

METHOD AND APPARATUS FOR X-RAY DIFFRACTION ANALYSIS

FIELD OF THE INVENTION

5 The invention concerns a method for transmission mode X-ray diffraction analysis of a sample by means of an apparatus comprising an X-Ray radiation source that provides X-ray radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted
10 by said sample.

The invention also concerns an apparatus for transmission mode X-ray diffraction analysis of a sample, said apparatus including an X-Ray radiation source that provides X-ray
15 radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted by said sample.

The invention further concerns a method for transmission
20 mode X-ray diffraction analysis of a plurality of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and diffracted by said sample.

25 The invention further concerns an apparatus for transmission mode X-ray diffraction analysis of a plurality of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and diffracted by a sample.

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BACKGROUND OF THE INVENTION

Combinatorial chemistry refers to techniques to fabricate, test, and store the resulting data for a material library
35 containing tens, hundreds or even thousands different materials or compounds. Combinatorial investigations require rapid screening techniques to test and evaluate variations

of composition, structure and property within a material library. X-ray diffraction analysis is one of the most suitable screening techniques of solid state properties because abundant information can be revealed from the diffraction pattern and X-ray diffraction analysis is fast and non-destructive.

Diffraction pattern analysis plays an important role in such diverse applications as solving molecular structures, identifying compounds, and the fabrication of materials. If a compound can be made to crystallize into sizeable crystals, diffraction patterns from single crystals can provide a good deal of information about the crystal structure of the compound. Many compounds, however, can only be obtained as powders. Although a powder diffraction pattern yields much less information than that generated by a single crystal, it is unique to each substance with a particular crystal structure, and is therefore highly useful for purposes of identification.

Scattering of incident X-ray radiation from a sample of material can yield information about the atomic structure of the material. When such a beam of radiation strikes a sample, a pattern of diffracted radiation is created, which has a spatial intensity distribution that depends on the wavelength of the incident radiation and the atomic structure of the material and that can be recorded on a suitable detector such as a point detector, a 1D detector or a 2D detector. Diffraction analysis is the method of choice for studying crystalline materials, crystallization behavior and liquid, gel or solid phase, or phase transitions of materials.

In certain circumstances, it is desirable to perform a sample analysis using transmission mode X-ray diffraction analysis due to various reasons, including the need for low

angle diffraction, and advantages when testing thin samples or samples in liquid environments.

A problem that is encountered with known powder diffraction analysis equipment using a 2D detector is that during detection of the diffraction radiation, single diffraction spots and arcs are often observed instead of rings, especially when organic crystalline material (such as pharmaceuticals) is irradiated. This may be the result of the fact that not all lattice planes of the crystalline powder material have or not been exposed to X-ray radiation for the same time or same amount, because the crystals were not random oriented or only a few crystals were present. As a result, the peak intensities of the powder diffraction patterns recorded with a point or a 1D detector (one-dimensional detector) are not correct, and no representative 1D-powder diffraction pattern (intensity vs. diffraction angle 2θ .) is created. This causes problems during comparison of diffraction patterns for identification.

SUMMARY OF THE INVENTION

Embodiments of the present disclosure aim to provide a method and an apparatus of the above mentioned kind which make possible to perform X-ray transmission diffraction analysis with significantly improved particle statistics. Particle statistics is a term known in the art. With achieving "improved particle statistics" is meant obtaining a powder diffraction pattern with more reliable diffracted beam intensities, or diffracted beam intensities with reduced standard deviation.

Furthermore, embodiments of the present disclosure aim to provide a method and an apparatus of the above mentioned kind which make possible to perform X-ray transmission diffraction analysis of a plurality of samples in a time effective way.

According to a first aspect, there is provided a method for transmission mode X-ray diffraction analysis of a sample by means of an apparatus comprising an X-Ray radiation source that provides X-ray radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said method comprising (a) placing a sample to be analyzed on a substrate which is adapted for receiving and holding said sample, said substrate being transparent to X-ray radiation, (b) generating by means of an X-Ray radiation source a strip-shaped X-Ray beam the central part of which extends along a plane, (c) positioning said substrate and thereby said sample in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam, (d) effecting the following movements of the substrate with respect to the above mentioned initial position thereof: (d.1) a rotation of said substrate and thereby of said sample around a rotation axis which is perpendicular to said substrate, said rotation covering a predetermined rotation angle, and (d.2) a tilting of said substrate and thereby of said sample around a tilting axis and over a tilting angle defined as the angle that said rotation axis forms with said plane through which the central part of said beam extends, said tilting axis lying in said plane through which the central part of said beam extends and being perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a first predetermined value and a second predetermined value, and (e) detecting with said detector X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the substrate are effected.

According to a second aspect, there is provided an apparatus for transmission mode X-ray diffraction analysis of a sample, said apparatus including an X-Ray radiation source that provides X-ray radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said apparatus comprising (a) an X-Ray radiation source which is adapted to provide a strip-shaped X-ray beam the central part of which extends along a plane, (b) a substrate which is adapted for receiving and holding a sample to be analyzed, said substrate being transparent to X-ray radiation, (c) means for positioning said substrate and thereby said sample in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam, (d) means for effecting the following movements of the substrate with respect to the above mentioned initial position: (d.1) a rotation of said substrate and thereby of said sample around a rotation axis which is perpendicular to said substrate, said rotation covering a predetermined rotation angle, and (d.2) a tilting of said substrate and thereby of said sample around a tilting axis which lies in said plane through which the central part of said beam extends and which is perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a tilting angle zero defined by said initial position of said substrate and a predetermined value greater than zero, and (e) a detector for detecting X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the substrate are effected.

The main advantage obtained with the method and apparatus according to the first and second aspect is that they make it possible to perform X-ray transmission diffraction analysis of a sample with significantly improved particle statistics.

According to a third aspect, there is provided a method for transmission mode X-ray diffraction analysis of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said method comprising (a) placing a plurality of samples to be analyzed on respective substrate elements of a sample holder, (b) generating by means of an X-Ray radiation source a strip-shaped X-ray beam the central part of which extends along a plane, (c) placing said sample holder in an apparatus comprising means for moving and positioning said sample holder so that a pre-selected sample can be positioned in the path of said beam, (d) positioning a pre-selected substrate element of said sample holder and thereby the sample on that substrate element in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam, (d) effecting the following movements of said pre-selected substrate element with respect to the above mentioned initial position: (d.1) a rotation of said pre-selected substrate element and thereby of said sample around a rotation axis which is perpendicular to said substrate element, said rotation covering a predetermined rotation angle, and (d.2) a tilting of said pre-selected substrate element and thereby of said sample around a tilting axis and over a tilting angle defined as the angle that said rotation axis forms with said plane through which the central part of said beam extends, said tilting axis lying in said plane through which the central part of said beam extends and being perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a first predetermined value and a second predetermined value, and (e) detecting with said detector X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the pre-selected substrate element are effected.

According to a fourth aspect, there is provided an apparatus for transmission mode X-ray diffraction analysis of a plurality of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and diffracted by a sample, said apparatus comprising (a) an X-Ray radiation source which is adapted to provide a strip-shaped X-ray beam the central part of which extends along a plane, (b) a sample holder comprising a plurality of substrate elements each of which is adapted for receiving and holding a sample to be analyzed, each of said substrate elements being transparent to X-ray radiation, (c) means for positioning a pre-selected substrate element and thereby a sample placed on that element in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam, (d) means for effecting the following movements of said pre-selected substrate element with respect to the above mentioned initial position thereof: (d.1) a rotation of said pre-selected substrate element and thereby of said sample around a rotation axis which is perpendicular to said substrate element, said rotation covering a predetermined rotation angle, and (d.2) a tilting of said pre-selected substrate element and thereby of said sample around a tilting axis which lies in said plane through which the central part of said beam extends and which is perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a tilting angle zero defined by said initial position of said substrate element and a predetermined value greater than zero, and (e) a detector for detecting X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the substrate element are effected.

The main advantage obtained with the method and apparatus according to the third and fourth aspect is that they make it possible to perform X-ray transmission diffraction analysis of a plurality of samples with significantly improved particle statistics and in a time effective way.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject invention will now be described in terms of its preferred embodiments with reference to the accompanying

drawings. These embodiments are set forth to aid the understanding of the invention, but are not to be construed as limiting.

- 5 Fig. 1 shows a schematic perspective view of a sample container 11 of multiple-sample holder 12 shown by Fig. 10 and of a strip-shaped X-ray beam 24 which irradiates a sample placed on a substrate 19.
- 10 Fig. 2 shows a schematic cross-sectional view of a sample container 11 taken along a plane which passes through symmetry axis 15 (shown in Fig. 1) of sample container 11 and which is the plane in which X-ray beam 24 extends.
- 15 Fig. 3 shows a schematic top view of sample container 11.
- Fig. 4 shows a schematic cross-sectional view of a sample container 11 taken along a plane which passes through symmetry axis 15 and which is perpendicular to the plane in which X-ray beam 24 extends. In this view sample container 11 is at an initial position with a tilting angle equal to zero.
- 20 Fig. 5 shows a schematic cross-sectional view of sample container 11 shown in Figures 1 to 4, but in this view sample container 11 is in a tilted position with a tilting angle T between the symmetry axis 15 of sample container 11 and the plane in which X-ray beam 24 extends.
- 25 Fig. 6 shows a schematic cross-sectional view of the structure of a first embodiment of an apparatus for carrying out a method according to the invention.
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- Fig. 7 shows a schematic cross-sectional view of the structure of a second embodiment of an apparatus for carrying out a method according to the invention.
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- Fig. 8 shows a schematic cross-sectional view of the structure of a third embodiment of an apparatus for carrying out a method according to the invention.
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- Fig. 9 shows a schematic cross-sectional view of the structure of a fourth embodiment of an apparatus for carrying out a method according to the invention.
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- Fig. 10 shows a schematic perspective view of an apparatus according to the invention for performing transmission mode X-ray diffraction analysis of a plurality of samples.
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- Figure 11 shows an X-Ray diffraction pattern which serves as reference for evaluating the quality of diffraction patterns obtained with different methods.
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- Fig. 12 shows an X-Ray diffraction pattern obtained with a stationary sample.
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- Fig. 13 shows an X-ray diffraction pattern obtained with a sample that is rotated 360 degrees during the detection of the radiation diffracted by a sample.
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- Fig. 14 shows an X-ray diffraction pattern obtained with a sample that is tilted over a certain tilting angle and rotated 360 degrees during the detection of the radiation diffracted by a sample.

- Fig.15 shows for the purpose of comparison 3 X-ray diffraction patterns obtained under the following conditions: the lower diffraction pattern is obtained with a stationary sample, the diffraction pattern in the center is obtained when the sample is rotated only during the measurement, the upper diffraction pattern is obtained with a sample that is rotated and tilted during the measurement.
- 10 Fig. 16 shows a schematic cross-sectional view of an embodiment of a sample container 11 wherein a foil 19 is the bottom wall of the sample container.

REFERENCE NUMERALS IN DRAWINGS

- 15
- 11 sample container / single well / a well of a multiple-well tray
- 12 multiple-sample holder / multiple-well tray
- 13 sample volume / sample layer
- 20 14 inner surface of the bottom wall 19 of sample container 11
- 15 symmetry axis of sample container 11
- 16 center of upper opening of sample container 11
- 17 center of planar substrate or substrate element 19
- 25 /center of the bottom wall 19
- 18 side wall of sample container 11
- 19 sample holding substrate / sample holding substrate element / bottom wall of sample container 11 / foil
- 20 primary X-ray beam
- 30 21 X-ray source
- 22 detector
- 23 monochromator for focusing X-ray beam onto a line segment
- 24 strip shaped X-ray beam directed onto sample
- 35 25 chamber
- 26 diffracted X-ray beam

27 slice of the sample / slice of volume 13 irradiated by
beam 24
28 tilting axis
29 rotation axis
5 30 detector circle

31 table for rotating and tilting multiple-sample holder
12
40 line segment
10 41 X-ray tube
42 shutter
43 Soller slit
44 curved monochromator
45 slit
15 46 slit
47 sample holding substrate
48 diffracted beam
49 Beryllium window
51 anode wire
20 52 delay line
53 position sensitive detector
54 circumference of the diffractometer / focusing circle
61 mounting plate
62 edge of mounting plate
25 63 edge of mounting plate
71 support frame
72 guide rail
73 guide rail
81 support frame
30 82 support
83 support
84 motor
85 mechanical transmission element
86 mechanical transmission element
35 0 Bragg angle
T tilting angle

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

- 5 In the following description the term "sample" is used to designate a sample comprising one or more crystals as well as a powder sample. A "powder sample" is defined herein as a powder sample of a compound of which the diffraction or crystallization behavior is to be determined. Such a
- 10 compound may be a chemical substance, or a mixture of different substances. A compound may comprise an organic or organo-metallic molecular compound, such as a pharmaceutically active molecule or catalyst-ligand complex or a dimer, salt, ester, solvate or functional part thereof.
- 15 A powder sample of the present invention may also comprise a biomolecule, for instance a nucleic acid (such as DNA, RNA and PNA), a polypeptide, peptides, glycoprotein and other proteinaceous substances, a lipoprotein, protein-nucleic acid complex, carbohydrate, biomimetic or a functional part,
- 20 derivative and/or analogue thereof.

It is to be noted that the powder sample may indeed be in the form of a powder. The person skilled in the art of diffraction analysis understands, however, that a "powder

25 sample" also includes a number of crystals which are contained in a solid material, such as is the case for metals, polymers, etc. Thus, in the latter case, the powder sample appears as a solid material in one piece. Moreover, the person skilled in the art of diffraction analysis

30 understands that powder samples may comprise only a limited number of crystals.

EXAMPLE 1: FIRST EMBODIMENT OF A METHOD ACCORDING TO THE INVENTION

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A first embodiment of a method according to the invention for transmission mode X-ray diffraction analysis of a single

sample is described hereinafter with reference to Figures 1 to 5.

Fig. 1 shows a schematic perspective view of a sample container 11, which is e.g. a single well or one of the wells of a multiple-well tray 12 shown by Fig. 10, and of a strip-shaped X-ray beam 24 which irradiates a sample placed on a substrate 19 which is e.g. the bottom wall of sample container 11. Within the context of the invention the term "strip-shaped X-ray beam" means that this beam extends along a planar, strip-shaped irradiation region and that this beam has a cross section which is approximately rectangular.

Coordinate axis X, Y, Z which are normal to each other are shown in Fig. 1 for reference.

The region irradiated by X-ray beam is the volume over which the X-ray beam extends. If the X-ray beam has approximately the shape of a flat strip, then the shape of the irradiated region is strip shaped, that is the irradiated region has e.g. approximately the shape of a right rectangular prism, the length of the prism being much than its width and the width of the prism being much larger than its thickness.

The term "strip-shaped irradiation region" thus means that the length of the irradiated region is much larger than its width and that the width of the irradiated region is much larger than the thickness thereof.

In the attached drawings, and in particular in Figures 1, 2, 4 and 5, strip-shaped X-ray beam 24 is schematically represented as a plane, but in fact only the central part of the beam extends along a plane.

Fig. 2 shows a schematic cross-sectional view of sample container 11 of Fig. 1 taken along a plane parallel to the X-Z-plane and which passes through symmetry axis 15 (shown

in Fig. 1) of sample container 11, and which is the plane in which X-ray beam 24 extends. As shown by Fig. 2, sample container 11 defines a chamber 25 which extends between the bottom wall 19 and the upper end of sample container 11.
5 Chamber 25 is e.g. cylindrical and has a circular cross section.

Fig. 3 shows a schematic top view of sample container 11 in Fig. 1.

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Fig. 4 shows a schematic cross-sectional view of sample container 11 of Fig. 1 taken along a plane parallel to the Y-Z-plane and which passes through symmetry axis 15 and which is perpendicular to the plane in which X-ray beam 24
15 extends. In this view sample container 11 is at an initial position with a tilting angle equal to zero.

Fig. 5 shows a schematic cross-sectional view of sample container 11 similar to the view shown in Figure 4, but in
20 this view sample container 11 is in a tilted position with a tilting angle T between the symmetry axis 15 of sample container 11 and the plane in which X-ray beam 24 extends.

The first embodiment of a method according to the invention
25 comprises the following steps:

(A1) a sample to be analyzed is placed on planar substrate 19 which is adapted for receiving and holding a sample and which is transparent to X-ray radiation,
30

(B1) a strip-shaped X-ray beam 24 is generated by means of an X-ray radiation source 21 (not shown in Figures 1 to 5). As shown by Figures 1, 2, 4 and 5, the central part of beam 24 extends along a plane,
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(C1) the substrate 19 and thereby the sample placed thereon are positioned by suitable electro-mechanical means

in the initial position shown by Fig. 4 in which that sample lies in the path of X-ray beam 24. When substrate 19 is in that initial position a slice 27 (shown by Fig. 3) of a volume element 13, which contains the sample, and thereby a slice of the sample itself is irradiated by beam 24,

(D1) the following movements of substrate 19 with respect to the above mentioned initial position thereof are effected:

10 (D1.1) a rotation of substrate 19 and thereby of the sample around a rotation axis 29, and

(D1.2) a tilting of substrate 19 and thereby of the sample around a tilting axis 28 and over a tilting angle T which varies between a first predetermined value and a
15 second predetermined value, and

(E1) X-ray radiation transmitted through and diffracted by said sample is detected during a time interval over which the above mentioned movements of the substrate 19 are effected.
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The above described method further comprises analyzing the detected radiation.

25 The method described above is advantageous, because by irradiating a sample slice with the X-ray beam more crystals contribute to diffraction and this improves the particle statistics as compared to a method wherein the sample is irradiated with an X-ray beam focused in a point. Moreover,
30 by irradiating a sample slice with the X-ray beam the irradiated area is larger than when a point focused beam is used and this reduces the measuring time, because a time consuming scanning of the sample with a point focused beam is not required.

Substrate 19 is for instance a wall or a foil made e.g. of an X-Ray transparent plastic material, e.g. Kapton® (Du Pont) or Mylar® (Du Pont).

- 5 Substrate 19 is preferably also optically transparent, i.e. transparent to visible radiation.

Substrate 19 is e.g. the planar bottom wall 19 of sample container, e.g. of a sample container 11, which has e.g. a
10 cylindrical side wall 18 and which has an upper opening.

The sample to be analyzed is placed in a volume element 13 which as shown in Fig. 1 is e.g. a thin layer located at the bottom of sample container 11 and on substrate 19. Volume
15 element 13 is designated hereinafter also as sample layer 13. The sample preferably occupies a substantial part of or the entire volume of volume element 13.

The strip-shaped X-ray beam 24 illuminates a line segment 40
20 which is oriented in the direction of tilting axis 28. Line segment 40 preferably coincides with tilting axis 28 and extends between points A and B shown in Figures 1, 2 and 3.

In a preferred embodiment the length of line segment 40 is
25 adjusted to be equal to or approximately equal to the inner diameter of the sample container.

As shown by Figures 1, 2 and 3 line segment 40 lies at the intersection of X-ray beam 24 with a plane which contains
30 tilting axis 28. As shown by Fig. 3 the latter plane preferably passes through the center of sample layer 13.

Substrate 19 has an inner surface 14. The sample to be analyzed is placed on this surface of substrate 19.
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As shown by Fig. 1, sample container 11 has a symmetry axis 15 which is perpendicular to substrate 19 and which passes

through the center 17 of substrate 19 and through the center 16 of the upper opening of sample container 11.

As shown by Figures 1 and 4, in a preferred embodiment the
5 central axis of beam 24 coincides with the symmetry axis 15 and with rotation axis 29 of sample container 11 when the tilting angle T is zero.

As shown by Fig. 5, the tilting angle T is the angle that
10 rotation axis 29 forms with the plane through which the central part of beam 24 extends.

As shown by Figures 1 to 5, tilting axis 28 lies in the
plane through which the central part of beam 24 extends and
15 is perpendicular to rotation axis 29. As shown in particular by Figures 2, 4 and 5 tilting axis 28 passes preferably through the center of sample layer 13.

In a preferred embodiment the tilting of substrate 19 covers
20 a tilting angle T that varies between a tilting angle zero defined by the initial position of substrate 19 and a predetermined value greater than zero, e.g. 10 degrees.

In a preferred embodiment the rotation and tilting movements
25 of substrate 19 are performed simultaneously and continuously.

In another preferred embodiment the tilting movement of
substrate 19 is performed stepwise and a rotation thereof
30 covering a predetermined rotation angle is performed for each tilting step.

Substrate 19 is preferably a planar wall or foil.

35 In a preferred embodiment the central axis of beam 24 coincides with the symmetry axis 15 and with rotation axis 29 of sample container 11 when the tilting angle T is zero.

In another preferred embodiment the central axis of beam 24 and rotation axis 29 pass through the center 17 of planar substrate 19 when the latter is in the above-mentioned
5 initial position.

In a preferred embodiment the radiation source 21 and thereby beam 24 are stationary and substrate 19 is moved with respect to beam 24.

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In a preferred embodiment the rotation of substrate 19 covers an angle which is equal to or close to 360 degrees.

In another embodiment the rotation of substrate 19 covers an
15 angle which is less than 360 degrees.

In another embodiment the rotation of substrate 19 covers an angle which is greater than 360 degrees.

20 **EXAMPLE 2: FIRST EMBODIMENT OF AN APPARATUS ACCORDING TO THE INVENTION**

Fig. 6 shows a schematic cross-sectional view of the structure of a first embodiment of an apparatus for carrying
25 out the above described method. The cross-section shown by Fig. 6 is taken along a plane parallel to the plane YZ in Fig. 1 and passing through the center of substrate element 19. The apparatus shown by Fig. 6 comprises an X-ray radiation source 21 that provides X-ray beam 24 for
30 irradiating a sample placed on a substrate 19 and a detector 22 for detecting X-ray radiation 26 transmitted through and diffracted by the sample. Fig. 6 shows the diffraction angle 2θ . θ is the Bragg angle.

35 The apparatus represented in Fig. 6 is a diffractometer and comprises an X-ray radiation source 21 which is adapted to provide a strip-shaped X-ray beam 24 the central part of

which extends along a plane as shown in Figures 1, 2, 4 and 5,

The apparatus schematically represented in Fig. 6 further
5 comprises electro-mechanical means (not shown in Fig. 6) for

- positioning substrate 19 and thereby the sample on that element in an initial position in which that sample lies in the path of beam 24 and a slice 27 (shown by Fig. 3)
10 of a volume element 13, which contains the sample, and thereby a slice of the sample itself is irradiated by beam 24,

- effecting the following movements of the substrate
15 19 with respect to the above mentioned initial position:

a rotation of substrate 19 and thereby of the sample around a rotation axis 29 which is perpendicular to the substrate, the rotation covering a predetermined rotation angle, and

20 a tilting of substrate 19 and thereby of the sample around a tilting axis 28 which lies in the plane through which the central part of beam 24 extends and which is perpendicular to rotation axis 29, the tilting covering a tilting angle T that varies between a tilting angle zero
25 defined by the initial position of substrate 19 and a predetermined value greater than zero, e.g. 10 degrees.

The apparatus schematically represented in Fig. 6 further comprises a detector 22 for detecting X-ray radiation
30 transmitted through and diffracted by the sample during a time interval over which the above mentioned movements of the substrate 19 are effected.

As already described with reference to Figures 1-4, in the
35 embodiment shown by Fig. 6 strip-shaped X-ray beam 24 illuminates a line segment 40 which is oriented in the direction of tilting axis 28. Line segment 40 preferably

coincides with tilting axis 28 and extends between points A and B shown in Figures 1, 2 and 3.

5 In a preferred embodiment the length of line segment 40 is adjusted to be equal to or approximately equal to the inner diameter of the sample container.

Substrate 19 is e.g. as described above with reference to Figures 1 to 5.

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Substrate 19 is e.g. the planar bottom wall 19 of sample container, e.g. of a sample container 11, which has e.g. a cylindrical side wall 18 and which has an upper opening.

15 Fig. 16 shows a schematic cross-sectional view of an embodiment of a sample container 11 wherein a foil 19 is the bottom wall of the sample container. The cross-section shown by Fig. 16 is taken along a plane parallel to the plane XZ in Fig. 1 and passing through the center of substrate
20 element 19.

As shown in the embodiment of sample container 11 represented in Fig. 16, the bottom wall of sample container 11, and therefore the substrate on which sample layer 13 is
25 deposited, is preferably a foil 19, e.g. a Kapton® foil, which closes the lower opening of a container 11 of the type shown in Figures 1-5 and which is transparent to X-ray radiation. In the embodiment shown in Fig. 16, a mounting plate 61 is used to fix foil 19 on the lower end of sample
30 container 11. For this purpose, sample container 11, foil 19 and mounting plate 61 are assembled together as shown by Fig. 16. Mounting plate 61 has e.g. a circular opening which is aligned with the cross section of chamber 25 of sample container 11 and thereby allows passage of a beam diffracted
35 by a sample deposited on foil 19 in chamber 25. As shown by Fig. 16, the circular opening has edges 62, 63 each of which forms an angle of e.g. about 45 degrees with the plane where

foil 19 lies. This shape of edges 62, 63 allows an enhancement of the region through which the diffracted beam passes.

- 5 When substrate 19 is in the above-mentioned initial position, the central axis of beam 24 and rotation axis 29 pass through the center 17 of substrate 19.

In a preferred embodiment detector 22 is a movable detector.

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In another preferred embodiment detector 22 is a stationary detector which lies in a portion of a spherical surface.

- 15 In a preferred embodiment of the above-described apparatus, the means for moving sample substrate 19 are adapted for effecting a rotation of substrate 19 covering an angle which is equal to or close to 360 degrees.

- 20 In another embodiment the rotation of substrate 19 covers an angle which is less than 360 degrees.

In another embodiment the rotation of substrate 19 covers an angle which is greater than 360 degrees.

25 **EXAMPLE 3: SECOND EMBODIMENT OF AN APPARATUS ACCORDING TO THE INVENTION**

- Fig. 7 shows a schematic cross-sectional view of the structure of a second embodiment of an apparatus for carrying out the above described method. The cross-section shown by Fig. 7 is taken along a plane parallel to the plane YZ in Fig. 1 and passing through the center of substrate element 19. The apparatus shown by Fig. 7 is a diffractometer and comprises basically the components of the apparatus described above with reference to Fig. 6 and in addition comprises means for focusing X-ray beam 24, e.g. a Germanium (111) monochromator 23 located in the path of beam
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24 and between X-ray source 21 and substrate 19 which holds the sample to be analyzed. In this embodiment detector 22 is a stationary detector which lies in a portion of a spherical surface 30.

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EXAMPLE 4: THIRD EMBODIMENT OF AN APPARATUS ACCORDING TO THE INVENTION

Fig. 8 shows a schematic cross-sectional view of the structure of a third embodiment of an apparatus for carrying out the above described method. The cross-section shown by Fig. 8 is taken along a plane parallel to the plane YZ in Fig. 1 and passing through the center of substrate element 19. The apparatus shown by Fig. 8 comprises the components of the diffractometer described above with reference to Fig. 7 with exception of the detector. In the embodiment shown by Fig. 8, the detector comprises at least one movable detector 22.

20 **EXAMPLE 5: FOURTH EMBODIMENT OF AN APPARATUS ACCORDING TO THE INVENTION**

Fig. 9 shows a schematic cross-sectional view of the structure of a fourth embodiment of an apparatus for carrying out the above described method. The cross-section shown by Fig. 9 is taken along a plane parallel to the plane YZ in Fig. 1 and passing through the center of substrate element 19. The apparatus shown by Fig. 9 has basically the structure of the apparatus described above with reference to Fig. 7.

A diffractometer according to this fourth embodiment comprises the following components arranged as shown in Fig. 9:

- 35 an X-Ray tube 41,
 a curved Germanium (111) monocromator 44 mounted on the circumference 54 of the diffractometer,

a position sensitive detector 53,
a shutter 42,
a Soller slit 43,
slits 45 and 46,
5 a substrate 47 that holds a sample, and
a Beryllium window 49.

Monocromator 44 receives a primary X-ray beam 20 provided by
X-ray tube 41 and supplies a convergent monochromatic $K\alpha_1$ X-
10 ray beam 24 which is focused in 20 at the point O. With the
arrangement shown in Fig. 9 diffracted beams 48 diffracted
by a sample placed on substrate 47 are focused on a circle
54 of radius $r = 130$ millimeter within a range 20 of about
40 degrees. This is advantageous for the use of a stationary
15 curved position sensitive detector (PSD) 53. Detector 53
comprises a delay line 52. The anode wire 51 of position
sensitive detector 53 lies on a circle segment which
coincides with a segment of the focusing circle 54 and the
diffracted beams 48 always enter perpendicular to the
20 counter surface in contrast to conventional Guinier or
Seemann-Bohlin techniques.

The apparatus shown by Fig. 9 comprises electro-mechanical
means for positioning and moving sample holding substrate
25 47. The latter means are as described above for the
embodiment described with reference to Fig. 6.

**EXAMPLE 6: SECOND EMBODIMENT OF A METHOD ACCORDING TO THE
INVENTION**

30 A second embodiment of a method according to the invention
for transmission mode X-ray diffraction analysis is
described hereinafter with reference to Figures 1 to 5 and
10. This method serves for transmission mode X-ray
35 diffraction analysis of a plurality of samples by means of
an apparatus comprising an X-ray radiation source 21 and a

detector 22 for detecting X-ray radiation transmitted through and diffracted by the sample.

Strip shaped X-ray beam 24, sample layer 13, line segment 40
5 and tilting axis 28 are as described above with reference to Figures 1-5.

Fig. 10 shows a schematic perspective view of an apparatus
10 for performing this second embodiment of a method according to the invention.

The second embodiment of a method according to the invention comprises the following steps:

15 (A2) a plurality of samples to be analyzed are placed on respective planar substrate elements 19 of a multiple-sample holder 12. Each of substrate elements 19 is adapted for receiving and holding a sample and is transparent to X-ray radiation,

20 (B2) a strip-shaped X-ray beam 24 is generated by means of an X-Ray radiation source 21 (shown in Fig. 10). As shown by Figures 1, 2, 4 and 5, the central part of beam 24 extends along a plane,

25 (C2) a multiple-sample holder 12 is placed in an apparatus comprising means for moving and positioning multiple-sample holder 12 so that a pre-selected substrate element 19 can be positioned in the path of beam 24. When
30 the pre-selected substrate element 19 is in that initial position a slice 27 (shown by Fig. 3) of a volume element 13, which contains the sample, and thereby a slice of the sample itself is irradiated by beam 24,

35 (D2) a pre-selected substrate element 19 of said multiple-sample holder 12 is positioned in an initial position in which said sample lies in the path of said beam

24 and a slice 27 of said sample is irradiated by said beam 24,

(E2) the following movements of said pre-selected
5 substrate element 19 with respect to the above mentioned initial position thereof are effected:

(E2.1) a rotation of the pre-selected substrate element 19 and thereby of the sample around a rotation axis 29, and

10 (E2.2) a tilting of the pre-selected substrate element 19 and thereby of the sample around a tilting axis 28 and over a tilting angle T which varies between a first predetermined value and a second predetermined value, and

15 (F2) X-ray radiation transmitted through and diffracted by said sample is detected during a time interval over which the above mentioned movements of the pre-selected substrate 19 are effected.

20 The above described method further comprises analyzing the detected radiation.

The positioning of the pre-selected substrate element 19 described above under (D2) is effected by suitable
25 translation and/or rotation movements of multiple-sample holder 12 that bring that substrate element to the above-mentioned initial position.

The movements described above under (E2.1) and (E2.2) are
30 effected by corresponding movements of multiple-sample holder 12.

Substrate element 19 is for instance a wall or a foil made e.g. of an X-Ray transparent plastic material, e.g. Kapton®
35 (Du Pont) or Mylar® (Du Pont).

Substrate element 19 is preferably also optically transparent, i.e. transparent to visible radiation.

As shown by Figures 2, 4 and 5 substrate element 19 is e.g. the planar bottom wall of sample container, e.g. of a sample container 11, which has e.g. a cylindrical side wall 18 and which has an upper opening.

The sample to be analyzed is placed in a volume element 13 which as shown in Fig. 1 is e.g. a thin layer located at the bottom of sample container 11 and on substrate element 19. Volume element 13 is designated hereinafter also as sample layer 13. The sample can but must not necessarily occupy the entire volume of volume element 13.

As shown by Fig. 1, sample container 11 has a symmetry axis 15 which is perpendicular to substrate element 19 and which passes through the center 17 of substrate element 19 and through the center 16 of the upper opening of sample container 11.

As shown by Figures 1, 4 and 5, in a preferred embodiment rotation axis 29 coincides with the symmetry axis 15 of sample container 11.

As shown by Fig. 5, the tilting angle T is the angle that rotation axis 29 forms with the plane through which the central part of beam 24 extends.

As shown by Figures 1 to 5, tilting axis 28 lies in the plane through which the central part of beam 24 extends and is perpendicular to rotation axis 29. As shown in particular by Figures 2, 4 and 5 tilting axis 28 passes preferably through the center of sample layer 13.

In a preferred embodiment the tilting of substrate element 19 covers a tilting angle T that varies between a tilting

angle zero defined by the initial position of substrate 19 and a predetermined value greater than zero, e.g. 10 degrees.

- 5 In a preferred embodiment the rotation and tilting movements of substrate element 19 are performed simultaneously and continuously.

10 In another preferred embodiment the tilting movement of substrate element 19 is performed stepwise and a rotation thereof covering a predetermined rotation angle is performed for each tilting step.

15 Substrate element 19 is preferably a planar wall or foil.

In a preferred embodiment the rotation axis 29 coincides with the symmetry axis 15 of sample container 11.

20 In another preferred embodiment the central axis of beam 24 and rotation axis 29 pass through the center 17 of planar substrate element 19 when the latter is in the above-mentioned initial position.

25 In a preferred embodiment the radiation source 21 and thereby beam 24 are stationary and substrate element 19 is moved with respect to beam 24.

30 In a preferred embodiment the rotation of substrate 19 covers an angle which is equal to or close to 360 degrees.

In another embodiment the rotation of substrate 19 covers an angle which is less than 360 degrees.

35 In another embodiment the rotation of substrate 19 covers an angle which is greater than 360 degrees.

EXAMPLE 7: FOURTH EMBODIMENT OF AN APPARATUS ACCORDING TO THE INVENTION

Fig. 10 shows a schematic perspective view of an apparatus according to the invention for performing transmission mode X-ray diffraction analysis of a plurality of samples. This apparatus comprises an X-ray radiation source 21 that provides X-ray beam 24 for irradiating a sample and a detector 22 for detecting X-ray radiation 26 transmitted through and diffracted by the sample.

The apparatus shown by Fig. 10 comprises:

an X-ray radiation source 21 which is adapted to provide a strip-shaped X-ray beam 24 the central part of which extends along a plane as shown in Figures 1, 2, 4 and 5,

a multiple-sample holder 12 which comprises a plurality of substrate elements 19 each of which is adapted for receiving and holding a sample to be analyzed. Each of said substrate elements 19 is transparent to X-ray radiation,

electromechanical-means for positioning a pre-selected substrate element of multiple-sample holder 12 and thereby a sample placed on that element in an initial position in which the sample lies in the path of said beam 24 and a slice 27 (shown by Fig. 3) of a volume element 13, which contains the sample, and thereby a slice of the sample itself is irradiated by beam 24, and

effecting the following movements of the pre-selected substrate element 19 with respect to the above mentioned initial position thereof:

- a rotation of the pre-selected substrate element 19 and thereby of the sample around a rotation axis 29 which is perpendicular to the pre-selected substrate element, said rotation covering a predetermined rotation angle, and

- a tilting of the pre-selected substrate element 19 and thereby of the sample around a tilting axis 28 which lies in the plane through which the central part of beam 24 extends and which is perpendicular to rotation axis 29, said tilting covering a tilting angle T that varies between a tilting angle zero defined by said initial position of said substrate element 19 and a predetermined value greater than zero, and

a detector 22 for detecting X-ray radiation transmitted through and diffracted by the sample during a time interval over which the above mentioned movements of the substrate element 19 are effected.

The above mentioned electromechanical-means comprise e.g. a table 31 for rotating and tilting multiple-sample holder 12 for effecting the above-mentioned movements. As shown by Fig. 10, table 31 comprises a movable support frame 71 which is adapted for receiving and holding multiple-sample holder 12, a guide rail 72 oriented in X-direction, a guide rail 73 oriented in Y-direction, and motors for moving support frame 71 on table 31 along guide rails 72 and 73 respectively. The apparatus shown in Fig. 10 further comprises means for rotating table 31 about rotation axis 29 which is perpendicular to the table 31. These means include motor and mechanical transmission means which are not shown in detail in Fig. 10. The apparatus shown in Fig. 10 further comprises tilting means for tilting table 31 about tilting axis 28. These tilting means comprise a support frame 81 which carries table 31 and the associated means for rotating table 31 around the rotating axis. As schematically shown in Fig. 10, support frame 81 is rotatably mounted on supports 82 and 83, and a motor 84 and mechanical transmission elements 85 and 86 allow to rotate support frame 81 about axis 29 of a desired angle and thereby to modify the tilting angle of table 31.

If the method according to the invention is not performed on a plurality samples on a multiple-sample holder 12, but on a sample contained in a single sample container 11, the apparatus required for positioning, rotating and tilting the
5 single sample container is much smaller than the one described above and comprises a sample container holder instead of table 31 and electro-mechanical means for positioning, rotating and tilting the sample holder.

10 Multiple-sample holder 12 comprises e.g. a matrix array of holes adapted for receiving respective sample containers 11 having the above described structure.

Substrate element 19 is e.g. as described above with
15 reference to Figures 1 to 5.

Substrate element 19 is preferably a planar wall or foil.

Substrate element 19 is e.g. the planar bottom wall 19 of
20 sample container, e.g. of a sample container 11, which has e.g. a cylindrical side wall 18 and which has an upper opening.

As already described with reference to Figures 1-4, in the
25 embodiment shown by Fig. 10 strip-shaped X-ray beam 24 illuminates a line segment 40 which is oriented in the direction of tilting axis 28. Line segment 40 preferably coincides with tilting axis 28 and extends between points A and B shown in Figures 1, 2 and 3.

30 In a preferred embodiment the length of line segment 40 is adjusted to be equal to, or approximately equal to the inner diameter of the sample container.

35 When substrate element 19 is in the above-mentioned initial position, the central axis of beam 24 and rotation axis 29 pass through the center 17 of substrate element 19.

In a preferred embodiment detector 22 is a movable detector.

In another preferred embodiment detector 22 is a stationary
5 detector which lies in a portion of a spherical surface.

In a preferred embodiment of the above-described apparatus,
the means for moving sample substrate element 19 are adapted
for effecting a rotation of substrate element 19 covering an
10 angle which is equal to or close to 360 degrees.

In another embodiment the rotation of substrate element 19
covers an angle which is less than 360 degrees.

15 In another embodiment the rotation of substrate element 19
covers an angle which is greater than 360 degrees.

In a preferred embodiment shown in Fig. 10 the apparatus
further comprises means for focusing X-ray beam 24, e.g. a
20 Germanium (111) monochromator 23 located in the path of beam
24 and between X-ray source 21 and pre-selected substrate
element 19 which holds the sample to be analyzed.

In a preferred embodiment the radiation source 21 and
25 thereby beam 24 are stationary and pre-selected substrate
element 19 is moved with respect to beam 24.

**MEASUREMENT RESULTS SHOWING THE IMPROVEMENT OBTAINED WITH
METHOD AND APPARATUS ACCORDING TO THE INVENTION**

30

The improvement obtained with the methods and apparatuses
according to the invention can be appreciated from the X-
ray-diffractograms shown by Figures 11 to 15. These are
diffractograms obtained for one of the same compound under
35 different measurement conditions. In Figures 11-15 the
vertical axis shows a parameter corresponding to the

intensity of the diffracted beam in arbitrary units (abbreviated a.u.).

As basis for evaluating the improvement of the measuring results with the methods and apparatus according to the invention, the reference diffractogram shown by Fig. 11 was obtained by measuring a sample in powder form contained in a capillary tube. The diffractograms shown by Figures 12 to 15 were obtained for one and the same sample of the compound having the diffractogram shown by Figure 11.

Figure 11 shows an X-ray diffraction pattern which serves as reference for evaluating the quality of diffraction patterns obtained with different methods.

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Fig. 12 shows an X-ray diffraction pattern obtained with a stationary sample. Compared with the diffractogram of Fig. 11, the diffractogram of Fig. 12 has much less diffracted peaks of radiation and some of these peaks have intensities which are disproportionately strong.

20

Fig. 13 shows an X-ray diffraction pattern obtained with a sample that is rotated 360 degrees during the detection of the radiation diffracted by a sample, but that is not tilted. Compared with the diffractogram of Fig. 12, the diffractogram of Fig. 13 has substantially more diffracted peaks of radiation, but not as many as the reference diffractogram of Fig. 11, and the intensity relationship of the peaks in Fig. 13 differ from the intensity relationship of the peaks in the reference diffractogram of Fig. 11.

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Fig. 14 shows an X-ray diffraction pattern obtained according to the invention - with a sample that is tilted over a certain tilting angle and rotated 360 degrees during the detection of the radiation diffracted by a sample. The diffracted peaks of radiation of this diffractogram

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correspond closely to those of the peaks of the reference diffractogram of Fig. 11.

Fig. 15 shows for the purpose of comparison 3 X-ray
5 diffraction patterns obtained under the following conditions:

the lower diffraction pattern in Fig. 15 is obtained with a stationary sample as for the obtention of the diffractogram of Fig. 12,

10 the diffraction pattern in the center of Fig. 15 is obtained when the sample is only rotated but not tilted during the measurement, as for the obtention of the diffractogram of Fig. 13,

the upper diffraction pattern in Fig. 15 is obtained with
15 a sample that is rotated and tilted during the measurement, as for the obtention of the diffractogram of Fig. 14.

Although a preferred embodiments of the invention have been described using specific terms, such description is for
20 illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.

- - - - -

Claims

1. A method for transmission mode X-ray diffraction analysis of a sample by means of an apparatus comprising an
5 X-Ray radiation source that provides X-ray radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said method comprising
- (a) placing a sample to be analyzed on a substrate
10 which is adapted for receiving and holding said sample, said substrate being transparent to X-ray radiation,
- (b) generating by means of an X-Ray radiation source a strip-shaped X-ray beam the central part of which extends along a plane,
- 15 (c) positioning said substrate and thereby said sample in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam,
- (d) effecting the following movements of the substrate
20 with respect to the above mentioned initial position thereof:
- (d.1) a rotation of said substrate and thereby of said sample around a rotation axis which is perpendicular to said substrate, said rotation covering a
25 predetermined rotation angle, and
- (d.2) a tilting of said substrate and thereby of said sample around a tilting axis and over a tilting angle defined as the angle that said rotation axis forms with said plane through which the central
30 part of said beam extends, said tilting axis lying in said plane through which the central part of said beam extends and being perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a first predetermined value and a second
35 predetermined value, and
- (e) detecting with said detector X-ray radiation transmitted through and diffracted by said sample during a

time interval over which the above mentioned movements of the substrate are effected.

2. A method according to claim 1, wherein said rotation and
5 tilting movements of said substrate are performed simultaneously and continuously.
3. A method according to claim 1, wherein said tilting
movement of said substrate is performed stepwise and a
10 rotation thereof covering a predetermined rotation angle is performed for each tilting step.
4. A method according to any of claims 1 to 3, wherein
said substrate is a planar substrate.
15
5. A method according to any of claims 1 to 4, wherein
the central axis of said beam and said rotation axis
pass through the center of said planar substrate
when the latter is in said initial position.
20
6. A method according to any of claims 1 to 5, wherein
said radiation source is stationary.
7. A method according to any of claims 1 to 6, wherein
25 said rotation of substrate covers an angle which is equal to or close to 360 degrees.
8. A method according to any of claims 1 to 6, wherein
said rotation of substrate covers an angle which is
30 less than 360 degrees.
9. A method according to any of claims 1 to 6, wherein
said rotation of substrate covers an angle which is
greater than 360 degrees.
35
10. A method according to any of claims 1 to 9, wherein
said X-ray beam illuminates a line segment which
substantially lies in said tilting axis .

11. A method according to claim 10, wherein said substrate is the bottom wall of a sample container, and wherein the length of the line segment is adjusted to be equal to or approximately equal to the inner diameter of the sample container.

12. An apparatus for transmission mode X-ray diffraction analysis of a sample, said apparatus including an X-Ray radiation source that provides X-ray radiation for irradiating said sample and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said apparatus comprising

(a) an X-Ray radiation source which is adapted to provide a strip-shaped X-ray beam the central part of which extends along a plane,

(b) a substrate which is adapted for receiving and holding a sample to be analyzed, said substrate being transparent to X-ray radiation,

(c) means for positioning said substrate and thereby said sample in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam,

(d) means for effecting the following movements of the substrate with respect to the above mentioned initial position:

(d.1) a rotation of said substrate and thereby of said sample around a rotation axis which is perpendicular to said substrate, said rotation covering a predetermined rotation angle, and

(d.2) a tilting of said substrate and thereby of said sample around a tilting axis which lies in said plane through which the central part of said beam extends and which is perpendicular to said rotation axis, said tilting covering a tilting angle that varies between a tilting angle zero defined by said initial position of said substrate and a predetermined value greater than zero, and

(e) a detector for detecting X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the substrate are effected.

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13. An apparatus according to claim 12, wherein said substrate is a planar substrate.

10 14. An apparatus according to claim 13, wherein said planar substrate is the bottom wall of a sample container .

15 15. An apparatus according to claim 14, wherein the width of said sample container is approximately equal to the width of said X-ray beam .

20 16. An apparatus according to any of claims 12 to 15, wherein the central axis of said beam and said rotation axis pass through the center of said planar substrate when the latter is in said initial position.

17. An apparatus according to any of claims 12 to 16, wherein said detector is a movable detector.

25 18. An apparatus according to any of claims 12 to 16, wherein said detector is a stationary detector which lies in a portion of a spherical surface.

30 19. An apparatus according to any of claims 12 to 18, said apparatus further comprising first focusing means located in the path of said X-ray beam and between said source and said sample substrate .

35 20. An apparatus according to any of claims 12 to 19, wherein said radiation source is stationary.

21. An apparatus according to any of claims 12 to 20, wherein said rotation covers an angle which is equal to or close to 360 degrees.
- 5 22. An apparatus according to any of claims 12 to 20, wherein said rotation covers an angle which is less than 360 degrees.
- 10 23. An apparatus according to any of claims 12 to 20, wherein said rotation covers an angle which is greater than 360 degrees.
- 15 24. An apparatus according to any of claims 19 to 23, wherein said focusing means focus said X-ray beam in a line segment which substantially lies in said tilting axis .
- 20 25. An apparatus according to claim 24, wherein the length of the line segment is adjusted to be equal to or approximately equal to the inner diameter of the sample container.
- 25 26. Method for transmission mode X-ray diffraction analysis of a plurality of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and diffracted by said sample, said method comprising
- 30 (a) placing a plurality of samples to be analyzed on respective substrate elements of a sample holder ,
- (b) generating by means of an X-Ray radiation source a strip-shaped X-ray beam the central part of which extends along a plane,
- 35 (c) placing said sample holder in an apparatus comprising means for moving and positioning said sample holder so that a pre-selected sample can be positioned in the path of said beam ,
- (d) positioning a pre-selected substrate element of said sample holder and thereby the sample on that

substrate element in an initial position in which said sample lies in the path of said beam and a slice of said sample is irradiated by said beam ,

(d) effecting the following movements of said pre-
5 selected substrate element with respect to the above mentioned initial position:

(d.1) a rotation of said pre-selected substrate element and thereby of said sample around a rotation axis which is perpendicular to said substrate element,
10 said rotation covering a predetermined rotation angle, and

(d.2) a tilting of said pre-selected substrate element and thereby of said sample around a tilting axis and over a tilting angle defined as the angle that said rotation axis forms with said plane through
15 which the central part of said beam extends, said tilting axis lying in said plane through which the central part of said beam extends and being perpendicular to said rotation axis , said tilting covering a tilting angle that varies between a first predetermined value
20 and a second predetermined value, and

(e) detecting with said detector X-ray radiation transmitted through and diffracted by said sample during a time interval over which the above mentioned movements of the pre-selected substrate element are effected.

25

27. A method according to claim 26, wherein said rotation and tilting movements of said substrate element are performed simultaneously and continuously.

30 28. A method according to claim 26, wherein said tilting movement of said substrate element is performed stepwise and a rotation thereof covering a predetermined rotation angle is performed for each tilting step.

35 29. A method according to any of claims 26 to 28, wherein said substrate element is a planar substrate element.

30. A method according to any of claims 26 to 29, wherein the central axis of said beam and said rotation axis pass through the center of said planar substrate element when the latter is in said initial position.
- 5
31. A method according to any of claims 26 to 30, wherein said radiation source is stationary.
32. A method according to any of claims 26 to 31, wherein
10 said rotation of substrate element covers an angle which is equal to or close to 360 degrees.
33. A method according to any of claims 26 to 31, wherein said rotation of substrate element covers an angle
15 which is less than 360 degrees.
34. A method according to any of claims 26 to 31, wherein said rotation of substrate element covers an angle which is greater than 360 degrees.
- 20
35. A method according to any of claims 26 to 34, wherein said X-ray beam is focused in a line segment which substantially lies in said tilting axis .
- 25
36. A method according to claim 35, wherein said substrate is the bottom wall of a sample container, and wherein the length of the line segment is adjusted to be equal to or approximately equal to the inner diameter of the sample container.
- 30
37. A method according to claim 26 further comprising repeating steps (d) and (e) for each one of the plurality of samples in the sample holder.
- 35
38. Apparatus for transmission mode X-ray diffraction analysis of a plurality of samples by means of an apparatus comprising an X-Ray radiation source and a detector for detecting X-ray radiation transmitted through and

diffracted by a sample, said apparatus comprising
(a) an X-Ray radiation source which is adapted to
provide a strip-shaped X-ray beam the central part of
which extends along a plane,

5 (b) a sample holder comprising a plurality of
substrate elements each of which is adapted for
receiving and holding a sample to be analyzed, each of said
substrate elements being transparent to X-ray radiation,

(c) means for positioning a pre-selected substrate
10 element and thereby a sample placed on that element in an
initial position in which said sample lies in the path of
said beam and a slice of said sample is irradiated
by said beam,

(d) means for effecting the following movements of
15 said pre-selected substrate element with respect to the
above mentioned initial position thereof:

(d.1) a rotation of said pre-selected substrate
element and thereby of said sample around a rotation
axis which is perpendicular to said substrate element,
20 said rotation covering a predetermined rotation angle, and

(d.2) a tilting of said pre-selected substrate
element and thereby of said sample around a tilting
axis which lies in said plane through which the central
part of said beam extends and which is perpendicular to
25 said rotation axis, said tilting covering a tilting
angle that varies between a tilting angle zero defined
by said initial position of said substrate element and
a predetermined value greater than zero, and

(e) a detector for detecting X-ray radiation
30 transmitted through and diffracted by said sample during a
time interval over which the above mentioned movements of
the substrate element are effected.

39. An apparatus according to claim 38, wherein each of
35 said substrate elements is a planar substrate element.

40. An apparatus according to claim 39, wherein each of said planar substrate elements is the bottom wall of a sample container .
- 5 41. An apparatus according to claim 40, wherein the width of said sample container is approximately equal to the width of said X-ray beam .
- 10 42. An apparatus according to any of claims 38 to 41, wherein the central axis of said beam and said rotation axis pass through the center of said planar substrate element when the latter is in said initial position.
- 15 43. An apparatus according to any of claims 38 to 42, wherein said detector is a movable detector.
- 20 44. An apparatus according to any of claims 38 to 42, wherein said detector is a stationary detector which lies in a portion of a spherical surface.
- 25 45. An apparatus according to any of claims 38 to 44, said apparatus further comprising first focusing means located in the path of said X-ray beam and between said source and one of said sample substrate elements .
46. An apparatus according to any of claims 38 to 45, wherein said radiation source is stationary.
- 30 47. An apparatus according to any of claims 38 to 46, wherein said rotation covers an angle which is equal to or close to 360 degrees.
- 35 48. An apparatus according to any of claims 38 to 46, wherein said rotation covers an angle which is less than 360 degrees.

49. An apparatus according to any of claims 38 to 46, wherein said rotation covers an angle which is greater than 360 degrees.
- 5 50. An apparatus according to any of claims 44 to 49, wherein said focusing means focus said X-ray beam in a line segment which substantially lies in said tilting axis .
- 10 51. An apparatus according to claim 50, wherein the length of the line segment is adjusted to be equal to or approximately equal to the inner diameter of the sample container.
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METHOD AND APPARATUS FOR X-RAY DIFFRACTION ANALYSIS

Abstract

A method for transmission mode X-ray diffraction analysis of a sample by means of an apparatus comprising an X-Ray
5 radiation source (21) that provides X-ray radiation for irradiating the sample and a detector (22) for detecting X-ray radiation transmitted through and diffracted by the sample.

The method comprises: (a) placing a sample to be analyzed on
10 a substrate (19), (b) generating a strip-shaped X-ray beam (24) the central part of which extends along a plane, (c) positioning the substrate (19) and thereby the sample in an initial position in which said sample lies in the path of beam (24) and a slice (27) of the sample is irradiated by
15 beam (24), (d) effecting the following movements of the substrate (19) with respect to the above mentioned initial position thereof:

(d.1) a rotation of the substrate (19) and thereby of the sample around a rotation axis (29) which is perpendicular to
20 the substrate, the rotation covering a predetermined rotation angle, and (d.2) a tilting of the substrate (19) and thereby of the sample around a tilting axis (28) and over a tilting angle (T) defined as the angle that the rotation axis (29) forms with the plane through which the
25 central part of the beam (24) extends, the tilting axis lying in the plane through which the central part of the beam (24) extends and being perpendicular to the rotation axis (29), the tilting covering a tilting angle (T) that varies between a first predetermined value and a second
30 predetermined value, and (e) detecting with the detector (22) X-ray radiation transmitted through and diffracted by the sample during a time interval over which the above mentioned movements of the substrate (19) are effected:

35 (Figure 1)