



(11) **EP 4 485 480 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.01.2025 Bulletin 2025/01

(51) International Patent Classification (IPC):
G21F 3/04 (2006.01) G21F 7/02 (2006.01)

(21) Application number: **23182403.8**

(52) Cooperative Patent Classification (CPC):
G21F 3/04; G21F 7/02

(22) Date of filing: **29.06.2023**

(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 ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

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(54) **RADIATION PROTECTION MODULE**

(57) A radiation protection module and a radiation protection structure comprising at least one radiation protection module are provided. The radiation protection module includes a first outer surface at one side and a second outer surface at the opposite side comprising openings in its surfaces, at least one radiation shielding layer and light guiding elements. The module acts like a trap for radiation while the light guiding elements are arranged to guide light from the openings at one side of the module to the opposite through the at least one radiation shielding layer to provide optical transparency which may facilitate operation, control, non-verbal communication, monitoring, etc.

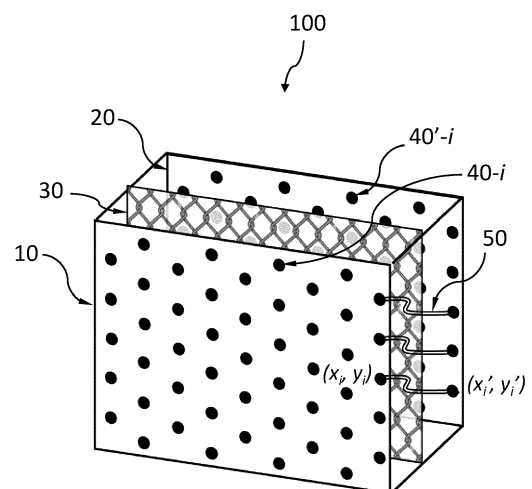


Fig. 1

Description

FIELD OF THE INVENTION

[0001] The invention generally relates to the field of radiation shielding. In particular, the invention relates to a radiation protection module, a radiation protection structure comprising at least one radiation protection module, and to the use of the radiation protection module in the fabrication of a radiation protection structure.

BACKGROUND OF THE INVENTION

[0002] Radiation is a form of energy that is naturally present all around us. Radiation is classified into two types: ionizing and non-ionizing type depending on its ability or inability to ionize matter. X-rays and gamma rays are examples of ionizing radiation. Visible light, infrared rays, radiofrequency (i.e., microwaves and radio waves) are examples of non-ionizing radiation.

Forms of ionizing radiation have enough energy to remove an electron from an atom. This can damage the DNA inside of cells, which can be harmful, e.g., it can sometimes lead to cancer. Exposure to very high levels of radiofrequency (RF) radiation can be harmful due to the ability of RF energy to rapidly heat biological tissue, which can lead to burns and body tissue damage.

[0003] Although high doses of radiation can be harmful to health, radiation provides diverse advantageous applications. RF radiation provides a wide range of applications, to name a few: in the telecommunication sector (broadcast, cellular phones, radio communications for police and fire-departments, microwave point-to-point links, satellite communications, etc.), but also in radar (applications such as traffic enforcement, air traffic control and military applications) and for industrial heating and sealing. Ionizing radiation and radioactive materials are also used every day in medical settings to improve health outcomes and even save lives. In diagnostic imaging, X-rays are used for plain film and computed tomography imaging, gamma rays are used in radionuclide imaging, and magnetic resonance imaging (MRI) uses RF radiation as a transmission medium. X-rays are also used for non-destructive testing, geological exploration, and in security systems.

[0004] Naturally, it is desired that people do not get more exposure to radiation than necessary, e.g., from imaging studies, from workplace environments, from education and training, etc. Therefore, activities where radiation is involved are subject to standards of safety where safe levels of exposure for both the general public and for workers are recommended. As a result, restrictive measures or actions may be necessary to ensure the safe use of these forms of energy (e.g., X-ray, RF energy). A basic protective measure in radiation safety is shielding. Radiation shielding is based on the principle of attenuation, i.e., on reducing a wave's or ray's effect by blocking or bouncing particles through a barrier material.

Hence, radiation shielding is accomplished by installing barriers around potential sources and victims of radiation (humans, animals, plants, or objects).

[0005] The most effective shielding depends on the kind of radiation. For example, X-rays are absorbed by heavy, dense materials, such as lead and cement. RF shielding requires barriers made of conductive and magnetic materials to block the RF signals that cause RF interference.

[0006] Radiation shielding can be incorporated in facilities, a region, or simply a barrier in for example, healthcare, military, banking, business, government, research, testing settings. An MRI room is an example of a facility needing RF shielding because interference with external RF signals and magnetic fields distorts the images, and MRI machines also emit electromagnetic radiation that can disrupt other medical equipment. X-ray technicians, doctors, or other occupational radiation workers may need a protective barrier or a shielded area to be protected from radiation generated from a radiation source used during a medical scan, an industrial test, a training session, or other technical, medical, or research activity.

[0007] It is often desirable that shielded barriers, areas, or facilities offer some degree of visibility to the operator for example, to facilitate operation, control and/or non-verbal communication. To provide optical transparency in at least a part of such protective structures, leaded glass or leaded acrylic are typically integrated into X-ray protective structures. Transparent RF shielding solutions include transparent conductive films for RF shielding of glass or use of a double layer of RF blocking material (e.g., wire cloth, mesh screen) with associated glazing. Lead glass is porous and fragile and is not suitable for use by itself in an exterior application. Generally, transportation and installation of glass-based panels may also need special precautions, and flexibility in their use may be limited. Moreover, often the conventional transparent shielding solutions are used for windows, i.e., openings on a structure, which means that part of the structure is transparent, and the rest is opaque. A radiation barrier can also be made from a safe glass material, while offering optical transparency throughout the whole structure, the barriers may be heavy, and their transportation needs to be handled with care.

SUMMARY OF THE INVENTION

[0008] It would be advantageous to have a more lightweight, safe radiation shielding solution that can combine both optical transparency and shielding in a more flexible manner. This would be especially advantageous to be able to adapt the shielding to the environmental situation; for example, in a medical environment such as mobile diagnostic imaging scenarios which are rapidly progressing, but also in a non-medical environment such as non-destructive testing.

[0009] The object of the invention is therefore to pro-

vide a radiation shielding module combining optical transparency and shielding in a flexible manner.

[0010] Thereto a radiation protection module and a radiation protection structure comprising at least one radiation protection module are provided, as well as the use of the radiation protection module in the fabrication of a radiation protection structure.

[0011] The radiation protection module comprises a first outer surface at one side and a second outer surface at the opposite side, at least one radiation shielding layer and light guiding elements. The first and second outer surfaces comprise openings in its surfaces and are separated from each other by a spacing. Within said spacing, the at least one radiation shielding layer and the light guiding elements are embedded. The light guiding elements are arranged such that at least one optical path (OP) is formed to guide light from an opening at the first outer surface, at a location (x_i, y_i) , to an opening at the second outer surface, at a location (x'_i, y'_i) , through the at least one radiation shielding layer. In this way, the module acts like a trap for radiation while at least one optical path is arranged through the module to provide optical transparency which may facilitate operation, control, non-verbal communication, monitoring, etc.

[0012] In an embodiment, the light guiding elements are arranged such that at least one optical path is formed to guide light from an opening at the first outer surface to an opening at the second outer surface whose positions at the corresponding outer surface are substantially the same. By interconnecting openings at the first outer surface with openings at the second outer surface that are substantially at the same positions at the corresponding outer surface, light in the visible spectrum may penetrate through the openings in the surfaces of the module to be guided by the light guiding elements and an image from the shielded area may be visible outside and vice versa. The sharpness and/or the definition of the image depends on the density of the openings in the first and second outer surfaces and the optical transmission paths. This way, the image may look well defined and undistorted, or it may be at least sufficiently recognizable. This may be advantageous for non-verbal communication and/or for monitoring purposes while still being provided with a barrier protection from harmful radiation.

[0013] In an embodiment the light guiding elements are provided by a reflector arrangement comprising an input port, an output port, a first reflective surface, and a second reflective surface. The first reflective surface is placed to reflect incoming light from the input port to the second reflective surface, which is placed to reflect said incoming light towards the output port. The reflective surfaces redirect light but do not redirect radiation. Hence, by having two reflective surfaces in this arrangement, the light is deflected and able to be propagated through, while a direct path for radiation from one side to the opposite side is prevented.

[0014] In an embodiment the light guiding elements comprise an input and an output port and are configured

to confine incoming light from the input port by total internal reflection (TIR) to be transmitted to the output port. Through TIR light rays may be conducted over long paths which may be of many forms. For example, optical paths may be curved so that a direct path for radiation is prevented while light is still propagated.

[0015] In an embodiment the at least one radiation shielding layer is provided by a wire mesh, a metal grid or an X-ray absorbing wall containing X-ray absorbing material for instance in the form of particles and/or liquid. The holes of a wire mesh or metal grid designed to block a specific electromagnetic wave may be leveraged to arrange the light guiding elements through the radiation shielding layer, provided that the size of the holes allows that. An X-ray absorbing wall containing X-ray absorbing material in the form of particles and/or liquid may be also more easily leveraged to arrange light guiding elements through it.

[0016] In an embodiment, the radiation protection module comprises at least one layer of light guiding elements and a plurality of radiation shielding layers. The radiation shielding layers comprise openings in its surfaces and are separated from each other by a spacing. Within said spacing, a layer of the at least one layer of light guiding elements is embedded and arranged to guide light from input to output ports through the openings of the radiation shielding layers. Further, for any consecutive radiation shielding layers (l_i, l_{i+1}) of the plurality of radiation shielding layers, the openings in one of the consecutive radiation shielding layers (l_i) have a substantially uniform offset (D) with respect to the openings in the other consecutive radiation shielding layer (l_{i+1}) such that radiation is substantially blocked by the combined plurality of radiation shielding layers. In this manner, radiation that is not blocked by the first radiation shielding layer is blocked by subsequent radiation shielding layers while light is still propagated through the module. The substantially uniform offset between openings may ease manufacture and the control of distortion of the image visible in the other side, e.g., by allowing the transmission of an image shifted sideways, but not deformed, or by allowing the transmission of a non-distorted image, i.e., a non-shifted image. However, for X-ray shielding, the uniformity may lead to X-ray hot-spots (an area emitting more X-rays than surrounding areas) which may be prevented by increasing the number of radiation shielding layers and/or by combining modules with different geometries for a more robust and homogeneous X-ray shielding.

[0017] In an embodiment involving the previous radiation protection module, the first radiation shielding layer of the plurality of radiation shielding layers is a first outer radiation shielding layer facing the first outer surface of the radiation protection module, and the last radiation shielding layer of the plurality of radiation shielding layers is a second outer radiation shielding layer facing the second outer surface of the radiation protection module, and the first and the second outer radiation shielding layers are in contact with the respective outer surface

of the radiation protection module. Optionally, the first and the second outer radiation shielding layers form the respective outer surface of the radiation protection module. In another alternative, either the first or the second outer radiation shielding layer is in contact with the respective outer surface of the radiation protection module and the other outer radiation shielding layer forms the respective outer surface of the radiation protection module. This provides different alternatives to implement the outer surfaces of the module including leveraging a radiation shielding layer to act as a possible outer surface of the module.

[0018] In an alternative embodiment, the radiation protection module comprises:

- a plurality of radiation shielding layers comprising openings in its surfaces and separated from each other by a spacing,
- a plurality of light guiding elements laid from an opening at the first outer surface, at a location (x_i, y_i) of said first surface, to an opening at the second outer surface, at a location (x_i', y_i') of said second surface, traversing the plurality of radiation shielding layers through an opening at a location (u_i, v_i) in each of its surfaces, wherein the locations of the openings in the surfaces of the plurality of radiation shielding layers have a random or pseudorandom offset with respect to each other such that radiation is substantially blocked by the combination of the plurality of radiation shielding layers. The random or pseudorandom arrangement favors a more homogeneous shielding by the combined radiation shielding layers which may be especially helpful for X-ray shielding.

[0019] In an embodiment, the plurality of radiation shielding layers comprises X-ray radiation shielding layers, or RF radiation shielding layers or a combination thereof. In this way, a module may be purely X-ray protective by comprising X-ray radiation shielding layers, or RF protective by comprising RF radiation shielding layers, but also both X-ray and RF shielding may be provided by a module if both types of shielding are present. The X-ray radiation shielding layers may be provided by X-ray absorbing walls containing any one of lead, molybdenum, tungsten, or a combination thereof. The RF radiation shielding layers may be provided by any one of metal grids, wire meshes, interconnected metal foils to provide a good conductivity and mitigate discontinuities on the shield, or a combination thereof.

[0020] In an embodiment, the light guiding elements comprise at least one optical fiber which may be used for any one of the following purposes such as transmission of light in the visible spectrum, data transmission, power transmission or a combination thereof. Optical fibers are versatile components which may be used to propagate light in the visible spectrum through the module to enable that an image from the shielding area may be visible outside and vice versa. Optical fibers are also advanta-

geous to provide high-speed communication lines for data transfer. Further, optical fibers may be leveraged for power transmission which is advantageous due to its lightweight, corrosion resistance, and robustness to electromagnetic interference and electric sparks. Optical power transmission eliminates the risk of being affected by intense magnetic fields such as those found in magnetic resonance imaging, and electromagnetic interference. Further, it prevents the emission of electromagnetic radiation that can interfere with other devices and does not generate any direct current magnetic fields.

[0021] According to a second aspect of the invention, there is a radiation protection structure comprising at least one of the radiation protection modules of the presently claimed invention. This way, a radiation protection structure may enjoy at least on a part, the advantages provided by the features of the presently claimed invention. Likewise, a plurality of any of the radiation protection modules of the presently claimed invention may be connected in a flexible manner to shield an area and fulfil safety regulations while offering optical transparency throughout the whole structure.

[0022] According to a third aspect of the invention, the process of fabricating a radiation protection structure may comprise using the radiation protection module of the presently claimed invention. Thereby enhancing conventional radiation shielding solutions.

[0023] These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE FIGURES

[0024] In the following drawings:

Fig. 1 schematically and exemplarily illustrates a radiation protection module with optical transparency as described in conjunction with the presently claimed invention.

Fig. 2 schematically illustrates an example of light guiding element based on a reflector arrangement. Fig. 2A illustrates an example of the reflector arrangement element. Fig. 2B illustrates an example of a layer of reflector arrangements.

Fig. 3 schematically illustrates an example of light guiding elements based on total internal reflection. Fig. 3A illustrates a waveguide structure. Fig. 3B illustrates an optical fiber.

Fig. 4 schematically illustrates a first set of examples of radiation protection modules with optical transparency in a cross-sectional view. Fig. 4A shows a cross-sectional view of a radiation protection module comprising two X-ray radiation shielding layers and a layer of reflector arrangements. Fig. 4B shows a cross-sectional view of a radiation protection module comprising three X-ray radiation shielding layers and correspondingly, two layers of reflector arrangements.

Fig. 5 schematically illustrates a second set of examples of radiation protection modules with optical transparency in a cross-sectional view. Fig. 5A illustrates a three-dimensional view of a simplified design of a radiation protection module comprising two radiation shielding layers and optical fibers as light guiding elements. Entry and exit points of the optical fiber are at the same position in the module surfaces. Fig. 5B illustrates a random arrangement of the locations of the openings in a first outer surface and an X-ray absorbing wall; the openings are interconnected by optical fibers. Fig. 5C illustrates a cross-sectional view of a simplified design of a radiation protection module comprising two radiation shielding layers and optical fibers as light guiding elements. Entry and exit points of the optical fiber are at different positions in the module surfaces. Fig. 6 illustrates a plurality of radiation protection modules assembled to form an optically transparent radiation protection structure.

[0025] The invention may take form in various components and arrangements of components, and in various processes operations and arrangements of process operations. The drawings are only for the purpose of illustrating the preferred embodiments and are not to be construed as limiting the invention. To better visualize certain features may be omitted or dimensions may be not according to scale. Like or similar components are given the same reference numerals in different figures.

DETAILED DESCRIPTION OF THE INVENTION

[0026] A technology is proposed to combine optical transparency with radiation shielding functionality in a flexible way. What is proposed herein is a radiation protection module with the ability to allow light to propagate through it while blocking harmful radiation. The technology also allows building radiation protection structures from constituent radiation protection modules. This way, modular elements may be connected to form a barrier, or a structure to shield an area and fulfil safety regulations.

[0027] Combining optical transparency with shielding functionality in a module requires to provide simultaneously a path for optical light to go through the module and a barrier for radiation. Fig. 1 illustrates a radiation protection module 100 with optical transparency characteristics. The module 100 comprises a first outer surface 10 at one side and a second outer surface 20 at the opposite side. The first 10 and second 20 outer surfaces comprise openings 40, 40' in its surfaces and are separated from each other by a spacing. In the figure, 40 represents all openings in the first outer surface and 40' represents all openings in the second outer surface; for clarity, only reference to a single opening (labeled with i) at each surface is made. The radiation protection module further comprises, embedded within the spacing

separating the first 10 and second 20 outer surfaces, at least one radiation shielding layer 30 and light guiding elements 50. The light guiding elements 50 are arranged to form at least one optical path OP that guides light from an opening 40-i at the first outer surface, at a location (x_i, y_i) , to an opening 40'-i at the second outer surface, at a location (x'_i, y'_i) , through the at least one radiation shielding layer 30. The light guiding elements 50 thereby enable that at least some of the incident light at the openings in either the first or second outer surface 40, 40' propagates through the radiation protection module to the openings at the opposite side of the module 40', 40, and together with the at least one radiation shielding layer, provide a barrier for radiation with optical transparency. Therefore, the light guiding elements forming the at least one optical path OP within the module are arranged to redirect light but not to redirect radiation, which is ultimately blocked by the at least one radiation shielding layer.

[0028] Openings in the first 40 and second 40' outer surfaces may have different patterns and/or arranged in a matrix of any size. The openings 40, 40' may be interconnected through the light guiding elements 50 in different ways to facilitate operation, control, non-verbal communication, monitoring, etc. For example, a control signal may be sent to indicate the radiation state (e.g., on/off) for safety purposes. For this purpose, light in the visible spectrum may be transmitted from selected openings in a region of one side 10 of the module to a region in the opposite side 20 of the module which may be a completely different region, or uniformly shifted with respect to the entry region for a sideways image transmission, or partially or overlapping with the entry region. In embodiments, the light guiding elements 50 are arranged such that at least one optical path is formed to guide light from an opening at the first outer surface 40-i to an opening at the second outer surface 40'-i whose positions at the corresponding outer surface are substantially the same. By interconnecting openings at the first outer surface with openings at the second outer surface that are substantially at the same positions at the corresponding outer surface, light in the visible spectrum may be propagated through the module and an undistorted image transmission is enabled. In other words, an image from the shielded area may be visible outside and vice versa wherein the sharpness and/or the definition of the image depends on the density of the openings in the first and second outer surfaces 40, 40' and the optical transmission paths. This way, the image may look undistorted and well-defined, or it may be at least sufficiently recognizable. This may be used for non-verbal communication and/or for monitoring purposes while still being provided with a barrier protection from harmful radiation.

[0029] Figs. 2 and 3 show exemplary light guiding elements 50.

[0030] Fig. 2A illustrates a light guiding element provided by a reflector arrangement 50-1. The light guiding element 50-1 comprises an input port 51, an output port

52, a first reflective surface 53, and a second reflective surface 54. The light guiding element 50-1 exploits specular or regular reflection of light and does not reflect X-rays. The first reflective surface is placed to reflect incoming light from the input port to the second reflective surface, which is placed to reflect said incoming light towards the output port. By having two reflective surfaces, light is deflected such that light goes through from one side to the opposite side, following the illustrated optical path OP. At the exit point 52 the light is shifted with respect to the input point 51.

[0031] The reflective surfaces capable of deflecting the direction of the visible light may be mirrored surfaces or prismatic structures. Mirrors may be formed by using a transparent material (such as plastic or glass) whose refractive index is sufficient to provide total reflection at the air interface at the preferred mirror angle of around 45 degrees. In other embodiments, mirror surfaces may be formed by superimposing a very thin reflective layer (such as a thin Al film - thin enough as to hardly scatter the radiation) on another substrate, which does not have to be transparent at all (e.g., wood, concrete). In other embodiments, the mirror could be a dielectric multi-layer mirror deposited on a transparent substrate, whereby the reflection characteristics may be optimized without inducing any X-ray scattering.

[0032] Light guiding elements may be arranged to form a layer. For example, Fig. 2B show reflector arrangements 50-1 laid up to form a layer, wherein the input ports 51 are facing one side, and the output ports are facing the opposite side.

[0033] A second class of light guiding elements 50-2 envisioned in the presently claimed invention exploits total internal reflection (TIR) of light and is illustrated in Fig. 3. TIR is a well-known optical phenomenon where waves arriving at the interface from one medium with refractive index n_1 to another with refractive index n_2 are not refracted into the second medium but are completely reflected back into the first medium. This occurs when the refractive index of the second medium is lower than the first one (i.e., $n_1 > n_2$), and the waves are incident at an angle that is greater than a certain limiting angle, called the critical angle θ_c , given by $\theta_c = \arcsin(n_2/n_1)$. The angle of incidence θ_i is measured relative to the normal (perpendicular) between the surfaces of the first and second medium. Through this phenomenon, light rays may be conducted over long paths by multiple total internal reflection in glass or plastic rods or waveguides or optical fibers. As such, Fig. 3 illustrates a light guiding element 50-2 comprising also an input 51, an output port 52, and configured to confine incoming light from the input port 51 by total internal reflection to be transmitted to the output port 52. Fig. 3A depicts a waveguide structure that may be also laid in a layer (not shown) with input ports 51 facing one side, and output ports facing the opposite side. Fig. 3B illustrates an optical fiber. Optical fibers can be used to transmit light in the visible spectrum but also infrared light suitable for multiple purposes such as data

transmission (where the light is a form of carrier wave that is modulated to carry information), power transmission (where optical power is generated from electric power, usually with a laser diode, and after transmission converted back to electrical power for some electronic device), sensing, etc.

[0034] There is a wide variety of radiation shielding materials that may be used for a radiation shielding layer.

[0035] Common RF shielding materials include copper, nickel silver (which is ideal for MRI machines RF shielding due to its permeability of 1), aluminum, steel, mu-metal (which has good ductility and malleability), conductive fabrics, etc. The shielding material may come in the form of a wire mesh or metal grid or a screen or a metal foil, and so are possible forms of the radiation shielding layer. The holes of a wire mesh or metal grid designed to block a specific electromagnetic wave may be leveraged to arrange the light guiding elements through the radiation shielding layer, provided that the size of the holes allows that. As an example, Fig. 1 illustrates this possibility. With respect to the effectiveness of RF shielding in reducing the amount of interference, this depends on the properties of the shielding material, design, thickness of the shield, electromagnetic frequency, and the size of discontinuities present on the shield.

[0036] A widely used X-ray shielding material is lead because of its compactness due to its higher density. Alternatives include lead-based composites using a mixture of lead and other light weight radiation attenuating metals, and non-lead or lead-free shielding materials which are made from other types of attenuating metals like antimony, tungsten, bismuth and tin. Molybdenum is also a possible material for an X-ray radiation shielding layer. Possible forms for the radiation shielding layer include sheets, plates and foils. However, a radiation protective wall may also contain X-ray absorbing material for instance, in the form of particles and/or liquid. For example, it could also contain a fluid with lead and/or other X-ray blocking particles. Many factors contribute to the shielding requirements (e.g., lead thickness) such as: the energy level of the equipment (how much radiation it produces and which direction it is pointed), surrounding areas (e.g., if neighboring area is a children's care unit, it will require much more shielding than if it is a storage area), etc. The choice of materials, or a combination thereof is guided by the shielding requirement but also by the legal and/or company or hospital requirement. A combination of materials for the design of energy specific shielding functionality may be possible which offers a flexible solution versus the alternative of heavy lead glass that only has a fixed absorption spectrum with its associated relatively high weight.

[0037] Figs. 4 and 5 illustrate radiation protection modules with optical transparency in various embodiments.

[0038] Specifically, Fig. 4A and Fig. 4B show exemplary cross-sectional views of radiation protection modules comprising a plurality of radiation shielding layers 30

and at least one layer of light guiding elements 50-L. The input ports 51 of the light guiding elements are facing one side, and the output ports of the light guiding elements are facing the opposite side. The illustrations show reflector arrangements as light guiding elements in a layer (e.g., as shown in Fig. 2B), however, other class of light guiding elements may be laid in a similar way through the radiation shielding layers to enable the formation of optical paths from one side of the module to the opposite. For example, those light guiding elements exploiting TIR to transport light from input to output ports which include waveguide structures and optical fibers, which depending on diameter, a bundle of fibers may be used. Similarly, the illustrated radiation shielding layers are X-ray radiation shielding layers that may be provided in the form of X-ray absorbing walls containing any one of lead, molybdenum, tungsten, or a combination thereof. However, the radiation shielding layers may be instead RF radiation shielding layers provided by any one of metal foils that are interconnected to mitigate the presence of discontinuities on the shield, metal grids, wire meshes, or a combination thereof. In more complex designs, yet being guided by the same principles, the plurality of radiation shielding layers may be a mix of X-ray radiation shielding layers and RF radiation shielding layers for increased functionality.

[0039] Continuing with the description of Fig. 4A and Fig. 4B, the radiation shielding layers comprise openings 31 in its surfaces and are separated from each other by a spacing. Within said spacing, a layer of light guiding elements 50-L is embedded and arranged to guide light from input to output ports through the openings of the radiation shielding layers. For any consecutive radiation shielding layers 30 (I_i , I_{i+1}), the openings in one of the consecutive radiation shielding layers (I_i) have a substantially uniform offset D with respect to the openings in the other consecutive radiation shielding layer (I_{i+1}) such that radiation is substantially blocked by the combined plurality of radiation shielding layers. The combined thickness of the radiation shielding layers defines the radiation absorption property. The first radiation shielding layer of the plurality of radiation shielding layers is defined as a first outer radiation shielding layer facing the first outer surface of the radiation protection module, and the last radiation shielding layer of the plurality of radiation shielding layers is defined as a second outer radiation shielding layer facing the second outer surface of the radiation protection module.

[0040] For clarity, in Fig. 4A and Fig. 4B the first and second outer surfaces of the radiation protection module are not shown. However, the first and the second outer radiation shielding layers may be in contact with the respective outer surface of the radiation protection module. Alternatively, the first and the second outer radiation shielding layers form the respective outer surface of the radiation protection module. Alternately, either the first or the second outer radiation shielding layer is in contact with the respective outer surface of the radiation protec-

tion module and the other outer radiation shielding layer forms the respective outer surface of the radiation protection module. As such, the openings at the first outer radiation shielding layer may correspond substantially to locations of openings at the first outer surface. Similarly, the locations of the openings at the second outer radiation shielding layer may correspond substantially to locations of openings at the second outer surface. For example, when employing reflector arrangements, a substantial correspondence between said openings may be preferred. Substantial in this context means that preferably most of the openings (e.g., >90%) at either the first or second outer radiation shielding layer overlap with locations of openings at either the first or second outer surface of the module. As a result, incoming light, or at least, most of the incoming light to the openings in the surfaces of the radiation protection module can be propagated through the module following the optical paths formed through the radiation shielding layers enabled by the light guiding elements. If employing for example optical fibers as light guiding elements, the correspondence between openings in the first/second outer radiation shielding layers with the respective outer surface of the module is inessential. This is because the optical fiber may be long and flexible so that it can be arranged as needed to guide the light through the module, traversing the outer surfaces of the module as well as the radiation shielding layers.

[0041] In more detail, Fig. 4A shows a cross-sectional view of a radiation protection module comprising two X-ray radiation shielding layers 30 and a layer of reflector arrangements 50-L embedded within the spacing between the radiation shielding layers. The light guiding elements 50-L are arranged to guide light from input to output ports through the openings of the radiation shielding layers. Further, the openings in one of the radiation shielding layers 30 (I_i) have a substantially uniform offset D with respect to the openings in the other radiation shielding layer 30 (I_{i+1}) such that radiation is substantially blocked by the combined radiation shielding layers 30. The substantially uniform offset between openings may ease manufacture, and as it will be elucidated in the next paragraphs, it also facilitates the control of distortion of the image visible in the other side.

[0042] In Fig. 4A as an example, two incident X-rays are illustrated as thick solid arrows. Clearly, the X-ray incident into the first radiation shielding layer (I_i) is blocked by the same. The other X-ray travels through one of the openings in the first radiation shielding layer (I_i) and is absorbed by the material of the second radiation shielding layer (I_{i+1}). Thereby in combination, the radiation shielding layers block the radiation. Thus, having openings in one of the radiation shielding layers 30 (I_i) that are at a uniform or substantially uniform offset D with respect to the openings in the other radiation shielding layer 30 (I_{i+1}) such that radiation is substantially blocked by the combined radiation shielding layers 30, means that the design or the geometry of the structure, i.e. the

dimensions and locations of the openings, prevents a direct path for radiation and/or a not obvious scattering path from one side to the opposite side of the module. As such, the cross-sectional view of the radiation shielding layer with openings may resemble a louvre structure with horizontal strips of width d_1 and d_2 , wherein to provide a good shielding, also for scattered X-rays, it is advantageous that d_2 exceeds d_1 by a factor of more than 1 (e.g., a factor of 1.5, 2, 4, etc.). By having a narrower d_1 with respect to d_2 according to said proportion, an X-ray travelling through an opening in the first louvre, i.e., the first radiation shielding layer, is blocked by the material of the second louvre, i.e. the second radiation shielding layer. The spacing of the louvre (d_1 and d_2) will be typically close to the thickness of the radiation shielding layers, which may be of the order of a few millimeters.

[0043] With continued reference to Fig. 4A, the dotted arrows illustrate a sample optical path enabled by a reflector arrangement for light to propagate through the module. Light in the visible spectrum is deflected by the reflector arrangement and emerges at the opposite side with a shift Δ in position with respect to the position it enters. Said shift Δ produces a distortion of the image visible outside and vice versa, wherein the severity of the distortion is proportional to the shift Δ . Still, the image visible at the other side is only shifted sideways and not deformed. In this embodiment to avoid X-ray leakage, the openings, of width d_1 , need to be relatively narrow compared to d_2 , which may impact the sharpness and definition of the image visible outside and vice versa. However, for control purposes and/or low-resolution optical checks this embodiment may be sufficient.

[0044] Continuing with Fig. 4B, the figure shows a cross-sectional view of a radiation protection module comprising three X-ray radiation shielding layers 30 and correspondingly, two layers of reflector arrangements 50-L, each layer embedded within the spacing between radiation shielding layers. The light guiding elements in a layer 50-L are arranged to guide light from input to output ports through the openings 31 of the radiation shielding layers 30 so that light is guided from one side of the module to the opposite through the openings 31 of the radiation shielding layers. In this case, the second layer of light guiding elements 50-L, is arranged so that light emerges in a position matching substantially the entry position. In this way, the substantially uniform offset D between openings combined with the arrangement of the layers of light guiding elements 50-L allow that the image is visible outside and vice versa without distortion, improving the image quality with respect to the embodiment of Fig. 4A. The sharpness and/or the definition of the image depend on the density of the openings in the first and second outer surfaces 40, 40' and the optical transmission paths through the radiation shielding layers 30. Moreover, in addition to the reflective surfaces, further optical structures can be advantageously incorporated, for example lens style structures (e.g., non-flat mirrors), spectral modification structures (e.g., color fil-

ters), etc. In this way, the image visible outside and vice versa may be modified to suit a particular need or fulfil a function.

[0045] With an increased number of radiation shielding layers 30, the X-ray shielding is also further improved by the exemplary design of Fig. 4B, even for Compton scattered rays from the module itself. The three X-ray shielding layers comprise openings in its surfaces, wherein for any consecutive radiation shielding layers the openings in one of the consecutive radiation shielding layers (I_i) have a substantially uniform offset D with respect to the openings in the other consecutive radiation shielding layer (I_{i+1}) such that radiation is substantially blocked by the combined plurality of radiation shielding layers. In the figure, incident X-rays are illustrated by thick solid lines. Some of the X-rays travel through an opening in the first radiation shielding layer and are absorbed by the material of the second radiation shielding layer. Another X-ray has an angle of incidence such that is able to travel through an opening in the second radiation shielding layer, however, the X-ray is absorbed by the third radiation layer. Thereby, in combination, the three radiation layers block the radiation, with the combined thickness of the layers defining the absorption property.

[0046] Fig. 5 refers to a second set of examples of a radiation protection module with optical transparency. The module comprises a plurality of radiation shielding layers 30 comprising openings 31 in its surfaces and separated each other by a spacing, and a plurality of light guiding elements 50. The light guiding elements are laid from an opening at the first outer surface of the module 10, at a location (x_i, y_i) of said first surface, to an opening at the second outer surface 20, at a location (x'_i, y'_i) of said second surface. The light guiding elements 50-2 comprise an input and an output port and are configured to confine incoming light from the input port by total internal reflection to be transmitted to the output port. The light guiding elements traverse the plurality of radiation shielding layers through an opening (31- i) at a location (u_i, v_i) in each of its surfaces, wherein the locations of the openings in the surfaces of the plurality of radiation shielding layers have a random or pseudorandom offset with respect to each other such that radiation is substantially blocked by the combination of the plurality of radiation shielding layers. In this set of examples, two X-ray radiation shielding layers are illustrated that may be also provided in the form of X-ray absorbing walls containing any one of lead, molybdenum, tungsten, or a combination thereof. However, the radiation shielding layers may be instead RF radiation shielding layers provided by any one of metal foils that are interconnected to mitigate the presence of discontinuities on the shield, metal grids, wire meshes, or a combination thereof. In more complex designs, yet being guided by the same principles, the plurality of radiation shielding layers may be a mix of one or more X-ray radiation shielding layers and one or more RF radiation shielding layers for increased functionality.

[0047] In the illustration of Fig. 5A, as a simplistic

example, an optical fiber 50 is laid from an opening A located at (x_1, y_1) in the first outer surface 10 of the module 100 to an opening B located at (x_2', y_2') in the second outer surface 20 of the module 100 traversing two radiation shielding layers 30. The fiber traverses the first radiation shielding layer 30 through an opening P at a location (u_1, v_1) and the second radiation shielding layer 30 through an opening Q at a location (u_2, v_2) . The locations of the openings P and Q have a random or pseudorandom offset with respect to each other such that radiation is substantially blocked by the combination of the two radiation shielding layers. In this way, u_1 is different from u_2 and v_1 is different from v_2 , and with that, there is no direct path for radiation. In an embodiment, the locations of the openings interconnected by one or more light guiding elements across the whole module, that is from an opening located at (x_1, y_1) in the first outer surface of the module 10, through the plurality of radiation shielding layers 30, and to an opening located at (x_2', y_2') in the second outer surface 20 of the module, follow a random or pseudorandom arrangement with respect to each other such that radiation is substantially blocked by the combined radiation shielding layers, i.e. a pattern for X-ray transmission is prevented. As an example, Fig. 5B illustrates a random arrangement of the locations of the openings 31 in an X-ray absorbing wall 30; the openings 31 are connected by optical fibers 50-2 to the openings of a first outer surface 10. In the figure, openings in the first outer surface 10 are arranged in a rectangular array through which visible light can penetrate to be propagated via the optical fibers 50-2. Depending on the diameter of the fiber, a bundle of fibers may be used such as to have a coverage of 1~10% of fibers versus shielding, so a maximum of ~10% of the radiation shielding layer is non-blocking, or in this example, X-ray transparent.

[0048] The position of an optical fiber at the entry point (x_i, y_i) , e.g. at the first outer surface of the module 10, with respect to the position of the fiber at the exit point (x_j, y_j) , e.g. at the second outer surface of the module 20, determines, if light in the visible spectrum is propagated, whether the optical image transfer from one side of the module to the opposite side of the module occurs with or without distortion. In an embodiment, entry and exit positions of the optical fiber are different at the surfaces of the module, i.e., they have a shift or an offset with respect to each other. In an embodiment, said offsets or shifts are substantially the same, and as a result, the image that is seen at the other side is only shifted sideways but not deformed. In another embodiment, exemplified by the illustration of Fig. 5A, entry and exit positions are the same at first and second outer surfaces of the module. With this, there is an undistorted image transmission with a sharpness and/or definition depending on the density of openings at first and second outer surfaces of the module and the optical transmission paths. Fig. 5C shows a cross-sectional view of a simplified radiation protection module with entry (x_i, y_i) and exit points (x_j', y_j') at different

positions in the outer surfaces of the module. The module comprises two radiation shielding layers 30, light guiding elements 50 (e.g., waveguide, optical fiber) in a support material 60 that direct the light in a non-regular optical transmission path traversing the radiation shielding layers at different positions such that radiation is substantially blocked by the combination of the two radiation shielding layers.

[0049] In another embodiment, the light guiding elements 50 of any of the radiation protection modules 100 described previously comprise at least one optical fiber 50-2. The at least one optical fiber may be used for any one of the following purposes, such as transmission of light in the visible spectrum, transmission of data, power transmission, or a combination thereof. As another example, if there are a plurality of optical fibers, some of them may be used for the transmission of light in the visible spectrum and/or some of them may be dedicated to transport infrared light for the transmission of data and/or power. Optical fibers provide high-speed communication lines for data transfer. Power transmission using optical fibers is advantageous due to its lightweight, corrosion resistance, and robustness to electromagnetic interference and electric sparks. Optical power transmission eliminates the risk of being affected by intense magnetic fields such as those found in magnetic resonance imaging, and electromagnetic interference. Further, it prevents the emission of electromagnetic radiation that can interfere with other devices and does not generate any direct current magnetic fields.

[0050] In general, the frame and the material of the light-guiding layers 50-L could be manifold, such as wood, concrete, plastic, etc., alternatively, they could also be of a shielding material. For lightweight radiation protection modules, plastic materials might be preferred. For example, if employing reflector arrangements, mirror coating may be applied on pyramid elements. Further, functional elements such as distance keeping elements but also mounting points and fixtures for the radiation shielding layers may be embedded in the design. If employing waveguides or optical fibers, these can be guided with the help of fixating layers that act as filling material between the radiation shielding layers but also ensure a stable positioning of the devices. The layer may be manufactured by injection molding and/or 3D printing but also stamping and other forming tools may be used.

[0051] Any of the radiation protection modules 100 described previously may be comprised in the fabrication of a radiation protection structure 200. Conventional radiation protection walls may be combined with any of the radiation protection modules 100 of the presently claimed invention to form a structure 200 having at least on a part, the advantages provided by the features of the presently claimed invention. Hence, a radiation protection structure 200 may comprise at least one of the radiation protection modules 100 of the presently claimed invention. Likewise, a plurality of any of the radiation protection modules 100 described previously may be

combined and assembled to form a radiation protection structure 200 offering optical transparency throughout the whole structure as illustrated in the example shown by Fig. 6. In general, the radiation protection structure may be suitable for medical, but also non-medical environments such as non-destructive testing. Medical environments include for example, shielding walls in X-ray, computed tomography, magnetic resonance imaging scenarios either in dedicated rooms or in mobile settings where the radiation shielding infrastructure must be adapted. The use of optical fibers as light guiding elements may be advantageous to achieve even more complicated shapes with walls and corners, thanks to their flexibility. Such light guiding elements may also provide light-guiding functionality around curves or even at interfaces from one modular element to the other.

[0052] 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. It is noted that the various embodiments may be combined to achieve further advantageous effects.

[0053] 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.

[0054] A single unit or device may fulfill the functions of several items recited in the claims. 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.

[0055] Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A radiation protection module (100), comprising:

- a first outer surface (10) at one side and a second outer surface (20) at the opposite side wherein the first and second outer surfaces comprise openings (40, 40') in its surfaces, and are separated from each other by a spacing,
- at least one radiation shielding layer (30),
- light guiding elements (50) arranged such that at least one optical path (OP) is formed to guide light from an opening at the first outer surface (40-i), at a location (x_i, y_i) , to an opening at the second outer surface (40'-i), at a location (x'_i, y'_i) , through the at least one radiation shielding layer, and
- wherein the at least one radiation shielding layer and the light guiding elements are embedded within the spacing separating the first and second outer surfaces.

2. The radiation protection module of claim 1 wherein the light guiding elements are arranged such that at

least one optical path is formed to guide light from an opening at the first outer surface to an opening at the second outer surface whose positions at the corresponding outer surface are substantially the same.

3. The radiation protection module of claims 1-2 wherein the light guiding elements are provided by a reflector arrangement (50-1) comprising an input port (51), an output port (52), a first reflective surface (53), and a second reflective surface (54); wherein the first reflective surface is placed to reflect incoming light from the input port to the second reflective surface, which is placed to reflect said incoming light towards the output port.

4. The radiation protection module of claims 1-2 wherein the light guiding elements (50-2) comprise an input (51) and an output (52) port and are configured to confine incoming light from the input port by total internal reflection to be transmitted to the output port (52).

5. The radiation protection module of claims 3-4 comprising:

- at least one layer of light guiding elements (50-L),
- a plurality of radiation shielding layers (30) comprising openings (31) in its surfaces, and separated from each other by a spacing,

wherein within said spacing, a layer of the at least one layer of light guiding elements (50-L) is embedded and arranged to guide light from input to output ports through the openings of the radiation shielding layers, wherein for any consecutive radiation shielding layers (I_i, I_{i+1}) of the plurality of radiation shielding layers, the openings in one of the consecutive radiation shielding layers (I_i) have a substantially uniform offset (D) with respect to the openings in the other consecutive radiation shielding layer (I_{i+1}) such that radiation is substantially blocked by the combined plurality of radiation shielding layers.

6. The radiation protection module of claim 5 wherein the first radiation shielding layer of the plurality of radiation shielding layers is a first outer radiation shielding layer facing the first outer surface of the radiation protection module,

wherein the last radiation shielding layer of the plurality of radiation shielding layers is a second outer radiation shielding layer facing the second outer surface of the radiation protection module, wherein the first and the second outer radiation

shielding layers are in contact with the respective outer surface of the radiation protection module, or

wherein the first and the second outer radiation shielding layers form the respective outer surface of the radiation protection module, or
 wherein either the first or the second outer radiation shielding layer is in contact with the respective outer surface of the radiation protection module and the other outer radiation shielding layer forms the respective outer surface of the radiation protection module.

spectrum, data transmission, power transmission, or a combination thereof.

7. The radiation protection module of claim 4 comprising:

- a plurality of radiation shielding layers (30) comprising openings in its surfaces (31) and separated from each other by a spacing,

- a plurality of light guiding elements (50) laid from an opening at the first outer surface (10), at a location (x_i, y_i) of said first surface, to an opening at the second outer surface (20), at a location (x'_i, y'_i) of said second surface, traversing the plurality of radiation shielding layers through an opening (31- i) at a location (u_i, v_i) in each of its surfaces, wherein the locations of the openings in the surfaces of the plurality of radiation shielding layers have a random or pseudorandom offset with respect to each other such that radiation is substantially blocked by the combination of the plurality of radiation shielding layers.

8. The radiation protection module of claims 1-4 wherein the at least one radiation shielding layer is provided by a wire mesh, a metal grid, or an X-ray absorbing wall containing X-ray absorbing material for instance in the form of particles and/or liquid.

9. The radiation protection module of claims 5-7 wherein the plurality of radiation shielding layers comprises X-ray radiation shielding layers or RF radiation shielding layers or a combination thereof.

10. The radiation protection module of claim 9 wherein the X-ray radiation shielding layers are provided by X-ray absorbing walls containing any one of lead, molybdenum, tungsten, or a combination thereof.

11. The radiation protection module of claim 9 wherein the RF radiation shielding layers are provided by any one of metal grids, wire meshes, interconnected metal foils, or a combination thereof.

12. The radiation protection module of any of the previous claims wherein the light guiding elements comprise at least one optical fiber for any one of the following purposes: transmission of light in the visible

13. A radiation protection structure (200) comprising at least one of the radiation protection modules (100) of any of the previous claims.

14. Use of the radiation protection module (100) of any of claims 1-12 in the fabrication of a radiation protection structure (200).

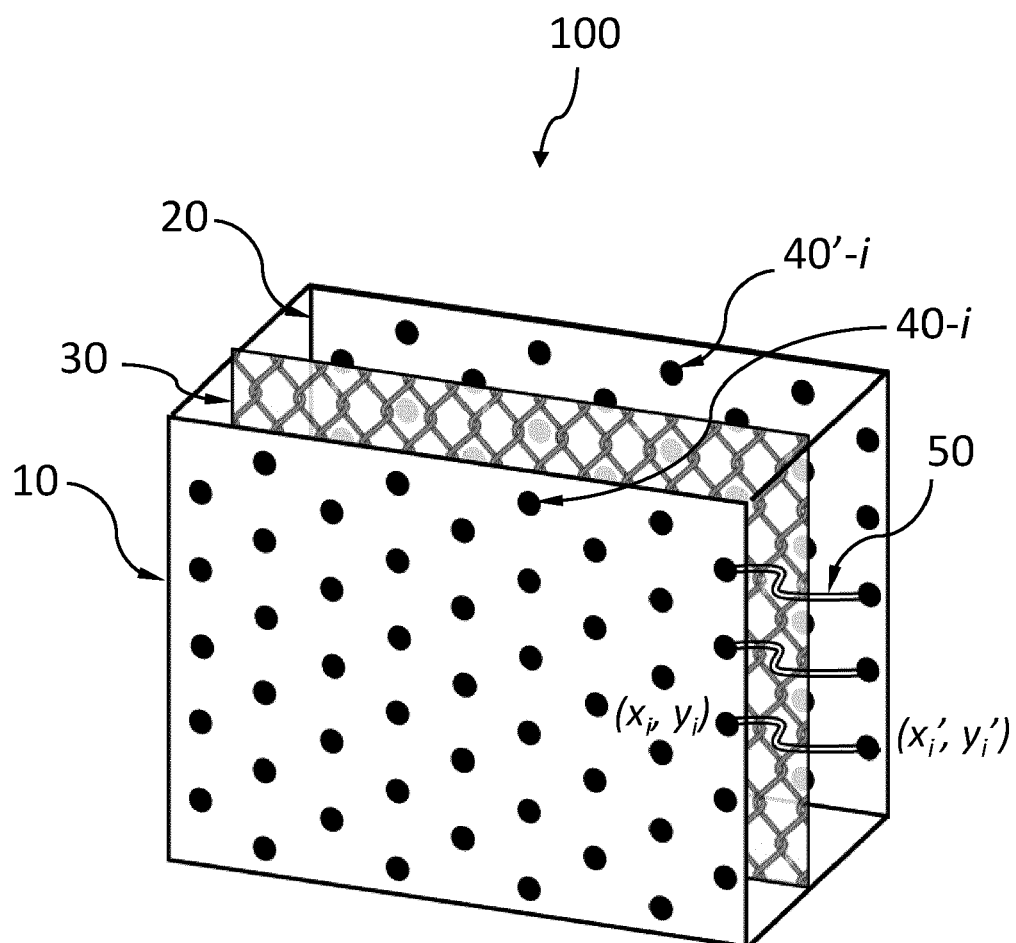


Fig. 1

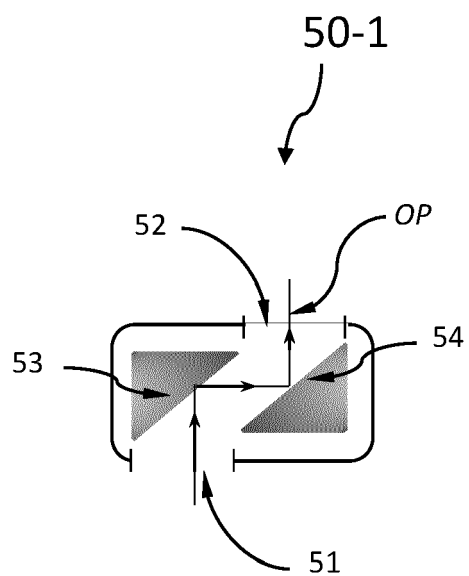


Fig. 2A

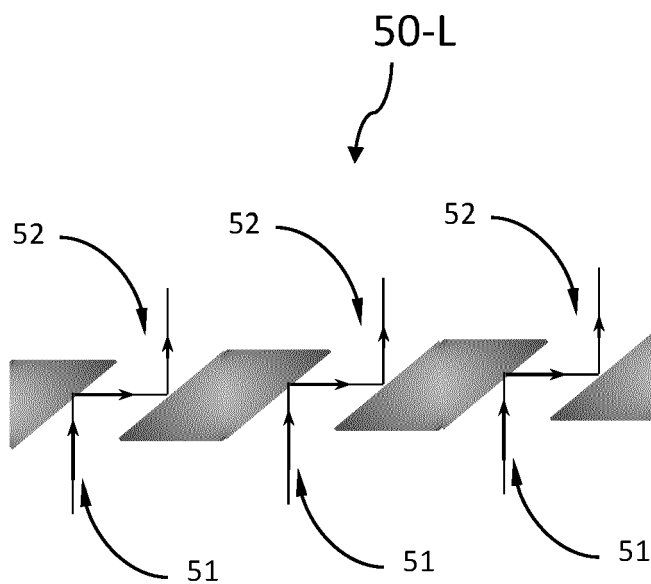


Fig. 2B

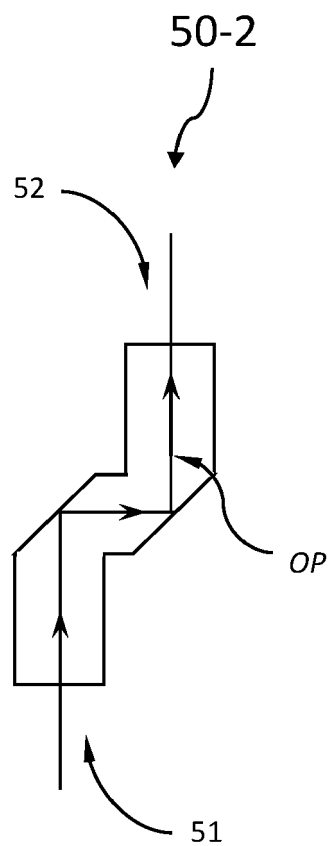


Fig. 3A

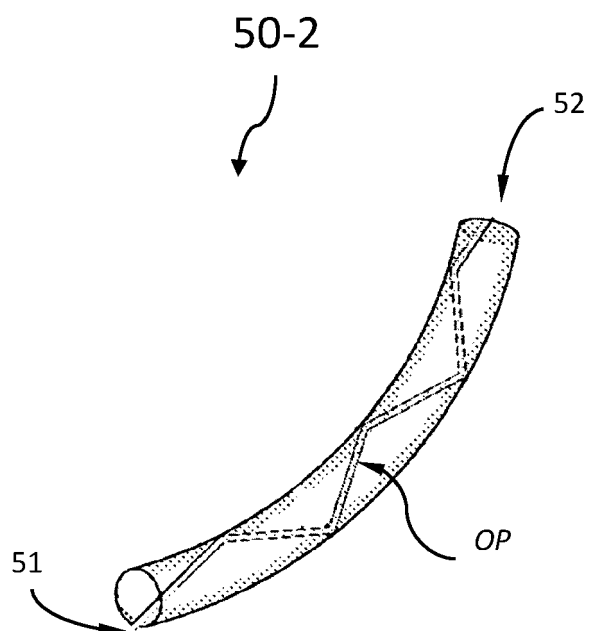


Fig. 3B

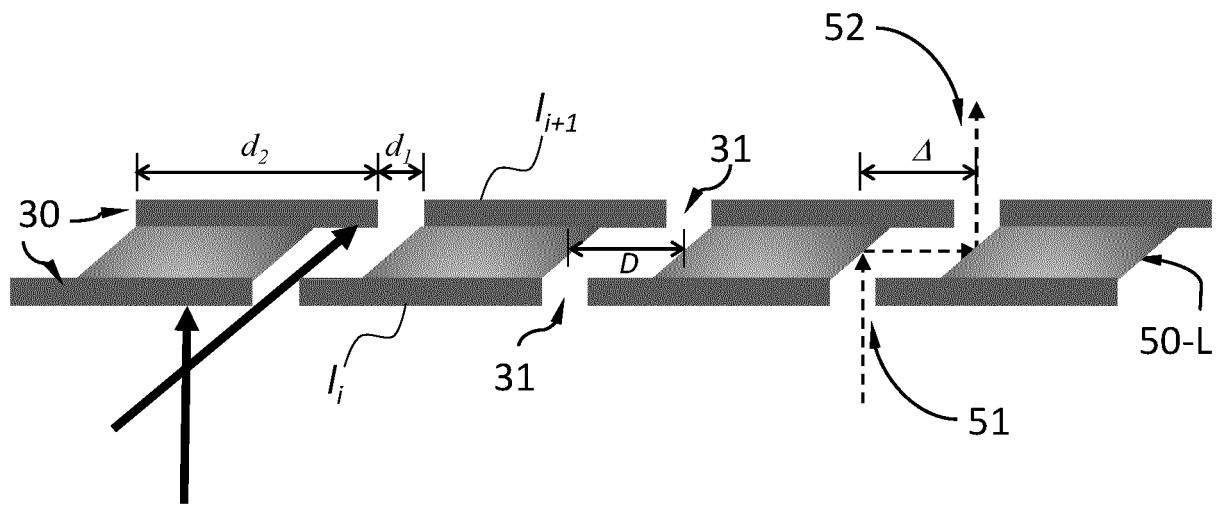


Fig. 4A

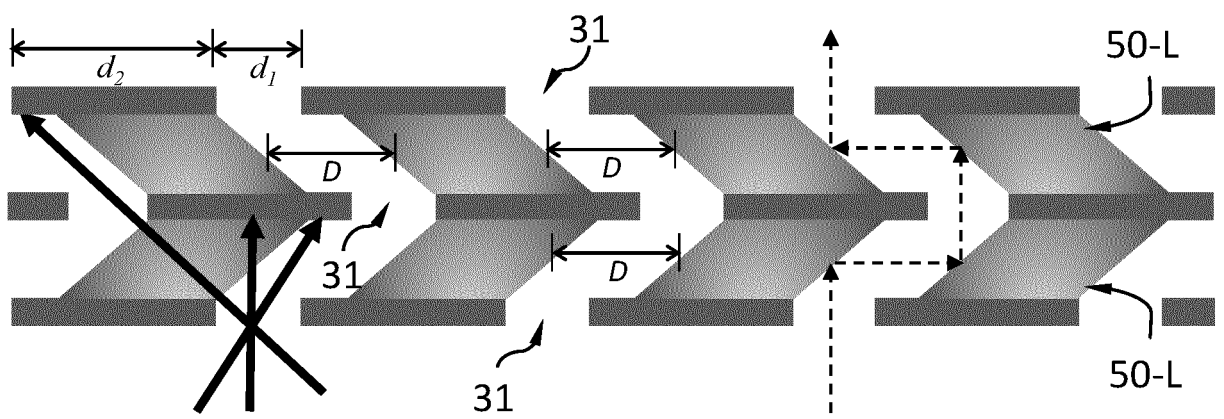


Fig. 4B

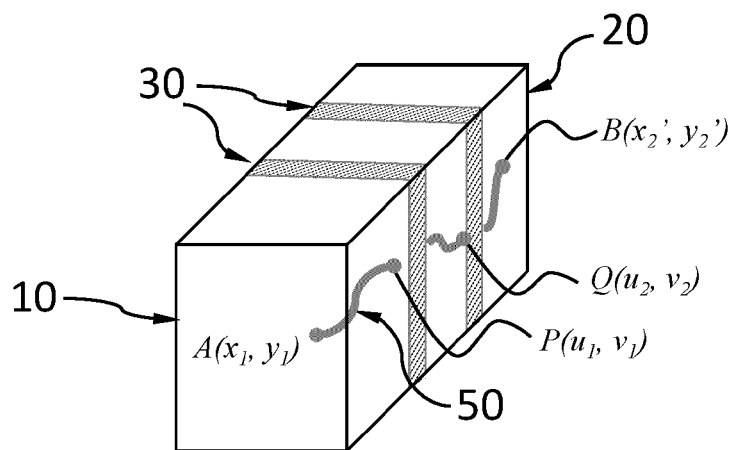


Fig. 5A

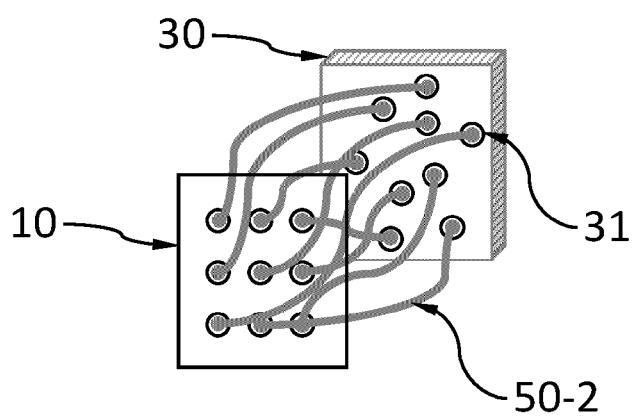


Fig. 5B

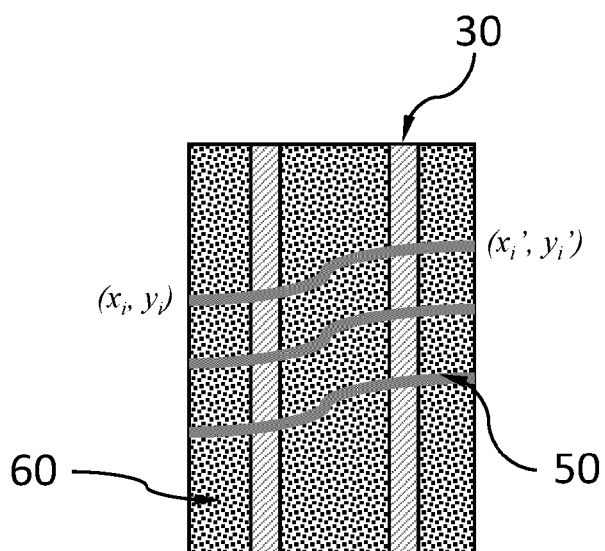


Fig. 5C

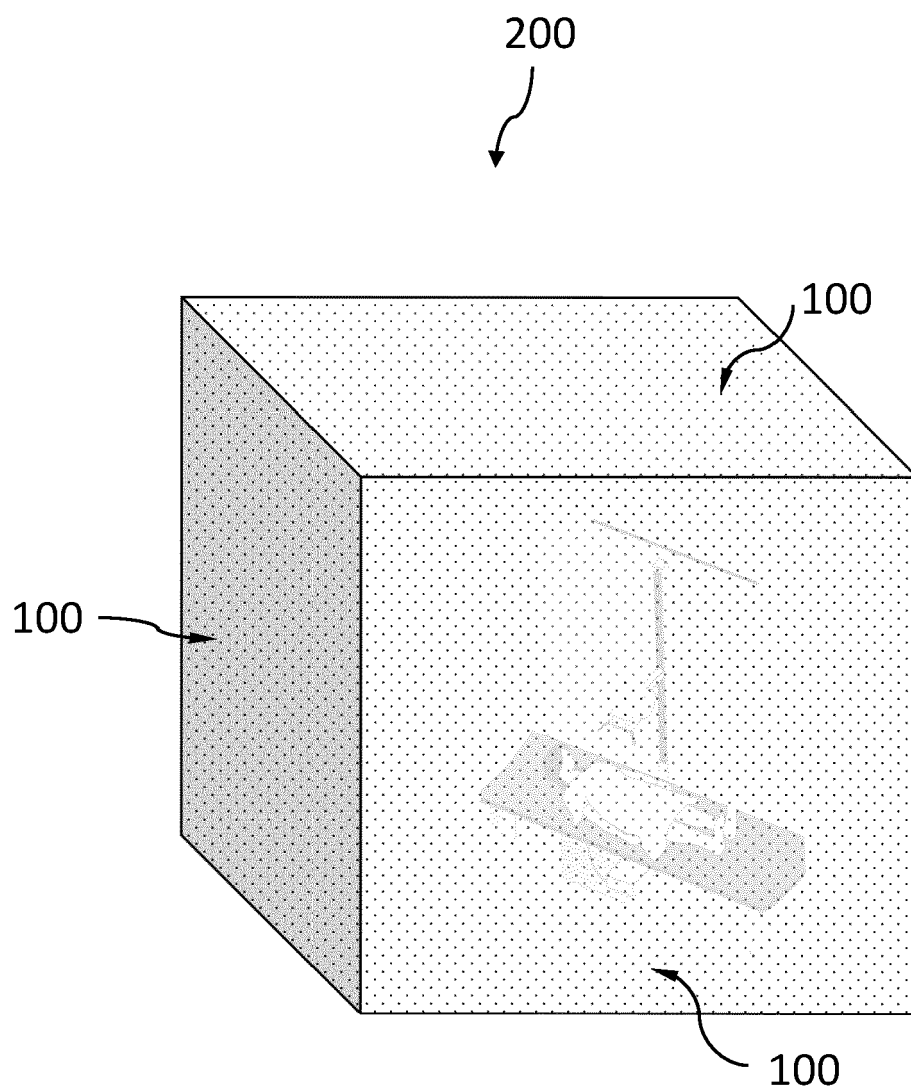


Fig. 6



EUROPEAN SEARCH REPORT

Application Number

EP 23 18 2403

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 A	US 2009/196400 A1 (SCHMITT PETER [DE] ET AL) 6 August 2009 (2009-08-06) * the whole document *	1, 3, 4, 8, 13, 14 5-7, 9-11	INV. G21F3/04 G21F7/02
X	US 6 391 434 B1 (DUCLOS STEVEN JUDE [US]) 21 May 2002 (2002-05-21) * the whole document *	1, 2, 4, 8, 12, 14	
X	FR 3 113 433 B1 (ISORG [FR]) 26 August 2022 (2022-08-26) * the whole document *	1, 13, 14	
			TECHNICAL FIELDS SEARCHED (IPC)
			G21F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 27 October 2023	Examiner Opitz-Coutureau, J
CATEGORY OF CITED DOCUMENTS		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	
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 23 18 2403

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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
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009196400 A1	06-08-2009	US 2009196399 A1	06-08-2009
		US 2009196400 A1	06-08-2009
		US 2010277593 A1	04-11-2010

US 6391434 B1	21-05-2002	DE 10021938 A1	07-12-2000
		JP 2001058881 A	06-03-2001
		US 6391434 B1	21-05-2002
		US 2002102395 A1	01-08-2002

FR 3113433 B1	26-08-2022	CN 217034782 U	22-07-2022
		EP 4196907 A1	21-06-2023
		FR 3113433 A1	18-02-2022
		JP 2023538625 A	08-09-2023
		US 2023298134 A1	21-09-2023
		WO 2022038044 A1	24-02-2022

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