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(54) Title: ATTENUATOR SCREEN FOR CONTROLLED TRANSMISSION OF ELECTROMAGNETIC ENERGY TO AN OPTICAL SENSOR FOR STRAY LIGHT REDUCTION

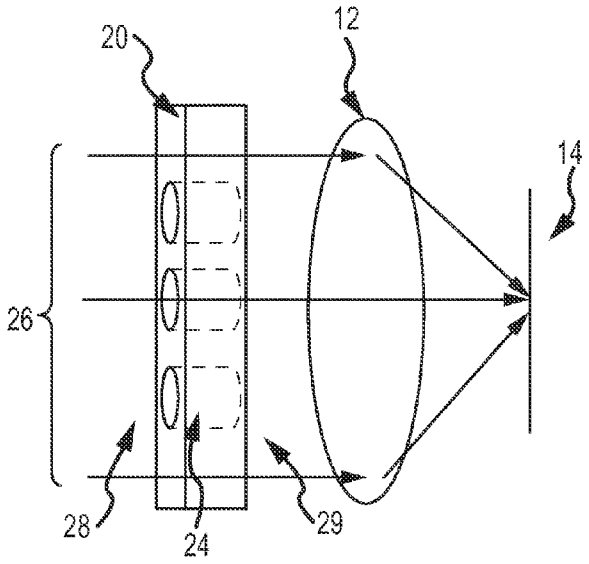


FIG.2

(57) Abstract: An attenuator screen is positioned in front of the focusing optics of an optical sensor to reduce stray light from getting into the FOV of the optical sensor's opto-electronic detector. The attenuator screen comprises a 2-D array of substantially tubular elements whose inner surfaces are optically black within the detection band. Incident EM energy is allowed to pass through the screen up to a cut-off angle beyond which the energy is largely absorbed. The tubular elements may be tapered to provide an approximately flat transmission across the FOV.

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ATTENUATOR SCREEN FOR CONTROLLED TRANSMISSION OF ELECTROMAGNETIC ENERGY TO AN OPTICAL SENSOR FOR STRAY LIGHT REDUCTION

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an apparatus for the controlled transmission of energy to an optical sensor to reduce the effects of stray light by preventing energy from sources beyond a given angle from illuminating the sensor. The invention is useful in combination with the guidance system of guided projectiles.

Description of the Related Art

An optical sensor may comprise focusing optics that focus incident energy at an image plane and an opto-electronic detector positioned at the image plane and configured to generate electronic signals corresponding to the transmitted optical energy incident upon the detector. The detector may be an imaging detector that generates an image of the incident energy or a non-imaging detector that outputs a location of the source of the transmitted energy. In general, the detector may be responsive to a band of electromagnetic (EM) energy that lies between approximately 0.01 um to approximately 15 um (UV 0.01-0.4 um, visible 0.4-0.7um, NIR 0.7-1.1um, SWIR 1.1-2.5 um, MWIR 3-5um or LWIR 8-14 um). Different detectors are configured to detect EM energy in specific bands.

The sensor is configured to detect sources of energy that lie within its Field-of-View (FOV). The sensor's FOV is largely determined by the focal length of the focusing optics and the size of the detector. In the case of a non-imaging detector (e.g. a semi-active laser (SAL) detector), the size of the incident spot of transmitted energy also affects the FOV. Energy that enters the system at an angle within the FOV is imaged onto the detector.

Laser guided ordinance is commonly used to engage targets with a high probability of success and minimal collateral damage. Such ordinance includes guided artillery projectiles, guided missiles, and guided bombs, all of which will be referred to herein as "guided projectiles". A laser guided projectile typically includes a semi-active laser (SAL) seeker to detect pulsed laser EM energy scattered from the intended target and to provide signals indicative of the target bearing such that the projectile can be guided to the target. The SAL may include a non-imaging optical system to capture and focus the scattered laser EM energy onto a quad-cell detector. The optical system may convert the target bearing to an irradiance distribution or "spot" positioned on the detector. As the target bearing changes the location of the spot on the detector changes. The location of the spot determines the bearing to target. The guidance computer is responsive to the location of the spot (bearing to target) to maneuver the projectile. The seeker's FOV is determined by the focal length of the optical system, the size of the detector and to a lesser extent the spot size. The optical system may also comprise a dielectric band pass filter that passes a narrowband of EM energy to the detector, typically 1.06 microns for SAL. The optical system may also comprise a diffuser that spatially homogenizes the incident EM energy to reduce aberrations caused by atmospheric scintillation.

The SAL seeker's optical system typically comprises one or more optical lenses or mirrors that serve to focus the incident EM energy at an image plane where the detector is positioned. Changing the seeker's FOV ordinarily involves increasing the size of the detector and/or altering the system's lenses or mirrors. Altering the lenses or mirrors may reduce the seeker's effectiveness because less energy may be transmitted to the detector. In addition, increasing the size of the detector tends to add cost and increase package size.

U.S. Patent No. 7,540,449 replaces the optical system including the focusing optics with an energy concentrator that is positioned between the dome and the detector. The energy concentrator is configured to transmit any energy entering the entrance through the exit if the energy enters the entrance within a predetermined acceptance angle, and reject (i.e. reflect) the energy entering the entrance if the energy enters the entrance outside the predetermined acceptance angle. The enegy concentrator defines the FOV, rejecting (reflecting) energy incident at angles greater

than the acceptance angle, and focuses the energy onto the detector. The inner surfaces of the concentrator are highly reflective to preserve the transmission efficiency of energy within the FOV as it may be reflected multiple times before being passed to the detector as shown in Figure 6 of the '449 patent. The concentrator uses geometry to reflect energy outside the FOV multiple times to turn the energy around and reflect it back away from the concentrator as shown in Figure 5 of the '449 patent .

SUMMARY OF THE INVENTION

The following is a summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not intended to identify key or critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description and the defining claims that are presented later.

The present invention provides means for reducing stray light in an optical sensor. An attenuator screen is positioned in front of the focusing optics of an optical sensor to reduce stray light from getting into the FOV of the optical sensor's opto-electronic detector. The attenuator screen comprises a 2-D array of substantially tubular elements whose inner surfaces are optically black within the detection band. Incident EM energy is allowed to pass through the screen up to a cut-off angle beyond which the energy is substantially absorbed. In an embodiment, the reflectance across all angles of incidence referenced to the screen is at most 10%. The tubular elements may be tapered to provide an approximately flat transmission across the FOV:

These and other features and advantages of the invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments, taken together with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram illustrating the effects of stray light on an optical sensor;

FIG. 2 is a diagram of an embodiment of an optical sensor comprising an attenuator screen;

FIG. 3 is a plan view of an embodiment of an attenuator screen;

FIGs. 4a through 4c are section views of different AOI of EM energy to the

tubular elements;

FIG. 5 is a plot transmittance versus angle of incidence for different aperture configurations;

FIG. 6 is a section view of an array of tapered tubular elements;

FIG. 7 is a plot of transmittance, absorbance and reflectance versus angle of incidence for an aperture configuration in which the roll-off angle is zero;

FIG8. 8 is a plan view of an embodiment of a 2-D array of tubular elements having varying entrance apertures;

FIGs. 9a and 9b are plan and section views of an embodiment of a 2-D array of tubular elements having varying length;

FIGs. 10a and 10b are a diagram of a guided projectile including an attenuator screen and a quad-cell detector; and

FIG. 11 is a plot of transmittance, absorbance and reflectance versus angle of incidence for a SAL seeker.

DETAILED DESCRIPTION OF THE INVENTION

As shown in Figure 1, an optical sensor **10** comprising focusing optics **12** and an opto-electronic detector **14** (nominally near to but not coincident with the image plane of the focusing optics) is configured to have a desired FOV **16**. Incident EM energy that enters within a predetermined acceptance angle is focused to a point on the detector. EM energy that enters outside the predetermined acceptance angle is rejected. However in any practical system, light anywhere in the hemisphere about the desired FOV may (a) scatter into the desired FOV prior to entering the optical system off for example a dome **18** or other physical structures or (b) enter the optical system and scatter/reflect into the desired FOV. This "stray light" degrades the performance of the detector. In an imaging system, stray light may create specific artifacts in the image or simply degrade overall Signal-to-Noise Ratio (SNR) of the image. In a non-imaging system, each cell of the detector integrates the incident energy so specific artifacts can shift the apparent location of the spot or reduce SNR. The goal is to keep ALL sources of light that originate outside the desired FOV from entering the desired FOV and being transmitted to the detector.

In standard optical systems, light at all angles enters the optical system. In

theory, light outside the FOV is rejected by focusing it to a spatial point outside the spatial extent of the detector. However, light outside the FOV may be scattered into the FOV prior to entering the optical system. Furthermore, light outside the FOV may enter the optical system and be scattered or ghost reflected (off multiple internal surfaces of refractive optics) into the desired FOV.

The use of a concentrator in non-imaging systems mitigates the latter stray light path by rejecting light outside the FOV. However, this rejected light is reflected backwards where it is scattered by the dome and other structures. A portion of this light will enter the desired FOV. Depending on many factors, the concentrator may actually increase the amount of stray light that enters the desired FOV and is focused onto the detector.

Referring now to Figures 2 and 3, an embodiment of the present invention places an attenuator screen **20** comprised of a 2-D array **22** of substantially tubular elements **24** at the entrance to the optical system to focusing optics **12** and opto-electronic detector **14**. The tubular elements may be integrally formed as through holes in a plate or individually formed and arranged into the 2-D array. The 2-D array may, for example, be a uniform grid or a honeycomb structure. As used herein the term tubular element is deemed to mean an element of a generally tubular configuration having any selected geometrical cross-sectional shape. The cross-sectional shape may or may not be uniform across the array. The scale of the cross-sectional shape may vary within a tubular element or across the array. The tubular elements may, for example, have a circular, oval, rectangular, triangular, hexagonal, etc. cross-sectional shape.

The attenuator screen transmits EM energy **26** in the desired FOV from an entrance **28** (front surface of the screen) through an exit **29** (back surface of the screen) to focusing optics **12** and largely absorbs energy at angles of incidence outside the FOV. The angles of incidence are measured with respect to the surface normal of the attenuator screen. For example, in an embodiment at most 10% of the incent EM energy is reflected whether inside or outside the FOV. By absorbing this energy the attenuator screen largely eliminates stray light entering the optical system outside the FOV and being scattered/reflected within the optics back into the FOV. Furthermore by absorbing this energy the attenuator screen reduces the amount of reflected energy that may be scattered/reflected outside the optical system and then reenter the optical system within

the desired FOV. By placing the attenuator screen up front, the major component of light originating from sources outside the FOV and passed through the dome is eliminated (or greatly attenuated) early on.

The mechanism by which the attenuator screen operates is to pass EM energy **26** that enters at an angle of incidence (AOI) whereby the EM energy does not contact an inner surface **30** of tubular element **24** (Figure 4a) and to absorb EM energy that enters at an AOI whereby the EM energy does contact the inner surface **30** (Figure 4b). At certain angles of incidence the EM energy will be partially transmitted at partially absorbed (Figure 4c). The fraction of EM energy that is transmitted by the screen (which is called the screen transmittance) at a given AOI is substantially determined by the geometric details of the tubular elements, such as their aspect ratio (length divided by width) and spacing.

In general, the screen transmittance **40** decreases as the AOI increases, dropping substantially to zero at AOIs greater than or equal to a given angle (called the cutoff angle **42**), as shown in Figure 5. The greater the aspect ratio of the tubular elements, the steeper the slope of the screen transmittance variation with AOI. The maximum value of the screen transmittance function occurs at normal incidence (AOI=0), and is determined by the areal density at which the tubular elements can be packed side-by-side and the diameter of their apertures. Because the packing density cannot be infinite, the maximum value of the screen transmittance is always less than 100%. In general, as the AOI increases, more EM energy strikes the inner diameters of the tubular elements, and thus less EM energy is transmitted. EM energy not transmitted by the attenuator screen is either absorbed or reflected/scattered by its material or coating. The more "optically black" this material or coating is over the wavelength band to which the detector is sensitive, the more EM energy is absorbed. In general, the fraction of EM energy absorbed by the coating varies with the AOI. This fraction is never 100%, and thus there is always some EM energy that is reflected/scattered.

In general, reflectance from an optically black material or coating is specified at at normal incidence (AOI=0). The reflectance increases as the AOI increases. In the attenuator screen the tubular elements are oriented, generally perpendicular to the surface of the screen, such that as the AOI referenced to the attenuator screen increases, the AOI referenced to the inner surfaces of the tubular elements decreases. Thus, for larger AOI

(referenced to the screen) outside the FOV the optically black surfaces absorb EM energy more efficiently.

The placement of the attenuator screen in the aperture of the optical system may result in significant loss of transmitted energy within the FOV. Unlike the human vision system, which can readily accommodate transmission losses, opto-electronic detectors can very sensitive to a reduction in incident signal energy, which in turn reduces the SNR. For applications such as a SAL seeker the loss of SNR directly affects acquisition range of the system. Those skilled in the art are in general agreement that placement of optical elements in the aperture that reduce transmission efficiency is undesirable.

If the tubular elements have a constant cross-section along the length of the element, transmittance **40** starts to decrease with any non-zero AOI (roll-off angle = 0). However, if as shown in Figure 6 tubular elements **24** are tapered from an entrance aperture **44** to a larger exit aperture **46** the transmittance will remain approximately flat up to a roll-off angle **48** and than roll-off to approximately zero transmittance at cut-off angle **42**. The taper allows EM energy **26** up to the roll-off angle **48** to pass through the optically black tubular element without clipping its inner surface and being at least partially absorbed. The greater the taper, the larger the roll-off angle. However, there is a distinct trade-off. Reducing the size of the entrance aperture **44** reduces the fill-factor (percentage of the front surface of the screen that constitutes openings), which in turn reduces the overall transmittance.

In an embodiment, the aspect ratio of the tubular elements is equal to the aspect ratio of the FOV of the optical sensor. This sets the acceptance angle of the FOV equal to the cut-off angle of the attenuator.

In another embodiment, the tubular elements are tapered such that acceptance angle of the FOV is approximately equal to the roll-off angle. Although generally undesirable to further reduce the transmittance, an approximately flat transmittance over the FOV may be advantageous. The existing electronics and control algorithms for many optical sensors are design for a flat transmittance over AOI. These electronics and control algorithms would have to be redesigned. In this configuration, some EM energy outside the FOV will pass through the attenuator screen but will be significantly attenuated.

In another embodiment, the tubular elements are tapered such that acceptance

angle of the FOV is positioned between the roll-off angle and the cut-off angle.

Figure 7 plots the transmittance **40**, absorbance **50** and reflectance **52** for the roll-off angle=0 configuration of the tubular elements. As transmittance **40** decreases with AOI absorbance **50** increases. In this embodiment, reflectance **52** is less than 10% of the incident EM energy across all angles of incidence. Thus, the EM energy can be passed onto the optic sensor within its FOV while substantially attenuating any reflections.

The tubular elements that makeup the 2-D array may or may not be uniform throughout the array. The tubular elements may be varied to improve "fill-factor" or to increase the slope of the transmittance from the roll-off angle to the cut-off angle, for example. The tubular elements may be varied by varying their entrance apertures or varying their length. The tubular elements may be parallel to each other or non-parallel.

Referring now to Figure 8, an embodiment of a 2-D array of tubular elements is depicted in which the diameter of the tubular elements **24** is varied. This allows the areal density of the tubular elements to be increased over an embodiment that uses tubular elements **24** of constant diameter, and thus the maximum transmittance **40** of the screen can be increased. This also makes the slope (transmittance/AOI) of the screen transmittance **40** less negative, which may or may not be desirable for a given system.

Referring now to Figures 9a-9b, an embodiment of a 2-D array of tubular elements is depicted in which the length of the tubular elements **24** is varied by varying the thickness of the screen **20** over its diameter. Tubular elements **24** with greater length result in a screen transmittance with a more negative slope, which may be desirable for some systems.

Stray light can be particularly problematic for SAL seekers used in guided projectiles. The SAL seeker attempts to locate the "spot" of laser energy reflected off a target to determine the bearing to target and maneuver the projectile. Stray light can distort the location of the spot, hence the bearing to target. Stray light may also cause the seeker's system transfer function that maps the detected spot location to target bearing to rollover at larger AOI thereby reducing the usable linear region of the seeker. This is particular true if a diffuser is inserted into the optical path to reduce atmospheric scintillation. Although inserting any optical element into the aperture that will reduce transmission is generally considered to be undesirable, the insertion of the attenuator screen to reduce stray light to both improve SNR and increase the usable linear region of

the system transfer function may in some cases offset the loss of transmitted energy.

Referring now to Figures 10a-10b, an embodiment of a guided projectile **60** comprises a projectile body **62**, a guidance controller **64** within the body, one or more control surfaces **66** (e.g. fins, canards, etc) connected to the body and responsive to the guidance controller, an optical window **68** connected to the body that transmits incident EM energy inside the body and an optical sensor **70** inside the body. Optical sensor **70** comprises focusing optics **72** that focus the incident EM energy and an opto-electronic detector **74** configured to generate signals corresponding to a location of the EM energy incident upon the detector and provide those signals to the guidance controller. Detector configurations such as the quad-cell detector shown in Figure 8b and techniques for processing the detected signals to generate the signals corresponding to the spot location, hence bearing to target are well known to those skilled in art. The focusing optics and detector define a FOV in which EM energy within a predetermined acceptance angle is focused onto the detector.

The optical sensor may also comprise a dielectric band pass filter **76** that passes a narrowband of EM energy to the detector, typically 1.064 microns for SAL, and/or a diffuser **78** that spatially homogenizes the incident EM energy to reduce aberrations caused by atmospheric scintillation. The band pass filter **76** reflects substantially all of the EM energy outside the narrow band around 1.064 microns and reflects the EM energy inside the narrow band at high AOI. To perform it's function diffuser **78** scatters light. Either the band pass filter or the diffuser can exacerbate the stray light problem.

An attenuator screen **80** is positioned between the focusing optics **72** and the incident EM energy. Attenuator screen **80** comprises a two-dimensional array of substantially tubular elements **82**. The tubular elements have inner surfaces that are substantially optically black in the detection band of the opto-electronic detector. The screen is configured to allow the EM energy to pass through the optically black tubular elements if the EM energy enters within a predetermined cut-off angle with at most 10% of the EM energy reflected and absorb at least 90% of the EM energy in the optically black inner surfaces of the tubular elements if the EM energy enters outside the predetermined cut-off angle. The predetermined acceptance angle is suitably less than or approximately equal to the cut-off angle.

Figure 11 is a plot of transmittance **90**, reflectance **92** and absorbance **94** for an

embodiment of a SAL seeker in which the tubular elements are tapered to provide a roll-off angle of approximately 15 degrees. Transmittance **90** is approximately flat for AOI from 0 to 15 degrees and rolls off to approximately zero at a cut-off angle of approximately 25 degrees. Reflectance **92** is less than 10% across all AOI. Essentially, energy that is not transmitted through the attenuator screen to the focusing optics and the detector is absorbed. The FOV of the SAL seeker may be set at approximate 15 degrees. As such the transmittance of EM energy through the focusing optics to the detector is essentially flat. The existing electronics and guidance algorithms for a SAL seeker assume this condition. Existing SAL designs may be retrofit to use the attenuator screen configured in this manner with minimal redesign.

While several illustrative embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Such variations and alternate embodiments are contemplated, and can be made without departing from the spirit and scope of the invention as defined in the appended claims.

WE CLAIM:

1. An optical sensor, comprising:

an attenuator screen comprising a two-dimensional array of substantially tubular elements, said tubular elements having inner surfaces that are substantially optically black in a detection band, said screen configured to:

allow electromagnetic (EM) energy to pass through the optically black tubular elements if the EM energy enters within a predetermined cut-off angle; and

absorb EM energy in the optically black inner surfaces of the tubular elements if the EM energy enters outside the predetermined cut-off;

focusing optics that focus the transmitted EM energy; and

an opto-electronic detector configured to generate signals corresponding to the transmitted EM energy incident upon the detector.

2. The optical sensor of claim 1, wherein the attenuator screen absorbs at least 90% and reflects less than 10% of the EM energy outside the predetermined cut-off angle.

3. The optical sensor of claim 1, wherein the attenuator screen reflects less than 10% of the EM energy within the predetermined cut-off angle.

4. The optical sensor of claim 1, wherein the focusing optics and detector define a field-of-view (FOV) in which EM energy within a predetermined acceptance angle is focused onto the detector.

5. The optical sensor of claim 4, wherein the focusing optics comprise one or more optical lenses, mirrors or concentrators.

6. The optical sensor of claim 4, wherein the predetermined acceptance angle is approximately equal to the predetermined cut-off angle.

7. The optical sensor of claim 4, wherein the transmission of EM energy through the exit is approximately flat out to a predetermined roll-off angle and rolls-off to

approximately zero at the cut-off angle.

8. The optical sensor of claim 7, wherein the predetermined acceptance angle is approximately equal to the roll-off angle.

9. The optical sensor of claim 7, wherein the predetermined acceptance angle is set between the roll-off angle and the cut-off angle.

10. The optical sensor of claim 7, wherein the tubular elements taper from an entrance aperture to a larger exit aperture to set the predetermined roll-off angle.

11. The optical sensor of claim 1, wherein the substantially tubular elements have an aspect ratio that varies over the array.

12. The optical sensor of claim 11, wherein the substantially tubular elements have entrance apertures that vary in size or shape.

13. The optical sensor of claim 11, wherein the length of the substantially tubular elements varies.

14. The optical sensor of claim 1, wherein the detector is configured to generate signals corresponding to a location of the transmitted EM energy incident upon the detector.

15. An optical sensor, comprising:

focusing optics that focus the incident electromagnetic (EM) energy;

an opto-electronic detector configured to generate signals corresponding to the EM energy incident upon the detector, said focusing optics and detector defining a field-of-view (FOV) in which EM energy within a predetermined acceptance angle is focused to a point on the detector; and

an attenuator screen between the focusing optics and the incident EM energy, said attenuator screen comprising a two-dimensional array of substantially tubular elements,

said tubular elements having inner surfaces that are substantially optically black in a detection band, said screen configured to:

allow the EM energy to pass through the optically black tubular elements if the EM energy enters within a predetermined cut-off angle set by an aperture ratio of the tubular elements with at most 10% of the EM energy reflected, the transmission of EM energy being approximately flat out to a predetermined roll-off angle and rolling off to approximately zero at the cut-off angle, said tubular elements tapering from an entrance aperture to a larger exit aperture to set the predetermined roll-off angle; and

absorb at least 90% of the EM energy in the optically black inner surfaces of the tubular elements if the EM energy enters outside the predetermined cut-off angle,

said predetermined acceptance angle being approximately equal to the roll-off angle so that the transmission of EM energy within the FOV to the detector is approximately flat.

16. A guided projectile, comprising:

a projectile body;

a guidance controller within the body;

a control surface connected to the body and responsive to the guidance controller;

an optical window connected to the body that transmits incident electromagnetic (EM) energy inside the body; and

an optical sensor inside the body, comprising:

focusing optics that focus the incident electromagnetic (EM) energy;

an opto-electronic detector configured to generate signals corresponding to a location of the EM energy incident upon the detector and provide those signals to the guidance controller, said focusing optics and detector defining a field-of-view (FOV) in which EM energy within a predetermined acceptance angle is focused to a point on the detector; and

an attenuator screen between the focusing optics and the incident EM energy, comprising a two-dimensional array of substantially tubular elements, said tubular elements having inner surfaces that are substantially optically black in a detection band, said screen configured to:

allow the EM energy to pass through the optically black tubular

elements if the EM energy enters within a predetermined cut-off angle with at most 10% of the EM energy reflected; and

absorb at least 90% of the EM energy in the optically black inner surfaces of the tubular elements if the EM energy enters outside the predetermined cut-off angle,

said predetermined acceptance angle being less than or approximately equal to the cut-off angle.

17. The guided projectile of claim 16, further comprising a diffuser between the attenuator screen and focusing optics.

18. The guided projectile of claim 16, further comprising a band pass filter between the attenuator screen and focusing optics.

19. The guided projectile of claim 16, wherein said tubular elements taper from an entrance aperture to a larger exit aperture to set a predetermined roll-off angle, the transmission of EM energy being approximately flat out to the predetermined roll-off angle and rolling off to approximately zero at the cut-off angle.

20. The guided projectile of claim 19, wherein said predetermined acceptance angle is approximately equal to the predetermined roll-off angle.

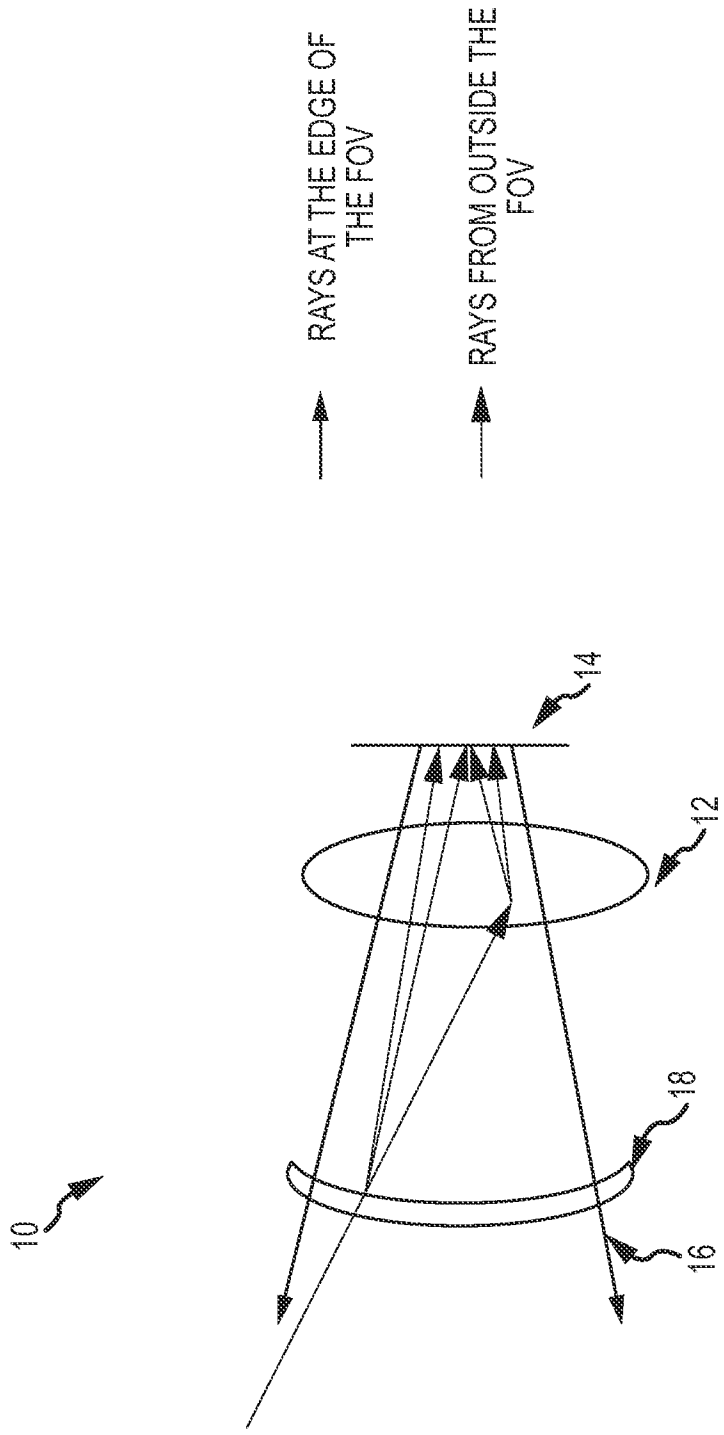

RAYS AT THE EDGE OF THE FOV
RAYS FROM OUTSIDE THE FOV
10
14
12
18
16

FIG. 1

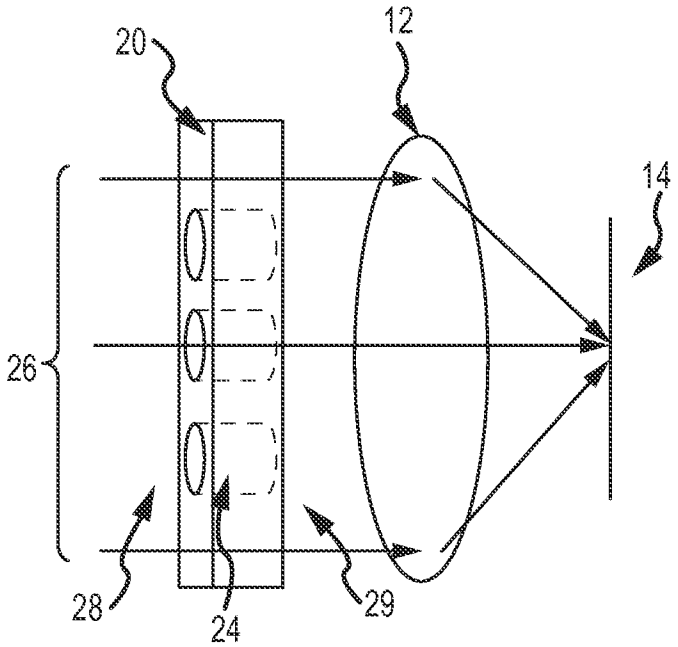


FIG.2

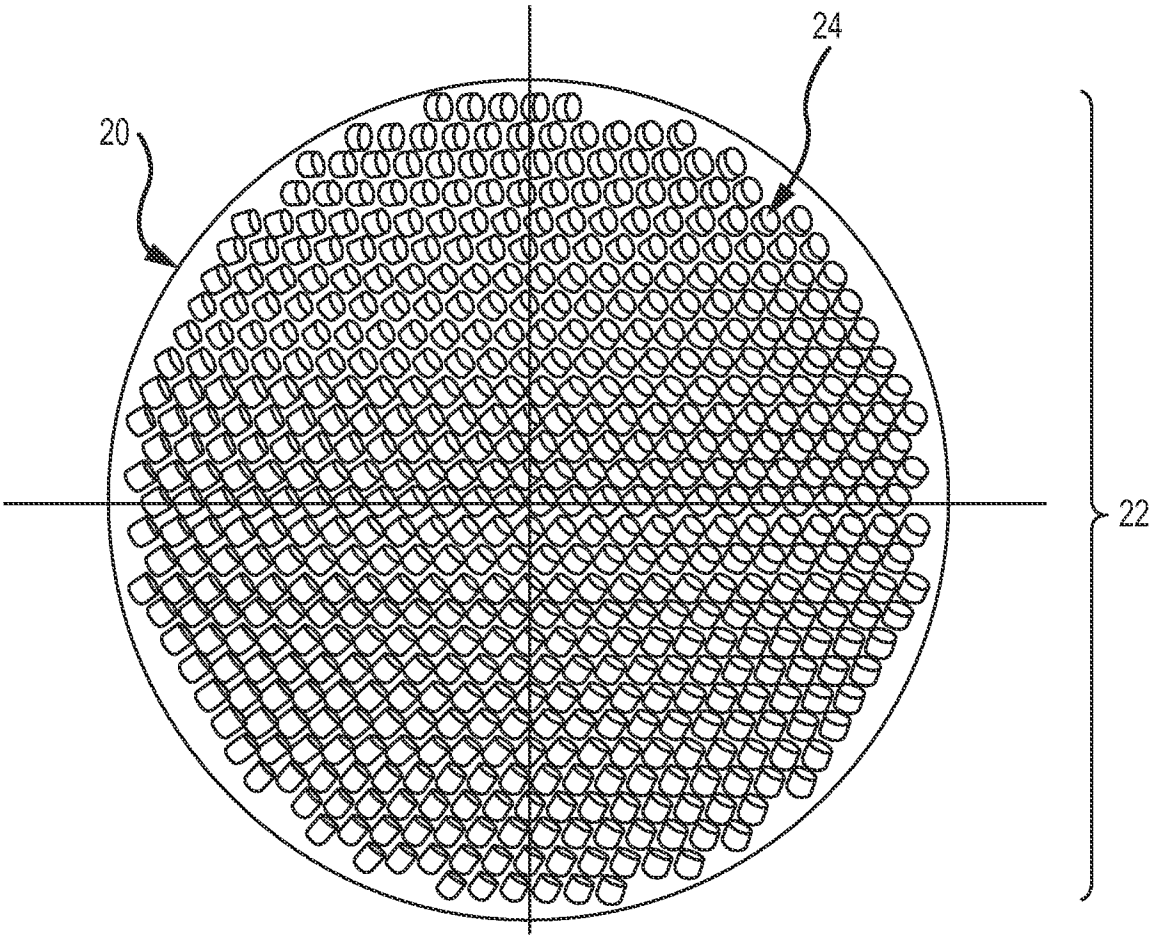


FIG.3

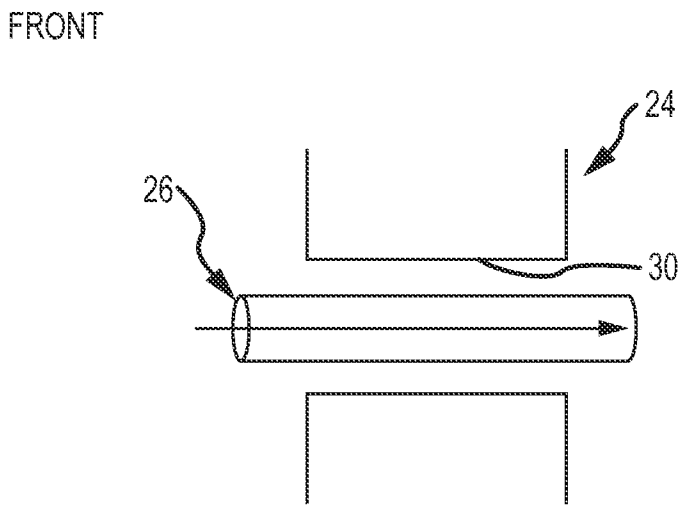


FIG.4a

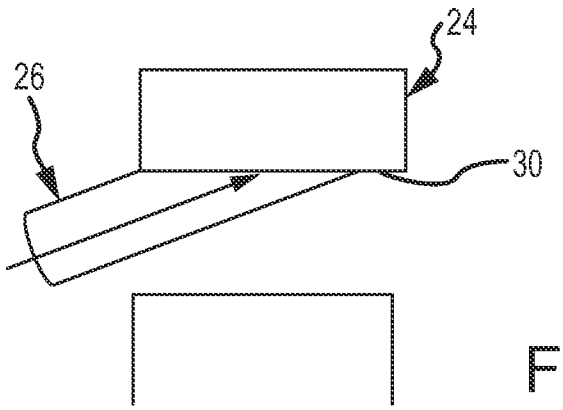


FIG.4b

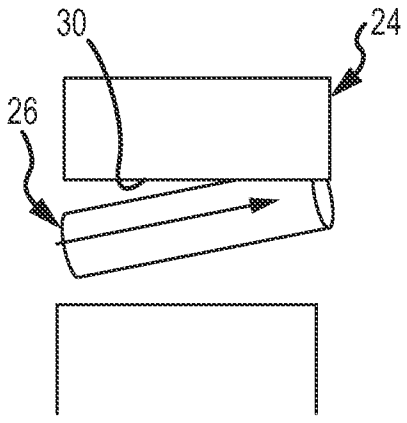


FIG.4c

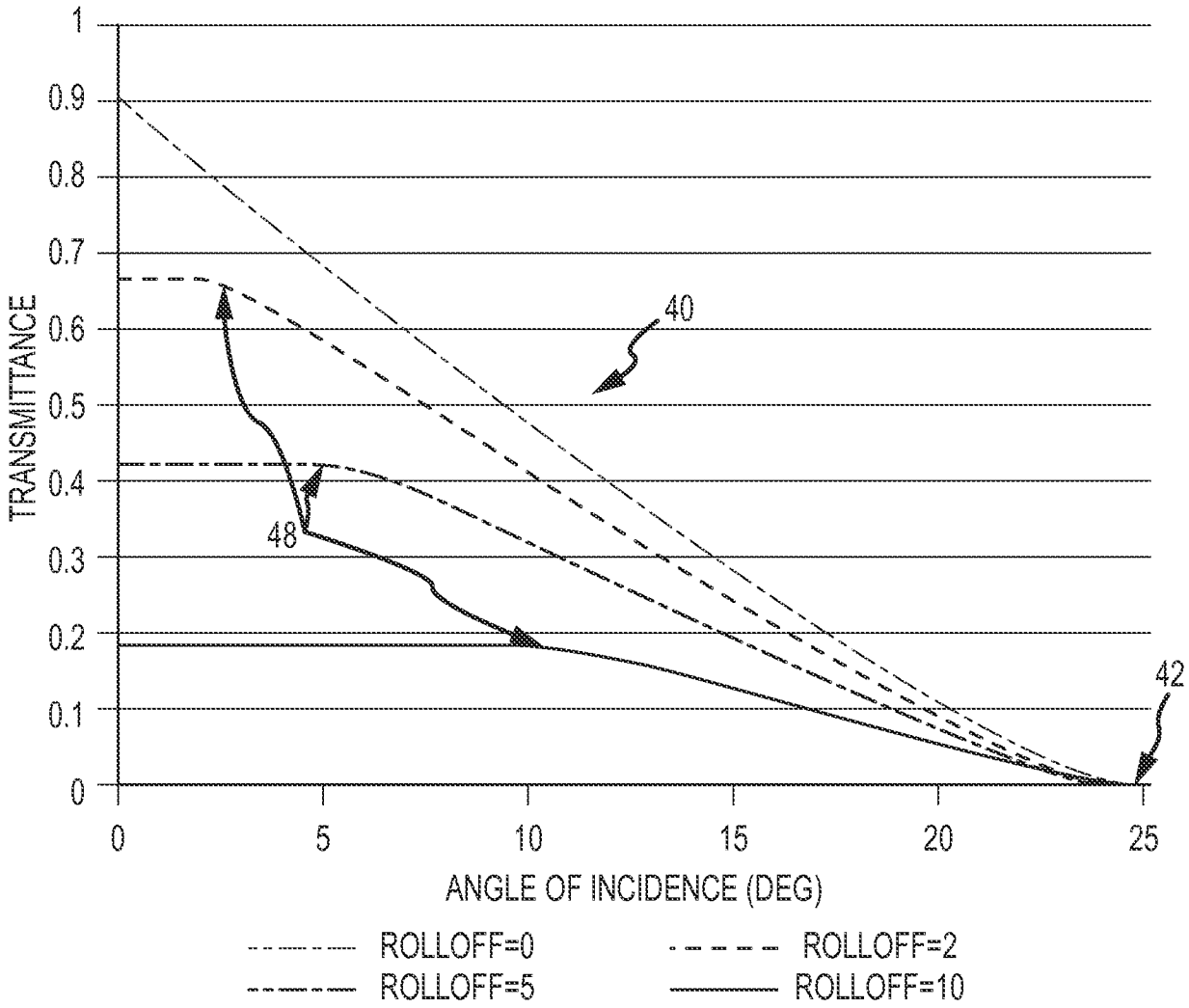

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0.2
0.1
0
TRANSMITTANCE
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10
15
20
25
ANGLE OF INCIDENCE (DEG)
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42
48
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ROLLOFF=2
ROLLOFF=5
ROLLOFF=10

FIG.5

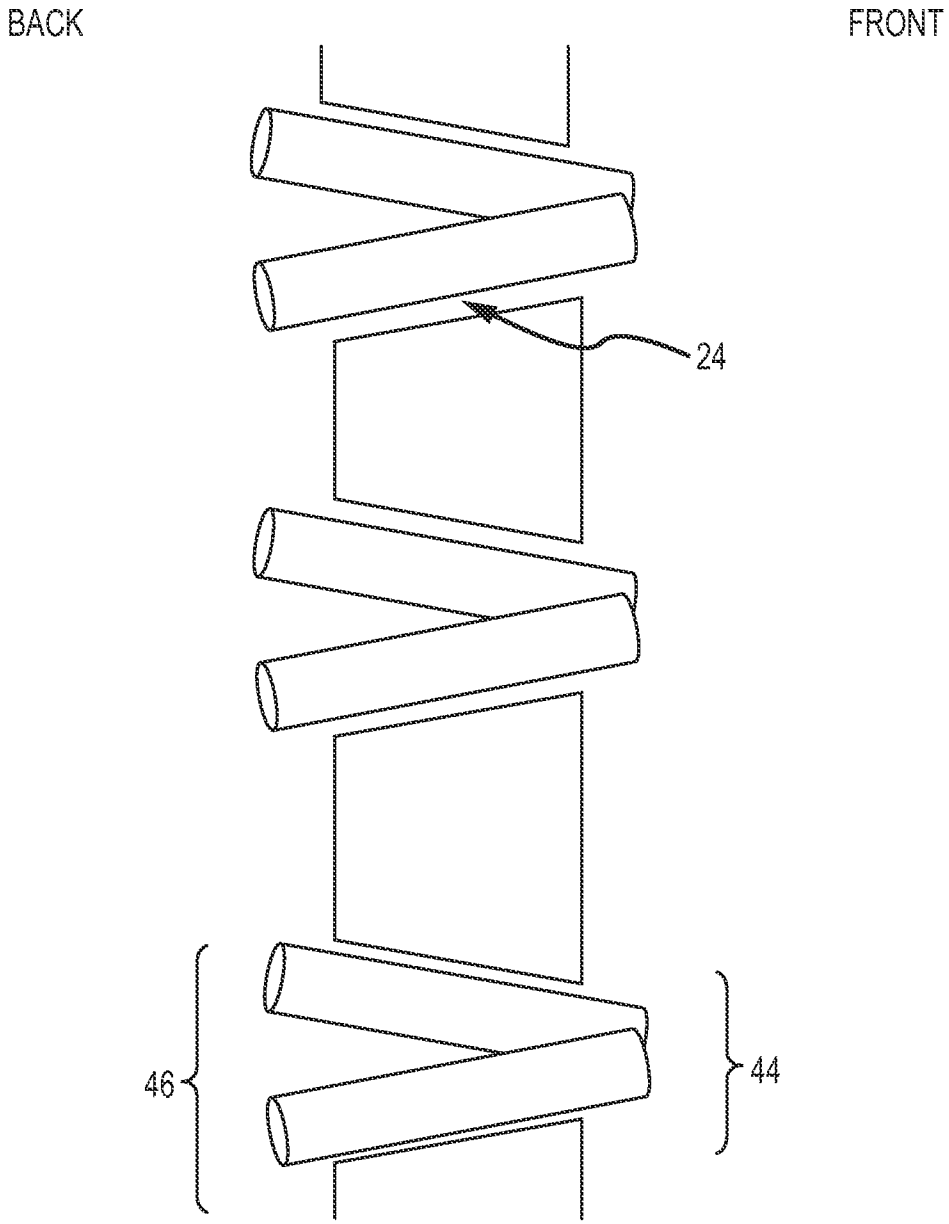


FIG.6

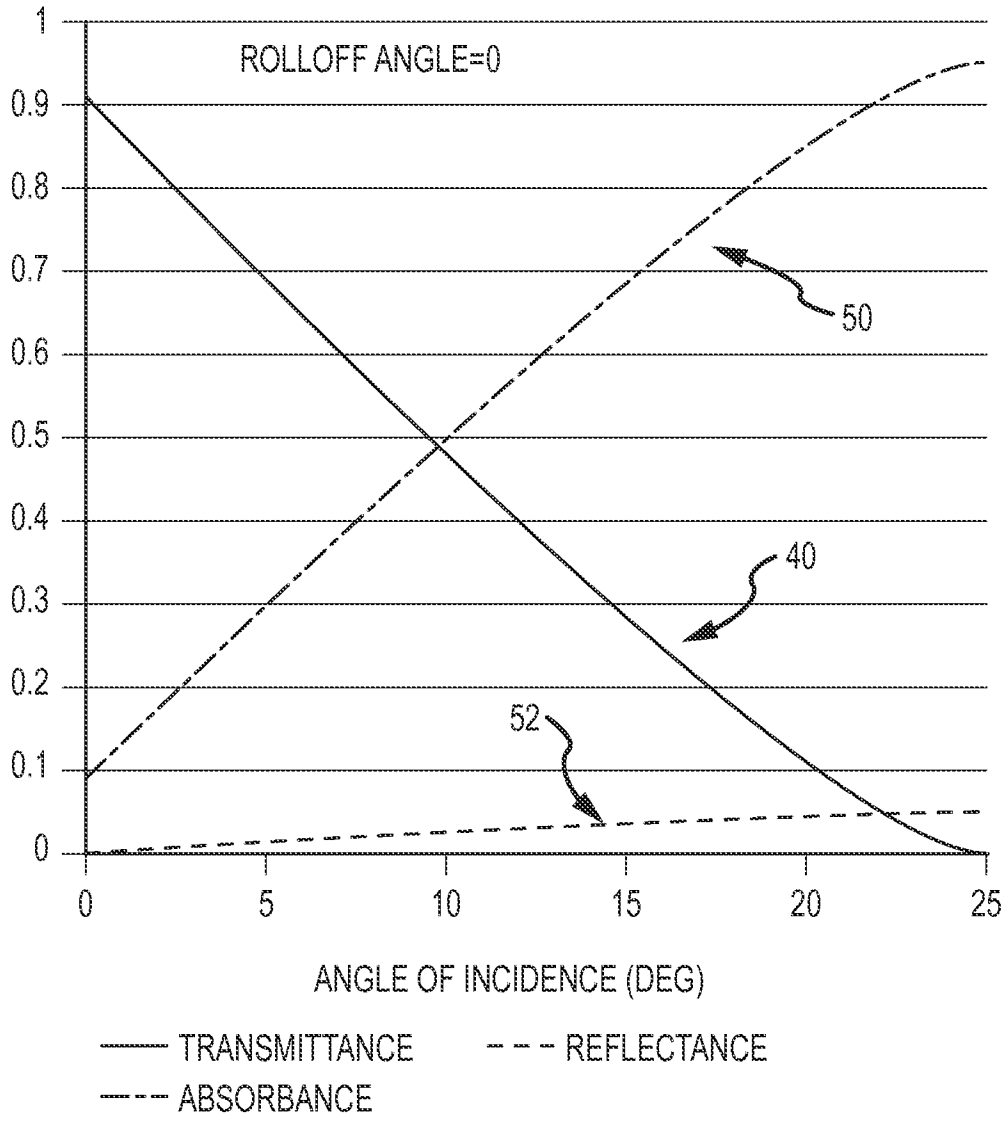

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0.2
0.1
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10
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20
25
50
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52
ANGLE OF INCIDENCE (DEG)
TRANSMITTANCE
REFLECTANCE
ABSORBANCE

FIG.7

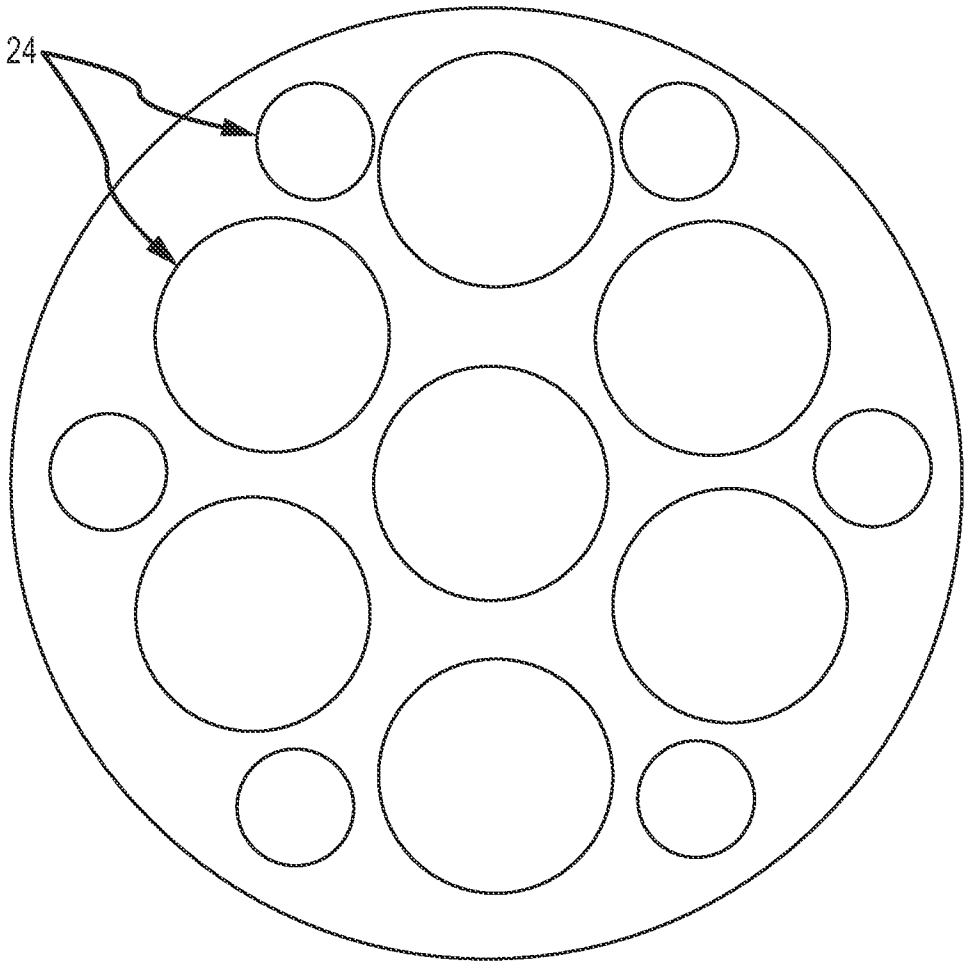


FIG.8

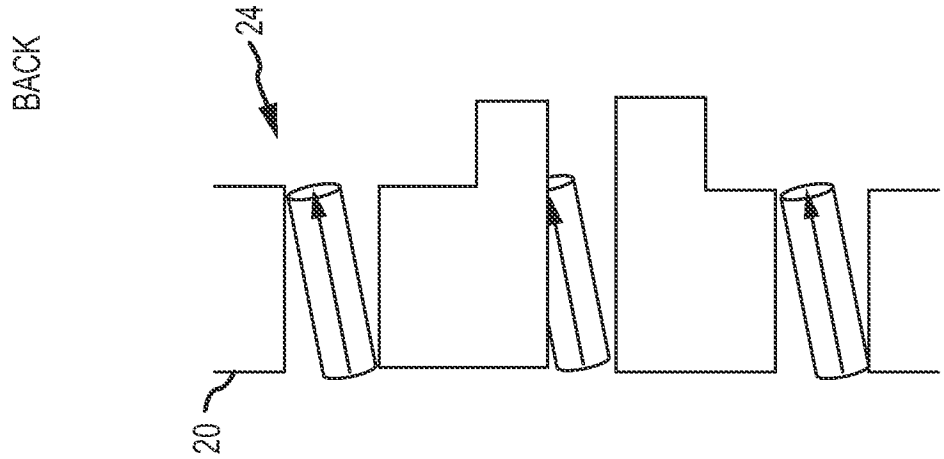


FIG.9b

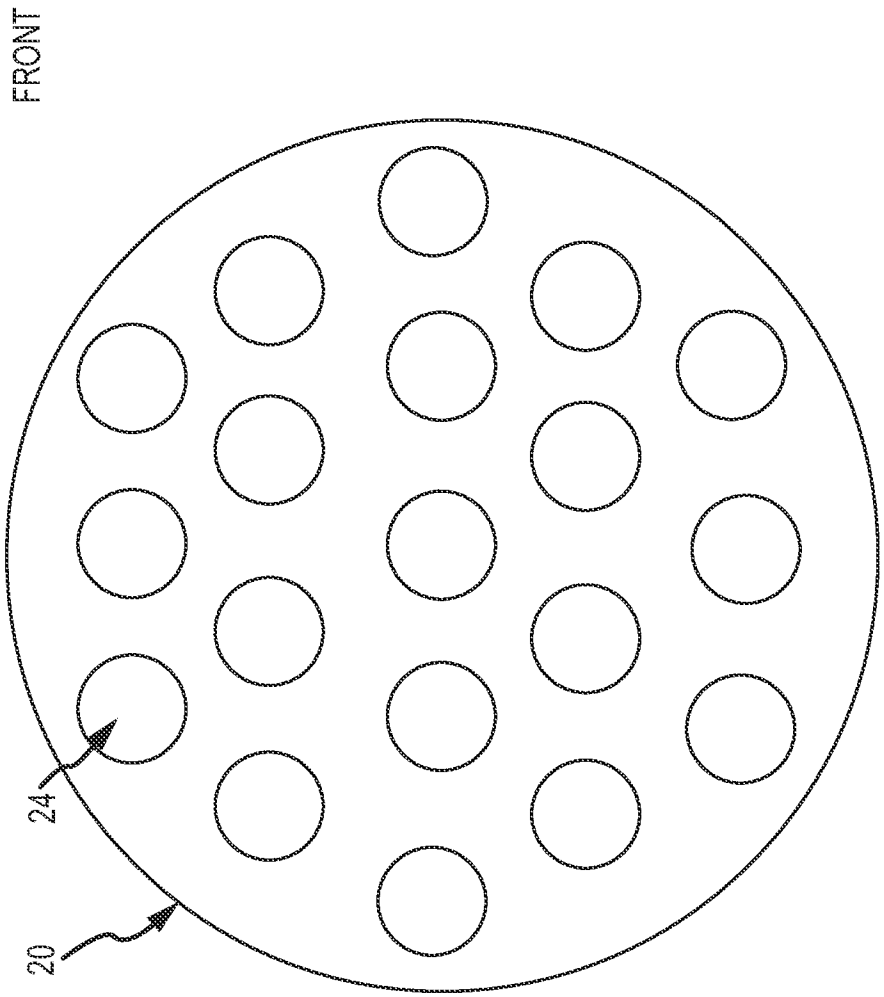


FIG.9a

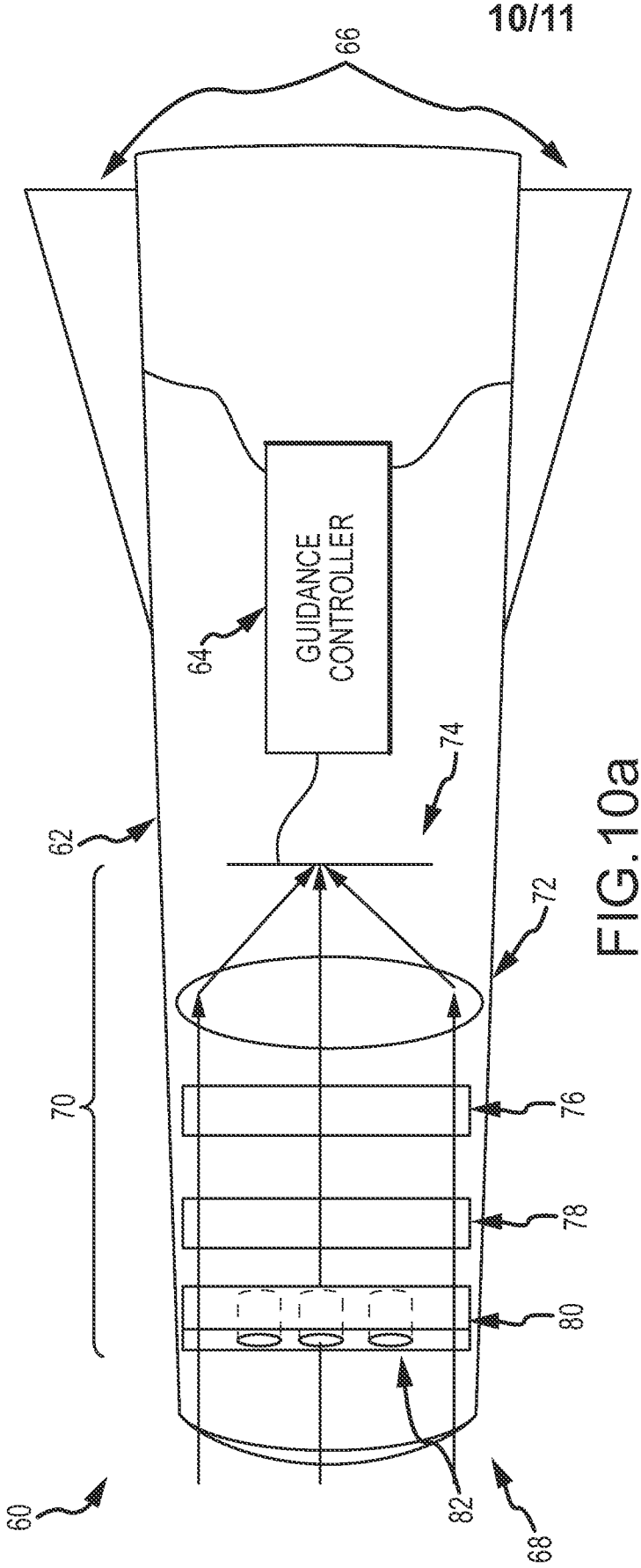


FIG.10a

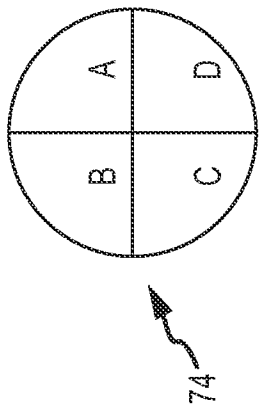


FIG.10b

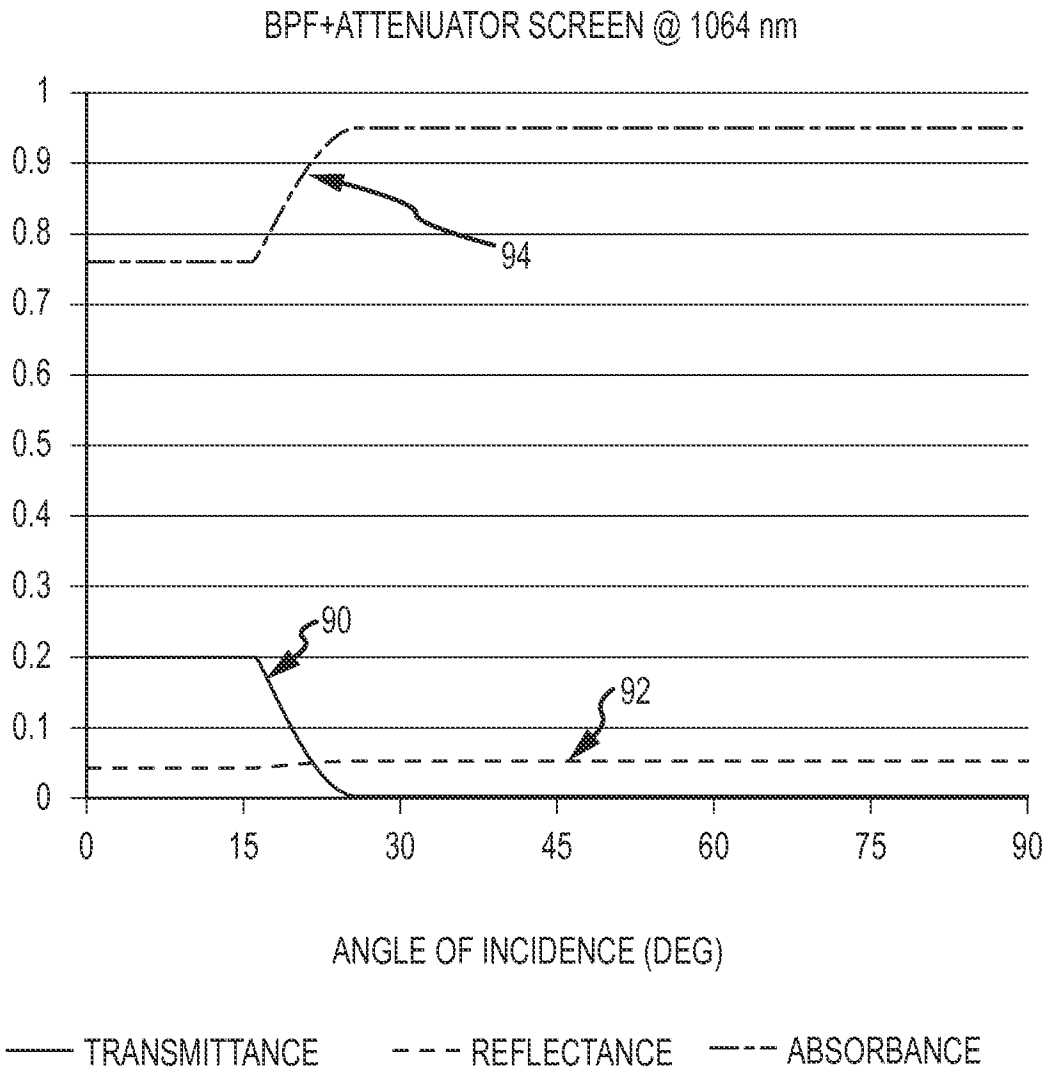

BPF+ATTENUATOR SCREEN @ 1064 nm
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
15
30
45
60
75
90
94
90
92
ANGLE OF INCIDENCE (DEG)
TRANSMITTANCE
REFLECTANCE
ABSORBANCE

FIG.11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/023898

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S3/781 G01S3/784 F41G7/22 G02B6/08
ADD.

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)
G01S F41G G02B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 183 664 A (RAMBAUSKE WERNER R [US]) 15 January 1980 (1980-01-15) abstract; figures 1,2,10 column 3, line 31 - column 5, line 63 -----	1-10, 14-20 11-13
Y	US 2010/238430 A1 (MEIJER EDUARD JOHANNES [NL] ET AL) 23 September 2010 (2010-09-23) abstract; figures 1-3 -----	11-13
A	US 6 851 645 B1 (WILLIAMS BRETT A [US] ET AL) 8 February 2005 (2005-02-08) abstract column 4, line 33 - line 55 -----	1-20

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

☒ See patent family annex.

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"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

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"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
8 June 2012	15/06/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vial, Antoine

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/023898

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 2205988 A2	14-07-2010
		JP 2011504225 A	03-02-2011
		KR 20100087183 A	03-08-2010
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		US 2010238430 A1	23-09-2010
		WO 2009053905 A2	30-04-2009
US 6851645 B1	08-02-2005	NONE	