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(71) Applicant *(for all designated States except US)*: **FORIMTECH SA** [CH/CH]; 8, place des Eaux-Vives, CH-1207 Genève (CH).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **GRIGORIEV, Eugene** [CH/CH]; 6, rue de la Dôle, CH-1203 Genève (CH).

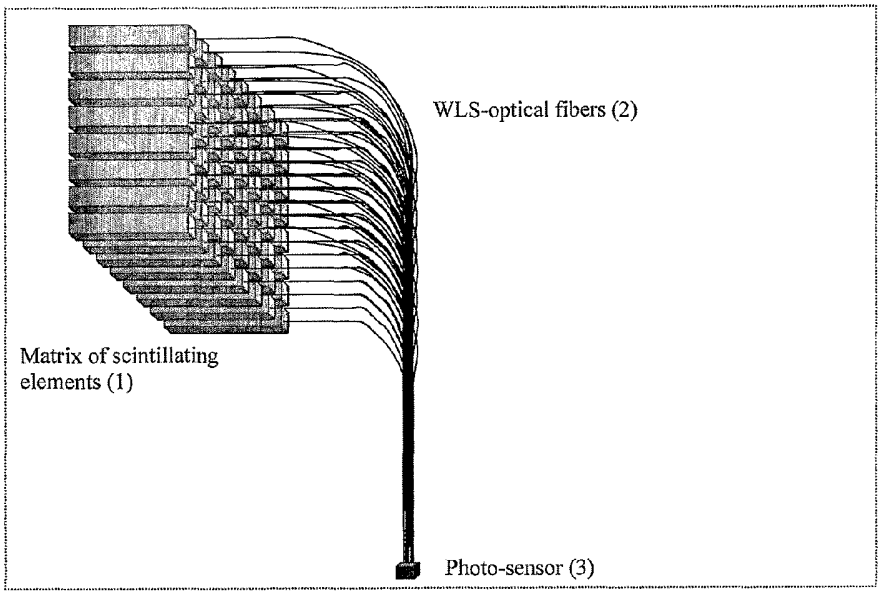
(74) Agent: **ROLAND, André**; c/o André Roland S.A., Avenue Tissot 15, P.O. Box 1255, CH-1001 Lausanne (CH).

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[Continued on next page]

(54) Title: LARGE AREA RADIATION IMAGING DETECTOR



(57) Abstract: Large area detector comprising a plurality of elements made of scintillating material, each of said element being optically coupled to a wavelength-shifting fiber individually coupled to a set of or individual photo-sensitive element of a segmented or monolithic photo-detector.

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Large area radiation imaging detector

Field of the invention

The present invention relates to large area detectors and more precisely to radiation-imaging detectors.

State of the art

Most of modern radiation (x-ray, gamma, neutron, etc.) imaging devices for digital radiography, portal imaging, non-destructive testing, security inspection, are based on amorphous silicon (a-Si) flat-panel, CCD or CMOS pixel photodetectors, coupled to a scintillating screen either directly or through an optical system and usually containing from 10**4 up to 10**7 sensitive elements (pixels). Physical dimensions of these devices are limited by the technology – typically 1-2 cm for CCD, few centimeters (up to 20-30) for CMOS sensors, and up to 40-50 cm for a-Si devices. Although they can reach very high resolution (pixel size down to several microns), it is difficult and expensive to cover large surfaces with such detectors. At the same time, there is a range of applications demanding large-area detectors of moderate cost with modest spatial resolution and high detection efficiency for high-energy x-rays (up to 30 MeV), gammas, neutrons or other penetrating radiation – portal imaging, security and customs inspection of trucks, trains and ships, non-destructive testing of large objects, etc.

The following patent documents disclose different types of detectors commonly used :

US 6167110, GB 2317742, US 5719400, US 5682411.

Most of the existing technologies have the following common feature – the size of the scintillator cell (in which primary x-ray photon or another particle undergoes interaction resulting in emission of visible light) is matching the size of photo-sensor element. Thus, a large-area scintillation detector requires a large-area photo-sensor, which is very expensive if ever feasible. There are two methods commonly used for image reduction: using optical system (mirrors and lenses) or fiber-optical coherent tapers (disclosed in patent WO 9115786). The latter one is very costly, feasible on for relatively small detector areas, the former one has the following drawbacks:

1. Scintillation screen has to be relatively thin in order to maintain reasonable spatial accuracy, therefore the detection efficiency is poor, especially at high energies of irradiating beam;
2. Optical system collects a very small fraction of generated photons of visible light, which are emitted from the screen isotropic in all directions.

Summary of the invention

The present invention is proposing a device and a method for building low-cost large-area radiation-imaging detectors. The main advantage of the invention is that it allows to increase easily the total area of the imager practically without any increase of the cost. Total cost depends merely on the total amount of channels (pixels on the acquired image), moreover, it can even go down with size, since mechanical precision requirements should become less stringent.

The device according to the invention comprises a great amount of relatively large (from several millimeters to several centimeters) blocks of scintillators which are optically coupled to a relatively small-size photo-sensor by means of wave-length shifting fibers embedded in the scintillator blocks.

The use of wave-length shifting fibers for optical connection of scintillating blocks to photo-detectors in radiation imaging devices has been disclosed in the following patents:

WO 95/30910 , US 6 078 052 , US 5 391 878, US 6 459 085, WO 9309447, US 6459085, WO 9423312, US 5783829, US 5281821, EP 0899588 A2, EP 1113291 A1, US 2002/0121604 A1, US 5600144, US 6479829 B1.

These patents disclose several different procedures, all of them having one of the following features: either each wave-length shifting fiber captures light from multiple scintillating elements or many fibers capture light emitted from a single scintillating block. Therefore, these detectors can work only in "single event detection" mode.

The novelty of the present disclosure is that it is for the first time proposed to keep one-to-one correspondence between the radiation-detecting cells and photo-detecting elements, i.e. dedicating one individual fiber to each radiation-sensitive cell and bringing it directly to the photo-sensor in a coherent or non-coherent bundle. In the latter case a decoding using cross-reference table will be required. This device is able to work both in "single event detection" mode and in integration mode, depending on particular application. Coupling the wave-length shifting fiber to one scintillating element allows optimization of layout for better light collection – embedding or enrolling the fiber inside the scintillator cell, external reflective coating, etc.

The device functions as follows :

Scintillation light, which is produced by an x-ray (or another penetrating particle used for imaging) interaction in the whole volume of a single scintillating cell, is captured, concentrated and transported to a small-area photo-detector by means of an individual wave-length-shifting (WLS) fiber. In order to reduce light losses, this fiber can be fused to a transparent optical fiber. Fibers from many cells can be coupled to a single segmented photo-sensor or an array of elementary photo-sensors. It is important that the signals from separate fibers are not mixed, but detected separately, keeping the number of pixels on an image unchanged. Thus, the area of the photo-sensor can be tens or hundreds times smaller that the sensitive area of the imaging detector. Consequently, it can be compact, cheap and fast in respect of time needed for data acquisition and analysis.

The invention permits the construction of detectors with large sensitive area from identical relatively small modules. The modules can be stitched

together to form a uniform detecting surface without any gaps (since they have no edges non-sensitive to radiation). Each module can have its independent relatively small and cheap segmented photo-sensor; therefore many modules can acquire and process data in parallel.

The usual method of imaging large-volume or large-area objects by means of penetrating radiation consists in scanning by a "flat" beam and an array of radiation detectors, as disclosed in patents:
US 3979592, US 6542580, WO 03021243, US 5917880.
This procedure is time-consuming and dose not provide a single-shot picture of an object.

Imaging by penetrating radiation using remote large-area detectors has the following advantages:

1. The whole large object can be pictured at once, without scanning, therefore the image is always sharp and instant even for moving objects,

2. Imaging detector can be placed at a large distance from the radiation source and from the object under study. This can be helpful for monitoring large volumes, such as access gates, checkpoints, etc. This not only facilitates the inspection process, but improves signal/noise ratio: at high energies, which are needed for imaging of thick targets, scattering processes in the target are very significant. Scattered particles are detected by the imager along with the primary ones, obscuring the image of the object. Since the scattered background is originating from the object, from merely geometrical considerations

the signal/noise ratio (which determines the quality of the image) improves with distance. Therefore, it is better to place the detector as far as possible from the object. At the same time, it is not necessary to increase the number of pixels (keeping spatial resolution constant), therefore the absolute size of a single detector cell grows with distance (and respectively the total area of the detector). Thus, macroscopic mechanical technology replaces microscopic one and significantly reduces production costs. It should be pointed out that for better signal/noise ratio the radiation should be emitted in pulses of shortest possible duration and highest possible intensity.

Detailed description of the invention

The following detailed description discusses some embodiments of the invention. It should be noted that the invention is not limited to those embodiments.

The following figures are used to better illustrate the invention :

Figure 1 shows a basic element (scintillator with optically coupled WLS fiber).

Figure 2 shows a first example of a detector according to the invention.

Figure 3 shows the construction of a monolithic module (only part of fibers shown completely)

There can be two basic options in construction of a module as defined previously.

Option 1

Each module is built of a certain number of identical basic elements. A basic element is shown schematically in Figure 1.

The element consists of a piece of scintillating material and a WLS fiber, embedded or optically coupled to it. The scintillator can have a shape of a hexagonal or square cylinder or pyramid, so that in an assembly the axes of all elements in a module (and in the whole imager) are directed to the focal point of the imaging beam. All external surfaces of the element should be painted with reflective material – to reflect light backwards into the scintillator and to eliminate cross-talks between elements. It can be also covered with a thin layer of a high-Z material in order to enhance conversion efficiency for x-rays, or another material enhancing interaction probability for neutrons (in neutron imaging). The light-collecting end of the WLS fiber should be also painted on its edge with reflective paint to enhance light collection.

A group of such elements assembled together will compose a module, which can be easily handled and combined with other modules. All fibers of a module can be assembled on the free end into a block polished on the edge and optically coupled to a segmented photo-detector, for example a CCD, or CMOS sensor, a hybrid photo-detector or a matrix of APDs, as shown in Figure 2.

One can see that the large imaging area (area which detects imaging particles) is converged to a much smaller area of the photo-detector. The bundle of fibers can be assembled either in a coherent way, in this case there should be one-to-one correspondence between the detected and optically recorded images, or randomly, in the latter case a mapping procedure would be needed to provide a one-to-one correspondence table between the detector scintillating elements and photo-detector cells.

Each fiber can be also optically coupled to an individual APD or another non-integrating photo-detector. In this case, each individual interaction can be detected, enabling large flexibility in fast signal analysis and background rejection.

Option 2

Each module is fabricated as a whole, as shown in Figure 3. It consists either of a plate of scintillator with gooves or holes for embedding WLS fibers, or a cuvette filled with liquid scintillator. The readout of fibers is done in the same way as described in Option 1. The scintillator can be loaded with particles of another material to enhance interactions of imaging particles (any high-Z material for x-gay or gamma-imaging, Gd or Boron, or another material with good neutron-capture properties – for neutron imaging). Thin sheets of solid or liquid scintillator can be also interspaced with plates of materials enhancing interaction probability. Light, produced in the scintillator, will be predominantly captured by the adjacent fibers. But the image quality can be enhanced by placing inter-fiber reflective separators.

They can be also made of material which enhance interaction probability for imaging beam.

Examples of implementation.

Technological implementation of the proposed method can be rather simple, allowing automated production of modules in large quantities. For Option 1 (illustrated by Figs.1-2) the manufacturing can be organized in three steps:

1. Fabrication of the basic element of the system, which consists of a piece of a wavelength-shifting fiber (WLSF) embedded in or optically coupled to a piece of scintillating material on one end, and painted (to prevent cross-talks and create some spacing for better separation between fibers on the image) on the other end. This can be done in several ways, for example - a high-Z ceramic scintillator (doped Gd2O2S) dissolved in a polyurethane substrate (commercial name is LANEX, trademark of KODAK) is deposed on one end of the fiber in a shape of a hexagonal or square cylinder or a truncated pyramid (diameter - several mm, length – up to several cm) and covered with a reflective paint on the outer surface. In another method, the end of the fiber is inserted in the inner hole of the same diameter of a piece of a plastic or inorganic scintillator, or a glass tube of similar shape and with dimensions as above, made of a heavy doped scintillating glass or another scintillating material, and covered by a reflective paint on the outer surface. In the easiest solution, the fiber can be just simply

glued on the surface of a piece of scintillator, and this assembly wrapped in a sheet of reflective material.

2. A certain amount of such elements are assembled together to constitute a module in such a way that all free ends of the fibers are assembled in a bundle, the area of which is well matching the area of the photo-sensor.
3. An imaging detector can be built-up from any amount of modules, which are driven in parallel by a common control and data-acquisition system.

The described technology allows easily to produce detection elements of any required thickness in the direction along the x-ray (or another particle) beam, ensuring high detection efficiency at any particular energy of the beam. This is a critical issue at high (MeV) energies generally required for imaging of thick objects. It also allows to assemble the imaging detector in an spherical geometry, with all individual elements pointed towards the focal point of the radiation source.

Depending on particular application and layout, the photo-sensor can be a CCD, CMOS sensor, hybrid photo-detector, or a matrix of avalanche photodiodes. In the latter case registration of individual hits is possible with a selectable cut on the pulse-height in every individual interaction. Therefore, one can select only events with high energy deposition, and in such a way to make the setup 'blind' to scattered background (which is a major problem at high energies). Moreover, such detector will serve at the same time as a very sensitive radiation monitor.

The following table provides an example of the light output and collection efficiency which may be obtained with the present invention :

	MIP in a plastic scintillator tile 50x50x5 mm3, fiber 1mm x 150mm (collection length)	1 MeV gamma in a Gd2O2S cell 3x3x20 mm3, fiber 0.2 mm x 20 mm (collection length)
Ratio external surface / fiber surface	6000 / 471 = 12.74	240 / 12.6 = 19.05
Quantum efficiency of the photodetector	30%	60%
Number of photons produced	~15 000	~30 000
Number of photons detected by the photosensor (per interaction)	13	Expected 13*2*12.7/19*2= 35

It should be noted that the quality of an image in x-ray imaging is intrinsically determined by the statistics of x-ray interacting in the sensor. Therefore, the minimal requirement for the signal detection and readout channel is that any statistical fluctuations should be much (roughly by a factor of 10) below the statistical fluctuations in the main process. In practice this means that ~10 photoelectrons should be produced in the

photodetector per one gamma interacting in the sensor. As one can see, the proposed layout is on the safe side from this point of view – 1 MeV gamma interacting in a cell is expected to give about 35 photoelectrons in the photosensor.

Examples of applications

The invention can be used in any imaging or dose-mapping device, which requires moderate resolution and large area coverage at relatively low cost. These devices can be used for:

- transmission imaging using x-rays, neutrons or any other penetrating particles, of large volumes in air, road or naval transport customs and security services;
- non-destructive industrial tests of large objects;
- portal imaging in radiotherapy;
- 2- or 3-dimensional dose mapping in radiotherapy.

In the latter case the detector can be made of an organic scintillator and organic WLS fibers, thus it be absolutely tissue-equivalent in the whole volume and easily embedded into tissue-equivalent phantom, photo-detectors being positioned outside.

Claims

1. A large area detector comprising a plurality of elements made of scintillating material, each of said element being optically coupled to a wavelength-shifting fiber individually coupled to a set of or individual photo-sensitive element of a segmented or monolithic photo-detector.

2. The device of Claim 1 wherein said elements are joined together into a single block.

3. The device of Claim 1 wherein each of said wavelength-shifting fiber is designed in such a way that the photons of light generated inside the scintillating material due to interaction of a particle from the external beam are partially captured said fiber, converted to photons with higher wavelength and transmitted along said fiber to the photo-detector.

4. The device of Claim 1, wherein the surface of each detecting element, sensitive to incoming radiation, is larger than the output surface of the fiber optically coupled to photo-sensor, thus resulting in a considerable reduction of the total area of the image, keeping constant spatial resolution (the amount of pixels on the image).

5. The device of Claim 1, wherein each wave-length shifting fiber is optically coupled to an optical fiber of close diameter, which in its turn is optically coupled to the photo-sensor.

6. The device of Claim 1, wherein the scintillating material is doped or loaded with pieces of material, which enhance probability of interaction of the particles from the irradiating beam inside the scintillating elements.

7. The device of Claim 1, wherein the photo-detector is a segmented CMOS photo-sensor or a CCD, or another segmented photo-sensor operating in charge-integrating mode.

8. The device of Claim 1, wherein the photo-detector is a hybrid photo-detector, or a matrix of avalanche photodiodes, or a set of individual avalanche photodiodes operating in single-event detection mode.

9. The device of Claim 1 wherein the scintillating material is a solid organic or inorganic, or ceramic scintillator, or a liquid scintillator contained in a sealed enclosure.

10. Use of the device according to anyone of the previous claims for the inspection of large sized objects such as trucks, trains or ships.

11. Use of the device according to anyone of the previous claims 1 to 9 for 2- or 3-dimensional dose-mapping and portal imaging in radiation therapy.

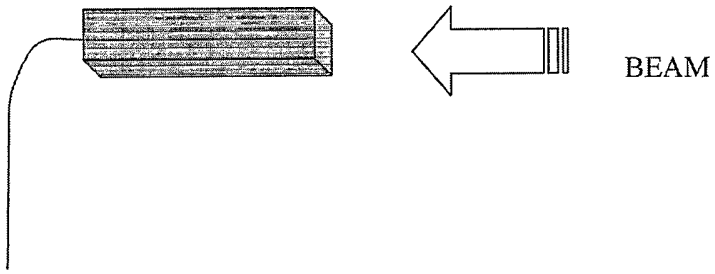


Fig. 1

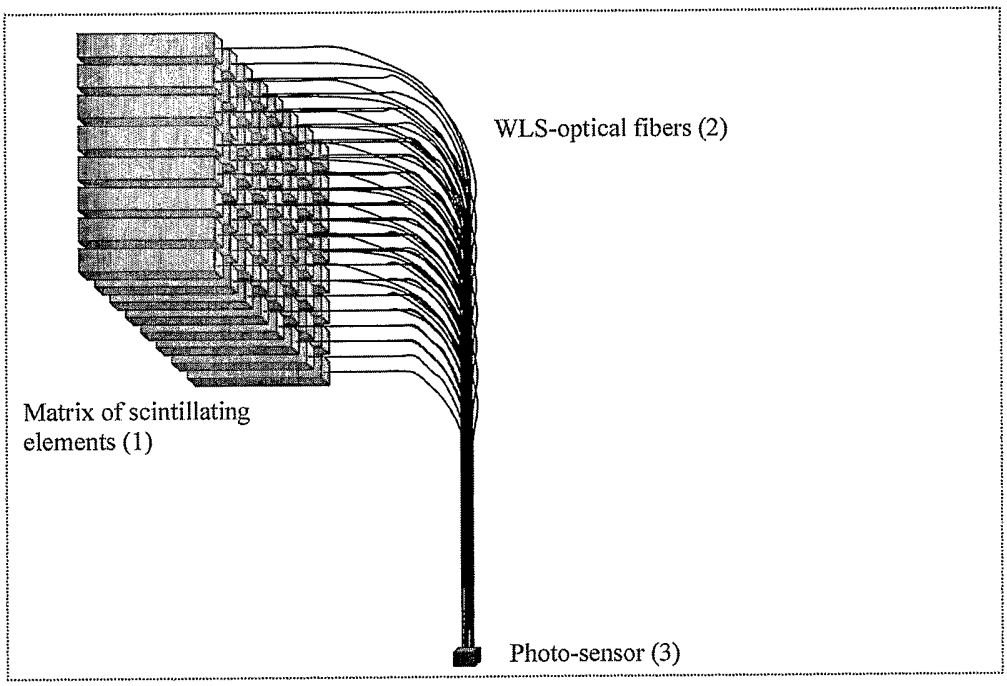

WLS-optical fibers (2)
Matrix of scintillating elements (1)
Photo-sensor (3)

Fig. 2

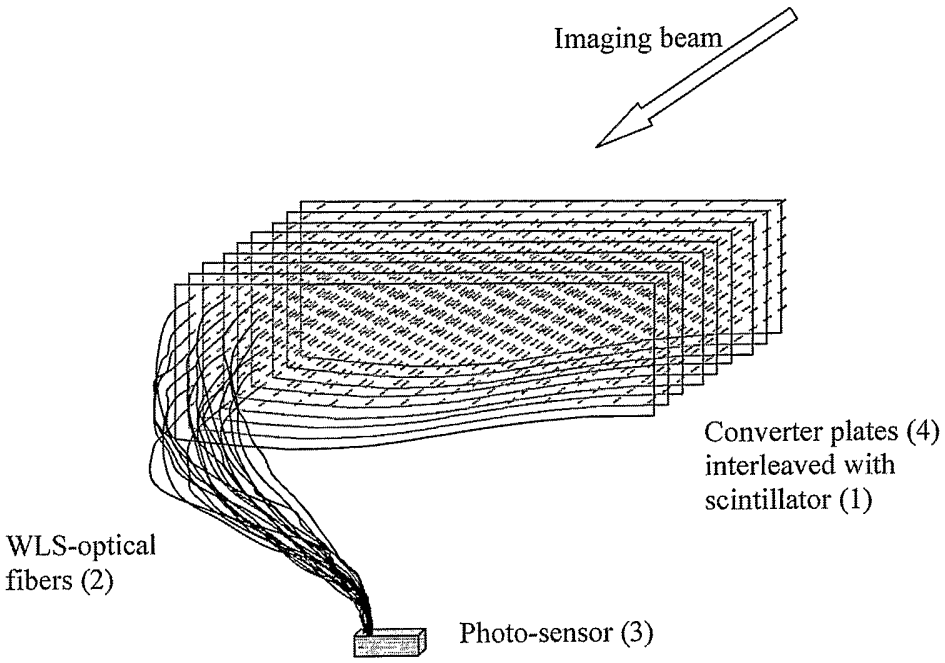

Imaging beam
Converter plates (4)
interleaved with
scintillator (1)
WLS-optical
fibers (2)
Photo-sensor (3)

Fig. 3

INTERNATIONAL SEARCH REPORT

In :ional Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01T1/20 G01V5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01T G01V

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	column 10, line 61 - line 64 column 7, line 42 - line 45	5
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Y	column 6, line 35 - line 43	5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 August 2005	30/08/2005

Name and mailing address of the ISA	Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

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