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(54) **OPTOELECTRONIC DEVICE HAVING IMPROVED OPTICAL COUPLING**

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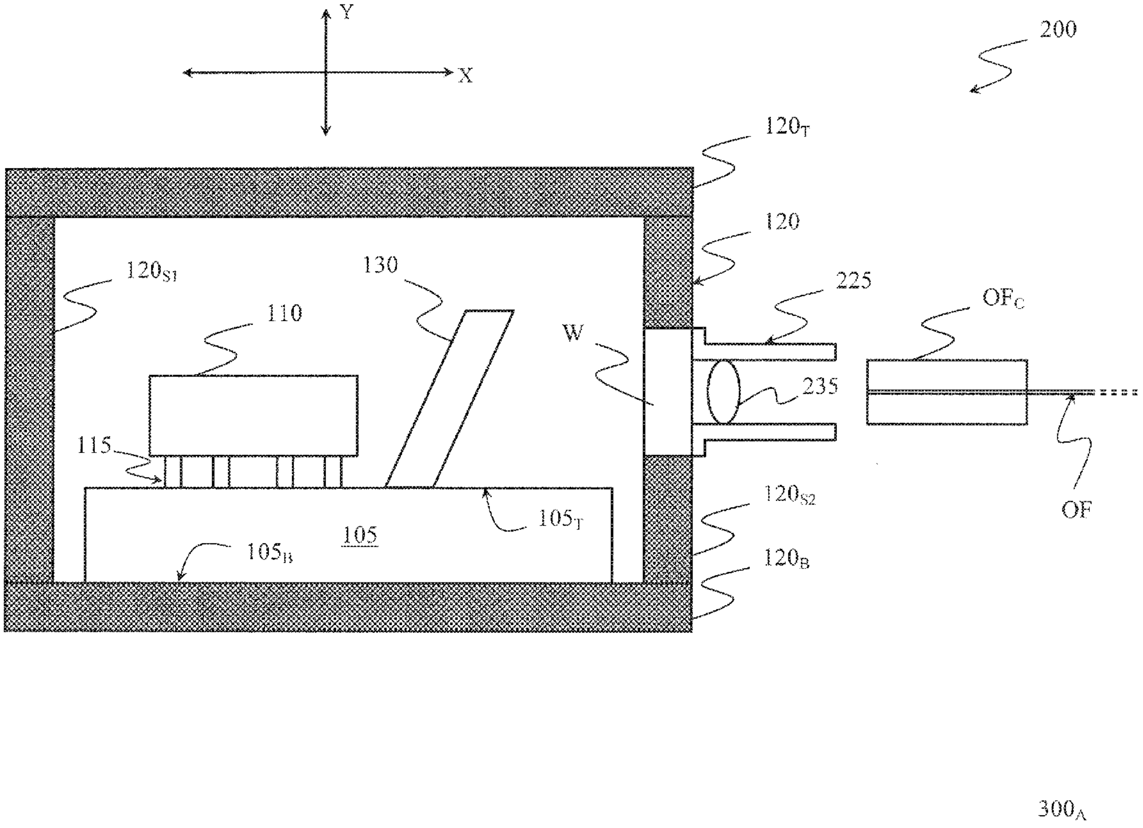
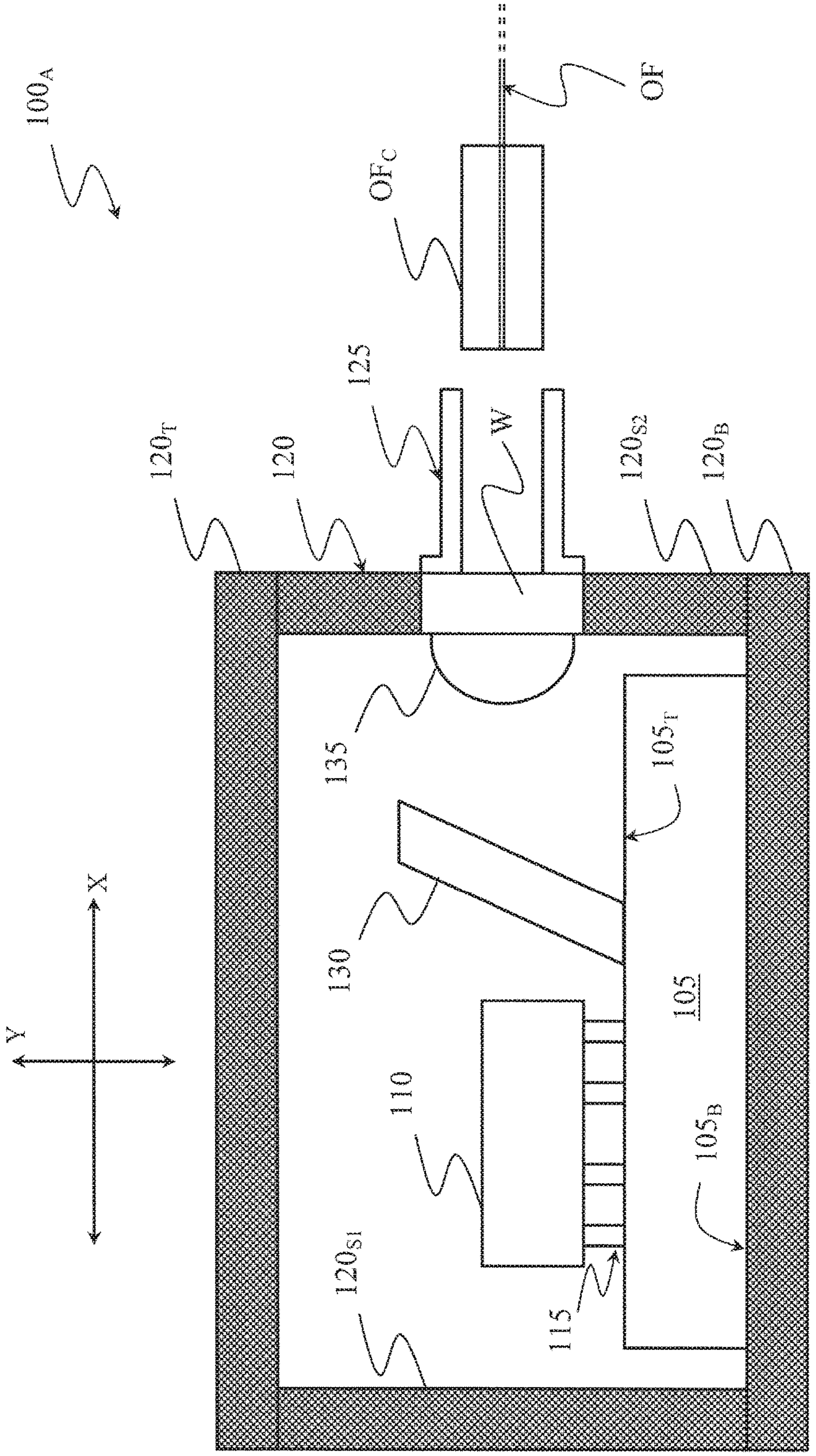
(57) **ABSTRACT**

An optoelectronic device may include a package having a component for sending/receiving optical signals along a first direction, and a chip of semiconductor material housed within the package. The chip may have a main surface and a portion exposed on the main surface for sending/receiving the optical signals along a second direction different from the first direction. The optoelectronic device may further include a component for deflecting the optical signals between the first direction and the second direction, the component being mounted on the main surface..

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OF
OF_C
125
W
120_T
120
120_{S2}
120_B
135
105_T
130
105
110
105_B
120_{S1}
115
X
Y

FIG.1A

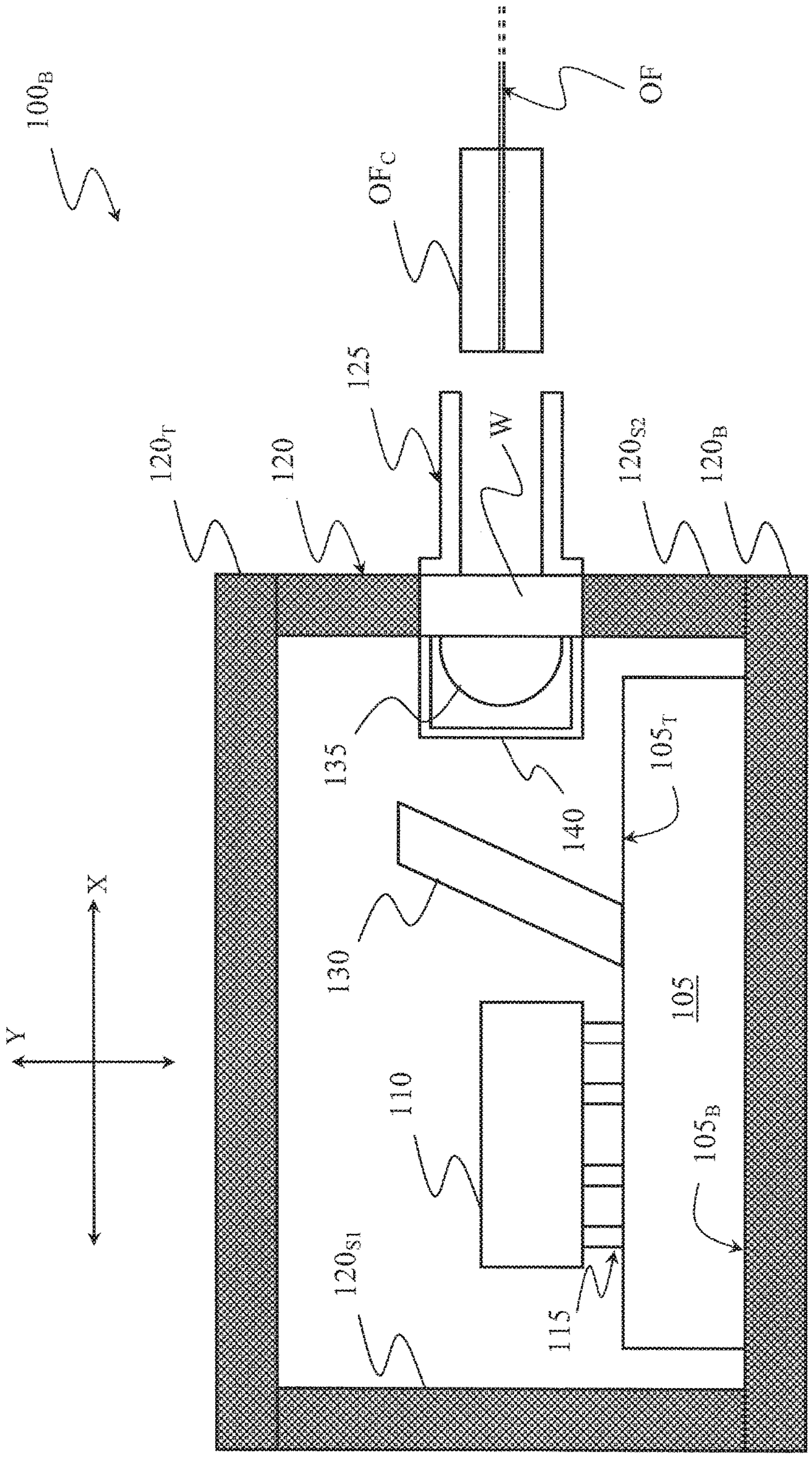
100_B
OF
OF_C
125
W
120_T
120
120_{S2}
120_B
135
140
105_T
X
Y
130
105
110
105_B
120_{S1}
115

FIG.1B

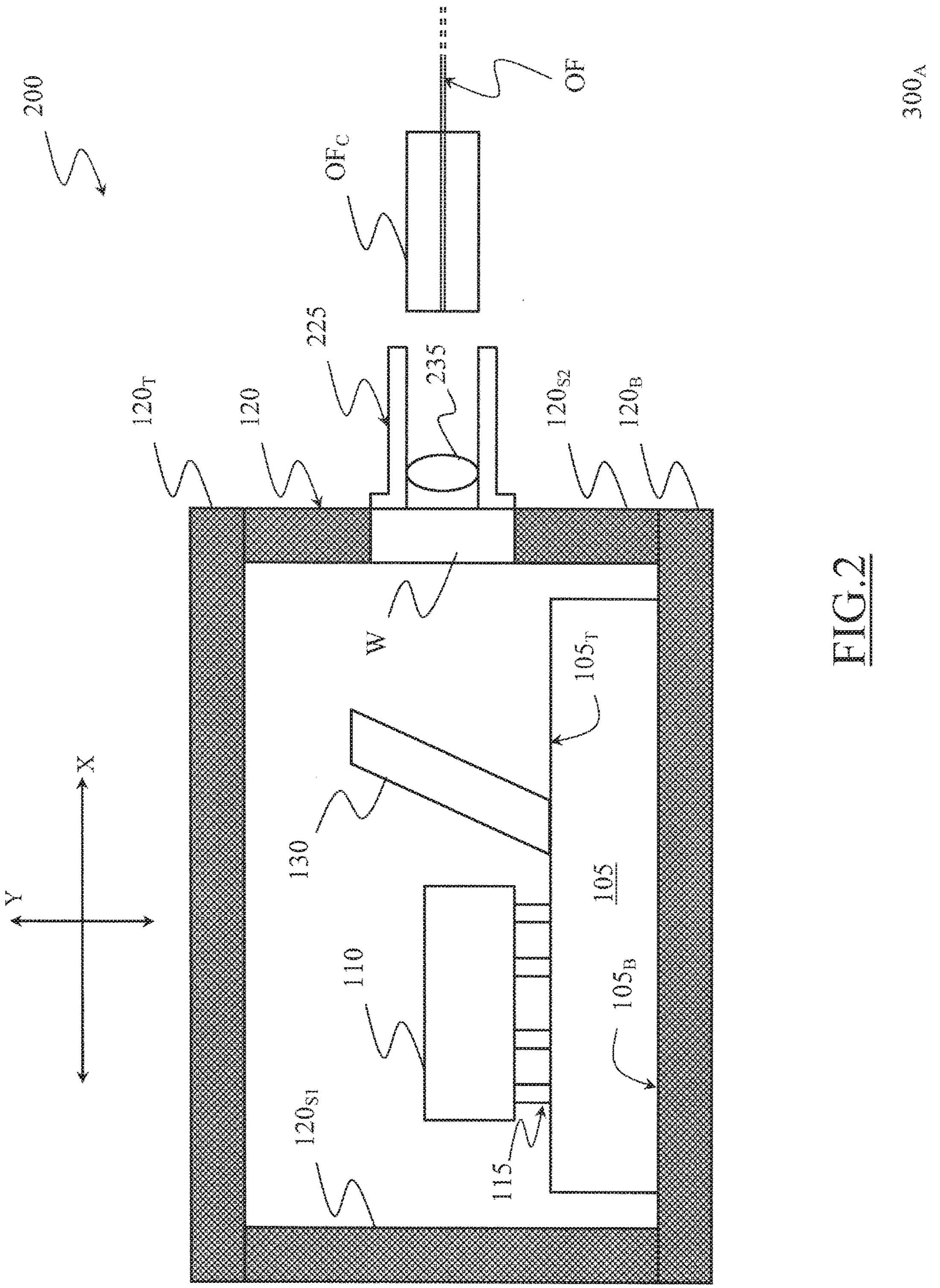
200
OF
OF_C
300_A
225
235
120_T
120
120_{S2}
120_B
W
105_T
130
105
110
105_B
120_{S1}
115
X
Y

FIG.2

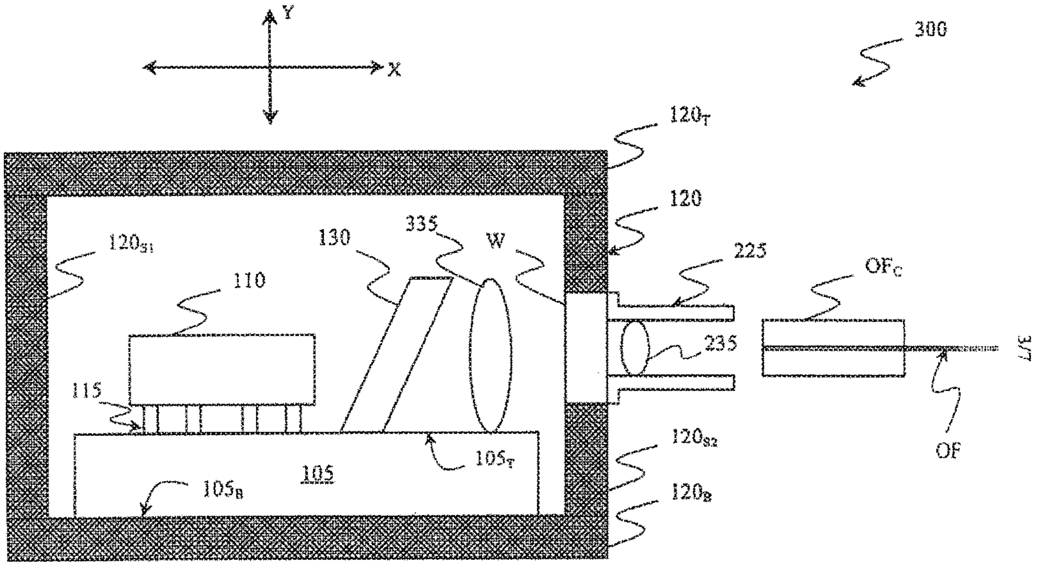
Y
X
300
120_T
120
120_{S1}
130
335
W
225
OF_C
110
235
115
3/7
120_{S2}
105
105_T
OF
105_B
120_B

FIG. 3A

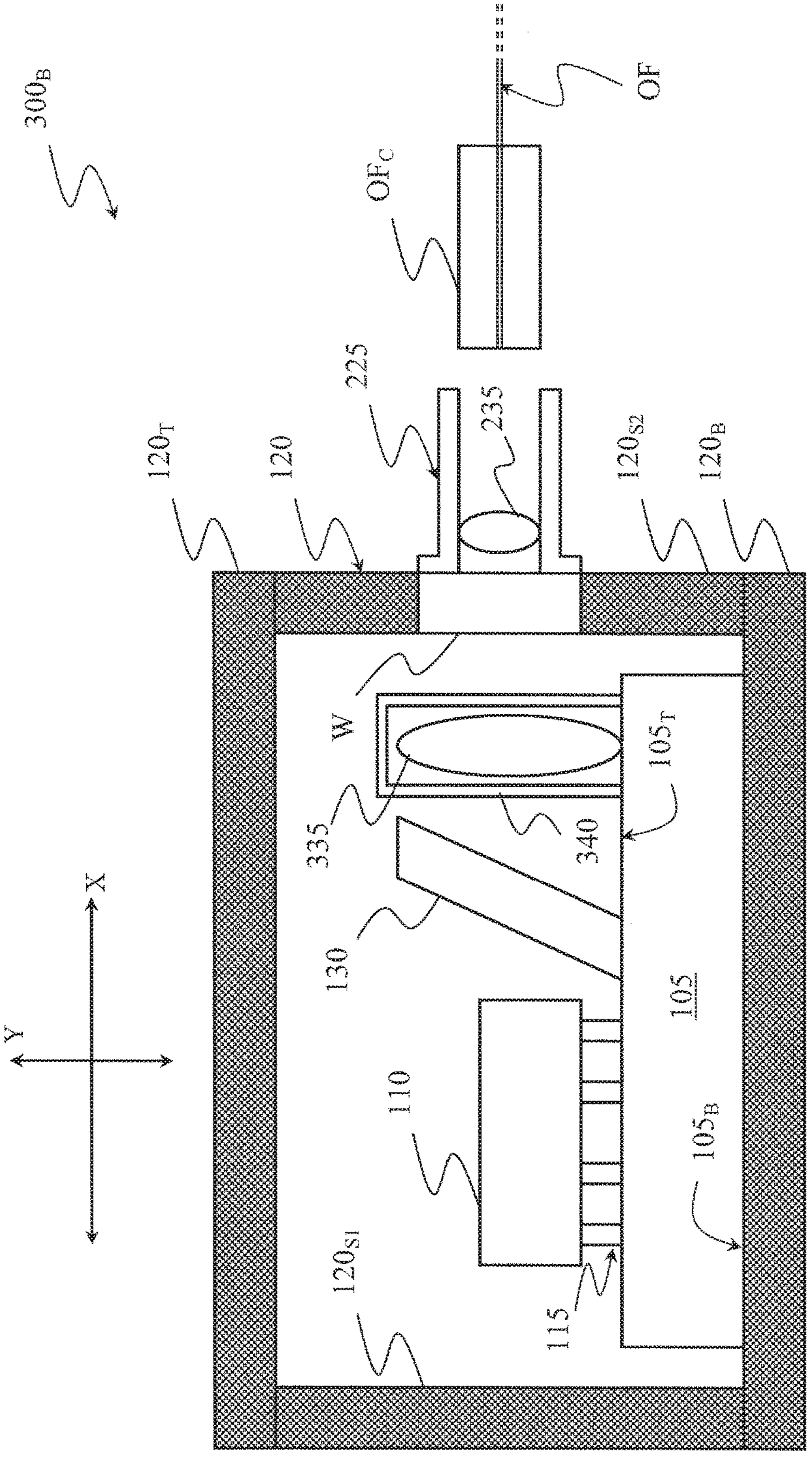
300_B
OF
OF_C
225
235
120_T
120
120_{S2}
120_B
W
105_T
335
340
130
105
110
105_B
120_{S1}
115
X
Y

FIG.3B

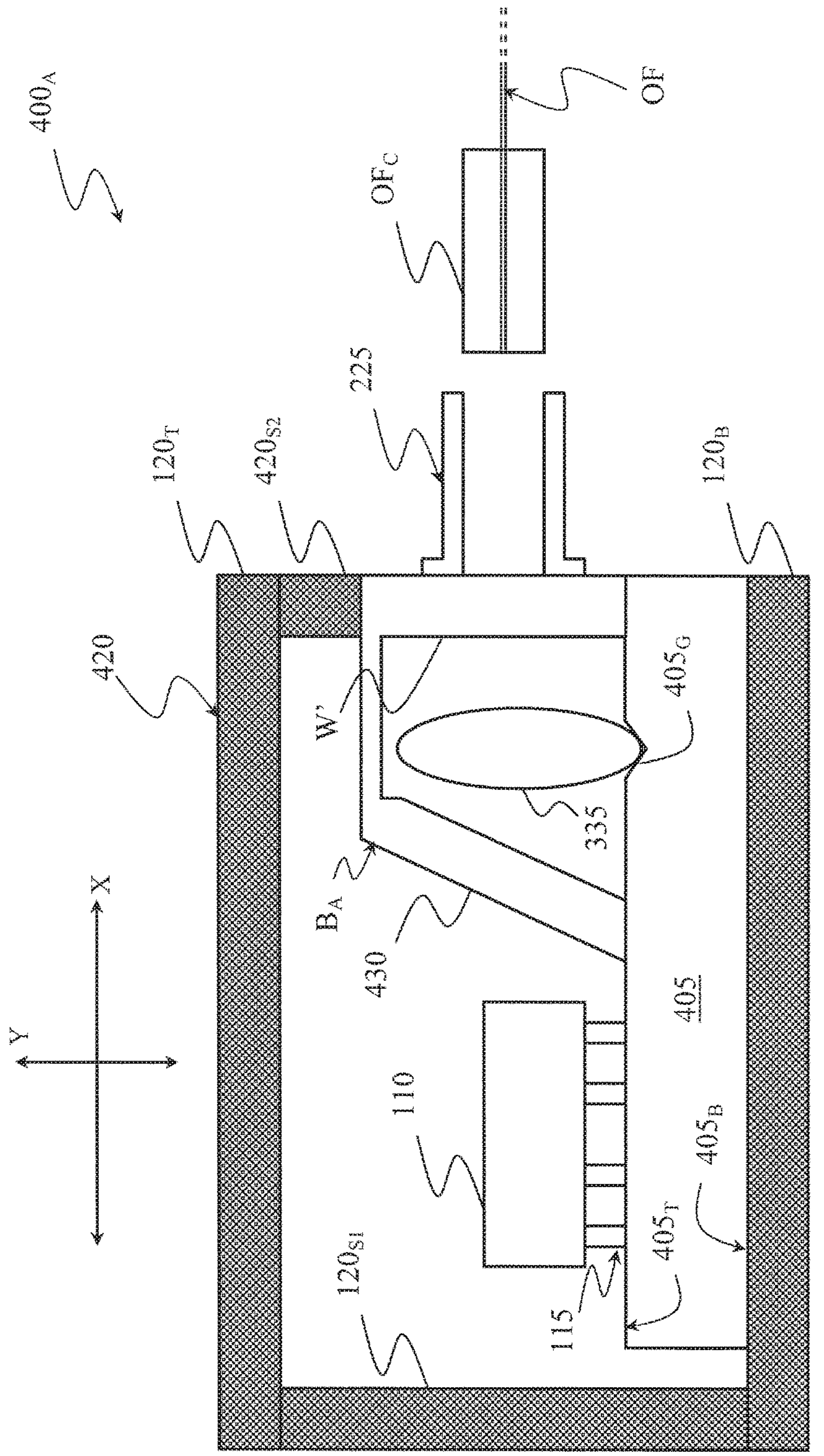
400_A
OF
OF_C
225
120_T
420_{S2}
120_B
420
W'
405_G
335
B_A
430
X
Y
405
110
405_B
405_T
115
120_{S1}

FIG.4A

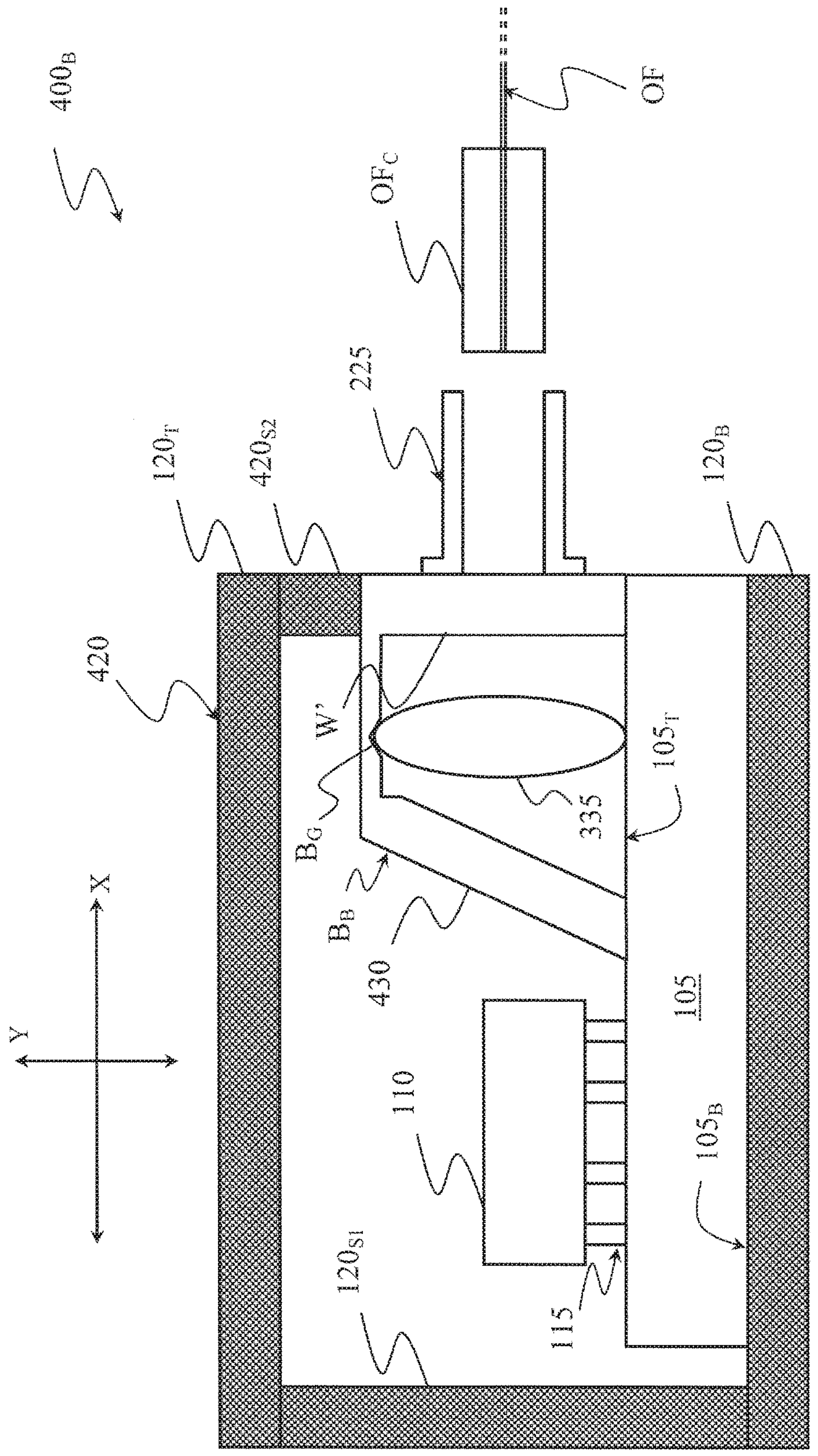
400_B
OF
OF_C
225
120_T
420_{S2}
120_B
420
W'
B_G
B_B
430
335
105_T
105
110
105_B
115
120_{S1}
X
Y

FIG.4B

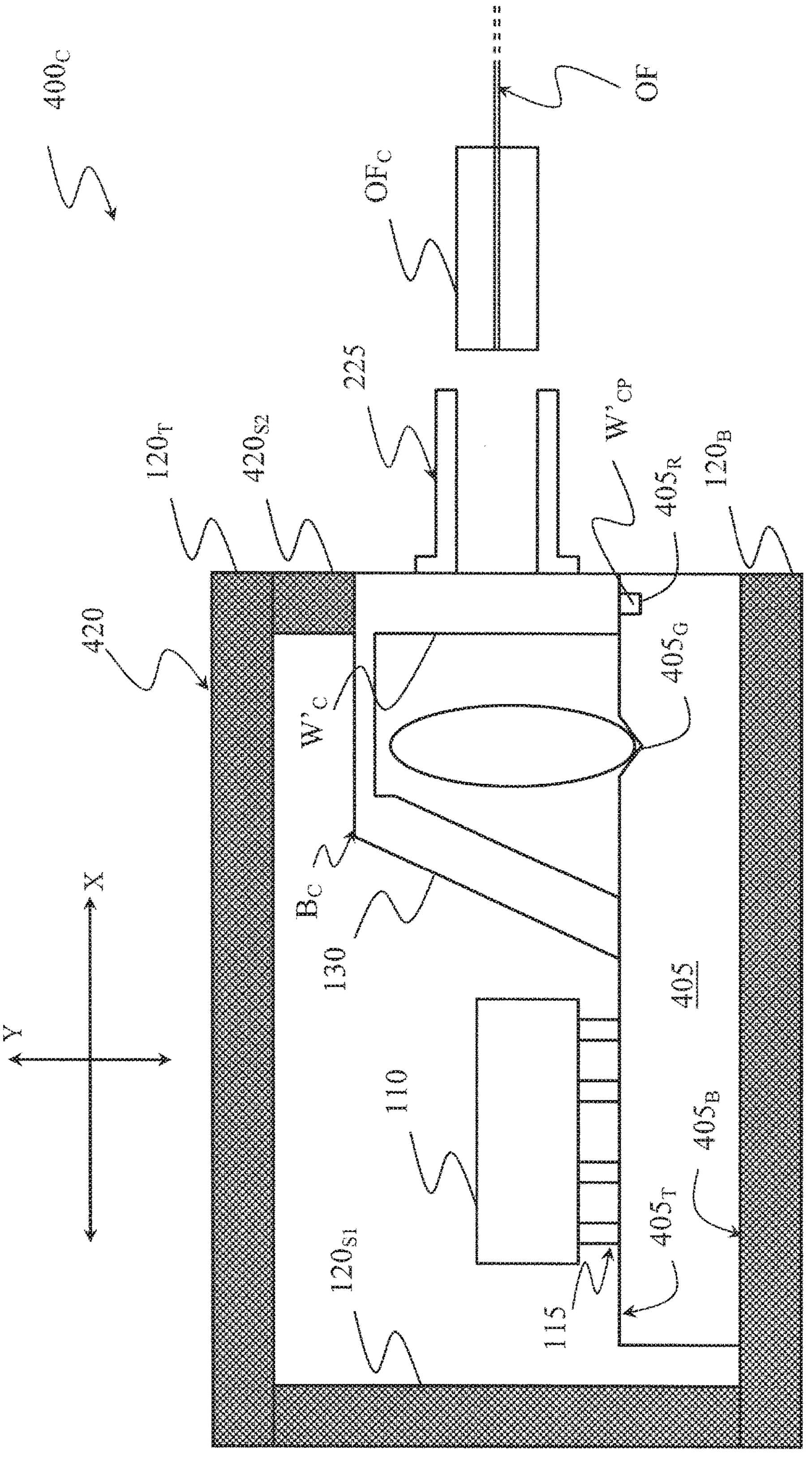
400_C
OF
OF_C
225
W'_{CP}
120_T
420_{S2}
405_R
120_B
420
405_G
W'_C
B_C
130
X
Y
405
110
405_B
405_T
120_{S1}
115

FIG.4C

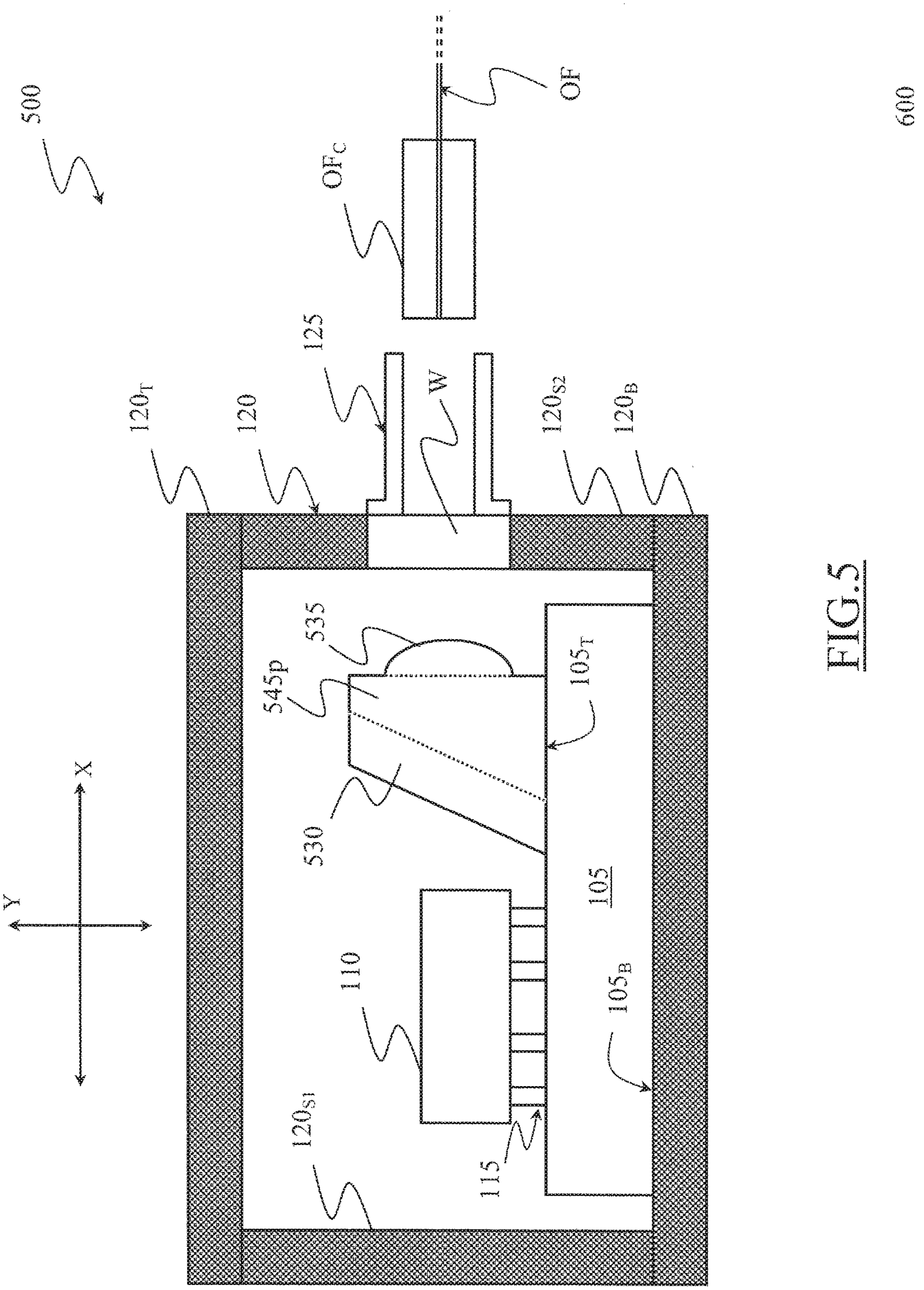
500
OF
OF_C
600
125
W
120_T
120
120_{S2}
120_B
535
545p
105_T
530
105
110
105_B
120_{S1}
115
X
Y

FIG. 5

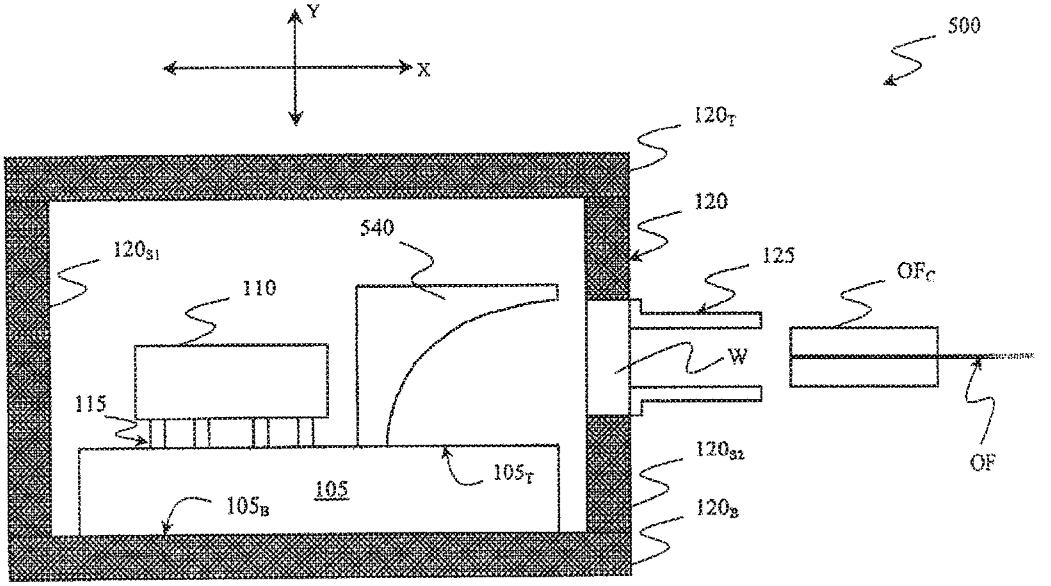
Y
X
500
120_T
120
120_{S1}
540
125
OF_C
110
W
115
105_T
105
105_B
120_{S2}
120_B
OF

FIG. 6

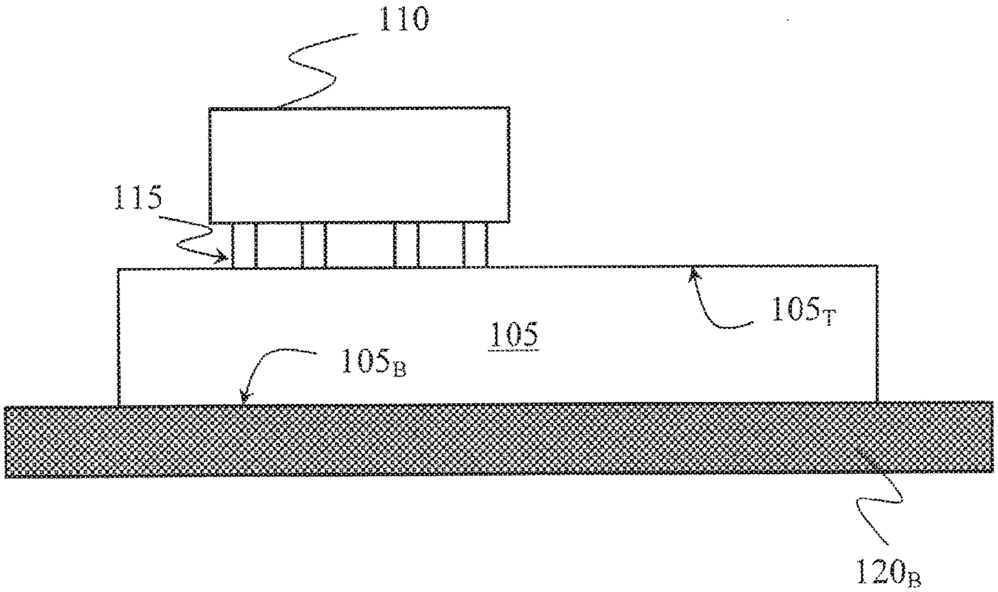
110
115
105_T
105
105_B
120_B

FIG.7A

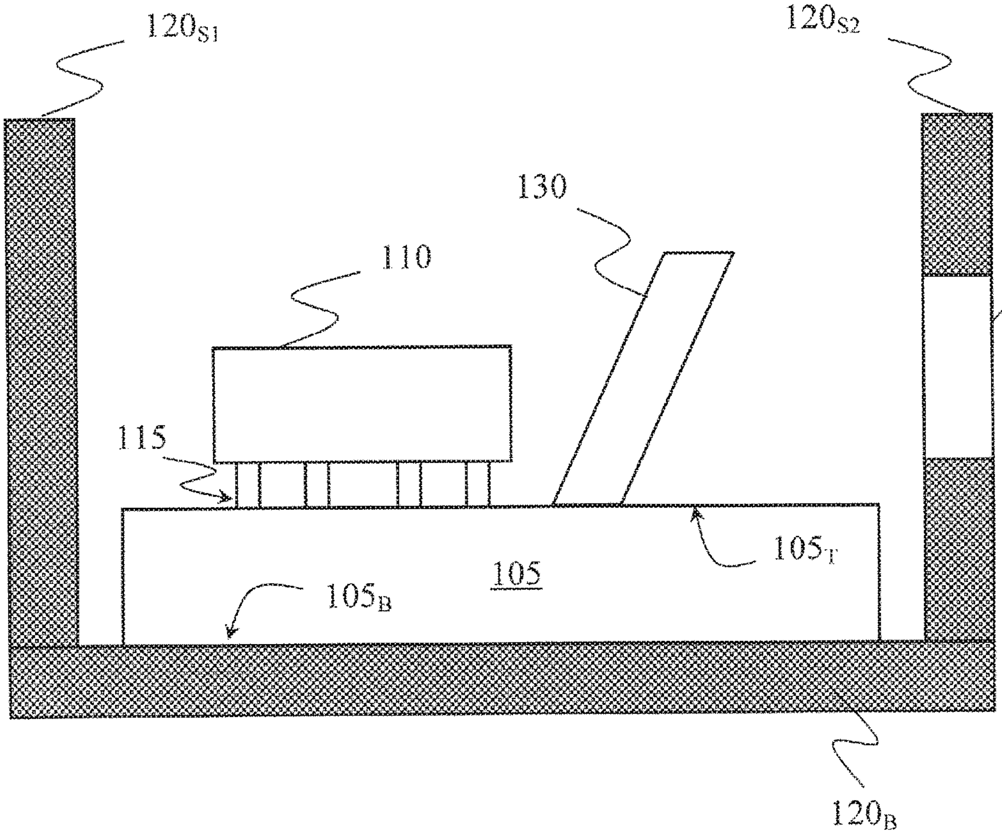
120_{S1}
120_{S2}
130
W
110
115
105_T
105
105_B
120_B

FIG.7B

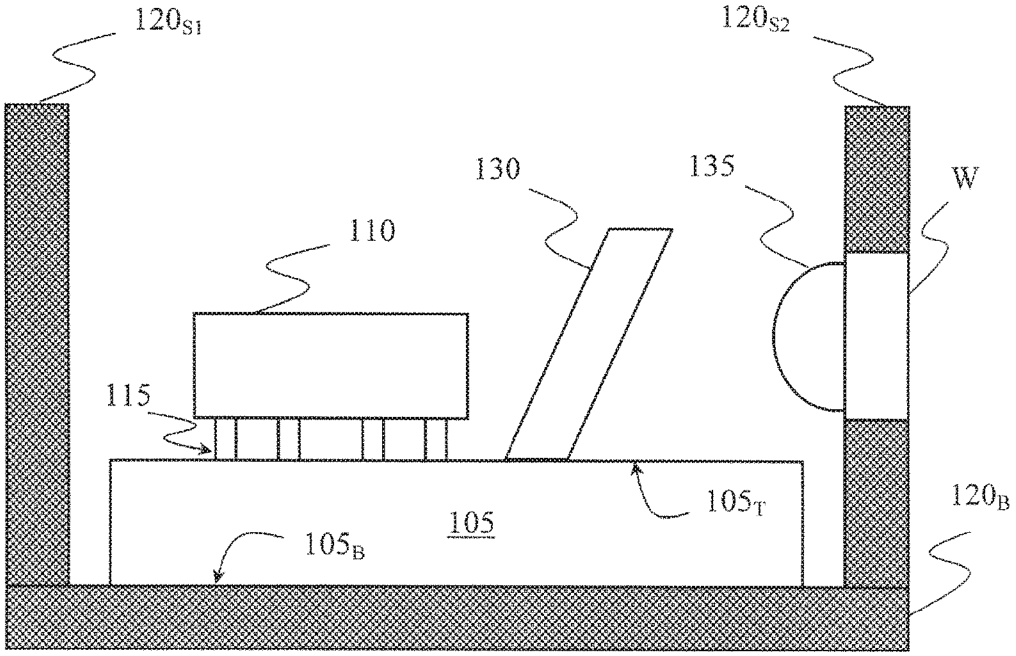
120_{S1}
120_{S2}
130
135
W
110
115
105_T
105
105_B
120_B

FIG.7C

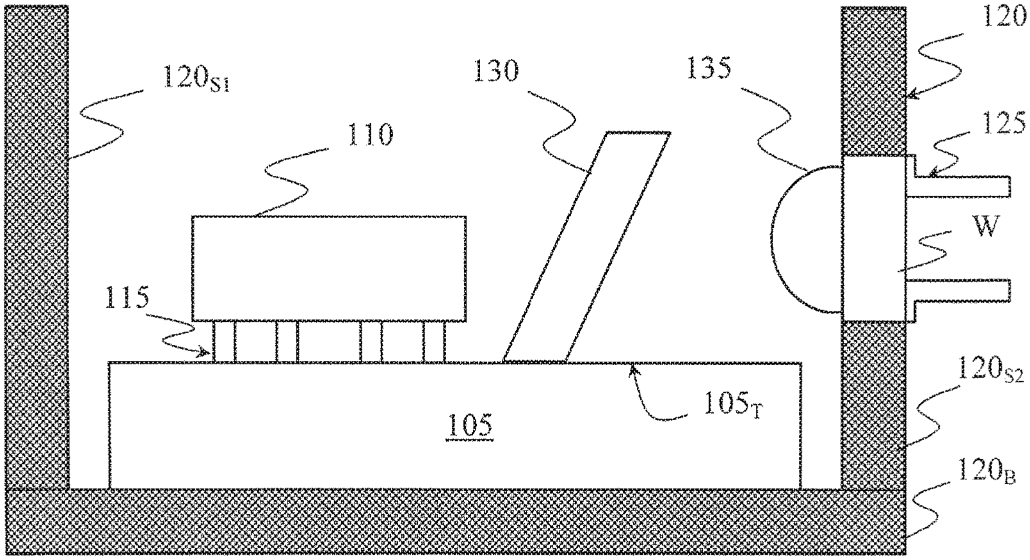
120
120_{S1}
130
135
125
110
W
115
105_T
105
120_{S2}
120_B

FIG.7D

OPTOELECTRONIC DEVICE HAVING IMPROVED OPTICAL COUPLING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation application of U.S. application Ser. No. 14/282,394, filed on May 20, 2014, which claims the benefit of Italy Application No. MI2013A000864, filed on May 28, 2013 which applications are hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of optoelectronic devices.

BACKGROUND

[0003] Optoelectronic devices are widely used in optical communication systems, where electrical signals containing information to be transmitted are modulated on corresponding optical signals. The optical signals are propagated between the optoelectronic devices through optical propagation channels (for example, optical fibers).

[0004] A typical optoelectronic device comprises a chip of semiconductor material with optical circuits integrated hereinafter OIC ("Optical Integrated Circuit") chip, for modulating/de-modulating the electrical/optical signals into the corresponding optical/electrical signals, respectively, a chip of semiconductor material where electronic circuits are integrated, hereinafter EIC ("Electrical Integrated Circuit") chip, for processing the electrical signals according to the specific functionality of the optoelectronic device, and optical components for transferring the optical signals to/from the OIC chip. The OIC chip generally comprises waveguides for propagating the optical signals among the optical circuits integrated therein, exposed regions (exposed on surfaces of the OIC chip) for sending/receiving the optical signals, and optical gratings for transferring the optical signals between the waveguides, where optical signal propagation takes place only along a longitudinal direction (i.e., parallel to a substrate of semiconductor material from which the OIC chip is formed). This may involve coupling difficulties between the OIC chip and the optical propagation channels.

[0005] Indeed, in the case of exposed regions being made on an upper surface of the OIC chip (so as to send/receive the optical signals along a transverse direction, perpendicular to the longitudinal direction), a vertical coupling between the optical propagation channel and the OIC chip may be needed. However, the vertical coupling may need structures for supporting the optical propagation channel, with a consequent increase of space occupation by the optoelectronic device. Moreover, in many implementations, the optical propagation channel is subject to non-negligible curvatures to achieve the vertical coupling. This may cause damage of the optical propagation channel, and/or propagation errors of the optical signals through it. Instead, in the case of exposed regions made on a side surface of the OIC chip (so as to send/receive the optical signals along the longitudinal direction), the production process of the OIC chip needs additional operations (for example, side surface lapping), and therefore an increase of the optoelectronic device costs.

[0006] For example, U.S. Patent Publication No. 2005/0163435 to Fincato discloses an optoelectronic device on a support substrate, and an optical component integrated within the substrate for coupling the optoelectronic device to an optical fiber. Some approaches, such as U.S. Patent Publication No. 2005/0163435 to Fincato, may include, in addition to what is discussed above, high manufacturing difficulties and reduced efficiency.

SUMMARY

[0007] An aspect is directed to an optoelectronic device comprising a package with a device for sending/receiving optical signals along a first direction, a chip housed within the package with a component exposed on a main surface thereof for sending/receiving the optical signals along a second direction different from the first direction, and a component, mounted on the main surface, for deflecting the optical signals between the first direction and the second direction. Another aspect is directed to a method for manufacturing such optoelectronic device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIGS. **1**A-**6** are schematic diagrams of sectional views of an optoelectronic device, according to embodiments of the present disclosure; and

[0009] FIGS. **7**A-**7**D are schematic diagrams of steps of the production process of the optoelectronic device of FIG. **1**A.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0010] With particular reference to FIG. **1**A, an optoelectronic device **100**.sub.A according to an embodiment of the present disclosure is now described. The optoelectronic device **100**.sub.A is suitable for use in optical communication systems where electrical signals containing information to be transmitted are modulated into corresponding optical signals. The optical signals are propagated through optical propagation channels. In the exemplary described embodiment, such optical propagation channels comprise optical fibers, such as the optical fiber OF, which the optoelectronic device **100**.sub.A is adapted to be mechanically connected to for receiving/sending the optical signals (as will be discussed below)

[0011] For the sake of ease, in the following description, only elements of the optoelectronic device **100**A deemed relevant for understanding the present embodiments will be introduced. In the following, directional terminology (for example, top, bottom, side, longitudinal, transverse) associated with such elements will be used only in connection with their orientation in the figures, and it will not be indicative of any specific orientation (between the various possible) such elements can be used. The term "substantially" will be used to take into account (desired or undesired) manufacturing tolerances.

[0012] The optoelectronic device **100**A comprises a chip of semiconductor material **105** where optical circuits are integrated for modulating/de-modulating the electrical/optical signals into the corresponding optical/electrical signals, respectively. Although not shown, the OIC chip **105** comprises a waveguide for propagating the optical signals (between optical circuits integrated within it) along a longitudinal direction X (substantially parallel to a substrate of the OIC chip **105**), an exposed region (on a main, for example, upper, surface **105**T of the OIC chip **105**) for sending/receiving the optical signals along a transverse direction Y (different from the longitudinal direction X, for example, substantially orthogonal thereto), and an optical grating for transferring the optical signals between the waveguide and the exposed region.

[0013] The optoelectronic device **100**A comprises another chip of semiconductor material **110** where electronic circuits are integrated, hereinafter EIC ("Electronic Integrated Circuit") chip, for processing the electrical signals according to the specific functionality of the optoelectronic device **100**A.

[0014] In order to allow the exchange of the electrical signals between the OIC chip **105** and the EIC chip **110**, while maintaining a reduced volume occupation, the EIC chip **110** is electrically connected to the OIC chip **105** in "flip chip" mode. According to "flip-chip" connection mode, the EIC chip **110** is mounted upside down on the OIC chip **105**, so that the corresponding terminals (not visible) are electrically connected to each other—directly, or, as shown in the figure, by way of intermediate coupling elements **115** (e.g., conductive bumps or pillars). The OIC chip **105** and the EIC chip **110** are housed, together with one or more optical components (discussed below), within a (e.g., hermetic or non-hermetic) package **120** of the optoelectronic device **100**A.

[0015] More particularly, the package **120** comprises a bottom wall **120**B that supports the OIC chip **105** on a rear surface **105**B thereof opposite the upper surface **105**T, a top wall **120**T (facing the upper surface **105**T and being parallel to the bottom wall **120**B) that encloses the optoelectronic device **100**A from above, and two reciprocally opposite side walls **120S1**, **120S2** (between the upper wall **120**T and the bottom wall **120**B, transversely to them). As visible in the figure, portions free from optical components are provided within the package **120** (with such free portions that are occupied by air, as herein assumed, or by any other transmission medium with appropriate refractive index) to allow free space propagation of the optical signals.

[0016] Preferably, the bottom **120**B, top **120**T, and side **120S1**, **120S2** walls of the package **120** are made of metal or ceramic material, with the exception of a portion of the side wall **120S2**, which is provided with an optical window W made of a light-transparent material (e.g., glass, plastic or silicon) for the exchange (i.e., sending and receiving) of the optical signals between the optical fiber OF and the optoelectronic device **100**A (when they are connected to each other). According to the exemplary embodiments of FIG. **1**A (under discussion) and of FIGS. **1**B-**3**B, **5** and **6** (discussed in the following), the optical window W is between (e.g., in the middle of) two walls portions of the side wall **120S2**, whereas according to alternative embodiments (such as those illustrated in FIGS. **4**A-**4**C, discussed in the following) the optical window is mounted directly on the upper surface of the OIC chip (with corresponding size reduction of the optoelectronic device).

[0017] Referring back to FIG. **1**A, in order to allow connection to the optical fiber OF, the optoelectronic device **100**A further comprises a housing **125** suitable for housing a connector OFC of the optical fiber OF. Preferably, the housing **125** is fixed (for example, glued or welded) on, and externally to, the side wall **120S2**, in correspondence of the optical window W. In the exemplary embodiment, the housing **125** is arranged such that the connector OFC, when inserted into the housing **125**, is located at a substantially central position with respect to the optical window W, and facing it. In other words, the exchange of the optical signals between the optical fiber OF and the optoelectronic device **100**A (through the optical window W) takes place along the longitudinal direction X (in any case, as will be apparent from the remainder of the description, it can take place along different directions, not necessarily orthogonal to the transverse direction Y).

[0018] The optoelectronic device **100**A further comprises optical components for converging the optical signals from the optical fiber OF to the OIC chip **105** and from the OIC chip **105** to the optical fiber OF. In the exemplary embodiments, such optical components comprise, between the optical window W and the EIC chip **110**, optical deflection members **130** (e.g., an optical deflector) for deflecting the optical signals between the longitudinal direction X and the transverse direction Y, and, between the housing **125** and the optical deflector **130**, optical focusing members (e.g., a system of, one or more, lenses) for focusing the optical signals along the longitudinal direction X. In other words, such optical components identify, between the connector OFC and the OIC chip **105**, an optical path for the optical signals. Such optical path extends both internally to the optoelectronic device **100**A (i.e., in the space delimited by the package **120**), both externally thereto (i.e., in the space, external to the package **120**, between the connector OFC and the optical window W).

[0019] The optical deflector **130**, fixed on the OIC chip **105** by way of adhesive resins with appropriate refractive indices, deflects (e.g., by using a metalized deflecting surface thereof) the optical signals from the optical window W (along the longitudinal direction X) towards the exposed region of the OIC chip **105** (along the transverse direction Y), and vice versa. The orientation of the optical deflector **130** with respect to the upper surface **105**T of the OIC chip **105**, non-limiting for the present embodiments, can be chosen based on specific design considerations (for example, in order to ensure that the optical signals come to the exposed region, and hence to the optical grating, with the correct spot size). The lens system focuses the optical signals between the optical fiber OF and the optical deflector **130**, and vice versa, thereby avoiding diffusion losses.

[0020] For example, in the embodiment illustrated in FIG. **1**A, the lens system comprises a lens **135** (for example, made of glass, silicon or any other material transparent to the optical signals) fixed, for example glued, to the optical window W—anyway, nothing prevents from making the lens **135** in a single piece with the optical window W. In this way, the diffusion of the optical signals along the longitudinal direction X (between the optical fiber OF and the optical deflector **130**) is reduced by the converging/focusing effect of the lens **135**, and the propagation of the optical signals within the optoelectronic device **100**A is allowed with very low (ideally zero) diffusion losses.

[0021] As mentioned above, the package **120** may be a non-hermetic package, in which case incoming humid air may cause refractive index changes (especially, at air/lens **135** interface), and hence errors in the propagation of the optical signals. In order to avoid that, an encasing structure **140** for encasing the lens **135** may be provided (as illustrated for the optoelectronic device **100**B of FIG. **1**B embodiment), so that an air gap between the encasing structure **140** and the lens **135** is defined as a result of the encasing. Due to the air gap, refractive index changes at air/lens **135** interface are substantially avoided, which allows optimal propagation of the optical signals. Preferably, the encasing structure **140** is made of a light-transparent material (e.g., glass, plastic or silicon), more preferably the encasing structure **140** is made of the same material as the optical window W, and even more preferably the encasing structure **140** is made in a single piece with the optical window W.

[0022] As should be readily understood, optoelectronic devices featuring hermetic packages may also benefit from the use of the encasing structure **140**. Indeed, even when using hermetic packages, refractive index changes at air/lens **135** interface may arise due, for example, to optical components gluing.

[0023] In the embodiment illustrated in FIG. **2**, the lens system of the optoelectronic device **200** comprises a lens **235** integrated within the housing **225**. For example, the lens **235** can be formed in a single piece with the housing **225**, or it can be made separately and be fixed, for example, glued, within it. In order to improve the optical coupling between the optical fiber OF and the optical deflector **130**, the lens system may comprise further lenses (or further optical components, for example, prisms, insulators) along the optical path. For example, in the embodiment illustrated in FIG. **3**A, the optoelectronic device **300**A comprises another lens **335**, in addition to the lens **235**, fixed (e.g., glued) on the OIC chip **105**, between the optical deflector **130** and the optical window W—nothing prevents incorporating the lens **335** in the embodiments of FIGS. **1**A-**1**B.

[0024] According to the embodiment illustrated in FIG. **3**B, an encasing structure **340** (similar to the encasing structure **140**) is provided for encasing the lens **335**, so that an air gap between the encasing structure **340** and the lens **335** is defined as a result of the encasing. As mentioned above, according to other embodiments (illustrated in FIGS. **4**A-**4**C), the optical window is mounted on the upper surface of the OIC chip, with the side wall **420**S**2** that is mounted on the optical window only (i.e., between the optical window and the top wall **120**T of the package **420**).

[0025] Preferably, as visible in FIG. **4**A, the optical deflector **430** and the optical window W' are formed in a single body (globally denoted by the reference BA). The body BA, which is adapted to be mounted on the upper surface **405**T of the OIC chip **405**, is shaped so as to define an air gap between it and the main surface of the OIC chip **405**, so that optimal propagation of the optical signals can be achieved—in other words, the body BA is functionally similar to the encasing structures **140**,**340**, but additionally incorporates the optical deflector **430** and the optical window W'.

[0026] Preferably, the lens **335** is immersed in the air gap, covered and enclosed by the body BA—however, in alternative embodiments (not shown), no lens **335** is enclosed by the body BA (similarly to the FIG. **1**A embodiment, wherein no lens is mounted on the upper surface **105**T of the OIC chip **205**, or to FIG. **2** embodiment, wherein the lens **235** is provided in the housing **225** only).

[0027] Preferably, a groove **405**G for aligning and attaching the lens **335** is provided on the upper surface **405**T of the chip **405** (as visible in FIG. **4**A). Alternatively, as visible in FIG. **4**B, a groove BG for aligning and attaching the lens **335** is provided on the body BG (preferably, as illustrated, at a horizontal wall thereof facing, and substantially parallel to, the upper surface **105**T of the chip **105**). In alternative embodiments (not shown), both grooves **405**G, BG are provided. Attaching of the lens **335** to the groove **405**G. BG is preferably achieved using a glue, which may be either an optical glue or a non-optical glue (e.g., a thixotropic glue).

[0028] According to the embodiment illustrated in FIG. **4**C, a recess **405**R is provided on the upper surface **405**T of the OIC chip **405** for receiving at least part of the optical window W'C thereto (e.g., a protruding part W'CP thereof), thus allowing aligning and attaching (e.g., using either an optical or non-optical glue) of the optical window W'C onto the chip **405**. As should be understood, provision of the recess **405**R may be independent from provision of the optical deflector **430** and of the optical window W'C in a single body BC (i.e., mounting of the optical window directly on the OIC chip, as well as a provision of the recess for facilitating it, may be implemented also in FIGS. **1**A-**3**B and in FIGS. **5**-**6** embodiments).

[0029] As will be understood, the optical deflector **130** and the lens **335** of the embodiments of FIGS. **1**A-**3**B may be replaced by any equivalent optical component with similar deflecting and converging properties (as shown in FIGS. **5** and **6** embodiments, discussed below). For example, in the embodiment illustrated in FIG. **5**, the optoelectronic device **500** comprises an optical deflector **530** (similar to the optical deflector **130**), a lens **535** (similar to the lens **335**), and a propagation portion **545**P (between the optical deflector **530** and the optical lens **535**) integrated in a single piece (for example, by typical molding techniques). In this way, the optical signals coming from the lens **535** converge, by propagating through the propagation portion **545**P, towards the optical deflector **530** (and hence to the optical grating of the OIC chip **105**), and vice versa. As will be understood, the optical deflector **530** and the lens **535** will have, by virtue of the optical characteristics of the propagation portion **545**P, different design parameters with respect to those of the optical deflector **130** and of the lens **335** (e.g., size and inclination of the optical deflector **530**, size and focal length of the lens **535**, and distance between the optical deflector **530** and the lens **535**—i.e., size of the propagation portion **545**P). The described approach is advantageous in that the making of the optical deflector **530** and of the lens **535** in a single piece avoids mutual misalignments that may cause degradation of the optical signals.

[0030] Although the optical deflector **530**/lens **535**/propagation portion **545**P assembly shown in FIG. **5** comprises a solid propagation portion **545**P, this should not be understood to be limiting. In fact, nothing prevents a propagation portion being internally hollow (not shown) that connects the optical deflector **530** and the lens **535** to each other, so that the optical signals coming from the lens **535** converge towards the optical deflector **530** by propagating through the air (similarly to FIG. **3**A embodiment).

[0031] In the embodiment illustrated in FIG. **6**, however, the optoelectronic device **600** comprises, instead of optical lenses and deflectors on the OIC chip **105**, a curved mirror **650**, for example, concave. By suitably sizing the curvature of the curved mirror **650**, and by placing it with the concave portion facing the optical window W at an appropriate distance, the optical signals from the optical window W, after propagating through the air, hit the surface of the curved mirror **650**, and are deflected and focused towards the (exposed region of) OIC chip **105** in a similar way as described in the previous embodiments.

[0032] As will be understood, the embodiments of FIGS. **5** and **6** may be used in the optoelectronic devices of FIGS. **1**A-**4**C, additionally or alternatively to at least part of the optical components illustrated therein. For example, although not shown, nothing prevents making the optical deflector **530**/lens **535**/propagation portion **545**P assembly, or the curved mirror **650**, in a single body with the optical window (with such an optical window that may be of the types illustrated in FIGS. **4**A-**4**C).

[0033] Turning to FIGS. **7**A-**7**D, some steps of the production process of the optoelectronic device **100**A according to an embodiment are now described. As will be understood, such production process, described here in detail in connection with the optoelectronic device of a specific embodiment of the present disclosure, can be applied in a similar manner also for the other described embodiments (and those having reference to them), with obvious and evident changes. Considering in particular FIG. **7**A, the production process starts with the mounting of the OIC chip **105** on the bottom wall **120**B, and with the "flip chip" mounting of the EIC chip **110** on the OIC chip **105**. As visible in the figure, in this phase the package is not yet completed (so as to facilitate the following positioning/alignment and mounting of the optical components).

[0034] Turning now to FIG. **7**B, the optical deflector **130** is positioned and mounted on the bottom wall **120**B. The side walls **120S1**, **120S2** (i.e., terminal portions thereof) are then fixed (for example, glued or welded) on opposite edge regions of the bottom wall **120**B. The positioning of the optical deflector **130**, made automatically by typical tools, may take place in active mode (i.e., with positioning control feedback), or in passive mode (i.e., without positioning control feedback). The use of the active mode (which allows achieving more accurate positioning/alignment) or of the passive mode (which allows achieving faster positioning/alignment) can be chosen on the basis of appropriate design considerations (e.g., tolerances of the optical components and of their mutual alignment, desired accuracy on the basis of the specific application where the optoelectronic device is intended to be used, and/or size of the optoelectronic device). Subsequently, the lens **135** is positioned (in active mode or in passive mode) and fixed, for example, glued, on the optical window W (FIG. **7**C)—with such step that can be omitted in the case that the lens **135** and the optical window W are formed in a single piece.

[0035] At this point, as shown in FIG. **7**D, the housing **125** is positioned (in active mode or in passive mode) and fixed, for example, glued or welded, outside the optical window W. Finally, the top wall **120**T is fixed on the side walls **120S1**, **120S2** (i.e., on free end portions thereof, opposite the end portions fixed to the bottom wall **120**B), thereby obtaining the optoelectronic device illustrated in FIG. **1**.

[0036] Naturally, in order to satisfy local and specific requirements, a person skilled in the art may apply to the approach described above many logical and/or physical modifications and alterations. More specifically, although this approach has been described with a certain degree of particularity with reference to one or more embodiments thereof, it should be understood that various omissions, substitutions and changes in the form and details as well as other embodiments are possible. Particularly, different embodiments of the present disclosure may even be practiced without the specific details (such as the numerical examples) set forth in the preceding description to provide a more thorough understanding thereof; conversely, well-known features may have been omitted or simplified in order not to obscure the description with unnecessary particulars. Moreover, it is expressly intended that specific elements and/or method steps described in connection with any embodiment of the disclosed approach may be incorporated in any other embodiment as a matter of general design choice.

[0037] For example, an aspect of the approach according to embodiments of the present disclosure proposes an optoelectronic device. The optoelectronic device comprises a package having means or a component for sending/receiving optical signals along a first direction, and a chip of semiconductor material housed within the package. The chip has a main surface and means exposed on the main surface for sending/receiving the optical signals along a second direction different from the first direction. The optoelectronic device further comprises means or a component for deflecting the optical signals between the first direction and the second direction, the component being mounted on the main surface.

[0038] Similar considerations apply if the optoelectronic device has a different structure or comprises equivalent components, or has other operating features. In any case, any component thereof can be separated into more elements, or two or more components can be combined in a single element. In addition, each component may be replicated to support the execution of the corresponding operations in parallel. It is also pointed out that (unless specified otherwise) any interaction between different components generally does not need to be continuous, and may be direct or indirect through one or more intermediaries.

[0039] For example, the component for deflecting the optical signals between the first direction and the second direction can be mounted directly on the main surface (as shown in the discussed embodiments), or indirectly (for example, by coupling layers with appropriate refractive indices). In addition, shape, size and proportions of the package are not limiting for the present disclosure, and can be chosen according to appropriate design considerations. According to an embodiment of the present disclosure, the second direction is substantially orthogonal to the main surface, and the first direction is substantially orthogonal to the second direction. However, depending on the specific implementation of the OIC chip (and in particular of the optical grating and of the exposed region thereof), the second direction may have an angle between 70.degree. and 110.degree. with respect to the main surface (in any case, these values, which mainly depend on the technology currently available for the making of the optical gratings, are not limiting for the present disclosure). Moreover, depending on the specific implementation of the package, the first direction can be non-orthogonal with respect to the second direction.

[0040] According to an embodiment, the package comprises a first wall for supporting the chip on a rear surface opposite to the main surface, a second wall facing the main surface, and a third wall between the first wall and the second wall. The component is for sending/receiving optical signals along a first direction comprising an optical window in at least one portion of the third wall.

[0041] The component for sending/receiving signals may comprise only an opening in the third wall (i.e., the side wall). Furthermore, although not shown, multiple optical windows (or openings) may be provided. In addition, the optical window can have any shape and/or size. Moreover, nothing prevents from making optical windows and/or openings distributed on different package walls (for example, on both side walls).

[0042] According to an embodiment, the optical window is made of a light-transparent plastic or glass material. According to an embodiment, the optical window is mounted on the main surface of the chip. According to an embodiment, the optoelectronic device further comprises a recess on the main surface of the chip for receiving at least part of the optical window thereto thereby allowing aligning and attaching of the optical window onto the chip. According to an embodiment, the optoelectronic device further comprises a housing or housing means for guided optical propagation of the optical signals, the housing being mounted on the optical window.

[0043] In this regard, although in the description explicit reference has been made to an optical fiber, this should not be understood to be limiting. In fact, the method of guided optical propagation may comprise any type of optical waveguide (single-mode or multi-mode). Furthermore, although the housing and the connector have been shown by schematic representations, it should be understood that shape and size thereof (as well as the specific design features necessary for their connection, not herein discussed) are not to be construed to be limiting.

[0044] In addition, nothing prevents from positioning the housing staggered with respect to the optical window. In this case, further optical deflectors (and/or other optical components with deflecting features) may be provided for deflecting the optical signals towards the optical window.

[0045] According to an embodiment, the optoelectronic device further comprises means or a component for focusing the optical signals along the first direction. According to an embodiment, the component for focusing the optical signals along the first direction is mounted on the main surface.

[0046] Similarly to what discussed above, the component for focusing the optical signals can be mounted directly on the main surface (as shown in the discussed embodiments), or indirectly (for example, by coupling layers with appropriate refractive indices). Additionally or alternatively, they (or a part thereof) can be fixed to the optical window or to the housing.

[0047] According to an embodiment, the optoelectronic device further comprises an encasing structure for encasing the component for focusing the optical signals, so that an air gap between the encasing structure and the component for focusing the optical signals is defined as a result of the encasing. Also, the encasing structure may also be omitted in a basic implementation.

[0048] According to an embodiment, the component for focusing the optical signals along the first direction and the component for deflecting the optical signals between the first direction and the second direction are formed in a single piece. In such case, as discussed in the description, a (solid or internally hollow) intermediate propagation portion may be provided.

[0049] As will be understood, the making in a single piece does not necessarily imply that the component for deflecting (for example, the optical deflector), the component for focusing (for example, the lens) and the intermediate propagation portion are to be formed in a same material. According to an embodiment, at least part of the component for focusing the optical signals along the first direction is formed in the housing.

[0050] As above mentioned, one or more lenses can be made in a single piece with the housing (not necessarily with the same material), or they may be implemented separately and mounted at a later stage. According to an embodiment, at least part of the component for focusing the optical signals along the first direction is fixed to the optical window.

[0051] Although in the description explicit reference has been made to a lens directly mounted on (or integrated to) the optical window within the package, this should not be understood to be limiting. In fact, additionally or alternatively, the lens, or one or more further lenses, can be mounted on (or integrated to) the optical window outside the package.

[0052] According to an embodiment, the component for deflecting the optical signals and the optical window is formed in a single body. The body may further comprise a groove for aligning and attaching the component for focusing the optical signals thereto. According to an embodiment, the optoelectronic device further comprises a groove on the main surface of the chip for aligning and attaching the component for focusing the optical signals thereto. According to an embodiment, the component for focusing the optical signals is attached to the groove by way of a glue, such as an optical glue or a thixotropic glue. The body may be shaped so as to define an air gap between it and the main surface of the chip, the component for focusing the optical signals being immersed in the air gap. According to an embodiment, the component for deflecting the optical signals may comprise a metalized deflecting surface.

[0053] Another aspect is directed to a method for making an optoelectronic device. The method comprises the steps of forming a package having means or a component for sending/receiving optical signals along a first direction, housing a chip of semiconductor material in the package, the chip having a main surface and means exposed on the main surface for sending/receiving the optical signals along a second direction different from the first direction, and mounting, on the main surface, means or a component for deflecting the optical signals between the first direction and the second direction.

[0054] The approach according to an embodiment of the present disclosure lends itself to be implemented through an equivalent method (by using similar steps, removing some non-essential steps, or adding additional optional steps). Moreover, the steps may be performed in a different order, in parallel or overlapped (at least in part).

What is claimed is:

1. A method for making an optoelectronic device comprising:

mounting an electronic integrated chip onto an optical integrated circuit that is supported by a bottom wall of a housing, the optical integrated circuit comprising a main surface;

mounting an optical deflector on the main surface of the optical integrated circuit;

attaching sidewalls on opposite edge regions of the bottom wall of the housing, wherein a first sidewall of the sidewalls comprises an optical window to send/receive optical signals along a first direction, and wherein the main surface of the optical integrated circuit includes an optical grating to send/receive optical signals along a second direction different from the first direction;

positioning a focusing lens to focus the optical signals to/from the optical window;

enclosing the focusing lens with an enclosure to include an air gap between the enclosure and the focusing lens; and attaching a top wall to the sidewalls so as to form a housing that encloses the electronic integrated chip and the optical integrated circuit, wherein, after the attaching, along the second direction, an outer surface of the enclosure is spaced from an internal surface of the top wall facing the major surface of the optical integrated circuit by a first fixed distance.

2. The method according to claim **1**, wherein the second direction is substantially orthogonal to the main surface, and wherein the first direction is substantially orthogonal to the second direction.

3. The method according to claim **1**, wherein the optical window comprises a transparent material.

4. The method according to claim **1**, further comprising providing a recess in the first sidewall for the optical window.

5. The method according to claim **1**, further comprising coupling a connector housing to the optical window to provide propagation of the optical signals.

6. The method according to claim **1**, wherein positioning the focusing lens comprises mounting the focusing lens on the main surface.

7. The method according to claim **1**, further comprising providing a groove configured to align and position the focusing lens.

8. The method according to claim **1**, wherein the main surface comprises a groove configured to align and position the focusing lens.

9. The method according to claim **8**, wherein the focusing lens is coupled to the groove with an optical adhesive material.

10. The method according to claim **1**, wherein, after the attaching, along the first direction, the outer surface of the enclosure is spaced from an internal surface of the optical window by a second fixed distance.

11. The method according to claim **1**, wherein mounting the electronic integrated chip onto the optical integrated circuit comprises flip-chip mounting.

12. A method for making an optoelectronic device comprising:

mounting an electronic integrated chip onto an optical integrated circuit that is supported by a bottom wall of a housing, the optical integrated circuit comprising a main surface;

attaching sidewalls on opposite edge regions of the bottom wall of the housing, wherein a first sidewall of the sidewalls comprises an optical window to send/receive optical signals along a first direction, and wherein the main surface of the optical integrated circuit includes an optical grating to send/receive optical signals along a second direction different from the first direction;

mounting an optical deflector on the main surface of the optical integrated circuit;

positioning a focusing lens to focus the optical signals to/from the optical window;

providing a propagation portion configured to propagate the optical signals from the optical deflector and the focusing lens, wherein the optical deflector, the focusing lens, and the propagation portion are integrated in a single monolithic piece, wherein the single monolithic piece comprises a curved outer surface facing the optical window; and

attaching a top wall to the sidewalls so as to form a housing that encloses the electronic integrated chip and the optical integrated circuit.

13. The method of claim **12**, wherein the curved outer surface comprises a curved mirror facing the optical window.

14. The method of claim **12**, wherein the curved outer surface comprises a convex outer surface facing the optical window.

15. The method of claim **12**, further comprising attaching an additional lens aligned to the optical window outside the housing.

16. The method of claim **12**, further comprising attaching a connector housing to an outer surface of the housing.

17. A method for making an optoelectronic device comprising:

mounting an electronic integrated chip onto an optical integrated circuit that is supported by a bottom wall of a housing, the optical integrated circuit comprising a main surface;

attaching sidewalls on opposite edge regions of the bottom wall of the housing, wherein a first sidewall of the sidewalls comprises an optical window to send/receive optical signals along a first direction, and wherein the main surface of the optical integrated circuit includes an optical grating to send/receive optical signals along a second direction different from the first direction;

mounting an optical deflector on the main surface of the optical integrated circuit;

positioning a focusing lens to focus the optical signals to/from the optical window;

providing a propagation portion configured to propagate the optical signals from the optical deflector and the focusing lens, wherein the optical deflector, the focusing lens, and the propagation portion are integrated in a single monolithic piece;

attaching a top wall to the sidewalls so as to form a housing that encloses the electronic integrated chip and the optical integrated circuit; and

attaching an additional lens aligned to the optical window outside the housing.

18. The method of claim **17**, wherein the single monolithic piece comprises a curved mirror facing the optical window.

19. The method of claim **17**, wherein the single monolithic piece comprises a convex outer surface facing the optical window.

20. The method of claim **17**, further comprising attaching a connector housing to an outer surface of the housing.

21. The method of claim **17**, further comprising enclosing the focusing lens with an enclosure to include an air gap between the enclosure and the focusing lens.

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