(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 March 2014 (27.03.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/046963 A1

(51) International Patent Classification:
G02B 6/32 (2006.01) *G02B 6/36* (2006.01)

(21) International Application Number:
PCT/US2013/059470

(22) International Filing Date:
12 September 2013 (12.09.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/704,192 21 September 2012 (21.09.2012) US

(71) Applicant: **TYCO ELECTRONICS CORPORATION** [US/US]; 1050 Westlakes Drive, Berwyn, PA 19312 (US).

(72) Inventors: **KADAR-KALLEN, Michael, Aaron**; 6439 Mccormick Lane, Harrisburg, PA 17111 (US). **GURRERI, Michael**; 2156 Rillian Lane, York, PA 17404 (US).

(74) Agent: **BRUESS, Steven, C.**; Merchant & Gould P.C., P.O. Box 2903, Minneapolis, MN 55402-0903 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

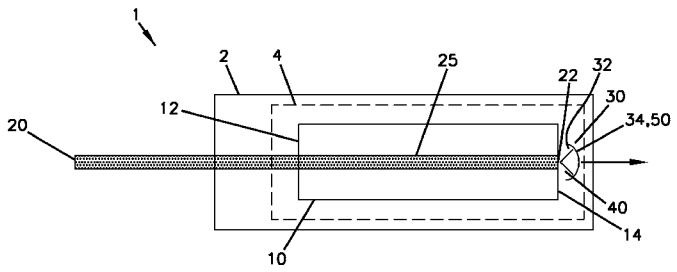
Published:

— *with international search report (Art. 21(3))*

WO 2014/046963 A1

(54) Title: EXPANDED BEAM OPTICAL CONNECTOR HAVING HYDROPHOBIC COATING ON LENS

FIG. 1



(57) Abstract: An expanded beam optical connector having a hydrophobic coating on the lens is disclosed. The disclosed expanded beam optical connector generally includes a ferrule adapted to receive one or more optical fibers; one or more optical fibers, wherein a terminating end of each optical fiber is presented by an endface of the ferrule; and a lens disposed opposite the terminating end of each optical fiber. The lens comprises first and second opposing faces wherein the first face of the lens is disposed opposite the terminating end of the optical fiber and the second face of the lens in association with the endface of the ferrule or a connector face of the ferrule forms a lens/air interface. At least a portion of the second face of the lens comprises a hydrophobic coating to resist deposition of water and/or dust on the lens or condensation of moisture on the lens. Non-lensed regions of the endface or connector face of the ferrule may optionally be coated with a hydrophilic coating to direct water away from the lens and/or to provide a surface for moisture to condense.

EXPANDED BEAM OPTICAL CONNECTOR HAVING HYDROPHOBIC COATING ON LENS

This application is being filed on 12 September 2013, as a PCT International Patent application and claims priority to U.S. Patent Application Serial No. 61/704,192 filed on 21 September 2012, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

Optical fiber connectors are an important aspect of optical fiber communication systems. Such connectors are used to join segments of fiber into longer lengths, to connect fiber to active devices, such as radiation sources, detectors and repeaters, and to connect fiber to passive devices, such as switches, multiplexers, and attenuators. Optical fibers are also increasingly being incorporated into microprocessor applications to accommodate higher data rates between chips and between boards. These systems require thousands of optical fiber interconnects.

The principal function of an optical fiber connector is to hold the fiber end such that the fiber's core is axially aligned with an optical pathway of the mating structure. In this way, light from the fiber is optically coupled to the optical pathway. Expanded beam optical connectors are commonly used in rugged or dirty environments, where "physical contact" between the fiber and the light path of a mating connector is problematic. In dirty environments, for example, dirt and/or dust particulates may become trapped between physical contact optical connectors during mating. Such particulates have a detrimental effect on the optical transmission of light across the connection as the particles are relatively large compared to the optical path (e.g., 10 microns diameter in single mode) and are therefore likely to block at least a portion of the optical transmission. Furthermore, in high-vibration environments, optical connectors having ferrules in physical contact tend to experience scratching at their interface. This scratching diminishes the finish of the fiber end face, thereby increasing reflective loss and scattering.

To avoid problems associated with debris and vibration, expanded beam connectors contain a lens which expands the optical beam and transmits the beam

over an air gap between the connectors. By expanding the beam, its relative size increases with respect to the dirt or dust particulates, making the beam less susceptible to interference. In addition, transmitting the beam over an air gap eliminates component-to-component wear observed in optical connectors having ferrules in physical contact, thereby increasing the connector's endurance to vibration.

Although the lens and air gap in expanded beam connectors address signal loss issues associated with particulates and component-to-component wear, water is another factor that can have a detrimental effect on signal transmission across an optical connection. Because expanded beam optical connectors are often used in environments where they are subject to water intrusion or condensation caused by temperature changes, water droplets can form on the surface of the lens and obstruct or refract the light beam thereby reducing the performance of the optical connection. To address issues associated with water intrusion or condensation, expanded beam connectors have evolved into a ruggedized multi-fiber connector comprising an outer housing which is configured to mate with the outer housing of a mating connector, typically through a screw connection.

The ruggedized housing generally contains one or more seals, such as an O-ring, to prevent infiltration of dust, debris, and moisture into the optical connection. However, the ruggedized housing increases the cost of the connector making these types of connectors unsuitable for use in applications, such as microprocessor applications or fiber-to-the home (FTTH), requiring thousands of interconnects. As expanded beam connectors are increasingly being incorporated into microprocessor and FTTH applications, a need exists for highly reliable, low cost optical connectors that are less sensitive to dust and water than conventional expanded beam optical connectors.

SUMMARY

Expanded beam connectors having improved resistance to dust and water are disclosed herein. The disclosed expanded beam connectors generally include a connector body adapted to releasably mate to another connector body to provide a separable optical interface between two optical components. The connector body

can be one of a variety of well-known connector types, including MPO, SC, FC, ST, LC, MT, and others. The connector body comprises a ferrule having one or more continuous axial bores or grooves running from a front face to an end face of the ferrule to accommodate optical fibers. An optical fiber is secured in each passage or groove such that the terminating end of the optical fiber is presented for optical coupling by the ferrule.

At the end face of the ferrule, a lens is disposed at the terminating end of each optical fiber such that a first face of the lens is disposed in optical alignment opposite the terminating end of each optical fiber. A second face of the lens forms a lens/air interface in which the second face of the lens is configured to transmit the optical beam through the air and into the light path of a mating structure. At least a portion of a surface of the second face of the lens is coated with an optically transparent hydrophobic or superhydrophobic coating to resist the deposition of water and/or dust on the surface of the lens at the lens/air interface.

Surfaces of the end face of the connector body, such as the endface or connector face of the ferrule, can optionally be coated with a hydrophilic coating to direct water away from the lens and/or to provide a surface for condensation of moisture so that the water does not affect the performance of the optical connection. The expanded beam connector can optionally include one or more drains in the connector body to facilitate removal of water from the end face of the connector body that may condense within or infiltrate the end face of the connector body when mated to another connector body.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an expanded beam optical connector in accordance with the principles of the present disclosure.

FIG. 2A is a schematic diagram of an expanded beam optical connector comprising a collimating lens.

FIG. 2B is a schematic diagram of an expanded beam optical connector comprising an imaging lens.

FIG. 3 is a perspective view of an expanded beam optical connector in accordance with the principles of the present disclosure.

FIG. 4 is a cross-sectional side view of an insert assembly in accordance with the principles of the present disclosure.

FIG. 5 is a cross-sectional side view of an alternative embodiment of the insert assembly of FIG. 4.

FIG. 6 is a cross-sectional side view of an alternative embodiment of the insert assembly of FIG. 4.

FIG. 7 is a cross-section side view of a ferrule assembly in accordance with the principles of the present disclosure.

FIG. 8 is a perspective view of a ferrule for an expanded beam optical connector in accordance with the principles of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

Expanded beam optical connectors having improved resistance to dust and water are disclosed herein. The expanded beam optical connectors of the disclosure generally include a connector body adapted to releasably mate to another connector body to provide a separable optical interface between two optical components. Conventionally, such connectors include a separate lens for each optical component. The following discussion refers to embodiments in which the optical components are optical fibers. However, it should be understood that this is merely exemplary and that the disclosure is applicable to the interfacing of any two optical components, including any combination of optical components such as optical fibers, wave guides, and optoelectronic devices, such as photodiodes, photodetectors, and optical and optoelectronic receivers, transmitters, and transceivers.

FIG. 1 is a schematic representation illustrating the basic components of an expanded beam optical connector 1 in accordance with the principles of the present disclosure. The connector 1 comprises a connector body 2, an optional insert body 4, one or more ferrules 10, which has one or more continuous axial passages or grooves 25 running from a front face 12 to an end face 14 of the ferrule 10 to accommodate optical fibers 20, and a fiber 20 secured in each passage or groove 25 such that the terminating end 22 of the fiber 20 is presented for optical coupling by the ferrule 10. Optical fiber 20 can be a single mode optical fiber or multimode optical fiber. Although FIG. 1 shows a ferrule 10 configured to receive single

optical fiber 20, the ferrule 10 can have many different shapes and configurations. For example, in FIGS. 2A and 2B the ferrule 10 is configured to receive multiple optical fibers 20. The connector body 2 can be one of a variety of well-known connector types, including MPO, SC, FC, ST, LC, MT, and others. In an embodiment, the connector body can be integral to the ferrule 10. For example, the ferrule can be molded integral of the connector body. In an embodiment, the connector 1 comprises a connector body 2 comprising one or more insert bodies 4 wherein each of the insert bodies 4 comprises one or more ferrules 10.

At the end face 14 of the ferrule 10, a lens 30 is disposed at the terminating end 22 of each fiber 20 such that a first face 32 of the lens 30 is disposed opposite the terminating end 22 of each fiber 20 and configured to receive an optical beam 40 emitted from the fiber 10. A second face 34 of the lens 30 forms a lens/air interface in which the second face 34 of the lens 30 is configured to transmit the optical beam 40 through the air and into the light path of a mating structure. In an embodiment, the optical beam is a light beam. When referring to the lens/air interface, this interface is the interface between the lens and the air gap formed by mating two expanded beam connectors. This air gap is defined by the lens/air interface in a first expanded beam connector and the lens/air interface in the mating second expanded beam connector when the first connector is mated to the second connector. At least a portion of a surface of the second face 34 of the lens 30 is coated with an optically transparent hydrophobic or superhydrophobic coating 50 to resist the deposition of water and/or dust on the surface of the lens at the lens/air interface.

A hydrophobic coating comprises a static water contact angle greater than 90°. Preferably the hydrophobic coating is a superhydrophobic coating. A superhydrophobic coating comprises a static water contact angle greater than 150°. The hydrophobic coating can be any such coating suitable for optical use. A hydrophobic coating having transparency greater than 80% is considered to be "optically transparent." Preferably, the transparency of the coating is 90% or greater. In embodiments, the transparency of the hydrophobic coating is 95% or greater. In embodiments, the hydrophobic coating is also anti-reflective. In such embodiments, the lens may or may not include an additional anti-reflective coating layer.

Suitable hydrophobic coatings include, but are not limited to, nanostructured coatings, silica based thin films, self-assembling organometallic monolayers, and silane, fluorocarbon, or methylacrylate based polymeric coatings. Such coatings are known and described, for example, in further detail in "Highly Durable, Superhyrdophobic and Oleophobic Coatings", http://neverwet.com/white-paper.php; Shang et al., 2005, "Optically Transparent Superhydrophobic Silica-Based Films", Thin Solid Films, 472:37-43; Roach et al., 2008, "Progress in Superhydrophobic Surface Development", Soft Matter, 4:224-240; Levkin et al., 2009, "Porous Polymer Coatings: A Versatile Approach to Superhydrophobic Surfaces", Adv. Funct. Mater., 19:1-6; Qu et al., "Superhydrophobicity, Learn from the Lotus Leaf", Biomimetics, Learning from Nature, Intech, March 2010; U.S. 6,245,387; U.S. 7,485,343; and U.S. 8,025,974. Commercially available hydrophobic coatings suitable for optical use include RAIN-X® (Ecolab, St. Paul, MN), NEVERWET™ (Ross Nanotechnologies, Leola, PA), SURFACE SEAL® (PPG Industries, Inc., Pittsburgh, PA), DIAMON FUSION® and CLEAR FUSION™ (Diamon Fusion Int., Irvine, CA), and LOTUS SHIELD™ (Lotus Leaf Coatings, Albuquerque, NM). Hydrophobic coatings suitable for optical use are also available from Hypho Technology (Singapore), Aculon (San Diego, CA), Sandia Corporation (Albuquerque, NM), and Oak Ridge National Laboratory (Oak Ridge, TN).

The hydrophobic coating can be applied to the lens surface by conventional methods including painting, wiping, brushing, dip coating, spin coating, spray coating, powder coating, sol-gel, chemical deposition, vapor phase deposition, plasma deposition, and the like. The hydrophobic coating can be applied to the lens using a process recommended by the coating manufacturer, or the application process can be selected by one of skill in the art based on the properties of the substrate and the selected coating. The hydrophobic coating generally forms a layer or film on the surface of the lens. In an embodiment, the thickness of the hydrophobic coating on the lens is less than 10 microns thick. In another embodiment, the thickness of the hydrophobic coating on the lens is less than 1 micron thick. In another embodiment, the thickness of the hydrophobic coating on the lens is less than 0.1 micron thick. In yet another embodiment, the thickness of the hydrophobic coating on the lens is less than 0.01 micron thick. In embodiments,

the surface of the lens comprises an anti-reflective (AR) coating and the hydrophobic coating is applied to the surface of the lens over the AR coating forming a laminate layer. In embodiments, the AR coating can be re-optimized for use with the hydrophobic coating. The thickness and index of refraction of the hydrophobic coating can be formulated such that the coating functions as an anti-reflective coating.

The lens 30 can have a variety of shapes and configurations. A suitable lens 30 for use in the disclosed expanded beam connector includes any optical component which is capable of expanding/focusing a light beam, including a ball lens, a gradient index (GRIN) lens (described in more detail for example in US 7,031,567), a singlet lens, a multi-piece lens, a holographic lens or etched lens (described in more detail for examples in US 6,012,852), a lens or lens assembly containing spherical or aspherical surfaces with uniform or graded index lenses, and others.

The lens 30 can be a collimating lens or an imaging lens. FIG. 2A is a schematic diagram illustrating the basic components of an expanded beam connector of the disclosure in which the lens 30 is a collimating lens 31. As shown in FIG. 2A, the collimating lens 31 is positioned in front of the end face 22 of each optical fiber 20. In order not to obfuscate the drawing, FIG. 2A illustrates the path of a light beam 40 for only one of the multiple optical fibers 20. A light beam 40 exits from each fiber 20 (only one beam, emanating from fiber 20a is shown) generally starts with a spot size approximately equal to the diameter of the fiber core and begins to expand as it diverges (see beam segment 40a) from the end face 22 of the fiber 20a. The collimating lens 31 functions, in one respect, to convert this expanding beam of light 40a into a large collimated beam (see beam segment 40b) for transmission through an air gap and into the light path of a mating structure, and, in another respect, to focus a relatively large collimated beam from the mating structuring into the fiber.

FIG. 2B is a schematic diagram illustrating the basic components of an expanded beam connector of the disclosure in which the lens 30 is an imaging lens 60. As shown in FIG. 2B, an imaging lens 60 expands the light beam 40 (as shown by beam segment 40a) emitted from optical fiber 20a and then images the beam 40

(as shown by beam segment 40c) to an image point p. Beyond image point p, the beam 40 diverges as shown by the beam segment 40d. Similar to the connector in FIG. 2A, at least a portion of a surface of the face 64 of the lens 60 can be coated with an optically transparent hydrophobic or superhydrophobic coating 50 to resist the deposition of water and/or dust on the surface of the lens at the lens/air interface. An expanded beam connector of the disclosure comprising an imaging lens can be coupled to an expanded beam connector comprising a collimating lens or imaging lens. Another advantage of an expanded beam connector of the disclosure comprising an imaging lens is that such a connector can be coupled to an optical connector with no optics in front of the fiber end faces, such as a physical contact optical connector. One of skill in the art will appreciate that the distance between the terminating end face of the optical fiber and the lens shown in FIGS. 1 and 2A and 2B can be adjusted dependent on the focal distance of the lens.

The expanded beam connector of the disclosure can be provided in many different configurations. The schematic representation shown in FIGS. 1 and 2A-B illustrate the basic components of an expanded beam optical connector in accordance with the principles of the present disclosure. Additional embodiments of the expanded beam connector of the disclosure in accordance with the principles of the present disclosure are shown in FIGS. 3-7. PRO BEAM® type connectors (Tyco Electronics Corp. Harrisburg, PA) comprise a connector body and an insert assembly comprising an insert body and one or more ferrule assemblies. The ferrule assembly is contained within the insert body and adapted to receive an optical fiber, and a lens at a mated end of the insert body optically connected to the interface. The ferrule assembly comprises a ferrule, which has one or more continuous axial passages to accommodate optical fibers, and an optical fiber secured in each passage such that the terminating end of the optical fiber is presented for optical coupling by the ferrule. The connector body is designed to engage a "mating structure" having an optical path to which the fiber optically couples during mating. The mating structure may be another connector or an active or passive device. Examples of these types of connectors are disclosed, for example, in U.S. 2008/0050073 and U.S. 2010/0104244, which are incorporated by reference herein. When two expanded

beam connectors are mated, there is an air gap between the lenses of each pair of optically coupled inserts.

Referring now to FIG. 3, a 4-channel PRO BEAM® style connector (Tyco Electronics Corp. Harrisburg, PA) is shown for illustrative purposes. Connector 100 comprises an insert assembly 105 and a connector body 115. The insert assembly 105 comprises an insert body 120 comprising one or more continuous axial passage 122 for receiving an optical fiber and ferrule assembly, a lens 130, and a guide pin 140 adapted to mate to a receiving bore hole 146 in a mating connector to align the optical paths of the lenses across the optical connection. The insert body 120 can be configured to receive one or more ferrule assemblies. FIG. 3 shows an insert body 120 configured to receive four ferrule assemblies in which each of the continuous axial passages 122 is configured to receive a ferrule assembly. The insert body 120 can be integral to the connector body 115. Lens 130 comprises a surface 131 which forms, in association with the non-lensed region 125 of the mating end of the insert body 120, a lens/air interface. The surface 131 is coated with an optically transparent hydrophobic or superhydrophobic coating 132 to resist the deposition of water and/or dust on the surface of the lens. The non-lensed region 125 of the insert body 120 can optionally be coated with a hydrophilic coating to direct water away from the lens 130 and/or to provide a surface for condensation of moisture within the connector so that the water does not affect the optical performance of the connector.

A hydrophilic coating comprises a static water contact angle less than 90°. In another embodiment, the hydrophilic coating comprises a static water contact angle less than 40°. In yet another embodiment, the hydrophilic coating comprises a static water contact angle less than 10°. Suitable hydrophilic coatings are known and include chromate, silicate, titanium dioxide, silicon dioxide, and fluorocarbon containing hydrophobic coatings and thin films. The hydrophilic coating can be applied to the non-lensed region 125 of the insert body 120 using conventional methods including painting, wiping, brushing, dip coating, spin coating, spray coating, powder coating, sol-gel, chemical deposition, vapor phase deposition, plasma deposition, and the like. The hydrophilic coating can be applied using a process recommended by the coating manufacturer, or the application process can be

selected by one of skill in the art based on the properties of the substrate and the selected coating. The hydrophilic coating generally forms a layer or film on the non-lensed region 125 of the insert body 120. In an embodiment, the thickness of the hydrophilic coating is less than 50 microns thick. In another embodiment, the thickness of the hydrophilic coating is less than 10 microns thick. In another embodiment, the thickness of the hydrophilic coating is less than 1 micron thick. In yet another embodiment, the thickness of the hydrophilic coating is less than 0.5 microns thick.

The connector body 115 or insert body 120 can optionally include one of more drains 145 to facilitate removal of water that may condense on the lens 130 and/or the non-lensed region 125 of the insert body 120 or infiltrate the non-lensed region 125 of the insert body 120 when mated to another connector body. The hydrophilic coating can be applied in a pattern on the non-lensed region 125 of the insert body 120 to direct water away from the lens 130 and toward the one or more drains 145. The components of such a connector are described in greater detail below.

FIG. 4 shows a cross-sectional view of an insert assembly 200. The insert assembly 200 comprises an insert body 215, one or more ferrule assemblies 220 contained within the insert body 215 and adapted to receive an optical fiber 230 and a lens 240 at a mating end of the insert body 215. Ferrule assembly 220 functions to hold the fiber 230 in precise position relative to the lens 240 both axially and radially. Ferrule assembly 220 comprises a ferrule 222 with a frontface 223 and an endface 224 and a continuous axial bore 225 running axially from the frontface 223 to the endface 224 of the ferrule 220 to accommodate the optical fiber 230. Fiber 230 is received and secured in the continuous axial bore 225 such that the terminating end 232 of fiber 230 is presented at endface 224 of the ferrule 220.

Insert body 215 is capable of receiving one or more ferrule assemblies 220 and holds the ferrule assembly 220 and lens 240 in a predetermined axial and radial relationship. The insert body 215 shown in FIG. 4 is designed to hold a single ferrule assembly; however, the insert body can be configured to hold multiple ferrule assemblies. FIG. 3, for example, shows an insert body 120 capable of receiving up to four ferrule assemblies. The insert body 215 comprises an elongated body having

a front and back orientation and defining one or more cavities 218 running from front to back of the insert body 215. Each cavity 218 is adapted to receive the ferrule assembly 220 from the back end of the insert body 215. In an embodiment, the insert assembly 200 is suitable for insertion into a larger multi-connector outer housing, such as the PRO BEAM® type connector.

The insert body 215 receives the ferrule 222 with very narrow tolerance such that the outer surface 226 of the ferrule 222 contacts the inner surface 216 of the insert body 215 to register the fiber(s) 230 contained within the ferrule 222 in a precise radial position with respect to the insert body 215. The insert body 215 includes a stop 250 comprising a register surface 227 essentially orthogonal to the fiber 230 to contact the ferrule assembly 220 to register the endface 224 of the ferrule 222 in a precise axial relationship with respect to the lens 240.

Affixing the ferrule assembly 220 to the insert body 215 can be performed using any known technique, including, for example, through an interference fit, adhesive bond, and welding. Preferably, the ferrule assembly is affixed to the insert body through an interference fit. To this end, the insert body 215 may be heated or the ferrule assembly 220 cooled to allow the insert body to receive the ferrule assembly. As the temperature difference between the two decreases, the ferrule assembly 220 would be secured in the insert body 215 by an interference fit. This technique is preferred as it allows the assembly to be reheated and the ferrule assembly removed and replaced if necessary.

The first stop 250 prevents the forward motion of the ferrule assembly 220 relative to the insert and a second stop 252 to prevent rearward movement of the lens 250. The distance between the first stop 250 and second stop 252 forms an air gap 255 between the lens 240 and endface 224 of the ferrule 222. In embodiments, the gap 255 between the lens 240 and terminating end 232 of the optical fiber 230 or endface 224 of the ferrule 222 comprises an index matching medium, such as a gel or adhesive, between the lens and fiber or ferrule endface.

In an alternative embodiment, shown in FIG. 5, the insert body 215 contains a stop 253 at a precise axial position to prevent the forward motion of the ferrule assembly 220 relative to the insert body 215 and the lens 240 is seated at the ferrule endface 224 such that the endface 232 of optical fiber 230 is in contact with the lens

240. When the insert assembly shown in FIG. 5 is assembled, the lens 240 is first seated on the stop 253 and epoxied in place. The ferrule assembly 220 is then urged forward against the lens 240 during the assembly process. In situations where there is not interference between the ferrule assembly 220 and continuous axial bore 225, a spring (as shown in FIG 4.) can be included to urge the ferrule assembly 220 against the lens 240.

In yet another alternative embodiment, shown in FIG. 6, the insert body 215 comprises a first stop 250 at a precise axial position to prevent the forward motion of the ferrule assembly 220 relative to the insert body 215 and a second stop 252 to prevent rearward movement of the lens 240 in which the fiber 230 protrudes from the endface 224 of ferrule 222 and the terminating end 232 of the fiber 230 is in contact with the lens 240.

The configurations shown in FIGS. 4 and 6 bias the ferrule assembly 220 forward to ensure constant contact with the first stop 250, thereby maintaining a constant and precise spatial relationship between the lens 240 and the endface 224 of the ferrule 222. The configuration shown in FIG. 5 biases the ferrule assembly 220 against the lens 240. To bias the ferrule assembly forward, the insert assembly 200 as shown in FIG. 4 comprises a spring 260 and a backplate 265 to provide a surface against which the spring 260 can push to urge the ferrule assembly 220 forward. Ferrule assembly 220 comprises a ferrule base 228 to provide a surface 228a against which the spring 260 urges the ferrule assembly 220 forward. In an embodiment, the ferrule base 228 is an arcuate shoulder encircling the rear portion of ferrule 220.

Although FIG. 4 shows a preferred configuration for registering the terminating end of fiber 230 in the insert body 215, other configurations are possible and within the scope of the disclosure. For example, rather than using a register surface 227 of the ferrule 222 to contact stop 250, it may be beneficial to provide the register surface on the leading surface 228b of the ferrule base 228 such that it contacts shoulder 217 of the insert body 215. Such a configuration eliminates molding or machining of another feature in the housing cavity 218. Since the shoulder 217 transitions the cavity 218 from a relatively-narrow, closely-toleranced portion with inner wall 216 for receiving the ferrule 222 to a relatively-wide portion

for receiving the ferrule base 228 and spring 260, the shoulder 217 could also be used to function as the first stop 250.

Rather than urging the ferrule assembly 220 forward so that it abuts the first stop 250, it may be preferable to employ an interference fit between the ferrule assembly 220 and the insert body 215. That is, rather than having the ferrule assembly 220 moveable within the insert body 215, it may be preferable to affix the ferrule assembly 220 to the insert body 215. Advantages to such a configuration include, for example, improved dimensional stability over a large temperature range (i.e., the axial and radial position of the fiber endface 232 and the lens 240 remains essentially constant), and reduced number of components (e.g., the spring 260 and ferrule base 228 and backplate 265 may be eliminated).

The insert assembly 200 can contain a glass element 270 and air gap 255 as shown in FIG.4 that can be adjusted to minimize signal loss of the connector. A glass element 270 having first and second surfaces 272, 274, is affixed to endface 224 of the ferrule 222 such that the first surface 272 of the glass element 270 is in physical contact with fiber end 232. The second surface 274 of the glass element 270 defines an air gap 255 between the second surface 274 and the lens 240. Preferably the second surface 274 of the glass element 270 comprises an anti-reflective (AR) coating 276.

Different wavelength signals result in different focal points. To couple the light effectively between the fiber 230 and the lens 240, the focal point should be coincident with the endface 232 of the fiber 230. For optimum coupling efficiency, the air gap 255 can be adjustable for different wavelength signals by adjusting the thickness of the glass element 270 or the position of first stop 250 or second stop 252. For example, if the ideal air gap (no glass) is H0, then this air gap can be provided by a physical gap of H, which is composed of a glass element 270 of thickness G and an air gap 255 of thickness A, where $H0=A+G/n$, where n is the index of refraction of the glass element 270. If the physical gap is a fixed distance, then the glass thickness is $G=(H-H0)/(1-1/n)$. A preferred way of determining the size of the air gap 255 is to use commercial-available optical modeling software such as ZEMAX™ (Radiant Zemax LLC, Redmond, WA). In an embodiment, the distance between the endface 224 of ferrule 222 and lens 230 is fixed and the

adjustment in air gap 255 is achieved by increasing or decreasing the thickness of the glass element 270 to achieve the desired air gap.

In an alternative embodiment, the connector body comprises a system of different ferrule assemblies 222 in which the air gap 255 is adjusted by varying the distance between the endface 224 of the ferrule 222 and the lens 240. Referring now to FIG. 7, ferrule assembly 300 comprises an endface 305 projecting from a register surface 310 at distance d_1. By varying the axial position of the endface 305 with respect to the register surface 310, the air gap between the endface 305 and the lens can be adjusted to accommodate different signal wavelengths. Unlike the ferrule assembly 220 shown in FIG. 4, the register surface 310 is not contiguous with the endface 305, but rather is a shoulder with the endface stepped therefrom. Alternatively, the register surface may be located on the leading surface 315 of the ferrule assembly base 320. Ferrule assemblies having end faces which project at varying lengths from the register surface can be prepared using jigs as described in US 2008/0050073.

Referring now to FIG. 4, lens 240 is an optical component which is capable of expanding/focusing a light beam, including a ball lens, a GRIN lens, a singlet lens, a multi-piece lens, a holographic lens, a lens or lens assembly containing spherical or aspherical surfaces with uniform or graded index lenses, and others. The lens 240 can be a collimating lens or an imaging lens. In a preferred embodiment, the lens 240 is a ball lens.

As shown in FIGS. 4-6, a first face 244 of the lens 240 is disposed opposite the terminating end 232 of the fiber 230 and configured to receive an optical beam emitted from the fiber. A second face 242 of the lens 240 forms a lens/air interface in which the second face 242 of the lens 240 is configured to transmit a beam from the endface 232 of fiber 230 through air and into the light path of a mating structure. At least the surface of the second face 242 of the lens 240 that the beam passes is coated with an anti-reflective (AR) material 246 to minimize light reflection/Fresnel loss at the lens/air interface. Such AR coatings are well known in optics. For an air-to-glass interface, an ideal coating will have an index of sqrt(n) where n is the index of refraction of the lens material relative to air. The coating thickness is $\lambda/(4n)$ where λ is the wavelength in air. In embodiments, the first 242 and/or second 244 faces of

the 240 lens may be uniformly coated with the AR material for ease of use and manufacturing.

The surface of the second face 242 of the lens 240 at the lens/air interface is coated with an optically transparent hydrophobic or superhydrophobic coating 248 to resist the deposition of water and/or dust on the lens 240. If the second face 242 of the lens 240 comprises an AR coating 246, the optically transparent hydrophobic or superhydrophobic coating 248 is applied over the AR coating forming a laminate coating layer. In embodiments, the thickness of the optically transparent hydrophobic or superhydrophobic coating 248 can be formulated such that the coating 248 has anti-reflective properties, wherein the thickness equals 1/(4*sqrt(n)) where n is the index of refraction of the lens 240 at the air-to-glass interface.

FIG. 8 shows another embodiment of an expanded beam connector of the disclosure. Referring to FIG. 8, a TELLMI™ style lensed ferrule (Tyco Electronics Corp. Harrisburg, PA) is shown. Connector 400 comprises a ferrule 410, a plurality of lenses 430, and bore holes 420 adapted to receive a guide pin of a mating connector to align the optical paths of the lenses across the optical connection. In an embodiment, ferrule 410 is a single molded plastic ferrule which can be installed in a variety of conventional connector bodies. Ferrule 410 contains a plurality of v-grooves 412, each v-groove adapted to receive an optical fiber such that the terminating end of each optical fiber is presented for optical coupling at the endface 415 of the ferrule 410. At the connector face 418 of the ferrule 410, a lens 430 is disposed at the terminating end of each fiber such that a first face 432 of the lens 430 is disposed in optical alignment opposite the terminating end of each fiber and is configured to receive an optical beam emitted from the fiber. A second face 434 of the lens 430 forms, in association with the non-lensed region 416 of ferrule 410, a lens/air interface in which the second face 434 of the lens 430 is configured to transmit the beam though air and into the light path of a mating structure.

Lens 430 is an optical component which is capable of expanding/focusing a light beam, including a ball lens, a GRIN lens, a singlet lens, a multi-piece lens, a holographic lens, a lens or lens assembly containing spherical or aspherical surfaces with uniform or graded index lenses, and others. The lens 430 can be a collimating lens or an imaging lens. In a preferred embodiment, the lens 430 is a singlet lens.

The distance between the terminating end of the optical fiber and the lens can be adjusted dependent on the focal distance of the lens.

At least a portion of the surface of the second face 434 of the lens 430 at the lens/air interface is coated with an optically transparent hydrophobic or superhydrophobic coating 435 to resist the deposition of water and/or dust on the surface of the lens. If the second face 434 of the lens 430 comprises an AR coating, the optically transparent hydrophobic or superhydrophobic coating 435 is applied over the AR coating forming a laminate layer on the lens 430.

The non-lensed region 416 of the ferrule 420 can optionally be coated with a hydrophilic coating to direct water away from the lens 430 and/or to provide a surface for condensation of moisture within the connector so that the water does not affect the optical performance of the connector. The non-lensed region 416 of the ferrule 420 can optionally include one of more drains 445 to facilitate removal of water that may condense on the lens 430 or non-lensed region 416 of the ferrule 420 or infiltrate the non-lensed region 416 of the ferrule 420 when mated to another connector body.

The above specification, examples, and data provide a complete description of the composition of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

What is claimed is:

1. An expanded beam optical connector, comprising:

a ferrule adapted to receive one or more optical fibers;

one or more optical fibers, wherein a terminating end of each optical fiber is presented by the ferrule; and

a lens disposed opposite the terminating end of each optical fiber, the lens comprising first and second opposing faces wherein the first face of the lens is disposed opposite the terminating end of the optical fiber and the second face of the lens forms a lens/air interface wherein at least a portion of the second face of the lens comprises a hydrophobic coating to resist deposition of water and/or dust on the lens or condensation of moisture on the lens.

2. The connector of claim 1, further comprising a connector body or insert body containing the ferrule, the connector body adapted to mate with another connector body.

3. The connector of claim 1, wherein the second face of the lens in association with the endface of the ferrule forms the lens-air interface.

4. The connector of claim 1, wherein the hydrophobic coating is a superhydrophobic coating.

5. The connector of claim 1, wherein at least the portion of the second surface of the lens exposed to air at the lens/air interface comprises the hydrophobic coating.

6. The connector of claim 1, wherein portions of the endface of the ferrule or a connector face of the ferrule comprises a hydrophilic coating to direct water away from the lens or to provide a surface for moisture to condense.

7. The connector of claim 6, wherein a non-lensed region at the endface or connector face of the ferrule comprises the hydrophilic coating.

8. The connector of claim 2, wherein the connector body or insert body comprises a drain to direct water away from the endface or connector face of the ferrule.

9. The connector of claim 1, wherein the lens comprises an anti-reflective (AR) coating and the hydrophobic coating is applied over the AR coating forming a laminate coating layer on the lens.

10. The connector of claim 1, wherein the hydrophobic coating is anti-reflective.

11. The connector of claim 2, wherein the connector body is a MPO, SC, FC, ST, LC, or MT connector body.

12. The connector of claim 1, wherein the lens is a ball lens or a singlet lens.

13. The connector of claim 1, wherein the lens is a collimating lens.

14. The connector of claim 1, wherein the lens is an imaging lens.

15. The connector of claim 1, wherein the endface of the ferrule or terminating end of the optical fiber is positioned at a focal distance of the lens.

16. The connector of claim 1, wherein the ferrule holds the terminating end of the optical fiber and the lens in optical alignment.

17. The connector of claim 1, wherein the ferrule comprises one or more continuous axial bores or grooves for holding the optical fiber.

18. The connector of claim 17, wherein an optical fiber is secured in each bore or groove of the ferrule such that the terminating end of the optical fiber is presented by the ferrule for optical coupling.

19. The connector of claim 2, wherein the insert body comprises one or more continuous axial passages for holding a ferrule assembly, the ferrule assembly comprising the ferrule and the one or more optical fibers.

20. The connector of claim 2, wherein the insert body is integral to the connector body.

21. The connector of claim 19, wherein a ferrule assembly is secured in each of the continuous axial passages of the insert body such that the terminating end of the optical fiber is presented by the ferrule assembly for optical coupling.

22. The connector of claim 21, wherein the insert body holds the terminating end of the optical fiber and the lens in optical alignment.

23. The connector of claim 21, wherein the second face of the lens in association with the mating end of the insert body forms the lens/air interface.

24. The connector of claim 1, wherein the connector comprises a gap between the first face of the lens and the terminating end of the optical fiber.

25. The connector of claim 24, wherein the gap comprises an index matching medium.

26. The connector of claim 1, wherein the first face of the lens comprises a hydrophobic coating.

27. The connector of claim 1, wherein the first face of the lens is configured to receive an optical beam emitted from the terminating end of the optical fiber and the second face of the lens is configured to transmit the optical beam.

28. The connector of claim 1, wherein the hydrophobic coating comprises a thickness and index of refraction such that the hydrophobic coating is anti-reflective.

29. The connector claim 13, wherein the collimating lens is a gradient index (GRIN) lens or etched lens.

30. The connector of claim 1, wherein the terminating end of each optical fiber is presented by an endface of the ferrule.

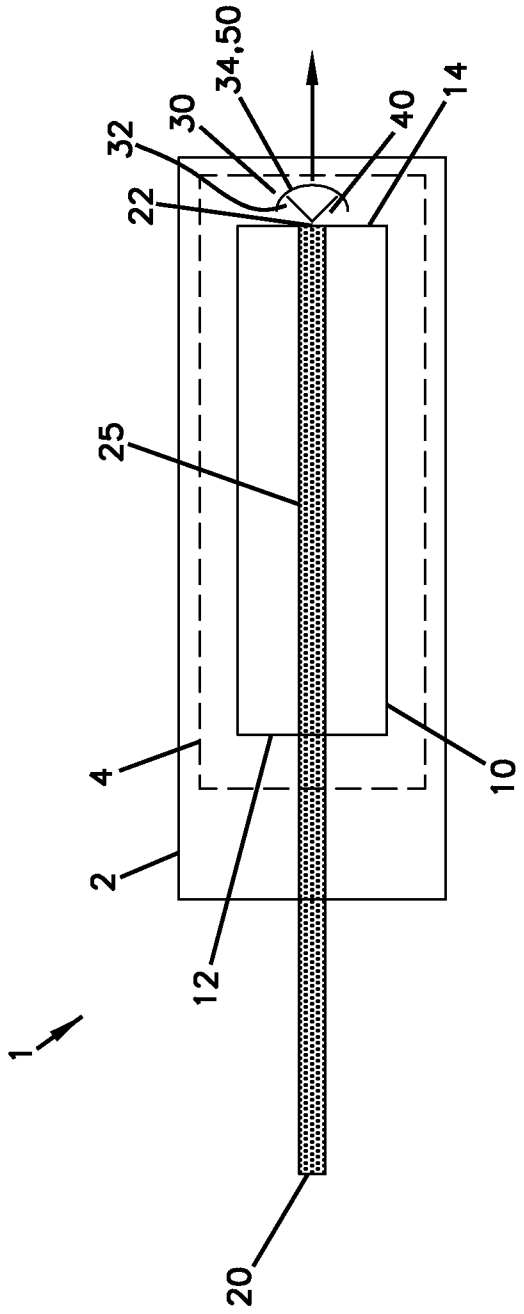


FIG. 1

FIG. 2A

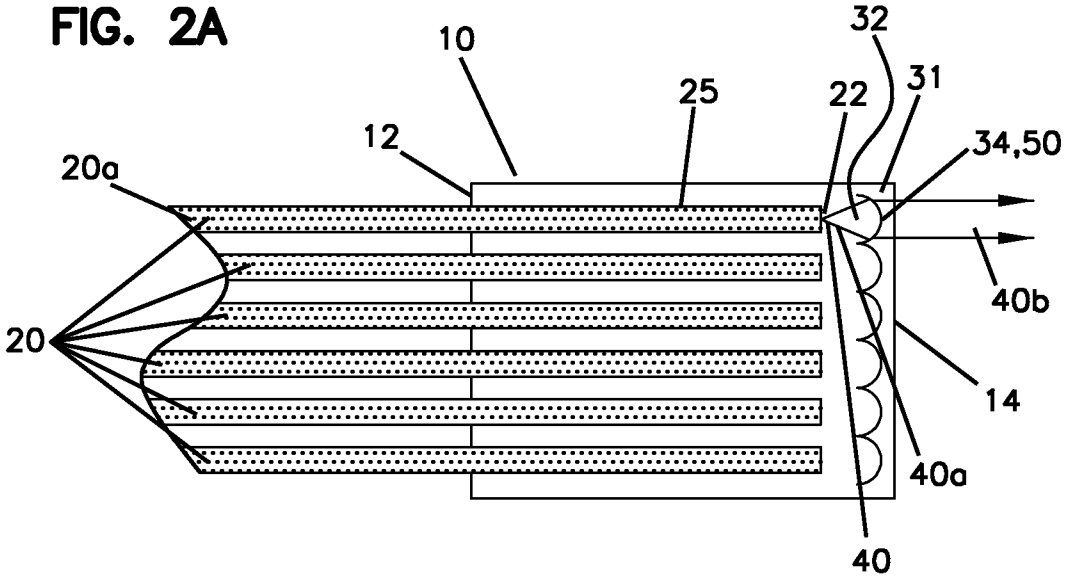

10
32
31
25
22
12
34,50
20a
20
40b
14
40a
40

FIG. 2B

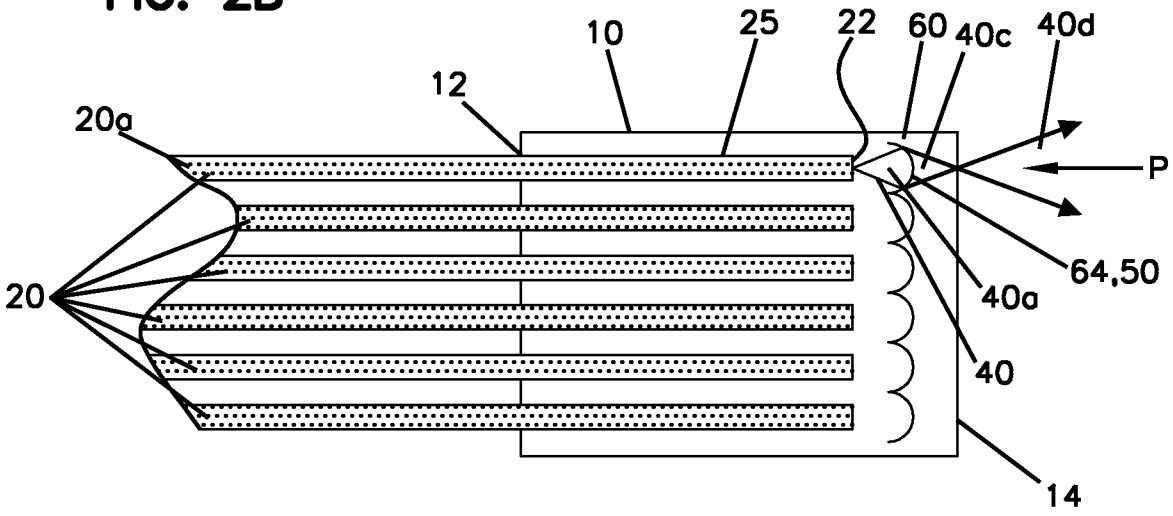

10
25
22
60
40c
40d
12
20a
P
64,50
20
40a
40
14

FIG. 3

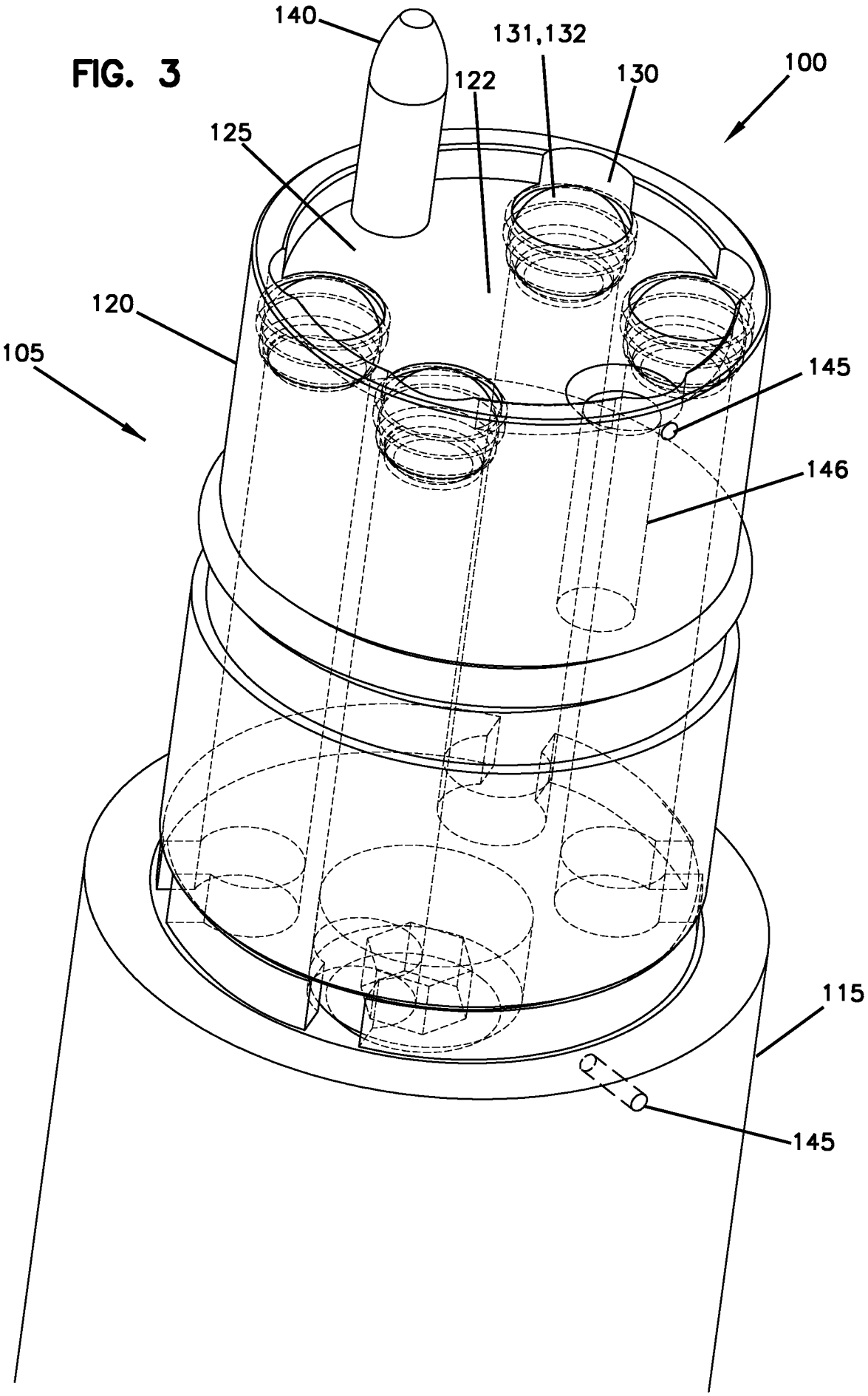


FIG. 4

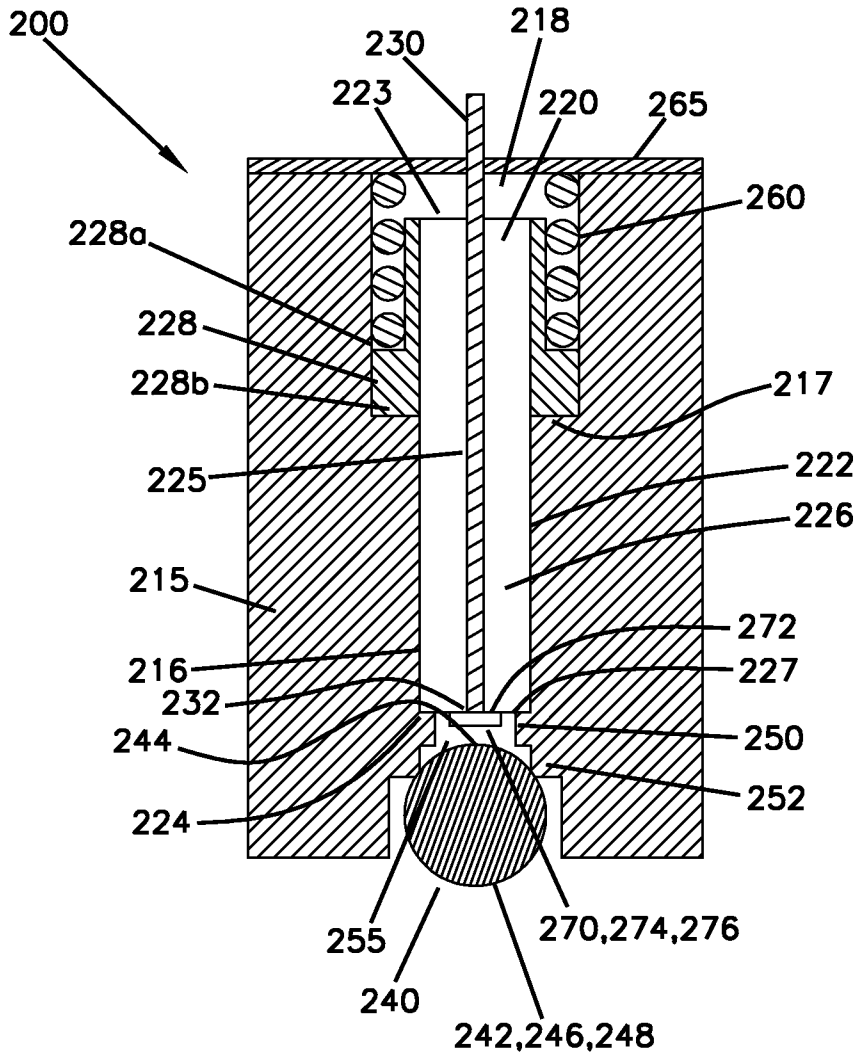
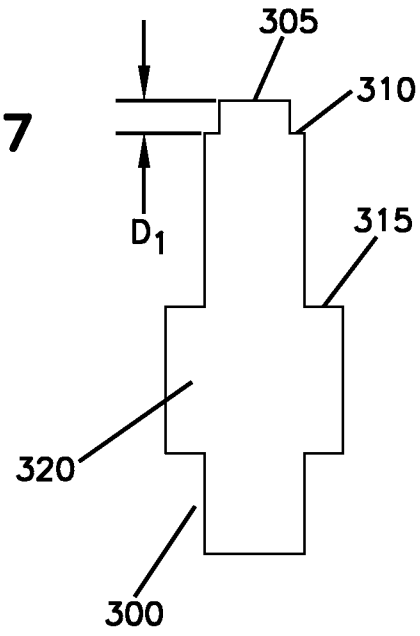

200
230
218
223
220
265
260
228a
228
228b
217
225
222
226
215
272
216
227
232
250
244
252
224
255
270,274,276
240
242,246,248

FIG. 7


305
310
D_1
315
320
300

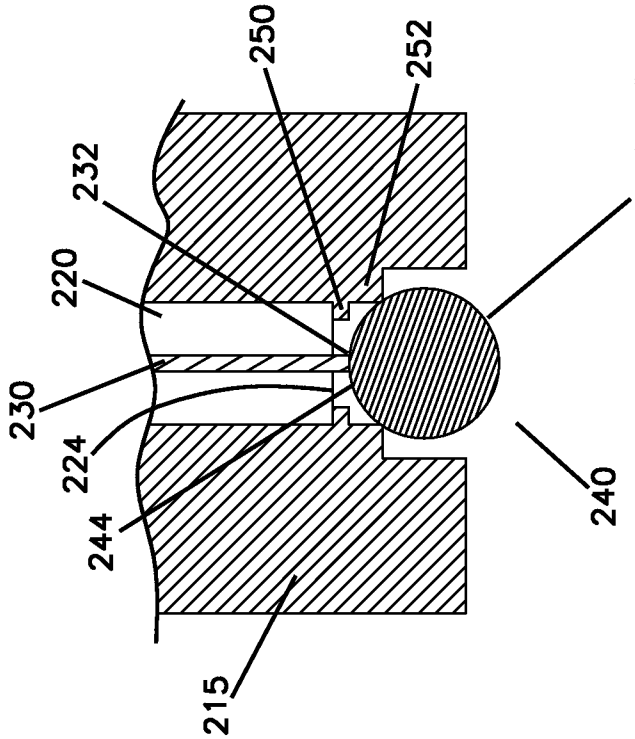

250
252
232
242,246,248
220
230
224
244
240
215

FIG. 6

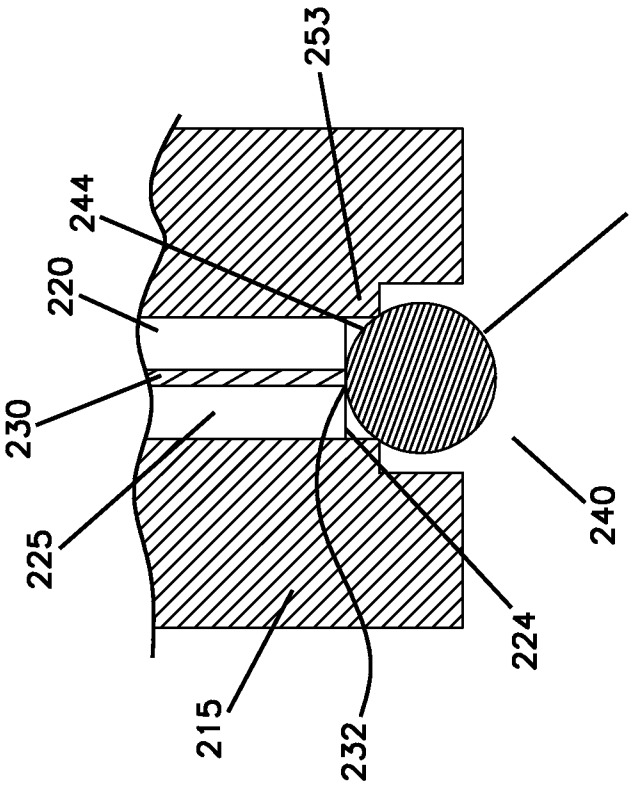

253
244
242,246,248
220
230
225
240
224
215
232

FIG. 5

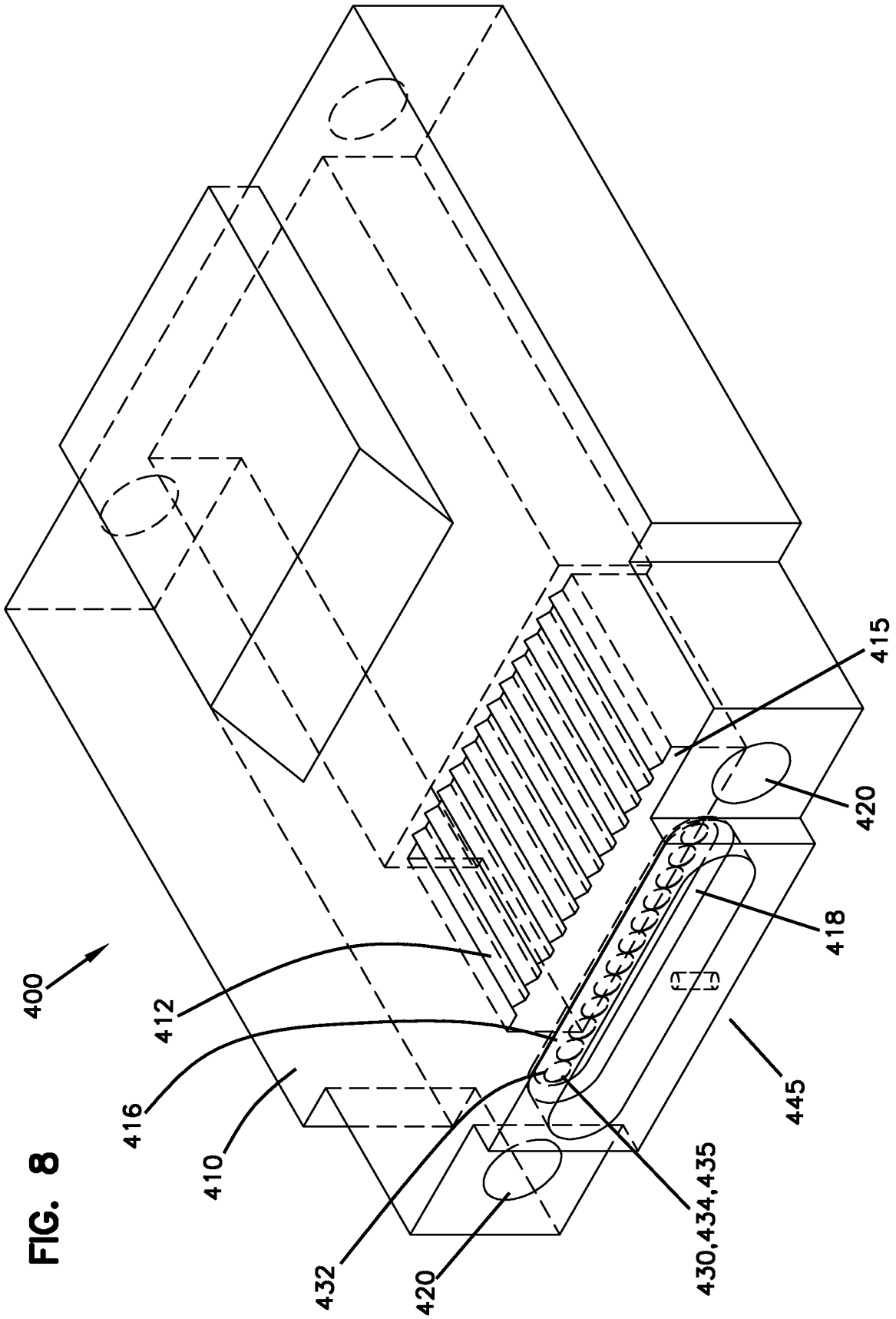


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/059470

A. CLASSIFICATION OF SUBJECT MATTER

G02B 6/32(2006.01)i, G02B 6/36(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)
G02B 6/32; H01R 11/00; G02B 6/38; G01N 21/01; H04B 10/00; B32B 37/12; G02B 6/00; B32B 7/12; G02B 6/36

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: hydrophobic coating, lens, optical fiber, ferrule

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012-078701 A1 (CORNING CABLE SYSTEMS LLC) 14 June 2012 See paragraphs [0050]-[0051], [0055], claims 1, 6, 11 and figures 4C-5, 14A-14D.	1-30
A	US 2010-0302530 A1 (LIU et al.) 02 December 2010 See claims 1-12 and figures 7, 12-14.	1-30
A	US 2010-0080563 A1 (DIFONZO et al.) 01 April 2010 See paragraphs [0047], [0060], [0063] and figure 7.	1-30
A	US 2011-0223418 A1 (HABASSI) 15 September 2011 See paragraphs [0070]-[0076] and claims 12-18.	1-30
A	US 2008-0310795 A1 (PARKMAN et al.) 18 December 2008 See claims 10-20 and figures 1-5.	1-30

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 December 2013 (13.12.2013)	**16 December 2013 (16.12.2013)**

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
KANG, Sung Chul
Telephone No. +82-42-481-8405

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2013/059470

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012-078701 A1	14/06/2012	TW 201232074 A	01/08/2012
		US 2012-0155803 A1	21/06/2012
US 2010-0302530 A1	02/12/2010	US 2010-0303434 A1	02/12/2010
		US 8330944 B2	11/12/2012
		WO 2010-138694 A1	02/12/2010
		WO 2010-138700 A1	02/12/2010
US 2010-0080563 A1	01/04/2010	AU 2009-298735 A1	08/04/2010
		CN 102227661 A	26/10/2011
		EP 2335107 A1	22/06/2011
		JP 2012-504312 A	16/02/2012
		KR 10-1278356 B1	25/06/2013
		KR 10-2011-0065543 A	15/06/2011
		KR 10-2012-0130794 A	03/12/2012
		MX 2011003422 A	21/04/2011
		US 2011-0038582 A1	17/02/2011
		US 2013-170794 A1	04/07/2013
		US 7841776 B2	30/11/2010
		WO 2010-039656 A1	08/04/2010
US 2011-0223418 A1	15/09/2011	AU 2009-315442 A1	20/05/2010
		CA 2743443 A1	20/05/2010
		CN 102216407 A	12/10/2011
		EP 2346957 A2	27/07/2011
		FR 2938255 A1	14/05/2010
		FR 2938255 B1	01/04/2011
		JP 2012-508906 A	12/04/2012
		KR 10-2011-0093798 A	18/08/2011
		MX 2011003714 A	10/05/2011
		US 8562781 B2	22/10/2013
		WO 2010-055261 A2	20/05/2010
		WO 2010-055261 A3	07/10/2010
US 2008-0310795 A1	18/12/2008	US 7945139 B2	17/05/2011