



EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.06.2021 Bulletin 2021/25

(51) Int Cl.:
B08B 17/02 (2006.01)

(21) Application number: **19219080.9**

(22) Date of filing: **20.12.2019**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
**BA ME
KH MA MD TN**

(72) Inventors:
• **Paulussen, Elvira Johanna Maria
5656 AE Eindhoven (NL)**
• **Wijnen, Merijn
5656 AE Eindhoven (NL)**
• **Jongerius, Michiel Johannes
5656 AE Eindhoven (NL)**

(71) Applicant: **Koninklijke Philips N.V.
5656 AG Eindhoven (NL)**

(74) Representative: **Philips Intellectual Property &
Standards
High Tech Campus 5
5656 AE Eindhoven (NL)**

(54) **AN ANTIFOULING LIGHTING SYSTEM**

(57) An anti-fouling lighting system is for mounting over a surface, comprising an array of LEDs (80) formed as a plurality of rows of LEDs. The LEDs (80) comprise side emitting LEDs, and each row of LEDs comprises a staggered arrangement of the LEDs with alternate LEDs positioned on opposite sides of a centerline (84) of the

row of LEDs. Each side emitting LED has a light output directed toward the centerline (84). This means the light output from one LED is directed partly towards the rear of two neighboring LEDs so that dark areas behind the LEDs are avoided.

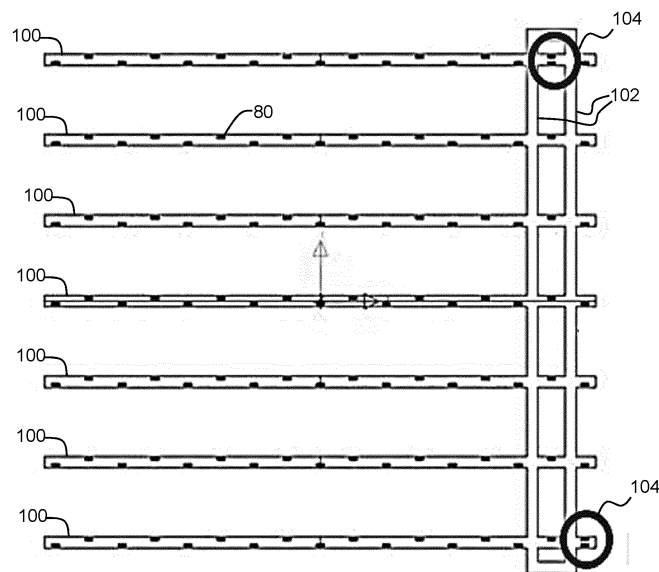


FIG. 10

Description

FIELD OF THE INVENTION

[0001] The present disclosure relates systems for preventing biofouling, or commonly referred to as anti-fouling, of surfaces.

BACKGROUND OF THE INVENTION

[0002] Lighting systems for application to a surface to prevent biofouling are known. Biofouling or biological fouling is the accumulation of microorganisms, plants, algae, and/or animals on surfaces. The variety among biofouling organisms is highly diverse and extends far beyond attachment of barnacles and seaweeds. According to some estimates, over 1700 species comprising over 4000 organisms are responsible for biofouling. Biofouling is divided into microfouling which includes biofilm formation and bacterial adhesion, and macrofouling which is the attachment of larger organisms. Due to the distinct chemistry and biology that determine what prevents organisms from settling, these organisms are also classified as hard or soft fouling types.

[0003] Calcareous (hard) fouling organisms include barnacles, encrusting bryozoans, mollusks, polychaete and other tube worms, and zebra mussels. Examples of non-calcareous (soft) fouling organisms are seaweed, hydroids, algae and biofilm "slime". Together, these organisms form a fouling community.

[0004] In several circumstances, biofouling creates substantial problems. Machinery stops working, water inlets get clogged, and hulls of ships suffer from increased drag. Hence the topic of anti-fouling, i.e. the process of removing or preventing fouling from forming, is well known.

[0005] In industrial processes, bio-dispersants can be used to control biofouling. In less controlled environments, organisms are killed or repelled with coatings using biocides, thermal treatments or pulses of energy. Nontoxic mechanical strategies that prevent organisms from attaching include choosing a material or coating with a slippery surface, or creation of nanoscale surface topologies similar to the skin of sharks and dolphins which only offer poor anchor points.

[0006] By way of example, biofouling on the hull of ships causes a severe increase in drag, and thus increased fuel consumption. It is estimated that an increase of up to 40% in fuel consumption can be attributed to biofouling. As large oil tankers or container transport ships can consume up to €200,000 a day in fuel, substantial savings are possible with an effective method of anti-biofouling.

[0007] WO 2014/188347 discloses a method and system for preventing biofouling in which all of a surface, or a significant amount of a surface, to be kept clean from fouling (e.g. the hull of a ship) is covered with a layer that emits germicidal light, in particular UV radiation. Thus, it

is known to adopt an optical method, in particular using ultra-violet light (UV). It is well-known that most microorganisms are killed, rendered inactive or unable to reproduce with sufficient UV radiation. This effect is mainly governed by the total dose of UV radiation. A typical dose to kill 90% of a certain micro-organism is 10 mW-hours per square meter.

[0008] Ultraviolet (UV) is that part of electromagnetic light bounded by the lower wavelength extreme of the visible spectrum and the X-ray radiation band. The spectral range of UV radiation is by definition between 100 and 400 nm and is invisible to human eyes. Using the CIE classification the UV spectrum is subdivided into three bands:

UVA (long-wave) from 315 to 400 nm
UVB (medium-wave) from 280 to 315 nm
UVC (short-wave) from 100 to 280 nm

[0009] Various light sources for generating UV are known, such as low-pressure mercury discharge lamps, medium pressure mercury discharge lamps and dielectric barrier discharge lamps.

[0010] A preferred option, for example as proposed in WO 2014/188347 is low cost, lower power UV LEDs. LEDs can generally be included in smaller packages and consume less power than other types of light sources. LEDs can be manufactured to emit (UV) light of various desired wavelengths and their operating parameters, most notably the output power, can be controlled to a high degree. A suitable germicidal dose can easily be achieved with existing UV LEDs.

[0011] It is necessary to deliver power to the light sources. For the example of biofouling prevention, the surface is exposed to water, giving rise to an electrical safety hazard as well as an issue of corrosion. An inductive power transfer arrangement is one known way to provide galvanic isolation between a power supply and circuit.

[0012] One issue with the known system is that it is desirable ensure illumination of the entire surface, with no regions of illumination below an intensity threshold. One known way to provide the illumination is with UV-C LEDs of output power in the range 1 mW to 2 mW embedded in a silicone light guide. Side-emitting LEDs may be used, within the silicone slab.

[0013] The area of the surface of the slab where effective UV radiation is achieved may be described as the clean area, with a corresponding clean diameter. The clean diameter achieved at the slab surface is limited by the absorption of the silicone. Rays propagating at a larger angle than the critical angle are total internally reflected and continue until scattered inside the silicone partly towards the slab surface.

[0014] However, near to the LED source and in particular behind the LED, the irradiance may drop below desired levels, because of the absorption of the carrier of the LED (e.g. a PCB) and because the light is emitted laterally away from this area. It is thus necessary to re-

ceive light from a LED positioned further away in order to illuminate this area, but the drop of irradiance with distance makes these regions difficult to illuminate to a desired level giving dark areas.

[0015] There is therefore a need for an improved design to give more uniform irradiance across the area covered by the lighting system.

SUMMARY OF THE INVENTION

[0016] The invention is defined by the claims.

[0017] According to examples in accordance with an aspect of the invention, there is provided an anti-fouling lighting system for mounting over a surface, comprising an array of LEDs formed as a plurality of rows of LEDs, each row of LEDs comprising a substrate portion and LEDs mounted along the substrate portion, wherein the LEDs comprises side emitting LEDs, wherein each row of LEDs comprises a staggered arrangement of the LEDs with alternate LEDs positioned on opposite sides of a centerline of the row of LEDs, and wherein each side emitting LED has a light output directed toward the centerline.

[0018] By this arrangement, one LED in the row can illuminate the back of the adjacent LEDs on each side along the row, and thereby reduce dark spots behind the LEDs, (wherein "behind" means in the opposite direction to the side-emission direction of the LEDs).

[0019] The system for example further comprises a light guide material formed over and between the rows of LEDs thereby to form a lighting panel (e.g. a tile).

[0020] The light guide material for example comprises a silicone. This is used to encase and therefore protect the LEDs as well as providing a light guiding structure so that light is spread over the entire surface of the system.

[0021] The back surface of the light guide for example has a back reflector, for example of aluminum. Thus, light which is emitted towards a lower (inwardly facing) surface of the light guide and which escapes is reflected back into the light guide so that there is illumination of the upper (outwardly facing) surface.

[0022] The LEDs for example comprise UV LEDs, such as UV-C LEDs. These provide anti bio-fouling illumination. The light source array is for example UV-C LEDs with wavelength between 270nm and 280nm.

[0023] The substrate portions over which the LEDs are mounted for example comprise a reflective upper surface, reflective for the output of the LEDs. In this way, the substrate portions redirect light upwardly. These substrate portions are nearest the LEDs so receive the highest irradiance. By arranging the PCB to be reflective, it is prevented the high irradiance light does not reach the general back reflector of the waveguide, which may be more sensitive to UV degradation.

[0024] The upper surface may be specular reflective or diffuse reflective.

[0025] The upper surface of the substrate may comprise a reflective coating of tin, gold, or aluminum.

[0026] A highest LED irradiance for example occurs above the respective substrate portion so that it can be designed to be able to tolerate the high intensity light levels, whereas a general reflector across the entire area of the lighting system may then have a lower cost design.

[0027] The substrate portion for example comprises a portion of a printed circuit board. Thus, a printed circuit board may be shaped to define a set of portions to form the rows of LEDs.

[0028] Each of said portions of the printed circuit board may be rectangular or serpentine. A serpentine arrangement follows the staggering of the LEDs and this enables a reduced area of the printed circuit board.

[0029] The system for example further comprises an inductive power receiver comprising one or more power receiving coils for delivering power to the array of LEDs. Thus, system may be a panel which implements wireless power reception for powering the LEDs.

[0030] The substrate may comprise a column or columns for the one or more power receiving coils and a set of orthogonal rows each forming a respective one of the substrate portions. This defines a grid-like printed circuit board.

[0031] The system may further comprise:
an inductive power transmitter comprising one or more primary coils for wireless transmission of power to the one or more power receiving coils.

[0032] In this arrangement, a set of power receiving panels are coupled to an inductive power transmitter. This provides an effective way to deliver power to the LED load extending over a large area. In particular, a grid of at least one power delivery transmitter and multiple power receiving panels may be formed, to cover a large area. The inductive power transmission enables the LED load to be isolated from the power source, in particular so that damage to the load does not result in an electrical short to the power supply. The use of overlapping primary and secondary coils enables a thin overall structure for example if coils formed as PCB tracks are used.

[0033] The use of wireless power transfer simplifies making a watertight arrangement. For example, the power receiving panels can be completely over-molded with no openings.

[0034] The inductive power transmitter can be designed with a low AC transmission line impedance leading to low losses. The inductive power transmitter can for example be made to be rollable and hence delivered on a drum.

[0035] The plurality of inductive power receiver panels are for example mounted over the inductive power transmitter. The inductive power transmitter is for example mounted over the surface, and the inductive power receiver panels overlap the inductive power transmitter. The inductive power receiver panels may cover a larger area than the inductive power transmitter. In particular, they distribute the power received at the secondary coils of the inductive power receiver to the load, and the load is for example distributed across the area of the panel.

[0036] The inductive power receiver for example comprises secondary windings formed on or in a printed circuit board, one such set of windings defining a secondary coil.

[0037] The inductive power transmitter for example comprises a strip, and the inductive power receiver panels each extend laterally from a respective position along the strip. The strip may be considered to define a column (e.g. extending vertically) and the inductive power receiver panels define rows (e.g. extending horizontally), together defining a grid structure.

[0038] The inductive power receiver panels for example have a thickness of less than 5mm, for example less than 4mm, for example less than 3mm. This thickness typically includes a printed circuit board and a protective coating. For example, the inductive power receiving panels may comprise a silicone coating. This coating perform a protective function by may also perform other functions such as an optical function, e.g. light guiding and/or light scattering.

[0039] The anti-fouling lighting system may further comprise a power source for delivering power to the inductive power transmitter.

[0040] The power source for the inductive power transmitter for example comprises a resonant circuit with a resonant frequency of 50kHz to 1MHz, for example 50kHz to 200kHz, for example 60kHz to 90kHz.

[0041] The invention also provides a marine object comprising an anti-fouling system as defined above. An outer surface of the marine object (i.e. a surface which is exposed to marine water) is the surface over which the inductive power transmitter and inductive power receiver panels are mounted.

[0042] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] For a better understanding of the invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, in which:

Fig. 1 shows an anti-fouling lighting system applied to a ship for protecting the surface of the ship in contact with water, i.e. the hull surface;

Fig. 2 shows a cross section (in a horizontal plane) through the inductive power transmitters and lighting panels;

Fig. 3 shows the coil arrangements in more detail;

Fig. 4 shows an example of the structure of the lighting panel;

Fig. 5 shows one possible electrical configuration of the primary and secondary coils;

Figs. 6A to 6D show four possible arrangements for a line of LEDs;

Fig. 7 shows a simulation of the light output intensity

for a vertical line of LEDs arranged in the manner shown in Fig. 6A;

Fig. 8 shows a corresponding simulation of the light output intensity for a vertical line of LEDs arranged in the manner shown in Fig. 6B;

Fig. 9 shows a corresponding simulation of the light output intensity for a vertical line of LEDs arranged in the manner shown in Fig. 6C;

Fig. 10 shows the structure of a PCB for carrying an array of LEDs arranged as rows using the LED positioning of Fig. 6C;

Fig. 11 shows a simulation (in water) of the optical irradiance distribution of the layout of Fig. 10;

Fig. 12 shows one preferred structure of the lighting system panel;

Fig. 13 shows a layout of two LEDs from above;

Fig. 14 shows the geometry more accurately; and

Fig. 15 shows how a minimum PCB length may be determined based on a simulation of the light output intensity for a single LED viewed from above.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0044] The invention will be described with reference to the Figures.

[0045] It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are intended for purposes of illustration only and are not intended to limit the scope of the invention. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

[0046] The invention provides an anti-fouling lighting system for mounting over a surface, comprising an array of LEDs formed as a plurality of rows of LEDs. The LEDs comprises side emitting LEDs, and each row of LEDs comprises a staggered arrangement of the LEDs with alternate LEDs positioned on opposite sides of a centerline of the row of LEDs. Each side emitting LED has a light output directed toward the centerline. This means the light output from one LED is directed partly towards the rear of two neighboring LEDs so that dark areas behind the LEDs are avoided.

[0047] Fig. 1 shows an anti-fouling lighting system, which may be adapted in accordance with the invention, applied to a ship 1, for protecting the surface of the ship in contact with water, i.e. the hull surface.

[0048] The anti-fouling lighting system comprises a set of inductive power transmitters 10 mounted over the surface. They take the form of power feeding lines, i.e. strips, which extend vertically against the hull. At the upper

ends, the feeding lines connect to a source of electric power (not shown). The inductive power transmitters each comprise one or more sets of primary windings. A set of primary windings (whether there is one or more than one winding) is referred to as a primary coil in this document. Thus, the inductive power transmitter has one or more primary coils.

[0049] A set of lighting panels 20 is also mounted over the surface. The lighting panels 20 are one example of possible inductive power receiving panels. The lighting panels each comprise a light source arrangement and an inductive power receiver with one or more sets of secondary windings for alignment with the primary windings. A set of secondary windings (whether there is one or more than one winding) is referred to as a secondary coil in this document. Thus, the term "coil" generally is used to denote a set of windings forming one side of a transformer. A primary coil is aligned with a secondary coil to form a transformer.

[0050] As will be clear from the description below, there may be multiple coils on each power feeding line, for example one or more coils along the power feeding line at the location of each lighting panel. Each power feeding line supplies power to multiple lighting panels, thus providing a space efficient arrangement. Each lighting panel may also have one secondary coil or multiple secondary coils (e.g. on opposite sides).

[0051] Fig. 2 shows a cross section (in a horizontal plane) through the power feeding lines (the inductive power transmitters 10) and through the lighting panels 20. Each lighting panel may be considered to form an anti-fouling lighting system.

[0052] The inductive power transmitters comprise a primary coil 12 and a ferrite sheet 14 between the windings of the primary coil and the metal of the hull 16 of the ship. The surface 18 of the hull is the surface to be protected from fouling. The ferrite sheets prevent Eddy currents in the metal of the ship's hull 16 thereby increasing the efficiency of energy transfer.

[0053] In the example shown, the surface 18 is essentially fully covered by the lighting panels. Thus, the surface 18 is protected by the lighting panels, and it is the exposed surface of the lighting panels which is vulnerable to fouling. Thus, the lighting provided by the lighting panels aims to prevent the formation of fouling organisms on the surface of the lighting panels.

[0054] However, this is still to be understood as forming a system for protecting the hull surface against biofouling (in that without the lighting system, the hull surface will suffer from biofouling).

[0055] An alternative arrangement for example may have lighting panels which only cover a small fraction of the surface to be protected, and the light is directed or guided towards the surface to be protected. In such a case, a major part of the hull surface is indeed exposed to water and therefor susceptible to biofouling.

[0056] In the example shown in Fig. 2, the inductive power transmitters 10 are mounted against the hull sur-

face 18 and the lighting panels 20 are mounted over the inductive power transmitters.

[0057] In particular, an edge region 22 of each lighting panel 20 overlaps the feeding lines. The lighting panels 20 each have a secondary coil 24 located in this edge region, and a light source arrangement 26.

[0058] The secondary windings are aligned with the primary windings to provide inductive power transfer. The wirelessly transmitted power is used by the lighting panels 20 to power the light source arrangements 26.

[0059] The primary coils may be formed on or within a printed circuit board of the feeding lines, and the secondary coils may also be formed on or within a printed circuit board of the lighting panel. The light source arrangement may also be formed on a printed circuit board, which may be separate to, or the same as, the printed circuit board of the secondary coils. A shared flexible printed circuit board may for example allow the lighting panels to adapt to the contour of the underlying feeding lines. Instead, there may be separate printed circuit boards in the lighting panel and an electrical connection between them.

[0060] The primary coils of the inductive power transmitters 10 may for example be supplied with a 100 kHz to 150 kHz sinewave during operation of the light emitting system. To compensate for a capacitive leakage current to the hull 16 at the position of the feeding lines, the feeding lines may further be provided with a capacitor to implement a low pass filter. This is for example of interest if high efficiency switched amplifiers are used to generate the AC supply. In such a case, the low pass filter is used to residual higher frequency harmonics of the amplifiers.

[0061] An alternative is to use a resonant circuit to generate the AC supply. For example, each feeding line may comprise a resonant circuit, based on a capacitive resonant circuit, with a resonance in the range 60kHz to 90kHz.

[0062] Generally, the frequency of operation (resonant or driven) may be in the range 50kHz to 1MHz, for example 50kHz to 200kHz, for example 60kHz to 90kHz.

[0063] Fig. 3 shows the coil arrangements.

[0064] The example of Fig. 2 has the lighting panels overlapping an associated feeding line at one edge. In Fig. 3, the lighting panels 20 overlap feeding lines 10 at both lateral edges, and each feeding line 10 has pairs of primary coils arranged along its length. One coil of a pair is for powering a lighting panel to one side and the other coil of the pair is for powering a lighting panel to the other side. In this way, each lighting panel is supplied by power from both sides.

[0065] All coils of the feeding lines can have the same phase, which contributes to electric redundancy of the light emitting system 40. The light source arrangements 26 can still function in their entirety if a feeding line is broken. In that respect, the feeding lines may be designed to deliver electric power at an increased level of two times a normal level.

[0066] Thus, there may be one coil assembly (i.e. primary coil and secondary coil) per lighting panel (Fig. 2)

or two coil assemblies per lighting panel (Fig. 3).

[0067] There may for example be between 2 and 50 lighting panels per feeding line, for example 20 rows of individual panels connected to a feeding line.

[0068] In the example shown, the feeding lines extend in a substantially vertical orientation along the side of the ship. However, any suitable arrangement of feeding lines is possible. The feeding lines may for example cover welding seams and/or other surface irregularities of the ship's hull.

[0069] Fig. 4 shows an example of a known structure of the lighting panel 20, having a plurality of light sources 40 which in this example are side-emitting UV-C LEDs, wherein the light is emitted primarily from a side of the LED, and more or less parallel to the surface. The light sources 40 are encapsulated in a liquid-tight optical medium 42 to guide at least part of the light 44 emitted from the light sources 40 via total internal reflection through the optical medium.

[0070] Optical structures 46 are provided to disrupt the total internal reflection and scatter light, and then guide the scattered light 48 out of the optical medium 42 towards a target for the light, which is an area where a biofouling organism is present.

[0071] A biofouling organism on the surface 52 will directly receive the light scattered light 48 before it enters the water.

[0072] Furthermore, some of the internally scattered light 48 that does enter the water will encounter external scattering sites. This creates illumination 50 within the water, some of which will also reflect back to the surface 52 of the lighting panel 20 where biofouling is to be prevented, although this is a much less significant anti-fouling process since these external scattering sites may also be absorbing.

[0073] The illumination means that single cell bio-mechanisms at the surface 52 will stop growing and dividing, and will therefore die under influence of the UV-C radiation.

[0074] The optical medium is relatively thin so that the lighting panel may be considered to be a two-dimensional structure. The optical structures 46 to scatter light may be spread in one or more portions of the optical medium material, possibly throughout all of it, and the light output may be generally homogeneous or else localized.

[0075] Internal scattering centers with different structural properties may be combined to provide optical as well as structural characteristics, such as resistance to wear and/or impact. Suitable scatterers comprise opaque objects but largely translucent objects may be used as well, e.g. small air bubbles, glass and/or silica; a requirement is merely that a change in refractive index occurs for the wavelength(s) used. The optical structures may be printed structures, such as of a UV reflective material such as barium nitride or aluminum oxide.

[0076] The principle of light guiding and spreading light over a surface is well-known and widely applied in various fields. Here, the principle is applied to UV radiation for

the purpose of anti-fouling.

[0077] To maintain the conditions for total internal reflection, the index of refraction of the light guiding material should be higher than that of the surrounding medium. However, the use of (partly) reflective coatings on the light guide and/or the use of the reflective properties of the protected surface, e.g. the hull of a ship, itself can also be used to establish the conditions for guiding the light through the optical medium.

[0078] In the example above, the lighting panels form a new surface over the surface to be protected, and light is directed outwardly from the surface to be protected. However, an alternative is for the lighting panel to be spaced over the surface to be protected and to direct light back towards the surface to be protected.

[0079] A small air gap may then be introduced between the light source arrangement of the lighting panel and the surface to be protected. UV radiation may travel better, with less absorption, in air than in an optical medium, even when this optical medium is designed as a light guiding material.

[0080] As most materials have a (very) limited transmittance for UV radiation, care has to be taken in the design of the optical medium. As a result, a relatively fine pitch of low power LEDs can be chosen, to minimize the distance light has to travel through the optical medium.

[0081] In one example, the optical medium 42 comprises a silicone, and one which is designed to have good UV-C transparency.

[0082] A solid encapsulation may be used, as shown in Fig. 4. However, a hollow structure may instead be used, such as a silicone mat with spacers that keep it a small distance away from the protected surface. This creates air channels, through which the UV radiation can propagate with higher efficiency. Use of gas filled channels provided by such structures allows distributing the UV radiation over significant distances in a optical medium of material that would otherwise absorb the UV radiation too strongly to be useful for anti-fouling. Liquid filled channels are also possible such as using a high refractive index fluid which is transparent for UV radiation. This could be a secondary layer over the encapsulated LEDs. Similarly, separate pockets may be formed.

[0083] Fig. 5 shows the electrical configuration.

[0084] The power source for delivering power to the inductive power transmitter comprises an AC driver 60, a tuning coil 62 and a tuning capacitor 64. The power source connects to the inductive power transmitter 10, i.e. the power feeding line, by a cable 66. In the arrangement shown, the inductive power transmitter 10 comprises a set of primary coils 12 arranged physically in a line along the feeding line, but electrically connected in parallel.

[0085] For long feeding lines for driving many panels, the feeding line should be fully balanced. The feeding line can then be driven with a balanced driver such as an H-bridge. The feeding line behaves as a balanced transmission line. This has advantages for electromag-

netic compatibility (EMC) and for the driver, for example because both PCB leads can see the same capacitance to the ship's hull and to the water. In a balanced situation the EMC stray fields, which deteriorate the emission behavior at radio frequency, will balance out. This improves antenna efficiency.

[0086] A two layer PCB design may be used to enable cross overs to be formed close to the coils.

[0087] The inductive power transmitter 10 has a feed line 70 and a return line 72. The lighting panel (only one of which is shown) includes the secondary coil 24, aligned with and therefore magnetically coupled to one of the primary coils 12.

[0088] To the extent described above with reference to Figs. 1 to 5, the anti-fouling lighting system is known.

[0089] This invention relates in particular to the arrangement of the LEDs.

[0090] Fig. 6 shows four possible arrangements for a line (e.g. row) of LEDs.

[0091] Fig. 6A shows side-emitting LEDs 80 located at the edge of a rectangular PCB 82 directing light outwardly from the PCB edge. By staggering the line of LEDs, they are nearest their local edge of the PCB.

[0092] Fig. 6B shows side-emitting LEDs 80 down a centerline 84 of the PCB 82 directing light outwardly alternately in the two sideways directions.

[0093] Fig. 6C shows an example of LED arrangement in accordance with the invention. The line of LEDs 80 is again staggered with side-emitting LEDs 80 located at the edge of a PCB 82. The PCB has a constant width so it is rectangular in this example. This gives simplified handling and processing. However, the LEDs direct light inwardly from the PCB edge towards the centerline 84. The light thus crosses the main width of the PCB before extending beyond the PCB edge.

[0094] By this arrangement, a row of LEDs comprises a staggered arrangement of the LEDs with alternate LEDs positioned on opposite sides of the centerline 84 of the row of LEDs. The staggering means that one LED in the row can illuminate the back of the adjacent LEDs on each side along the row, and thereby reduce dark spots behind the LEDs, i.e. in the opposite direction to the side-emission direction of the LEDs.

[0095] Fig. 6D shows a second example of LED arrangement in accordance with the invention. The PCB 82 is shaped as a serpentine so it follows the path of the staggered LEDs, to reduce the amount of PCB material used.

[0096] The advantage of the arrangements of Figs. 6C and 6D will now be shown.

[0097] Fig. 7 shows a simulation of the light output intensity for a vertical line of LEDs arranged in the manner shown in Fig. 6A, viewed from above the row of LEDs.

[0098] The top left image shows a representation where different grey levels represent different irradiance, at the surface which coincides with the area for which anti-fouling is performed. The bottom left image shows an irradiance plot along line 92 and the right image shows

an irradiance plot along line 94.

[0099] Fig. 7 shows a dark low irradiance region 90 behind the LEDs (with respect to the side-emission direction).

[0100] Fig. 8 shows a corresponding simulation of the light output intensity for a vertical line of LEDs arranged in the manner shown in Fig. 6B.

[0101] The top left image again shows a representation where different grey levels represent different irradiance. The bottom left image shows an irradiance plot along line 92 and the right image shows an irradiance plot along line 94.

[0102] The dark line of Fig. 7 has reduced.

[0103] Fig. 9 shows a corresponding simulation of the light output intensity for a vertical line of LEDs arranged in the manner shown in Fig. 6C.

[0104] The top left image again shows a representation where different grey levels represent different irradiance, at the surface which coincides with the area for which anti-fouling is performed. The bottom left image again shows an irradiance plot along line 92 and the right image shows an irradiance plot along line 94.

[0105] In this case, the areas with irradiance below a threshold, such as 10^{-9}W/mm^2 , have been avoided completely.

[0106] Fig. 10 shows the structure of a PCB for carrying an array of LED arranged as rows using the LED positioning of Fig. 6C.

[0107] Each row of LEDs is provided over a respective substrate portion 100. They extend laterally from substrate columns 102 (or a single wider column) over which a power receiving coil (or coils) is provided. If a planar PCB is used, the coil height (in the PCB thickness direction) in this example is the same as for the PCB rows 100. In particular, the relative height above the PCB material remains the same over the whole panel. Consequently, the UV LED irradiates above and across the coil and the emission is not limited by any obstacle.

[0108] The PCB area (column 102) may be higher than the rest of the panel, but the light guiding ability is preserved by making use of a smooth transition in the shape of the light guiding material.

[0109] Some extra LEDs, such as shown in regions 104, are placed around the power receiving coil ensure the entire panel provides sufficient UV radiation.

[0110] A simulation (in water) of the optical irradiance distribution of the layout of Fig. 10 is shown in Fig. 11 (assuming a planar top surface of the coil columns and PCB rows). This simulation is for a single panel of dimensions 50cm x 50cm. Many panels are necessary to cover a complete ship hull for example.

[0111] By way of example the UV-C power of individual LEDs is 0.35 mW and the threshold value for preventing biofouling at the surface is 10^{-9}W/mm^2 . The dark areas over the LEDs correspond to a high peak irradiance.

[0112] In Fig. 11, the PCB rows 100 with their UV-C LEDs 80 are visible. UV radiation of adjacent panels can also be transmitted if the panels are aligned properly or

connected with each other by a UV transparent silicone fill material between the panels. Then, the irradiance levels further add up to higher levels.

[0113] Fig. 12 shows one preferred structure of the lighting system panel. Note that the thickness dimension is greatly exaggerated to enable the different layers to be seen.

[0114] One substrate portion (i.e. a printed circuit board row 100) is shown in cross section perpendicular to the row length. Other rows of LEDs will be to the right and left of the single row shown in Fig. 12. A light guide material 120 such as silicone is formed over and between the rows of LEDs thereby to form a lighting panel.

[0115] The underside of the lighting system has a reflective backing 122 such as an anodized aluminum layer.

[0116] The printed circuit board has a reflective upper surface (reflective to the UV output), for example formed by a layer 124. The upper surface may be specular reflective or diffuse reflective.

[0117] The layer 124 may for example comprise a reflective coating of tin, gold, or aluminum.

[0118] Fig. 12 shows the coating layer 124 on top of the PCB 100 locally so that at the location of the LED no coating is shown. In practice, the coating 124 may be used to form the electrodes where the LED connects to the PCB. Part of the coating is removed (or not formed) around the electrodes so that the electrodes can be electrically isolated. A thin gold layer may for example be provided on top of the whole PCB, with isolation (no coating) around the electrodes. Thus, some of the coating will then extend under the LED footprint. The reflector 122 extends under the PCB as well as under the silicone layer as shown, but it could also be omitted underneath the PCB 100.

[0119] By making the printed circuit board at least partly reflective, the lighting level behind the LED again increases. A reflection of 25% at the PCB surface has been found to be sufficient to achieve an irradiance level above a minimum threshold level, which can be achieved with tin, (anodized) aluminum or gold reflectors. Preferably, materials with a reflection coefficient of above 35% are applied.

[0120] In the arrangement of Fig. 12 (and Figs. 6C and 6D), the highest power density output by the LED occurs above the PCB 100 and not at the more fragile aluminum thin layer 122 attached to the bottom of the light guide. The PCB dimensions are for example chosen such that the irradiance is reduced by more than two orders of magnitudes when the back reflector aluminum coating 122 is reached. This results in a longer lifetime of the product.

[0121] By way of example, the width W (perpendicular to the row direction) the PCB may be 10 mm. The LED light output surface 81 may be a distance d1 of 7 mm from the edge of the PCB in the light output direction and a distance d2 of 3 mm from the edge of the PCB in the opposite direction. The light guide thickness Th is for example 2mm (hence it can be seen that the thickness di-

mension is exaggerated in Fig. 12).

[0122] Fig. 13 shows a layout of two LEDs from above. The distance (pitch P) between the centers of the LEDs is for example 30 mm.

[0123] The light output face of one LED is in line with or behind the light output face of the adjacent LED. Fig. 13 shows an angle θ between the light emission direction and the line joining the center of the light output face of one LED with the center of the light output surface of an adjacent LED. An aligned condition gives $\theta=90$ degrees. The values $d1=7\text{mm}$, $d2=3\text{mm}$ and $P=30\text{mm}$ give $\theta=82.4$ degrees. Preferably θ is in the range 75 to 90 degrees, such as 75 to 85 degrees.

[0124] Preferably, for a light guide thickness of 2 mm, distance $d1>4\text{mm}$ and $d2<2\text{mm}$, assuming the LED is in the middle of thickness of the light guide, i.e. 1mm from the bottom.

[0125] Fig. 14 shows the geometry more accurately. The length of the PCB 100 can be seen in the light emission direction, which ensures that a highest LED irradiance occurs above the substrate. Fig. 14 shows that the dimension d1 scales with the height h. $d1 \sim 2 h/\tan(90^\circ - \text{TIR})$ where TIR is the total internal reflection angle.

[0126] Fig. 15 shows how a minimum PCB width from the LED output surface to the edge of the PCB (arrow 150) may be determined.

[0127] Fig. 15 shows a simulation of the light output intensity for a single LED viewed from above. The y-axis corresponds to the light emission direction. The row direction is left to right.

[0128] The top left image again shows a representation where different grey levels represent different irradiance. The bottom left image shows an irradiance plot along line 152 and the right image shows an irradiance plot along line 154.

[0129] The PCB width from the LED output surface to the edge of the PCB (the dimension d1) is chosen such that the irradiance level at the end of the PCB has dropped below a threshold level.

[0130] Generally, the lighting panels for example have a PCB thickness of 0.8mm, and the total thickness with the silicone of below 5mm, for example in the range 2mm to 4mm.

[0131] The lighting panels for example have a length (along the horizontal row direction) in the range 1m to 5m and a height (along the vertical column direction) in the range 50cm to 150cm. For example a small panel dimension may be 600mm x 1200mm and a large panel dimension may be 1m x 4m. An example area to be covered, e.g. one side of a ship hull, may be of the order of 100m length by 10m height.

[0132] The anti-fouling implementation of the invention is of interest for marine objects although not limited to objects for use in seawater, but also in any type of water that is known to contain biofouling organisms. Examples of marine objects include ships and other vessels, marine stations, sea-based oil or gas installations, buoyancy devices, support structures for wind turbines at sea, struc-

tures for harvesting wave/tidal energy, sea chests, underwater tools, etc.

[0133] In preferred examples, the light sources are UV LEDs as explained above. A grid of UV LEDs may be encapsulated in a liquid-tight encapsulation, of which silicone is only one example. The UV LEDs may be electrically connected in a series and/or parallel arrangement. The UV LEDs are for example packaged surface mount LEDs, in which case they already may include an optical element to distribute the light emitted from the LED package across a wide emission angle. In other embodiments, the UV LEDs may be LED dies, typically not comprising optical elements but being significantly thinner than packaged LEDs. As an example, LED dies could be picked and placed onto a surface of the optical medium

[0134] The silicone material can be selected to provide optical transmission for UV radiation with little loss compared to other materials. This is in particular the case for shorter wavelength light, e.g. UV radiation with wavelengths below 300 nm. A particularly efficient group of silicone materials is, or at least comprises, so-called methyl silicones, according to the general chemical formula $\text{CH}_3[\text{Si}(\text{CH}_3)_2\text{O}]_n\text{Si}(\text{CH}_3)_3$, with "n" indicating any suitable integral.

[0135] Silicone materials are also flexible and resilient so that they are robust, durable and capable of withstanding compression such as due to bumps, collisions etc. of objects against the surface, e.g. bumping of a ship against a quay. Furthermore, deformation due to temperature fluctuation, pounding by waves, flexion of the ship over swell etc. may be accommodated.

[0136] At least part of light emitted by the one or more light sources may be spread in a direction having a component substantially parallel to the surface to be protected. This facilitates distributing the light over significant distances along the protected surface, or the application surface of the foil, which assists in obtaining a suitable intensity distribution of the anti-fouling light.

[0137] A wavelength conversion material may be comprised in the optical medium and at least part of the anti-fouling light may be generated by photo-exciting the wavelength conversion material with light having a first wavelength causing the wavelength conversion material to emit the anti-fouling light at another wavelength. The wavelength conversion material may be provided as an up-conversion phosphor, quantum dots, nonlinear media such as one or more photonic crystal fibers etc. Since absorption and/or scattering losses in the optical medium for light of different, mostly longer, wavelengths than UV radiation tend to be less pronounced in the optical media, it may be more energy-efficient to generate non-UV radiation and transmit that through the optical medium and to generate UV anti-fouling light at or near the desired location of use thereof (i.e. emission from the surface into the liquid environment).

[0138] One example described above makes use of inherently side-emitting LEDs and optical scattering sites. However, light spreading arrangements may be

used to create the sideways light. This still results in side-emitting LEDs.

[0139] For example, a cone may be arranged in the optical medium and positioned opposite the light source, where the opposing cone has a surface area with a 45° angle perpendicular to the protected surface for reflecting light emitted by the light source perpendicular to said surface in a direction substantially parallel to said surface.

[0140] The LEDs may be DC driven. However, a pair of back to back parallel LEDs may be driven by an AC drive signal.

[0141] The anti-fouling use of the invention can be applied to a wide variety of fields. Almost any object coming into contact with natural water, will over time be subject to biofouling. This can hinder e.g. water inlets of desalination plants, block pipes of pumping stations, or even cover the walls and bottom of an outdoor pool. All of these applications would benefit from the presently provided method, lighting modules and/or system, i.e. an effective thin additional surface layer, which prevents biofouling on the entire surface area.

[0142] Although UV radiation is the preferred solution, other wavelengths are envisaged as well. Non-UV radiation (e.g. visible light) is also effective against biofouling. Typical micro-organisms are less sensitive to non-UV radiation than to UV radiation, but a much higher dose can be generated in the visible spectrum per unit input power to the light sources.

[0143] In the examples above, the lighting panel overlaps the feeding lines. This provides galvanic isolation between the power supply and the structure which is exposed to the water. The lighting panel also protects the underlying feeding line. Instead, the feeding lines may be provided over the lighting panels. A separate electrical isolation may be provided (e.g. at the top of the feeding lines). The surface of the feeding lines will then be susceptible to biofouling, so it should then be ensured that light reaches the surface of the feeding lines, either by transmission through the feeding lines or by reflection or waveguide transmission within the lighting panels. Thus, the inductive power transmitter and the lighting panel are both for mounting over the surface, but in either order.

[0144] Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. If the term "adapted to" is used in the claims or description, it is noted the term "adapted to" is intended to be equivalent to the term "configured to". Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. An anti-fouling lighting system for mounting over a surface, comprising an array of LEDs (80) formed as a plurality of rows of LEDs, each row of LEDs comprising a substrate portion (100) and LEDs (80) mounted along the substrate portion, wherein the LEDs (80) comprises side emitting LEDs (80), wherein each row of LEDs (80) comprises a staggered arrangement of the LEDs with alternate LEDs positioned on opposite sides of a centerline (84) of the row of LEDs, and wherein each side emitting LED has a light output directed toward the centerline (84). 5
2. The system as claimed in claim 1, further comprising a light guide material (120) formed over and between the rows of LEDs thereby to form a lighting panel. 10
3. The system as claimed in claim 1 or 2, wherein the LEDs (80) comprise UV LEDs. 15
4. The system as claimed in any preceding claim, wherein the substrate portions (100) comprise a reflective upper surface (124), reflective for the output of the LEDs. 20
5. The system as claimed in claim 4, wherein the upper surface (124) is specular reflective or diffuse reflective. 25
6. The system as claimed in any preceding claim, wherein the upper surface of the substrate comprises a reflective coating (124) of tin, gold, or aluminum. 30
7. The system as claimed in any preceding claim, wherein a highest LED irradiance occurs above the respective substrate portion (100). 35
8. The system as claimed in any preceding claim, wherein the substrate portion (100) comprises a portion of a printed circuit board. 40
9. The system as claimed in claim 8, wherein each of said portions (100) of the printed circuit board is rectangular or serpentine. 45
10. The system as claimed in any preceding claim, further comprising an inductive power receiver (24) comprising one or more power receiving coils for delivering power to the array of LEDs. 50
11. The system as claimed in claim 10, wherein the substrate comprises a column or columns (102) for the one or more power receiving coils and a set of orthogonal rows each forming a respective one of the substrate portions (100). 55
12. The system as claimed in claim 10 or 11, further comprising: an inductive power transmitter (10) comprising one or more primary coils (12) for wireless transmission of power to the one or more power receiving coils.
13. The system as claimed in claim 12, wherein the plurality of inductive power receiver panels are mounted over the inductive power transmitter.
14. The system as claimed in any one of claims 12 to 13, wherein the inductive power receiver panels have a thickness of less than 5mm, for example less than 4mm, for example less than 3mm.
15. The system as claimed in any one of claims 12 to 14, further comprising a power source for delivering power to the inductive power transmitter.

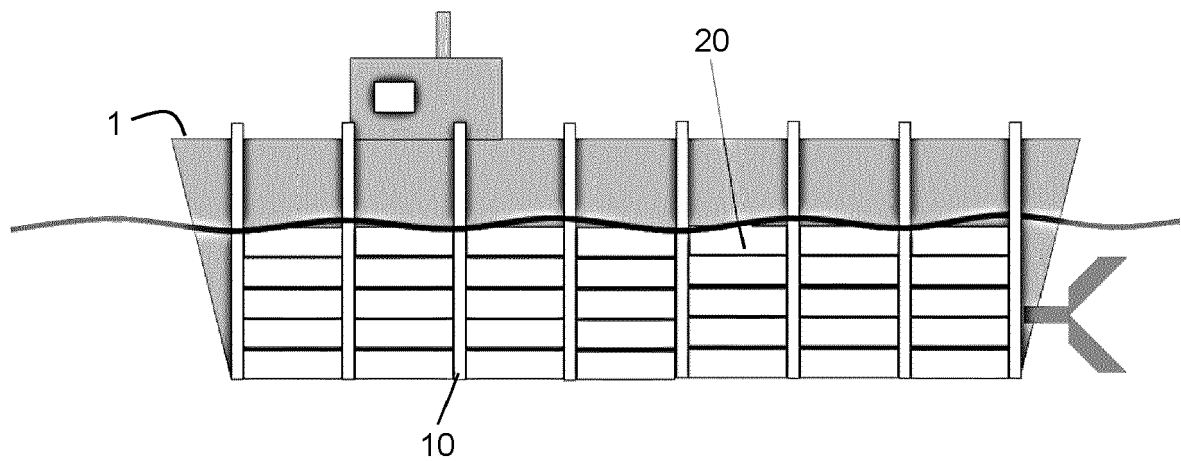


FIG. 1

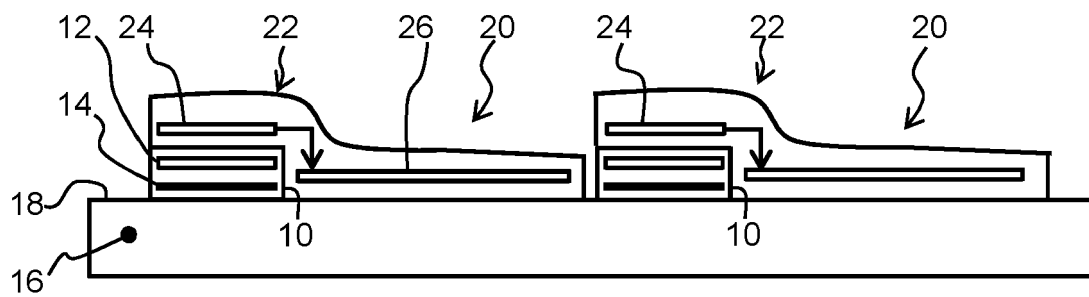


FIG. 2

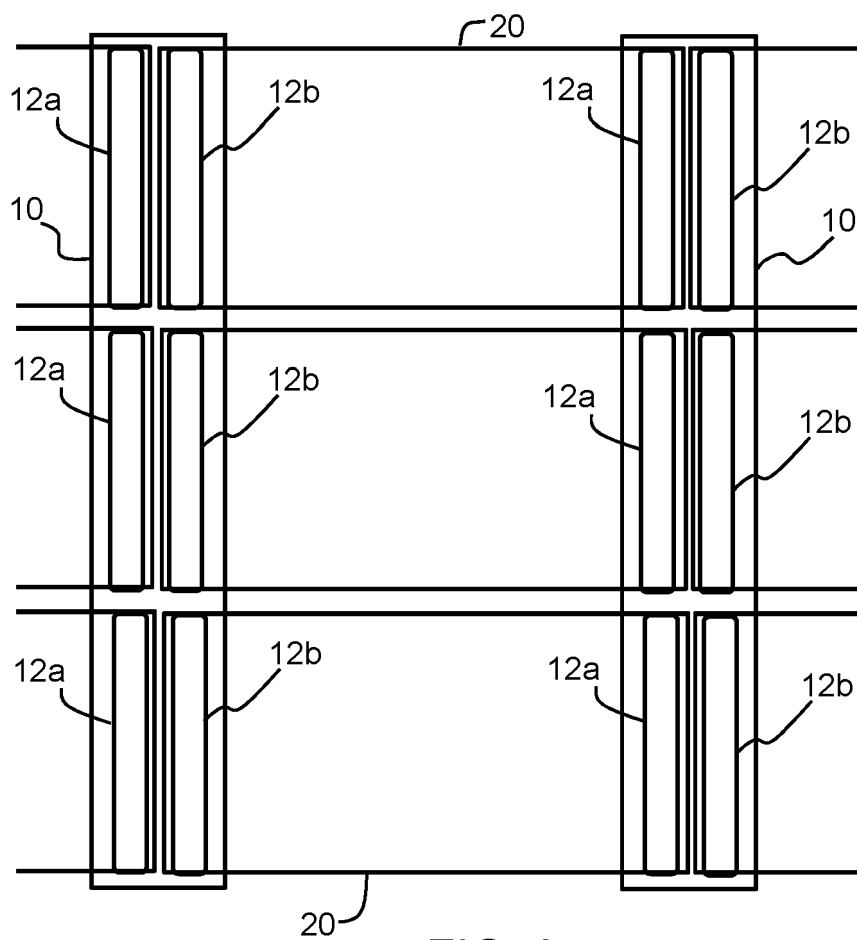


FIG. 3

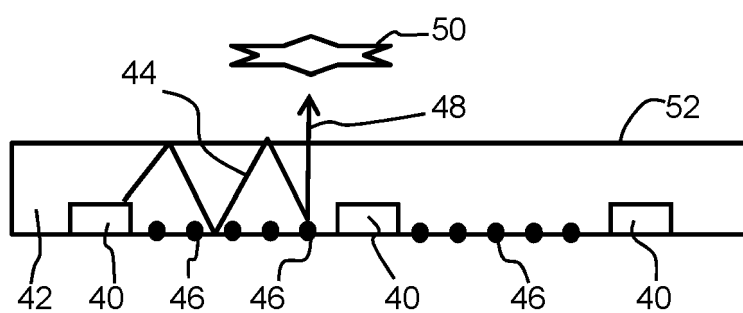


FIG. 4

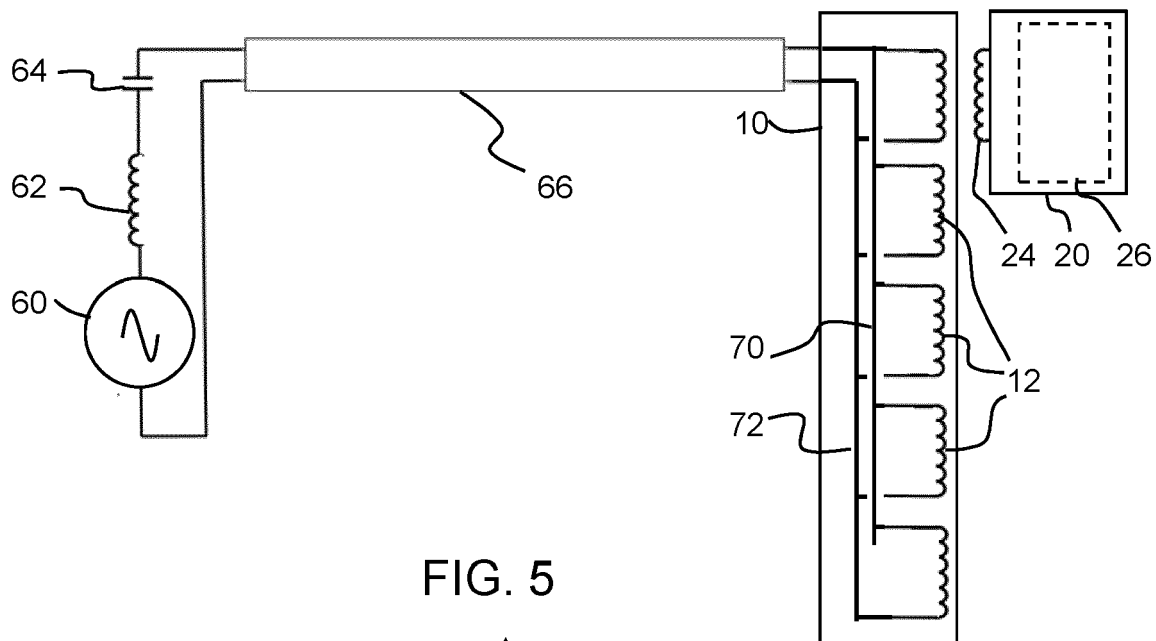


FIG. 5

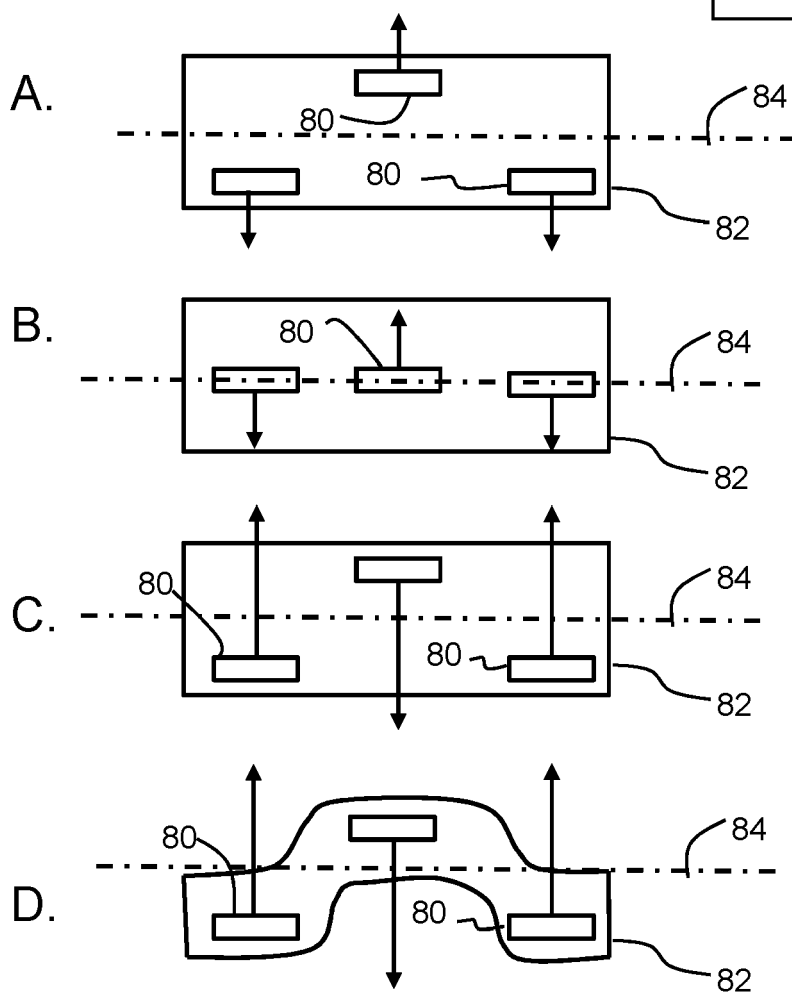


FIG. 6

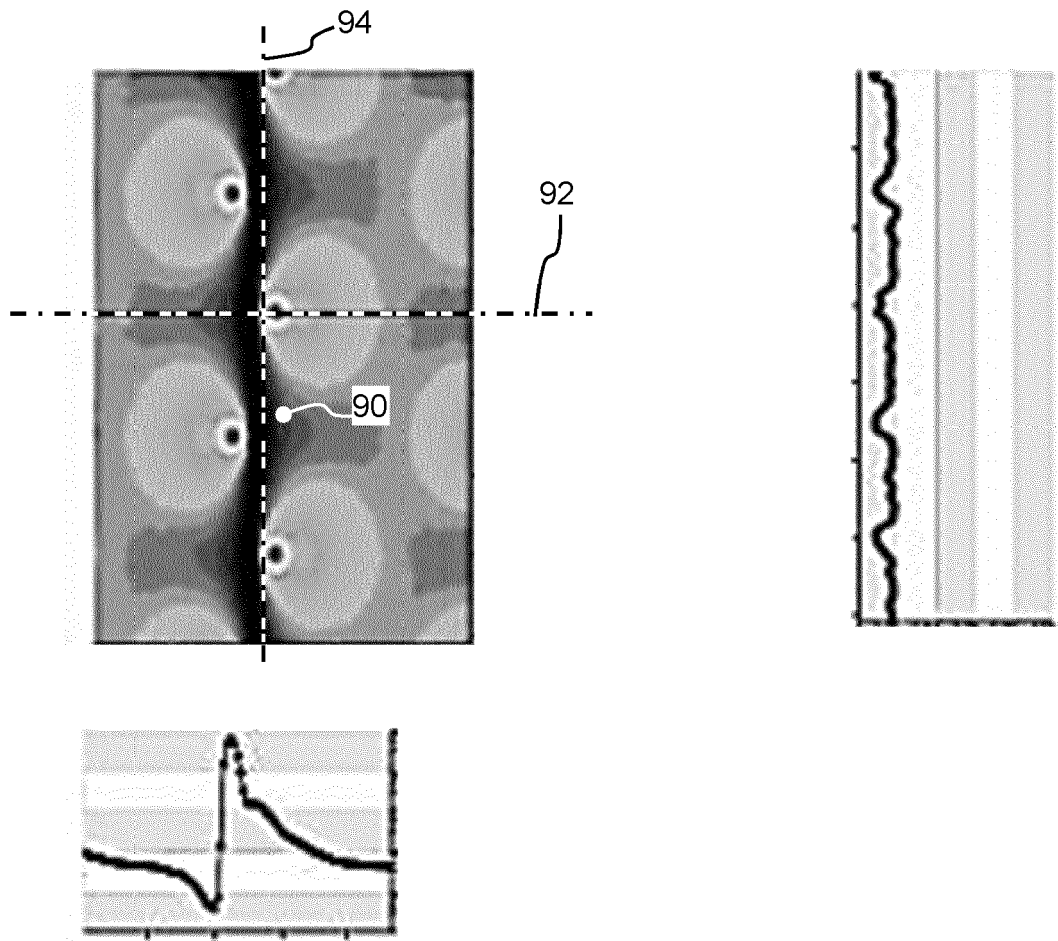


FIG. 7

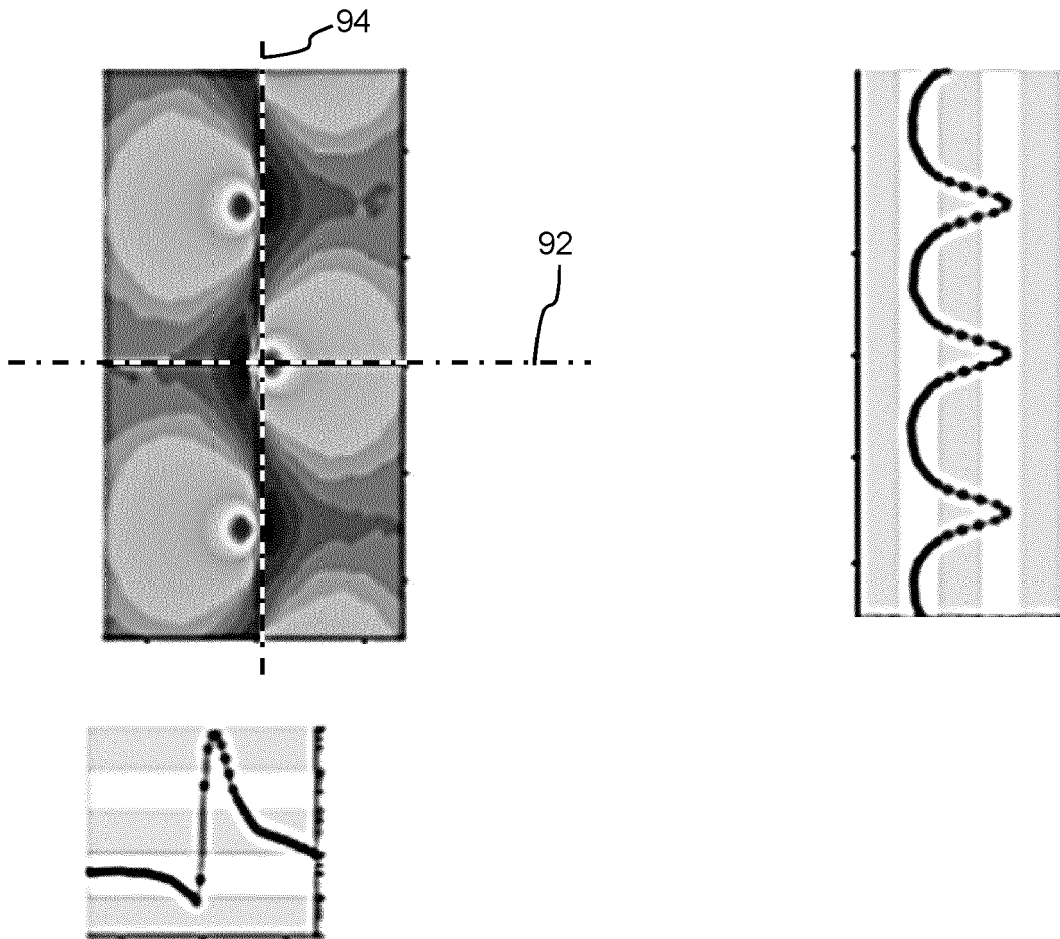


FIG. 8

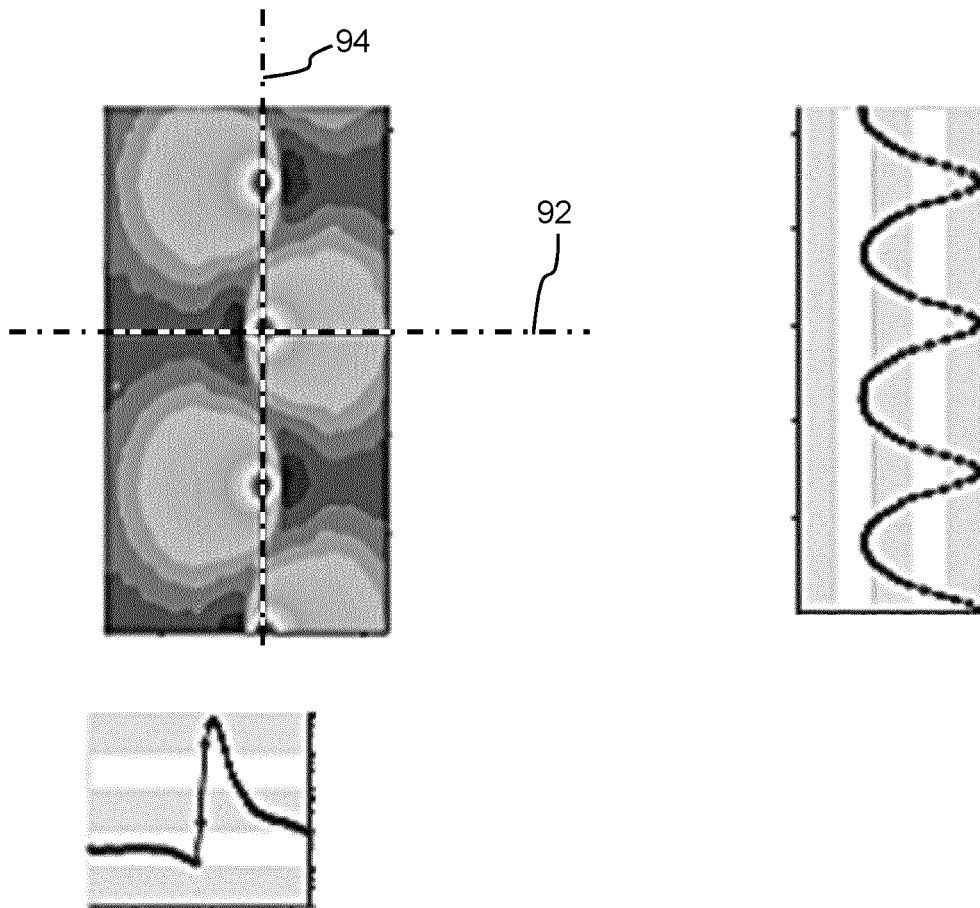


FIG. 9

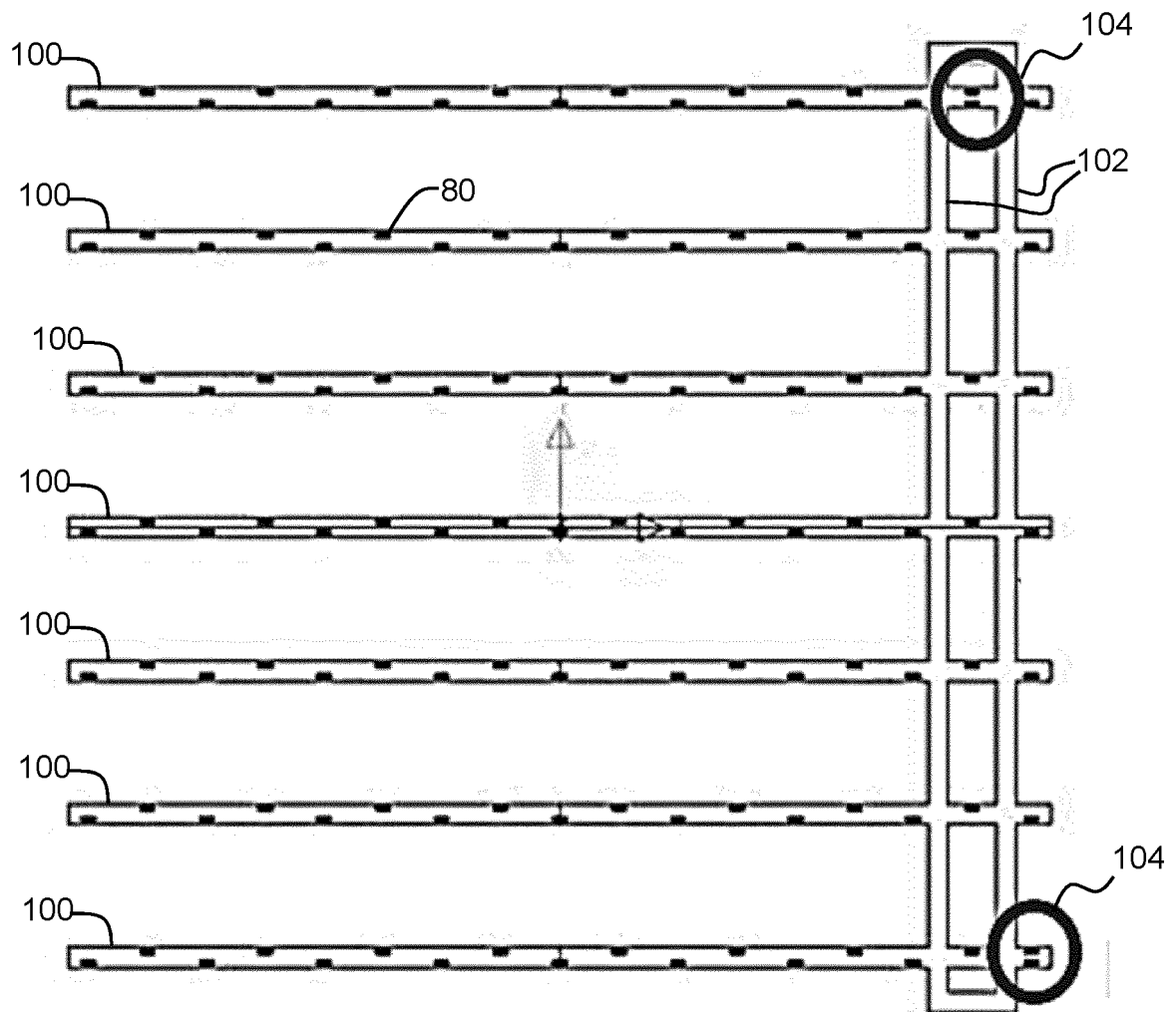


FIG. 10

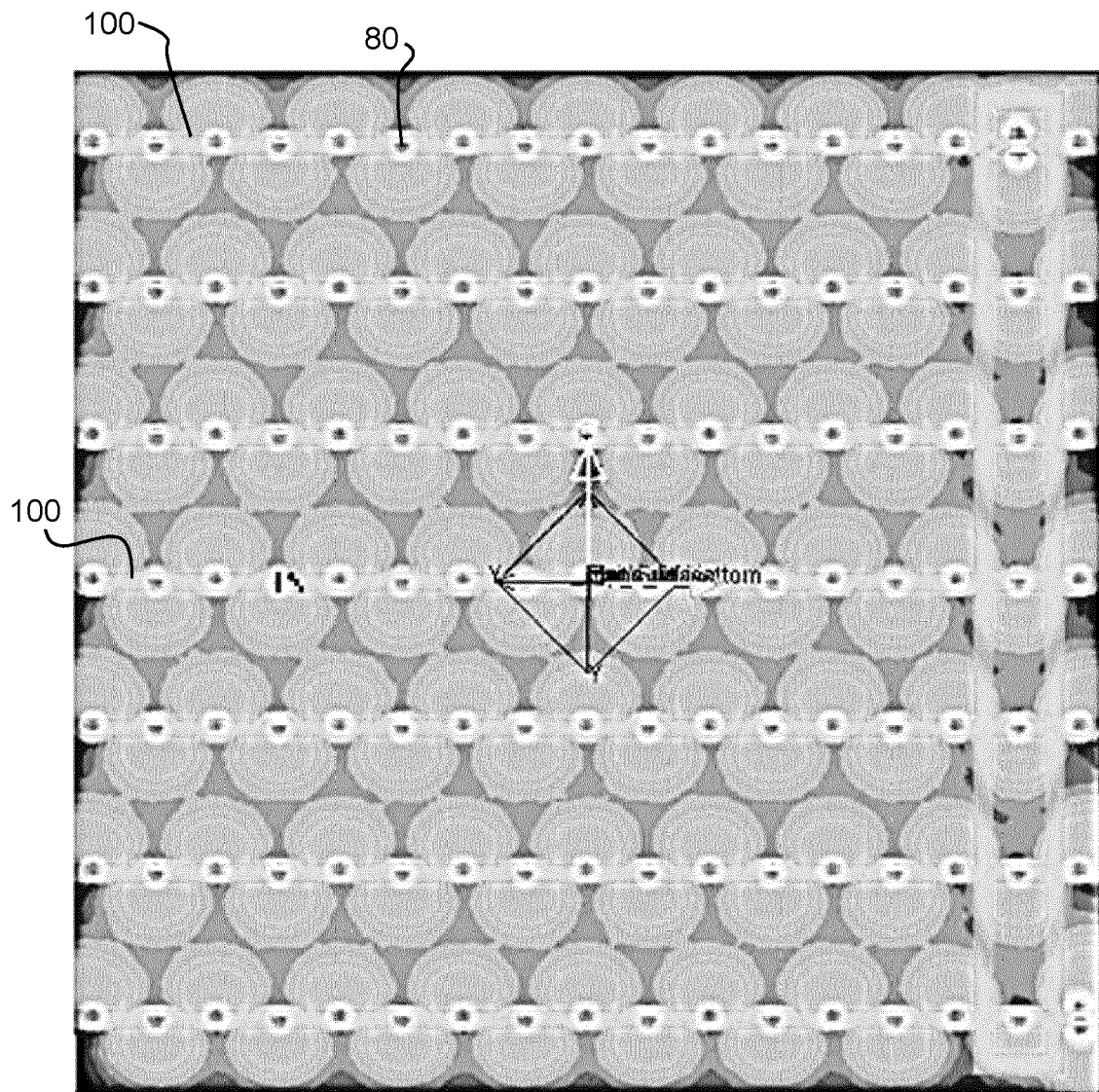


FIG. 11

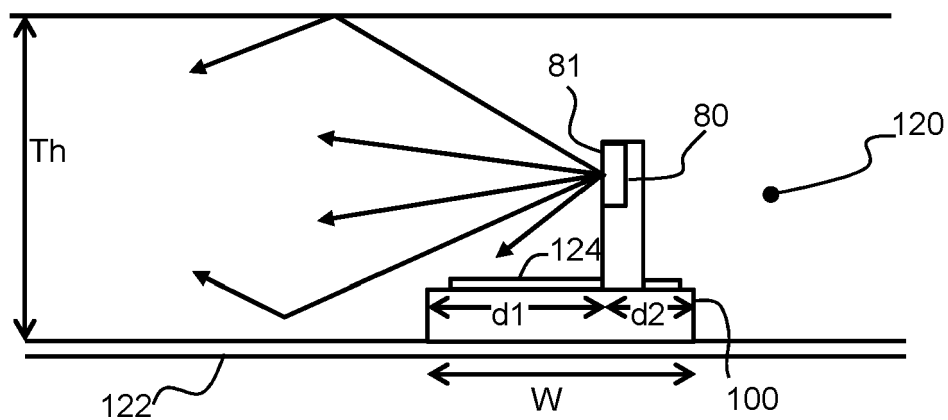


FIG. 12

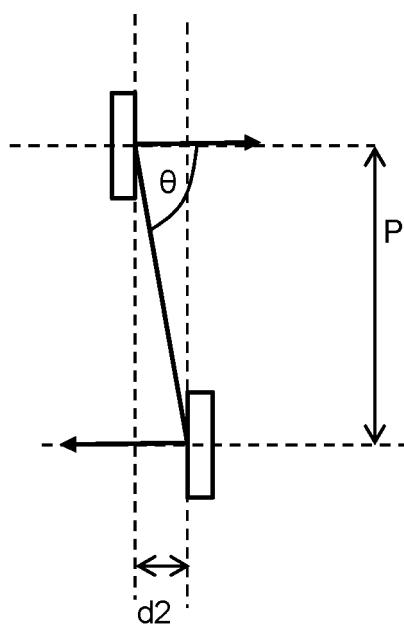


FIG. 13

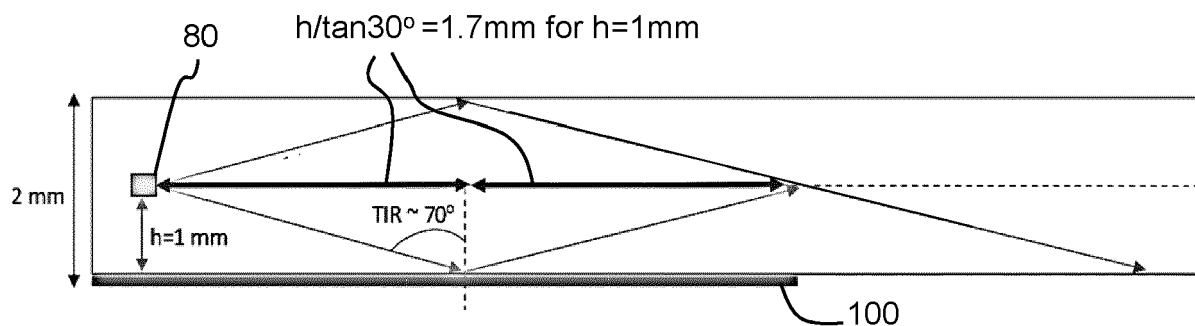


FIG. 14

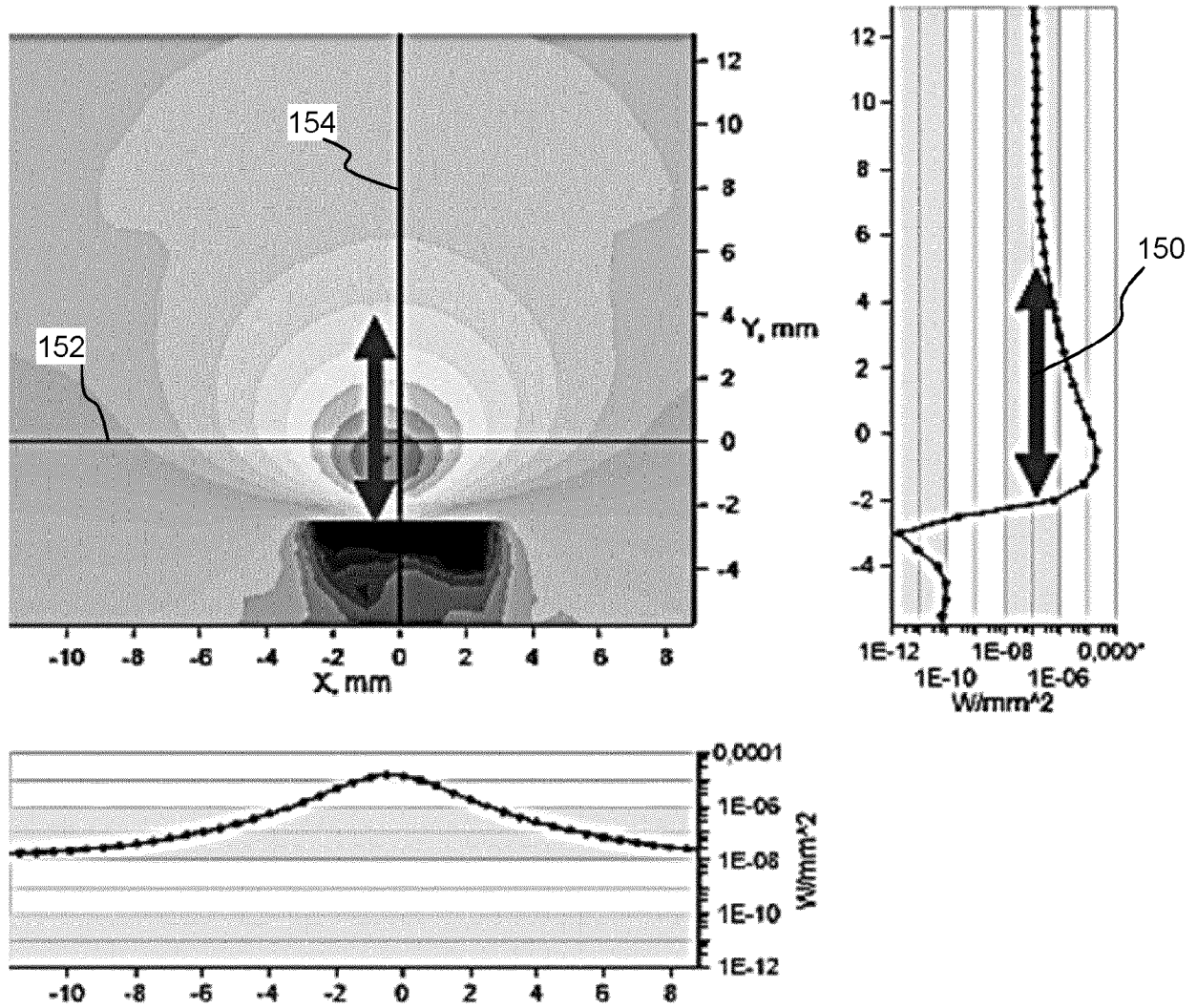


FIG. 15



EUROPEAN SEARCH REPORT

Application Number
EP 19 21 9080

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 3 431 867 A1 (KONINKLIJKE PHILIPS NV [NL]) 23 January 2019 (2019-01-23) * abstract * * paragraph [0003] - paragraph [0005] * * paragraph [0075] * * paragraph [0133] - paragraph [0148] * * claims * * figures *	1-15	INV. B08B17/02
X	GB 2 468 410 A (ITI SCOTLAND LTD [GB]) 8 September 2010 (2010-09-08) * abstract * * page 10, line 3 - line 10 * * page 11, line 1 - page 12, line 6 * * page 17, line 1 - page 18, line 30 * * claims * * figures *	1-15	
A	US 10 436 437 B1 (USHER SCOTT D [US] ET AL) 8 October 2019 (2019-10-08) * abstract * * column 1, line 8 - line 16 * * column 3, line 34 - column 4, line 27 * * column 6, line 15 - line 28 * * column 6, line 54 - column 7, line 3 * * column 7, line 28 - column 8, line 11 * * column 8, line 39 - line 54 * * column 9, line 17 - line 57 * * claims * * figures *	1,3,7-15	TECHNICAL FIELDS SEARCHED (IPC) B08B B63B G02B F21K
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 12 June 2020	Examiner van der Zee, Willem
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 19 21 9080

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D	WO 2014/188347 A1 (KONINKLIJKE PHILIPS NV [NL]) 27 November 2014 (2014-11-27) * abstract * * page 1, line 2 - line 4 * * page 2, line 6 - line 9 * * page 3, line 22 - line 24 * * page 12, line 14 - line 25 * * page 14, line 20 - page 16, line 3 * * page 18, line 31 - page 19, line 14 * * page 19, line 23 - line 26 * * claims * * figures * -----	1-7	
			TECHNICAL FIELDS SEARCHED (IPC)
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 12 June 2020	Examiner van der Zee, Willem
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 21 9080

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

12-06-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3431867 A1	23-01-2019	AU 2018303204 A1	05-03-2020
		CA 3070023 A1	24-01-2019
		CN 111094846 A	01-05-2020
		EP 3431867 A1	23-01-2019
		EP 3655699 A1	27-05-2020
		KR 20200031660 A	24-03-2020
		TW 201921013 A	01-06-2019
		US 2020183119 A1	11-06-2020
		WO 2019016291 A1	24-01-2019

GB 2468410 A	08-09-2010	CN 102341734 A	01-02-2012
		EP 2404201 A1	11-01-2012
		GB 2468410 A	08-09-2010
		JP 2012519931 A	30-08-2012
		KR 20110126741 A	23-11-2011
		TW 201040635 A	16-11-2010
		US 2012002438 A1	05-01-2012
		WO 2010100504 A1	10-09-2010

US 10436437 B1	08-10-2019	NONE	

WO 2014188347 A1	27-11-2014	AU 2014270018 A1	21-01-2016
		AU 2018247328 A1	08-11-2018
		BR 112015028954 A2	25-07-2017
		CA 2913190 A1	27-11-2014
		CN 105209187 A	30-12-2015
		CN 109201693 A	15-01-2019
		EP 2999553 A1	30-03-2016
		EP 3520912 A2	07-08-2019
		JP 2016525932 A	01-09-2016
		KR 20160012190 A	02-02-2016
		RU 2015154739 A	29-06-2017
		US 2016137276 A1	19-05-2016
		US 2017210450 A1	27-07-2017
		US 2020023924 A1	23-01-2020
		WO 2014188347 A1	27-11-2014

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2014188347 A [0007] [0010]