and

a connecting surface connecting the upper contact surface and the lower contact surface.

2. The optical ferrule of claim 1, wherein:

the mating surface is configured to slidably engage with a mating surface of a mating optical ferrule; and

the upper and lower contact surfaces are configured to respectively contact lower and upper contact surfaces of the mating ferrule.

3. An optical ferrule, comprising:

a first surface comprising:

one or more substantially parallel grooves oriented for receiving one or more optical waveguides, and;

a plurality of light redirecting members configured to be optically coupled to the optical waveguides;

an opposing second surface comprising a mating surface that defines a mating plane, the mating surface including an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule; and

first and second compound stop features respectively disposed at opposing sides of the optical ferrule, each compound stop feature comprising:

an upper stop surface;

a lower stop surface, the lower stop surface offset from the upper stop surface along a mating axis of the optical ferrule and along an a thickness axis perpendicular to the mating surface; and

a ramp surface connecting the upper stop surface and the lower stop surface, the ramp surface inclined at an angle with respect to the mating surface over a majority of a length of the ramp surface.

4. The optical ferrule of claim 3, wherein the mating surface comprises:

a main portion that is parallel to the mating plane; and

one or more pads extending from the main portion, and wherein the pads are configured to rest on corresponding pads of the mating optical ferrule after mating.

5. An optical ferrule, comprising:

a first surface comprising:

one or more substantially parallel grooves oriented for receiving one or more optical waveguides, and;

a plurality of light redirecting members configured to be optically coupled to the optical waveguides;

an opposing second surface comprising a mating surface that defines a mating plane, the mating surface including an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule; and

first and second compound stop features respectively disposed at opposing sides of the optical ferrule, each compound stop feature comprising:

an upper stop surface;

a lower stop surface, the lower stop surface offset from the upper stop surface along a mating axis of the optical ferrule and along a thickness axis perpendicular to the mating surface; and

a connecting surface connecting the lower stop surface and the upper stop surface, wherein a slope of the connecting surface relative to the mating axis is greater than zero over a majority of a length of the connecting surface.

6. The optical ferrule of claim 5, wherein the connecting surface has a substantially constant non-zero slope over the majority of the length of the connecting surface.

7. An optical assembly, comprising:

an optical ferrule mated to a mating optical ferrule, each optical ferrule comprising:

a first surface comprising:

one or more substantially parallel grooves oriented for receiving one or more optical waveguides, and;

a plurality of light redirecting members configured to be optically coupled to the optical waveguides;

an opposing second surface comprising a mating surface that defines a mating plane, the mating surface including an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule; and

first and second compound stop features respectively disposed at opposing sides of the optical ferrule, each compound stop feature comprising:

upper and lower contact surfaces, the lower contact surface having an offset below the mating plane along a thickness axis perpendicular to the mating surface, the upper contact surface having an offset above the mating plane along the thickness axis, and the lower contact surface having an offset forward from the upper stop surface along a mating direction of the optical ferrule; and

a connecting surface connecting the upper contact surface and the lower contact surface,

wherein the optical ferrule and the mating optical ferrule are configured to mate along the mating axis such that the optical signal is transmitted through the optically transmitting window of the optical ferrule to the optically transmitting window of the mating optical ferrule and wherein the upper and lower stop surfaces of the optical ferrule are configured to make contact with the lower and upper stop surfaces of the mating optical ferrule to restrict relative movement between the optical ferrule and the mating optical ferrule along the mating axis.

8. The optical assembly of claim 7, wherein:

the mating surface comprises a main portion that is parallel to the mating plane; and

one or more pads extending from the mating portion; and

9. An optical ferrule, comprising:

a first surface comprising:

one or more substantially parallel grooves oriented for receiving one or more optical waveguides, and;

a plurality of light redirecting members configured to be optically coupled to the optical waveguides;

an opposing second surface comprising a mating surface that defines a mating plane, the mating surface including an optically transmitting window for propagating an optical signal therethrough to an optically transmitting window of a mating optical ferrule; and

first and second compound stop features respectively disposed at opposing sides of the optical ferrule, each compound stop feature comprising:

an upper stop surface;

a lower stop surface, the lower stop surface offset from the upper stop surface along a mating axis of the optical ferrule and along a thickness axis perpendicular to the mating surface; and

a connecting surface connecting the upper stop surface and the lower stop surface, the connecting surface having a length between the upper stop surface and the lower stop surface in a range of about 10 % to about 50 % of a thickness of the optical ferrule taken along the thickness axis perpendicular to the mating surface.

10. The optical ferrule of claim 9, wherein a thickness and a flexural modulus of the optical ferrule are configured to allow the optical ferrule to flex during mating with the mating optical ferrule.

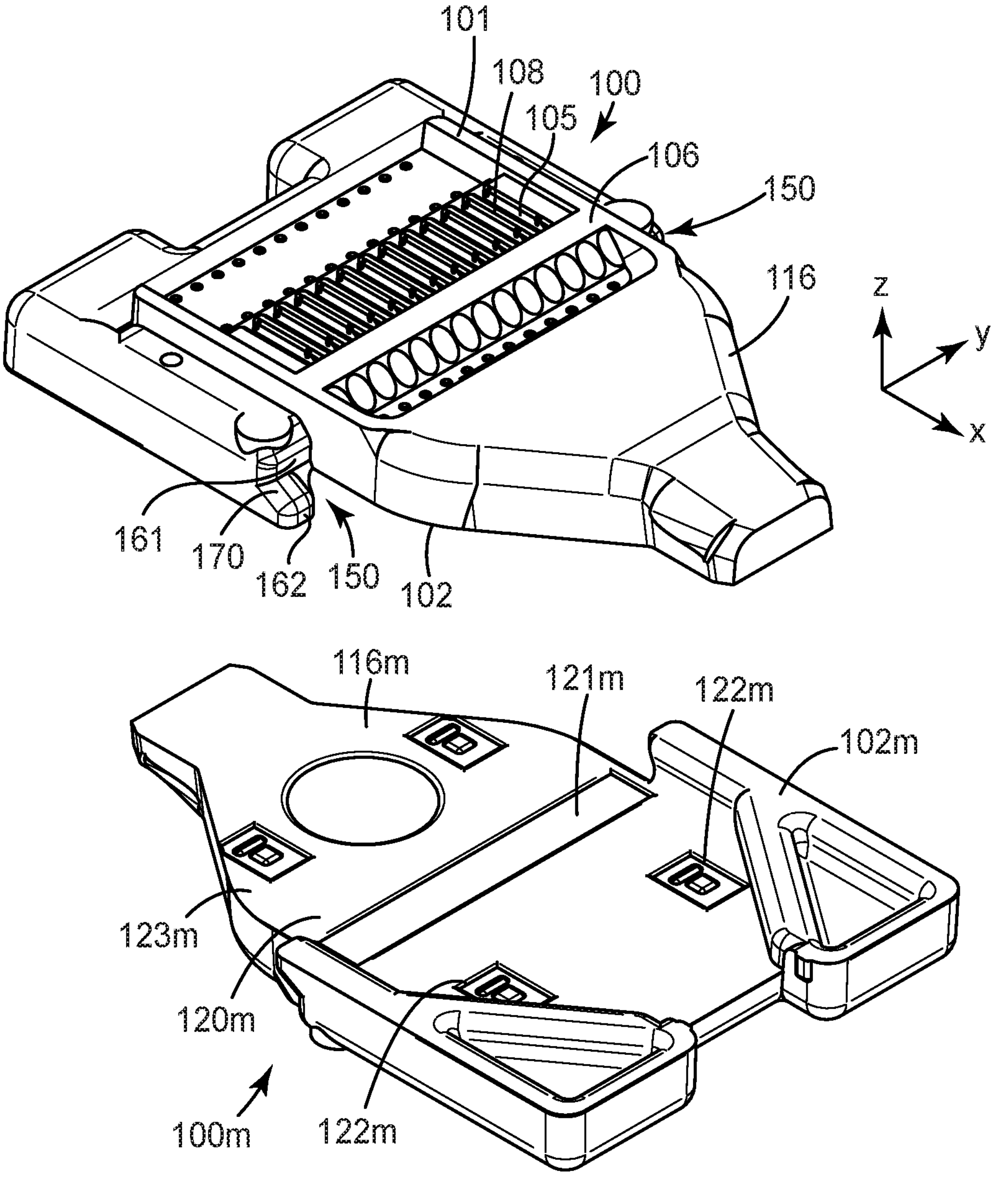
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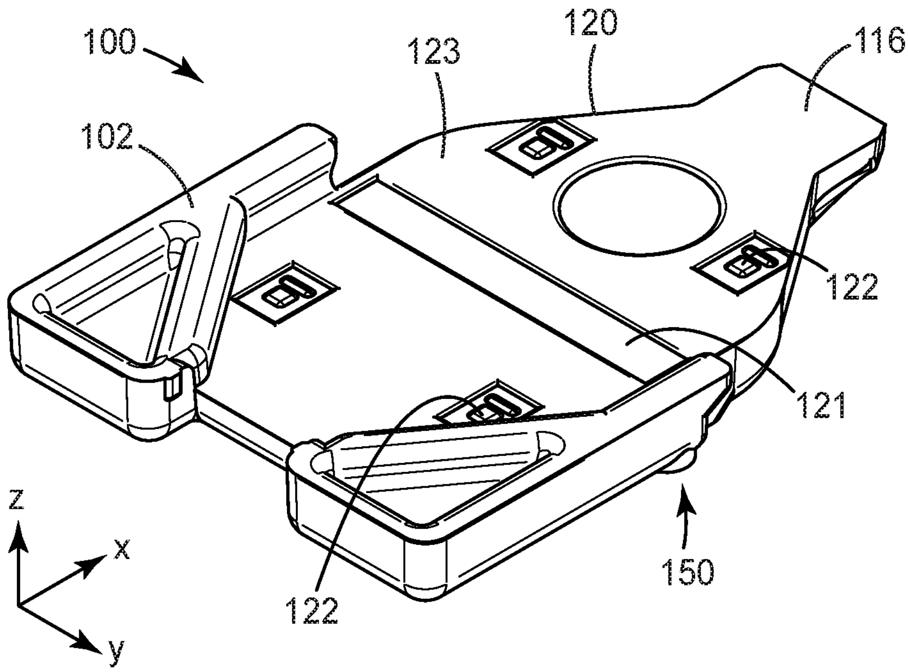
FIG. 1A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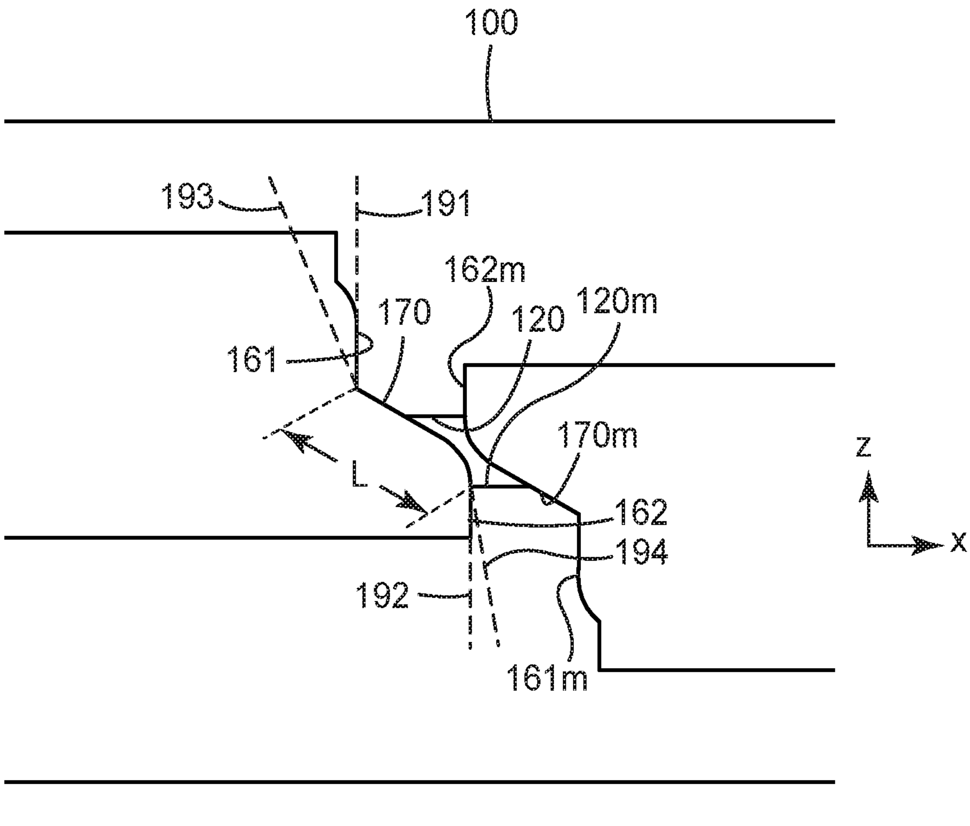
122

FIG. 1B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z
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FIG. 1C

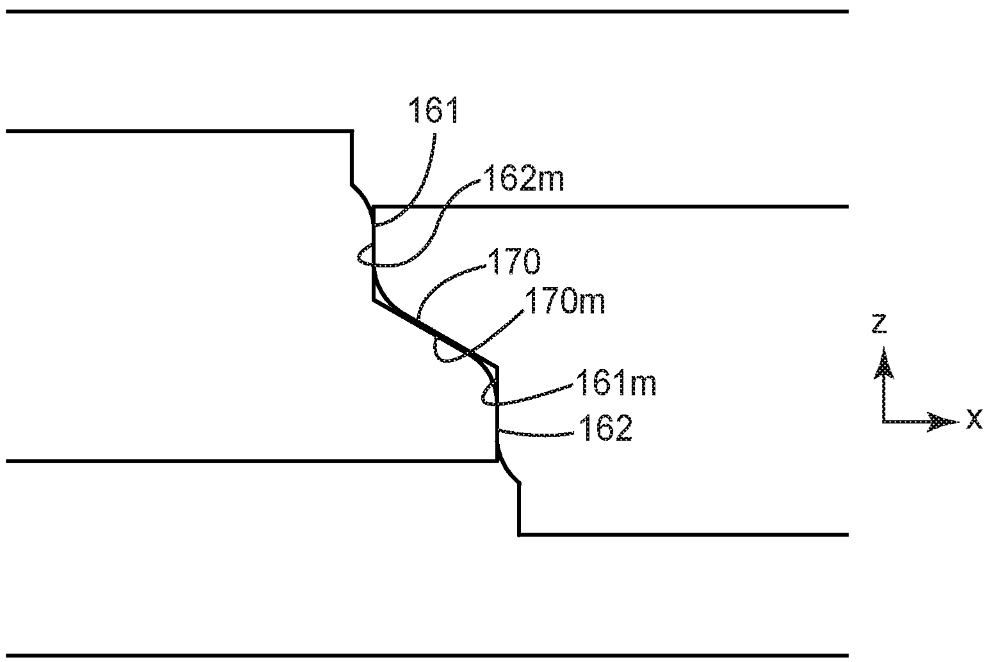
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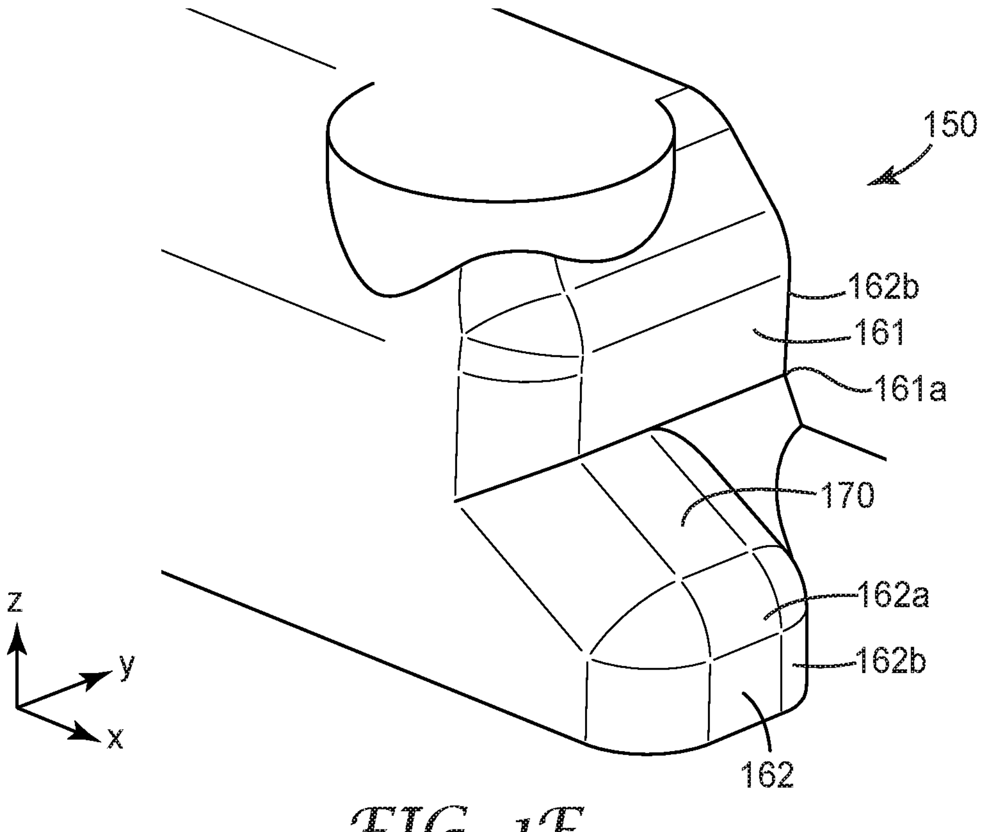
FIG. 1D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161a
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162a
162b
162
z
y
x

FIG. 1E

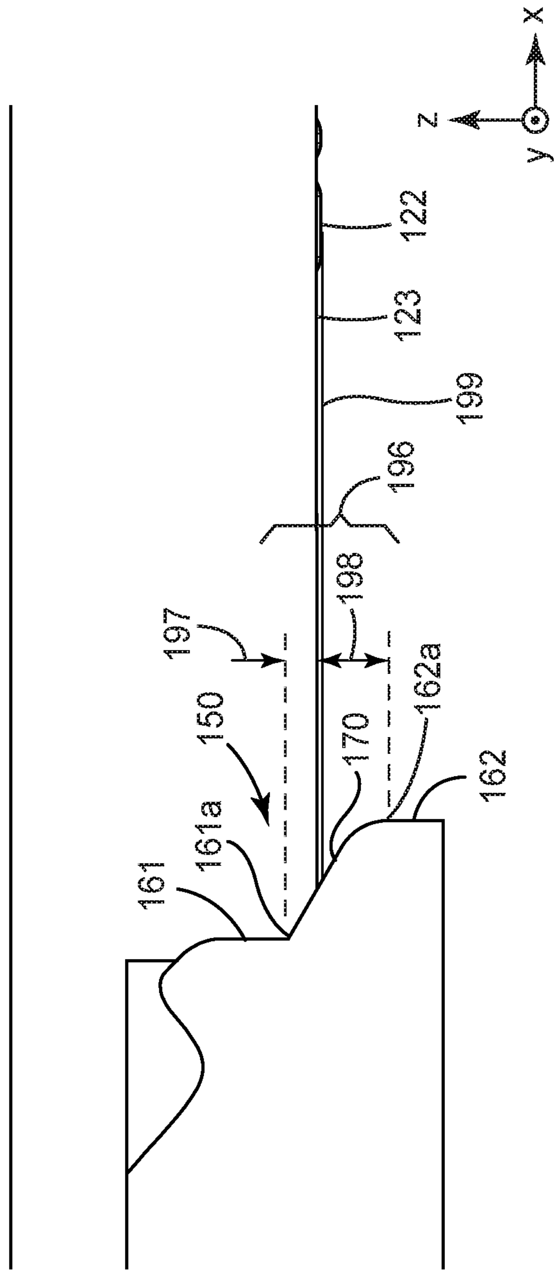


FIG. 1F

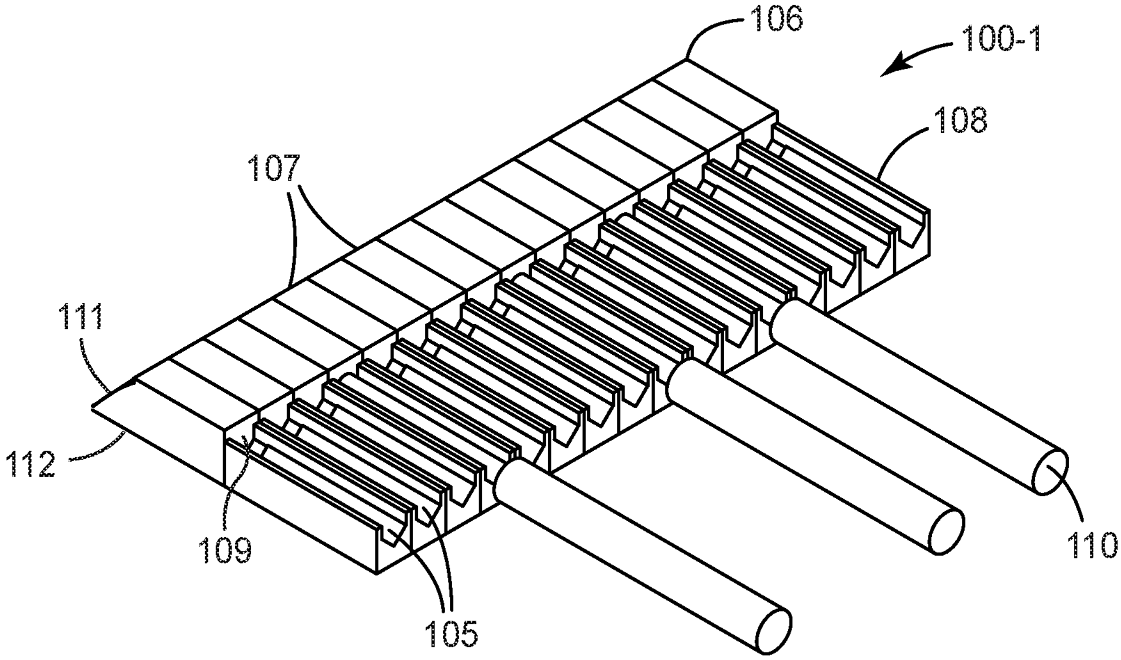


FIG. 2

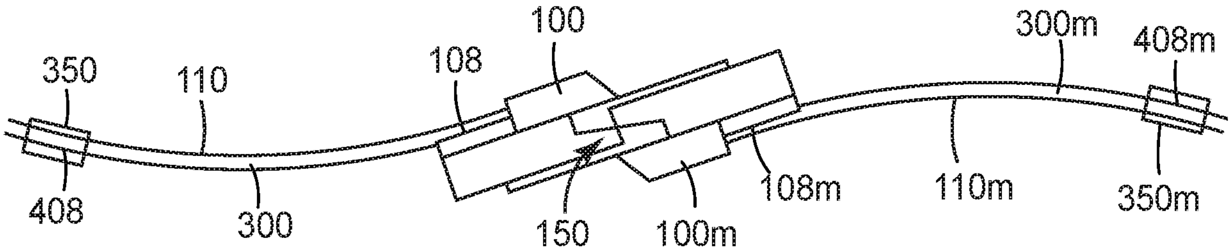


FIG. 3

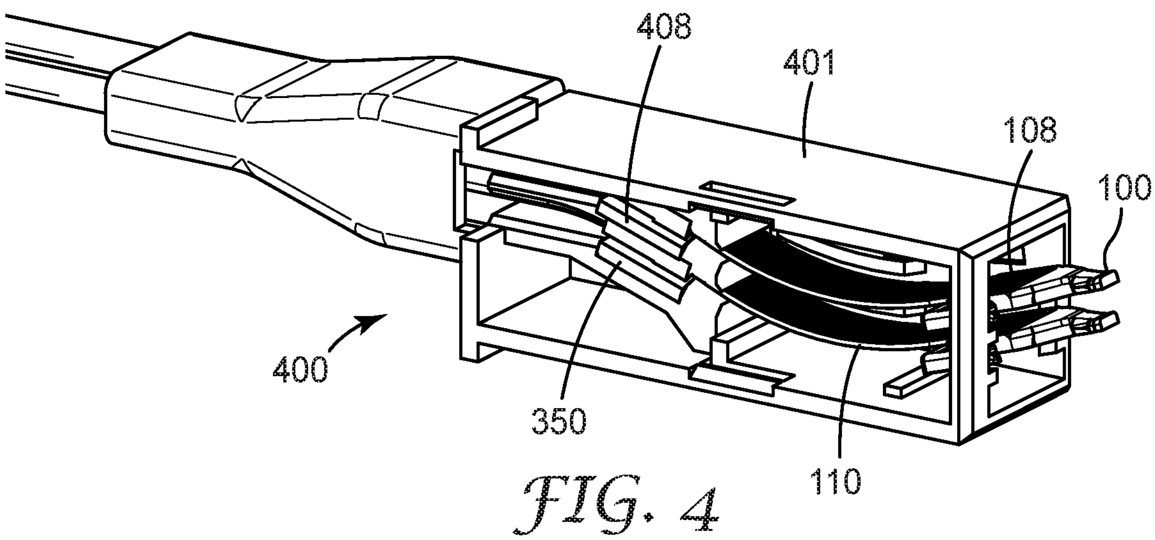
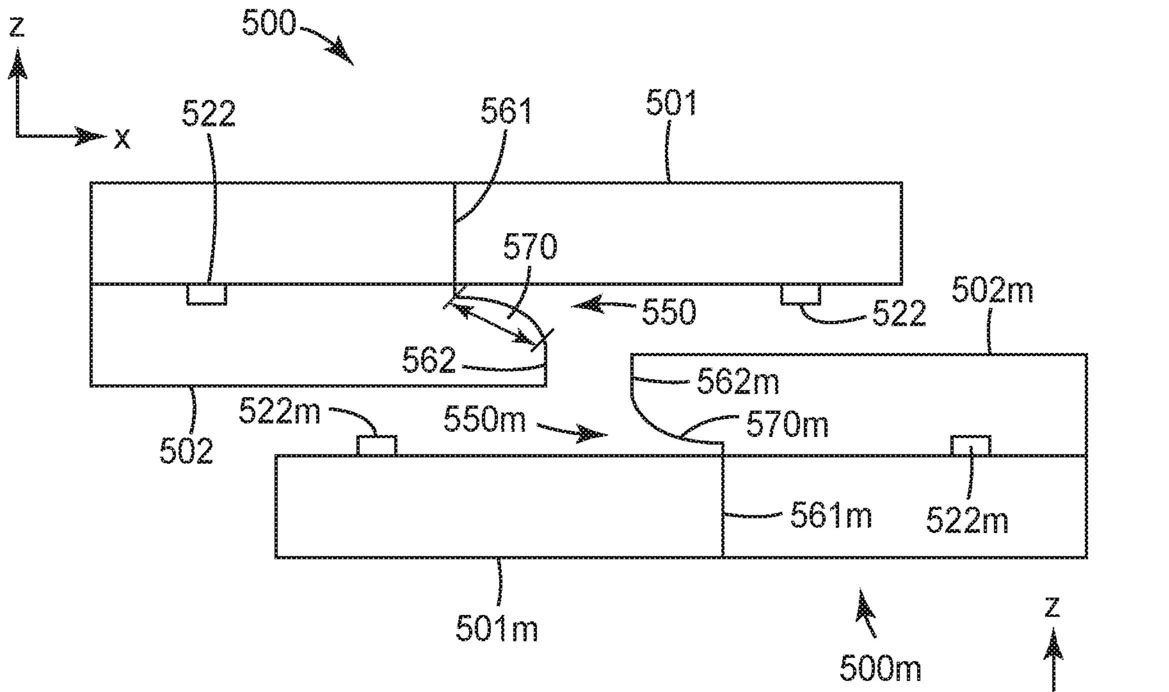


FIG. 4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x
522
561
501
570
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522
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562
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500m
z
x

FIG. 5A

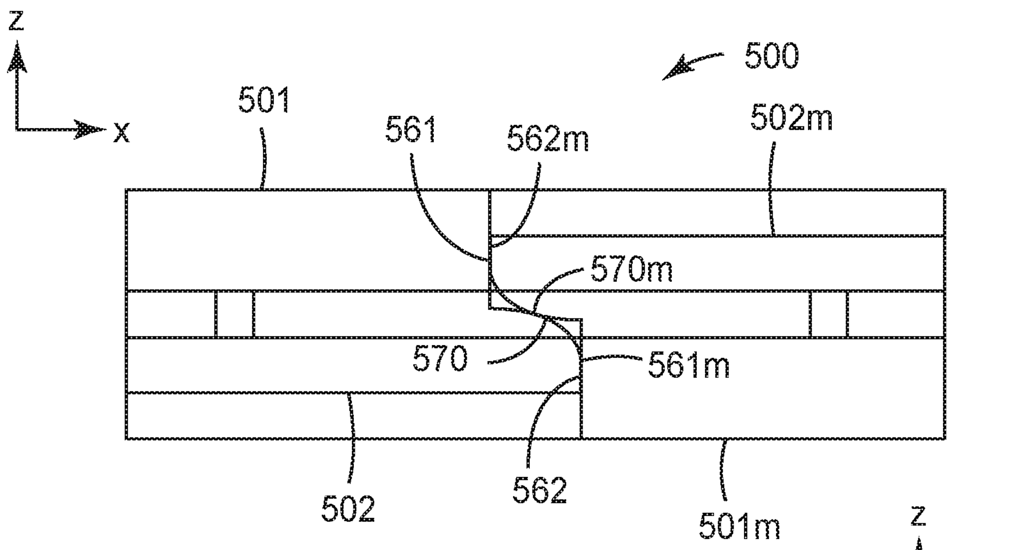
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FIG. 5B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2019/055336

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. G02B6/40(2006.01)i, G02B6/26(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. G02B6/24, G02B6/255-6/27, G02B6/30-6/34, G02B6/36-6/43

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2019
Registered utility model specifications of Japan 1996-2019
Published registered utility model applications of Japan 1994-2019

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/0219863 A1 (HAASE et al.) 2015.08.06, paragraph[0041],Fig.4 & JP 2019-53285 A & WO 2014/055361 A1 & CN 104781709 A	1-10
A	WO 2017/066138 A1 (3M INNOVATIVE PROPERTIES COMPANY) 2017.04.20, Fig.1 & JP 2018-534633 A & US 2018/0275354 A1 & CN 108139545 A & KR 10-2018-0067580 A	1-10
A	US 2017/0059785 A1 (SMITH et al.) 2017.03.02, paragraphs[0072]-[0073],Fig.4 & JP 2017-513055 A & WO 2015/142551 A1 & KR 10-2016-0134772 A & CN 106104337 A	1-10

☑ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06.11.2019	19.11.2019

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office	OKUMURA, Masato 2L 4752
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No. +81-3-3581-1101 Ext. 3295

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2002/0114582 A1 (OTERA) 2002.08.22, Fig.5 & JP 2002-243984 A	1-10