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(54) **X-Ray anode**

(57) An X-ray anode includes a first material 34 in a first region 36 and a second material 38 in a second region 40 of the target surface 26 of the anode. The first region 36 corresponds to the focal spot. Electrons 42 incident on the first region 36 generate X-rays at the characteristic energy required. Scattered electrons 44 incident on the second region generate fewer X-rays and/or X rays at a different energy reducing the effects of the scattered electrons 44 and X-rays produced by the scattered electrons 44 on the effective size of the X-ray spot.

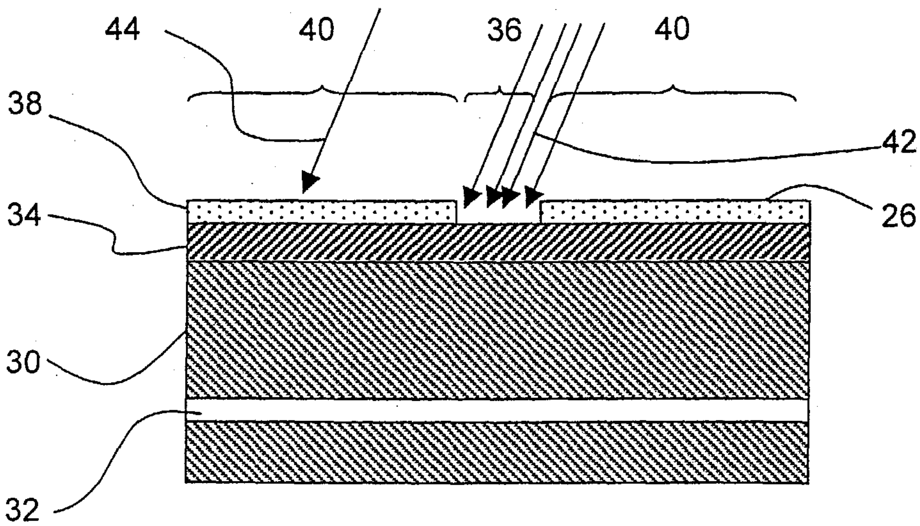

Fig. 3

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Description

Field Of Invention

[0001] The invention relates to an X-ray anode and apparatus for generating X-rays including an X-ray anode.

Related Art

[0002] X-rays are conveniently produced by an X-ray source or tube by firing electrons from a cathode against an anode. An X-ray tube thus typically includes a cathode and an anode in an evacuated enclosure. In use, a voltage of several tens of kV is applied between the cathode and anode with a positive voltage on the anode. Electrons are emitted from the cathode and are accelerated by the electric field between cathode and anode. The electrons hit the anode, which in turn emits X-rays.

[0003] A typical anode is a copper anode, with a copper target layer, and a thick support plate below the target layer to provide mechanical stiffness and to ensure that the enclosure remains evacuated. When electrons hit the anode, they generate heat, so circulating cooling water may be provided within or adjacent to the support plate to cool the support plate and hence the anode.

[0004] Different target materials generate X-rays with characteristic X-ray photons of different energies, that is to say of different wavelengths. Longer wavelengths correspond to lower energies. As a rough guide, lighter elements are used to produce X-rays of longer wavelength and lower energy than heavier elements, though the X-rays produced depend also on the energy of the electrons impacting the target material which must have sufficient energy to produce the respective X-ray photons. Lower energy, longer wavelength X-rays, known as "soft" X-rays typically have less penetrating power than higher energy "hard" X-rays.

[0005] Suitable target materials can be selected depending on the energy of X-ray photons required.

[0006] The X-ray source is typically arranged to direct electrons from the cathode to hit the anode on a predetermined area, known as the focal spot, that may be for example a line 12mm long by 0.4mm wide. In some applications, the well-defined shape of this area is important - this is especially true of X-ray diffraction applications but can also be true of other applications such as X-ray fluorescence or X-ray radiography or X-Ray imaging.

[0007] However, inevitably not all electrons will hit the focal spot, and some electrons will hit the anode away from the focal spot. The X-rays from outside the focal spot can cause additional broadening in spectra and/or images captured using the X-ray source. Thus, a well defined focal spot is important.

Summary of Invention

[0008] According to the invention there is provided an X-ray source for emitting X-rays at a target characteristic wavelength, comprising:

an anode having a surface for generating X-rays when electrons impact the target surface;
a cathode for emitting electrons, to fire electrons from the cathode onto a predetermined focal spot region at the anode;
the target surface of the anode in the predetermined focal spot region is of a first material structure for generating X-rays at the target characteristic wavelength; and
the target surface of the anode outside the predetermined focal spot region is of a second material structure different to the first material structure for generating fewer X-rays at the target characteristic wavelength than the first material structure.

[0009] By providing a first material structure in the focal spot region of the target surface X-rays at the characteristic wavelength may be generated normally. These may be used in an X-ray system which is designed to use X-rays at this characteristic wavelength.

[0010] In X-ray systems, however, the focussing of the electrons on the focal spot is inevitably imperfect and some electrons inevitably hit the target area of the anode outside the focal spot. In conventional systems these can generate significant intensity in areas far from the focal spot. These X-rays result in a badly defined X-ray source, leading to high background intensity detected at the detector and broad peaks.

[0011] In contrast, using the approach of the invention, electrons hitting the anode outside the focal spot hit a different material structure which provides a reduced X-ray intensity or eliminates all X-rays at the characteristic wavelength away from the focal spot.

[0012] The first material structure may differ from the second material structure by being of a different material emitting X-rays at a different wavelength.

[0013] For example, the first material structure may be of a first element and the second material structure is of a second element, wherein the second element is lighter than the first element in the periodic table. The first material structure may be of one of Cu, Mo, W, Co, Cr, Au, Ag and Fe and the second material structure may then be of a different material.

[0014] In a particular embodiment the first material may be Cu and the second material structure of one of C, Mg, Al, Si, Ca, Sc,V, Cr, Mn, Ti, Co, or Ni.

[0015] Alternatively or additionally, the first material structure may be flat and the second material structure rougher. For example, the second material structure may be porous or contain regular grooves.

[0016] In embodiments, a different porous material may be used, such as porous carbon as the second material structure and solid copper as the first material structure. Alternatively, the same material may be used, for example solid copper as the first material structure and porous copper as the second material structure.

[0017] The X-ray source may include a housing and the inside of the housing may be coated with a material different to the material of the focal spot. This can still further reduce stray radiation.

[0018] The X-ray source may be used in any X-ray equipment.

[0019] An X-ray absorber may be provided for absorbing X-rays emitted by the second material structure.

[0020] Alternatively or additionally, the X-ray source may be used in X-ray equipment with optics arranged to remove the X-rays emitted from the second material structure. This is possible because the use of a different material structure allows the characteristic X-rays from the second material structure to be distinguished from those emitted from the first material structure, typically by being at a different wavelength, in preferred examples of longer wavelength and hence with X-ray photons of lower energy.

[0021] The source is particularly useful for scattering and diffractometer equipment, such as small angle X-ray scattering equipment. The source is also particularly useful in X-Ray diffraction high-resolution equipment.

[0022] For example, in embodiments there is provided an X-ray system for measuring X-ray diffraction or scattering, including an X-ray source as set out above for generating a beam of X-rays from the focal spot; a sample stage for a sample and an X-ray detector.

[0023] The X-ray system may include an optics system arranged to pass the characteristic X-rays emitted by the first material structure preferentially to the characteristic X-rays emitted by the second material structure.

[0024] The optics may include an X-ray mirror, an X-ray lens and/or a crystal monochromator.

[0025] The system may further comprise an energy discriminating x-ray detector for discriminating between X-rays at the the target characteristic wavelength and X-rays emitted at other wavelengths. In this way unwanted characteristic radiation may be reduced also by photons energy discrimination. The discrimination may take place in the detector electronics alone or in combination with other methods.

[0026] The system may supply a predetermined useful characteristic radiation component, the target material producing at least two characteristic radiation components including the predetermined useful characteristic radiation component and another characteristic radiation component. The X-ray system may be arranged to reduce the effect of the other characteristic radiation component compared with the predetermined useful characteristic radiation component.

[0027] Note that the "useful" radiation is simply the radiation required by the experiment. For example, if pure CuKβ is required the optics may include a mirror to select CuKβ radiation.

[0028] The invention makes it possible to select peaks not being the dominant peak. In prior arrangements, if a mirror was used to select a component such as CuKβ that was less intense than another component such as CuKa, the useful CuKβ could be swamped by CuKa from away from the focal spot. By ensuring that no CuKa radiation is generated by the anode away from the focal spot, this problem can be alleviated.

[0029] In another aspect, the invention also relates to an X-ray anode for use in an X-ray source having an X-ray cathode directing electrons at a predetermined focal spot region of the X-ray anode, the X-ray anode comprising:

> a target surface for generating X-rays when electrons impact the target surface;
> wherein the target surface in the predetermined focal spot region is of a first material structure for generating X-rays at a predetermined wavelength; and
> the target surface outside the predetermined focal spot region is of a second material structure different to the first material structure for generating fewer X-rays at the predetermined wavelength than the first material structure.

Brief Description of the Drawings

[0030] For a better understanding of the invention, embodiments will now be described, purely by way of example, with reference to the accompanying drawings, in which:

> Figure 1 shows an X-ray system according to a first embodiment of the invention;
> Figure 2 shows a top view of the surface of the X-ray anode of the first embodiment of the invention;
> Figure 3 shows a side view of the X-ray anode of Figure 2;
> Figure 4 shows the X-ray intensity as a function of angle for the X-ray source of the first embodiment and for a comparative example;
> Figure 5 shows an X-ray anode according to a second embodiment of the invention; and
> Figure 6 shows an X-ray system according to a third embodiment of the invention. Like or corresponding components are given corresponding reference numerals in the different figures.

[0031] Referring to Figure 1, an X-ray diffraction system 2 according to the first embodiment of the invention includes an X-ray source 4, a sample stage 6, an X-ray detector 8, X-ray optics 10, including a collimator and a discriminator crystal, together with movement means in the form of one or more motors 12 for moving and/or rotating the source 4, sample stage 6, detector 8 and optics 10 with respect to one another in order to carry out a scan. In use, a sample 14 is mounted on the sample stage, X-rays are generated from the X-ray source 4, incident on the sample, and diffracted through the optics to the X-ray detector. A scan is carried out by moving and/or rotating the source 4, sample stage 6, detector 8 and optics 10 with respect to one another as is known in the art, generally to obtain measurements of scattering intensity as a function of one or more variables, conventionally the scattering angle 2θ and Ω.

[0032] The X-ray source 4 includes a cathode 16 and anode 18 in a source housing 20. To generate X-rays, a voltage is applied between the cathode 16 and anode 18, electrons are emitted from the cathode, for example by heating the cathode so that it is incandescent, and directed onto the anode where the electrons impact the anode at speed, generating X-rays. These X-rays are then emitted through exit window 22 in the source housing 20 into the rest of the diffraction system 2. the exit window 22 being made for example of beryllium.

[0033] The X-ray source 4 is arranged so that the electron beam from the cathode 16 is incident on a predetermined, small region of the X-ray anode, as will be familiar to those skilled in the art. This region is known as the focal spot 24, as illustrated in Figures 2 and 3 which shows the front, target surface 26 of the anode 18 in top view and side view respectively.

[0034] In the embodiment, the anode is made of a rear block 30, through which cooling tubes 32 pass. These tubes carry cooling fluid, for example of water, to reduce the risk of the anode overheating in use.

[0035] Above the rear block 30 is provided target material 34, in the form of a block in front of the rear block. In the embodiment, the target material 34 is of copper (Cu).

[0036] Target material 34 is only exposed at the front of the anode 18 over a first region 36. The rest of the target material 34 is covered by a coating 38, over a second region 40. Alternatively, the coating can be applied by other techniques, such as sputtering and/or electrolysis.

[0037] The first region 36 is arranged to correspond to the focal spot 24, so that electrons hitting the focal spot 24 arrive at the first region 36 of the target surface 26 where they hit the target material, here Cu. Electrons not hitting the focal spot 24 arrive at the second region 40 where they impact the second material coating 38.

[0038] Electrons 42 incident on the anode in focal spot 24 hit the Cu target material 34 and hence produce Cu Ka radiation, which is used for analysis. In contrast, electrons 44 hitting the anode 18 outside the focal spot 24 hit the second material coating and hence produce radiation at a different, longer, characteristic wavelength. In other embodiments it is the radiation need not necessarily be of longer characteristic wavelength.

[0039] The characteristic radiation at a different wavelength from the second material can be substantially removed so that it does not affect the measured intensity. In the first embodiment, this is done using optics 10 that effectively eliminates the effect of this radiation. In particular, the optics 10 in this X-ray diffractometer embodiment includes a x-ray mirror that effectively acts as a monochromator and hence removes the characteristic photons emitted by the second material.

[0040] Figure 4 illustrates how the focal spot shape is improved using the invention. Experiments were carried out using two targets, one a comparative copper anode without coating layer 38, and one using an anode according to the invention with a coating layer 38 covering the copper target material 34 away from the focal point 24. The results were measured by moving the detector along a 2θ axis with a high resolution monochromator positioned between the x-ray tube and detector.

[0041] Figure 4 shows the narrow peak (solid line) obtained using the anode according to the invention and the peak with much broader "tails" (dotted line) obtained using the prior art anode.

[0042] As will be appreciated, in cases where the diffraction pattern is complicated broadening of peaks can cause real difficulty in interpreting data - this can be reduced using the anode of the invention.

[0043] The invention will work with a wide choice of materials as the target material, not merely Cu but also, for example, Mo, W, Co, Cr, Au, Ag or Fe or any other material.

[0044] The main requirement for the coating material 38 is that it is different to the target material, preferably that the coating material 38 generates X-rays of different wavelength to the target material 34 when electrons are incident.

[0045] When the target material is of copper, the coating 38 may accordingly be of Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Co, Ni., not the same as the target material 34. Other materials may be suitable as coatings for different target materials.

[0046] In preferred examples the coating material and the target materials are both elements, not compounds and the element of the coating material is lighter than the element of the target material which in general will assist in producing lower energy characteristic X-ray photons from the coating than from the target. This in turn makes it easier to select only the photons from the target, not the coating.

[0047] Note that the target material may on occasion emit more than one wavelength of X-ray; for example copper may emit CuKa and CuKb radiation. The optics and tube can preferentially select for the desired radiation, for example the CuKa radiation, and select against the undesired radiation, for example the CuKb radiation.

[0048] The invention gives particular benefits where the desired radiation is emitted at lower intensity than the undesired radiation. In prior arrangements, if the desired radiation were selected using a monochromator crystal, oriented to pass the desired radiation from the focal spot, then significant undesired radiation from away from the focal spot can be passed together with the desired radiation. By using the invention, much purer desired radiation can be obtained.

[0049] It is not essential to use elements, especially for the coating, and alloys or compounds may also be used if required.

[0050] Optionally, the source housing 20 may be coated on its inner surface with a different material to the focal spot to reduce the effect of scattered electrons impacting the housing 20.

[0051] Figure 5 shows an alternative embodiment of an anode according to the invention which does not use a separate coating but instead renders the copper of the target material 34 porous in the second region 40, constituting here a porous material 46 of different material structure to the copper of the first region 36 by virtue of the different structure rather than the use of a different material.

[0052] The porous structure can be created by etching the target material 34 in the second region 40.

[0053] Both incident electrons and emitted electromagnetic radiation can be trapped in the porous second region 40 of the target material 34 thereby greatly reducing the amount of X-rays emitted at low angles by electons incident on the second region than the first.

[0054] An alternative embodiment (refer back to Figure 3) coats the target material 34 with a coating 38 a porous layer of a material, that can be of the same or preferably a different material to the target material. For example, porous graphite can be used as coating 38.

[0055] The invention is generally applicable to X-ray apparatus, not merely to X-ray diffraction apparatus, including for example X-ray radiography.

[0056] Figure 6 schematically illustrates such X-ray apparatus, with an X-ray anode 16 having a target material 34 of W and a coating 38 outside the focal spot.

[0057] In this case, there are no "optics" as such - the detector 50 is a two dimensional detector 50. In this embodiment the discrimination between X-rays from the focal spot and those emitted from coating is achieved using a thin filter 48 between the anode 16 and sample 14. The filter 48 preferentially filters out the X-rays emitted by the coating 38.

[0058] Further selection is provided by the X-ray detector 50 which is an energy-sensitive X-ray detector and hence able to select the desired X-rays from the focal spot by their energy.

[0059] In this example, the use of a standard anode can easily result in smearing in the detected pattern. By using the invention, the X-rays from away from the focal spot 24 are filtered out by means of the filter 48, reducing smearing and improving the spatial discrimination of the apparatus.

[0060] In alternative embodiments, both optics 10 such as x-ray mirrors and filters 48 can be used to remove unwanted X-rays from the second region of the anode.

[0061] It will be appreciated that the invention is also applicable to other forms of X-ray apparatus, such as X-ray fluorescence apparatus, etc.

[0062] The above examples are not intended to be limiting and those skilled in the art will be aware of many variations in the design of the X-ray apparatus, the X-ray source, and X-ray anode and the materials and arrangements of these components, that may be adopted.

Claims

1. An X-ray source for emitting X-rays at a target characteristic wavelength, comprising:

an anode having a surface for generating X-rays when electrons impact the target surface;
a cathode for emitting electrons, to fire electrons from the cathode onto a predetermined focal spot region at the anode;
the target surface of the anode in the predetermined focal spot region is of a first material structure for generating X-rays at the target characteristic wavelength; and
the target surface of the anode outside the predetermined focal spot region is of a second material structure different to the first material structure for generating fewer X-rays at the target characteristic wavelength than the first material structure.

2. An X-ray source according to claim 1 wherein the surface of the anode has the second material structure over the whole of the target surface of the anode around the predetermined focal spot region.

3. An X-ray source according to claim 1 or 2 wherein the first material structure differs from the second material structure by being of a different material emitting X-rays of a different charateristic wavelength.

4. An X-ray source according to claim 3 wherein the first material structure is of a first element and the second material structure is of a second element, wherein the second element is lighter than the first element in the periodic table.

5. An X-ray source according to claim 3 or 4 wherein the material of the first material structure is one of Cu, Mo, W, Co, Cr, Au, Ag and Fe.

6. An X-ray source according to claim 4 wherein the first material is Cu and the second material is C, Mg, Al, Si, Ca, Sc,V, Cr, Mn, Ti, Co, or Ni.

7. An X-ray source according to any preceding claim wherein the first material structure is substantially flat and the second material structure is rougher than the first material structure.

8. An X-ray source according to any preceding claim including a housing containing the anode and the cathode, wherein the inside of the housing is coated with a material different to the material of the focal spot.

9. An X-ray system comprising an X-ray source according to any preceding claim.

10. An X-ray system according to claim 9 further comprising an X-ray absorber for absorbing the characteristic X-rays emitted by the second material structure preferentially to the characteristic X-rays emitted by the first material structure.

11. An X-ray system according to claim 9 or 10 wherein the X-ray system includes an optics system arranged to pass the characteristic X-rays emitted by the first material structure preferentially to the characteristic X-rays emitted by the second material structure.

12. An X-ray system according to claim 11 wherein the optics includes an X-ray mirror, an X-ray lens and/or a crystal monochromator.

13. An X-ray system according to any of claims 9 to 11 further comprising an energy discriminating x-ray detector for discriminating between X-rays at the the target characteristic wavelength and X-rays emitted at other wavelengths.

14. An X-ray system according to any of claims 11 to 13 for supplying a predetermined useful characteristic radiation component, wherein
the target material produces at least two characteristic radiation components including the predetermined useful characteristic radiation component and another characteristic radiation component, and
the X-ray system is arranged to reduce the effect of the other characteristic radiation component compared with the predetermined useful characteristic radiation component.

15. An X-ray system according to any of claims 9 to 14 for measuring X-ray diffraction or X-ray scattering, comprising:

the X-ray source generating a beam of X-rays from the focal spot;
a sample stage for a sample; and
an X-ray detector for measuring X-rays from the source scattered or diffracted from the sample.

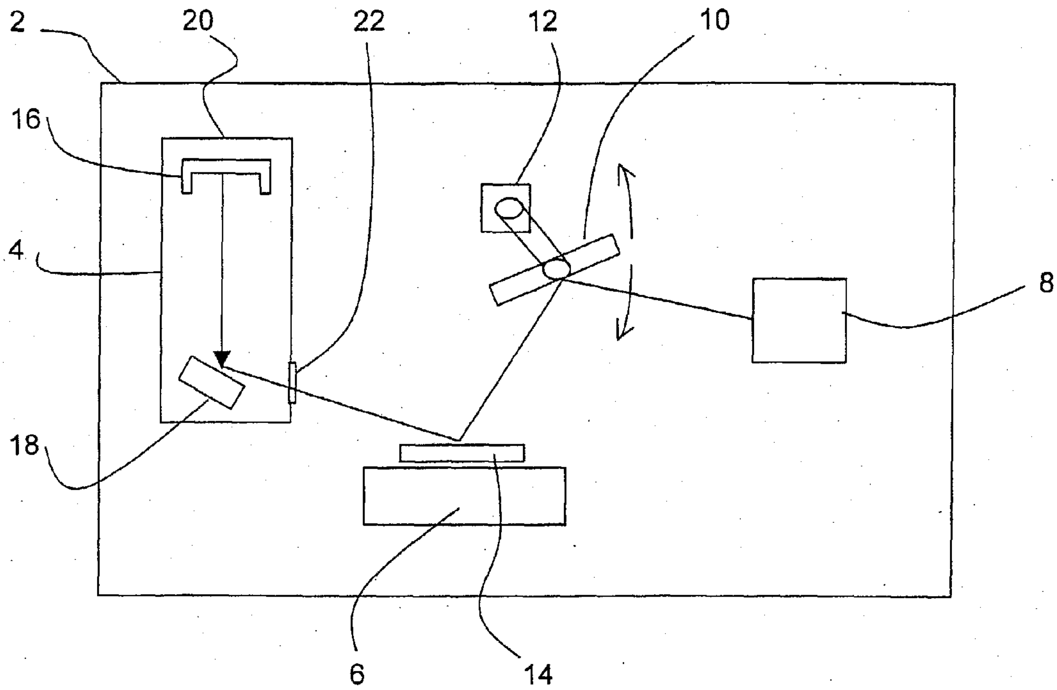

Fig. 1

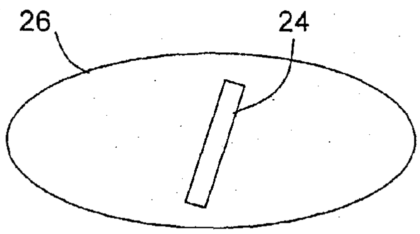

Fig. 2

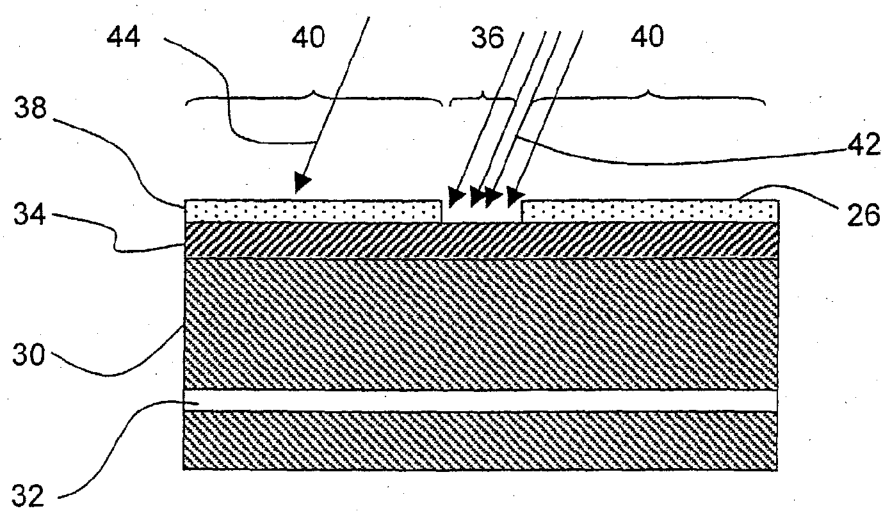
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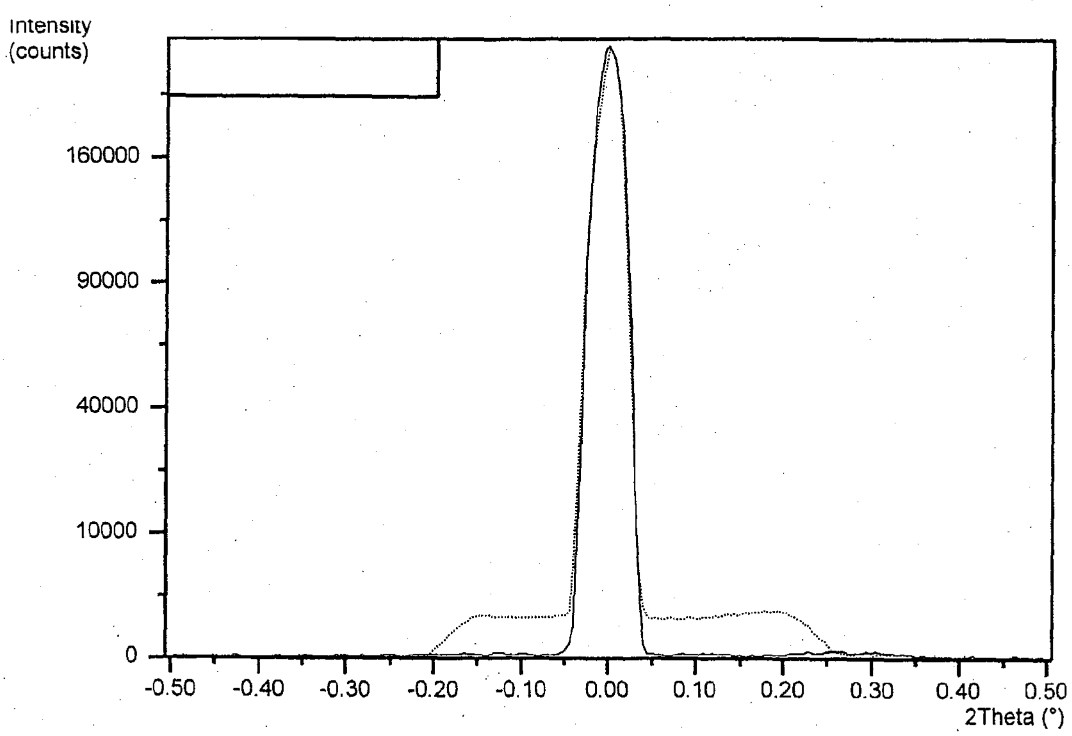
Fig. 3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90000
40000
10000
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-0.40
-0.30
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-0.10
0.00
0.10
0.20
0.30
0.40
0.50
2Theta (°)

Fig. 4

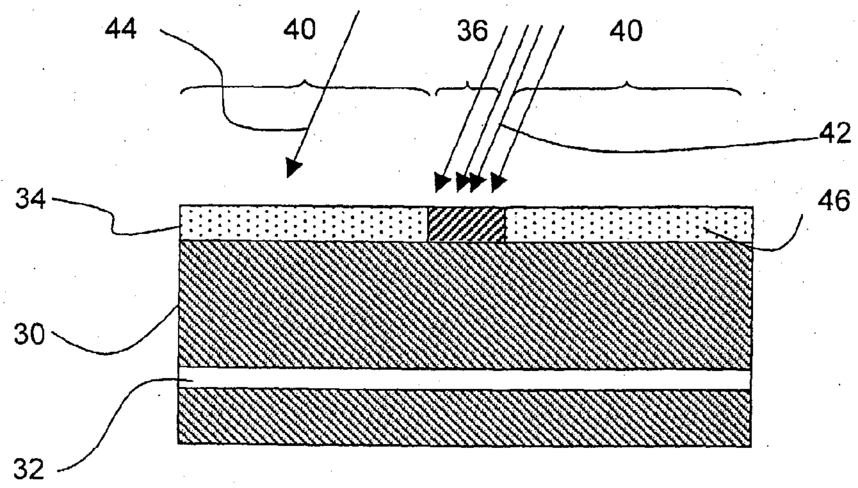

Fig. 5

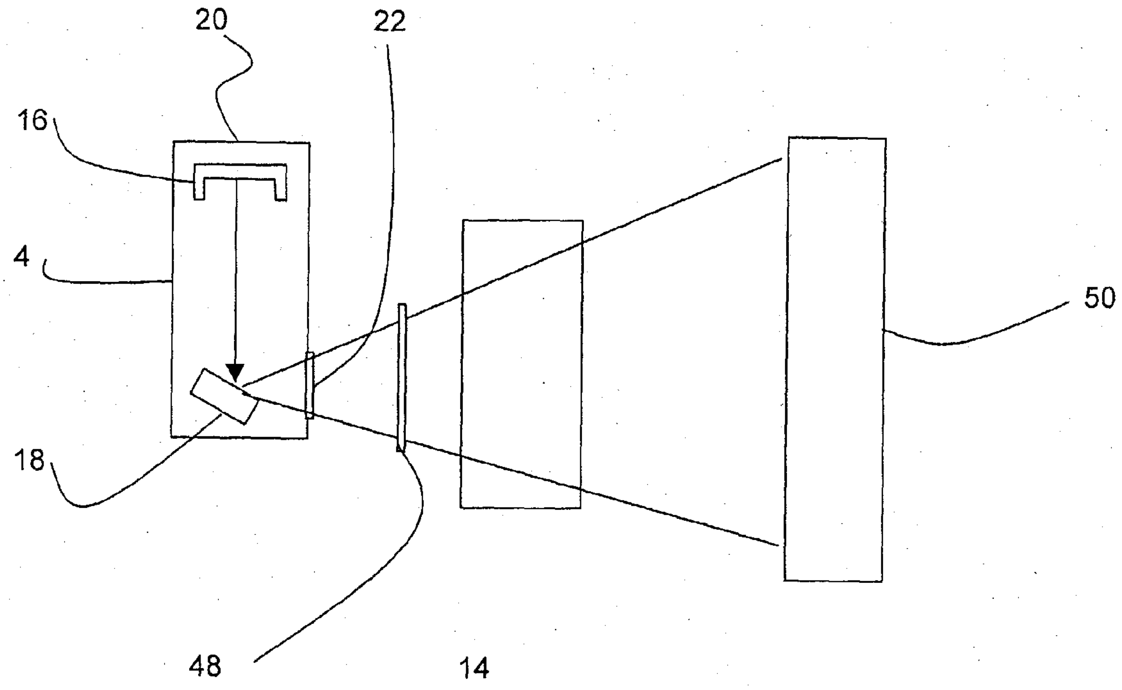

Fig. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 25 3244

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X Y	US 2003/086533 A1 (JANIK GARY ET AL) 8 May 2003 (2003-05-08) * paragraphs [0040], [0041], [0050]; figures 6,9a *	1-6,9, 11,12, 14,15 8,13	H01J37/08 H01J35/14
Y A	EP 0 432 568 A (GENERAL ELECTRIC COMPANY) 19 June 1991 (1991-06-19) * page 2, column 2, lines 21-25 *	8 4,5	
Y	DREVER J I; FITZGERALD R W: "Fluorescence elimination in X-ray diffractometry with solid state detectors" MATERIALS RESEARCH BULLETIN, vol. 5, February 1970 (1970-02), pages 101-107, XP009056018 USA * pages 103-106 *	13	
X	DE 22 03 403 A1 (SIEMENS AG) 9 August 1973 (1973-08-09) * page 2, paragraph 2 - page 4; figures 1,2 *	1-7,9,15	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H01J
X	US 3 795 832 A (HOLLAND W,US) 5 March 1974 (1974-03-05) * column 2, lines 4-22 * * column 5, line 66 - column 6, line 48; figures 1,2,6,7 *	1-6,9, 10,14	
X	US 4 573 185 A (LOUNSBERRY ET AL) 25 February 1986 (1986-02-25) * column 2, lines 16-47; figure 1 *	1-6,9,15	
X	DE 39 34 321 A1 (SIEMENS AG, 1000 BERLIN UND 8000 MUENCHEN, DE) 18 April 1991 (1991-04-18) * column 1, line 66 - column 2, line 27; figure 1 *	1,2,7,9, 10	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	26 October 2005	Krauss, J

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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26-10-2005

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003086533 A1	08-05-2003	WO 03040714 A1	15-05-2003
EP 0432568 A	19-06-1991	JP 4144045 A	18-05-1992
DE 2203403 A1	09-08-1973	NONE	
US 3795832 A	05-03-1974	NONE	
US 4573185 A	25-02-1986	AT 394471 B	10-04-1992
		AT 179585 A	15-09-1991
		DE 3521787 A1	09-01-1986
		FR 2566961 A1	03-01-1986
		JP 61024134 A	01-02-1986
DE 3934321 A1	18-04-1991	NONE	

EPO FORM P0459

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