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(54) Title: CATHODE-RAY TUBE ULTRAVIOLET LIGHT SOURCE

(57) Abstract: A cathode-ray ultraviolet light source comprising: an elongated glass envelope having a first end and second end, the glass envelope defining an evacuated volume; an electron gun positioned within the evacuated volume proximate to the first end and being capable of developing an electron beam; a target disposed within the evacuated volume between the first and second end of the glass envelope, the target comprising a phosphor material covered with a reflective metal film; and an electron beam focusing and deflecting mechanism disposed within the evacuated volume between the electron gun and the target to direct the electron beam towards the reflective metal film of the target.

CATHODE-RAY TUBE ULTRAVIOLET LIGHT SOURCE

BACKGROUND

[0001] Ultraviolet (UV) light is a form of electromagnetic radiation with wavelengths from about 10 nanometers (nm) to 400 nm. UV light has a shorter wavelength than visible light, but longer than X-rays. Short wave ultraviolet light damages DNA and sterilizes surfaces with which it comes into contact. For humans, suntan and sunburn are familiar effects of exposure of the skin to UV light, along with increased risk of skin cancer.

[0002] There are no natural sources of UV light below about 280 nm due to atmospheric absorption. This includes the UVC spectrum of 190 nm to 280 nm, which can be used for disinfection because UVC light is strongly absorbed by nucleic acids which can damage DNA and RNA. However, since mammalian DNA is confined to the nucleus of cells, proteins in the cell's cytoplasm effectively shield mammalian nucleus DNA from <230 nm UV light. Therefore, a UVC light source with a wavelength from 190-230 nm is effective at sterilizing surfaces without posing a danger to humans in the vicinity. Below 190 nm a UV light would produce significant amounts of ozone, which have been known to have deleterious effects on humans.

[0003] Due to atmospheric absorption of light below about 280 nm, this portion of the spectrum is also known as the solar blind spectrum. Due to atmospheric absorption UV light with a wavelength <280 nm has a limited range of transmission and is also efficiently scattered by aerosols and molecules in air. Because of these factors, light with a wavelength <280 nm may also be used for non-line of sight (NLOS) covert communication systems.

[0004] Low pressure mercury vapor lamps have been used to produce UVC light for sterilization. Such lamps are energy efficient and cost effective but suffer from their use of mercury, which is an environmental hazard and can be toxic to humans. There has been a movement away from the use of low pressure mercury vapor lamps in recent years due to environmental and health concerns.

[0005] Light Emitting Diodes have also been used to produce UVC light. While they do not include mercury or other heavy metals, they are not very efficient and are relative low capacity compared to other UVC light technologies.

[0006] Pulsed Xenon lamps produce a wide spectrum of UV light but are relatively expensive compared to other technologies. Since the spectrum of UV is so wide, the output of the lamps need to be filtered to attenuate wavelengths outside of the 190-230 nm range.

[0007] These and other limitations of the prior art will become apparent to those of skill in the art upon a reading of the following descriptions and a study of the several figures of the drawing.

SUMMARY

[0008] A cathode-ray ultraviolet light source includes: an elongated glass envelope having a first end and second end, the glass envelope defining an evacuated volume; an electron gun positioned within the evacuated volume proximate to the first end and being capable of developing an electron beam; a target disposed within the evacuated volume between the first and second end of the glass envelope, the target comprising a phosphor material covered with a reflective metal film; and an electron beam focusing and deflecting mechanism disposed within the evacuated volume between the electron gun and the target to direct the electron beam towards the reflective metal film of the target.

[0009] A method for operating a cathode-ray tube ultraviolet light source includes directing an electron beam to reflective metal film covering a phosphor in an evacuated glass envelope and emitting ultraviolet light from the phosphor the glass envelope. In an embodiment, the electron beam is focused and steered across the reflective metal film in a pattern.

[00010] Advantages of various embodiments are that UVC light can be produced in an efficient, cost-effective manner without the use of dangerous and environmentally unfriendly heavy metals such as mercury.

[00011] These and other embodiments, features and advantages will become apparent to those of skill in the art upon a reading of the following descriptions and a study of the several figures of the drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

[00012] Several example embodiments will now be described with reference to the drawings, wherein like components are provided with like reference numerals. The example embodiments are intended to illustrate, but not to limit, the invention. The drawings include the following figures:

[00013] Figure 1 is an illustration of a first example cathode-ray ultraviolet light source;

[00014] Figure 2 is an illustration of a second example cathode-ray ultraviolet light source;

[00015] Figure 3 is a perspective view of a beam shaper;

[00016] Figure 4 is an end view a beam shaper;

[00017] Figure 5 is a first diagram illustrating an ideal and actual radiant intensity graph for illuminating the walls of a square room;

[00018] Figure 6 is a second diagram illustrating an ideal and actual radiant intensity graph for illuminating the walls of a square room;

[00019] Figure 7 is an illustration of a third example cathode-ray ultraviolet light source;

[00020] Figure 8 is an illustration of a fourth example cathode-ray ultraviolet light source;

[00021] Figure 9 is an illustration of a fifth example cathode-ray ultraviolet light source;

[00022] Figure 10 is an illustration of a sixth example cathode-ray ultraviolet light source; and

[00023] Figure 11 illustrates a spectral tuning method for a cathode-ray tube ultraviolet light source using a plurality of phosphors.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[00025] Fig. 1 is an illustration of a first example cathode-ray ultraviolet light source 10 including an elongated glass envelope 12 having a first end 14 and a second end 16 and defining an evacuated volume 18. An electron gun 20 is positioned within the evacuated volume 18 near the first end 14 and is capable of developing an electron beam 22. A target 24 is disposed within the evacuated volume 18 between the first end 14 and the second end 16 of the glass envelope 12. An electron beam focusing and deflecting mechanism 25 is used to focus the electron beam 22 and to steer the beam across the surface of the target 24.

[00026] In this example, a target 24 is disposed within the evacuated volume 18 proximate the second end 16 of the glass envelope 12. The target 24 includes a phosphor material 26 covered with a reflective metal film 28. When the electron beam 22 impinges upon the reflective metal film 28, it penetrates the film and causes the phosphor material 26 to emit ultraviolet (UV) light from the second end 16 of the glass envelope 12 with relatively little internal loss due to the reflective film 28.

[00027] Fig. 2 is an illustration of a second example cathode-ray ultraviolet light source 10' which is similar to the first example of Fig. 1 with the exception of the target 24' configuration and location, where like reference numerals refer to like components, portions or elements. In this example, the target 24' is provided upon one or more side portions 30 of the glass envelope 12. The targets 24' include phosphor materials 26' covered with reflective metal films 28'. When the electron beam 22 impinges upon the reflective metal films 28' under the influence of the deflecting mechanism 25, it penetrates the film to cause the phosphor material 26' to emit UV light from the side portions 30 of the glass envelope 12 with relatively little internal loss due to the reflective film 28'.

[00028] Fig. 3 is a perspective view and Figure 4 is an end view of a beam shaper 32 for the light source 10' of Fig. 2, where like reference numerals refer to like components, portions or elements. The beam shaper 32 is substantially cylindrical in shape and includes cylindrical opening 34 in an end plate 36 that is receptive to the glass envelope 12 of light

source 10'. The end plate 36 supports a number of radial fins 38 and has an alignment slot 35. Ultraviolet light emitted by the light source 10' is shaped by the fins 38 to provide a desired distribution of UV light into the ambient environment. The alignment slot 35 ensures a fixed position and orientation of the beam shaper 32 with respect to the light source 10' inserted into opening 34 to provide consistent emission patterns for the UV light.

[00029] Fig. 5 is a diagram 39 illustrating an ideal radiant intensity graph 41 and an actual radiant intensity graph 43 of an example light source for illuminating the walls of a square room. The ideal radiant intensity is show in dotted lines while the actual radiant energy is shown in dashed lines.

[00030] Fig. 6 is a second diagram 45 illustrating an ideal radiant intensity graph 47 and an actual radiant intensity graph 49 of the example light source for illuminating the walls of a square room. Again, the ideal radiant intensity is show in dotted lines while the actual radiant energy is shown in dashed lines.

[00031] Fig. 7 is an illustration of a third example cathode-ray ultraviolet light source 10" which has a glass envelope 12'' with an enlarged second end 16" , where like reference numerals refer to like components, portions or elements. The target 24" includes, as in the previous embodiments, a target 24'' having a phosphor material covered by a reflective metal film. This example further includes an external reflector 40 to help direct the UV light emanating from second end 16" of the light source. A combination of beam steering, variable focus and intensity control allows the beam angle to be controlled between about 5 degrees and 120+ degrees.

[00032] Fig. 8 is an illustration of a fourth example cathode-ray ultraviolet light source 10''' which has a target 24''' covering the internal side and end portions of a glass envelope 12''', where like reference numerals refer to like components, portions or elements. The target 24''' includes, as in the previous embodiments, a target 24''' having a phosphor material covered by a reflective metal film. This example further includes an external reflector 42 to help direct the UV light emanating from the light source. A combination of beam steering, variable focus and intensity control allows the beam angle to be controlled between about 5 degrees and 120+ degrees.

[00033] Fig. 9 is an illustration of a fifth example cathode-ray ultraviolet light source 10'''' which has a glass envelope 12'''' with a bulbous second end 16'''', where like reference numerals refer to like components, portions or elements. In this embodiment, a target 24'''' is suspended within the evacuated volume 18 of the glass envelope by a UV light diffusion body 44. The target 24'''' includes, as in the previous embodiments, a phosphor material covered by a reflective metal film and has a concave configuration with the metal film facing the electron beam 22. Ultraviolet light emitted from the phosphor of the target 24'''' is diffused by the light diffusion body 24 to provide nearly 360° of light emission coverage.

[00034] Fig. 10 is an illustration of a sixth example cathode-ray ultraviolet light source 10''''' which is essentially the same as the example of Fig. 9 with the exception that the light diffusion body 44 has been omitted, where like reference numerals refer to like components, portions or elements. In this example, the target 24'''' directs UV light in a somewhat conical fashion from the second end 16'''' of the light source.

[00035] Figure 11 illustrates a spectral tuning method for a cathode-ray tube ultraviolet light source using a plurality of phosphors. In this example four different phosphors are laid out in a 2x2 grid 46 and comprise a Material A, Material B, Material C and Material D. As seen at 46A, a "spirograph" type pattern 48A over Material A produces an emission spectra 50A. As seen at 46B, a spirograph type pattern 48B over Material C and Material D produces a different emission spectra 50B.

[00036] The emission wavelength of a light source 10 is determined by the phosphor material being irradiated. For example, AlN is a material that can emit UVC light at 210 nm. As another example, AlGaN can emit at different (longer) wavelengths. For AlGaN, the amount of gallium will determine the emission wavelength which will increase with the amount of gallium added to the alloy. Furthermore, dopants can be added to AlN or AlGaN to change their emission wavelengths. As still another example, hexagonal boron nitride will emit UVC light in the range of 210-220 nm.

[00037] Other phosphor materials that emit UV light in the range of 190 – 280 nm include:

- LuF_3:Nd
- $Sr(Al,Mg)_{12}O_{19}$:Pr
- $Ca_2Al_2SizO_7$:Pr
- $YSiO_5$:Pr
- Lu_2SiO_5:Pr
- $Ca_2P_2O_7$: Pr
- $LaPO_4$:Pr
- $(Lu,Y,Sc)_3(Al,Ga)_5O_{12}$
- $(Lu,Y,Sc)(Al,Ga)O_3$:Pr
- $(Y,Lu)_3(Al,Ga)_5O_{12}$:La
- YBO_3:Pr
- $Sr_3Y_2Si_6O_{18}$:Pr

[00038] Since the human visual system is incapable of detecting light in with a wavelength less than about 360 nm, in some embodiments a phosphor material that emits in the wavelength range of about 450 nm to about 650 nm may be incorporated with a phosphor material that emits in the wavelength range of about 190 nm to about 280 nm in order to provide a visual indication that the device is operating. It should be noted that while a preferred wavelength range for safety is 190-230 nm, for certain applications this range may be extended up to about 280 nm. Depending upon the sterilization target, some wavelengths <280 nm may be optimal, although special precautions are recommended outside of the optimal 190-230 nm range.

[00039] Preferred electron beam energy is 6,000 to 34,000 V. Beam current can range from 1 μA to 5 mA. Suitable spot sizes for certain applications is in the range of 0.1 to 1.0 mm in diameter. For some applications, a maximum spot size of up to about 5 mm in diameter may be desirable.

[00040] Although various embodiments have been described using specific terms and devices, such description is for illustrative purposes only. The words used are words of description rather than of limitation. It is to be understood that changes and variations may be made by those of ordinary skill in the art without departing from the spirit or the scope of various inventions supported by the written disclosure and the drawings. In addition, it should be understood that aspects of various other embodiments may be interchanged either in whole or in part. It is therefore intended that the claims be interpreted in accordance with the true spirit and scope of the invention without limitation or estoppel.

[00041] *WHAT IS CLAIMED IS:*

CLAIMS

1. A cathode-ray ultraviolet light source comprising:

an elongated glass envelope having a first end and second end, the glass envelope defining an evacuated volume;

an electron gun positioned within the evacuated volume proximate to the first end and being capable of developing an electron beam;

a target disposed within the evacuated volume between the first and second end of the glass envelope, the target comprising a phosphor material covered with a reflective metal film; and

an electron beam focusing and deflecting mechanism disposed within the evacuated volume between the electron gun and the target to direct the electron beam towards the reflective metal film of the target.

2. A cathode-ray ultraviolet light source as recited in claim 1 wherein the target forms a coating on an inner wall portion of the glass envelope.

3. A cathode-ray ultraviolet light source as recited in claim 2 wherein the inner wall portion is at the second end of the glass envelope.

4. A cathode-ray ultraviolet light source as recited in claim 3 wherein the inner wall portion is also on a sidewall portion of the glass envelope.

5. A cathode-ray ultraviolet light source as recited in claim 1 wherein the target is suspended within the evacuated volume of the glass envelope.

6. A cathode-ray ultraviolet light source as recited in claim 5 wherein the target has a concave configuration with the reflective metal film facing the electron gun.

7. A cathode-ray ultraviolet light source as recited in claim 6 wherein the target is part of a light diffusion body.

8. A cathode-ray ultraviolet light source as recited in claim 1 further comprising an exterior reflector coupled to the glass envelope to direct UV light emitted by the light source.

9. A cathode-ray ultraviolet light source as recited in claim 1 further comprising an exterior beam shaper coupled to the glass envelope to shape UV light emitted by the light source.

10. A method for operating a cathode-ray tube ultraviolet light source comprising:

directing an electron beam to reflective metal film covering a phosphor in an evacuated glass envelope; and

emitting ultraviolet light from the phosphor the glass envelope.

11. A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 further comprising focusing the electron beam on the reflective metal film.

12. A method for operating a cathode-ray tube ultraviolet light source as recited in claim 11 further comprising steering the electron beam across the reflective metal film.

13. A method for operating a cathode-ray tube ultraviolet light source as recited in claim 12 wherein the phosphor is one of a plurality of phosphors, and wherein the electron beam is steered in a pattern across the reflective metal film over one or more of the plurality of phosphors.

AMENDED CLAIMS
received by the International Bureau on 9 February 2023 (09.02.2023)

[Claim 1] A cathode-ray ultraviolet light source comprising:
an elongated glass envelope having a first end and second end, the glass envelope defining an evacuated volume;
an electron gun positioned within the evacuated volume proximate to the first end and being capable of developing an electron beam;
a target suspended within the evacuated volume between the first and second end of the glass envelope, the target comprising a phosphor material covered with a reflective metal film, wherein the phosphor material emits ultraviolet (UV) light in the wavelength range of 190-280 nm;
an electron beam focusing and deflecting mechanism disposed within the evacuated volume between the electron gun and the target to direct the electron beam towards the reflective metal film of the target to penetrate the metal film and cause the phosphor material to emit UV light.

[Claim 2] A cathode-ray ultraviolet light source as recited in claim 1 wherein the phosphor material comprises AlN.

[Claim 3] A cathode-ray ultraviolet light source as recited in claim 1 wherein the phosphor material comprises AlGaN.

[Claim 4] A cathode-ray ultraviolet light source as recited in claim 1 wherein the phosphor material comprises hexagonal boron nitride.

[Claim 5] A cathode-ray ultraviolet light source as recited in claim 1 wherein the phosphor material is selected from one or more of the following materials: LuF_3:Nd; $Sr(Al,Mg)_{12}O_{19}$:Pr; $Ca_2Al_2Si_2O_7$:Pr; $YSiO_5$:Pr; Lu_2SiO_5:Pr; $Ca_2P_2O_7$: Pr; $LaPO_4$:Pr; $(Lu,Y,Sc)_3(Al,Ga)_5O_{12}$; $(Lu,Y,Sc)(Al,Ga)O_3$:Pr; $(Y,Lu)_3(Al,Ga)_5O_{12}$:La; YBO_3:Pr; $Sr_3Y_2Si_6O_{18}$:Pr.

[Claim 6] A cathode-ray ultraviolet light source as recited in claim 1 wherein the target has a concave configuration with the reflective metal film facing the electron gun.

[Claim 7] A cathode-ray ultraviolet light source as recited in claim 6 wherein the target is part of a light diffusion body.

[Claim 8] A cathode-ray ultraviolet light source as recited in claim 1 further comprising an exterior reflector coupled to the glass envelope to direct UV light emitted by the light source.

[Claim 9] A cathode-ray ultraviolet light source as recited in claim 1 further comprising an exterior beam shaper coupled to the glass envelope to shape UV light emitted by the light source.

[Claim 10] A method for operating a cathode-ray tube ultraviolet light source comprising:
directing an electron beam to a reflective metal film covering a phosphor suspended in an evacuated glass envelope; and
emitting ultraviolet light from the phosphor due to the electron beam penetrating the metal film, wherein the phosphor material emits UV light in the wavelength range of 190-280 nm; and
shaping the emitted UV light with at least one of an exterior beam shaper and an exterior reflector.

[Claim 11] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 further comprising focusing the electron beam on the reflective metal film.

[Claim 12] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 11 further comprising steering the electron beam across the reflective metal film.

[Claim 13] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 12 wherein the phosphor is one of a plurality of phosphors, and wherein the electron beam is steered in a pattern across the reflective metal film over one or more of the plurality of phosphors.

[Claim 14] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 wherein the phosphor material comprises AlN.

[Claim 15] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 wherein the phosphor material comprises AlGaN.

[Claim 16] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 wherein the phosphor material comprises hexagonal boron nitride.

[Claim 17] A method for operating a cathode-ray tube ultraviolet light source as recited in claim 10 wherein the phosphor material is selected from one or more of the following materials: LuF_3:Nd; $Sr(Al,Mg)_{12}O_{19}$:Pr; $Ca_2Al_2Si_2O_7$:Pr; $YSiO_5$:Pr; Lu_2SiO_5:Pr; $Ca_2P_2O_7$: Pr; $LaPO_4$:Pr; $(Lu,Y,Sc)_3(Al,Ga)_5O_{12}$; $(Lu,Y,Sc)(Al,Ga)O_3$:Pr; $(Y,Lu)_3(Al,Ga)_5O_{12}$:La; YBO_3:Pr; $Sr_3Y_2Si_6O_{18}$:Pr.

STATEMENT UNDER ARTICLE 19 (1)

The Article 19 amendments of the claims are for the purpose of publication should not be interpreted either agreement or disagreement with the Written Opinion of the International Searching Authority (ISA). Applicant reserves the right to address the Written Opinion of the ISA under Article 34 as the written opinion of the International Preliminary Examining Authority (IPEA) without limitation or estoppel.

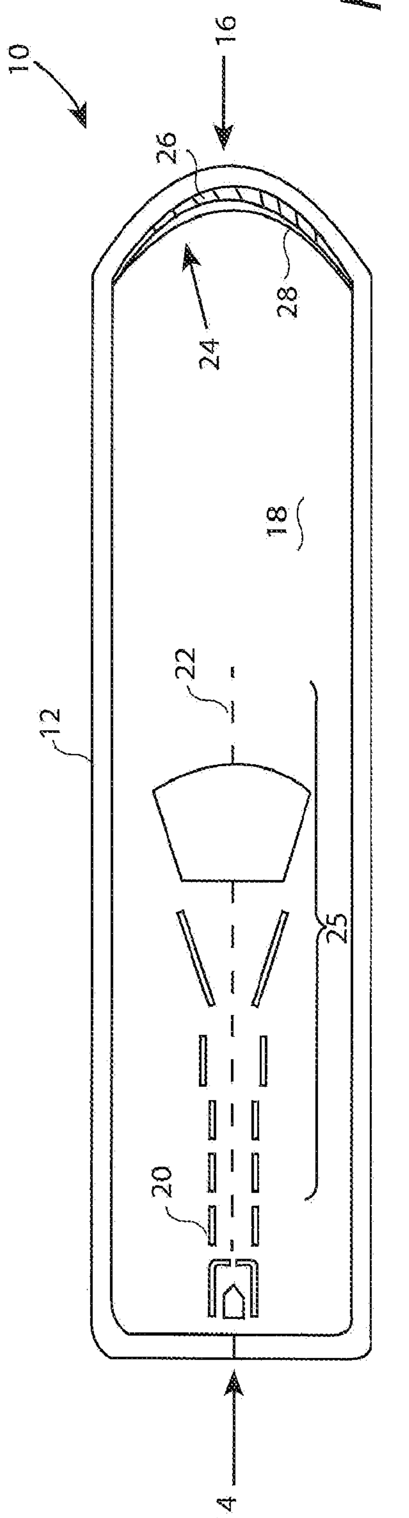

Fig. 1

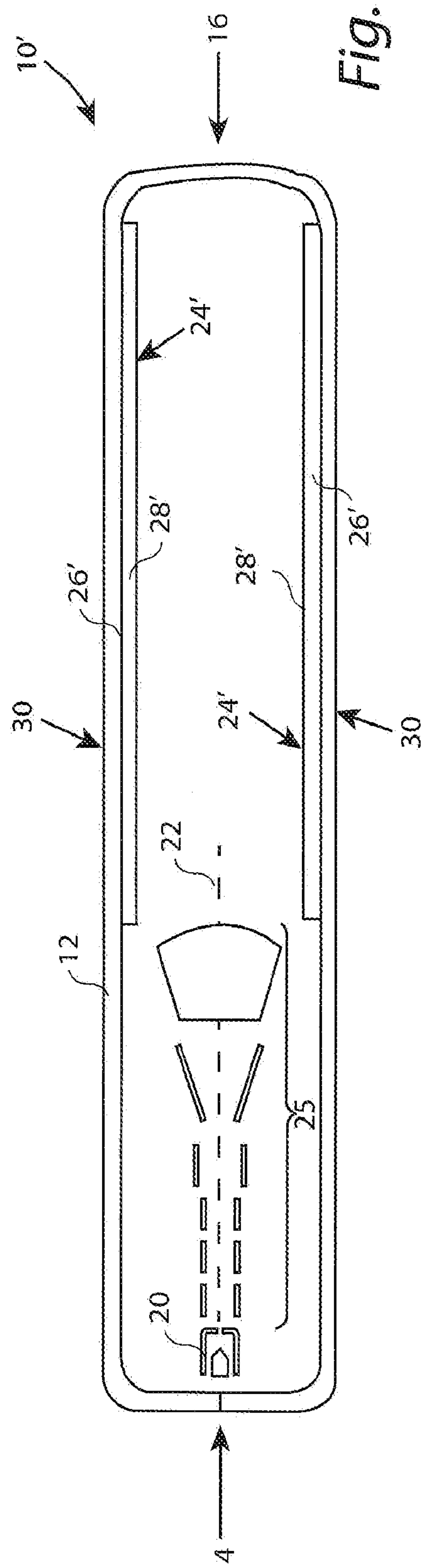

Fig. 2

SUBSTITUTE SHEET (RULE 26)

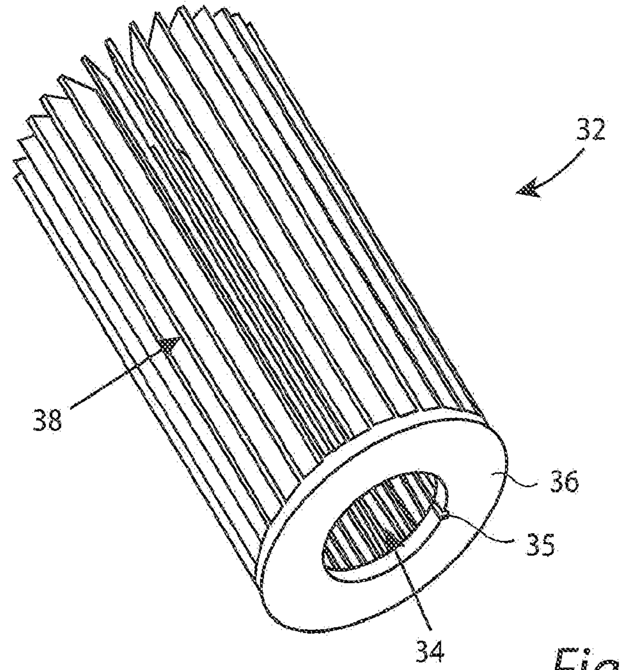

Fig. 3

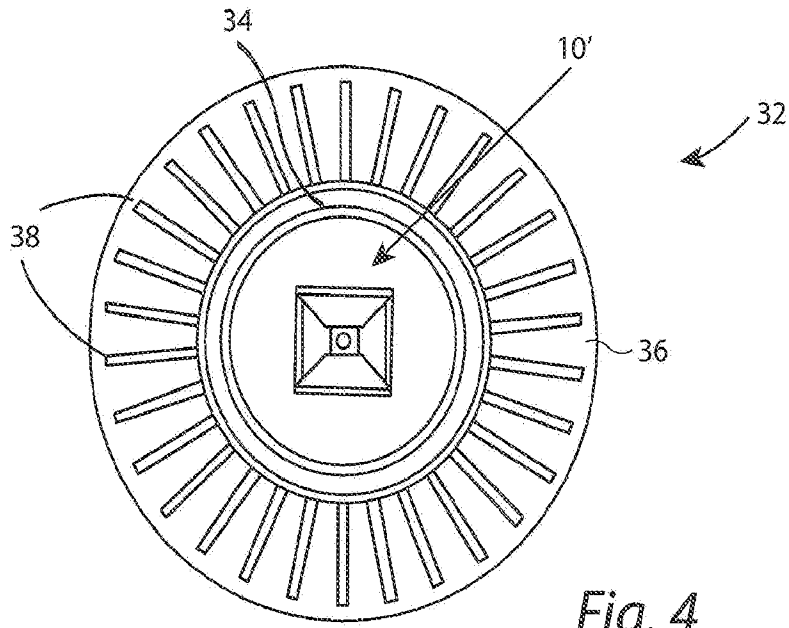

Fig. 4

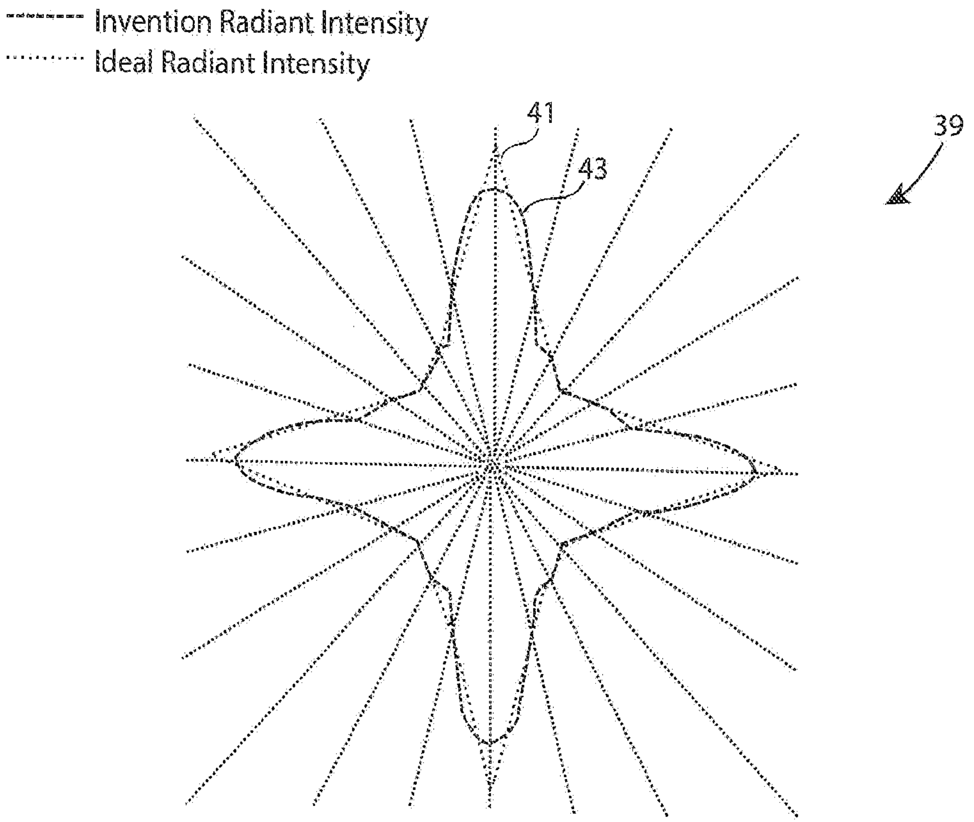
Invention Radiant Intensity
Ideal Radiant Intensity
41
43
39

Fig. 5

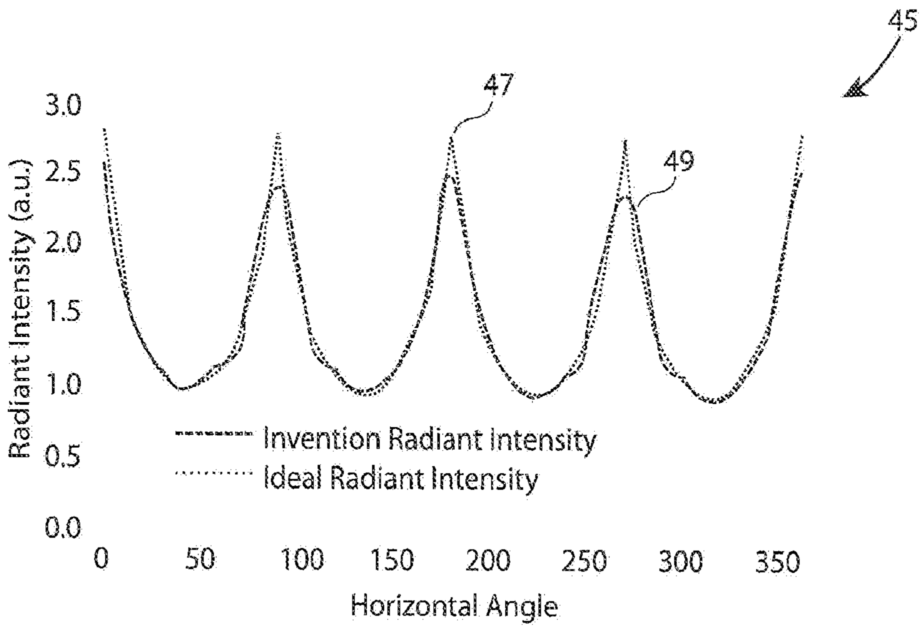
45
47
49
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Radiant Intensity (a.u.)
Invention Radiant Intensity
Ideal Radiant Intensity
0
50
100
150
200
250
300
350
Horizontal Angle

Fig. 6

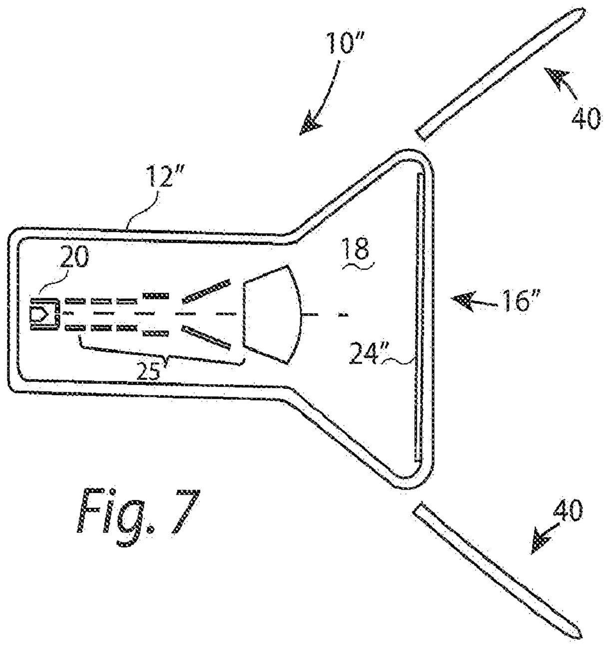

Fig. 7

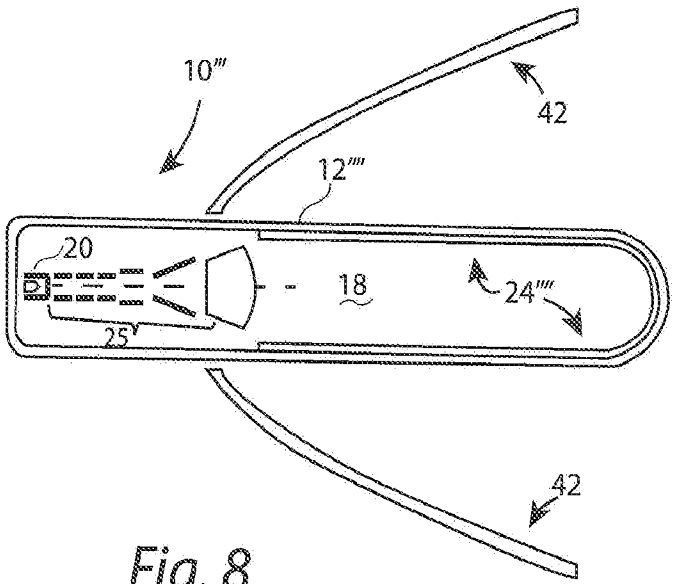

Fig. 8

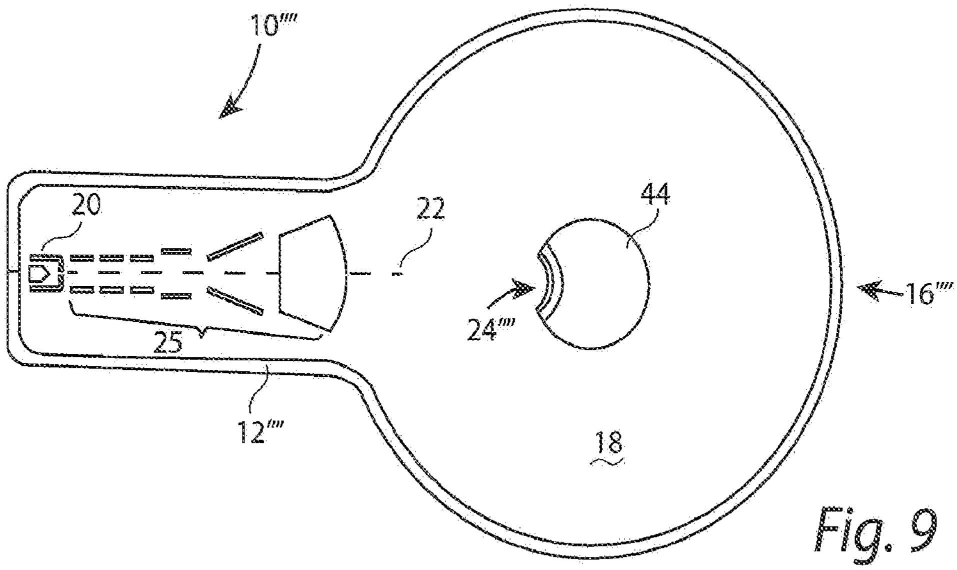

Fig. 9

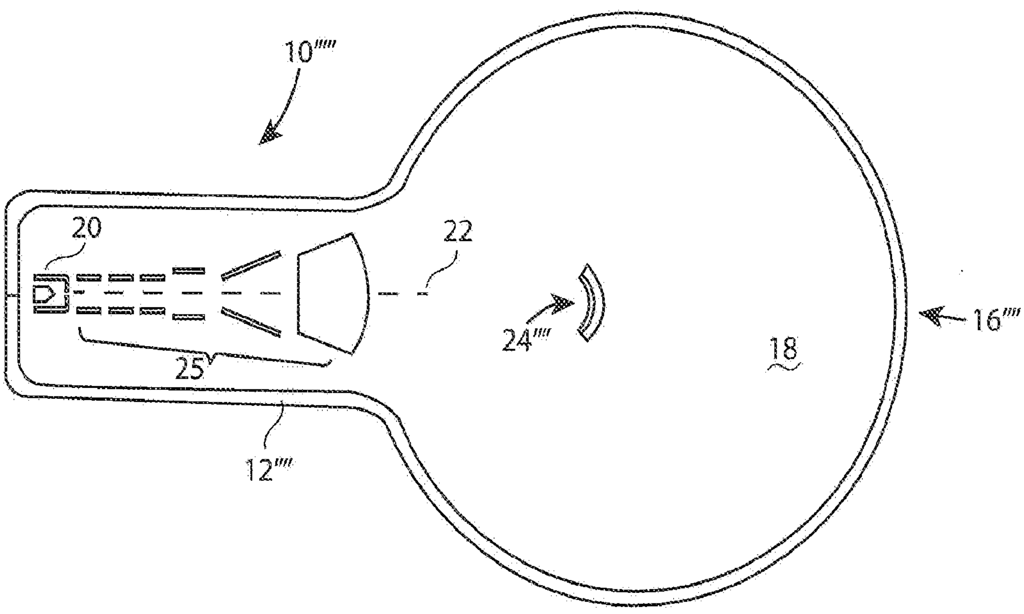

Fig. 10

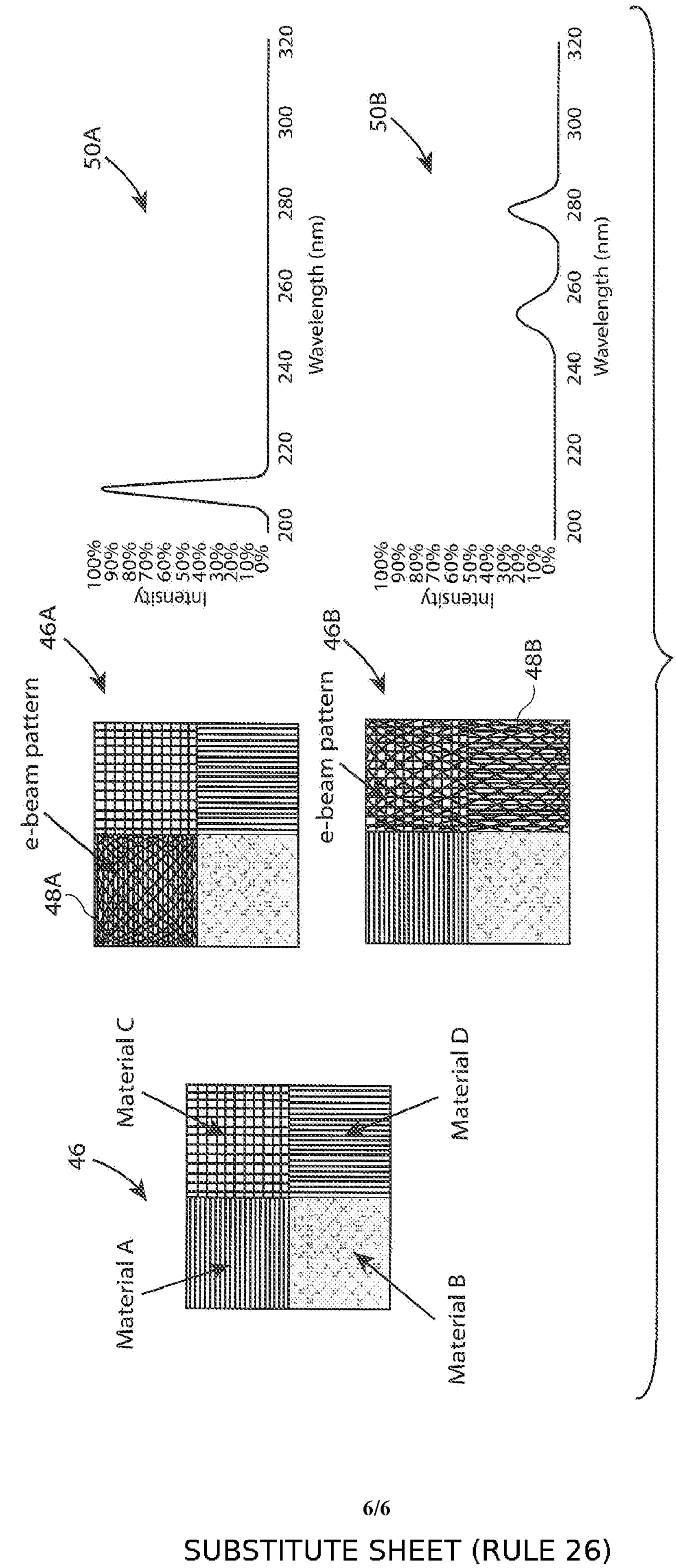
46
Material A
Material B
Material C
Material D
46A
48A
e-beam pattern
46B
48B
e-beam pattern
50A
50B
Intensity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
200
220
240
260
280
300
320
Wavelength (nm)

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 22/42265

A. CLASSIFICATION OF SUBJECT MATTER
IPC - INV. H01J 63/06 (2022.01)
ADD. H01J 63/02 (2022.01)
CPC - INV. H01J 63/06, H01J 2229/507
ADD. H01J 63/02

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)
See Search History document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

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 5,644,193 A (Matsuda et al.) 1 July 1997 (01.07.1997) Entire document, especially Abstract, col 4 ln 33-37; col 5 ln 12-13; col 6 ln 38-43; col 7 ln 64-67; col 9 ln 17-22; col 11 ln 1-4; col 15 ln 37-39; col 16 ln 45-49; col 18 ln 3-6; Fig. 1	1-4, 10-11 -------- 5-9, 12-13
Y	US 8,282,243 B2 (Uemoto et al.) 9 October 2012 (09.10.2012) Entire document, especially Abstract, col 2 ln 14-19, 41-44; col 3 ln 46-49; col 5 ln 31-45	5-7
Y	US 7,828,459 B2 (Rains) 9 November 2010 (09.11.2010) Entire document, especially Abstract, col 5 ln 56-58; col 6 ln 12-15; col 7 ln 9-26; col 8 ln 23-34; col 9 ln 3-11	8-9
Y	US 2004/0140432 A1 (Maldonado et al.) 22 July 2004 (22.07.2004) Entire document, especially Abstract, para [0011]; [0047]	12-13
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☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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3 November 2022 (03.11.2022)	DEC 09 2022
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