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(54) **LIGHT DETECTING AND RANGING SENSING APPARATUS AND METHODS**

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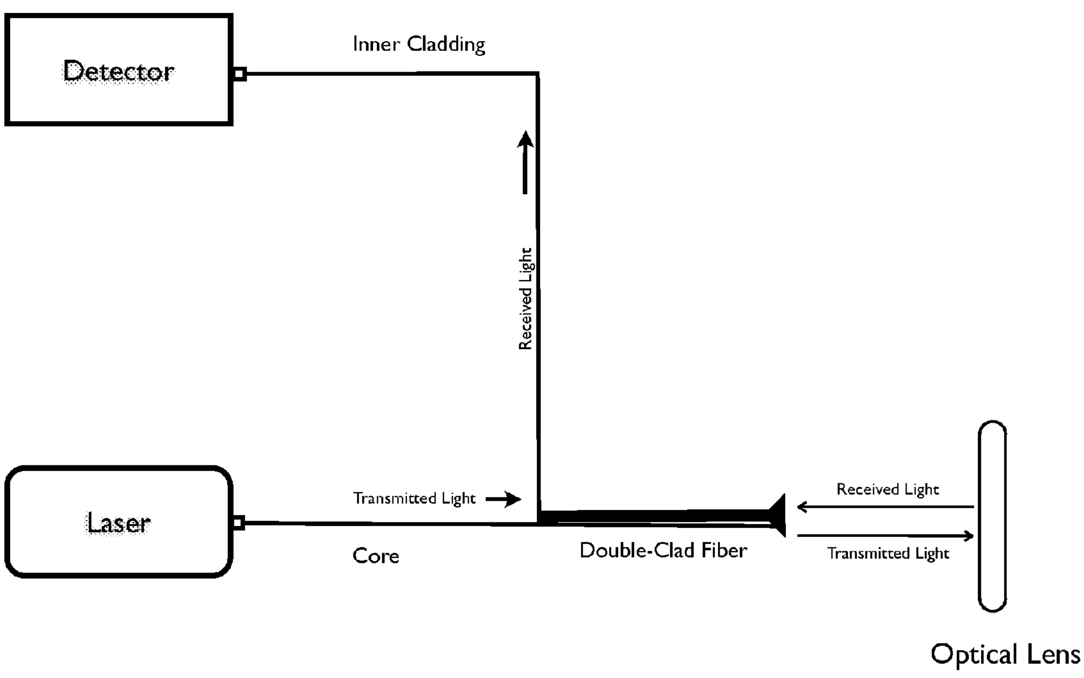
(57) **ABSTRACT**

According to one aspect, an optical apparatus for a light detecting and ranging (LiDAR) sensing system is provided. The optical apparatus can comprise an optical directing device; and a multi clad optical fiber, wherein said multi clad optical fiber comprises a core, at least one inner cladding, and an outer cladding. The core is arranged to receive optical rays transmitted from a light source of said sensing system and route said transmitted optical rays on an optical path leading to optical directing device. The optical directing device is configured both to direct said routed transmitted optical rays on an optical path leading to a target to be sensed and direct optical rays reflected from said target on an optical path leading to said inner cladding of said multi clad optical fiber. The inner cladding is configured to receive said reflected optical rays and route said reflected optical rays on an optical path leading to a detector for receiving reflected optical rays of said sensing system.



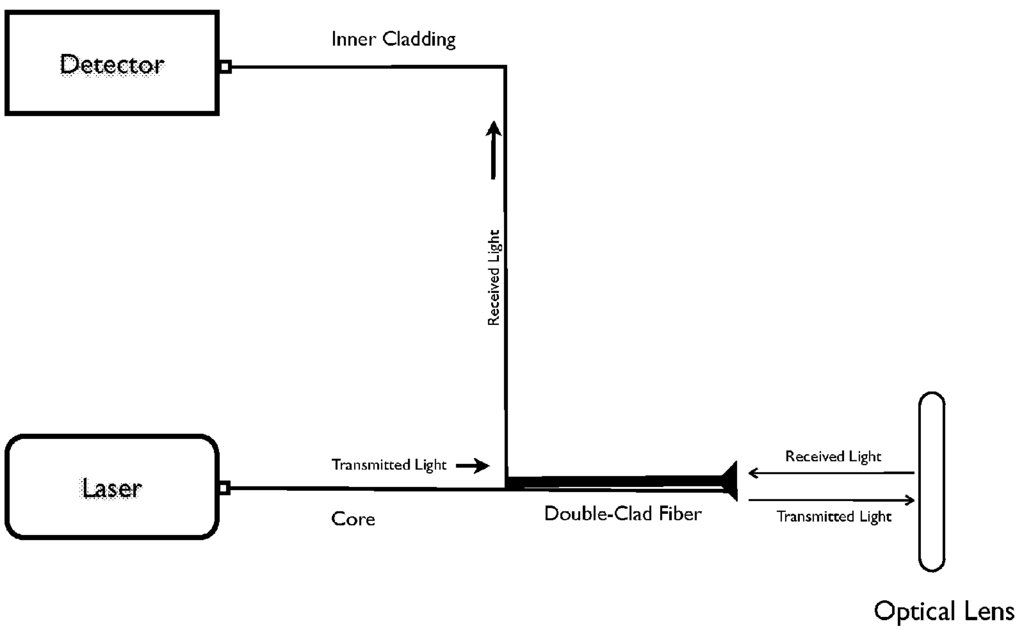

Detector
Inner Cladding
Received Light
Laser
Transmitted Light
Core
Double-Clad Fiber
Received Light
Transmitted Light
Optical Lens

FIG. 1

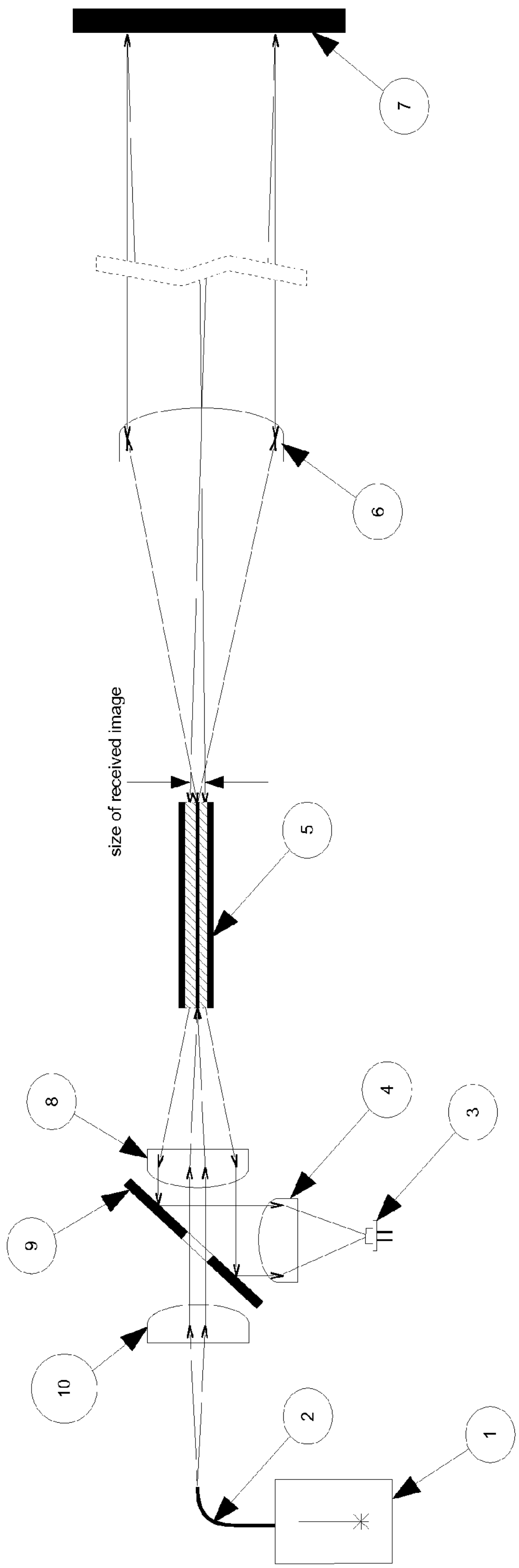


FIG .2

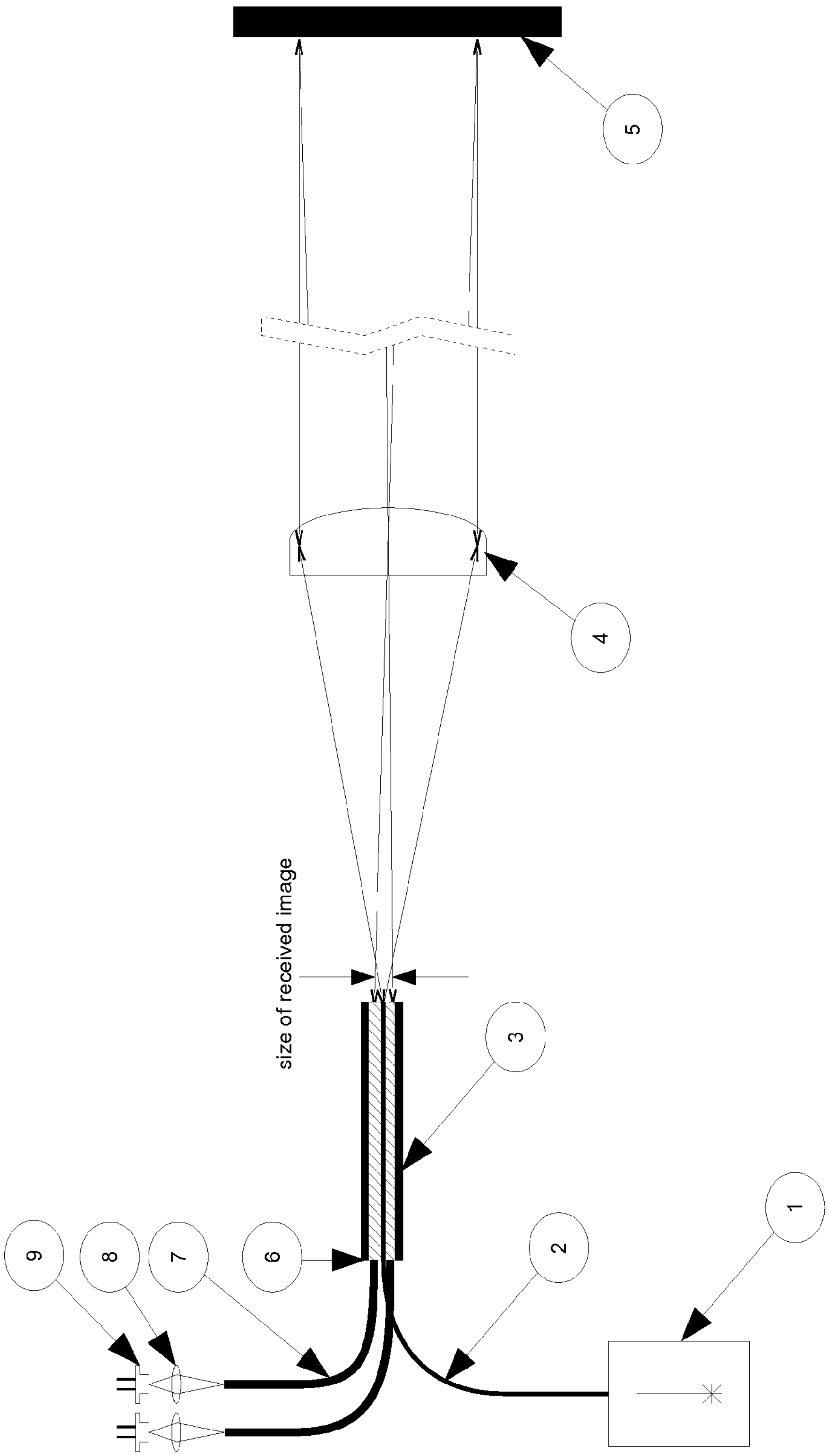


FIG.3

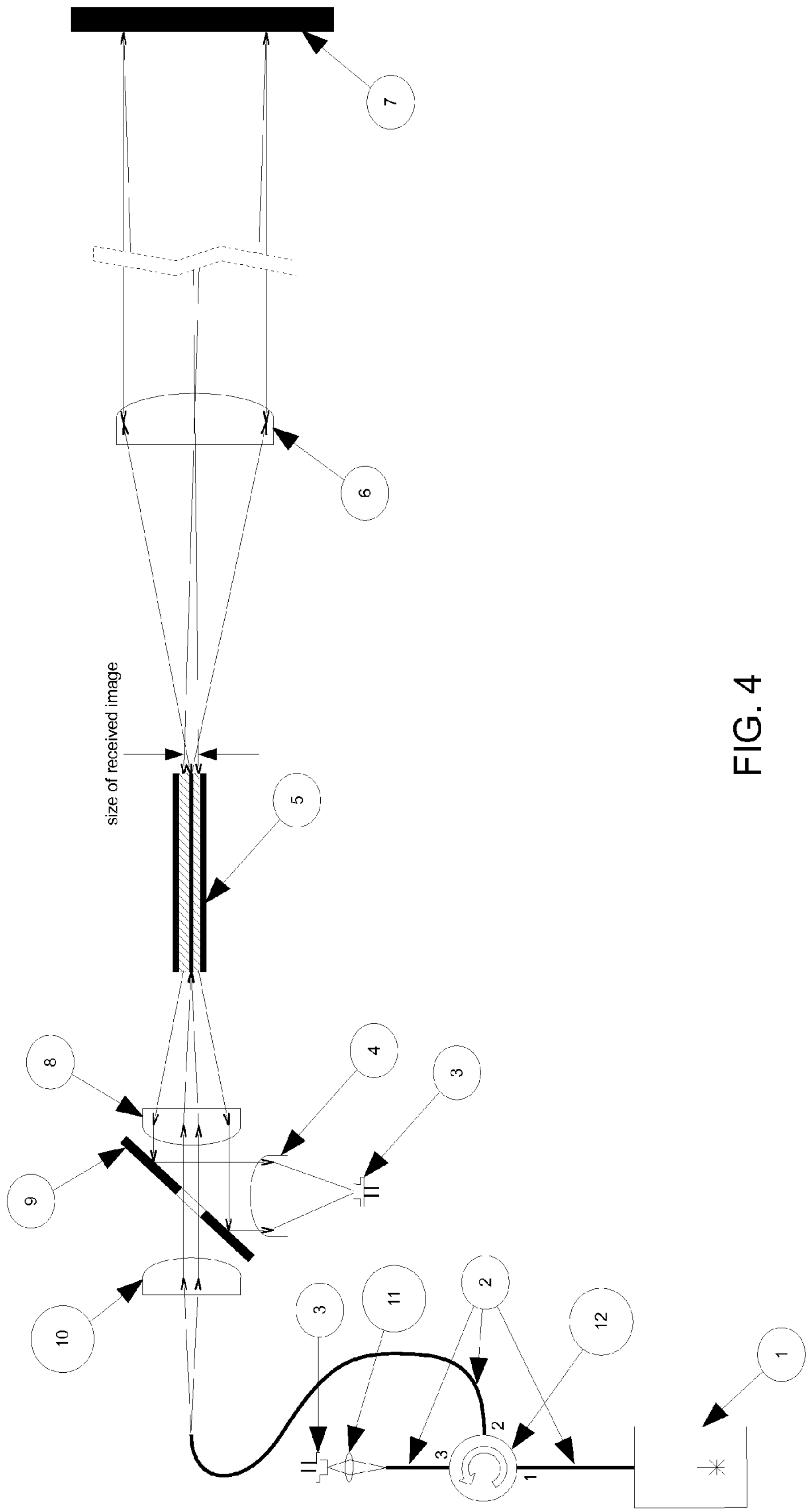


FIG. 4

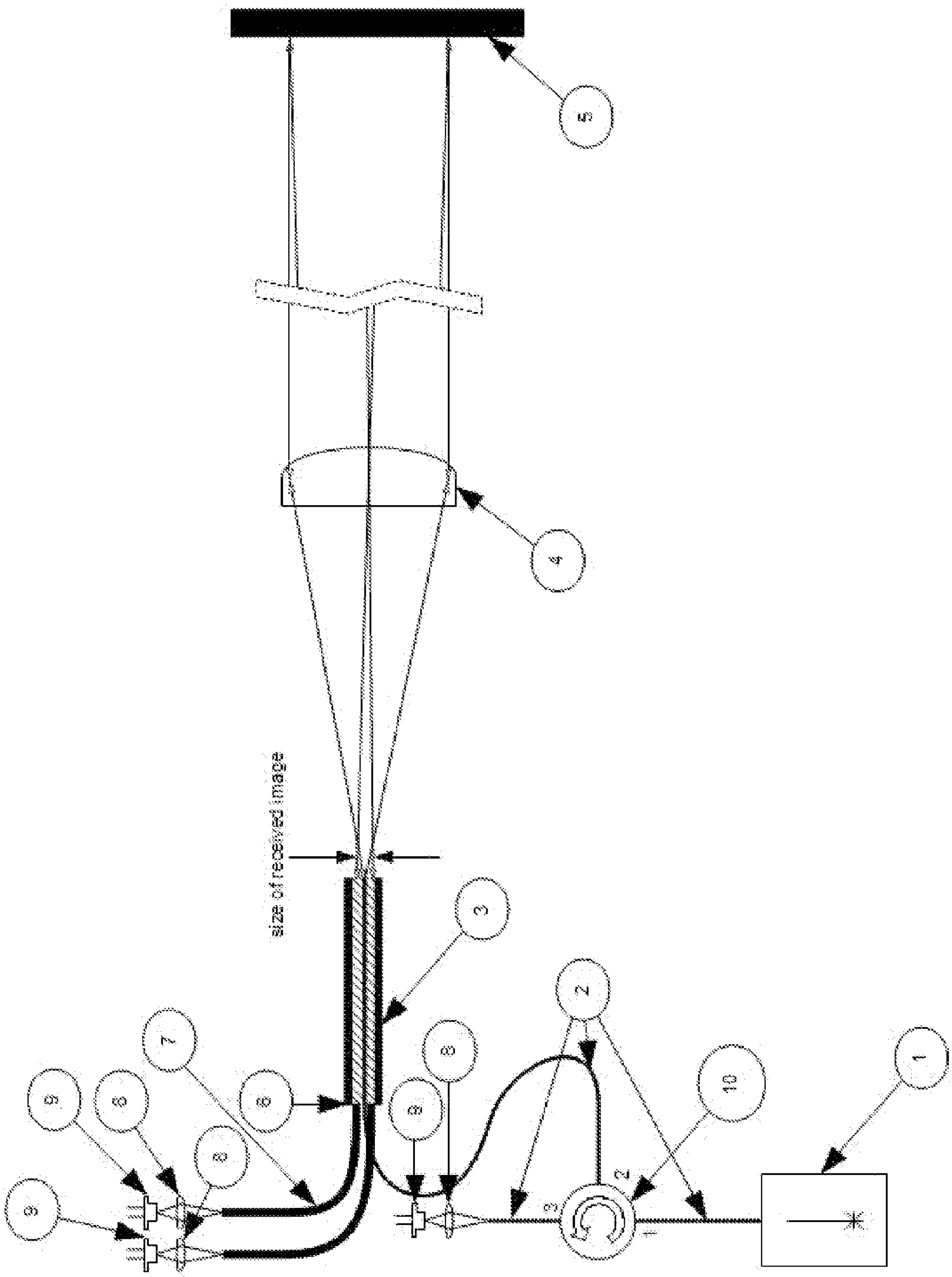


FIG. 5

LIGHT DETECTING AND RANGING SENSING APPARATUS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Ser. No. 61/738,646 (filed 18 Dec. 2012), the entirety of which is hereby expressly incorporated by reference herein.

BACKGROUND

[0003] 1. Technical Field

[0004] Embodiments relate to optical apparatus and, more particularly but not exclusively, to light detecting and range sensor (LiDAR) optical apparatus. Embodiments also relate to optical methods, and more particularly but not exclusively, to light detecting and range sensor (LiDAR) optical methods. Embodiments also relate to LiDAR sensors.

[0005] 2. Description of the Related Art

[0006] Light detecting and ranging (LiDAR) sensors are utilized in a variety of applications to measure the distance to a target, to determine the location of a target, the speed of a target, the shape of a target, the reflectance of a target or other target associated parameter.

[0007] There is a need to provide an improved optical apparatus and method for light detecting and range sensing.

SUMMARY

[0008] According to one aspect, an optical apparatus for a light detecting and ranging (LiDAR) sensing system is provided. The optical apparatus can comprise an optical directing device; and a multi clad optical fiber, wherein said multi clad optical fiber comprises a core, at least one inner cladding, and an outer cladding. The core is arranged to receive optical rays transmitted from a light source of said sensing system and route said transmitted optical rays on an optical path leading to optical directing device. The optical directing device is configured both to direct said routed transmitted optical rays on an optical path leading to a target to be sensed and direct optical rays reflected from said target on an optical path leading to said inner cladding of said multi clad optical fiber. The inner cladding is configured to receive said reflected optical rays and route said reflected optical rays on an optical path leading to a detector for receiving reflected optical rays of said sensing system.

[0009] By configuring the multi-clad optical fiber and optical directing device to direct the transmitted optical rays on an optical pathway leading to the target and direct the reflected optical rays on an optical pathway leading to the detector in the aforesaid manner, parallax error problems that occur in LiDAR sensors using separate optical lenses for directing transmitted and reflected optical rays respectively, are eliminated.

[0010] According to another aspect, a method for a light detecting and ranging (LiDAR) sensing system is provided. The method can comprise receiving, in a core of a multi clad optical fiber, optical rays transmitted from a light source of said sensing system; routing said transmitted optical rays through said core, directing said transmitted optical rays routed through said core on an optical path leading to a target to be sensed; receiving optical rays reflected from said target and directing said reflected optical rays to an inner cladding of said multi clad optical fiber; and routing said reflected optical rays through said inner cladding for receiving by a detector of said sensing system.

[0011] According to yet other aspects, one or more light detecting and ranging (LiDAR) sensors are provided including the aforesaid optical apparatus.

[0012] According to yet other aspects, one or more methods of light detecting and ranging (LiDAR) sensors are provided including the aforesaid optical methods.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is a schematic system diagram illustrating a light detecting and ranging (LiDAR) sensing system according to an embodiment;

[0014] FIG. **2** depicts a light detecting and ranging (LiDAR) sensing system according to an embodiment;

[0015] FIG. **3** depicts a light detecting and ranging (LiDAR) sensing system according to an embodiment;

[0016] FIG. **4** depicts a light detecting and ranging (LiDAR) sensing system including an optical circulator according to an embodiment; and

[0017] FIG. **5** depicts a light detecting and ranging (LiDAR) sensing system including an optical circulator according to an embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular embodiments, procedures, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details.

[0019] Technical features described in this application can be used to construct various embodiments of methods and apparatus for light detecting and range sensing. In one approach, a light detecting and ranging (LiDAR) sensor uses an optical directing device; a multi clad optical fiber, a light source, and a detector. Optical coupling operably couples the light source to a core of the multi-clad optical fiber. Optical coupling operably couples the inner cladding to the detector. The core of the multi-clad fiber is arranged to receive optical rays transmitted from the light source and route the transmitted optical rays on an optical path leading to the optical directing device. The optical directing device is configured both to direct the transmitted optical rays routed through the core towards a target to be sensed and direct optical rays reflected from the target on an optical path leading to the inner cladding of the optical fiber. The inner cladding is configured to receive the reflected optical rays and route the reflected optical rays on an optical path leading to the detector. The detector is configured to detect the reflected optical rays.

[0020] Applicant has identified that LiDAR sensors hitherto now used an approach in which optical rays had been routed from a laser out through a lens, and the returning light had been directed back through a separate lens toward a detector. Such an approach suffered from a parallax error that is created by the distance between the positions of the transmitting and receiving lenses. The parallax error manifested itself in a reduced amount of optical ray reaching the detector and a subsequent weaker signal. The weaker signal reduced the sensor's overall performance for measuring distances and calculating reflectance values for objects near the sensor. One or more embodiments described herein has several advantages over existing LiDAR sensors. The first is the elimination of a lens. This reduces the LiDAR's bill of material and eliminates the parallax error. Eliminating the lens also eliminates the time and labor of aligning the second lens. This approach also has fewer connections, which subsequently improves reliability, as cable connections are a common point of failure in existing LiDAR sensors.

[0021] Reference will now be made to the drawings in which the various elements of embodiments will be given numerical designations and in which embodiments will be discussed so as to enable one skilled in the art to make and use the invention.

[0022] Referring to FIG. **1** of the accompanying drawings, which illustrates a light detecting and ranging sensor (LiDAR) system according to one embodiment, in one non-limiting example, double-clad optical fiber is used to transmit and receive optical rays within the LiDAR sensor. The optical rays can be pulsed optical rays. Using double-Clad Optical Fiber enables a single Lens for the transmission and reception of optical rays for the Light Detecting and Ranging Sensor. The multi-clad optical fiber transmits and receives optical rays, eliminating the need for a second lens and the parallax error. A laser fires an optical ray that travels through the core of a multi-clad optical fiber and is projected through an optical directing device. In the example of FIG. **1**, the optical directing device is a single lens. When the optical ray returns, the optical ray is focused by the same lens back into the inner cladding of the same multi-clad optical fiber and continues its journey to a detector for processing into an analog signal.

[0023] The LiDAR sensor of FIG. **1** transmits and receives optical rays to measure the sensor's distance to a target and calculate a reflectance value for that target. The process starts when the laser fires an optical rays into the core of a multi-clad optical fiber, and the optical rays is transmitted through a lens towards targets down range. The optical rays strikes a target and is reflected back towards the same lens. The lens focuses the reflected optical rays into the inner cladding of the multi-clad fiber and onto the detector. In other embodiments, the optical directing device can be for example a parabolic reflector. In yet other examples, any component(s) or mechanism that is capable of focusing the optical rays down into the multi clad optical fiber can serve as the optical directing device.

[0024] In another approach, optical circulator is integrated into the design to capture the optical rays received by the core of the multi-clad fiber. The optical circulator directs the optical rays out through the core and direct the optical ray received by the core to the optical directing device. Reflected optical rays that returns through the optical directing device is focused into both the inner cladding and core of the multi-clad fiber. Reflected optical rays received into the core returns to the optical circulator. The optical rays that enter the optical circulator exit it towards the detector. The optical circulator blocks the reflected optical rays from returning to the light source. The optical circulator also blocks optical rays from passing directly through it to the detector.

[0025] In yet another approach, the number of detectors in the design is increased to increase the dynamic range of reflected optical rays the sensor can process. The reflected optical rays is either split evenly among multiple detectors so that highly reflective targets do not saturate any one detector or the reflected optical rays or split unevenly so that at least one detector is not saturated by highly reflective targets.

[0026] In yet another approach, the sensor system of one or more embodiments is integrated into a multiple laser/multiple detector LiDAR sensor design for three dimensional scanning. Normally, a multiple channel LiDAR sensor requires each laser emitter and detector pair to be precisely aligned. Additionally if the sensor design transmits through one lens and received through a second lens, parallax errors will be present. Integrating this invention into a multiple channel LiDAR sensor enables multiple laser emitter and detector pairs to be intrinsically self-aligned and eliminates the need to align separate physical elements and prevents parallax errors. The sensor system of the one or more embodiments also enables manufacture of a multiple laser LiDAR sensor with smaller dimensions.

[0027] Reference will now be made to examples of embodiments employing the aforementioned approaches. FIG. **2** depicts a light detecting and ranging (LiDAR) sensing system according to an embodiment. In the example of FIG. **2**, the LiDAR sensing system is an air-coupled LiDAR sensor. The light detecting and ranging (LiDAR) sensor device has a light source, which in this example is a laser **1**. The sensor also has an optical fiber **2**, detector **3**, which in this example is an avalanche photodiode (APD). In other examples, other types of diodes or light to electrical transducers can be used as the detector. Also included in the sensor is a multi clad optical fiber **5**, optical directing device in the form of lens **6**, lens **9**, minor with hole **9** and optical lenses **8** & **10**. Multi-clad optical fiber **5** has a core, inner cladding and outer cladding. Optical elements **2**, **4**, **8**, **9** and **10** form optical coupling that couples the fiber core to laser **1** and optically couples the fiber inner cladding to the detector **3**.

[0028] In FIG. **2**, the fiber core is arranged to receive optical rays transmitted from the light source **1** and route the transmitted optical rays towards optical lens **6**. Optical lens **6** is configured both to direct the transmitted optical rays routed through the core towards a target surface **7** to be sensed and direct optical rays reflected from the target towards the inner cladding of the optical fiber **5**. The inner cladding is configured to receive the reflected optical rays and route the reflected optical rays towards the detector **11**. The detector is configured to detect the reflected optical rays. In other embodiments, the optical directing device can be for example a parabolic reflector. In yet other examples, any component(s) or mechanism that is capable of focusing the optical rays down into the multi clad optical fiber can serve as the optical directing device.

[0029] The commercial advantage of using the LiDAR sensor of the one or more embodiments are:

[0030] 1. Elimination of the parallax error problem that creates inaccuracies in distance measurements and reflective calculations in targets near the sensor. The LiDAR of one more embodiments will be more accurate at closer ranges then known LiDAR sensors.

[0031] 2. A simpler design that is easier and less expensive to build. It has only one lens instead of two. It eliminates the need to precisely align the laser emitter and detector behind this lens. The embodiments are more reliable in the field than competitors' LiDAR sensors. Small displacements of the double clad fiber relative to the lens, caused by vibration or temperature change, will not result in a loss of alignment between the laser emitter and detector.

[0032] Referring now to FIG. **3**, which depicts a light detecting and ranging (LiDAR) sensing system according to another embodiment; the LiDAR sensor system has a laser **1**, optical fiber **2**, multi-clad optical fiber **3**, an optical directing device in the form of optical lens **4**, optical fiber splice location **6**, a plurality of optical lenses **8**, a plurality of optical fibers **7** and a plurality of avalanche photodiode-detectors **9**. Multi-clad optical fiber **3** has a core, an inner cladding and outer cladding. In this example, the core of the multi-clad fiber is optically coupled to the light source **1** by optical fiber **2**. The inner cladding of the multi-clad fiber **3** is optically coupled to the plurality of photo detectors by optical fibers **7**.

[0033] In FIG. **3**, the core of the multi-clad fiber **3** is arranged to receive optical rays transmitted from light source **1** via coupling fiber **2** and route the transmitted optical rays towards the optical lens **4**. The optical lens **4** is configured both to direct the transmitted rays routed through the core towards a target **5** to be sensed and direct reflected optical rays from the target towards the inner cladding of the multi-clad fiber **3**. The inner cladding is configured to receive the reflected optical rays and route the reflected optical rays towards the optical splicing location **6**. At the optical splicing location the fiber splits the reflected optical rays routed through the inner cladding into a plurality of reflected optical ray beams. The plurality of LiDAR detectors **9** are optically coupled to the multi-clad inner cladding by fibers **7** to respectively to detect the reflected plurality of beams. In other embodiments, the optical directing device can be for example a parabolic reflector. In yet other examples, any component(s) or mechanism that is capable of focusing the optical rays down into the multi clad optical fiber can serve as the optical directing device. In other examples, other types of diodes or light to electrical transducers can be used as each detector **9**. Also, in other examples, the detectors **9** may be different from one another.

[0034] FIG. **4** depicts a light detecting and ranging (LiDAR) sensing system according to another embodiment. In the example of FIG. **4**, the LiDAR sensing system comprises an air-coupled LiDAR sensor as shown in FIG. **2** and an optical circulator integrated in the system. The light detecting and ranging (LiDAR) sensor system shown in FIG. **4** has a light source, which in this example is a laser **1**, optical fibers **2**, detectors **3**, which in this example are avalanche photodiode-detector, multi clad optical fiber **5**, optical directing device in the form of optical lens **6**, minor with hole **9** and further optical lenses **4**, **8**, **10** and **11**. Multi-clad optical fiber has a core, inner cladding and outer cladding. Optical fiber **2** and lens **11** optical couples detector **3** to the optical circulator port (3). Optical fibers **2**, lenses **4**, **8**, **10** and mirror with hole **9** form optical couplings which couple the laser **1** to port (1) of the optical circulator **12** and on to fiber core via circulator port (2) and which optically couple the fiber inner cladding to another detector **3**, which in this example is avalanche photodiode-detector.

[0035] In FIG, **4**, optical circulator **12** is arranged to direct optical rays transmitted from the light source **1** of the sensing system through port (1) and on towards the fiber core via port (2) and to block any of these transmitted optical rays from reaching detector **3** coupled to port 3. The multi clad fiber core is arranged to receive the optical rays from the optical circulator port 2 via the optical coupling and route the transmitted optical rays towards optical lens **6**. Optical lens **6** is configured both to direct the routed transmitted optical rays on to a target to be sensed and direct reflected optical rays from target **7** towards the inner cladding of the multi clad fiber. The inner cladding is configured to receive the reflected optical rays and route the reflected optical rays for receiving by the detector of the sensing system. Optical circulator **12** is arranged to allow any reflected optical rays, received and routed by the core of the optical fiber to port (2) of optical circulator, to reach other detector **3** via circulator port (3). In other embodiments, the optical directing device can be for example a parabolic reflector. In yet other examples, any component(s) or mechanism that is capable of focusing the optical rays down into the multi clad optical fiber can serve as the optical directing device. In other examples, other types of diodes or light to electrical transducers can be used as each detector **3**. Also, in other examples, the detectors **9** may be different from one another.

[0036] Referring to FIG. **5**, which depicts a light detecting and ranging (LiDAR) sensing system including an optical circulator according to another embodiment; the sensing system comprises an LiDAR sensor as shown in FIG. **3** and an optical circulator **10** integrated in the sensor system.

[0037] In FIG. **5**, optical rays are transmitted from light source **1** through coupling fiber **2** into port(1) of optical circulator **10** and out of optical circulator port (2) to the core of the multi clad fiber **3** which is arranged to receive and route the transmitted optical rays towards optical directing device in the form of optical lens **4**. Optical circulator **10** blocks the optical rays transmitted from light source **1** from reaching the detector **9** optically coupling circulator port 3. Optical lens **4** is configured both to direct the routed transmitted rays on to a target **5** to be sensed and direct reflected optical rays from a target **5** towards the inner cladding of the optical fiber. The inner cladding is configured to receive the reflected optical rays and route the reflected optical rays to splicing location **6**. At the optical splicing location, the fiber splits the reflected optical rays routed through the inner cladding into a plurality of reflected optical ray beams. A plurality of avalanche photodiode detectors **9**, in addition to the detector coupled to port 3, is respectively optically coupled to the multi-clad inner cladding by coupling fibers **7** to respectively detect the reflected plurality of beams. Optical circulator **10** is arranged to allow any reflected optical rays, received and routed by the core of the optical fiber towards the optical circulator, to reach detector **9** coupled to port 3. Optical lenses **8** are configured to focus the optical rays to the detectors **9**. In other embodiments, the optical directing device can be for example a parabolic reflector. In yet other examples, any component(s) or mechanism that is capable of focusing the optical rays down into the multi clad optical fiber can serve as the optical directing device. In other examples, other types of diodes or light to electrical transducers can be used as each detector **9**. Also, in other examples, one or more of the detectors **9** can be a different type of detector.

[0038] Specific reference to components, process steps, and other elements are not intended to be limiting. It will be further noted that the Figures are schematic and provided for guidance to the skilled reader and are not necessarily drawn to scale. Rather, the various drawing scales, aspect ratios, and numbers of components shown in the Figures may be purposely distorted to make certain features or relationships easier to understand.

[0039] While preferred embodiments of the present invention have been described and illustrated in detail, it is to be understood that many modifications can be made to the embodiments, and features can be interchanged between embodiments, without departing from the spirit of the invention.

1. (canceled)

2. (canceled)

3. (canceled)

4. (canceled)

5. (canceled)

6. (canceled)

7. (canceled)

8. (canceled)

9. (canceled)

10. (canceled)

11. An optical apparatus for use in a LiDAR sensing system, the optical apparatus comprising:

an optical circulator positioned to receive and direct optical rays;

an optical directing device;

an optical detector; and

an optical fiber,

wherein the optical fiber is positioned to receive outgoing optical rays directed to the optical fiber by the optical circulator and to direct the outgoing optical rays toward the optical directing device,

the optical directing device is configured to focus the outgoing optical rays toward a target, and further to focus reflected optical rays reflected from the target toward the optical fiber,

the optical fiber is positioned to receive the reflected optical rays focused from the optical directing device and to direct the reflected optical rays toward the optical circulator, and

the optical circulator is positioned to direct the reflected optical rays toward the detector.

12. The optical apparatus of claim **11**, wherein the optical circulator receives the outgoing optical rays from a light source and blocks the reflected optical rays from returning to the light source.

13. The optical apparatus of claim **11**, wherein the optical fiber is a multi-clad fiber comprising a core, an inner cladding, and an outer cladding.

14. The optical apparatus of claim **11**, wherein the optical directing device consists of a single lens.

15. The optical apparatus of claim **11**, wherein the optical directing device consists of a single mirror.

16. The optical apparatus of claim **11**, wherein the optical directing device comprises at least one of a lens and a mirror, and both the outgoing and reflected optical rays are directed by the same at least one of a lens and a mirror.

17. The optical apparatus of claim **11**, comprising a plurality of detectors, the reflected optical rays being split among the plurality of detectors.

18. The optical apparatus of claim **11**, wherein the detector is an avalanche photodiode.

19. A LiDAR sensor comprising the optical apparatus of claim **11**, and further comprising a laser configured to generate the outgoing optical rays.

20. The LiDAR sensor of claim **19**, comprising a plurality of the optical apparatuses of claim **1** and lasers configured to generate the outgoing optical rays.

21. An optical apparatus for use in a LiDAR sensing system, the optical apparatus comprising:

an optical directing device comprising at least one of a lens and a mirror;

an optical detector; and

an optical fiber,

wherein the optical fiber is positioned to receive outgoing optical rays directed to the optical fiber from a light source and to direct the outgoing optical rays toward the optical directing device,

the optical directing device is configured to focus the outgoing optical rays toward a target through the at least one of a lens and a mirror, and further to focus reflected optical rays reflected from the target toward the optical fiber through the same at least one of a lens and a mirror, and

the optical fiber is positioned to receive the reflected optical rays focused from the optical directing device and to direct the reflected optical rays toward the detector.

22. The optical apparatus of claim **21**, wherein the optical fiber is a multi-clad fiber comprising a core, an inner cladding, and an outer cladding.

23. The optical apparatus of claim **21**, wherein the optical directing device consists of a single lens.

24. The optical apparatus of claim **21**, wherein the optical directing device consists of a single mirror.

25. The optical apparatus of claim **21**, wherein the optical directing device consists of a plurality of optical elements selected from the group consisting of lenses and mirrors.

26. The optical apparatus of claim **21**, comprising a plurality of detectors, the reflected optical rays being split among the plurality of detectors.

27. The optical apparatus of claim **21**, wherein the detector is an avalanche photodiode.

28. A LiDAR sensor comprising the optical apparatus of claim **21**, and further comprising a laser configured to generate the outgoing optical rays.

29. The LiDAR sensor of claim **28**, comprising a plurality of the optical apparatuses of claim **1** and lasers configured to generate the outgoing optical rays.

30. A LiDAR sensor comprising a means for elimination of the parallax error problem, said LiDAR sensor further comprising an optical circulator.

31. A LiDAR sensor comprising a means for elimination of the parallax error problem, wherein at least one of a lens and a mirror is configured to both direct outgoing optical rays toward a target and direct reflected optical rays toward a detector.

* * * * *