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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 June 2013 (20.06.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/090175 Al

(51) International Patent Classification:
G01T 1/20 (2006.01)

(21) International Application Number:
PCT/US20 12/068700

(22) International Filing Date:
10 December 2012 (10. 12.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/569,607 12 December 201 1 (12. 12.201 1) US

(71) Applicant: **SAINT-GOBAIN CERAMICS & PLASTICS, INC.** [US/US]; One New Bond Street, Worcester, MA 01615-0138 (US).

(72) Inventor: **WILSON, Lance J.;** 3387 Chalfant Road, Shaker Heights, OH 44120 (US).

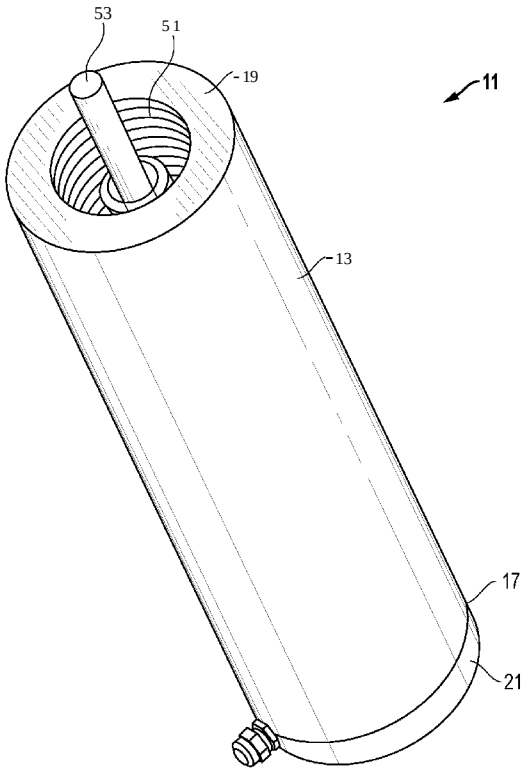
(74) Agents: **ABEL LAW GROUP, LLP** et al; 891 1 North Capital of Texas Hwy, Bldg. 4, Suite 4200 , Austin, TX 78759 (US).

(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, KM, 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, 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,

[Continued on nextpage]

(54) Title: STAND-ALONE PHOTOSENSOR ASSEMBLY



(57) Abstract: A stand-alone photosensor assembly has a housing with an axis, a first axial end and a second axial end opposite the first axial end. An adapter may be threadingly coupled to the first axial end of the housing. The adapter may be adapted to mount the housing to a scintillator. A photosensor element may be located inside the housing and adapted to be optically coupled to the scintillator. A sub-housing may be located inside the housing, at least a portion of which is located radially between the housing and the photosensor element. A scintillator assembly may include a scintillator and the photosensor assembly. A machine, such as a radiation detector, may include the scintillator and the photosensor assembly coupled to the scintillator. The machine also may include an output device to generate output in response to the photosensor assembly, and a user interface coupled to the output device.

WO 2013/090175 A1

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, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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

— *with amended claims (Art. 19(1))*

STAND-ALONE PHOTOSENSOR ASSEMBLY

Field of the Disclosure

The present disclosure is generally related to radiation detectors and, more particularly, to a ruggedized photosensor assembly for a radiation detector.

BACKGROUND

A radiation detector can include a plastic scintillator, such as BC-704™-brand scintillator available from Saint-Gobain Crystals of Hiram, Ohio, USA. The BC-704™-brand scintillator includes alternating layers of wavelength shifting fibers and phosphorescent materials. A light shield is typically attached to each of the scintillators and contains a photosensor, such as a photomultiplier tube (PMT). The PMT is protected from exposure to light by the light shield.

Some security-related operating environments require the PMT to withstand substantial shock, vibration and temperature extremes. Various designs have been attempted for this purpose. Some designs are directly bonded to the scintillators with epoxy. Others bolt onto the scintillators and require additional gaskets and epoxy to form a light-tight seal. The epoxied-on light shield designs use only epoxy to create a seal for the light shield assembly and the internal electronics. These designs are not removable and be difficult to work on if they need maintenance. Moreover, these designs also can fail when subjected to vibration. Accordingly, improved light shield designs continue to be of interest.

SUMMARY

Embodiments of a system, method and apparatus for a stand-alone photosensor assembly are disclosed. The assembly may comprise a housing having an axis, a first axial end and a second axial end opposite the first axial end. An adapter may be threadingly coupled to the first axial end of the housing. The adapter may be adapted to mount the housing to a scintillator. A photosensor element may be located inside the housing and adapted to be optically coupled to the scintillator. A

sub-housing may be located inside the housing, at least a portion of which is located radially between the housing and the photosensor element.

In other embodiments, a scintillator assembly may comprise a scintillator and a photosensor assembly as described herein. In still other embodiments, a machine, such as a radiation detector, may comprise a scintillator and a photosensor assembly coupled to the scintillator. The photosensor assembly may comprise the embodiments disclosed herein. The machine may further comprise an output device to generate output in response to the photosensor assembly, and a user interface coupled to the output device.

The foregoing and other objects and advantages of these embodiments will be apparent to those of ordinary skill in the art in view of the following detailed description, taken in conjunction with the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments are illustrated by way of example and are not limited in the accompanying figures.

FIGS. 1 and 2 are isometric and sectional side views of an embodiment of a photosensor assembly;

FIGS. 3 and 4 are isometric and partial sectional side views of an embodiment of a photosensor assembly mounted to a scintillator; and

FIG. 5 is a perspective view of an embodiment of a "port-of-entry" radiation detection apparatus in operation.

Skilled artisans appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the invention.

DETAILED DESCRIPTION

The following description in combination with the drawings is provided to assist in understanding the teachings disclosed herein. The following discussion focuses on specific implementations and embodiments of the teachings. This focus is provided to assist in describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings.

FIGS. 1 and 2 depict a stand-alone photosensor assembly 11. The term "stand-alone," as used herein, means that the photosensor assembly 11 requires no other component to complete its assembly or to render it operative. The photosensor 11 may comprise a housing 13 having an axis 15, a first axial end 17 and a second axial end 19 opposite the first axial end 17.

An adapter 21 is threadingly coupled to and, in some embodiments, extends from the first axial end 17 of the housing 13. The adapter 21 may be adapted to mount the housing 13 directly to a scintillator 101, as shown in FIGS. 3 and 4.

The adapter 21 may be provided with an external thread received by an internal thread adjacent the first axial end 17 of the housing 13. The adapter 21 may axially abut an optical pad 33 opposite the photosensor element 31. The adapter 21 may be adapted to be adhesively or mechanically attached to the scintillator 101. The scintillator 101 and the photosensor assembly 11 may be coaxial or not coaxial via adapter 21.

A photosensor element 31 may be located inside the housing 13 and adapted to be optically coupled to the scintillator 101. For example, the photosensor element 31 may be optically coupled to the scintillator 101 using grease and/or the optical pad 33 (FIG. 2). The photosensor element 31 may comprise, for example, a photomultiplier tube (PMT), a photodiode, an avalanche photodiode or a silicon photomultiplier.

The housing 13 may provide magnetic shielding for the photosensor element 31. The housing may include an alloy material, such as aluminum alloys or stainless steel with Mu metal electrically conductive to the base substrate. Mu metal is an alloy that may comprise approximately 77% nickel, 16% iron, 5% copper and 2%

chromium or molybdenum, in some versions. Mu metal is notable for its high magnetic permeability. The high permeability makes mu metal very effective at screening static or low frequency magnetic fields, which may not be attenuated by other methods. The name originates from the Greek letter mu (μ) which represents permeability.

A sub-housing 41 also may be located inside the housing 13. At least a portion of the sub-housing 41 may be located radially between the housing 13 and the photosensor element 31. The sub-housing 41 may comprise electronics coupled to the photosensor element 31 for converting input from the photosensor element 31 to an output signal. The sub-housing 41 may comprise a voltage divider, electronics, power supply, pre-amp or a temperature sensor, or any combination thereof.

The sub-housing 41 may be located radially between the housing 13 and at least a portion 49 of the photosensor element 31. The sub-housing 41 may be located axially between the second axial end 19 of the housing 13 and the photosensor element 31.

An annular seal 43, such as one or more o-rings, may be positioned between the sub-housing 41 and the housing 13 to form a light-tight seal adjacent second axial end 19.

The housing 13 may comprise a single integrated component, or two or more components that are coupled together to form light-tight seals therebetween. In an embodiment comprising two components to form housing 13, the two components may connect to each other near the o-ring 43 (e.g., just above o-ring 43 in FIG. 2).

Embodiments may further comprise weather stripping 45 between the photosensor element 31 and the housing 13. An axial space 47 may be provided between the sub-housing 41 and the weatherstripping 45. In some versions, only a portion 49 of the photosensor element 31 is surrounded by the sub-housing 41 and the weatherstripping 45.

The stand-alone photosensor assembly 11 may further comprise a spring 51 inside the housing 13 between the second axial end 19 and the sub-housing 41. The spring 51 may be configured to mechanically bias the sub-housing 41 and the

photosensor element 31 away from the second axial end 19 of the housing 13 and maintain electrical continuity therebetween for grounding purposes. The spring 51 may comprise, for example, a wave spring, a die spring, or a wire compression spring with a single turn or multiple turns.

A cable 53 may extend from the electronics, through the sub-housing 41 and the spring 51, and out of an aperture 55 in the second axial end 19 of the housing 13 to transmit the output signal from the electronics to an exterior of the housing 13. The cable 53 may be spaced apart from the aperture 55 as shown. In some embodiments, the photosensor assembly 11 is substantially free of any adhesive compound.

In other embodiments, a scintillator assembly (FIGS. 3 and 4) comprise the scintillator 101 and the photosensor assembly 11 as described herein. The scintillator 101 may comprise, for example, a neutron sensor comprising ^{6}LiF or ZnS:(Ag or Cu).

The scintillator 101 also may comprise a gamma radiation sensor, an alpha radiation sensor or a beta radiation sensor. Some gamma sensors may comprise polyvinyl toluene (PVT) or styrene with at least one fluorescent additive. The fluorescent additive may comprise a compound having at least three linearly-connected aromatic rings. The aromatic rings may be homo-aromatic or hetero-aromatic. In some embodiments, the fluorescent additive may comprise p-terphenyl (Ci_8H_{14}), 2-(4-Biphenylyl)-5-phenyl-l,3,4-oxadiazole (PBD, or $C_2oHi_4N_20$), butyl PBD ($C_{24}H_{22}N_20$), 2,5-Diphenyloxazole (PPO, or Ci_5HnNO), and a wavelength shifter such as l,4-bis(5-phenyloxazol-2-yl) benzene (POPOP) ($C_{24}Hi_6N_20$).

In still other embodiments, a machine such as radiation detector may comprise the scintillator 101, a photosensor assembly 11 coupled to the scintillator 101 as described herein, an output device 103 (FIG. 4) to generate output in response to the photosensor assembly 11, and a user interface 105 coupled to the output device.

Some scintillators comprise organic devices formed from organic compounds that are not hydroscopic. Such compounds may be configured with an inorganic liner or shell, such as plastic. The designs disclosed herein are well suited for mounting optical fiber bundles.

In operation (FIG. 5), an object 504 can be placed near or pass through an opening within a machine or radiation detection apparatus 502, such as a port-of-entry radiation detector. Radiation detection apparatus 502 may be configured with the various embodiments disclosed herein. The object 504 may be a vehicle such as a truck. The radiation detection apparatus 502 can capture at least part of the targeted radiation emitted by the object 504. The radiation sensors can emit scintillating light or wavelength shifted light that is converted to an electronic signal by the photosensors. The electronic signal can be transmitted to a control module (not illustrated) for further analysis.

In some embodiments (FIG. 3), the scintillator 101 may be located in a second housing 301 that is separate from the housing 13 of the photosensor assembly 11. In addition, a moderator box 303 may contain the photosensor assembly 11 and the scintillator 101. The photosensor assembly 11 may comprise at least two photosensor assemblies 11, both of which are located in the moderator box 303. Some embodiments further comprise a weatherproof enclosure 502 (FIGS. 3 and 5) in which the moderator box 303 is located.

The embodiments disclosed herein have numerous advantages. No epoxy or other adhesive is used to form the light-tight seal inside of the light shield assembly. Conventional designs require epoxy to be applied to the seams of their light shields to prevent light leaks.

The threaded adapter design disclosed not only allows for easy removal of the light shield assembly, but creates a more reliable, light tight seal. The threaded adapter used in the embodiments disclosed herein helps form a light-tight seal inside of the light shield. In addition, the adapter also allows for easy removal of the light shield assembly from the scintillating element of the detector. The adapter may be modified to fit almost any detector manufactured.

The threaded adapter attaches to the scintillator by gluing the scintillator or light guide inside of the adapter. The rest of the light shield assembly is simply threaded tight onto the adapter creating a secure, light-tight fit. No epoxy is used to secure the adapter to the light shield assembly, thus making removal and replacement very easy.

The addition of an o-ring to the design adds ruggedness and additional radial support. Minimizing the allowable movement of internal electrical components increases the accuracy of the assembly. The integrated O-Ring, applied weather stripping, and wave spring give this assembly excellent vibration protection by preventing the PMT and other electronics from hitting the light shield wall in both the axial and lateral directions.

Conventional epoxy designs fail at about 2 g's of random vibration. In contrast, the embodiments disclosed herein perform well when subjected to more than 2 g's of force, more than 2.5 g's of force, more than 3 g's of force, or more than 3.5 g's of force. Thus, these designs can withstand and operate in g-forces in excess of 2.

In some embodiments, the pressure applied by the wave spring on the electronic components is approximately 12.5 pounds. This pressure assists the o-ring and the weather stripping in preventing internal movement and further ruggedizes the assembly. Advantageously, the spring is electrically conductive to maintain electrical continuity between the housing and the electronics or voltage divider.

The integrated o-ring, along with the threads connecting the light shield to the adapter, form a light-tight environment that prevents the PMT from outputting false readings due to light leaks.

An additional benefit of this design is the greatly simplified and minimal manufacturing time required to complete the assembly. The photosensor assembly itself requires to bonding or adhesive and thus no cure time. In some embodiments, only the adapter is adhesively bonded or mechanically joined to the scintillator. Thus, the assembly is completed in a few minutes, rather than days as required by conventional designs because of the cure times associated with the bonding materials needed to complete those types of assemblies.

In addition, the spring between the housing and the voltage divider maintains electrical continuity within the assembly. Thus, this design requires no grounding strap as is required by some conventional designs.

As used herein, the terms "comprises," "comprising," "includes, " "including, " "has, " "having," or any other variation thereof, are intended to cover a non-

exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

The use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and may be found in textbooks and other sources within the scintillation and radiation detection arts.

Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein. After reading this specification, skilled artisans will appreciate that those aspects and embodiments are only illustrative and do not limit the scope of the present invention. Additionally, those skilled in the art will understand that some embodiments that include analog circuits can be similarly implemented using digital circuits, and vice versa.

Note that not all of the activities described above in the general description or the examples are required, that a portion of a specific activity may not be required, and that one or more further activities may be performed in addition to those described. Still further, the order in which activities are listed is not necessarily the order in which they are performed.

Certain features that are, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

WHAT IS CLAIMED IS:

1. A stand-alone photosensor assembly, comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element.

2. A scintillator assembly, comprising:

a scintillator; and

a photosensor assembly comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element.

3. A machine, comprising:

a scintillator;

a photosensor assembly coupled to the scintillator, the photosensor assembly comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element; and

the machine further comprising:

an output device to generate output in response to the photosensor assembly; and

a user interface coupled to the output device.

4. A device according to any of the preceding claims, further comprising an annular seal between the sub-housing and the housing.

5. A device according to any of Claims 1-3, further comprising at least one o-ring between the sub-housing and the housing.

6. A device according to any of Claims 1-3, further comprising weather stripping axially disposed between the adapter and an annular seal or at least one o-ring.

7. A device according to any of the preceding claims, further comprising a spring inside the housing between the second axial end of the housing and the sub-housing, the spring being configured to mechanically bias the sub-housing and the photosensor element away from the second axial end of the housing and maintain electrical continuity therebetween.

8. A device according to any of the preceding claims, further comprising a wave spring, a die spring, or a wire compression spring with a single turn or multiple turns.

9. A device according to any of Claims 2-8, wherein the adapter has an external thread received by an internal thread on the first axial end of the housing, the adapter axially abuts an optical pad opposite the photosensor element, and the adapter is adapted to be adhesively or mechanically attached to the scintillator.

10. A device according to any of the preceding claims, wherein the sub-housing comprises electronics coupled to the photosensor element for converting input from the photosensor element to an output signal.

11. A device according to any of the preceding claims, further comprising a cable extending from electronics, through the sub-housing and a spring, and out of an aperture in the second axial end of the housing to transmit the output signal from the electronics to an electrical connector.

12. A device according to any of the preceding claims, wherein a cable is spaced apart from an aperture in the second axial end of the housing.

13. A device according to any of the preceding claims, wherein the photosensor element comprises a photomultiplier tube **(PMT).**

14. A device according to any of the preceding claims, wherein the housing provides magnetic shielding for the photosensor element.

15. A device according to any of the preceding claims, wherein the housing includes an alloy material.

16. A device according to any of the preceding claims, wherein the housing comprises an aluminum alloy or stainless steel.

17. A device according to any of Claims 1-15, wherein the housing comprises nickel, iron and copper and one of chromium or molybdenum.

18. A device according to any of the preceding claims, further comprising weather stripping between the photosensor element and the housing.

19. A device according to any of the preceding claims, further comprising an axial space between the sub-housing and weather stripping.

20. A device according to any of the preceding claims, wherein only a portion of the photosensor element is surrounded by the sub-housing and weather stripping.

21. A device according to any of the preceding claims, wherein the photosensor element comprises a photomultiplier tube **(PMT),** and the sub-housing comprises a voltage divider, electronics, power supply, pre-amp, temperature sensor or any combination thereof.

22. A device according to any of the preceding claims, wherein the sub-housing is located radially between the housing and at least a portion of the photosensor element, and the sub-housing is located axially between the second axial end of the housing and the photosensor element.

23. A device according to any of Claims 2-22, wherein the photosensor assembly is substantially free of any adhesive compound.

24. A device according to any of the preceding claims, wherein the housing comprises two or more components joined together to form light-tight seals therebetween.

25. A device according to any of Claims 2-24, wherein the scintillator is located in a second housing that is separate from the housing of the photosensor assembly.

26. A device according to any of Claims 2-25, wherein the scintillator is a neutron sensor comprising ^{6}LiF or ZnS:(Ag or Cu).

27. A device according to any of Claims 2-26, further comprising a moderator box containing the photosensor assembly and the scintillator.

28. A device according to any of Claims 2-27, wherein the photosensor assembly comprises at least two photosensor assemblies, both of which are located in a moderator box.

29. A device according to any of Claims 2-25, 27, 28, wherein the scintillator is a gamma radiation sensor, an alpha radiation sensor or a beta radiation sensor.

30. A device according to any of Claims 2-29, wherein the scintillator and the photosensor assembly are coaxial.

31. A device according to any of Claims 2-29, wherein the scintillator and the photosensor assembly are not coaxial.

32. A device according to any of Claims 2-31, wherein the photosensor assembly is configured to withstand and operate in a g-force in excess of 2.

33. A device according to any of Claims 2-25,27, 28, 30-32, wherein the scintillator is a gamma sensor comprising polyvinyl toluene (PVT) or styrene with a fluorescent additive, and the fluorescent additive comprises a compound having at least three linearly-connected aromatic rings.

34. A device according to any of Claims 2-25, 27, 28, 30-33, wherein the scintillator comprises aromatic rings that are homo-aromatic.

35. A device according to any of Claims 2-25, 27, 28, 30-34, wherein the scintillator comprises aromatic rings that are hetero-aromatic.

36. A device according to any of Claims 2-25, 27, 28, 30-35, wherein the scintillator comprises a fluorescent additive comprising p-terphenyl ($C_{18}H_{14}$), 2-(4-Biphenylyl)-5-phenyl-l,3,4-oxadiazole (PBD, or $C_{2}oHi_{4}N_{2}0$), butyl PBD ($C_{24}H_{22}N_{2}0$), 2,5-Diphenyloxazole (PPO, or $C_{15}HnNO$), or a wavelength shifter 1,4-bis(5-phenyloxazol-2-yl) benzene (POPOP) ($C_{24}H_{16}N_{2}0$).

AMENDED CLAIMS
received by the International Bureau on 13 May 201 3(1 3.05.201 3)

1. A stand-alone photosensor assembly, comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element.

2. A scintillator assembly, comprising:

a scintillator; and

a photosensor assembly comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element.

3. A machine, comprising:

a scintillator;

a photosensor assembly coupled to the scintillator, the photosensor assembly comprising:

a housing having an axis, a first axial end and a second axial end opposite the first axial end;

an adapter threadingly coupled to the first axial end of the housing, the adapter being adapted to mount the housing to a scintillator;

a photosensor element inside the housing adapted to be optically coupled to the scintillator; and

a sub-housing inside the housing, at least a portion of which is located radially between the housing and the photosensor element; and the machine further comprising:

an output device to generate output in response to the photosensor assembly; and

a user interface coupled to the output device.

4. A device according to any of the preceding claims, further comprising an annular seal between the sub-housing and the housing.

5. A device according to any of Claims 1-3, further comprising at least one o-ring between the sub-housing and the housing.

6. A device according to any of Claims 1-3, further comprising weather stripping axially disposed between the adapter and an annular seal or at least one o-ring.

7. A device according to any one of the preceding claims, further comprising a spring inside the housing between the second axial end of the housing and the sub-housing, the spring being configured to mechanically bias the sub-housing and the photosensor element away from the second axial end of the housing and maintain electrical continuity therebetween.

8. A device according to any one of the preceding claims, further comprising a wave spring, a die spring, or a wire compression spring with a single turn or multiple turns.

9. A device according to any one of Claims 2-8, wherein the adapter has an external thread received by an internal thread on the first axial end of the housing, the adapter axially abuts an optical pad opposite the photosensor element, and the adapter is adapted to be adhesively or mechanically attached to the scintillator.

10. A device according to any one of the preceding claims, wherein the sub-housing comprises electronics coupled to the photosensor element for converting input from the photosensor element to an output signal.

11. A device according to any one of the preceding claims, further comprising a cable extending from electronics, through the sub-housing and a spring, and out of an aperture in the second axial end of the housing to transmit the output signal from the electronics to an electrical connector.

12. A device according to any one of the preceding claims, wherein a cable is spaced apart from an aperture in the second axial end of the housing.

13. A device according to any one of the preceding claims, wherein the photosensor element comprises a photomultiplier tube (PMT).

14. A device according to any one of the preceding claims, wherein the housing provides magnetic shielding for the photosensor element.

15. A device according to any one of the preceding claims, wherein the housing includes an alloy material.

16. A device according to any one of the preceding claims, wherein the housing comprises an aluminum alloy or stainless steel.

17. A device according to any one of Claims 1-15, wherein the housing comprises nickel, iron and copper and one of chromium or molybdenum.

18. A device according to any one of the preceding claims, further comprising weather stripping between the photosensor element and the housing.

19. A device according to any one of the preceding claims, further comprising an axial space between the sub-housing and weather stripping.

20. A device according to any one of the preceding claims, wherein only a portion of the photosensor element is surrounded by the sub-housing and weather stripping.

21. A device according to any one of the preceding claims, wherein the photosensor element comprises a photomultiplier tube (PMT), and the sub-housing comprises a voltage divider, electronics, power supply, pre-amp, temperature sensor or any combination thereof.

22. A device according to any one of the preceding claims, wherein the sub-housing is located radially between the housing and at least a portion of the photosensor element, and the sub-housing is located axially between the second axial end of the housing and the photosensor element.

23. A device according to any one of Claims 2-22, wherein the photosensor assembly is substantially free of any adhesive compound.

24. A device according to any one of the preceding claims, wherein the housing comprises two or more components joined together to form light-tight seals therebetween.

25. A device according to any one of Claims 2-24, wherein the scintillator is located in a second housing that is separate from the housing of the photosensor assembly.

26. A device according to any one of Claims 2-25, wherein the scintillator is a neutron sensor comprising ^{6}LiF or ZnS:(Ag or Cu).

27. A device according to any one of Claims 2-26, further comprising a moderator box containing the photosensor assembly and the scintillator.

28. A device according to any one of Claims 2-27, wherein the photosensor assembly comprises at least two photosensor assemblies, both of which are located in a moderator box.

29. A device according to any one of Claims 2-25, 27, 28, wherein the scintillator is a gamma radiation sensor, an alpha radiation sensor or a beta radiation sensor.

30. A device according to any one of Claims 2-29, wherein the scintillator and the photosensor assembly are coaxial.

31. A device according to any one of Claims 2-29, wherein the scintillator and the photosensor assembly are not coaxial.

32. A device according to any one of Claims 2-31, wherein the photosensor assembly is configured to withstand and operate in a g-force in excess of 2.

33. A device according to any one of Claims 2-25,27, 28, 30-32, wherein the scintillator is a gamma sensor comprising polyvinyl toluene (PVT) or styrene with a fluorescent additive, and the fluorescent additive comprises a compound having at least three linearly-connected aromatic rings.

34. A device according to any one of Claims 2-25, 27, 28, 30-33, wherein the scintillator comprises aromatic rings that are homo-aromatic.

35. A device according to any one of Claims 2-25, 27, 28, 30-34, wherein the scintillator comprises aromatic rings that are hetero-aromatic.

36. A device according to any one of Claims 2-25, 27, 28, 30-35, wherein the scintillator comprises a fluorescent additive comprising p-terphenyl **(Ci_8H_{14}),** 2-(4-Biphenylyl)-5-phenyl-1,3,4-oxadiazole (PBD, or $C_{20}H_{14}N_20$), butyl PBD ($C_{24}H_{22}N_2O$), 2,5-Diphenyloxazole (PPO, or $C_{15}H_{11}NO$), or a wavelength shifter l,4-bis(5-phenyloxazol-2-yl) benzene (POPOP) **($C_{24}Hi_6N_20$**).

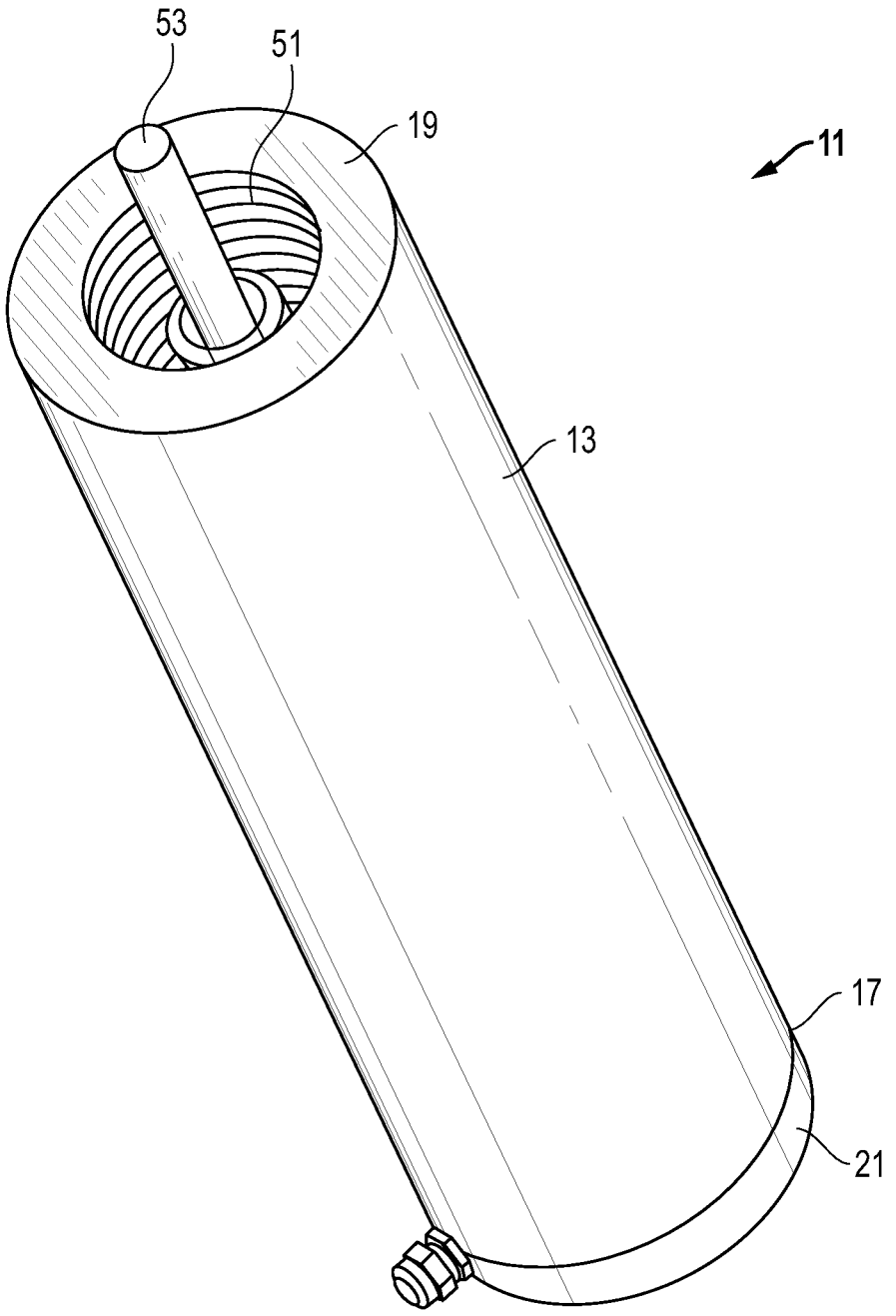


FIG. 1

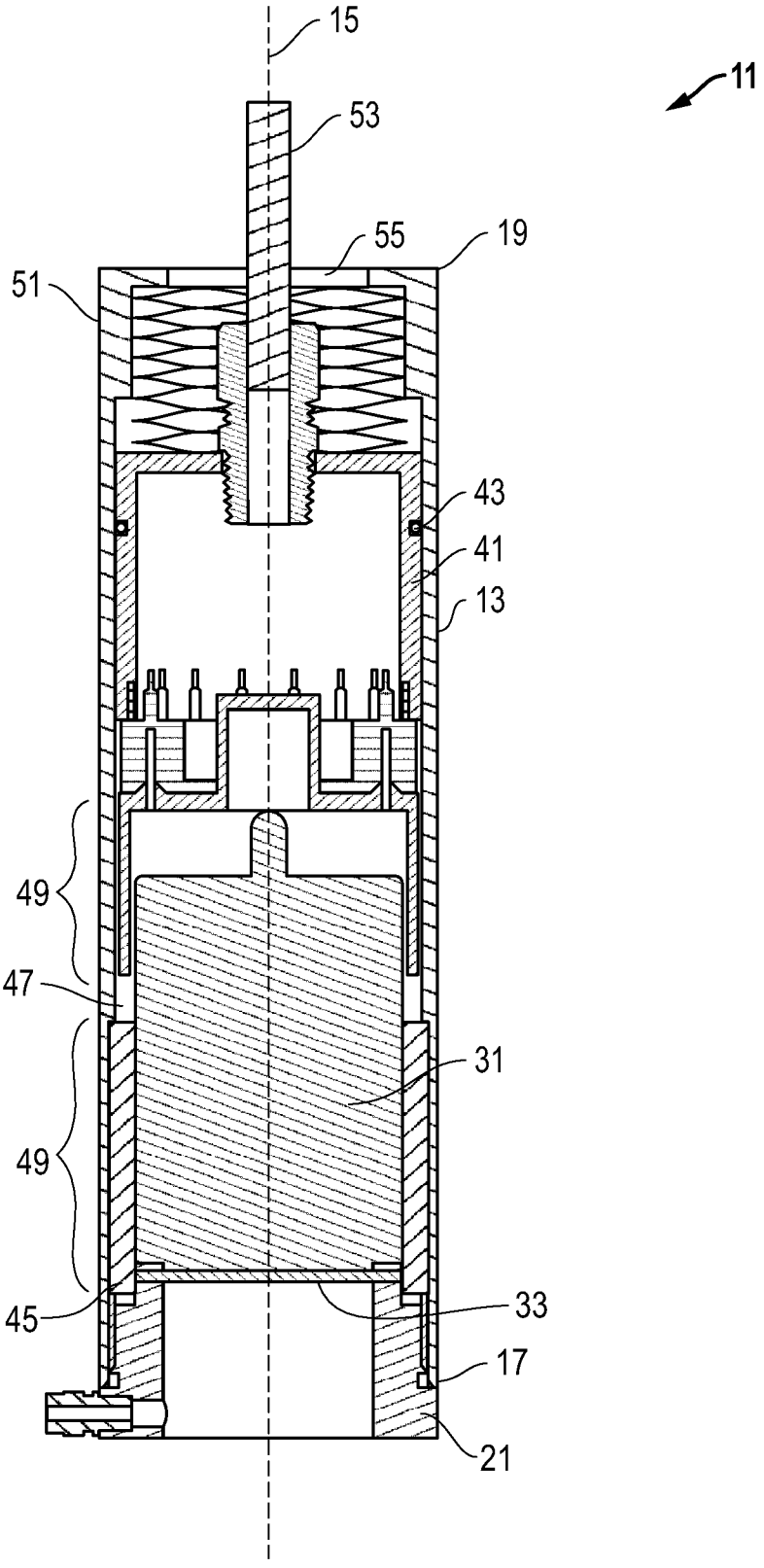


FIG. 2

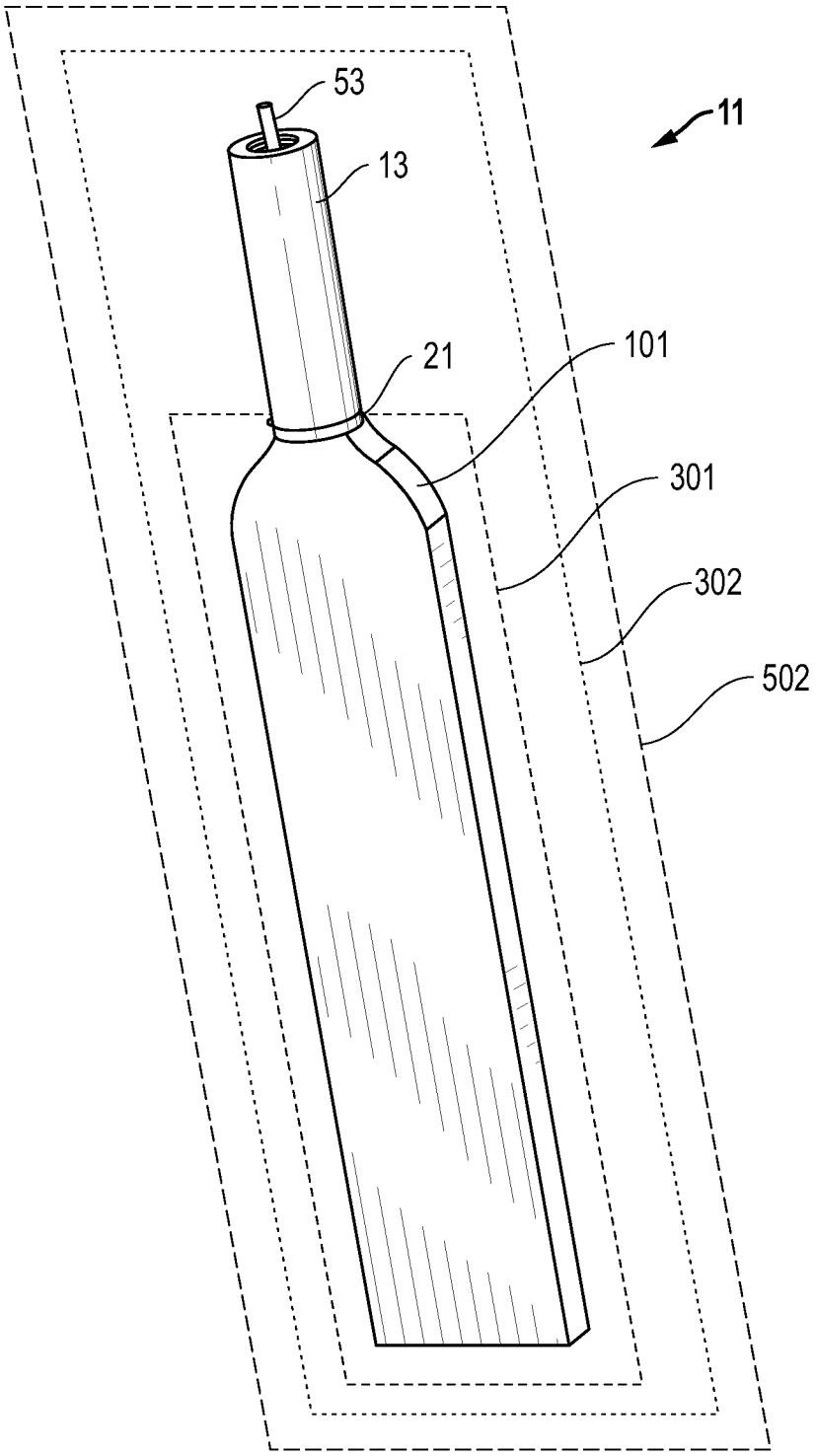


FIG. 3

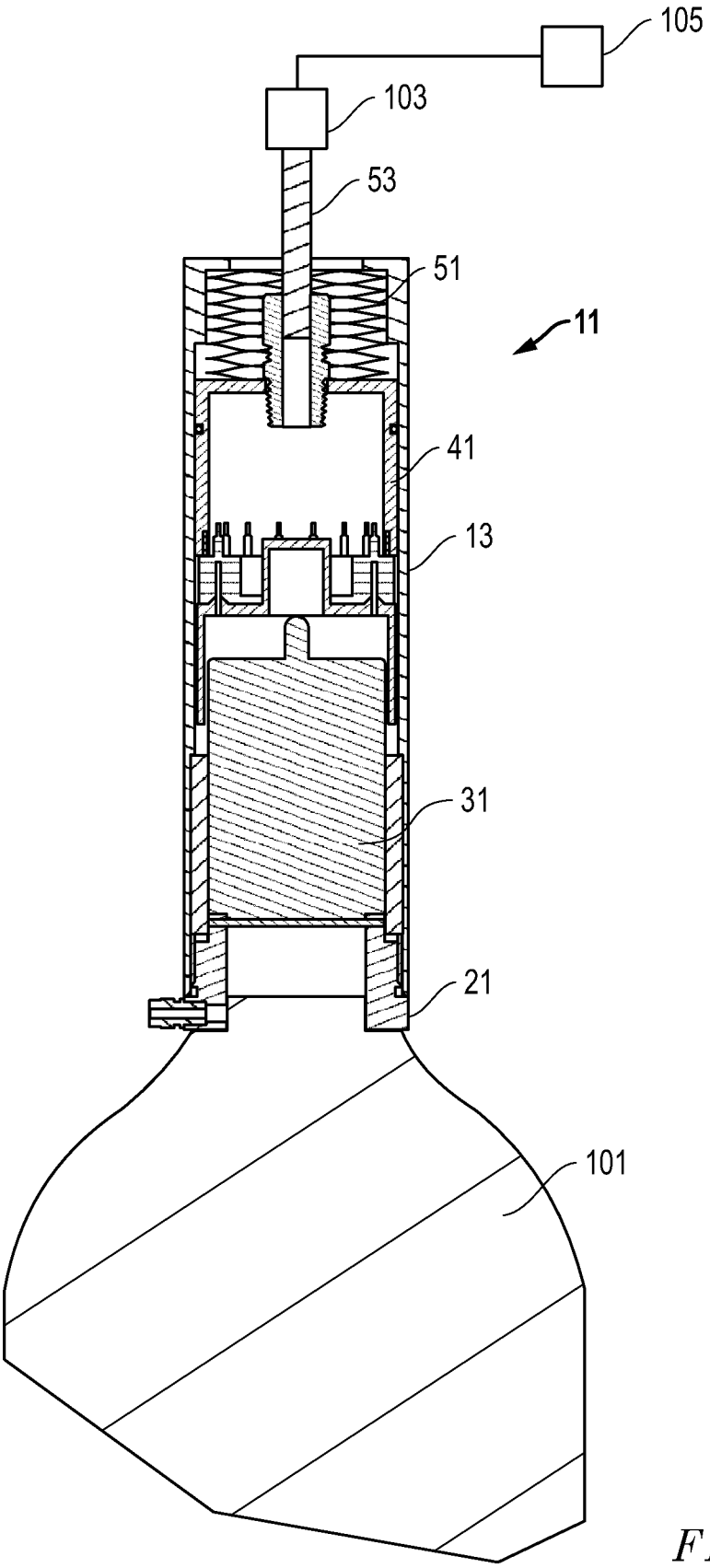


FIG. 4

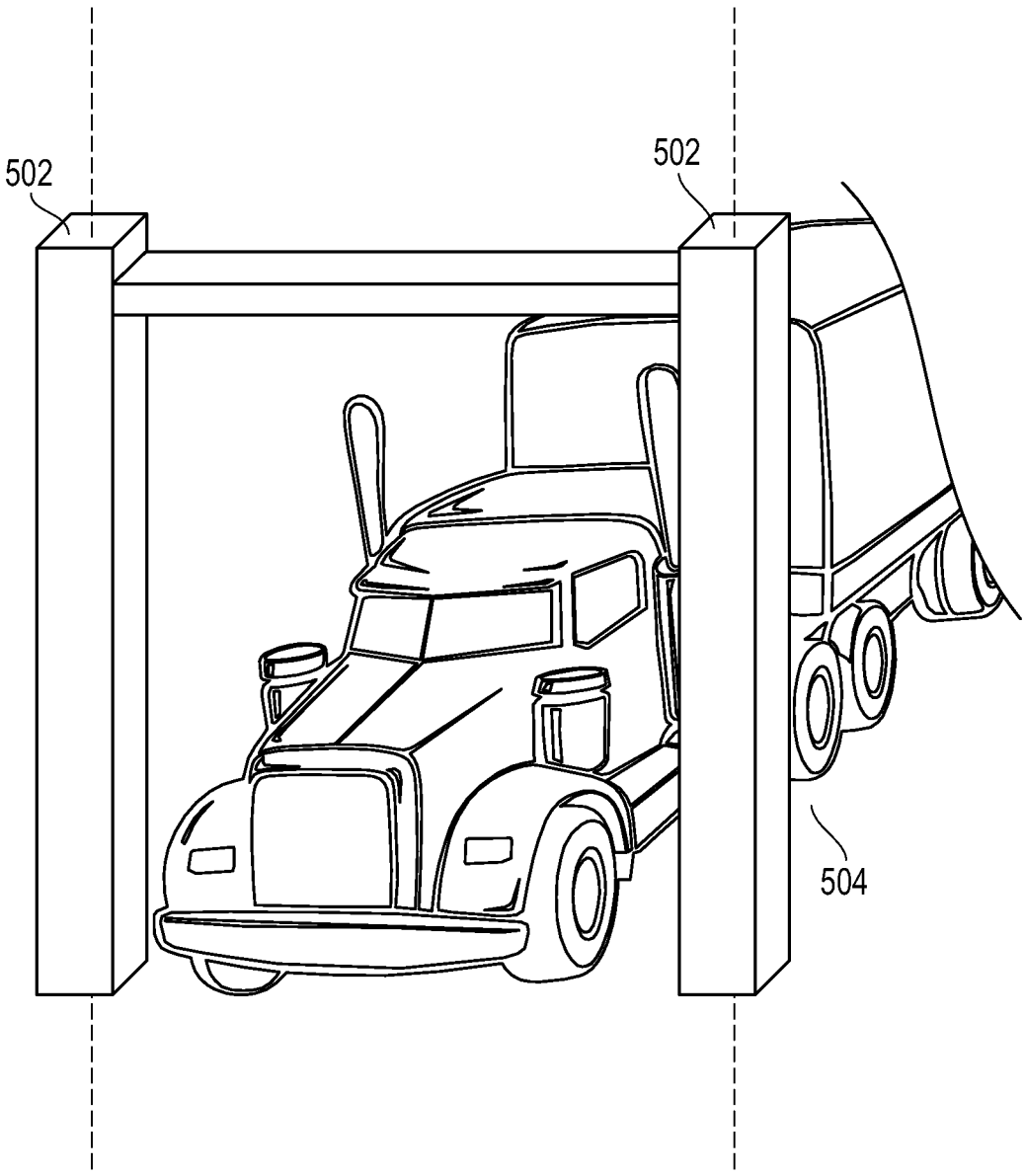


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/068700

A. CLASSIFICATION OF SUBJECT MATTER

GOIT 1/20(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)

GOIT 1/20; GOIT 1/202; GOIV 5/04; B32B 5/00; G01T 1/164; G01T 3/06; G01N 31/00

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: photosensor, scintillator, housing, adapter and seal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 05229604 A (LARSON et al.) 20 July 1993	1
Y	See abstract; column 3, line 15 - column 4, line 39 and figure 1.	2-6
Y	US 20II-029I0I4 Al (KUSNER, MICHAEL R.) 01 December 2011	2-6
A	See abstract; paragraphs 24-54 and figures 1-4.	1
A	US 2010-0163735 Al (MENGE et al.) 01 July 2010 See abstract; paragraphs 28-40 and figures 1-10.	1-6
A	EP 2071359 A2 (GENERAL ELECTRIC COMPANY) 17 June 2009 See abstract and figure 1.	1-6
A	US 05548116 A (PANDELISEV, KIRIL A.) 20 August 1996 See abstract and figure 1.	1-6

☐ 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
18 MARCH 2013 (18.03.2013)	**19 MARCH 2013 (19.03.2013)**

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

AHN, Jae Yul

Telephone No. 82-42-481-8525

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/068700

Box No. I Nucleotide and/or amino acid sequence(s) (Continuation of iteml.c of the first sheet)

1. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of :

a. **a sequence listing filed or furnished**
- ☐ on paper
- ☐ in electronic form

b. time of filing or furnishing
- ☐ contained in the international application as filed
- ☐ filed together with the international application in electronic form
- ☐ furnished subsequently to this Authority for the purposes of search

2. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

3. Additional comments:

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/068700

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 7-36
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. Ill Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/068700

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 05229604 A	20.07. 1993	US 05229604 A	20.07. 1993
US 2011-0291014 A1	01. 12.2011	W0 2011-153280 A2	08. 12.2011
		W0 2011-153280 A3	05.04.2012
US 2010-0163735 A1	01.07.2010	SG 172388 A1	28.07.2011
		W0 2010-078170 A2	08.07.2010
		W0 2010-078170 A3	10.09.2010
EP 2071359 A2	17.06.2009	CN 101452080 A	10.06.2009
		US 2009-0140150 A1	04.06.2009
		US 7626178 B2	01. 12.2009
US 05548116 A	20.08. 1996	EP 0871901 A1	21. 10. 1998
		EP 0871901 A4	01. 12. 1999
		EP 0871901 B1	02.05.2003
		WO 95-23983 A1	08.09. 1995