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Patent Centre****Zikova 4****166 36 Praha 6 (CZ)**(54) **X-ray telescope**

(57) X-ray telescope which displays the X-ray radiation with wavelength (λ) is formed by a parabolic strip assembled from bent monocrystalline plates (1,2) with atomic planes (5) parallel with the surface of these monocrystalline plates (1,2), where their mutual distance in each monocrystalline plate (1,2) varies according to the equation

$$d = \frac{n\lambda}{2p} \sqrt{x^2 + p^2},$$

where n is a natural number, which determines the number of wavelengths (λ) belonging to the difference of the ray travel distances when reflecting from two neighbouring atomic planes (5), and p is double the distance of the focal line (F) from the vertex line (V) of the parabolic strip,

i.e. for given monocrystalline plate (1,2) laid between ($x_{\min}$) and ($x_{\max}$) the following equation applies

$$\frac{d}{d_0} = \frac{\sqrt{x^2 + p^2}}{\sqrt{x_{\min}^2 + p^2}},$$

where (d_0) is the distance between the neighboring atomic planes (5) at the point with coordinate ($x_{\min}$) and (d) is the distance between the atomic planes (5) at the point with coordinate (x). Such course can be achieved by distribution of temperatures in different places according to experimentally measured dependence of the grid parameter y on the temperature

$$T(x) = T(x_{\min}) + \frac{1}{\gamma} \left[\frac{n\lambda}{2pd_0} \sqrt{x^2 + p^2} - 1 \right].$$

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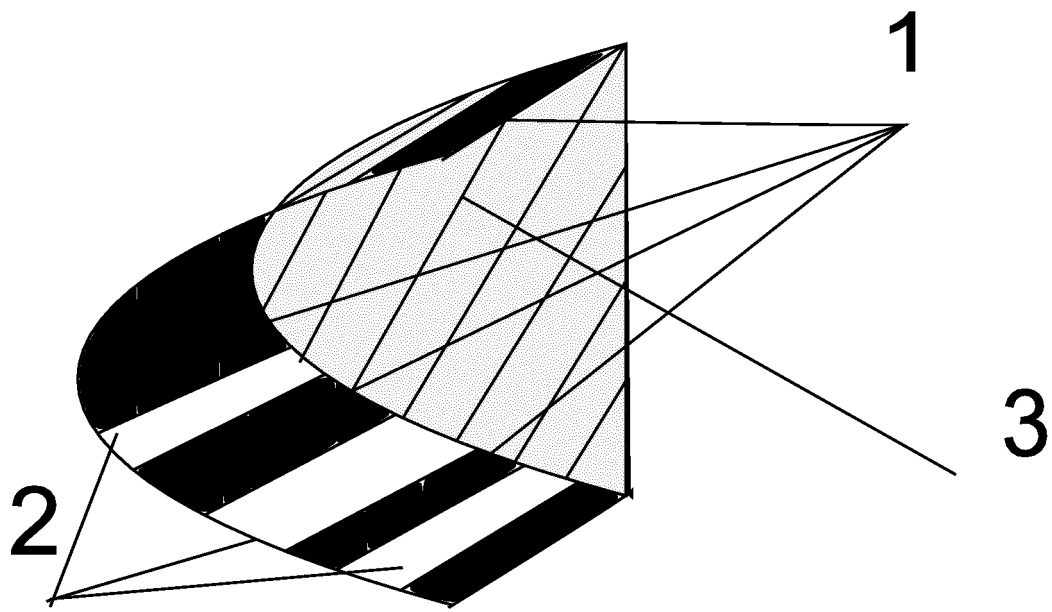


FIG. 1

DescriptionBackground of the Invention

[0001] Presented solution deals with an X-ray telescope for objects imaging in monochromatic X-ray radiation.

Description of Prior Art

[0002] X-ray radiation means an electromagnetic radiation with wavelengths shorter than 10 nm. Instead of optical lenses used in the visible light range, the X-ray telescope still uses as lenses mainly combinations of hyperboloid of revolution with paraboloid of revolution, which exploits two total reflections of rays under small angles resulting from the fact that refractive index on metals for these rays is less than one.

[0003] Since the possible incidence angles are small, from several degrees for energies 0.1 keV up to several minutes for 10 keV and for the respective wavelengths 10 nm to 0.1 nm, the lens must be assembled from multiple systems inserted one into another projecting to the same focus in order to enlarge the lens area. The higher the energy, the more systems within each other for the same area. These telescopes are called Wolter telescopes. There are three types of Wolter telescopes, the first two ones are various set-ups of hyperboloid and paraboloid and the third one is a combination of ellipsoid of revolution and paraboloid of revolution.

[0004] Another principle used for construction of X-ray telescopes is the X-ray radiation collimation by a number of parallel direct channels in absorption material, through which the radiation passes, while they determine the direction, from which the incident radiation is detected.

[0005] Another principle is so-called lobster's eye, either one-dimensional, or two-dimensional. It works again on the principle of full reflection of the X-ray radiation from the system of thin plates bent into a parabolic strip, which reflect the radiation into a single line. Two-dimensional lobster's eye is a combination of two one-dimensional, mutually perpendicular systems, which reflect the radiation into a point.

[0006] Also known is the Kirkpatrick-Baez telescope, which is formed by two mutually perpendicular parabolic mirrors where the first one displays the object into a line and the other to a point. Again, due to small incidence angle, the telescope consists of many layers with common focus.

[0007] All telescopes described above exploit the fact that the refractive index of some materials for the X-ray radiation is only slightly greater than one and under small angles they create total reflection. In addition, the refractive index depends on the X-ray radiation energy and for higher energies the usability is limited. All types feature relatively long focal distances.

[0008] All examples described above cause relatively high absorption of the X-ray radiation and all systems also have relatively long focal distances, it means the image and object distances, and work for longer wavelengths - around 10 nm. Moreover, manufacture of such parts puts rather high demands for the production equipment and therefore it is costly.

Summary of the Invention

[0009] All setbacks described above are improved by an X-ray telescope using monocrystals, which displays the X-ray radiation with wavelength λ according to the presented solution. Its principle is that it is formed by a parabolic strip with the vertex line at the coordinates origin ($x=0, y=0$) and the focal line with coordinates ($x=0, y=p/2$), which is assembled from bent rectangular monocrystalline plates, cut in such a way that the atomic planes are parallel with the surface of the monocrystalline plates. These monocrystalline plates are by their edges fixed in two holders with parallel orientation, which ensure the parabolic geometry of the strip. Mutual distance between the atomic planes of given monocrystalline plate, marked with letter d , is variable in such a way that the shortest distance d_0 is at the ends located closer to the vertex line of the parabolic strip in the point $x_{\min}$ and the longest distance $d_{\max}$ is at the ends located farther from the vertex line of the parabolic strip in the point $x_{\max}$. Between these ends the mutual distance d of the neighboring atomic planes in each monocrystalline plate varies depending on the amount of the distance of the coordinate x from the vertex line of the parabolic strip according to equation

$$d = \frac{n\lambda}{2p} \sqrt{x^2 + p^2},$$

where n is a natural number, which determines the number of wavelengths belonging to the difference of the ray travel distances when reflecting from two neighbouring atomic planes, which is the interference condition, and p is double the distance of the focal line from the vertex line of the parabolic strip, and for the temperature course along the given

monocrystalline plate in the x-axis direction in individual points corresponding to the x-coordinate the following condition is fulfilled

$$T(x) = T(x_{\min}) + \frac{1}{\gamma} \left[\frac{n\lambda}{2pd_0} \sqrt{x^2 + p^2} - 1 \right],$$

where γ is the thermal expansion factor of the given monocrystalline plate in direction perpendicular to its surface.

[0010] In one preferred embodiment the parabolic strip is formed by monocrystalline plates of monocrystal of one kind. In other embodiment the parabolic strip may consist of monocrystalline plates of at least two kinds of monocrystals. Also possible is the embodiment where between the monocrystalline plates are gaps.

[0011] Monocrystalline plates may also be made of monocrystals, the surface of which is parallel with different atomic planes.

[0012] The advantage of this arrangement is that it displays monochromatic X-ray radiation with wavelength λ to the focal line and for displaying it can exploit maximum surface area of the parabolic strip, which means that the area, which is blind and non-reflecting, can be reduced by selection of materials in theory arbitrarily.

Explanation of Drawings

[0013] Schematic design of the X-ray telescope according to the presented solution is shown in attached drawings. Fig. 1 shows an example of the parabolic strip formed by bent plates of different monocrystals. Fig. 2 shows the vertex and focal lines and the rays coming from a distant source, which reflect themselves from any point at each monocrystalline plate to the line in focus of the parabolic strip. Fig. 3 shows a section view of individual monocrystalline plates in the parabolic strip located between the coordinates $x_{\min}$ and $x_{\max}$. Fig. 4 shows a single plate from the strip with indicated atomic planes.

Detailed Description of the Preferred Embodiments

[0014] Reflection of radiation under greater angle is only possible when the Bragg condition is fulfilled. According to the presented solution X-ray telescope is formed by thin rectangular plates with atomic planes 5 parallel with the surface of monocrystals. These plates are bent and arranged next to each other in such a way that they create parts of the parabolic strip, as shown in Fig. 1. In the given example the parabolic strip is formed by two kinds of monocrystalline little plates 1 and 2, which alternate in such a way that after each plate 1, 2 get warmed up in various points to the temperature determined by the equation (3) defined hereinbelow, they at all points fulfill the Bragg condition for reflection of the X-ray radiation to the focal line E of the parabolic strip. Monocrystalline plates are fixed on their sides in two holders 3 with parallel orientation, which ensure the parabolic geometry of the strip.

[0015] Fig. 2 shows separate X-ray rays 4, which reflect from the monocrystalline plates of the parabolic strip to the focal line E of the parabolic strip. X-ray rays 4 coming from a distant object are reflected to the focal line E where

constructive interference occurs. Equation of parabola is defined by the equation $y = \frac{x^2}{2p}$, where p is double the

distance of the focal line E from the vertex line V of the parabolic strip, the vertex line V of the parabolic strip lies in the coordinates origin, i.e. in point $x=0$ a $y=0$.

[0016] In order to fulfill Bragg condition at every point it is necessary that the distance between atomic planes 5 in each monocrystal plate along the parabolic strip changes as well. The strip may be composed of one kind of monocrystal, broken by spaces of gaps between them, or advantageously the strip can consist of plates of at least two kinds of monocrystals, here two kinds of monocrystalline plates 1 and 2 are described, and the gaps can be reduced or excluded, possibly combined with monocrystals with surfaces parallel with different atomic planes 5. This will ensure that the radiation of given wavelength from a distant source is reflected to the focal line E of the parabolic strip. Change of distance between the atomic planes 5 in the monocrystalline plate can be created by changing the concentration of admixtures or by different thermal expansion caused by uneven heat distribution in various places of the monocrystalline plate. In case the temperatures along the strip are varied, it is possible, within limited extent, to change also the measured wavelength by changing the temperature course in different places of the monocrystalline plates and in different places along the strip. The distance between the planes of the monocrystalline plate is d and it is variable in such a way that the shortest distance d₀ is closer to the vertex line V of the parabolic strip and the longest distance d_{max} is at the farther

end of the monocrystalline plate from the vertex line $\underline{V}$ of the parabolic strip. For the incidenting X-ray ray $\underline{4}$ forming the angle α with the normal line against the area it fulfills the Bragg condition

$$2d \cos \alpha = n\lambda ,$$

where n is a natural number and λ is the wavelength of displayed X-ray radiation.

[0017] One bent monocrystalline plate in the parabolic strip with indicated atomic planes $\underline{5}$ and with indicated distances between separate atomic planes $\underline{5}$, which vary from d_0 to $d_{\max}$, is shown in Fig. 4.

[0018] If the Bragg condition for a monocrystalline plate in the parabolic strip is expressed as a function of the coordinate x , the result is

$$d = \frac{n\lambda}{2p} \sqrt{x^2 + p^2} . \quad (1)$$

where n is a natural number, which determines the number of wavelengths belonging to the difference of the ray travel distances when reflecting from two neighbouring atomic planes $\underline{5}$, and p is double the distance of the focal line $\underline{E}$ from the vertex line $\underline{V}$ of the parabolic strip.

[0019] When varied temperature distribution is used, the equation for thermal expansion of the distance between neighboring atomic planes is

$$d = d_0 (1 + \gamma \Delta T) , \quad (2)$$

where γ is the thermal expansion factor of given monocrystalline plate in direction perpendicular to this monocrystalline plate and ΔT is the temperature difference between places on the monocrystalline plate with coordinates x and $x_{\min}$. For the course of temperature along the monocrystalline plate in direction of the $\underline{x}$ -axis at individual points with given x -coordinate the following equation must be fulfilled

$$T(x) = T(x_{\min}) + \frac{1}{\gamma} \left[\frac{n\lambda}{2pd_0} \sqrt{x^2 + p^2} - 1 \right] , \quad (3)$$

where d_0 is the distance between the neighboring atomic planes $\underline{5}$ at point $x_{\min}$, i.e. on the edge of the monocrystalline plate closer to the vertex line $\underline{V}$ of the parabolic strip.

[0020] For placement and manufacture of a monocrystalline plate the following equation may be used for a plate located between the x -coordinates $x_{\min}$ and $x_{\max}$

$$\frac{x_{\max}^2}{x_{\min}^2} = \frac{4d_{\max}^2 - n^2 \lambda^2}{4d_0^2 - n^2 \lambda^2} \quad (4)$$

[0021] For a plate made of germanium monocrystal and temperatures between 250 and 1000 K, for the wavelength of 0.5 nm the value is $\frac{x_{\max}}{x_{\min}} = 1.023$, and for the wavelength 0.55 nm the value is $\frac{x_{\max}}{x_{\min}} = 1.08$, i.e. for example

for $x_{\min} = 10$ cm the value of $x_{\max} = 10,8$ cm. The closer the value of the product of $n\lambda$, i.e. of the natural number and the wavelength, will be to the double of d_0 , the better the resulting ratio. It means that at point $x_{\min}$, which fulfills the

condition for d_0 , the beginning of the monocrystalline plate will be at the temperature of 250 K and it will end at point $x_{\max}$ at the temperature of 1000 K.

Industrial Applicability

[0022] This X-ray telescope can be exploited in particular in the X-ray telescopes to focus the monochromatic radiation into a line segment.

Claims

1. X-ray telescope which displays the X-ray radiation with wavelength (λ) **characterized by the fact that** it is formed by a parabolic strip with the vertex line (V) at the coordinates origin ($x=0, y=0$) and the focal line (F) with coordinates ($x=0, y=p/2$), which is assembled from bent rectangular monocrystalline plates, cut in such a way that their atomic planes (5) are parallel with the surface of the monocrystalline plates, where such monocrystalline plates are by their edges fixed in two holders (3) with parallel orientation, which ensure the parabolic geometry of the strip, where the mutual distance (d) between the neighboring atomic planes (5) of given monocrystalline plate is variable in such a way that the shortest distance (d_0) is at the ends located closer to the vertex line (V) of the parabolic strip in the point ($x_{\min}$) and the longest distance ($d_{\max}$) is at the ends located farther from the vertex line (V) of the parabolic strip in the point ($x_{\max}$), and between these ends the mutual distance (d) of the atomic planes (5) in each monocrystalline plate varies depending on the amount of the distance of the coordinate (x) from the vertex line (V) of the parabolic strip according to equation

$$d = \frac{n\lambda}{2p} \sqrt{x^2 + p^2},$$

where n is a natural number, which determines the number of wavelengths (λ) belonging to the difference of the ray travel distances when reflecting from two neighbouring atomic planes (5), and p is double the distance of the focal line (F) from the vertex line (V) of the parabolic strip, and for the temperature course along the given monocrystalline plate in the (x)-axis direction at individual points corresponding to the x -coordinate the following condition is fulfilled

$$T(x) = T(x_{\min}) + \frac{1}{\gamma} \left[\frac{n\lambda}{2pd_0} \sqrt{x^2 + p^2} - 1 \right],$$

where γ is the thermal expansion factor of the given monocrystalline plate in direction perpendicular to its surface.

2. X-ray telescope according to claim 1 **characterized by the fact that** the parabolic strip is formed by monocrystalline plates (1) of monocrystal of one kind.
3. X-ray telescope according to claim 1 **characterized by the fact that** the parabolic strip is formed by monocrystalline plates (1,2) of at least two kinds of monocrystals.
4. X-ray telescope according to any of claims 1 to 3 **characterized by the fact that** between the monocrystalline plates (1,2) are gaps.
5. X-ray telescope according to any of claims 1 to 4 **characterized by the fact that** the monocrystalline plates (1,2) are made of monocrystals, the surface of which is parallel with different atomic planes (5).

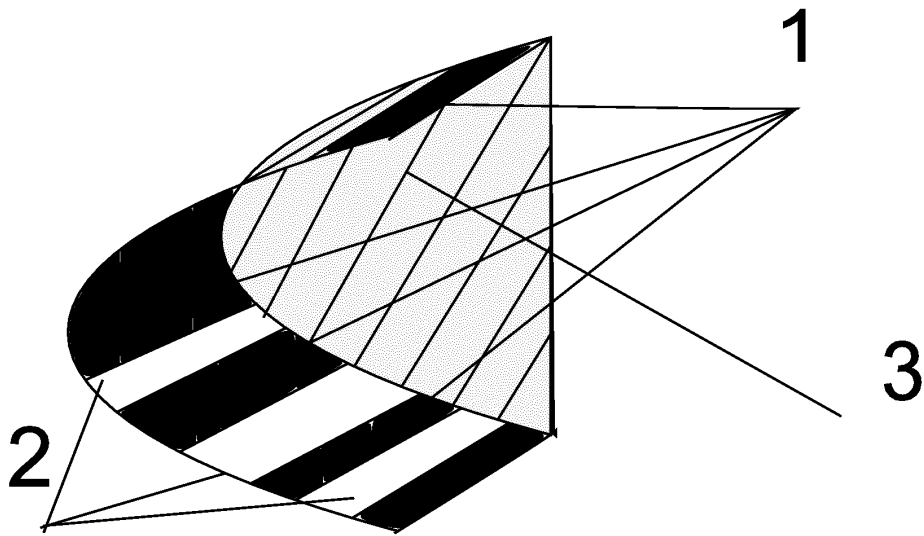


FIG. 1

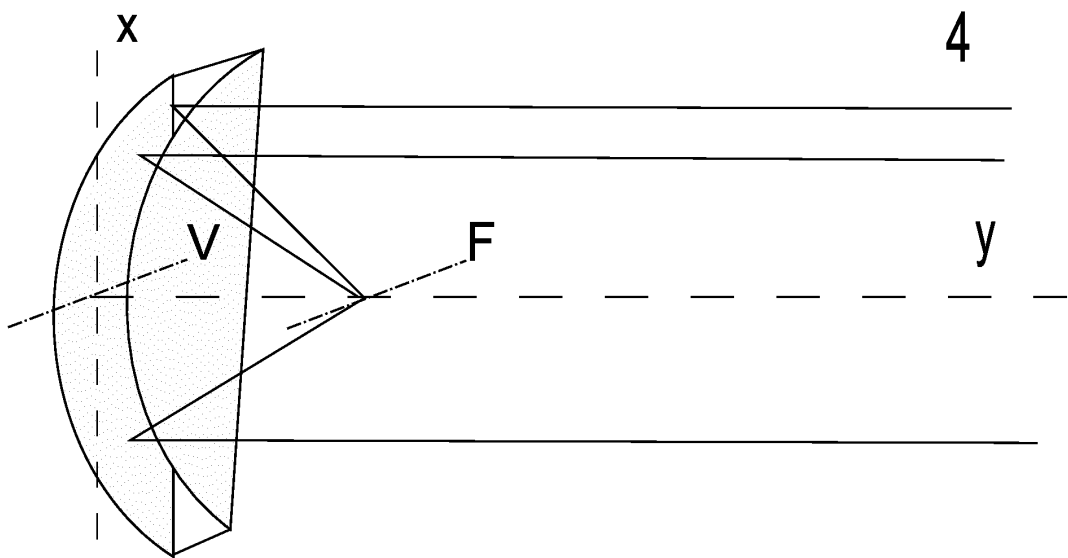


FIG. 2

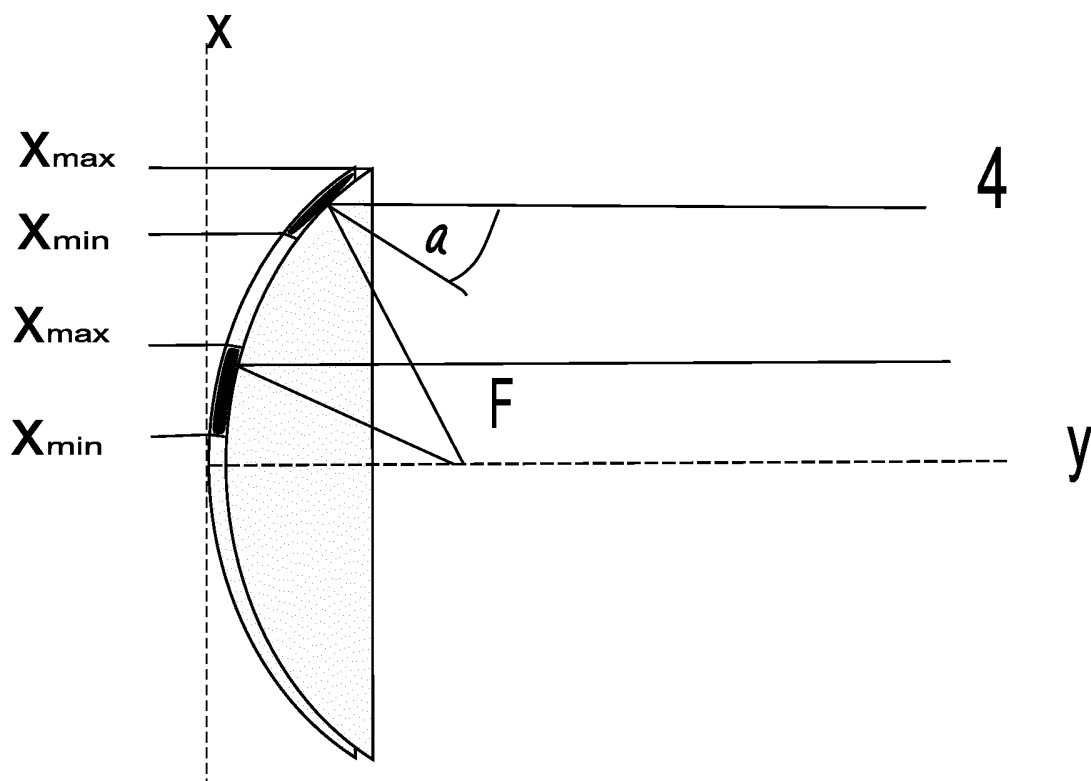


FIG. 3

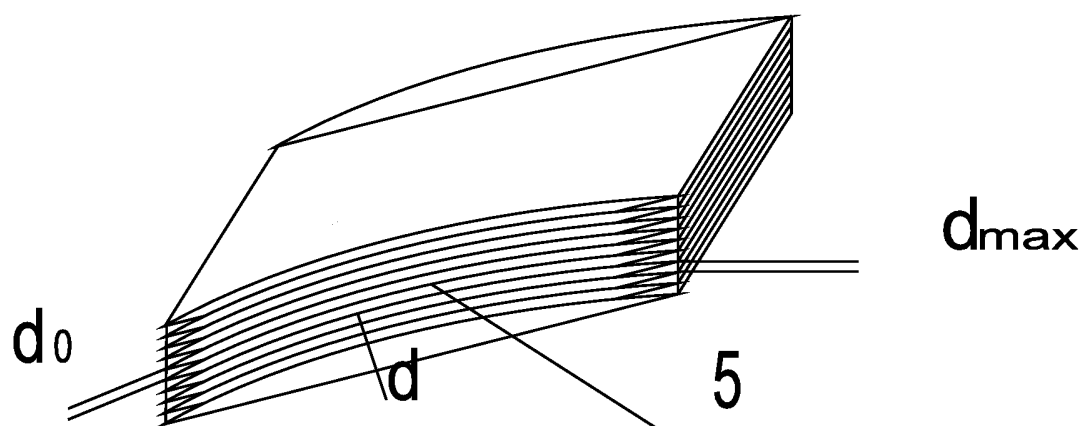


FIG. 4