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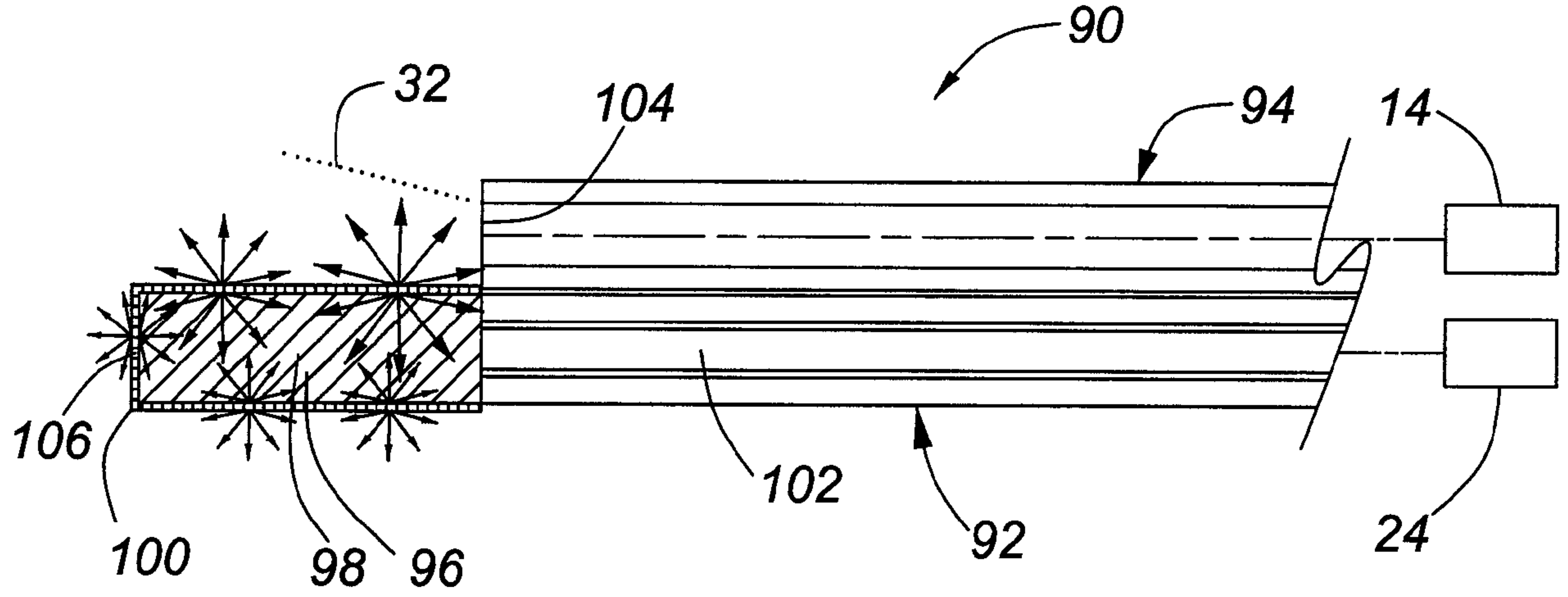

(57) **Abrégé/Abstract:**
A fiber optic probe for detecting the presence or absence of one or more substances within a medium. The probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the illuminating optical fiber. A film or an immersion medium is provided for emitting light when illuminated by the excitation light. The emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber is provided to receive and guide the emitted light. The receiving fiber may be a photonic crystal fiber having an end portion which is a solid segment of glass for improved light collection efficiency. A lens may be provided at the end of the receiving fiber. Detection means are provided for detecting light from the receiving optical fiber.

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ABSTRACT

A fiber optic probe for detecting the presence or absence of one or more substances within a medium. The probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the illuminating optical fiber. A film or an immersion medium is provided for emitting light when illuminated by the excitation light. The emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber is provided to receive and guide the emitted light. The receiving fiber may be a photonic crystal fiber having an end portion which is a solid segment of glass for improved light collection efficiency. A lens may be provided at the end of the receiving fiber. Detection means are provided for detecting light from the receiving optical fiber.

TITLE OF THE INVENTION

FIBER OPTIC PROBE

FIELD OF THE INVENTION

[0001] The present invention relates to fiber optic probes.

BACKGROUND OF THE INVENTION

[0002] Thin film coated, intensity based fiber-optic probes for the detection of fluorescence have found many applications due to their small size and versatility. These applications include chemical research, biomedical research and clinical surgery. Other applications include waste water monitoring and explosive detection as well as the detection of leaks from containers of corrosive liquids and the like.

[0003] Fluorescent signals are usually very weak and disperse in all directions. Measurement of these signals relies heavily on the light collection efficiency of the measurement device.

[0004] A first known type of probe comprises a single optical fiber having a core covered with a film. When illuminated, the film emits light via fluorescence. Typically, the core is only covered at an end portion of the fiber (i.e. the probe tip) and light collected by the probe is measured to determine the presence of certain materials or effects. These measurements are based upon collected fluorescent light as a result of evanescent waves existing in the fiber cladding area (and beyond). The amount of collected fluorescent light will change if the refractive index of the film changes as a result of being in contact with those materials or effects (for example if the film absorbs liquid).

[0005] A second known type of probe comprises an optical fiber (or multiple optical fibers including at least one illuminating fiber and at least one receiving fiber) having a film coating attached to the end face of the receiving fiber or placed at a certain distance from its end face. Again, light collected by the probe is measured to determine the presence of certain materials or effects.

[0006] Careful consideration of the refractive index of film coatings for known probe designs is required to meet the guiding condition of the fiber. Often, the cladding of the receiving optical fiber has to be removed and replaced with certain specific materials possessing a refractive index lower than that of the fiber core material to match the guiding condition of the receiving optical fiber.

SUMMARY OF THE INVENTION

[0007] The present invention provides a fiber optic probe having a simple and rugged configuration, high light collection efficiency and improved signal-to-noise ratio. The fiber optic probe may have the objects of being relatively low cost and reusable. The improved performance of this probe facilitates traditionally difficult measurements, such as analysis of turbid waste water and low concentration explosive vapors to identify the existence of explosives.

[0008] According to a first aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within a medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. At least one film is provided for emitting film-emitted light when illuminated by the excitation light. The film-emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber receives and guides the film-emitted light. The at least one receiving optical fiber is a photonic crystal fiber and an end portion of the at least one receiving optical fiber is a solid segment of glass. Detection means may be provided for detecting light from the receiving optical fiber.

[0009] According to a second aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within a medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. The fiber optic probe also comprises at least one film for emitting film-emitted light when illuminated by the excitation light, the film-emitted light having a central wavelength that is different than a central wavelength of the excitation light and at least one receiving optical fiber for receiving and guiding the film-emitted light. A lens covers at least a portion of an end of the at least one receiving optical fiber and the film covers at least a portion of an outer surface of the lens. The lens and the receiving fiber are arranged so that at least part of the film is illuminated by the excitation light. The lens may be generally spherical or any other suitable shape. Finally, the fiber optic probe also comprises detection means coupled to the at least one receiving optical fiber for detecting the film-emitted light.

[0010] According to a third aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within a medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. The fiber optic probe also comprises at least one film for emitting film-emitted light when illuminated by the excitation light. The film-emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber receives and guides the film-emitted light. The at least one receiving fiber is arranged so that an end portion of the at least one receiving fiber protrudes past the end face of the at least one illuminating fiber. The illuminating and receiving fibers may be physically joined together within a single probe structure. The respective fibers may be in side-by-side parallel relationship, either abutting or spaced apart, or alternatively may meet at an angle whereby the fibers converge towards their illuminating and receiving ends, respectively. At least part of the end portion of the at least one receiving fiber is illuminated by the excitation light. Finally, the fiber optic probe also comprises detection means coupled to the at least one receiving optical fiber for detecting the film-emitted light.

[0011] According to a fourth aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within a medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. At least one film is provided for emitting film-emitted light when illuminated by the excitation light. The film-emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber receives and guides the film-emitted light. The film covers a thin cladding of a portion of the receiving optical fiber. The thin cladding transmits the film-emitted light into a core of the at least one receiving optical fiber. Finally, detection means are coupled to the at least one receiving optical fiber for detecting the film-emitted light.

[0012] According to a fifth aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within an immersion medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. An immersion medium emits immersion-emitted light when illuminated by the excitation light. The immersion-emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber is positioned alongside the at least one illuminating optical fiber for receiving and guiding the immersion-emitted light. The at least one receiving optical fiber is a photonic crystal fiber. An end portion of the at least one receiving optical fiber is a solid segment of glass. Detection means are provided for detecting the immersion-emitted light from at least one receiving optical fiber.

[0013] According to a sixth aspect of an embodiment of the invention, there is provided a fiber optic probe for detecting the presence or absence of one or more substances within an immersion medium. The fiber optic probe comprises at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of the at least one illuminating optical fiber. An immersion medium emits immersion-emitted light when illuminated by the excitation light. The immersion-emitted light has a central wavelength that is different than a central wavelength of the excitation light. At least one receiving optical fiber is positioned alongside the illuminating optical fiber for receiving and guiding the immersion-emitted light. An end face of the at least one receiving optical fiber is aligned with the end face of the at least one illuminating optical fiber. A lens covering the end face of the at least one illuminating optical fiber and the end face of the at least one receiving optical fiber. The lens couples the immersion-emitted light into the at least one receiving optical fiber. The lens may be generally spherical or any other suitable shape. Detection means are provided for detecting light from at least one receiving optical fiber.

[0014] The term "photonic crystal fiber" is intended to refer to an index-guiding type of photonic crystal fiber having a core of high refractive index surrounded by a cladding having a lower refractive index. The cladding comprises a tiny array of air-holes. Both the core and cladding of a photonic crystal fiber can be formed from the same material, *e.g.* pure silica.

[0015] The term "launching cone" will refer herein to the reception and launching cone of an optical fiber. The launching cone is determined by that fiber's numerical aperture as well as other conditions including the characteristics and launching conditions of the light source at the entry end of the illuminating fiber. It is also related to the fiber core and cladding sizes.

[0016] The term "standard fiber" will refer herein to any suitable type of fiber with core and cladding having different refractive indices as would be understood by a person skilled in the art.

[0017] The term "light" refers to both visible and invisible forms of electromagnetic radiation having a wavelength suitable for transmission by various types of waveguides, including optical fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] An embodiment of the invention will now be described by way of example with reference to the accompanying drawings, in which:

[0019] Figure 1 is a diagrammatic side section view of a non-limiting embodiment of the invention;

[0020] Figure 2 is an alternative arrangement of the embodiment of Figure 1;

[0021] Figure 3 is another alternative arrangement of the embodiment of Figure 1;

[0022] Figure 4 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0023] Figure 5 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0024] Figure 6 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0025] Figure 7 illustrates a diagrammatic cross-section of an example photonic crystal fiber;

[0026] Figure 8 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0027] Figure 9 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0028] Figure 10 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0029] Figure 11 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0030] Figure 12 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0031] Figure 13 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0032] Figure 14 is an alternative arrangement of the embodiment of Figure 13;

[0033] Figure 15 is another alternative arrangement of the embodiment of Figure 13;

[0034] Figure 16 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0035] Figure 17 is a diagrammatic side section view of another non-limiting embodiment of the invention;

[0036] Figure 18 is an alternative arrangement of the embodiment of Figure 17; and

[0037] Figure 19 is another alternative arrangement of the embodiment of Figure 17.

DETAILED DESCRIPTION

[0038] According to a non-limiting embodiment of the invention, Figure 1 illustrates a fiber optic probe 10 comprising an illuminating optical fiber 12 (hereinafter the 'illuminating fiber') for guiding excitation light from a light source 14 to be launched from an end face 16 of the illuminating fiber 12. A second, receiving optical fiber 18 (hereinafter the 'receiving fiber') is arranged so that an end portion 20 of the receiving fiber 18 protrudes past the end face 16 of the illuminating fiber 12. At least part of the end portion 20 of the receiving fiber 18 is illuminated by the excitation light.

[0039] The illuminating fiber 12 and the receiving fiber 18 may be in contact with each other or spaced apart (although a higher level of effectiveness is achieved with the fibers being in close proximity or in contact).

[0040] The end portion 20 of the receiving fiber 18 is at least partly covered by a film 22 which emits light, as indicated in Figure 1 by outwardly radiating arrows, when at least part of the film 22 is illuminated by excitation light launched from the end face 16 of the illuminating fiber 12. (Light emitted by film 22 and any other film described in this specification will be similarly indicated by outwardly radiating arrows.)

[0041] The film-emitted light has a central wavelength that is different than a central wavelength of the excitation light. Of course, it should be understood that the film-emitted light and the excitation light will both have a certain spectral width and the central wavelength is merely referred to herein as a convenient reference wavelength, as would be understood by the person skilled in the art.

[0042] The probe 10 is intended to be used in a medium for detection of the presence or absence of one more selected target substances in the medium. Typically, the medium is a liquid or gas. More specifically, the intensity and/or spectral characteristics of the light emitted by the film 22 then subsequently detected and measured by detection means 24 may be indicative of the presence of a target substance.

[0043] In this specification, light launched from the illuminating fiber 12 (and other illuminating fibers described herein) will be referred to as 'excitation light'. Similarly, light emitted by the film 22 (and other films described herein) will be referred to as 'film-emitted light'.

[0044] Film-emitted light 22 is coupled into the receiving fiber 18 and guided along the length of the receiving fiber 18 to detection means 24. The receiving fiber 18 may be connected directly to detection means 24, or via intervening optical elements such as an additional optical fiber. Detection means 24 may be, for example, a spectrometer or any other light detector, typically equipped with a filter to remove stray excitation light. A suitable spectrometer is the USB2000 spectrometer with OOIBase32 software from Ocean Optics™.

[0045] More specifically, the film 22 is a thin film of material which, when illuminated, emits light by fluorescence, i.e. the film material is excited by absorbing the excitation photons and emits lower-energy photons. For example, a suitable film may be a polymer having a refractive index n=1.62, which is higher than the refractive index of the fiber core material, and an emission wavelength of 642 nm which can be excited by, for example, a high power Ar+ laser with 488 nm and 514 nm emission lines. Examples of suitable materials are disclosed in S.M. MacKinnon and Z.Y. Wang, "*Synthesis and characterization of poly(aryl ether imide)s containing electroactive perylene diimide and naphthalene diimide units*", J. Polym. Sci., Part A: Polym. Chem., col. 38, p. 3467-3475, 2000. It should of course be understood that the choice of film material will depend upon the probe application and the wavelength and power of the excitation light.

[0046] As a further example, the film 22 may be a fluorescence quenching material which will emit significantly less light when in the presence of a chemical substance, for example a substance which indicates the presence of explosives, than it would if it were not in the presence of such material.

[0047] The film 22 is either applied directly to the core 28 of the receiving fiber 18 (by first stripping the cladding 26, then applying the film 22) or applied to the cladding 26 of the receiving fiber 18. If the film is applied to the cladding 26, then the cladding 26 must be sufficiently thin that light emitted by the film 22 will penetrate the cladding 26 and will be coupled into the core 28. The end face 36 may also be covered by the film 18 (as shown). For example, the receiving fiber 18 might be a CF01493-11 step index multimode fiber available from 3M™ having a core diameter of 300 µm, a cladding diameter of 330 µm and a numerical aperture of 0.37. Thus, the cladding in this example has a thickness of only 15 µm. The illuminating fiber may be a standard fiber or the same type of fiber as the receiving fiber. Of course, fibers with different core/cladding sizes may be selected. For example, fibers with smaller core and cladding sizes may be selected to reduce the size of the tip of the probe. As a further example, a receiving fiber with a larger core size will collect a larger amount of film-emitted light.

[0048] Where the film is applied directly to the core 28, the dead space between the illuminating fiber 12 and the receiving fiber 18 is not significant, as the excitation light will illuminate the film directly. Similarly, keeping the cladding 26 of the receiving fiber 18 thin will also keep the dead space between them relatively small. The amount of film-emitted light collected by the receiving fiber increases as the dead space is decreased, thus enhancing the light collection efficiency of the probe 10. The light collection efficiency refers to the ratio of the amount of light emitted by the film 22 to the amount of light coupled into the core 28 of the receiving fiber 18 (subsequently detected by the detection means 24). By increasing the light collection efficiency, a significant reduction in integration time can be achieved (approximately 20 times lower in comparison with the performance of a probe comprising two fibers with aligned end faces and a tilted film placed in front of the fibers).

[0049] The thickness of the film 22 depends on many factors, including the absorption of excitation light for a particular material and the quantum yield of the material (*i.e.* the percentage of excitation photons which are converted to fluorescence photons). The thickness should be carefully controlled as the signal-to-noise ratio of the signal detected by the detection means 24 depends upon the film thickness. A very thin film will cause more stray excitation light to penetrate into the receiving fiber, thereby increasing noise. Similarly, a very thick film will deliver very limited excitation light into the area close to the fiber core. As such, there will be an optimum film thickness for the probe taking into account the fiber geometry, choice of film material and so on.

[0050] The signal-to-noise ratio of the detected signal also depends upon a separation or retreat length 30, i.e. the length of the end portion 20 of the receiving fiber 18 which protrudes past the end face 16 of the illuminating fiber 12. The separation 30 and the thickness of the film 22 can each be adjusted to optimize the signal-to-noise ratio. Of course, the signal-to-noise ratio is also dependent upon other factors, such as the quality of the beam formed by the light coupled into the receiving fiber 18 from the film 22, as would be understood by the person skilled in the art.

[0051] As shown in Figure 1, the illuminating fiber 12 and the receiving fiber 18 are in side-by-side parallel relation. The launching cone 32 of the illuminating fiber 12 will be generally symmetric about the optical axis 34 of the illuminating fiber 12.

[0052] Alternatively, as shown in Figure 2, the illuminating fiber 12 may be disposed at a non-parallel angle α from the receiving fiber 18 to 'bend' or direct the launching cone 32 of the illuminating fiber 12 towards the film 22. By directing the launching cone 32 of the illuminating fiber 12 towards the film 22, the intensity of light impinging upon the film 22 will be increased and the amount of light emitted by the film 22 and coupled into the receiving fiber 18 will increase. This angle α can range anywhere from about 0° to about 90°.

[0053] Alternatively, as shown in Figure 3, the end face 16 of the illuminating optical fiber 12 can be cut or polished at an angle to 'bend' or direct the launching cone 32 of the illuminating fiber 12 towards the film 22. As explained previously, by directing the launching cone 32 of the illuminating fiber 12 towards the film 22, the intensity of light impinging upon the film 22 will be increased and the amount of light emitted by the film 22 and coupled into the receiving fiber 18 will also be increased.

[0054] While in Figures 1, 2 and 3, the end face 36 of the receiving fiber 18 is flat, it may be angled (either cut or polished) to reduce back reflection. The end face 36 may also be covered by high refractive index material to reduce back reflection. Alternatively, the end portion 20 of the receiving fiber 18 may be tapered to further increase the light collection efficiency.

[0055] In accordance with another non-limiting embodiment of the invention, Figure 4 illustrates a fiber optic probe 50 which is generally similar to the fiber optic probe 10 as illustrated in Figure 1 but in which a film 52 does not cover the cladding of the receiving fiber 54 but rather is provided on a separate member spaced from the end face 56 of the illuminating fiber 58 and positioned to receive light from the illuminating fiber 58. The end portion 60 of the illuminating fiber 58 protrudes past the end face 62 of the receiving fiber 54 (by a protrusion length 64). The illuminating and receiving fibers may be standard fibers. Alternatively, the end faces of the fibers may be aligned. The end faces of the fibers may be angle polished to improve light collection efficiency. The end portion of the receiving fiber may be tapered to improve light collection efficiency.

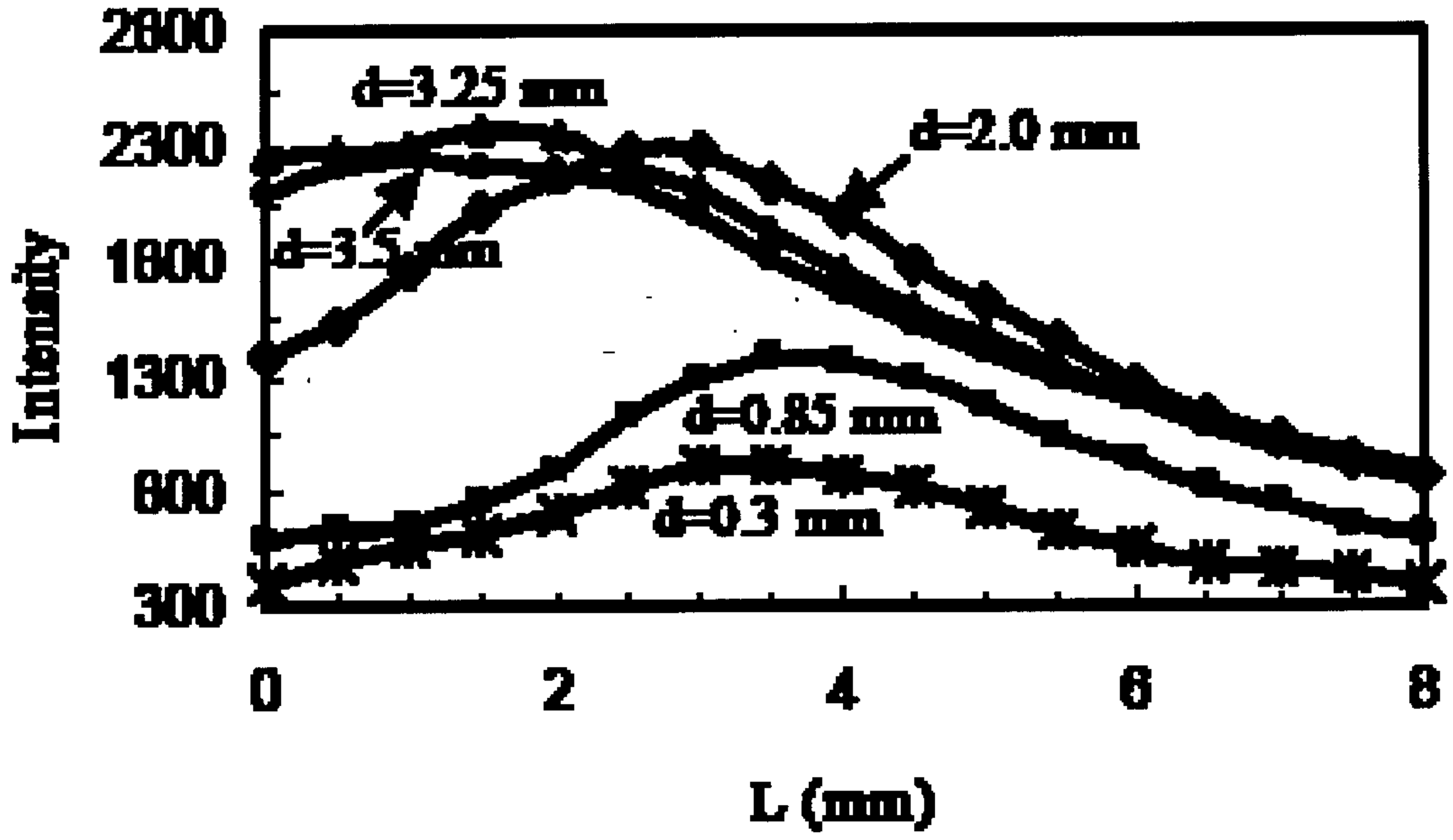
[0056] The film 52 may be, for example, a solid film or a film coating on a glass slide 66. The film 52 is disposed at an angle (*e.g.* 37° to the fiber end face) to the end face 62 of the receiving fiber 54. Light emitted by the film 52 is coupled into the core 68 of the receiving fiber 54 via the end face 62 of the receiving fiber 54. The coupling efficiency of this probe is optimized at certain values of the protrusion length 64.

[0057] The thickness of the film 52 may be larger than the thickness of the film 22 described previously.

[0058] Measurements of the intensity of film-emitted light measured by the detection means 24 are shown in *Graph 1* below. For these measurements, the protrusion length 64 (L) was varied for a number of positions of the film 52, where the position of the film 52 is set out as the separation (d) of the film from the end face of the illuminating fiber (as the film is tilted, d is measured from the end of the film closest to the illuminating fiber). The film 52 used in these experiments had a fluorescent emission wavelength (central wavelength) of 642 nm. The maximum relative collection efficiency ${}^{d}\eta_{\max}$ associated with each film position is given by

$${}^{d}\eta_{\max}(\%) = \frac{{}^{d}I_{F-\max}(L \neq 0) - {}^{d}I_{F}(L = 0)}{{}^{d}I_{F-\max}(L \neq 0)}$$

[0059] where ${}^{d}I_{F-\max}(L \neq 0)$ is the maximum fluorescent intensity received by the spectrometer for each separation d, ${}^{d}I_{F}(L = 0)$ is the fluorescent intensity received by the spectrometer when the receiving fiber aligned with the illuminating fiber. As is clearly shown, the maximum relative collection efficiency value ${}^{d}\eta_{\max}$ occurs at non-zero values of the retreat length L. As is also clearly shown, the relative collection efficiency decreases again after the protrusion length (L) reaches that maximum value.



Graph 1: Intensity of film-emitted light measured as a function of protrusion length L for a number of film positions (d)

[0060] In accordance with another non-limiting embodiment of the invention, Figure 5 illustrates a fiber optic probe 70 comprising a single optical fiber 72 which acts as both an illuminating fiber and a receiving fiber. This embodiment might be particularly advantageous for applications where small size is desirable. An end portion 74 of the fiber 72 is at least partly covered by a film 76 which is similar to the films described previously. As described previously with respect to the non-limiting embodiment of Figure 1, the film 76 at least partially covers the thin cladding 78 and/or end face of the fiber 72. Of course, if the cladding 78 the removed (as described previously with reference to Figure 1), the film 76 will cover the side wall of the core. The end face of the fiber may be angle polished and covered by a high refractive index material to reduce back reflections, as described previously with reference to the receiving fiber of Figures 1, 2 and 3. The end portion 74 of the fiber 72 may be tapered to further increase the light collection efficiency.

[0061] For the single-fiber probe 70, the detection means 24 may also comprise a beam splitter 80 in order to separate the excitation light and the film-emitted light. The beam splitter 80 will be placed between the source 14 and the input end of the fiber 72 to pass the excitation light and reflect the film-emitted light. An additional filter may be placed before the detection means 24 to remove any stray light. The beam splitter 80 may be a dichroic beam splitter to effectively separate the excitation light and the film-emitted light.

[0062] In the absence of direct illumination, or in combination with direct illumination (when the environment surrounding the probe is reflective), the film 76 will be excited by evanescent light formed by the higher order modes propagating along the fiber 72. As the amount of energy in the higher order modes of the fiber 72 is much less than the amount of energy in the lower order modes, the amount of evanescent light is quite small and the detected signal will be weaker than the signal produced by the non-limiting embodiments described previously (*i.e.* considering the same intensity level of excitation light from the source 14).

[0063] At least a thin layer of the film 76 (on the order of a wavelength) which is close to the surface of the thin cladding 78 or the side wall of the fiber core will interact with the evanescent light. The evanescent light will only excite the film 76 within the thickness of approximately one wavelength. The signal is free from the interference beyond this thickness.

[0064] In accordance with another non-limiting embodiment of the invention, Figure 6 illustrates a fiber optic probe 90 of similar geometry to the fiber optic probe 10 illustrated in Figure 1, but wherein the receiving optical fiber 92 is a photonic crystal fiber. The illuminating fiber 94 may also be a photonic crystal fiber.

[0065] Through a thermal fusing process (using, for example, a fiber splicer), a segment of air holes at an end portion 96 of the receiving fiber 92 may be sealed together to form a segment 98 of solid glass. The segment 98 is at least partly covered by a film 100 (similar to the films described previously). Light emitted by the film 100 will pass though the segment 98 to the core 102 of the receiving fiber 92. This segment of glass improves the light collection efficiency of the probe. The length of the segment 98 may be optimized (the optimum length will depend upon a number of factors including, but not limited to, the fiber type).

[0066] Figure 7 illustrates a cross-section of a suitable photonic crystal fiber having a high numerical aperture. The cladding 60 of this fiber comprises a plurality of air holes. The air holes approximate the index of refraction of air ($n \approx 1$). Light is guided within the core 62. The cladding 60 is surrounded by a layer 64, which is the same material as the fiber core. It should be understood that other types of photonic crystal fibers would be suitable for this application and the fiber illustrated in Figure 7 is merely an example. The fiber illustrated in Figure 7 is similar to the MM-HN-200 PCF available from Crystal-Fiber A/S.

[0067] Referring back to Figure 6, the illuminating fiber 94 of the probe 90 may be angled with respect to the receiving fiber 92, as described previously with reference to the non-limiting embodiment illustrated in Figure 2. Likewise, the end face 104 of the illuminating fiber 94 may be cut or polished at an angle, as described previously with reference to the non-limiting embodiment illustrated in Figure 3. Similarly, the end face 106 of the receiving fiber 92 may be cut or polished at an angle and covered by a high refractive index material, as described previously with reference to the non-limiting embodiment illustrated in Figures 1, 2 and 3. Further, the end portion 96 of the receiving fiber 92 may be tapered to further increase the light collection efficiency.

[0068] According to another non-limiting embodiment of the invention, Figure 8 illustrates fiber optic probe 108 comprising a single photonic crystal fiber 110. The end portion 112 of the fiber 110 is fused to form a solid glass segment 113 (similar to segment 98 described previously) which is at least partly covered with a film 114. Excitation light propagating along the fiber 110 from the source 14 will encounter the segment 113. Light emitted by the film 114 will pass though the segment 113 to the core 118 of the fiber 114 without significant attenuation. Any suitable length of segment 112 may be used. Improved signal quality may be achieved by angle polishing the end face 116 and coating it with a high refractive index figure. The end portion 112 of the fiber 110 may be tapered to further increase the light collection efficiency.

[0069] As in Figure 5, the detection means 24 of Figure 8 may also comprise a beam splitter 119 in order to separate the excitation light and the film-emitted light. The beam splitter 119 will be placed between the source 14 and the input end of the fiber 72, as described previously.

[0070] According to another non-limiting embodiment of the invention, Figure 9 illustrates a fiber optic probe 120 comprising an illuminating fiber 122 for guiding excitation light from a light source 14 to be launched from an end face 124 of the illuminating fiber 122 and a second, receiving fiber 126 positioned alongside illuminating fiber 122. The receiving fiber 126 is a photonic crystal fiber. The illuminating fiber 122 may also be a photonic crystal fiber. The end face 128 of receiving fiber 126 and the end face 124 of illuminating fiber 122 are generally aligned, as shown. Alternatively, there may be a separation between the end face 128 of receiving fiber 126 and the end face 124 of illuminating fiber 122.

[0071] A film 130 is spaced from the end faces 124 and 128 of the illuminating fiber 122 and the receiving fiber 126, respectively. The film 130 is similar the other films described previously, and may be applied in a similar way to film 52 as a solid film or a film coating on a glass slide 132.

[0072] Light emitted by the film 130 is coupled into the core 134 of the receiving fiber 126 via the end face 128 of the receiving fiber 126. The end portion 136 of the receiving fiber 126 is fused to form a solid glass segment (as described previously with reference to Figure 6) so that the light collection efficiency of the probe 120 is enhanced. The end face 128 of the receiving fiber 126 may be cut or polished at an angle to enhance light collection efficiency of the probe. The illuminating fiber 122 may also be a photonic crystal fiber which may have a fused end portion as well (and may be cut or polished at an angle as well).

[0073] In experiments comparing the performance of a receiving fiber 126 having a segment 136 and a receiving fiber 126 having no such segment, an improvement in collection efficiency was greatly improved (on the order of 55%). Also, a receiving fiber 126 having a longer segment 136 of glass has a higher collection efficiency than a receiving fiber 126 having a shorter segment 136.

[0074] This effect can be described conceptually with reference to the projections of the light reception and launching cones of the illuminating fiber 122 and the receiving fiber 126, respectively. These projections are sometimes referred to as fields of view and have an elliptical shape when projected on the titled film 130. The field of view of the fiber having a segment 136 is larger than the field of view of a fiber having no such segment. The distance between the center of the field of view (or Fresnel diffraction field) of the illuminating fiber and the center of the field of view of the receiving fiber determines how much of the film-emitted light will be coupled into the receiving fiber. Thus, if the field of view of a fiber having a segment 136 is larger, the overlap will be greater and the light collection efficiency of the probe will be enhanced. However, there will obviously be an upper limit to the size of the segment 136. There will be an optimum segment length for each fiber type, separation of film 130, and so on. For example, in an embodiment similar to that illustrated in Figure 9, the optimum segment length is on the order of three times the cladding diameter of the receiving fiber.

[0075] It should be noted that the size of the field of view of the illuminating fiber depends upon a number of factors including the light intensity distribution at the end face 124 of the illuminating fiber 122 (which is in turn determined by the source 14 and the launching conditions at the entry end of the illuminating fiber 122). This field of view is also related to the fiber core and cladding sizes. The field of view of the receiving fiber 126 is determined by the smaller angle of the maximum reception angle of the receiving fiber 126 and the maximum acceptance angle of the detection means 24.

[0076] According to another non-limiting embodiment of the invention, Figure 10 illustrates a fiber optic probe 150 comprising an illuminating fiber 152 for guiding excitation light from a light source 14 to be launched from an end face 154 of the illuminating fiber 152 and a second, receiving fiber 156 positioned alongside illuminating fiber 152. The receiving fiber 156 is a photonic crystal fiber. The illuminating fiber 152 may also be a photonic crystal fiber. The end face 158 of receiving fiber 156 and the end face 154 of illuminating fiber 152 are generally aligned.

[0077] The probe 150 may be used in a liquid immersion medium 160. Liquid immersion media which emit light by fluorescence are known. For example, a suitable liquid immersion medium could be Alexa Fluor™ 635 dye conjugate diluted in a 0.1 M phosphate-buffered saline (PBS), the PBS liquid containing 0.1 M NaCl and 2 mM N_3Na and having a pH value of 7.5. This dye may be excited by a suitable source, such as a He-Ne laser operating at 633 nm, to fluoresce at 647 nm (central wavelength). It should be noted that light collection efficiency of the probe will increase for higher concentrations of the liquid immersion sample. It should also be noted that the immersion medium may emit light by another process, such as Raman scattering.

[0078] Light emitted by the immersion medium 160 is coupled into the core 162 of the receiving fiber 156 via the end face 158 of the receiving fiber 156. In order to optimize this coupling, the receiving fiber 156 has a fused end portion 157 as described previously with reference to Figure 6. The end face 158 of the receiving fiber 156 and/or the illuminating fiber 152 may also be cut or polished at an angle. This glass segment will convert at least part of the dead zone immediately in front of the probe to an active volume. This can be explained conceptually in a similar fashion to the example embodiment of Figure 9. Here, the volume overlap of the light reception and launching cones is increased by fusing the end portion 157 of the receiving fiber 156 which results in an increase in the amount of light collected by the receiving fiber 156. It should be noted that the glass segment, and other similar glass segments described herein will have extremely low attenuation. This is particularly beneficial when operating the probe 150 in an immersion medium having a higher level of attenuation and/or absorption. More specifically, it allows immersion-emitted light to travel a shorted path to reach the fiber core (which is difficult to achieve with conventional fiber). Similarly, if the measurement volume of the medium is very small, the enhanced light collection efficiency of the probe 150 will provide a strong enough signal to offer useful measurements.

[0079] The fused end portion 157 of the receiving fiber will also prevent the uptake of fluid into the air holes of the photonic crystal fiber(s) by capillary action. This is particularly advantageous for chemical or biological sensing where the fiber is in contact with fluids. Uptake of fluid can drastically change the optical properties of the fiber.

[0080] According to another non-limiting embodiment of the invention, Figure 11 illustrates a fiber optic probe 180 comprising an illuminating optical fiber 182 for guiding excitation light from a light source 14 to be launched from an end 184 of the illuminating fiber 182. A second, receiving fiber 186 is positioned alongside illuminating fiber 182. Both fibers can be standard fibers.

[0081] The end 188 of the receiving fiber 186 and the end 184 of illuminating fiber 182 are generally aligned and are covered by a shared lens

190. The lens 190 may be formed by fusing or heating the end 188 of the receiving fiber 186 and the end 184 of illuminating fiber 182. Alternatively, the lens 190 may be glued to the end 188 of the receiving fiber 186 and the end 184 of illuminating fiber 182.

[0082] It should be noted that this lens 190 and other lenses referred to in this specification may be of many shapes, as would be understood by the person skilled in the art. This type of lens is sometimes referred to as a micro lens. The formation of such lenses involves a reshaping of the fiber tip by fusing or heating the end, as mentioned previously. For example, a so-called 'ball lens' which approximates a spherical lens may be formed. The focusing effect of the lens will depend upon the size and shape of the lens.

[0083] At least a portion of an outer surface 192 of the lens 190 is covered by a film 194 which is similar to the films described previously. Excitation light launched from the illuminating fiber 182 will illuminate the at least part of the film 194. The film 194 will emit light, as described previously, which will be coupled into the receiving fiber 186 via the lens 190. After being excited by the illuminating light, the film-emitted light will travel inside the lens 190 and experience multiple internal reflections at the boundary of the lens 190 and the film 194. A portion of that film-emitted light is received by the receiving fiber 186 and guided along the length of the receiving fiber 186 to detection means 24.

[0084] The thickness of the film 194 will be controlled to optimize the signal to noise ratio. Light emitted by the film 194 will pass through the lens 190 into the core 196 of the receiving fiber 186 without significant attenuation, thus enhancing the light collection efficiency of the probe 180.

[0085] According to another non-limiting embodiment of the invention, Figure 12 illustrates a fiber optic probe 200 comprising an illuminating optical fiber 202 for guiding excitation light from a light source 14 to be launched from an end 204 of the illuminating fiber 202. A second, receiving fiber 206 is positioned alongside illuminating fiber 202.

[0086] The end 208 of the receiving fiber 206 and the end 204 of illuminating fiber 202 are generally aligned and are covered by a shared lens 210, similar to the lens 190 described previously (without the film 194). The probe 200 may be used in a liquid immersion medium 212 similar to the liquid immersion medium 160 described previously with reference to Figure 10. Light emitted by the immersion medium 212 is coupled into the core 214 of the receiving fiber 206 via the lens 210. Both fibers can be standard fibers.

[0087] According to another non-limiting embodiment of the invention, Figure 13 illustrates a fiber optic probe 220 comprising an illuminating fiber 222 for guiding excitation light from a light source 14 to be launched from an end face 224 of the illuminating fiber 222. A second, receiving fiber 226 is arranged so that an end portion 228 of the receiving fiber 226 protrudes past the end face of the illuminating fiber 222. Both fibers can be standard fibers.

[0088] At least a portion of the end 230 of the receiving fiber 226 is covered by a lens 232. The lens 232 may be formed by fusing or heating the end face 230 of the receiving fiber 226. Alternatively, the lens 232 may be glued to the end 230 of the receiving fiber 226. At least a portion of an outer surface 234 of the lens 232 is covered by a film 236 which is similar to the films described previously. Excitation light emitted from an end face 224 of the illuminating fiber 222 will illuminate at least part of the film 236. The film will emit light, as described previously with reference to lens 190, which will be coupled into the receiving fiber 226 via the lens 232.

[0089] The lens 232 is preferably formed or attached in such a way that it extends towards the end face 224 of the illuminating optical fiber 222, as shown, to optimize illumination of the film 236 by the illuminating optical fiber 222.

[0090] As shown in Figure 13, the illuminating fiber 222 and the receiving fiber 226 are in side-by-side parallel relation. The launching cone 238 of the illuminating fiber 222 will be generally symmetric about the optical axis 240 of the illuminating fiber 222.

[0091] Alternatively, as shown in Figure 14, the illuminating fiber 222 may be disposed at a non-parallel angle α from the receiving fiber 226 to 'bend' or direct the launching cone 238 of the illuminating fiber 222 towards the film 236. By directing the launching cone 236 of the illuminating fiber 222 towards the film 236, the intensity of light impinging upon the film 236 will be increased and the amount of light emitted by the film 236 and coupled into the receiving fiber 226 will increase. This angle α can range anywhere from about 0° to about 90°.

[0092] Alternatively, as shown in Figure 15, the end face 224 of the illuminating optical fiber 222 can be cut or polished at an angle to 'bend' or direct the launching cone 238 of the illuminating fiber 222 towards the film 236. As explained previously, by directing the launching cone 238 of the illuminating fiber 222 towards the film 236, the intensity of excitation light impinging upon the film 236 will be increased and the amount of light emitted by the film 236 and coupled into the receiving fiber 226 will increase.

[0093] According to another non-limiting embodiment of the invention, Figure 16 illustrates a fiber optic probe 250 comprising an illuminating optical fiber 252 for guiding excitation light from a light source 14. A second, receiving fiber 256 is positioned alongside illuminating fiber 252. The illuminating fiber 252 and/or the receiving fiber 256 may be photonic crystal fibers, similar to the photonic crystal fibers described previously. The illuminating fiber may also be a standard fiber.

[0094] The end 258 of the receiving fiber 256 and the end 254 of illuminating fiber 252 are generally aligned and are covered by a shared lens 260. The shared lens 260 may be formed by fusing or heating the end face 254 of the illuminating fiber 252 and the end face 258 of the receiving fiber 256 (or glued thereto, as described previously with regard to other embodiments having a lens). Fusing or heating the end faces of the fibers will also seal the air holes. At least a portion of an outer surface 262 of the lens 260 is covered by a film 264 which is similar to the films described previously. Excitation light launched from an end 254 of the illuminating fiber 252 will illuminate the film 264. The film will emit light, as described previously, which will be coupled into the receiving fiber 256 via the lens 260. After being excited by the illuminating light, the film-emitted light will travel inside the lens and experience multiple internal reflections at the boundary of the lens and the film. A portion of that film-emitted light is eventually received by the receiving fiber 256.

[0095] The probe 250 may be used in a liquid immersion medium similar to the liquid immersion medium 160 described previously with reference to Figure 12 (without the film 264, of course).

[0096] According to another non-limiting embodiment of the invention, Figure 17 illustrates a fiber optic probe 270 comprising an illuminating fiber 272 for guiding excitation light from a light source 14 to be launched from an end face 274 of the illuminating fiber 272. A second, receiving fiber 276 is arranged so that an end portion 278 of the receiving fiber protrudes past the end face 274 of the illuminating fiber 272. The receiving fiber 276 is a photonic crystal fiber. The illuminating fiber may also be a photonic crystal fiber.

[0097] At least a portion of the end 278 of the receiving fiber 276 is covered by a lens 280, similar to the lens 232 described previously with respect to Figures 13, 14 and 15. As such, at least a portion of an outer surface 282 of the lens 280 is covered by a film 284 which is similar to the films described previously. The lens 280 is preferably formed or attached in such a way that it extends towards the end face 274 of the illuminating optical fiber 272, as shown, to optimize illumination of the film 284 by the illuminating optical fiber 272.

[0098] As shown in Figure 17, the illuminating fiber 272 and the receiving fiber 276 are in side-by-side parallel relation. The launching cone 286 of the illuminating fiber 272 will be generally symmetric about the optical axis 288 of the illuminating fiber 272.

[0099] Alternatively, as shown in Figure 18, the illuminating fiber 272 may be disposed at a non-parallel angle α from the receiving fiber 276 to 'bend' or direct the launching cone 286 of the illuminating fiber 272 towards the film 284. By directing the launching cone 286 of the illuminating fiber 272 towards the film

284, the intensity of excitation light impinging upon the film 284 will be increased and the amount of light emitted by the film 284 and coupled into the receiving fiber 276 will increase. This angle α can range anywhere from about 0° to about 90°.

[00100] Alternatively, as shown in Figure 19, the end face 274 of the illuminating optical fiber 272 can be cut or polished at an angle to 'bend' or direct the launching cone 286 of the illuminating fiber 272 towards the film 284. As explained previously, by directing the launching cone 286 of the illuminating fiber 272 towards the film 284, the intensity of excitation light impinging upon the film 284 will be increased and the amount of light emitted by the film 284 and coupled into the receiving fiber 276 will increase.

[00101] Various fixtures may be implemented to hold the fiber(s) of any of the above described embodiments. Such fixtures are greatly simplified in the non-limiting embodiments described previously in which the film is applied directly to the fiber as the film itself does not need to be separately supported.

[00102] It should also be understood that, while in the above description of various embodiments of the invention, there is a single receiving fiber and a single illuminating fiber, embodiments of the invention may comprise multiple receiving fibers and/or multiple illuminating fibers. For example, a ring of receiving fibers may be provided around a single illuminating fiber.

[00103] It should be understood that a glass segment may be employed in example embodiments described herein having standard fibers by attaching a glass rod to the end of the receiving fiber via a gluing process, fusing process or any other suitable process. Such a glass segment would improve the light collection efficiency of the fiber in accordance with the principles described herein with reference to photonic crystal fiber.

[00104] It should be noted that various details related to the present invention are disclosed in the following papers:

i) Jianjun Ma and Wojtek J. Bock, "*Modeling of photonic crystal fiber with air holes sealed at the fiber end and its application to fluorescent light collection efficiency enhancement*", Opt. Express 13, 2385-2393 (2005)

ii) Jianjun Ma *et al.*, "*Towards optimum sample-probe-spectrometer system design by adjusting receiving fiber end face position and probe-membrane sample separation*", Opt. Express 13, 9492-9501 (2005)

iii) J. Ma *et al.*, "*Investigation of large-core photonic crystal fiber sensor for enhancement of fluorescent light collection of polymer membrane*", Photonic Applications in Devices and Communication Systems, Proc. Of SPIE Vol. 5970,597006 (2005)

[00105] While the invention has been described in detail in the foregoing specification, it will be understood by those skilled in the art that variations may be made without departing from the spirit and scope of the invention, being limited only by the appended claims.

WHAT WE CLAIM AS OUR INVENTION IS:

1. A fiber optic probe for detecting the presence or absence of one or more substances within a medium, said fiber optic probe comprising:

   at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

   at least one film for emitting film-emitted light when illuminated by said excitation light, said film-emitted light having a central wavelength that is different than a central wavelength of said excitation light; and

   at least one receiving optical fiber for receiving and guiding said film-emitted light, said at least one receiving optical fiber being a photonic crystal fiber, an end portion of said at least one receiving optical fiber being a solid segment of glass.

2. A fiber optic probe according to claim 1, wherein said receiving fiber is positioned alongside said at least one illuminating fiber.

3. A fiber optic probe according to claim 1, wherein said at least one illuminating optical fiber and said at least one receiving optical fiber are in side-by-side parallel relation.

4. A fiber optic probe according to claim 1, wherein an end portion of said at least one receiving fiber protrudes past an end face of said at least one receiving fiber.

5. A fiber optic probe according to claim 1, wherein said at least one illuminating optical fiber has an angled end face.

6. A fiber optic probe according to claim 1, wherein said at least one illuminating optical fiber is angled with respect to said at least one receiving optical fiber.

7. A fiber optic probe according to claim 1, wherein said end portion of said at least one receiving optical fiber is tapered.

8. A fiber optic probe according to claim 1, wherein said at least one film is spaced from an end portion of said at least one receiving optical fiber, said at least one film disposed at an angle to an end face of said at least one illuminating optical fiber for receiving said excitation light to be illuminated thereby and transmitting said film-emitted light to said receiving optical fiber.

9. A fiber optic probe according to claim 1, wherein said film is disposed on a surface of said solid segment of glass.

10. A fiber optic probe according to claim 1, wherein said at least one illuminating optical fiber is a photonic crystal fiber.

11. A fiber optic probe according to claim 1, wherein a segment of air holes at an end portion of said receiving fiber are fused together to form said solid segment of glass.

12. A fiber optic probe according to claim 1, wherein said at least one illuminating optical fiber and said at least one receiving optical fiber are the same individual fiber.

13. A fiber optic probe according to claim 1, further comprising a lens covering at least a portion of an end of said at least one receiving optical fiber, said film covering at least a portion of an outer surface of said lens.

14. A fiber optic probe according to claim 13, wherein said lens is generally spherical.

15. A fiber optic probe according to claim 1, wherein said film emits said film-emitted light by fluorescence.

16. A fiber optic probe for detecting the presence or absence of one or more substances within a medium, said fiber optic probe comprising:

at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

at least one film for emitting film-emitted light when illuminated by said excitation light, said film-emitted light having a central wavelength that is different than a central wavelength of said excitation light;

at least one receiving optical fiber for receiving and guiding said film-emitted light; and

a lens covering at least a portion of an end of said at least one receiving optical fiber, said film covering at least a portion of an outer surface of said lens, said lens and receiving fiber arranged so that at least part of said film is illuminated by said excitation light.

17. A fiber optic probe according to claim 16, wherein said lens is formed by at least one of fusing and heating the end portion of said at least one receiving optical fiber.

18. A fiber optic probe according to claim 16, wherein said lens is generally spherical.

19. A fiber optic probe according to claim 16, wherein said lens also covers at least a portion of an end of said at least one illuminating optical fiber.

20. A fiber optic probe according to claim 16, wherein said at least one illuminating optical fiber and said at least one receiving optical fiber are in side-by-side parallel relation.

21. A fiber optic probe according to claim 16, wherein an end portion of said at least one receiving fiber protrudes past an end face of said at least one receiving fiber.

22. A fiber optic probe according to claim 16, wherein said at least one illuminating optical fiber has an angled end face.

23. A fiber optic probe according to claim 16, wherein said at least one illuminating optical fiber is angled with respect to said at least one receiving optical fiber.

24. A fiber optic probe according to claim 16, wherein said at least one illuminating fiber is a photonic crystal fiber.

25. A fiber optic probe according to claim 16, wherein said at least one receiving optical fiber is a photonic crystal fiber.

26. A fiber optic probe according to claim 16, wherein said film emits said film-emitted light by fluorescence.

27. A fiber optic probe for detecting the presence or absence of one or more substances within a medium, said fiber optic probe comprising:

at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

at least one film for emitting film-emitted light when illuminated by said excitation light, said film-emitted light having a central wavelength that is different than a central wavelength of said excitation light; and

at least one receiving optical fiber for receiving and guiding said film-emitted light, said at least one receiving fiber arranged so that an end portion of said at least one receiving fiber protrudes past said end face of said at least one illuminating fiber, at least part of said end portion of said at least one receiving fiber being illuminated by said excitation light.

28. A fiber optic probe according to claim 27, wherein said at least one film covers a thin cladding of at least one portion of said at least one receiving optical fiber and said cladding transmits said film-emitted light, said film-

emitted light being coupled into a core of said at least one receiving optical fiber.

29. A fiber optic probe according to claim 27, wherein a portion of a cladding of said at least one receiving fiber is removed and said at least one film covers a portion of said core of said at least one receiving fiber where said cladding of said at least one receiving fiber is removed, said film-emitted light being coupled into said core of said at least one receiving fiber.

30. A fiber optic probe according to claim 27, wherein said film emits said film-emitted light by fluorescence.

31. A fiber optic probe according to claim 27, wherein said at least one illuminating optical fiber and said at least one receiving optical fiber are in side-by-side parallel relation.

32. A fiber optic probe according to claim 27, wherein said end face of said at least one illuminating optical fiber is angled.

33. A fiber optic probe according to claim 27, wherein an end face of said at least one receiving optical fiber is angled.

34. A fiber optic probe according to claim 27, wherein said at least one illuminating optical fiber is angled with respect to said at least one receiving optical fiber by between about 0° and about 90°.

35. A fiber optic probe according to claim 27, wherein said end portion of said at least one receiving optical fiber is tapered.

36. A fiber optic probe according to claim 27, wherein said at least one illuminating fiber is a photonic crystal fiber.

37. A fiber optic probe according to claim 27, wherein said at least one receiving optical fiber is a photonic crystal fiber.

38. A fiber optic probe according to claim 37, wherein air holes at an end portion of said photonic crystal fiber are fused together to form a solid segment of glass.

39. A fiber optic probe according to claim 38, wherein said film covers an outer surface of said segment and said film-emitted light is coupled into a core of said receiving optical fiber via said segment.

40. A fiber optic probe according to claim 27, wherein said end portion of said at least one receiving optical fiber is a solid segment of glass.

41. A fiber optic probe for detecting the presence or absence of one or more substances within a medium, said fiber optic probe comprising:

at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

at least one film for emitting film-emitted light when illuminated by said excitation light, said film-emitted light having a central wavelength that is different than a central wavelength of said excitation light; and

at least one receiving optical fiber for receiving and guiding said film-emitted light, said film covering a thin cladding of a portion of said receiving optical fiber, said thin cladding of said at least one receiving optical fiber transmitting said film-emitted light into a core of said at least one receiving optical fiber, said at least one receiving optical fiber arranged so that at least part of said portion of said at least one receiving optical fiber is illuminated by said excitation light.

42. A fiber optic probe according to claim 41, wherein the at least one receiving optical fiber and the at least one illuminating optical fiber are the same individual fiber.

43. A fiber optic probe according to claim 41, wherein said film emits said film-emitted light by fluorescence.

44. A fiber optic probe for detecting the presence or absence of one or more substances within an immersion medium, said fiber optic probe comprising:

at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

an immersion medium for emitting immersion-emitted light when illuminated by said excitation light, said immersion-emitted light having a central wavelength that is different than a central wavelength of said excitation light; and

at least one receiving optical fiber positioned alongside said at least one illuminating optical fiber for receiving and guiding said immersion-emitted light, said at least one receiving optical fiber being a photonic crystal fiber, an end portion of said at least one receiving optical fiber being a solid segment of glass.

45. A fiber optic probe according to claim 44, wherein said immersion medium emits said immersion-emitted light by fluorescence.

46. A fiber optic probe for detecting the presence or absence of one or more substances within an immersion medium, said fiber optic probe comprising:

at least one illuminating optical fiber for guiding excitation light from a light source to be launched from an end face of said at least one illuminating optical fiber;

an immersion medium for emitting immersion-emitted light when illuminated by said excitation light, said immersion-emitted light having a central wavelength that is different than a central wavelength of said excitation light;

at least one receiving optical fiber positioned alongside said illuminating optical fiber for receiving and guiding said immersion-emitted light, an end face of said at least one receiving optical fiber being aligned with said end face of said at least one illuminating optical fiber;

a lens covering said end face of said at least one illuminating optical fiber and said end face of said at least one receiving optical fiber, said lens coupling said immersion-emitted light into said at least one receiving optical fiber;

detection means for detecting light from at least one receiving optical fiber.

47. A fiber optic probe according to claim 46, wherein said immersion medium emits said immersion-emitted light by fluorescence.

48. A fiber optic probe according to any one of claims 1 to 47, further comprising detection means for detecting light from at least one receiving optical fiber.

49. A fiber optic probe according to any one of claims 1 to 47, further comprising a light source.

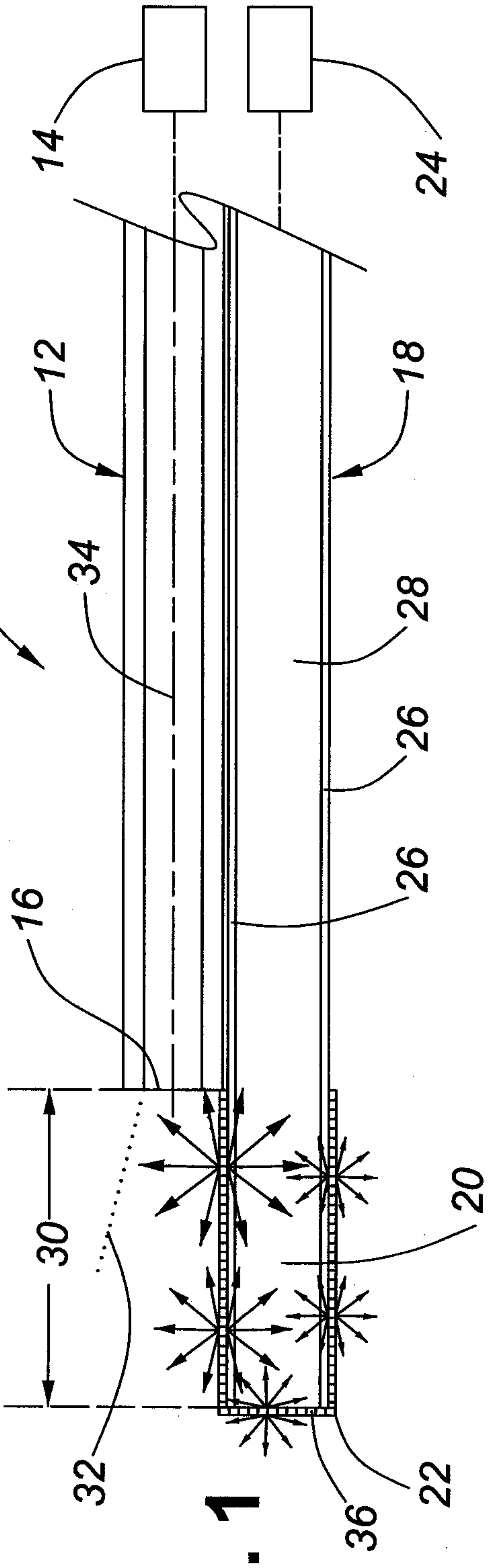

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FIG. 1

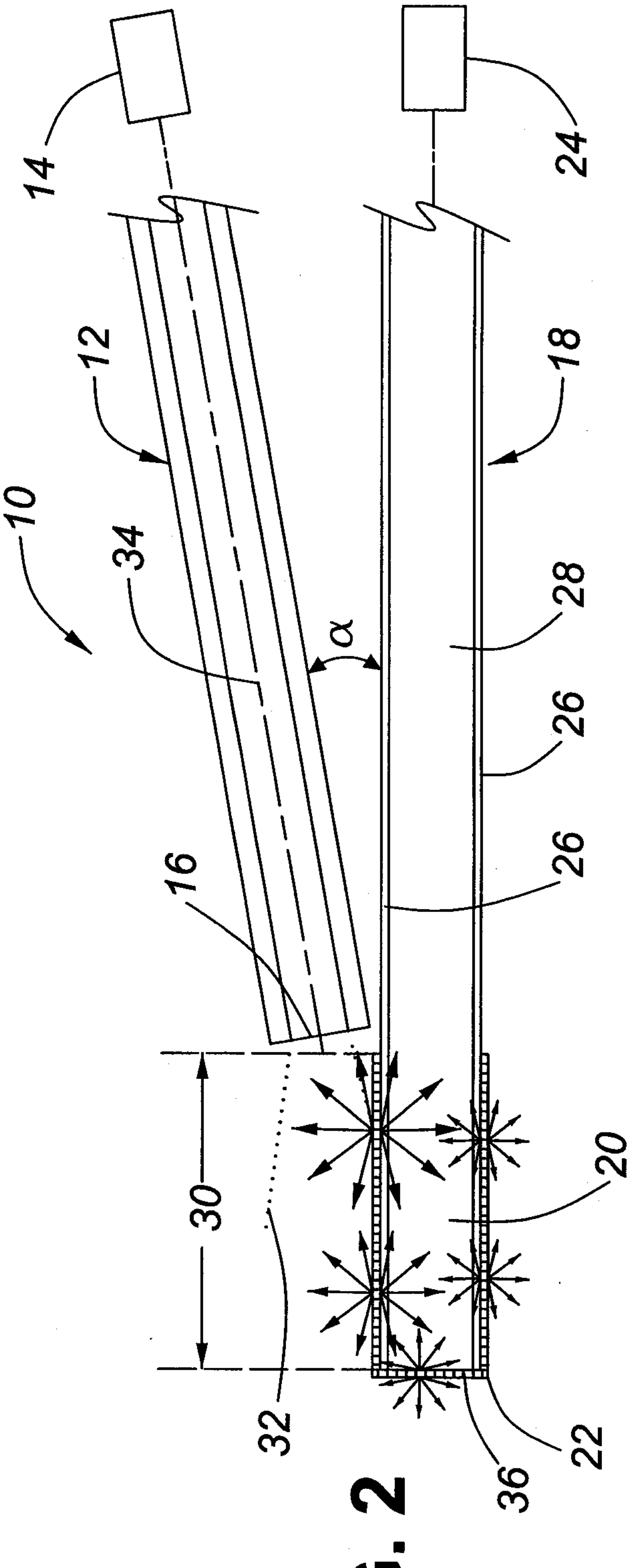
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FIG. 2

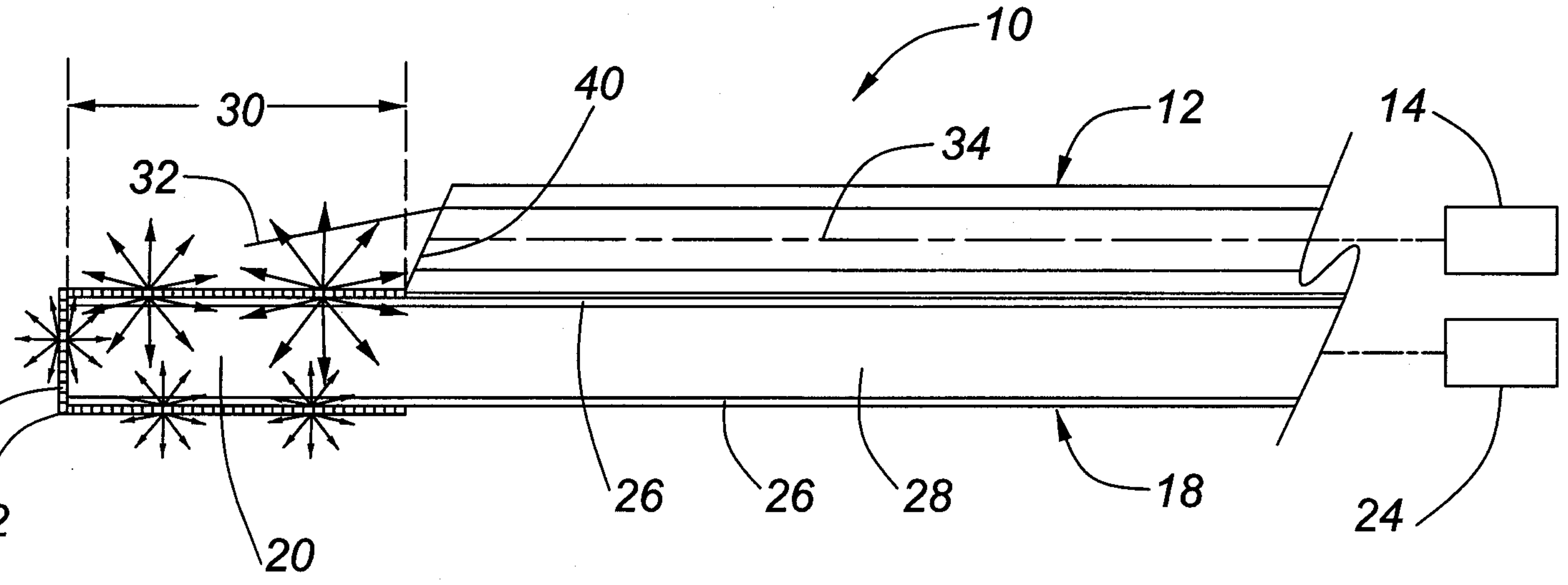
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FIG. 3

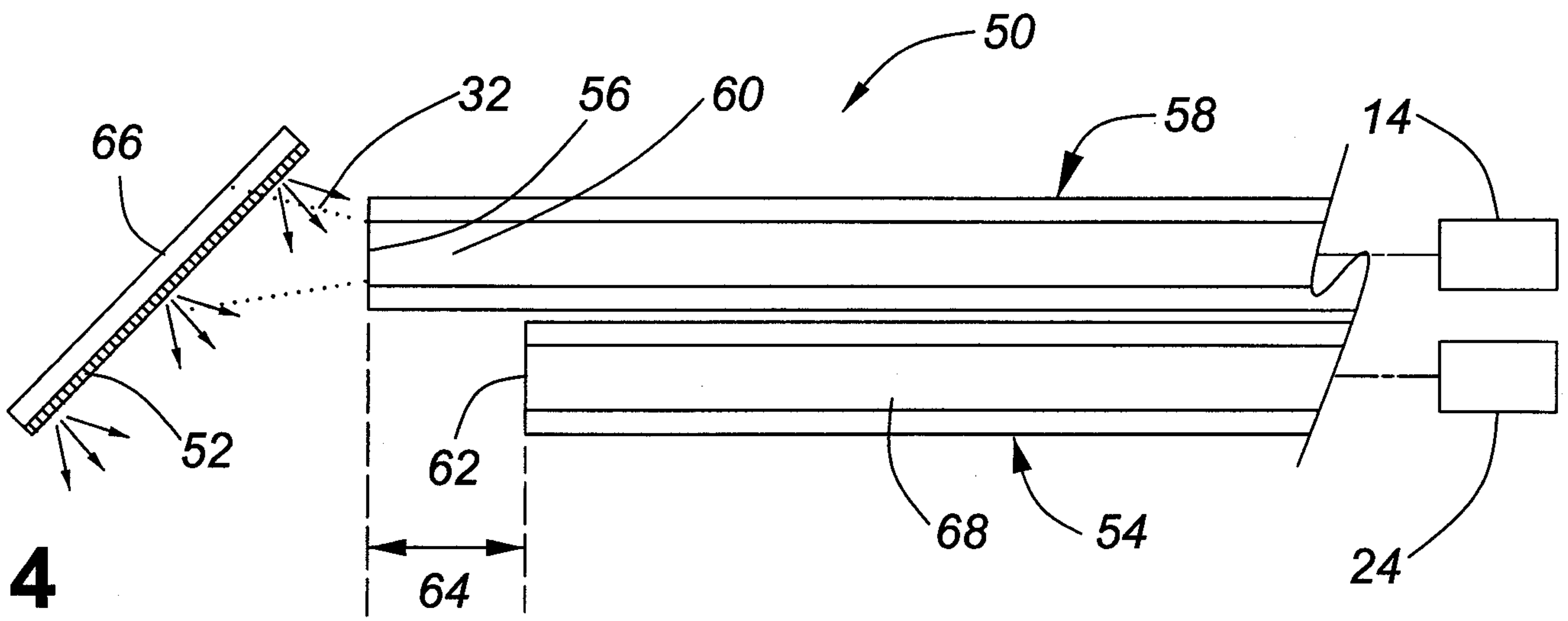
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FIG. 4

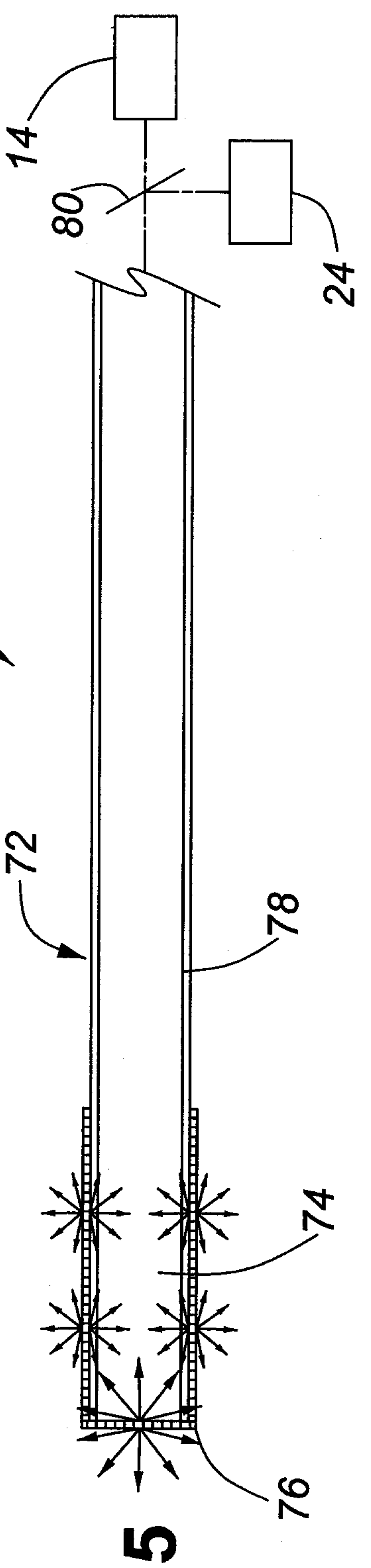

FIG. 5

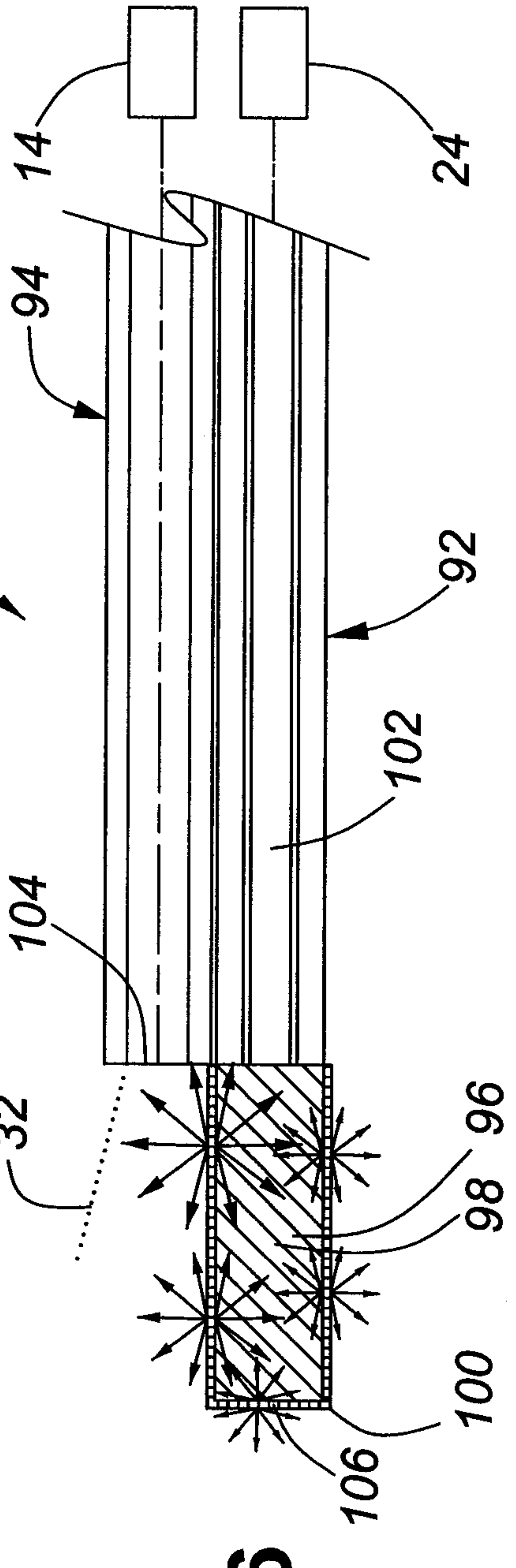

FIG. 6

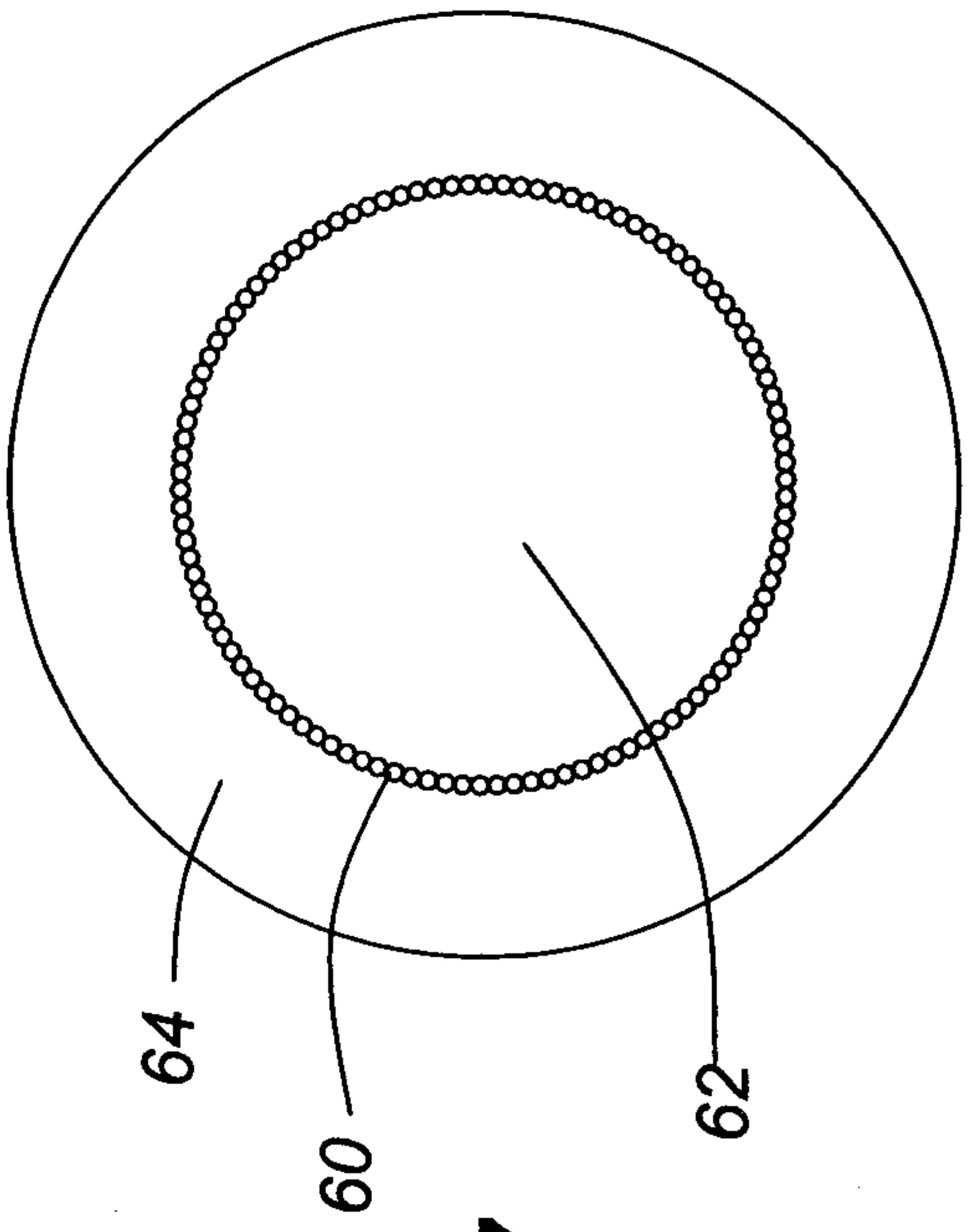

FIG. 7

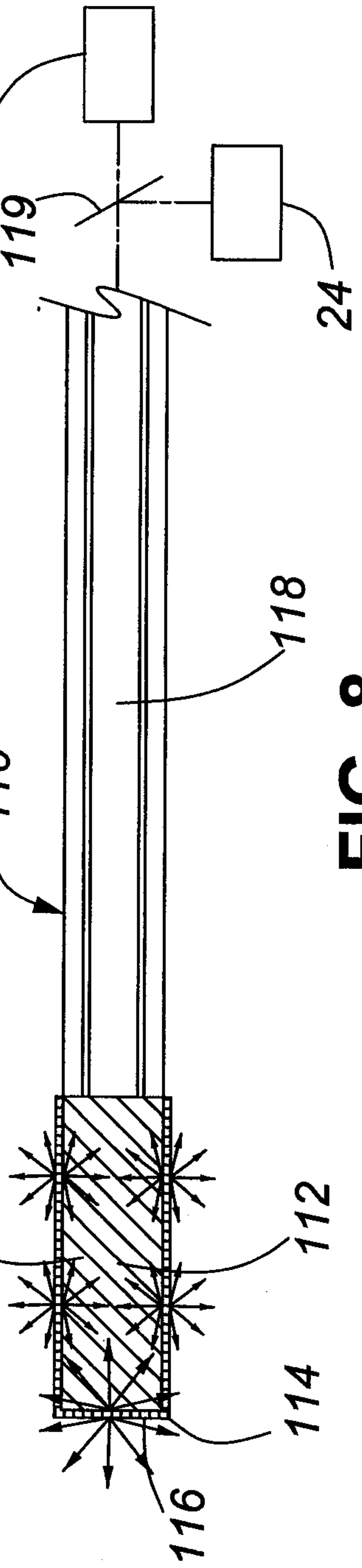

FIG. 8

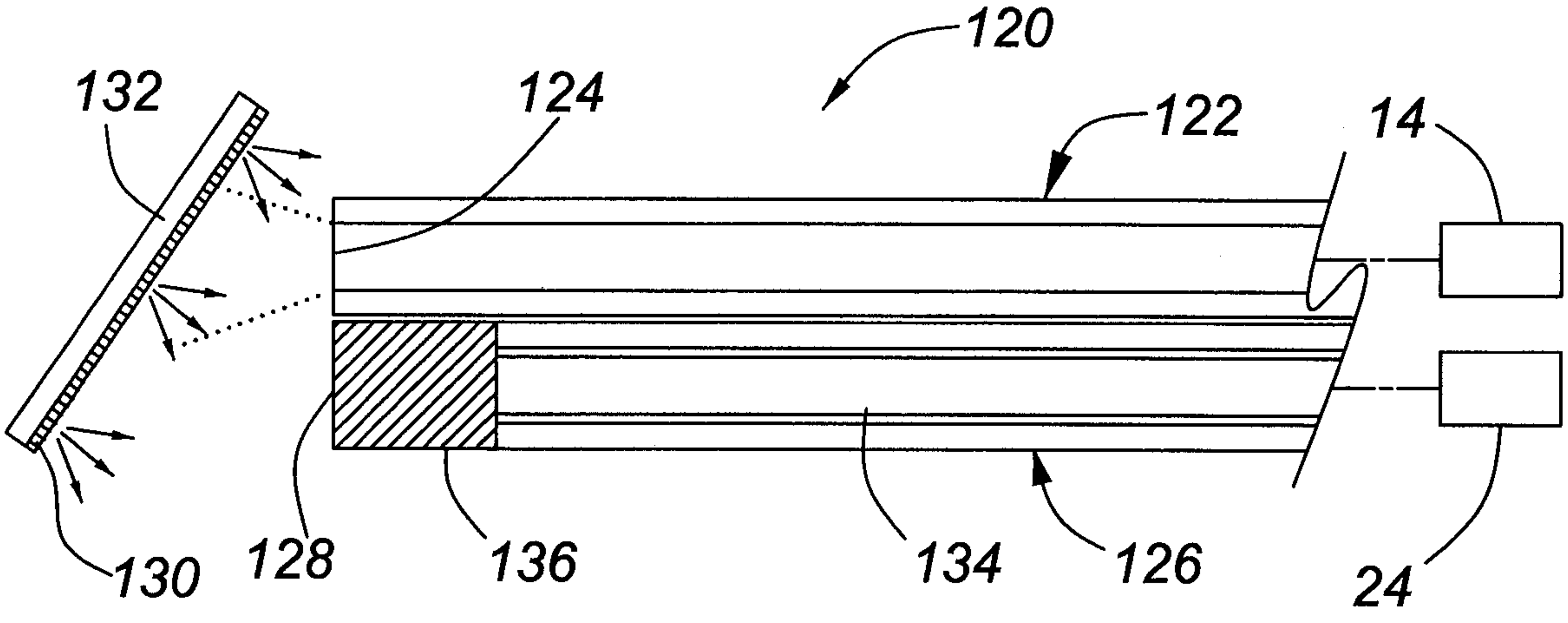
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FIG. 9

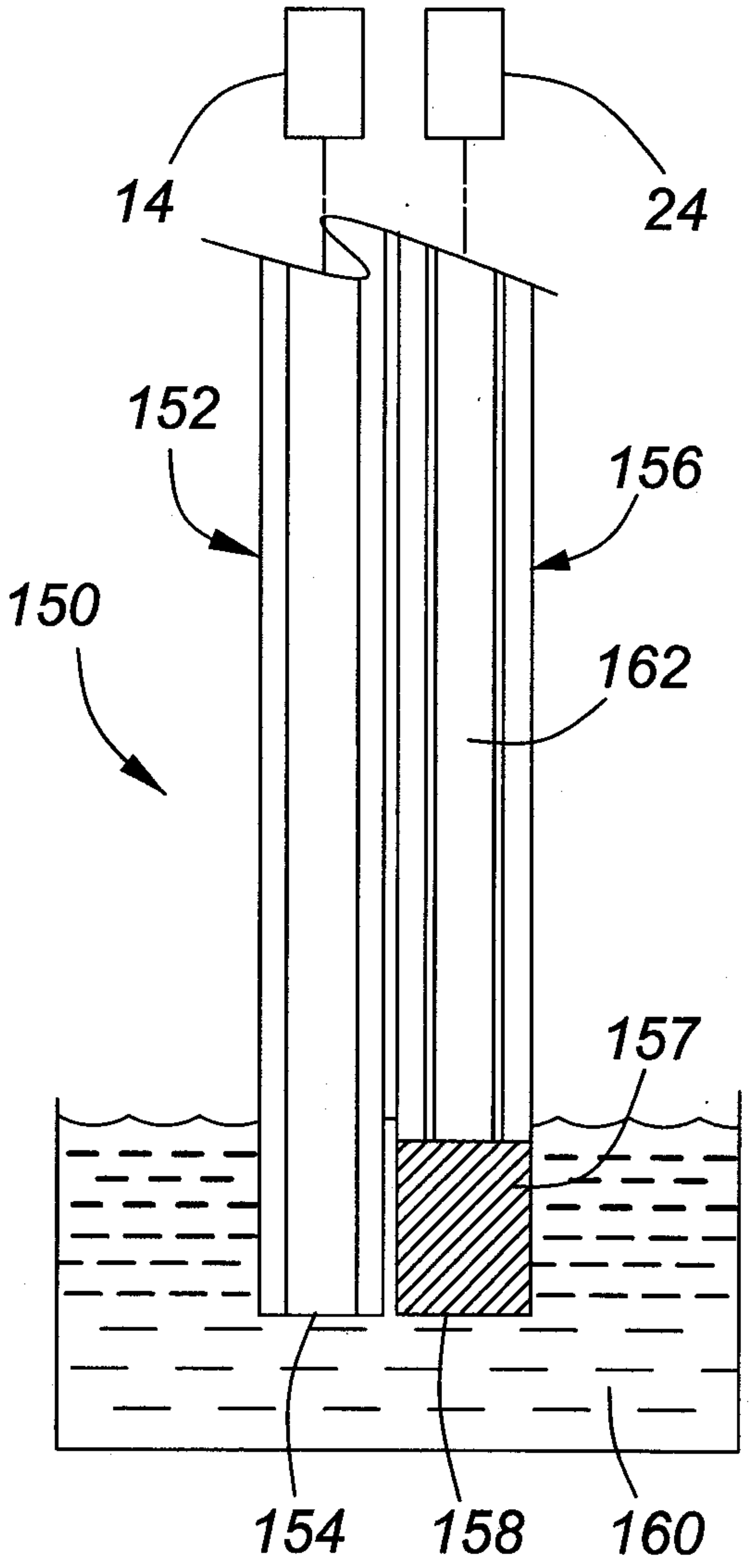
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FIG. 10

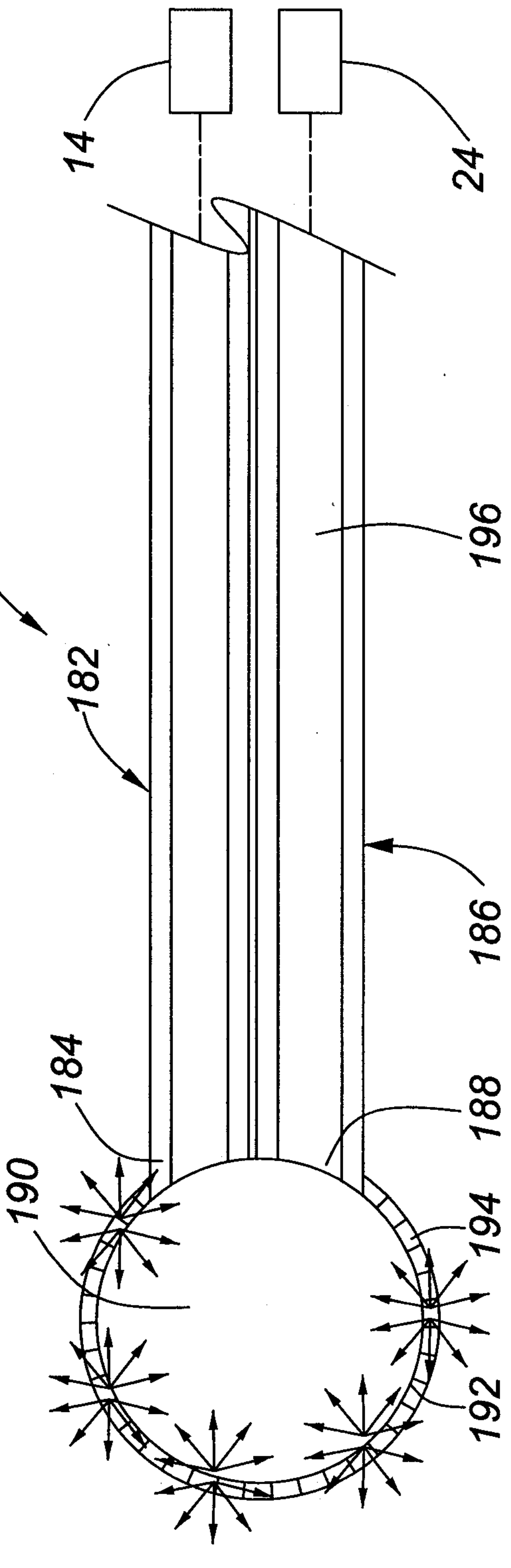

FIG. 11

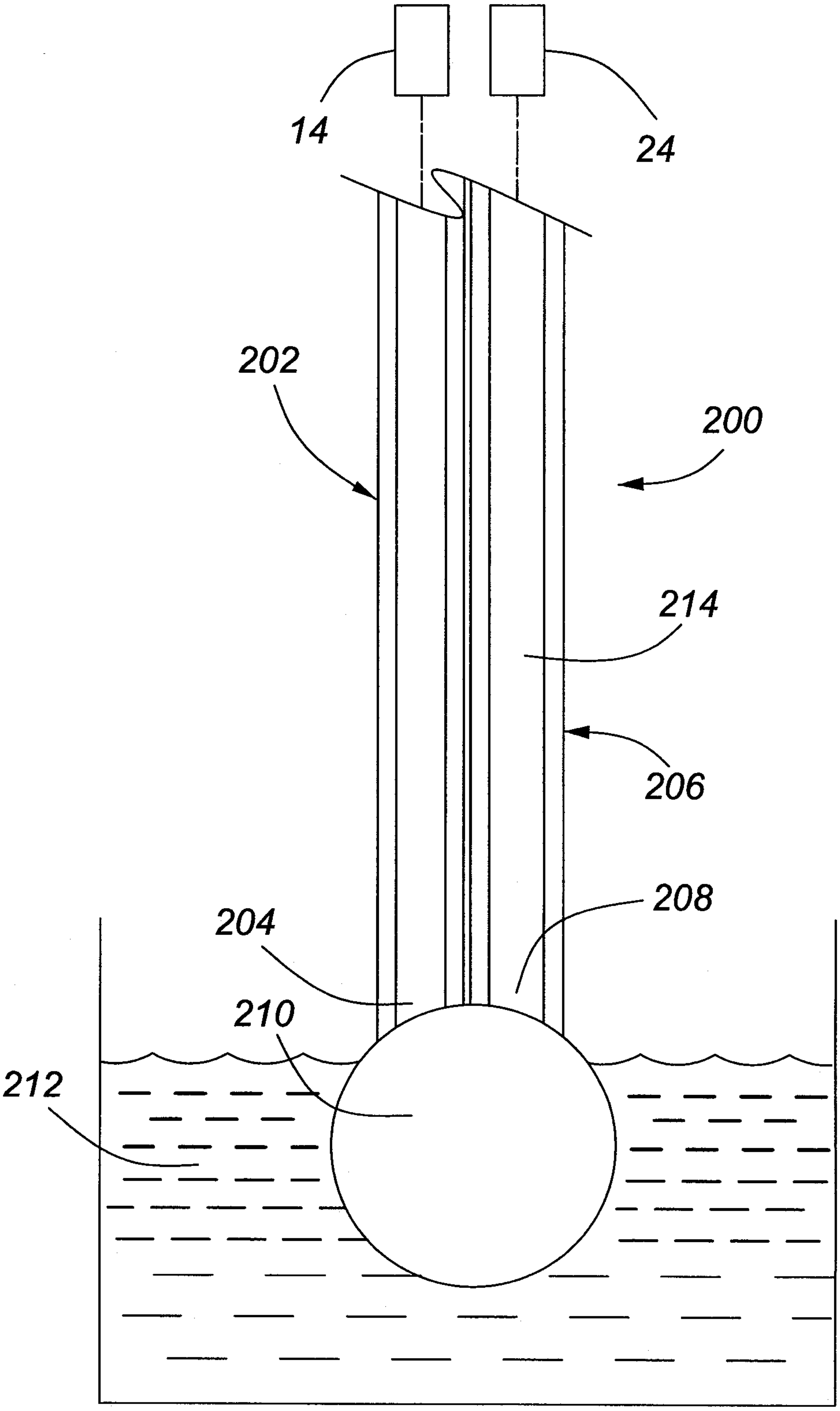

FIG. 12

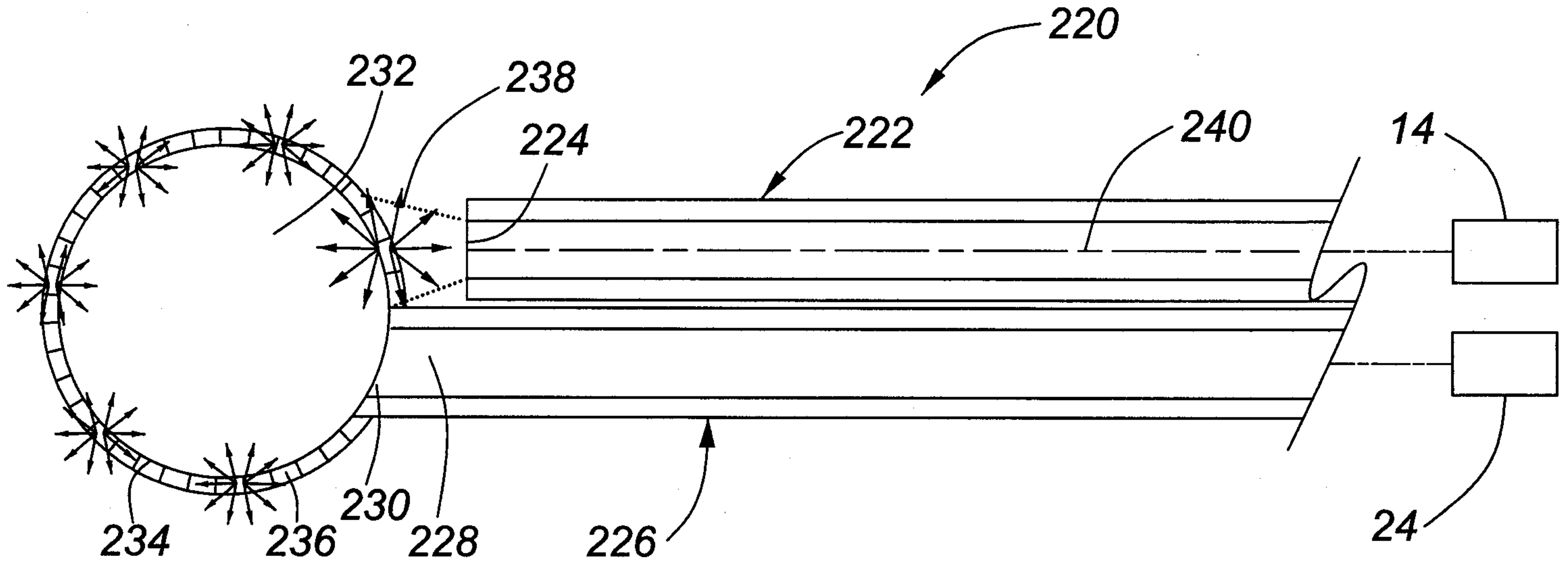
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FIG. 13

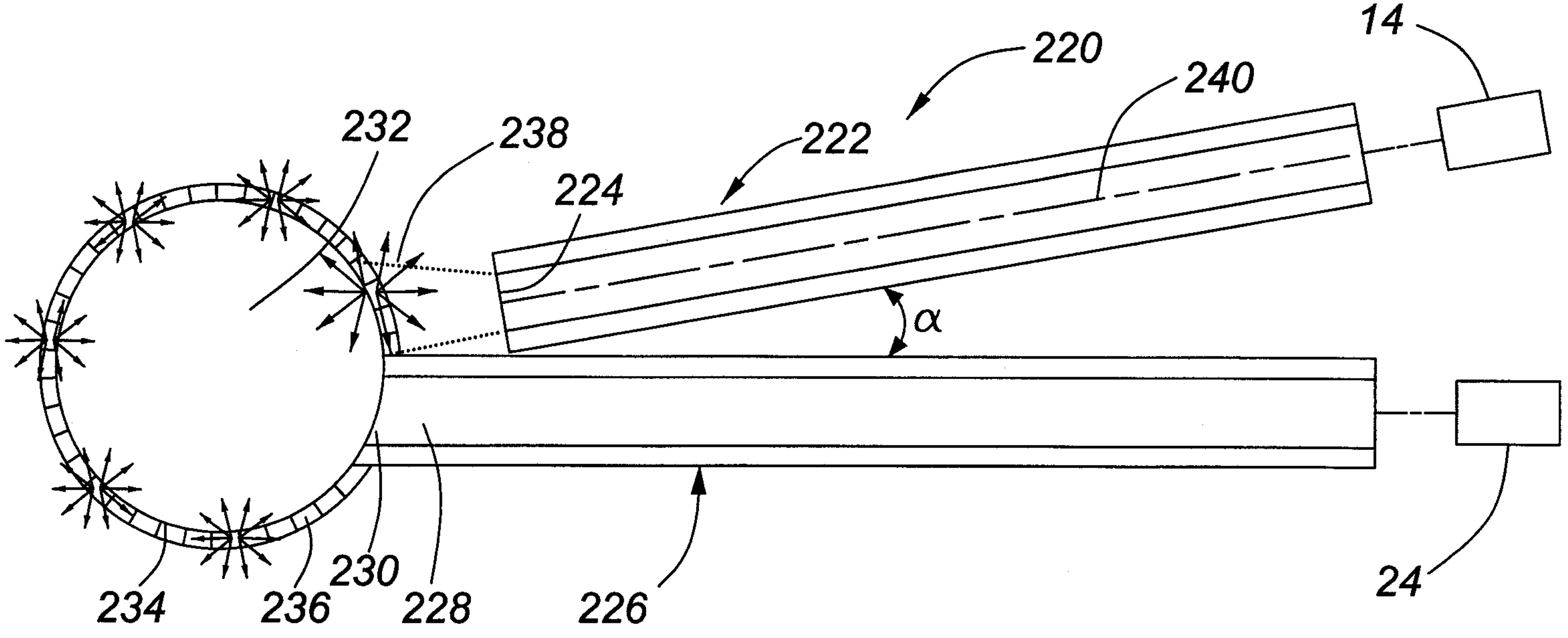
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FIG. 14

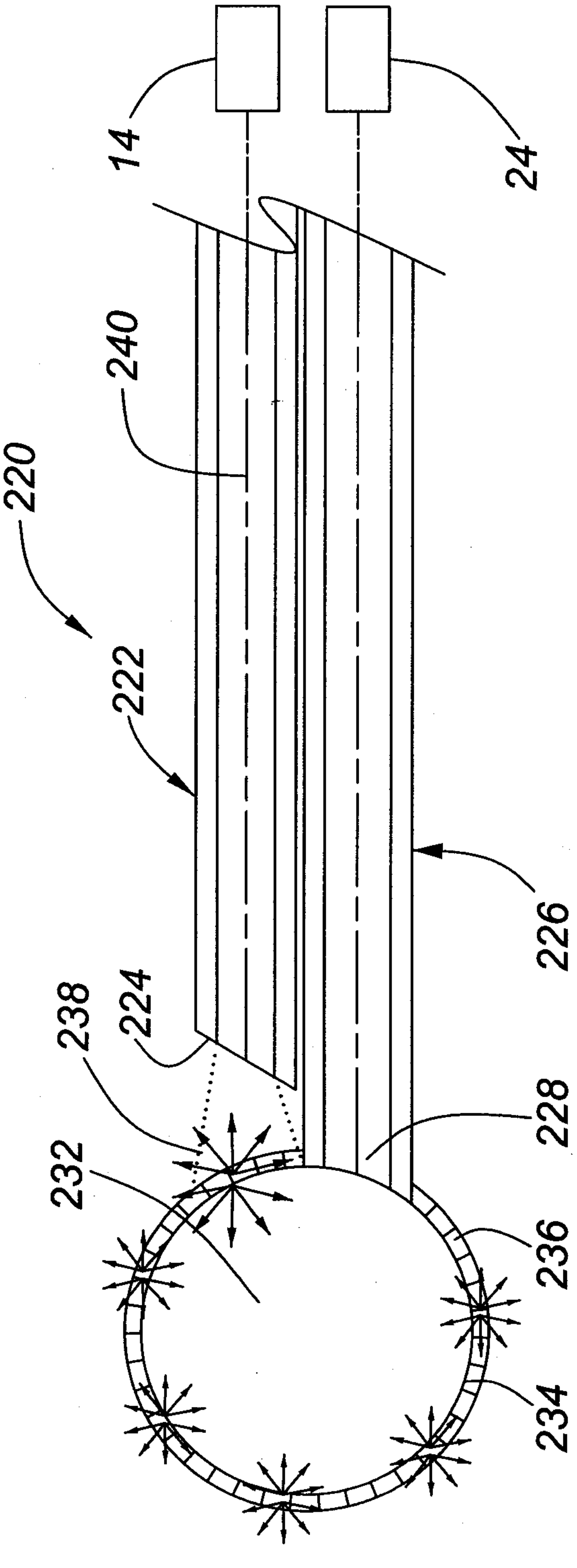

FIG. 15

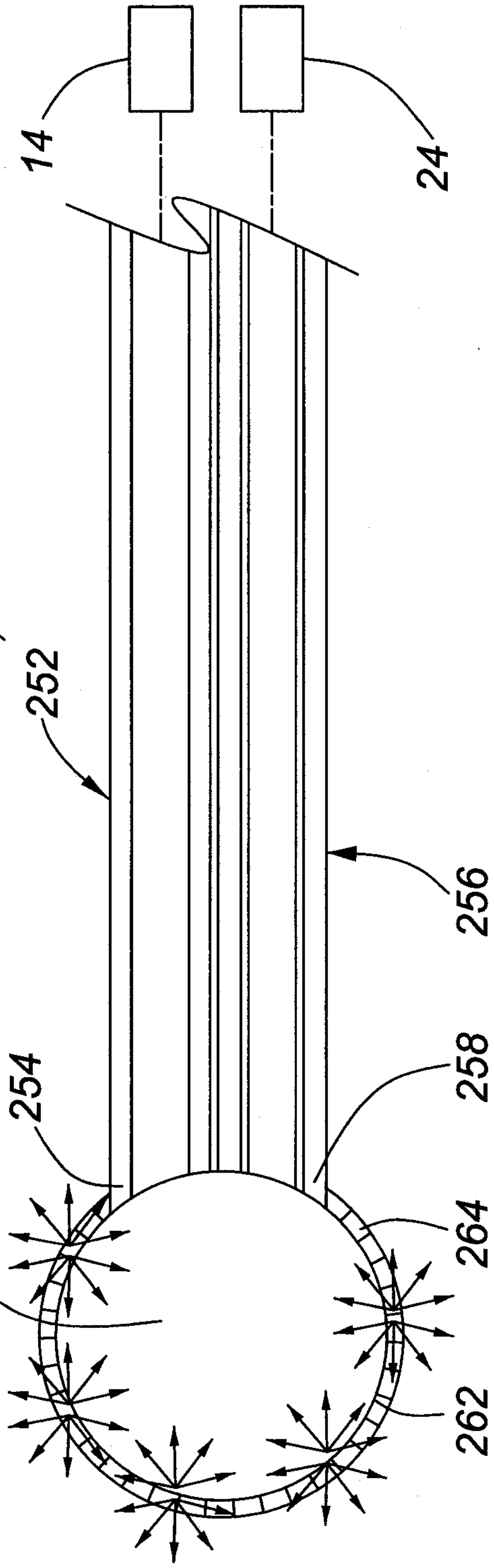

FIG. 16

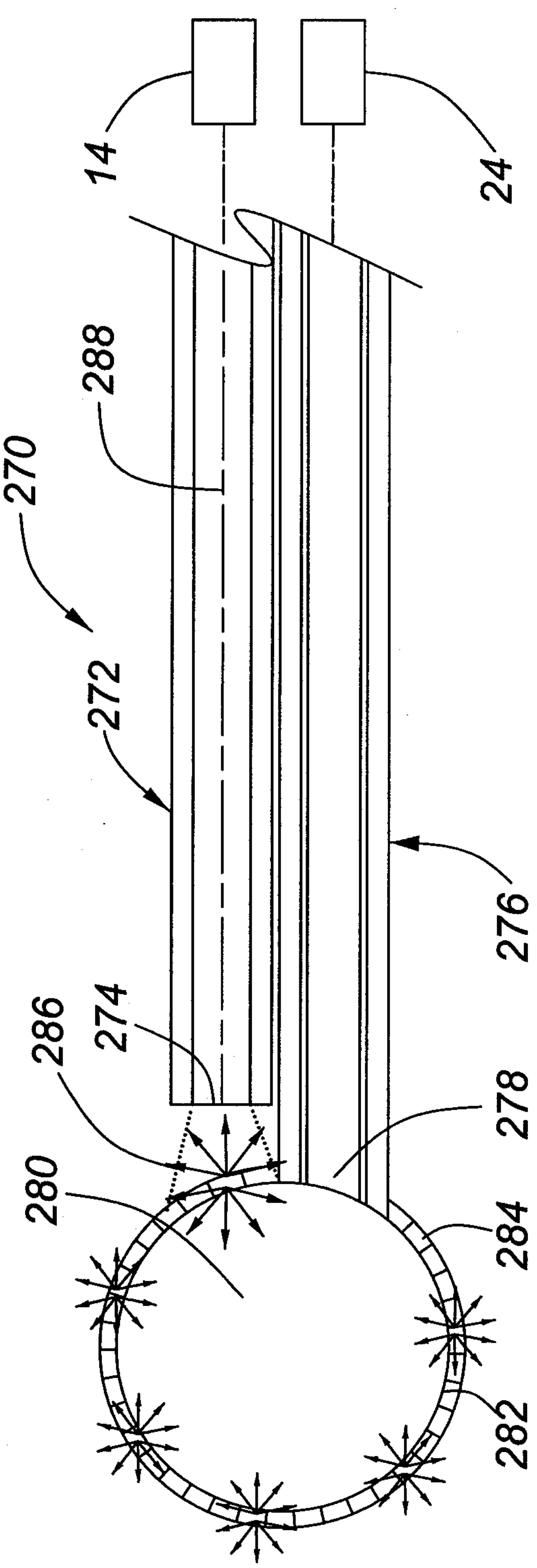
270
272
288
14
24
276
274
286
280
278
284
282

FIG. 17

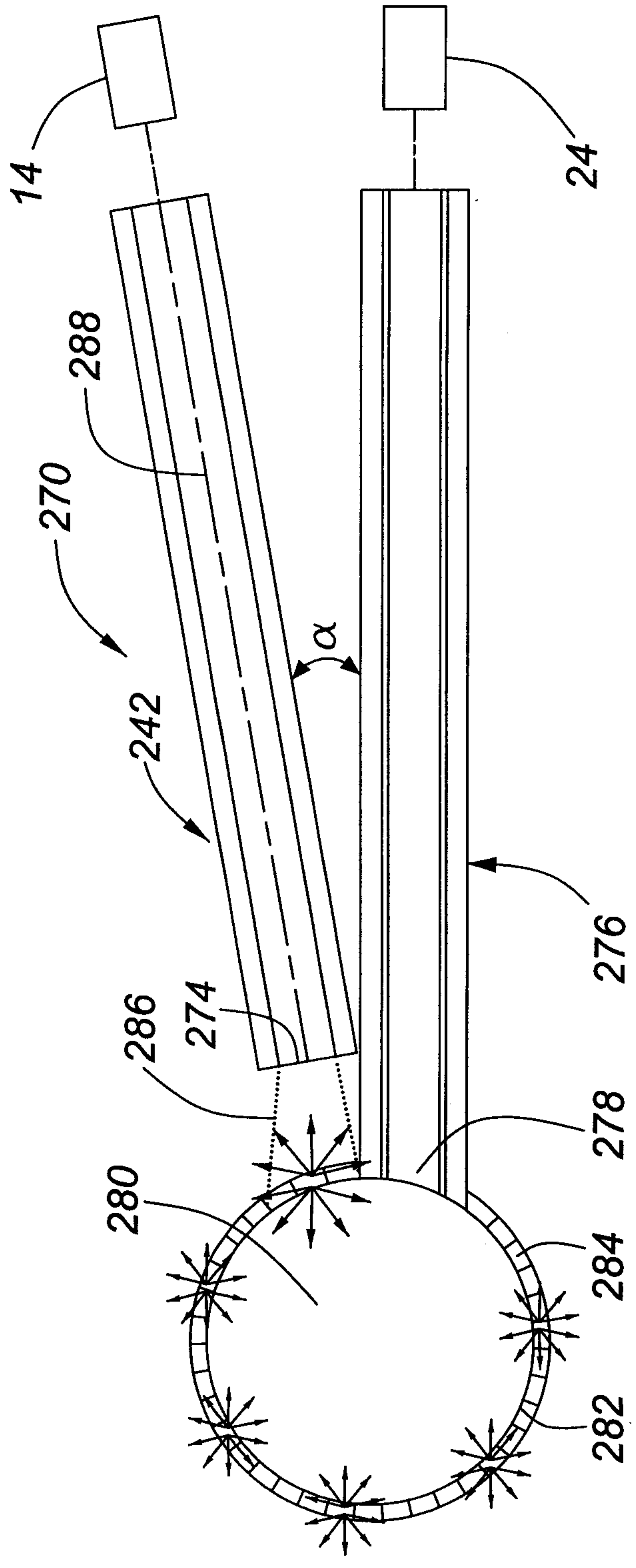
270
242
288
14
24
α
276
274
286
280
278
284
282

FIG. 18

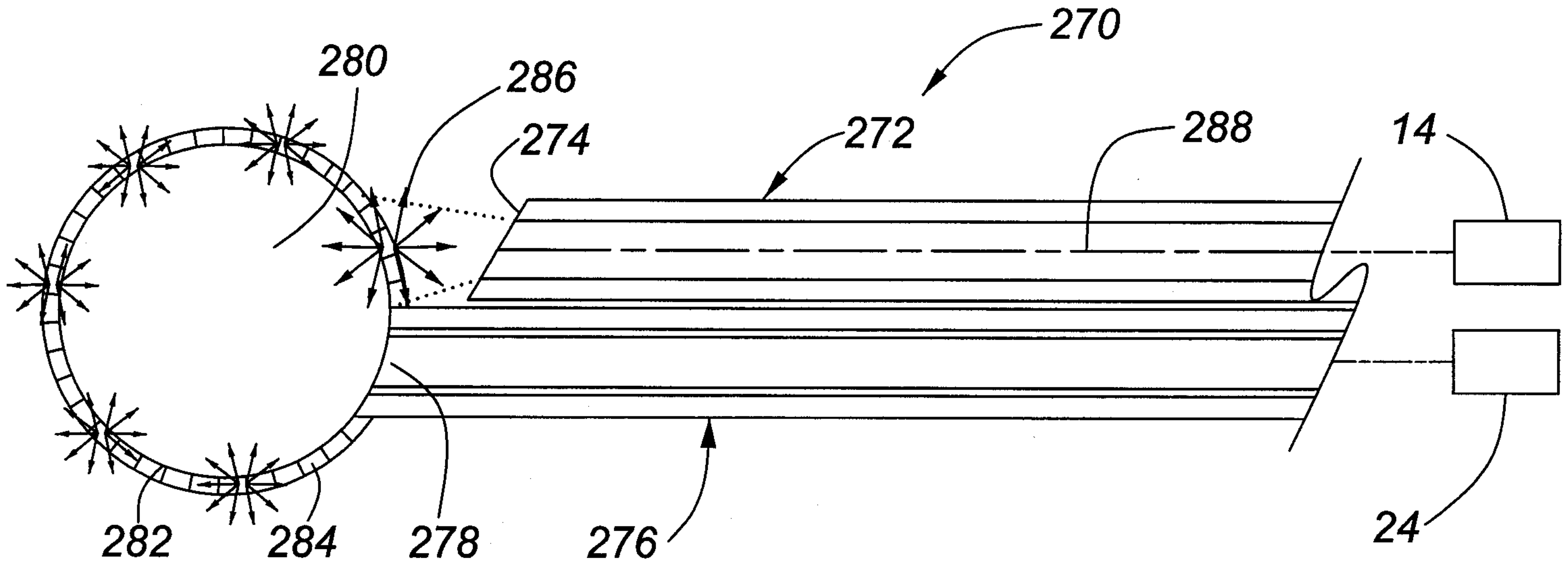

FIG. 19


90
32
104
94
14
106
100
98
96
102
92
24