X-ray collinator having plates with periodic rectangular openings

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Van Der Borst et al.

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[54] **X-RAY COLLINATOR HAVING PLATES WITH PERIODIC RECTANGULAR OPENINGS**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**^{6} **G21K 1/02**

[52] **U.S. Cl.** **378/149**; 378/147

[58] **Field of Search** 378/147, 148, 378/149, 154

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,465,540 8/1984 Albert 156/252

5,436,958 7/1995 Taylor 378/147

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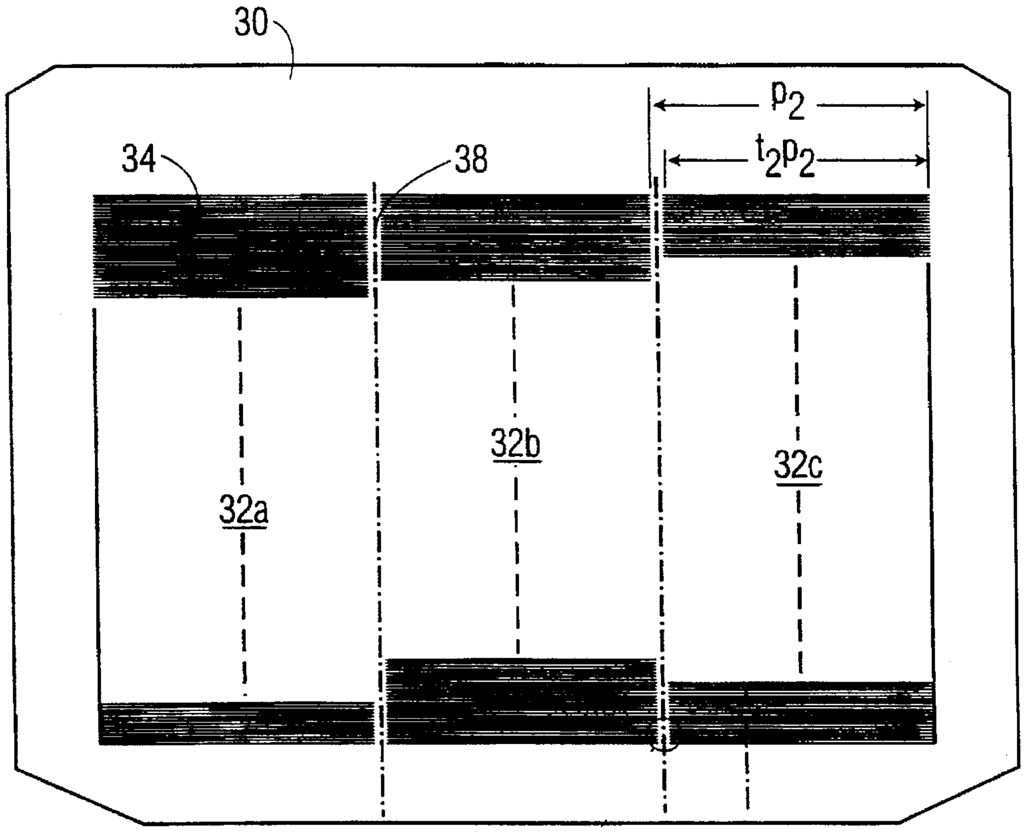
[57] **ABSTRACT**

An X-ray collimator in an X-ray analysis apparatus, consisting of plates of X-ray absorbing material, for example tungsten, which are arranged transversely of the X-ray beam. The plates are identical and provided with a pattern of rows and columns of rectangular openings **40**, **42** which have a vertical period p_1 and a horizontal period p_2. The openings take up an opening fraction t_1 and t_2 of the periods p_1 and p_2, respectively. The plates are arranged in the collimator in a series in which the ratio between two successive distances (d_i, d_{i+1}) between the plates of the series is equal to the given opening fractions t_1 and t_2 of the periods p_1 and p_2, respectively. It has been found that all directions in the X-ray beam are then intercepted except for the direction to be collimated. Moreover, this configuration also enables transverse collimation. The collimator thus formed has a substantially smaller weight and also offers space to accommodate further elements for influencing the X-ray beam.

4 Claims, 3 Drawing Sheets



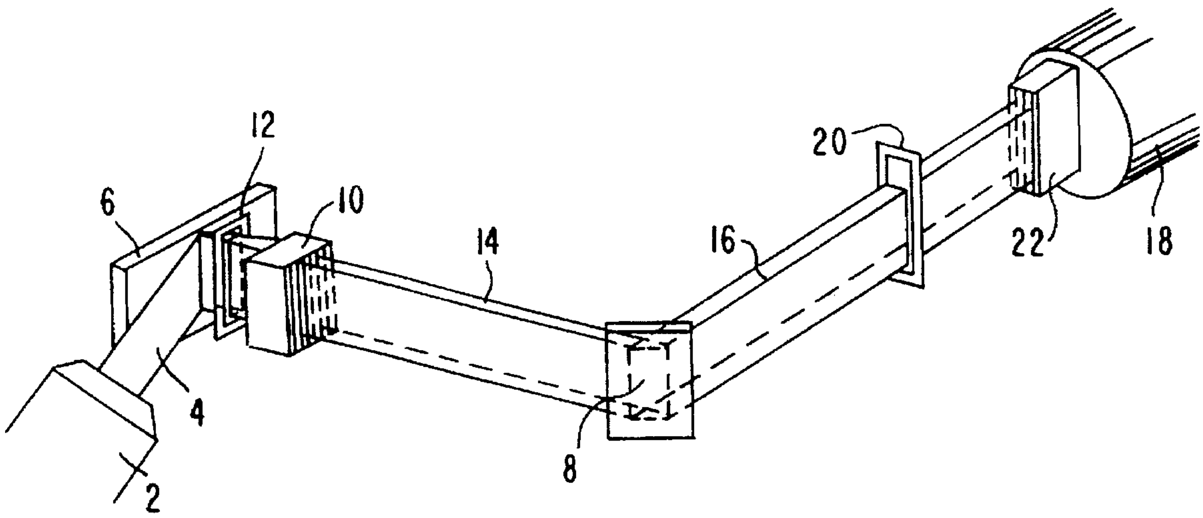


FIG. 1

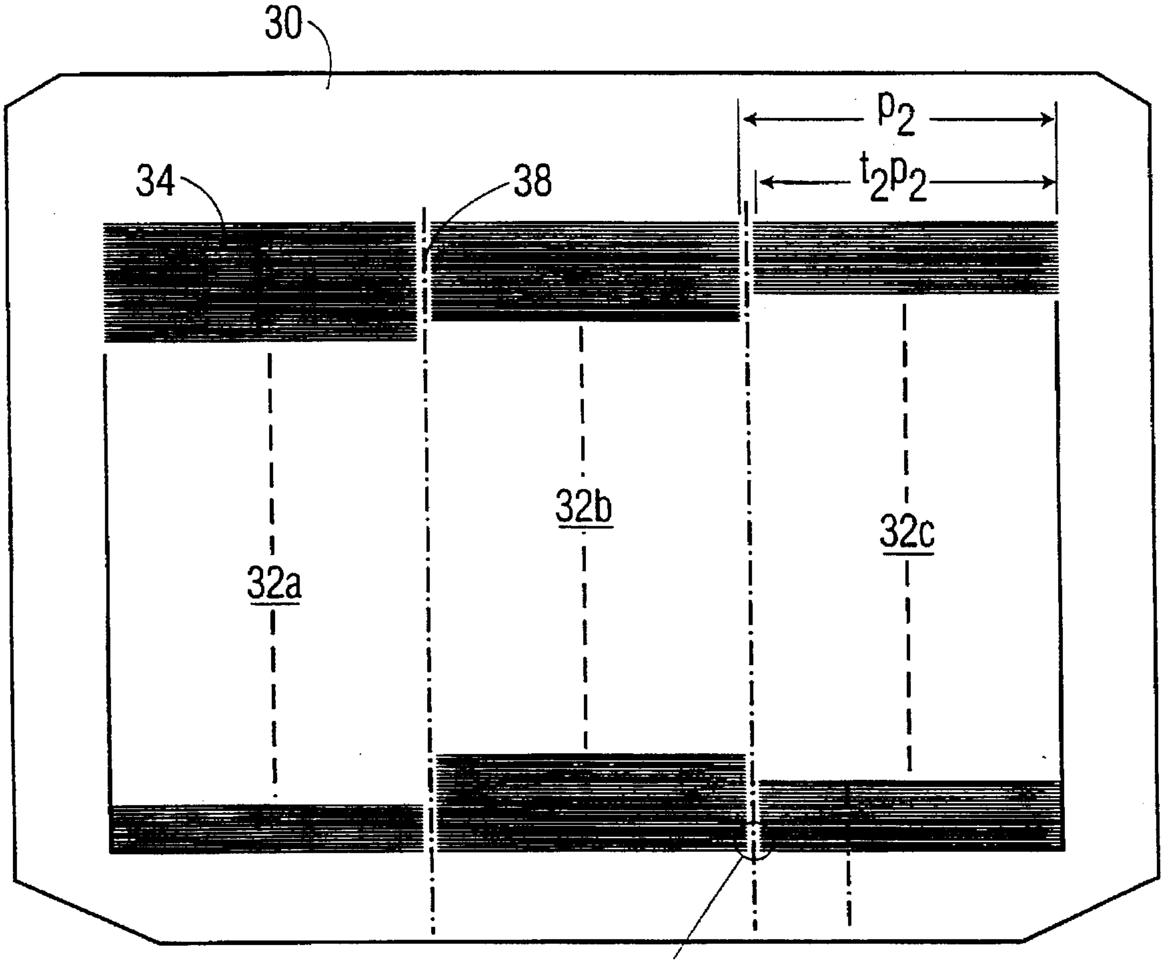


FIG. 2A

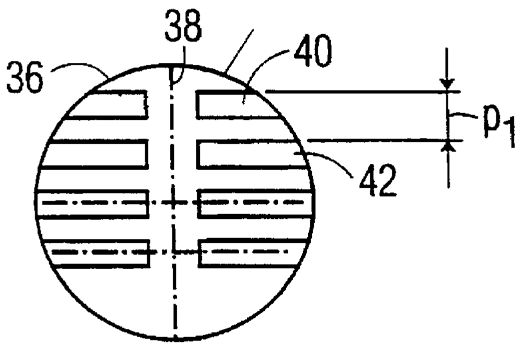


FIG. 2B

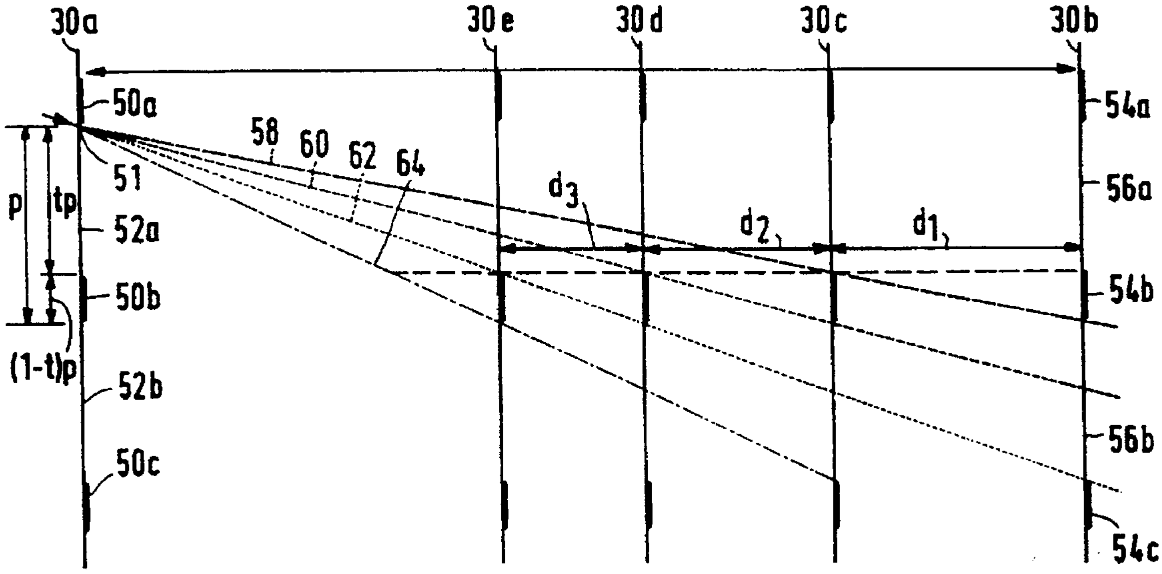

30a
30e
30d
30c
30b
50a
51
p
tp
52a
50b
(1-t)p
52b
50c
58
60
62
64
d3
d2
d1
54a
56a
54b
56b
54c

FIG.3

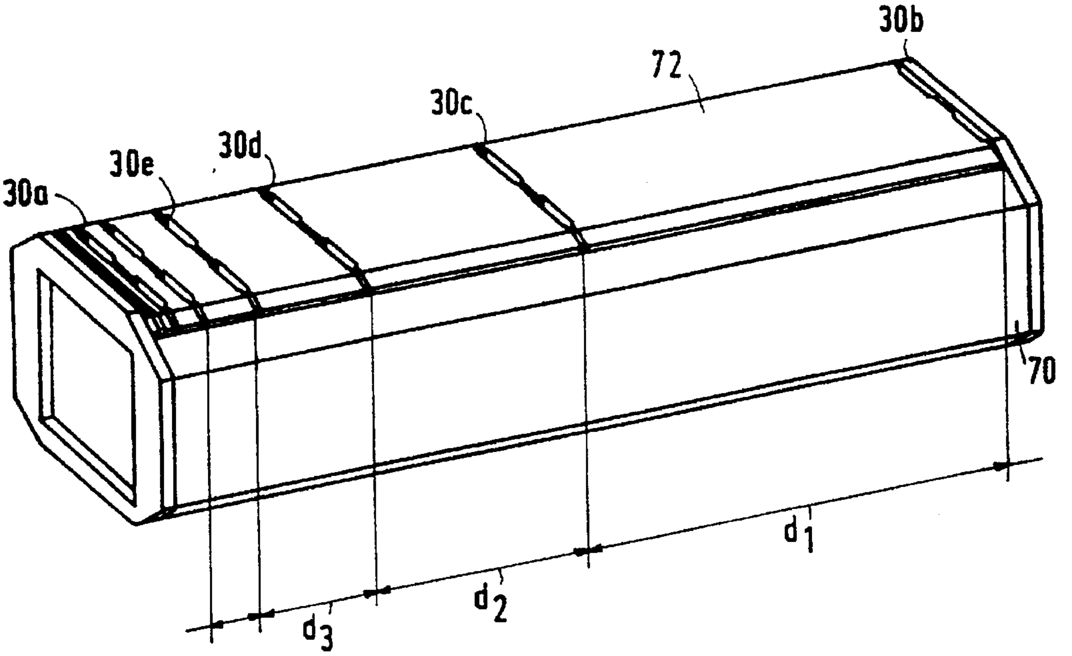

30b
72
30c
30d
30e
30a
70
d1
d2
d3

FIG.4

X-RAY COLLINATOR HAVING PLATES WITH PERIODIC RECTANGULAR OPENINGS

The invention relates to an X-ray analysis apparatus comprising an X-ray collimator which comprises a plurality of plates of a radiation absorbing material which are provided with openings and which are arranged so as to extend parallel and offset relative to one another in the propagation direction of the radiation, each plate comprising a pattern of holes with a given period p_1 in a direction perpendicular to one of the sides of the holes, said period having a given opening fraction t_1.

The invention also relates to a collimator for use in such an X-ray analysis apparatus.

A collimator of the described kind is known from U.S. patent specification Ser. No. 4,465,540. The collimator described therein, notably with reference to FIG. **5**, consists of a number of collimator plates which are arranged consecutively in parallel (in the direction of the X-rays to be collimated).

The plates shown in the cited document comprise a pattern of square holes arranged in mutually parallel rows. The rows are situated at equal distances from one another, so that they occur with a period p_1, being the distance between, for example the upper sides of the holes in two successive rows. This period thus consists of two parts, i.e. a part which is formed by the hole and which amounts to the fraction t_1 (the opening fraction), so that the dimension of the hole in this direction equals t_1p_1, and a pan which is formed by the intermediate absorbing material and which amounts to the fraction $(1-t_1)$, so that the dimension of the intermediate absorbing material in this direction equals $(1-t_1)p_1$.

The plates in this known collimator are arranged at equal distances from one another. The distance between these plates is determined by thin plate-shaped spacers which are clamped between the collimator plates and which are made of a material which transmits the relevant X-rays.

Collimators of this kind are comparatively heavy because a substantial fraction of their volume is filled with plates of an absorbing material. Moreover, this material, for example lead, tin or molybdenum, is heavy. The intermediate spacers also absorb a given amount of X-rays which is undesirable for some applications, notably in analysis equipment.

It is an object of the invention to provide a collimator of the kind set forth which has a lower weight and a negligibly low absorption of X-rays in the desired transmission direction.

To this end, the collimator in accordance with the invention is characterized in that the holes have a rectangular shape and that the collimator is provided with a first series of plates in which the ratio of two successive distances (d_i, d_{i+1}) between the plates of the series is equal to the given opening fraction t_1 of the period p_1.

It can be geometrically demonstrated that said arrangement of collimator plates suffices for all X-rays which do not extend in the desired transmission direction to be intercepted by at least one plate. Moreover, this results in a collimator whose weight is much lower weight and in which a large clearance exists between the collimator plates, which clearance can be used to accommodate a variety of elements for influencing or manipulating the X-ray beam.

In an attractive embodiment of the invention, the X-ray analysis apparatus is characterized in that the holes furthermore have a given second period p_2 in a second direction in the plane of the plates, perpendicular to the first direction, said second period having a given second opening fraction t_2, the collimator being provided with a second series of plates in which the ratio of two successive distances between the plates of the second series equals the given second opening fraction t_2 of the second period p_2.

These steps result in a collimator whereby collimation can be performed in two mutually perpendicular directions, the degree of collimation in one direction being independent of that in the other direction. This is achieved in that the length/width ratio of the rectangular holes is decisive in this respect.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

In the drawings:

FIG. **1** shows an X-ray analysis apparatus in which the collimator in accordance with the invention can be used;

FIG. **2** shows a collimator plate for use in a collimator in accordance with the invention;

FIG. **3** shows a geometrical diagram illustrating the operation of the collimator in accordance with the invention, and

FIG. **4** shows a housing for the collimator plates in accordance with the invention.

FIG. **1** shows a relevant part of an X-ray analysis apparatus in which the collimator in accordance with the invention can be used. An X-ray source **2** produces an X-ray beam **4** which is incident on a specimen **6** to be examined. In the specimen **6** the X-ray beam **4** excites X-rays which are analysed according to wavelength by an analyser crystal **8**. As this analyser crystal operates according to the well-known Bragg law $2d.\sin\delta=n\lambda$ (d=distance between the reflecting lattice planes in the analyser crystal, δ=the angle between the incident X-ray beam and the lattice planes, n=the order of the reflection, and λ=the X-ray wavelength), the X-rays incident on the analyser crystal must be parallel, i.e. have only one value of δ. To this end, the specimen to be examined is succeeded by a first collimator **10** which selects only the radiation extending in parallel within the (narrow) divergence range of the collimator from the X-ray beam emanating from the specimen **6**. The collimator **10** is preceded by a first beam limiter **12** for a first coarse directional selection of the X-rays emanating from the specimen. Depending on the angular position δ of the analyser crystal **8** relative to the X-ray beam incident on the crystal, a given wavelength λ in conformity with said Bragg law is selected. This beam is reflected, in the form of a reflected beam **16**, in the direction of the X-ray detector, via a second beam limiter **20** and a second collimator **22**. The second beam limiter **20** intercepts X-rays scattered upstream of the beam limiter in a variety of locations within the analysis apparatus. The second collimator **22** parallelizes the analysed beam again in order to remove non-desirable directions from the X-rays emanating from the analyser crystal. Finally, the detector **18** measures the intensity of the wavelength thus selected so that after all desired wavelengths have been covered by rotation of the analyser crystal, the intensity has been determined in dependence on the wavelength.

FIG. **2** shows a collimator plate for use in a collimator in accordance with the invention. The collimator plate **30** (having a height of, for example 29 mm and a width of, for example 36 mm) is made of tungsten and has a thickness of, for example 0.1 mm. The plate is subdivided into three areas **32***a*, **32***b* and **32***c* with rectangular holes **34**, each of which has a width of 9.8 mm and a height of 0.1 mm. These holes can be formed by way of a customary precision manufacturing method, for example by photochemical etching as is customary in the manufacture of integrated circuits. Even though in reality all three areas are fully subdivided into holes, for the sake clarity the Figure does not show the three areas completely filled with holes. As appears more clearly from the part **36** which is shown at an enlarged scale, between the rows of holes **32***a*, **32***b* and **32***c* there is situated a non-interrupted part **38** which has a width of 0.2 mm and serves to strengthen the collimator plate **30**. The holes are provided in rows of three adjacent columns, each of which is subdivided into a large number of rows which are situated one over the other. Within a column a vertical period p_1 of 0.2 mm exists, which period equals the distance between two corresponding points of two rows situated one above the other in a column, for example the distance between the upper sides of the rectangular hole **40** and the rectangular hole **42**. The period p_1 has a fraction t_1 (of, for example 50%) which is taken up by the opening, for example **40** or **42**, so that the vertical dimension of this opening equals t_1p_1, being 0.1 mm in this numerical example. Similarly, the collimator plate **30** has a period p_2 of 10 mm with an opening fraction t_2 of 98% in the horizontal direction, so that the absolute value of the opening in this direction equals t_2p_2, being 9.8 mm in this numerical example.

FIG. **3** shows a geometrical diagram illustrating the operation of the collimator in accordance with the invention. The Figure is a diagrammatic cross-sectional view of two collimator plates **30***a* and **30***b* as shown in FIG. **2**. Each of the plates **30***a* and **30***b* is subdivided into openings **52***a*, **52***b* etc. and **56***a*, **56***b* etc. which correspond to the openings **40** or **42** in FIG. **2**. Between the openings **52** and **56** there are provided areas **50***a*, **50***b*, **50***c* and **54***a*, **54***b*, **54***c*, respectively, having X-ray absorbing properties. The distance between the openings is determined by the period p which may represent the vertical period p_1 as well as the horizontal period p_2. The period p is subdivided into transmissive areas **52** and **56** amounting to a fraction t, so that the open part is dimensioned t.p, and non-transmissive areas **50** and **54** amounting to a fraction 1–t, so that the non-transmissive part is dimensioned (1–t).p.

The collimator is bounded by two outer, identical plates **30***a* and **30***b* wherebetween further identical collimator plates are arranged. The outer plates are arranged at a distance d_c from one another, d_c being determined from the maximum desirable angular divergence (defined as half the angle between two extreme rays) of the transmitted X-ray beam, amounting to $t.p/d_c$.

It is assumed that the X-ray beam to be collimated originates from an X-ray source which is not shown in FIG. **3** and which has a large emissive surface area, so that X-rays extending in all directions are present in the X-ray beam incident on the collimator plate **30***a*. This means that at the top **51** of the opening **52***a* X-rays extend in all directions, notably in the directions **58**, **60**, **62** and **64** indicated. X-rays emanating from the point **51** may be transmitted by the corresponding opening **56***a* in the plate **30***b*, but not by the other openings **56***b* etc. in this plate. A boundary line of the beam aimed at the inhibited opening **56***b* is formed by the line **58**. The beam emanating from the point **51** is tangent to the lower side of the absorbing part **54***b* by way of the line **58**; a part of the beam emanating from the point **51** is intercepted by arranging a plate **30***c* between the plate **30***a* and the plate **30***b*, i.e. the part which is tangent to said lower side. This situation occurs if the distance d_1 between the plate **30***b* and the intermediate plate **30***c* is:

$$d_1:d_c=(1-t).p:p \tag{1}$$

wherefrom it follows that:

$$d_1=d_c(1-t) \tag{2}$$

Below the part of the X-ray beam thus intercepted there is situated a further part which can be intercepted by arranging a further intermediate plate **30***d* at a distance d_2 from the plate **30***c*, in which case it analogously holds that (using $d_1=d_c(1-t)$):

$$d_2:\{d_c-d_c(1-t)\}=\{(1-t)p\}:p \tag{3}$$

wherefrom it follows that:

$$d_2=d_c.t.(1-t) \tag{4}$$

Similarly, for the distance d_3 between a possibly further plate **30***e* and **30***d* it can be deduced that:

$$d_3=d_c.t^2.(1-t) \tag{5}$$

When this procedure is continued, the general expression for the distance d_n is:

$$d_n=d_c.t^{n-1}.(1-t) \tag{6}$$

Comparison of the formules (2), (4) and (5) teaches that the ratio of two successive distances between the plates equals the opening fraction t of the period p.

A comparable derivation can be performed for a period and an opening fraction extending perpendicularly to the above period and opening fraction, so that transverse collimation can thus be achieved by choosing a different (or the same) value for t (i.e. t_2) in a direction transversely of the direction of the first value of t (i.e. t_1).

FIG. **4** shows a housing for the collimator plates in accordance with the invention. The housing consists of a bottom section **70** and a lid section **72**. In the bottom section there are provided slots (not shown) in which the collimator plates **30** can be arranged. The position of the collimator plates is thus defined. In the lid section there are also provided slots in which the collimator plates can be arranged. The Figure clearly shows the spacings d_1, d_2, d_3 etc. It is equally visible that the distance between the plates **30***b* and **30***c* is comparatively large, so that further elements for influencing the X-ray beam to be collimated can be accommodated in the collimator housing.

We claim:

1. An X-ray analysis apparatus comprising an X-ray collimator,

which collimator comprises a plurality of plates (**30***a*, **30***b* etc.) of a radiation absorbing material which are provided with openings,

which plates are arranged so as to extend parallel and offset relative to one another in the propagation direction of the radiation,

each plate comprising a pattern of holes (**40**, **42**) with a given period p_1 in a direction perpendicular to one of the sides of the holes, said period having a given opening fraction t_1,

characterized in that

the holes (**40**, **42**) have a rectangular shape, and

the collimator is provided with a first series of plates in which the ratio of two successive distances (d_i, d_{i+1})

between the plates of the series is equal to the given opening fraction t_1 of the period p_1.

2. An X-ray analysis apparatus as claimed in claim **1**, characterized in that the holes furthermore have a given second period p_2 in a second direction in the plane of the plates, perpendicular to the first direction, said second period having a given second opening fraction t_2, the collimator being provided with a second series of plates in which the ratio of two successive distances between the plates of the second series equals the given second opening fraction t_2 of the second period p_2.

3. An X-ray collimator, comprising

a plurality of plates (**30***a*, **30***b* etc.) of a radiation absorbing material which are provided with openings,

which plates are arranged so as to extend parallel and offset relative to one another in the propagation direction of the radiation,

each plate comprising a pattern of holes (**40**, **42**) with a given period p_1 in a direction perpendicular to one of the sides of the holes, said period having a given opening fraction t_1,

characterized in that

the holes (**40**, **42**) have a rectangular shape, and

the collimator is provided with a first series of plates in which the ratio of two successive distances (d_i, d_{i+1}) between the plates of the series is equal to the given opening fraction t_1 of the period p_1.

4. A collimator as claimed in claim **3**, characterized in that the holes furthermore have a given second period p_2 in a second direction in the plane of the plates, perpendicular to the first direction, said second period having a given second opening fraction t_2, the collimator being provided with a second series of plates in which the ratio of two successive distances between the plates of the second series equals the given second opening fraction t_2 of the second period p_2.

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