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(54) Title: CAMERA FOR RADIATION

(57) Abstract: The invention relates to a camera for producing an image of an object by use of radiation. The camera comprises a position-sensitive light sensor and light conductor elements manufactured form scintillator material. According to the invention, a part of the light conductor elements is positioned at an angle of less than 90° relative to the surface of the light sensor. In this manner, with the camera according to the invention an increased resolution can be achieved without loss of sensitivity.

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Title: Camera for radiation

The present invention relates to a camera for producing an image of an object on the basis of radiation such as X-ray radiation or gamma radiation coming from the object, which camera comprises a position-sensitive light sensor unit and at least one group of light conductor elements, the light conductor elements comprising a material for converting the radiation into light to which the light sensor unit is sensitive, and the group of light conductor elements being arranged for conducting the light to the light sensor unit.

Such a camera is known in the art. For instance, Nagarkar V.V. et al. (IEEE Transactions on Nuclear Science (1996), 43(3), pp. 1559-63) describe the manufacture of image sensors with a large surface, for imaging applications using X-ray radiation. As a material for converting radiation into light, CsI(Tl) scintillators with a surface of 15 x 15 cm are used. The scintillating material consists of a 2,000 µm-thick film with columnar crystals by means of which a high spatial resolution is achieved compared to other techniques, in that lateral spread of scintillation light is suppressed.

The radiation coming from the object can be radiation emitted by the object itself (emission; typically gamma radiation) as well as radiation from a radiation source radiating through the object (transmission; typically X-ray radiation).

It is an object of the present invention to provide a camera with an improved sensitivity and imaging resolution.

For this purpose, the camera according to the invention is characterized in that the light conductor elements each comprise a light conducting path along which, in use, the light is conducted to the light sensor unit, while a plurality of the light conducting paths at least partly
diverge relative to each other in a direction towards the light sensor unit, while the light conductor elements forming the diverging light conducting paths are provided with ends which are located at the sides of the light conductor elements proximal to the light sensor unit and which ends are two-dimensionally distributed in a surface.

Thus, without loss of sensitivity, an improved resolution is achieved. This is because a beam of photons of the radiation will generally diverge in a direction towards the camera so that such a beam will generate relatively much light in one of the light conductor elements and will generate relatively little or no light in neighboring light conductor elements.

In particular, a plurality of the light conductor elements of the group of light conductor elements at least partly diverge in a longitudinal direction of the light conductor elements and in a direction towards the light sensor unit.

In particular, at the sides of these light conductor elements proximal to the light sensor unit, the ends of these light conductor elements form a two-dimensional pattern. Further, in particular, the surface is a surface of the light sensor unit where the light of the light conductor elements enters. The ends of the group of light conductor elements can thus form a two-dimensional array. A two-dimensional array or pattern can have any shape, but will generally be round, rectangular or square. At least the outer light conductor elements, i.e. the light conductor elements located at a largest possible distance from each other, preferably include an angle with a surface of the light sensor unit where the light enters which is smaller than 90°. Here, this surface is understood to be flat. The actual angle can, preferably, vary gradually and will generally be larger than 60°. If use is made of a number of one-dimensional arrays of light conductor elements, an array can be positioned as a whole at an angle with another array in order to have the light conductor elements make an acute angle with each other at the object side. Here, within an array with a one-dimensional array, the
outer light conductor elements are preferably also at such an acute angle with each other. The light sensor unit is, for instance, a flat light sensor. The term "radiation" comprises any form of radiation which requires conversion into light with a wavelength detectable for the light sensor, and in particular gamma radiation and X-ray radiation.

Preferably, the positioning pattern of the light conductor elements is a two-dimensional fan shape.

A two-dimensional fan shape is understood to mean that the light conductor elements, whose ends form a two-dimensional pattern, all point to one point (located outside the surface of the two-dimensional pattern). Thus, over the whole light sensor surface served by the light conductor elements, an optimal resolution is ensured.

According to a preferred embodiment, the camera possesses an element manufactured from material which blocks radiation, the element is provided with an opening for transmitting radiation, and the light conductor elements are directed towards the opening.

The opening will typically be a pinhole, and in that case, the positioning pattern of the light conductor elements is preferably such that all light conductor elements are directed towards one point (the pinhole).

The opening can also have the form of an elongated bore, in which case the light conductor elements point to the respective bore and are preferably substantially uniformly grouped around the center line of the bore.

According to a preferred embodiment, the element possesses a plurality of openings in the form of bores, which bores together form a converging collimator.

By the use of multiple openings, for instance in the form of channels, which are also referred to as bores, a collimator is provided which contributes to imaging and a highest possible radiation sensitivity. The converging collimator is preferably a fan-beam collimator or a cone-beam collimator. Then, each of the light conductor elements can be at least partly
aligned with one of the bores. Each bore then preferably corresponds with at least one light conductor element aligned with the respective bore.

It is noted that, in the case that multiple openings are used, for instance in the form of pinholes, for instance, also, multiple groups of light conductor elements can be distinguished, with each opening serving at least one group of light conductor elements of its own. The light conductor elements of this group or these groups of its own are thus directed towards that respective opening as set out hereinabove.

Preferably, the position-sensitive light sensor unit is provided with a sensor array.

Such an array is, for instance, formed by a CCD, optionally with an electronic image amplifier positioned before it. Also, optionally, a position-sensitive photo multiplier tube can be used.

If desired, at the light sensor unit side, the light conductor elements are provided with a thin layer which can convert radiation into light to which the light sensor is sensitive.

This thin scintillator layer contributes to the light output without compromising the resolution.

The invention further relates to methods for manufacturing an oriented plurality of light conductor elements for a camera for producing an image of an object. A possible method is characterized in that a stack of parallel light conductor elements is contacted with a surface provided with a relief pattern, chosen from a one-dimensional and a two-dimensional relief pattern, the surface being positioned at an angle relative to the longitudinal axis of one of the light conductor elements, such that proximal ends of the light conductor elements fall into successive recesses of the profile surface, after which the angle between the profile surface and a centrally located light conductor element can be set at approximately 90°.

Thus, in a simple and efficient manner, light conductor elements can be positioned at an angle of less than 90° relative to the surface of the light
sensor unit (or a scintillator layer present thereon). A one-dimensional pattern is particularly suitable for the manufacture of a fan-shaped group (one-dimensional or two-dimensional) of light conductor elements. The two-dimensional pattern is particularly suitable for the manufacture of a group of light conductor elements with ends ordered according to a two-dimensional array, which light conductor elements are disposed with the above-described two-dimensional fan-shaped positioning pattern.

The invention also relates to an apparatus for producing an image of an object, which apparatus possesses a radiation source and a camera and the object can be positioned between the radiation source and the camera, the camera being a camera according to the invention.

Thus, an apparatus is provided where the object itself does not need to emit radiation (for instance radioactive radiation as coming from the decay of $^{99m}$Tc), but use can be made of a radiation source, such as X-ray radiation or a radioactive point source. Then, this radiation source is actually part of the camera.

The radiation source and/or the (rest of the) camera (excluding radiation source) can be disposed movably and/or rotatably relative to each other, as is known per se, for producing tomographic images. It is also possible for the radiation source and/or the (rest of the) camera (excluding radiation source) on the one hand and the object on the other hand to be disposed movably relative to each other.

Preferably, the light conductor elements are directed towards the radiation source.

Thus, if no use is made of an element manufactured from material which blocks radiation and is provided with one or more openings for transmitting radiation, an optimal capture of radiation is achieved.

The invention will now be elucidated on the basis of the following exemplary embodiment and with reference to the drawing, in which:
Fig. 1a shows a side elevational view of a possible embodiment of a camera according to the invention;

Fig. 1b shows a side elevational view of the camera of Fig. 1a in the direction of arrow P;

Fig. 1c shows a top plan view in the direction of arrow Q of Fig. 1a of ends of the light conductor elements;

Fig. 1d and Fig. 1e show an alternative possibility for a relative ordering of the ends of the light conductor elements of Fig. 1a;

Fig. 2 shows a second possible embodiment of a camera according to the invention;

Fig. 3 shows a third possible embodiment of a camera according to the invention;

Fig. 4 shows a fourth possible embodiment of a camera according to the invention;

Fig. 5 shows a fifth possible embodiment of a camera according to the invention;

Fig. 6 shows a sixth possible embodiment of a camera according to the invention;

Fig. 7 shows a seventh possible embodiment of a camera according to the invention;

Figs. 8a and 8b show a possible method for manufacturing a group of light conductor elements according to the invention;

Figs. 9a and 9b show a second possible method for manufacturing a group of light conductor elements according to the invention;

Figs. 10a to 10c show a third possible method for manufacturing a group of light conductor elements according to the invention;

Fig. 11 shows an eighth possible embodiment of a camera according to the invention; and

Figs. 12a and 12b show a camera known per se not according to the invention.
In Fig. 1, a camera for producing an image of an object 3 according to the invention is designated by reference numeral 1. The object is, for instance, a part of a human body emitting gamma and/or X-ray radiation. For this purpose, a radioactive material known per se which emits gamma radiation can have been administered to the body. The camera 1 is provided with a position-sensitive light sensor unit 2 and a group 4 of light conductor elements 6, which group comprises a plurality of light conductor elements 6. In this example, the light conductor elements have an elongated design. The light conductor elements comprise a material which conducts light. Also, the light conductor elements comprise a material for converting radiation into light to which the light sensor unit 2 is sensitive. The two materials can be one and the same material. The respective radiation can, for instance, be X-ray radiation and/or gamma radiation. As a material for converting radiation into light, use can made of, for instance, CsI(Tl). This material can be included in as well as on the light conducting material. In the latter case, it may be a coating. For instance, the material for converting the radiation into light can be applied on the outer side of, for instance, an elongated body. Also, this material can, at the same time, be the light conducting material.

The group of light conductor elements 6 is arranged for conducting the light generated to the light sensor. The group 4 of light conductor elements is provided with a number of light conductor elements each comprising a light conducting path along which, in use, light is conducted to the light sensor unit. In this example, the light conductor elements each have a rod-shaped design. In this example, an axial axis of a light conductor element, on the whole, at least substantially coincides with a light conducting path of a light conductor element. This is inter alia related to the fact that, in the example, each light conductor element is designed so as to be mirror-symmetrical in relation to its axial axis. If this were not the case, locally, the light conducting path of a light conductor element could slightly
deviate from the axial axis of the light conductor element. However, on average, the axial axis will coincide with the light conducting path of the light conductor element over the whole length of the light conductor element since the light conductor element in this example has an elongated design.

In this example, the group 4 is provided with light conductor elements each comprising a light conducting path along which, in use, the light is conducted to the light sensor unit, while a plurality of the light conducting paths, in this example each of the light conducting paths, diverge, at least partly, relative to each other in a direction towards the light sensor unit. In this example, in fact, the light conducting paths of all light conductor elements of the group 4 diverge relative to each other over their whole length in a direction towards the light sensor unit 2. Neighboring light conductor elements include an angle $\alpha$ which is preferably acute. Non-neighboring light conductor elements can include an angle $\beta$ which may be acute as well as obtuse.

In this example, the light conductor elements diverge, at least partly, away from each other in a longitudinal direction of the light conductor elements and in a direction of the light sensor unit. This is caused by the fact that the light conducting paths coincide with the longitudinal direction of the light conductor elements.

Because the light conductor elements in this example each have a straight design (not bent), in addition, the light conductor elements diverge, at least virtually wholly (i.e. at least virtually over their whole length), in a longitudinal direction of the light conductor elements and in a direction towards the light sensor unit.

The ends 24 of the light conductor elements are located in a surface 26 which is flat in this example. These ends are located at sides of the light conductor elements proximal to the light sensor unit and are two-dimensionally distributed in the surface 26. So, the light conductor elements forming the diverging light conducting paths are provided with
ends located at the sides of the light conductor elements proximal to the light sensor unit. Also, in this example, the ends of these light conductor elements at the sides of the light conductor elements proximal to the light sensor unit form a two-dimensional pattern. In this example, these ends form a two-dimensional array (matrix form). In this example, Fig. 1c shows a top plan view of this matrix form. In this example, the camera is further provided with an element 8 comprising a material such as lead which blocks the radiation. The element 8 is provided with at least one opening 10, in this example a pinhole, for transmitting X-ray radiation and/or gamma radiation 12 coming from the (measuring) object 3 and of which an image is to be produced. The light conductor elements extend between the at least one opening and the light sensor. So, in this example, the light conductor elements of the group 4 converge in a direction from the light sensor unit 2 towards the opening 10. More in particular, the light conductor elements of the group are each directed in a direction of the opening 10. In this example, the element 8 has a plate-shaped design and comprises a first side 14 and a second side 16. The light sensor unit 2 and the group 4 are located at the second side 16. The photons of the X-ray radiation and/or gamma radiation by means of which an image is to be produced propagate at the first side 14 in the direction of the opening 10. A fraction of the photons is transmitted through the opening and form a diverging beam 20 at the side 16. This beam 20 will, at least substantially, extend in line with the light conductor elements. The beam 20 can imaginarily be divided into sub-beams 21, with a sub-beam extending in line with each one of the light conductor elements. As a result, such a sub-beam 21 will, at least substantially, generate light in one of the light conductor elements. This yields an increased resolution.

All this can best be seen with reference to a camera which is not designed according to the invention. Here, the parts corresponding to Fig. 1 have identical reference numerals. As can be seen, with the camera according to Fig. 12, the sub-beam 21 will pass a large number of light
conductor elements 6. This beam will generate light in each of these light
conductor elements 6. Each light conductor element will then conduct this
light to the light sensor unit 2. Then, the sub-beam 21 will generate an
image signal in an area of the light sensor unit 2, designated by reference
numeral 22 in Fig. 12. This area is relatively large, which results in a poor
resolution. In Fig. 1a and Fig. 1b, the corresponding area is designated 22',
which area is much smaller than the area 22. All this is caused by the fact
that the light conducting paths of the light conductor elements diverge, at
least partly, relative to each other in a direction towards the light sensor
unit. It is noted that Fig. 1 diagrammatically shows only a small number of
light conductor elements. Depending on the thickness (diameter) of the light
conductor elements, there may be many more of them. In Fig. 1, the outer
surface 26 of the light sensor unit 2 where the light enters has a flat design.
As a result, most light conductor elements are directed in a direction which
deviates from the normal 32 to the surface 26 (with the exception of the
middle light conductor element of the group 4). The angle $\phi$ made relative to
the normal is thus generally larger than 0° and the angle 90° - $\phi$ which a
light conductor element makes with the surface 26 near the surface 26 is
thus generally smaller than 90°. In other words, most of the light conductor
elements are positioned at an angle of less than 90° relative to the surface of
the light sensor unit. In addition, the light conductor elements make
angles $\alpha$ with each other at the object side 14, the largest angle $\alpha$, in Fig. 1a
designated as $\beta$, in particular, being smaller than 60°. However, this last is
not requisite. So, at the object side, the light conductor elements include an
angle $\beta$ which is smaller than 180°.

Fig. 2 shows a second embodiment of a camera according to the
invention. Here, parts corresponding to Fig. 1 are designated by the same
reference numerals.

In Fig. 2, the ends 24 are also ordered relative to each other according
to a two-dimensional array, as shown in Fig. 1c. A side elevational view in
the direction of arrow P of Fig. 2 would result in a Figure according to Fig. 2
(it is already noted here that such a note also applies to Figs. 3-7 and 11). In
Fig. 2, the light conductor elements do not have a straight, but a slightly
bent design. The result of this is that a resolution is obtained which is better
than discussed with reference to Fig. 12, but slightly poorer than discussed
with reference to Fig. 1. This is because, also in this example, the greater
part of the radiation will generate light in just one of the light conductor
elements and to a much lesser extent in other, neighboring light conductor
elements. This is because the greater part of the radiation which is
converted into light is converted into light in the upper part 41 of the light
conductor elements, whereas the density of the light conductor elements in
a lower part 43 of the light conductor elements is smaller than in the upper
part 41.

A similar note applies to the camera of Fig. 3. Here, an upper part 30
of the light conductor elements corresponds to a great extent to the light
conductor elements of Fig. 1a with respect to their orientation relative to
each other. In Fig. 3, the ends 24 are also ordered relative to each other
according to a two-dimensional array as shown in Fig. 1c. The major part of
the light generated by the radiation is generated in the part 30 of the light
conductor elements and this results in a high resolution. In the area 32 of
the light conductor elements, at least virtually, no light is generated. This is
because a considerable part of the radiation has already been priorly
converted into light and because it is in the lower part that the neighboring
light conductor elements are located at a relatively large distance from each
other. In the area 32, the light conductor elements 6 are slightly bent
towards each other so that a relatively small light sensor unit 2 can be used.

In the example of Fig. 4, the outer surface 26 of the light sensor unit
where the light enters has a concave design. In this example, further, the
longitudinal directions of, at least virtually, all light conductor elements 6 of
the group 4 near the outer surface 26 of the light sensor unit include angles
with a locally corresponding normal 32 of the outer surface (two of which are shown in this example) which are approximately equal to 0°. This also further improves the resolution in that, in this manner, the end 24 of a light conductor covers a relatively smaller part of the surface 26 than in the example of Fig. 1a.

In this example, in fact, the longitudinal directions of at least virtually all light conductors of the group 4 near the outer surface 26 of the light sensor unit 2 include angles with a locally corresponding normal of the outer surface which are approximately equal to 0°. In Fig. 4, the ends 24 are also ordered relative to each other according to a two-dimensional array as shown in Fig. 1c. However, here, the surface in which the respective ends are two-dimensionally distributed, is the surface 26 which is concave.

In the example of Figs. 1-4, the light sensor unit is provided with a sensor array 36 known per se, such as for instance a CCD. It is also possible for the light sensor unit to be further provided with a fiber optic taper 38 included between the light sensor 36 and the group 4 of light conductor elements 6. All this is shown in Fig. 5. The light which enters via the surface 26 of the light sensor unit near the fiber optic taper 38, is conducted by means of the fiber optic taper 38 to the light sensor 36, which light sensor 36 has a light-sensitive surface 40 smaller than the surface 26. In the example of Fig. 5, the group 4 of the light conductor elements 6 is ordered as discussed with reference to Fig. 1.

Variations in Fig. 5, as for instance discussed with reference to Figs. 2-4, are of course also possible. For instance, Fig. 6 shows that the surface 26 of the light sensor unit, in this example formed by an outer surface of the fiber optic taper 38, can also have a concave design as discussed with reference to Fig. 4. An advantage of the apparatus of Fig. 6 is that, on the one hand, as a result of the light conductor elements diverging towards the light sensor unit 2, the resolution is increased. Because, in addition, the surface 26 has a concave design, the resolution is further
increased. In addition, thanks to the fiber optic taper, by means of a relatively small light sensor 36, an image with a high resolution can be obtained.

In the camera of Fig. 7, the element 8 is provided with a plurality of openings 10, pinholes in this example. In this example, the element 8 is provided with four openings, two of which are shown. A side elevational view in the direction of arrow P of Fig. 7 will result in a same side elevational view as show in Fig. 7. In this example, further, per opening 10.i (i =1,2,3,4), the camera is provided with a group 4.i (i = 1,2,3,4) of light conductor elements. The camera is further provided with a fiber optic taper 38 to conduct the light generated by means of the groups 4.1 to 4.4 to a, in this example single, sensor 36. It is of course also possible to provide the camera with a light sensor 36 per group 4.i or to provide the camera with a light sensor unit per group 4.i (so, also a fiber optic taper per group).

Also, per group 4.i, a light sensor unit 2 of the type as shown in Fig. 1 or 4 can be used. In Fig. 7, the ends 24 of a group are also ordered relative to each other according to a two-dimensional array as shown in Fig. 1c. Also, the ends of a first group 4.1 and a second group 4.2 can each form a one-dimensional array as shown in Fig. 1, where the first group and the second group together form a group whose ends are arranged so as to be two-dimensionally distributed in the surface 26.

In each of the above-described examples, the light conductor elements of a group converge in a direction of the light sensor unit towards the element 8 towards one of the openings 10. In addition, the light conductor elements of the group are each, at least partly, directed in a direction of the at least one opening, or point to the at least one opening. In the apparatus according to Figs. 1, 4, 5, 6 and 7, the light conductor elements of a group are each, at least virtually, wholly directed in the direction of one of the openings because the light conductor elements have a straight design. In
Fig. 2, this applies only to a part 41 of the light conductor elements and in Fig. 3, to a part 30 of the light conductor elements.

Fig. 11 shows an embodiment of a camera where the element 8 possesses a plurality of openings 10 in the form of channels, more in particular bores, which bores together form a collimator converging in one direction away from the light conductor elements. In this example, this is a cone-beam collimator.

In the example of Fig. 11, the directions of the light conductor elements aligned with a particular bore correspond to the direction of the bore. The sensor unit 2 is designed as discussed with reference to Fig. 4. The camera according to Fig. 11 is particularly suitable for obtaining transmission images, with X-ray radiation from an X-ray radiation source 42 propagating through an object 44 in the direction of the collimator 8. So, here, also, an image is produced on the basis of radiation coming from the object. In this example, however, the object 44 itself is not the source of the radiation as is the case for object 3 of Fig. 1. In this example, the source 42 is a point source. Because, again, both the bores 10 and the light conductors 26 diverge in a direction towards the light sensor unit 2 and therefore converge in a direction away from the light sensor unit, a high resolution is obtained. In particular, the light conductor elements 40 and the bores 10 each converge to a point coinciding with the position of the X-ray radiation source 42. In that case, the ends 24 of the light conductor elements 4 also form a two-dimensional array as shown in Fig. 1c. Also in that case, the light conductor elements are two-dimensionally distributed in a surface 26 which is, for instance, flat or, in this example, bent.

In the apparatus of Fig. 11, instead of a cone-beam collimator, a fan-beam collimator could also be used, where each time, the bores are provided in parallel surfaces and form one converging collimator per surface. In that case, the ends of the light conductor elements could also form a two-dimensional array as shown in Fig. 1c. Also in that case, the
light conductor elements are two-dimensionally distributed in a surface 26 which is, for instance, flat (or bent). The bores are preferably directed towards the source 42. In the case of a fan-beam collimator, the source 42 will preferably be a line source.

It is noted that, in the above-described embodiments, the ends 24 of the group of light conductor elements 6 are ordered relative to each other according to a matrix as shown in Fig. 1c. Because the relative distances between the ends 24 of Fig. 1c are each time the same, this is, moreover, a linear two-dimensional array. Other set-ups are also possible. For instance, instead of according to a rectangular matrix, the ends 24 can also be ordered relative to each other according to a pattern with concentric circles as shown in Fig. 1d or according to a different regular or irregular two-dimensional pattern.

With reference to Figs. 8a and 8b, a method is discussed for manufacturing an oriented quantity of light conductor elements 6 which are to form a group 4 for a camera for producing an image of an object. The starting point is a light conductor material 50 on which a material 51 which can generate light under the influence of the said radiation is applied (shown hatched). This material can, for instance, be applied by chemical vapor deposition. From an outer surface 52 of this whole, a plurality of saw cuts 54 crossing each other are provided which extend through the material 51 into the material 50. The light conductor material is provided with a light sensor 36 at a side 56 opposite the side 52. In this example, a lower part 38 of the light conductor material already has the form of a fiber optic taper. However, this last is not requisite. The lower part 38 can also not be tapered in a direction of the light sensor 36. In the light conductor material, the light conductor elements 6 are formed between the saw cuts 54. These each have a free end 57 located at the surface 52 of the light conductor material. Then, the free ends 57 of the light conductor elements are moved towards each other, for instance by clamping the light conductor
material 50 in directions Q and Q' so that the light conductor elements at least partly diverge towards each other in a direction from the saw cuts towards the free ends. This clamping can, for instance, be realized by tying a band around the light conductor elements 6 and pulling or drawing this band tight (not shown). The material 51 which generates light under the influence of radiation is not clamped because it is rather brittle. Thus, at its upper side, the light conductor material forms the light conductor elements 6 and, at its lower side, the taper 38 (Fig. 8b). Of course, there where the light conductor elements are formed, the light conductor material is already provided with a material which generates light under the influence of radiation.

An alternative manner for manufacturing an oriented plurality of light conductor elements is discussed with reference to Fig. 9b. Here, use is made of a group of individual elongated light conductor elements 70.i (i = 1, 2, 3 to n), two of which, 70.1 and 70.2, are shown in Fig. 9a. The light conductor elements again comprise a material 50 which conducts light and material 51 applied thereon (for instance again by chemical vapor disposition) which generates light under the influence of radiation (in this example X-ray radiation). The elongated light conductor elements are each provided with a first and second end 72, 74. The first ends 72 of the light conductor elements 70.1, 70.2 respectively are provided with a surface whose normal has a predetermined direction. Within the group of light conductor elements, these ends are provided with surfaces with normals (directions) different from each other relative to the longitudinal direction of the light conductor elements. Fig. 9a shows that the normal 76.1 of light conductor element 70.1 has a different direction than the normal 76.2 of the light conductor element 70.2. Then, the light conductor elements are positioned by the respective surfaces 72 on a surface 26 (in this example the surface of a light sensor unit 2, see Fig. 9b), such that the light conductor elements, at least partly, diverge relative to each other in a direction away
from the surface 26. In the example of Fig. 9b, two light conductor
elements 70.1 and 70.2 are shown. Thus, a group of light conductor
elements can be obtained as, for instance, discussed with reference to
Figs. 1-7 as well as with reference to Fig. 11.

With reference to Figs. 10a-10c, an alternative method for
manufacturing an oriented quantity of light conductor elements will
presently be described.

Fig. 10a shows a stack of elongated light conductor elements 6. The
light conductor elements 6 are, for instance, obtained by using the method of
Nagarkar V.V. et al. (supra) by cautiously breaking up the film described
therein. This can, for instance, be done in a liquid bath (where the liquid is
substantially no solvent) and by using sound waves. If desired, the
substrate on which the film is applied is removed first, for instance
mechanically by means of grinding, or physically (dissolving) and the like.

In view of the small diameter of the separate light conductor elements 6,
bundles of light conductor elements 6 not further broken up can be used,
where a bundle will illuminate an array element of a light sensor. The light
conductor elements comprise a material which generates light under the
influence of (for instance gamma) radiation as discussed hereinafore. If a
bundle extends over two array elements of the light sensor, this has less
objectionable consequences for the resolution than a single light conductor
extending over two array elements of the light sensor.

Fig. 10a also shows a plate 101, whose surface is provided with a
two-dimensional pattern 102 by use of techniques well known from chip
technology or by use of, for instance, laser technology. Here, the period of
the pattern 102 in both the X-direction and the Y-direction (of the plate
surface) is slightly larger than the thickness of the (bundles of) light
conductor elements 6 to be directed towards the surface. The light conductor
elements 6 can be connected to each other at the opposite ends 104, for
instance by applying glue. The ends of the light conductor elements 6
remote from the plate 101 can, for instance, be provided with a reflective coating, for instance applied in the form of a reflective tape, by means of which the light output on the light sensor (not shown) can be increased. This is known per se from Nagarkar (supra).

In the embodiment shown here, the light conductor elements 6 kept together by small bars 108 are pushed against the plate 101 (Fig. 10b). The plate 101 can be manufactured from any material such as glass or plastic, and, after fixing the light conductor elements 6 in a desired position, it can optionally be wholly or partly removed again. This removing can, for instance, be done by means of grinding. Preferably, plate 101 will be a plate from scintillation material, which, once provided with light conductor elements 6, is, in its turn, provided on a position-sensitive light sensor.

Preferably, the plate 101 is ground down so far that the ends proximal to the light sensor are located at the ground surface of the plate. Thus, refractive index transitions limiting the sensitivity are efficiently avoided.

Prior to fixing, all light conductor elements 6 are put on the plate surface at an angle of 90° or slightly smaller. So, the light conductor elements coincide with the normal (Z-direction) of the plate. Although it is possible to tilt and to shift the small bars 108 to achieve the desired effect, gravity is used with advantage and the plate 101 and the light conductor elements 6 positioned against it are also tilted, such that the light conductor elements 6 come to rest on top of the plate 101 (Fig. 10c shows a side elevational view in the Y-direction; a side elevational view in the X-direction would show a same view as in Fig. 10b).

The pattern 102 on the surface of the plate 101 can be formed by a fusible material. This can then be thermally softened and be cooled down again, so that the light conductor elements 6 are fixed. Here, the material also provides an improved light incoupling of light from the light conductor elements 6 towards the light sensor surface.
So, here, use is made of a surface provided with a plurality of recesses ordered relative to each other according to a particular pattern and elongated light conductor elements each provided with a first and second end, the respective first ends of the light conductor elements being inserted in the recesses and the second ends of the light conductor elements being brought closer to each other compared to the first ends, so that the light conductor elements at least partly diverge relative to each other in a direction from the first ends towards the second ends.

As will be readily apparent to a common skilled person, the invention can be varied in several manners within the scope of the appended claims. For instance, instead of breaking up the film formed using the method of Nagarkar, it can be sawed into slices, yielding elongated (quasi-one-dimensional) arrays 105 of light conductor elements. Each light conductor element can consist of a bundle of substantially parallel sub-light conductor elements such as fibers. Also, these sub-light conductor elements can diverge within a same light conductor element in a same direction as that in which the light conductor elements mutually diverge. It is also possible that low-reflective plastic such as Teflon is provided between the light conductor elements. This can, for instance, be done using the method according to Fig. 8 by depositing the respective low-reflective material into the saw cuts after the saw cuts have been provided and then bringing the light conductor elements towards each other at their free ends as discussed with reference to Fig. 8b. Also, each light conductor element can be built up from an array of more or less parallel sub-light conductor elements, or an array of (sub-)light conductor elements. It is also possible to include another light conducting system such as an optical system between the light conductor elements and the light sensor. In fact, then, this system is part of the light sensor unit. It is also possible to omit element 8 in any of the above-described embodiments of Figs. 1-7. The said plurality of light conducting paths and/or light conductor elements will then preferably
converge in or point to the object 3 forming the radiation source. Also, in Fig. 11, element 8 can be omitted. Then, also, the said light conducting paths and/or light conductor elements will converge in or point to radiation source 42. Such variants are each understood to be within the scope of the invention.
CLAIMS

1. A camera for producing an image of an object on the basis of radiation such as X-ray radiation or gamma radiation coming from the object, which camera comprises a position-sensitive light sensor unit and at least one group of light conductor elements, wherein the light conductor elements comprise a material for converting the radiation into light to which the light sensor unit is sensitive and wherein the group of light conductor elements is arranged for conducting the light to the light sensor unit, characterized in that the light conductor elements each comprise a light conducting path along which, in use, the light is conducted to the light sensor unit, wherein a plurality of the light conducting paths at least partly diverge relative to each other in a direction towards the light sensor unit, wherein the light conductor elements forming the diverging light conducting paths are provided with ends which are located at the sides of the light conductor elements proximal to the light sensor unit and which are two-dimensionally distributed in a surface.

2. A camera according to claim 1, characterized in that a plurality of the light conductor elements of the group of light conductor elements at least partly diverge in a longitudinal direction of the light conductor elements and in a direction towards the light sensor unit.

3. A camera according to claim 2, characterized in that the plurality of the light conductor elements diverge at least virtually wholly in a longitudinal direction of the light conductor elements and in a direction towards the light sensor unit.

4. A camera according to any one of the preceding claims, characterized in that the ends of these light conductor elements, at the sides of these light conductor elements proximal to the light sensor unit, form a two-dimensional pattern.
5. A camera according to any one of the preceding claims, characterized in that the surface is a surface of the light sensor unit where the light of the light conductor elements enters.

6. A camera according to any one of the preceding claims, characterized in that the camera is further provided with an element comprising a material which blocks radiation, wherein the element is provided with at least one opening for transmitting the radiation coming from the object, wherein a plurality of the light conductor elements of the group extend between the at least one opening and the light sensor unit.

7. A camera according to claim 6, characterized in that, in a direction from the light sensor unit towards the element, the plurality of the light conductor elements of the group are directed relative to each other such that at least a part of the light conductor elements at least virtually converge to the at least one opening.

8. A camera according to claim 6 or 7, characterized in that the plurality of the light conductor elements of the group each at least partly point to the at least one opening.

9. A camera according to claim 6, characterized in that the element possesses a plurality of openings in the form of channels, such as bores, which channels are directed such that the element forms a collimator converging in a direction away from the group of light conductor elements.

10. A camera according to claim 9, characterized in that the plurality of the light conductor elements of the group are each aligned with one of the channels.

11. A camera according to claim 6, 7 or 8, characterized in that the element is provided with at least one opening in the form of a pinhole.

12. A camera according to claims 6, 7, 8 or 11, characterized in that the camera is provided with a plurality of groups and the element is provided with a plurality of openings, wherein the plurality of the light conductor elements of each group at least partly converge or point to one of the
openings and wherein the plurality of the light conductor elements of a number of different groups converge or point to a number of different openings.

13. A camera according to any one of the preceding claims, characterized in that the light sensor unit is provided with a position-sensitive sensor such as a CCD.

14. A camera according to claim 13, characterized in that the light sensor unit is further provided with a fiber optic taper included between the light sensor and the group of light conductor elements.

15. A camera according to any one of the preceding claims 13 or 14, characterized in that the light sensor unit comprises a sensor array.

16. A camera according to any one of the preceding claims, characterized in that an outer surface of the light sensor unit where the light enters has a flat design.

17. A camera according to any one of the preceding claims 1-15, characterized in that an outer surface of the light sensor unit where the light enters has a concave design.

18. A camera according to claim 16, characterized in that the longitudinal directions of at least virtually all light conductor elements of the group, near the outer surface of the light sensor unit, include angles with a locally corresponding normal of the outer surface which are larger than zero degrees.

19. A camera according to claim 17, characterized in that the longitudinal directions of at least virtually all light conductor elements of the group, near the outer surface of the light sensor unit, include angles with a locally corresponding normal of the outer surface which are approximately equal to zero degrees.

20. A camera according to any one of the preceding claims, characterized in that the camera is provided with a plurality of groups of light conductor elements.
21. A camera according to claims 6 and 20, characterized in that the plurality of the light conductor elements of each group at least partly converge in a direction of one of the openings.

22. A camera according to any one of the preceding claims, characterized in that the light conductor elements are each provided with a layer which can convert radiation into light to which the light sensor unit is sensitive.

23. A camera according to any one of the preceding claims, characterized in that a reflective plastic such as Teflon is provided between the light conductor elements of the group.

24. A camera according to claim 1, characterized in that at least a part of the light conductor elements is positioned at an angle of less than 90° relative to the surface of the light sensor unit, such that the light conductor elements make an acute angle with each other at the object side.

25. A camera according to claim 24, characterized in that the positioning pattern of the light conductor elements is chosen from a fan shape and a two-dimensional fan shape.

26. A camera according to claim 24 or 25, characterized in that the camera possesses an element manufactured from material which blocks radiation, the element is provided with an opening for transmitting radiation, and the light conductor elements are directed towards the opening.

27. A camera according to claim 26, characterized in that the element possesses a plurality of openings in the form of bores, which bores together form a converging collimator.

28. A camera according to any one of the preceding claims 24-27, characterized in that the light sensor is a sensor array.

29. A camera according to any one of the preceding claims 24-28, characterized in that, at the light sensor side, the light conductor elements are provided with a layer which can convert radiation into light to which the light sensor is sensitive.
30. A camera according to any one of the preceding claims, characterized in that the camera is further provided with a radiation source, wherein a plurality of the light conductor elements of the at least one group at least partly point to the radiation source.

31. A camera according to claim 9 or 10, characterized in that the camera is further provided with a radiation source, wherein the channels of the collimator point to the radiation source.

32. A camera according to claim 31, characterized in that a plurality of the light conductor elements of the at least one group at least partly point to the radiation source.

33. An apparatus for producing an image of an object, which apparatus possesses at least one radiation source and at least one camera, wherein the object can be positioned between the radiation source and the camera, characterized in that the camera is a camera according to any one of the preceding claims 1-29.

34. An apparatus according to claim 33, characterized in that the light conductor elements are directed towards the radiation source.

35. A method for manufacturing an oriented plurality of light conductor elements for a camera for producing an image of an object, characterized in that use is made of a surface provided with a plurality of recesses ordered relative to each other according to a particular pattern and elongated light conductor elements each provided with a first and second end, wherein the first ends of the light conductor elements are respectively inserted in the recesses and wherein the second ends of the light conductor elements are brought closer to each other compared to the first ends, so that the light conductor elements at least partly diverge relative to each other in a direction from the second ends towards the first ends.

36. A method for manufacturing an oriented plurality of light conductor elements for a camera for producing an image of an object, characterized in that a plurality of saw cuts crossing each other are provided in the light
conductor material, wherein, in the light conductor material between the saw cuts, light conductor elements are formed which each have a free end located at a surface of the light conductor material, wherein the light conductor elements are each provided with a material which generates light under the influence of radiation and wherein the free ends are then moved towards each other, for instance by clamping the light conductor material so that the light conductor elements at least partly diverge relative to each other in a direction from the saw cuts towards the free ends.

37. A method for manufacturing an oriented plurality of light conductor elements for a camera for producing an image of an object, characterized in that use is made of a group of individual elongated light conductor elements each provided with a material which generates light under the influence of radiation and each provided with a first and second end, wherein the first ends of the light conductor elements are respectively provided with a surface, wherein the group is provided with surfaces with normals different from each other relative to a longitudinal direction of the light conductor elements, wherein the light conductor elements are positioned by the surfaces on a surface such that the light conductor elements at least partly diverge relative to each other in a direction away from the surface.

38. A method for manufacturing an oriented plurality of light conductor elements for a camera for producing an image of an object, characterized in that a stack of parallel light conductor elements is contacted with a surface provided with a relief pattern chosen from a one-dimensional and a two-dimensional relief pattern, wherein the surface is positioned at an angle relative to the longitudinal axis of one of the light conductor elements, such that proximal ends of the light conductor elements fall into successive recesses of the profile surface, after which the angle between the profile surface and a centrally located light conductor element is set at approximately 90°.
39. A camera for producing an image of an object, which camera comprises a position-sensitive light sensor and is provided with a plurality of light conductor elements manufactured from material for converting radiation into light to which the light sensor is sensitive, and the light conductor elements are arranged for conducting the light to the light sensor, characterized in that at least a part of the light conductor elements is positioned at an angle of less than 90° relative to the surface of the light sensor, such that the light conductor elements make an acute angle with each other at the object side.

40. A camera according to claim 39, characterized in that the positioning pattern of the light conductor elements is chosen from a fan shape and a two-dimensional fan shape.

41. A camera according to claim 39 or 40, characterized in that the camera possesses an element manufactured from material which blocks radiation, the element is provided with an opening for transmitting radiation, and the light conductor elements are directed towards the opening.

42. A camera according to claim 41, characterized in that the element possesses a plurality of openings in the form of bores, which bores together form a converging collimator.

43. A camera according to any one of the preceding claims 39-42, characterized in that the light sensor is a sensor array.

44. A camera according to any one of the preceding claims 39-43, characterized in that, at the light sensor side, the light conductor elements are provided with a layer which can convert radiation into light to which the light sensor is sensitive.

45. An apparatus for producing an image of an object, which apparatus possesses a radiation source and a camera and wherein the object can be positioned between the radiation source and the camera, characterized in that the camera is a camera according to any one of claims 39 to 44.
46. An apparatus according to claim 45, characterized in that the light conductor elements are directed towards the radiation source.