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Discovery of a Planar Waveguide for an X-Ray Radiation

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A simple model of X-Ray standing waves (XSW) formation in the slit of a planar waveguide of X-Ray radiation beam for the angle area restricted by the critical total reflection angle is developed. It is shown that the model is true for a case of the Bragg reflection. The conditions required for XSW to appear in the space between two polished parallel plane plates are formulated and a slit size interval conforming to these conditions is evaluated. A mechanism of a XSW intensity decrease in a planar waveguide is proposed. This mechanism explains a high efficiency of slitless collimator application for the transportation of narrow X-Ray beams.

Some recommendations on the application of the planar X-Ray waveguide in X-Ray structural and spectral studies of surface are presented.

Key words: total reflection, X-Ray standing wave (XSW), planar X-Ray waveguide, planar X-Ray waveguide-monochromator

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Introduction

A slit former of X-Ray beams with extensive plane restraints has long been used as one of the basic components in X-Ray optics. A well-known example is the Soller slit that contains a set of closely spaced thin parallel metallic plates ensuring an X-Ray beam with a required divergence \[1, 2\]. Another example of the unit is an aligned diffractometric slit 50 mm long with a clearance size between the parallel quartz plates of 0.1 mm \[1, 3\].

These slits are sometimes used to form an X-Ray excitation beam in TXRF spectrometry \[1, 4\]. For example, an X-Ray collimator formed by two quartz parallel plates with a 0.1 mm clearance served as a double X-Ray beam reflector to form an excitation beam for total X-Ray reflection fluorescence analysis \[1\].

In X-Ray diffraction practices the plane slit monochromators used for the X-Ray line narrowing in an excited beam has a wide application \[6, 7\]. This devices designates as Bonse-Hart monochromators are distinguished by multiple reflections within a groove cut into a large single crystal or within a slit formed by two oriented monocrystal plates.

Lately, in addition to X-Ray planar extensive collimators characterized by the visible size of a clearance between solid reflectors formed it, so called slitless X-Ray collimators has come into use for X-Ray fluorescence analysis \[8, 9, 10, 11, 12\]. The slitless collimator applied in those works was formed by two quartz polished plates mated together. The clearance in it was formed due to roughness and microsphericity of the plates, which size been made as evaluation rather laborious and ambiguous. Experiments showed, that these slitless collimators could transport X-Ray radiation over a distance of 100 mm without visible intensity decrease. Because the hypothesis multiple total reflection of an X-Ray beam in the microclearance of a slitless collimator failed to explain the experimental data obtained in \[8, 11\], a hypothesis of an X-Ray standing wave (XSW) formation in the microclearance was proposed in \[11, 12\]. The present work is devoted to further development of this hypothesis.

Formation of an X-Ray standing wave upon specular reflection of a plane wave

Assume that an electromagnetic monochromatic plane travelling wave with the $\sigma$-polarization (i.e. $\vec{E}_0$ perpendicular to the x-z plane in Fig. 1), wave-
length $\lambda_0$ and wave vector $k_0 = \frac{1}{\lambda_0}$ impinges on the boundary separating two materials. If the materials have different refraction indices, part of the wave energy is reflected and the remainder passes to the second material or is refracted. An interference field appears in the first material irrespective of the remainder value. The interference field area depends on the width of an incident plane wave and the incidence angle $\theta$. The intensity of the interference area is directly determined by the reflection factor on the boundary between materials and peaks at the total reflection of an incident radiation beam. Referring to Fig. 1a, the incident and reflected travelling E-field plane waves can be described as [13]:

$$\vec{A}_0(\vec{r}; t) = \vec{E}_0 e^{i[\omega t - 2\pi(\vec{k}_x x - \vec{k}_z z)]}$$  \hspace{1cm} (1)$$

and

$$\vec{A}_R(\vec{r}; t) = \vec{E}_R e^{i[\omega t - 2\pi(\vec{k}_x x + \vec{k}_z z)]}$$  \hspace{1cm} (2)$$

For the sake of convenience, let $z = 0$ corresponds to the reflector surface. By locating the intersections of the crests and troughs of the two travelling plane waves in Fig. 1a, one can easily show that the interference between the two coherent waves generates a standing wave with planes of maximum and minimum intensity parallel to the boundary surface. The period of the standing wave is defined by expression [14]:

$$D = \frac{\lambda}{2 \cdot \sin \theta}$$  \hspace{1cm} (3)$$

In a general case the amplitude relation between the incident and reflected waves is described by the Fresnel equations [13]:

$$\left| \frac{\vec{E}_R}{\vec{E}_0} \right| = \frac{\sin \theta - n \sin \varphi}{\sin \theta + n \sin \varphi}$$  \hspace{1cm} (4)$$

where $\varphi$ is the refraction angle and $n$ is the relative refraction index. The phase change of the electric vector between the incident and reflected waves $\psi$ is defined by expression:

$$\tan \frac{\psi}{2} = \frac{\sqrt{\cos^2 \theta - n^2}}{\sin \theta}$$  \hspace{1cm} (5)$$

Equations (3), (4) and (5) describe the reflection phenomenon for any electromagnetic plane wave on a plane interface between two materials. They can also be used to describe, as a first approximation, a total external X-Ray reflection on a vacuum - material interface, which is usually represented as
the specular reflection of an X-Ray plane wave, for the sake of simplification\(^2\).

The interaction of X-Ray radiation with a material is characterized by the refractive index \(n\) equal to unity for vacuum and less than unity for most materials. It can be written as \([16]\):

\[
\begin{align*}
    n &= 1 - \delta - i\beta \\
    \delta &= \frac{\theta_c^2}{2} \\
    \beta &= \frac{\lambda}{4\pi\mu}
\end{align*}
\]

where \(\delta\) is the real part of the refraction index deviation from unity and reflects the material polarization degree upon X-Ray excitation. The imaginary part \(\beta\) characteristics the degree of radiation attenuation in the material. Values of \(\delta\) and \(\beta\) for various media are listed in \([17]\) and do not exceed \(1 \cdot 10^{-5}\).

The polarization factor magnitude is directly connected with the critical angle of total X-Ray beam reflection \(\theta_c\) \([16]\):

\[
\delta = \frac{\theta_c^2}{2}
\]

and can be expressed by the wavelength of incident radiation \(\lambda_0\) and common material parameters \([16]\):

\[
\delta = \frac{e^2 N Z' \rho \lambda^2}{2\pi mc^2 A}
\]

where \(e\) and \(m\) are the charge and the mass of an electron, \(c\) is the light velocity, \(N\) is the Avogadro number, \(Z'\) and \(A\) are the effective charge and atomic mass for the reflectors material, and \(\rho\) is its density. The attenuation factor can be expressed by the linear coefficient of material absorption \(\mu\) \([16]\):

\[
\beta = \frac{\lambda}{4\pi\mu}
\]

In the conjunction of the secular reflection for an X-Ray radiation the amplitude relation between electric vectors of the incident and reflected waves and the phase expression have the form \([14, 16, 17]\):

\[
\left| \frac{\vec{E}_R}{\vec{E}_0} \right|_\perp = \frac{\theta - \sqrt{\theta^2 - 2\delta - 2i\beta}}{\theta + \sqrt{\theta^2 - 2\delta - 2i\beta}}
\]

and

\(^2\) This simplified representation disregards the Goos-Hanchen wave front displacement at total wave reflection \([13]\), and the radiation penetration to top layers of the material plate.
\[
\cos \psi = \begin{cases} 
2 \left( \frac{\theta}{\theta_c} \right)^2 - 1 & \text{for } \theta \leq \theta_c \\
1 & \text{for } \theta > \theta_c
\end{cases}
\]  

(11)

The X-Ray radiation intensity in the vacuum over the boundary surface in the interference field area usually defined as \( |\vec{A}_0 + \vec{A}_R|^2 \) can be presented by the next formula [14]:

\[
I(\theta, z) = |\vec{E}_0|^2 \left[ 1 + R + 2\sqrt{R} \cos \left( \psi - \frac{2\pi z}{D} \right) \right]
\]  

(12)

where \( D \) is the standing wave period along the \( z \)-coordinate, expressed by Eqn.(3) and \( R \) is the reflectivity factor which is a complicated function of the incident angle \( \theta \) [16]:

\[
R = \left| \frac{\vec{E}_R}{\vec{E}_0} \right|_\perp^2 = \frac{(\theta - a)^2 + b^2}{(\theta + a)^2 + b^2}
\]  

(13)

where \( a \) and \( b \) are determined by the expressions:

\[
\begin{align*}
 a^2 &= \frac{1}{2} \left[ \sqrt{(\theta^2 - 2\delta)^2 + 4\beta^2} + (\theta^2 - 2\delta) \right] \\
b^2 &= \frac{1}{2} \left[ \sqrt{(\theta^2 - 2\delta)^2 + 4\beta^2} - (\theta^2 - 2\delta) \right]
\end{align*}
\]  

(14)

The interference field can be observed both at \( \theta < \theta_c \) and \( \theta > \theta_c \), but in the latter angle range its intensity decreases abruptly [17]. The standing wave period \( D \) achieves its minimum at \( \theta = \theta_c \) in the \( 0 \leq \theta \leq \theta_c \) range. As the incident angle decreases, the period \( D \) increases to become infinitely large at the grazing incident angle (\( \theta = 0 \)). But this is not case in practice, because the coherence of incidence and reflected beams is broken. The most obvious factor causing the interference field erosion is the width finiteness of incident radiation lines \( \Delta \lambda \) [13]. It is generally accepted, that the interference field does not become smeared, if the condition [16]:

\[
\Delta \lambda \leq \frac{\lambda}{4}
\]  

(15)

holds.

Another factor influencing the interference field picture is the roughness of a reflecting surface. Evaluations show that the interference field does not undergo smearing at \( \theta = \theta_c \) when the height of microheterogeneities on the reflected surface does not exceed the critical size \( h_c \) [14]:

\[
h_c = \frac{\lambda}{8\sqrt{2\delta}} = \frac{1}{8} \sqrt{\frac{\pi mc^2 A}{e^2 N \rho Z'}}
\]  

(16)
The critical roughness parameter does not depend on the wavelength of the incident radiation. Its magnitude for polished optical quartz plates is equal to 5 nm.

Standing wave formation in the slit of an X-Ray planar waveguide

A successive reflection of a plane electromagnetic wave in the slit formed by two parallel plates results in the formation of several interference field areas in it (Fig. 1b). Varying the slit size can lead to overlapping the areas to create the uniform interference field zone within the total clearance of the slit (Fig. 1c)\(^3\). So, it can be expected that an XSW excitation can be formed in the plane slit, when it width falls within a certain range. The minimum slit size for this can be evaluated from expression (3) for the critical angle of total reflection:

\[
D_{\text{min}} = \frac{\lambda}{2 \sin \theta_c} \approx \frac{\lambda}{2 \theta_c} = \sqrt{\frac{\pi mc^2 A}{2 e^2 NZ' \rho}}
\] (17)

The minimum slit size promoting the XSW formation is independent of an X-Ray incident radiation wavelength. The material structure density \(\rho\) of reflectors is a real factor influencing the minimum size \(D_{\text{min}}\). Its magnitude for quartz reflectors \((Z = 10; A = 20)\) is 21 nm. In practice the \(D_{\text{min}}\) value is smaller because an XSW is characterized by a visible intensity up to the X-Ray penetration depth \(z_e\) into a top layer of a target material, defined by expression [16]:

\[
(z_e)^2 = \frac{\lambda^2}{8 \pi^2} \cdot \frac{1}{\sqrt{(\theta_c^2 - \theta)^2 + 4 \beta^2 + (\theta_c^2 - \beta^2)}}
\] (18)

The average value of the penetration depth parameter for an X-Ray slitless collimator introduced in the work [11] as \(\bar{z}_e = z_e (\frac{\theta}{\lambda})\) is 3.6 nm for MoK\(_\alpha\).

\(^3\)It is very important to notice that the uniform interference field zone will be appear, in the context of the specular reflection model, for the some specific reflection angles, only. The uniform interference field zone appearance for any reflection angle can be obtained by taking into consideration the expansion of the interference field into top layers of reflectors and the Goos-Hanchen displacement.
radiation impinging on a quartz plate. So, the real size of the minimum clearance between the quartz plates $D_{\min}^*$ is found to be approximately 14 nm. This value is comparable with the double roughness of reflectors 10 nm.

The upper restriction for the slit in an X-Ray waveguide can be evaluated using ratio Eqn. (15):

$$D_{\max} = \frac{\lambda}{4 \left(\frac{\Delta \lambda}{\lambda}\right)} = \frac{\lambda^2}{4\Delta \lambda}$$

(19)

For MoK$_{\alpha}$ radiation, the wavelength is $\lambda = 0.707 \cdot 10^{-1}$ nm and $\Delta \lambda = 0.29 \cdot 10^{-4}$ nm [18]. Substituting these values into Eqn. (19) gives $D_{\max} = 43\,\text{nm}$. In practice, its magnitude is $D_{\max}^* = 36\,\text{nm}$. Similar value for CuK$_{\alpha}$ radiation is equal to $D_{\max}^* = 91\,\text{nm}$. Analogous parameters calculated for the set of X-Ray and gamma radiation are collected in Table 1. Quartz total reflection parameters peculiar to the radiation set are represented in the same place. It should be stressed that the X-Ray spectra in incident and emergent beams do not agree between them. For example, if we shall try to form the X-Ray beam excited by X-Ray tube with Mo anode by using of an X-Ray waveguide with a slit size $D > D_{\max}$, we shall not find the characteristic deposit in the spectrum of an emergent beam. But if the size will be not exceed the value $D_{\max}$ ($D_{\min} < D < D_{\max}$), the characteristic radiation MoK$_{\alpha}$ will be present in the emergent beam X-Ray spectrum with a great intensity. It can be expected that the slit width varying in a waveguide would cause the X-Ray spectrum modification in the emergent beam at the transportation of the white X-Ray radiation.

Minimum slit sizes presented in Table 1 (without correction on the X-Ray depth penetration) are the constant. Maximum values of this parameter are near 100 nm for the K$_{\alpha}$ radiation of Fe group elements. $D_{\max}$ and $D_{\min}$ magnitudes approach each other for the hard X-Ray radiation (MoK$_{\alpha}$, AgK$_{\alpha}$). The greatest values of $D_{\max}$ for the gamma radiation have engaged our attention primarily. A significant difference between $D_{\max}$ values for X-Ray and nuclear radiations presents a unique possibility for its separation in complicated spectra, even though the radiation wavelengths coincide.

The absolute values of slit widths obtained by calculations have attracted some attention. The average value of a slit width accommodating an XSW is only by an order of magnitude higher than the total surface roughness in an X-Ray waveguide. If taking also into account that polished surfaces are characterized by macroheterogeneities, the a high efficiency of a slitless waveguide.
collimator application for TXRF analysis become evident [9, 10, 11, 12].

Attenuation of an X-Ray standing wave in a planar slit waveguide

The excitation of a standing wave in a waveguide slit gives rise to a stationary distribution of the interference field intensity both along the slit channel (along axis $x$) and crosswise (along axis $z$). This distribution is pictured in Fig. 2 to fit the input of a waveguide ($x = 0$). The distribution is plotted for a plane X-Ray beam (CuK$_\alpha$) impinging into a slit of the quartz waveguide under an angle $\theta = 0.92 \cdot \theta_c$ on the reflector surface. The reflection conditions correspond to a value phase variation $\psi \simeq 45^\circ$ and a standing wavelength $D \approx 1.1 \cdot D_{\text{min}}$. The arising standing wave is characterized by the penetration depth $z_e = 8.6$ nm. Hence, the distribution shown in Fig. 2 obeys the expression $z_e \approx 0.4 \cdot D_{\text{min}}$.

The standing wave intensity within the slit is described by expression (12). Outside the slit, the intensity decreases with decrement $\frac{1}{z_e}$:

$$J(z) = I(\theta_c; z) e^{-z/z_e}$$

where $I(\theta_c; z)$ is the undisturbed function of a standing wave intensity defined by expression (12). Integration of Eqn.(12) and Eqn.(20) produces the total intensity for a standing wave in the cross-section of an X-Ray waveguide. The domain of integration for expression (12) is equal to a slit size. The standing wave total intensity in the reflector top layers can be calculated, to a first approximation, by integrating of function Eqn.(20) in the top layer domain $1.5 \cdot D_{\text{min}}$ for each reflector. Calculations for the CuK$_\alpha$ radiation in the quartz waveguide show that the total intensity concentrated in the slit is equal to $L(0) \sim 9.2 \cdot E_0^2 D_{\text{min}}$ and the total intensity connected with top layers of the reflectors is $M(0) \sim 1.2 \cdot E_0^2 D_{\text{min}}$. The standing wave propagation along the slit channel of a waveguide is characterized by retaining the energy relation between a slit and top layers of the reflectors. It means that the relation between the energy in top layers and the total energy of a standing wave holds too:

$$\alpha(x) = \frac{M(x)}{L(x) + M(x)} = \text{const}$$

Because attenuation of a standing wave occurs only by the absorption in reflector top layers, equality (21) implies continuous energy transfer between
different standing wave parts. The attenuation of a standing wave intensity can then be described by the expression:

\[ W(x) = [L(0) + M(0)]e^{-\alpha \mu x} \]  \hspace{1cm} (22)

The magnitude of \( \alpha \) depends on the wavelength of incident radiation, the reflector material properties, the angle of radiation impinging and the width of a waveguide slit. The dependence of \( \alpha \) on the incident angle can be evaluated by calculating its variation with some incident angles area of CuK\( _{\alpha} \) radiation in the quartz waveguide. This gives the values: \( \alpha(\theta_c) = 0.8; \alpha(\theta_c/2) = 0.05 \). The value of \( \alpha \) decreases abruptly, if the slit width exceeds the wavelength of a standing wave.

Using formula (22), the values of \( \alpha \) for the incident angle \( \theta = 0.92\theta_c \) and the condition \( s_{\text{slit}} \approx 4D \), we one can calculate the total intensity attenuation for a standing wave of CuK\( _{\alpha} \) radiation in the planar quartz extensible waveguide. The total intensity of a standing wave after passing the way \( \Delta x = 10 \text{ mm} \) in the waveguide is \( W(\theta_c) = 0.3 \ W_0 \) and \( W(\theta_c/2) = 0.6 \ W_0 \). Note that the model of multiple total successive reflection under similar conditions gives: \( W_0 \cdot 10^{-27} \) and \( 0.006 \ W_0 \), respectively.

The calculated data for the total intensity attenuation of an XSW in a waveguide lend an explanation of the high efficiency of X-Ray slitless collimators for X-Ray radiation transport over long distances \([8, 10, 11, 12]\). However, the evaluations of clearance sizes between the mated quartz plates in those works strongly disagree (\( D \approx 30 \text{ nm} \) \([11]\), \( D \sim 150 \text{ nm} \) \([8]\)). Moreover, the slit width in the collimators is not a stable parameter and can vary along the collimator length. Therefore, the evaluations of quantity parameters of the emergent beam intensities for a slitless collimator must be treated with caution. In addition, note that the slit width variation can bring about a considerable modification of the X-Ray spectrum of an emergent beam, if the initial X-Ray radiation is a mixed type (white and characteristics).

The above results help to elucidate the advantages and shortcomings of X-Ray slitless collimators. Moreover, they can become the basis for an X-Ray waveguide designing with properties predicted and high intensity of an emergent beam.
Application aspects of a planar X-Ray radiation waveguide

An X-Ray slitless collimator is an X-Ray planar waveguide with an uncontrolled size of the waveguide slit, which can be varied during one experiment. Although these variations are not great, an X-Ray slitless collimator should be regarded as a simple and convenient experimental model. For practical purposes, slit waveguides are needed with the greatest possible slit size for a chosen wavelength. Quartz waveguides with slit sizes 36 nm and 91 nm are best suited for MoK$_\alpha$ and CuK$_\alpha$ radiations, respectively. To manufacture such waveguides, the metal thin strips are deposited on to edges of one quartz reflector of a waveguide, and then the waveguide is uniformly compressed between metal plates. The clearance magnitude of a slit can be controlled by the Optical Attenuated Total Reflection method [19].

An X-Ray slitless collimator came into use for X-Ray fluorescence analysis of plane surfaces and thin films (TXRF-SC analysis) some years ago [10]. The substitution of the slitless collimator by an X-Ray waveguide considerably increases X-Ray radiation density on the surface of a target analyzed and ensures the diagnostic reproduction. Furthermore, an X-Ray waveguide helps avoid the target contact with reflector surfaces. Otherwise, an X-Ray planar waveguide retains all advantages of a slitless collimator in TXRF spectroscopy. But it is notice that the spurious peaks do not disappear of the waveguide application.

Another important field of a planar waveguide application is in X-Ray diffraction research. It can be used for structure investigation of monocrystal surfaces and epitaxial films at the total reflection of an incident X-Ray beam in the parallel and perpendicular geometries [20] because a waveguide ensures high X-Ray radiation density in the beam. One more application is for X-Ray energy-dispersive diffractometry of polycrystal thin films because this waveguide is a beautiful former of a narrow high intensity beam of the “white” X-Ray radiation. The planar X-Ray waveguide holds greatest promise for using in commercial diffractometers for symmetrical and asymmetrical geometries.

Special choice of materials for the reflectors top layers is liable to provide pseudo-monochromatization of X-Ray radiation in an emergent beam. The waveguide-X-Ray concentrator may be prepared by a surface implantation of reflectors plates with variation of high number ion concentration (Pb, Bi) alone of its length ($n$ – variation in top layers).
Planar X-Ray Waveguide – Monochromator

Preceding sections are devoted to discussion of the planar X-Ray waveguide using the total X-Ray reflection phenomenon for the standing wave generation in a slit space of the device. But it is well known that the excitation of X-Ray standing wave is possible for the Bragg geometry too [21]. The X-Ray standing wave arises in a slit space between two parallel polished reflectors, if the reflectors are perfect monocrystal been orientated mutually. The mechanism of the standing wave formation in Bragg reflection conditions is not practically differed from one in the case of a total X-Ray reflection (Fig. 1). But a formal consideration of a standing wave formation in Bragg planar X-Ray waveguide (waveguide-monochromator) requests replacement of the X-Ray depth penetration parameter $z_e$ on the parameter of the primary extinction length $z_{ext}$ [22]:

$$z_{ext} = \frac{1}{\sigma} \cdot \frac{\sin \theta_b}{2\lambda|c|} \cdot \frac{mc^2}{e^2} \cdot \frac{v}{|F_h|}$$

(23)

where $\sigma$ is the extinction factor, $c$ is the polarization factor been equal to unity for a $\sigma$-polarization, $c$ is the light velocity, $m$ and $e$ are the electron characteristics, $v$ is the unit cell volume for the reflector material, $F_h$ is the relative structure factor of the chosen reflection. The $z_{ext}$ magnitude defines the crystal thickness attenuated of the X-Ray beam intensity falling on the crystal under Bragg angle with $\theta_b$ factor. It is significantly that the primary extinction length is not depended on a wavelength of an X-Ray radiation. Magnitudes of the primary extinction length are usually two orders higher as values of the depth penetration at the X-Ray total reflection. For example, the magnitude of $z_{ext}$ for (200) NaCl reflection is equal to 660 nm [22]. Because of this, the practical size of a waveguide-monochromator slit may be visibly differed from one calculated and its efficiency must be lower as compared to a waveguide built on the total reflection phenomenon. But the X-Ray radiation density in its emergent beam will be significantly higher as one for the conventional Bonse-Hart monochromator. The planar X-Ray waveguide-monochromator application is conceptually identical with the Borrmann effect manifestation in perfect crystals [23, 24]. Authors hope to give a comprehensive analysis of peculiarities which are typical for the planar X-Ray waveguide-monochromator in other work.
Conclusion

The model of XSW excitation in a planar slit waveguide has been developed by employing the interference wave theory to treat areas whose size considerably exceeds the wavelength of initial radiation but the coherence conditions are still valid. An example of practical embodiment of the idea of such a waveguide is an X-Ray slitless collimator whose unique properties could only be explained in terms of the model of XSW excitation. The evaluation of the upper and lower boundaries for the slit width which provide XSW excitation, points out the way to waveguides building with most efficient for particular purposes.

The presented model is a simple one and disregards some phenomena as such existence of the X-Ray interference field in top layers of waveguide reflectors, the Goos-Hanchen effect, monotonous modification of the refraction index on a vacuum-material interface \[25\] and others. However, even the simplified evaluations made in the work show that a planar X-Ray waveguide and a waveguide-monochromator can became useful tools for the X-Ray diffraction and spectroscopic investigations, especially for the work with synchrotron radiation.

*It is very important that the model can be applied for the neutron and electron beams and will stimulate the waveguides creation both for the white radiation and for the monochromatic one for them.* The waveguide-monochromator can be basis for the building of a laser pumping system applied for the hard X-Ray and gamma radiation. The idea of the simplest X-Ray accumulator functioned on base of the waveguide-monochromator will be described in another place.

Direct experiments with planar X-Ray waveguides is carried out today and will be published soon after.

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Captions to the Figures

Figure 1. Classical scheme of the standing wave field formation at a specular reflection of a plane monochromatic wave above the mirror surface (a), a scheme of the standing wave field formation at multiple successive reflection of a plane monochromatic wave (b), the principle scheme explaining the formation of the standing wave uniform zone upon trapping monochromatic plane wave radiation by a planar extensive waveguide (c).

Figure 2. Intensity distribution function for an XSW in a waveguide slit and a top layer of quartz reflectors for an X-Ray beam impinging on the slit under a certain angle of total reflection $\theta$ for the quartz reflectors. The function without absorption upon total reflection is shown by a dashed line. The function reflects the picture for $\lambda = 0.1541 \, \text{nm} \, (\text{Cu} K_\alpha)\,; \, \theta = 0.92 \cdot \theta_c; \, s = 97 \, \text{nm}$. 
Table 1. Slit size values $D_{\text{min}}$ and $D_{\text{max}}$ allowing an X-Ray standing wave in the clearance of planar X-Ray waveguide with quartz reflectors for the set of X-Ray and gamma radiation are collected. Some attendant parameters are presented too.

| Radiation | $E_0$ (keV) | $\lambda_0$ (nm) | $\Delta \lambda$ (nm) | $D_{\text{min}}$ (nm) | $D_{\text{max}}$ (nm) | $\theta_c$ | $\chi_e(\theta_c)$ |
|-----------|-------------|-----------------|---------------------------|------------------------|------------------------|-----------|-------------------|
| AlK$_{\alpha}$ | 1.486 | 0.8337 | $4.1\cdot10^{-4}$ (1) | 21 | 424 | 1.16$^\circ$ | \
| SiK$_{\alpha_1}$ | 1.740 | 0.7135 | $3.5\cdot10^{-4}$ (1) | 21 | 364 | 0.99$^\circ$ | \
| CaK$_{\alpha_1}$ | 3.691 | 0.3358 | $1.6\cdot10^{-4}$ | 21 | 176 | 0.46$^\circ$ | \
| CrK$_{\alpha_1}$ | 5.414 | 0.2290 | $1.03\cdot10^{-4}$ | 21 | 127 | 0.32$^\circ$ | \
| FeK$_{\alpha_1}$ | 6.403 | 0.1936 | $1.01\cdot10^{-4}$ | 21 | 93 | 0.27$^\circ$ | \
| CoK$_{\alpha_1}$ | 6.929 | 0.1789 | $8.1\cdot10^{-4}$ | 21 | 99 | 0.25$^\circ$ | \
| CuK$_{\alpha_1}$ | 8.046 | 0.1541 | $5.8\cdot10^{-4}$ | 21 | 102 | 0.21$^\circ$ | \
| GeK$_{\alpha_1}$ | 9.885 | 0.1254 | $4.9\cdot10^{-4}$ | 21 | 93 | 0.17$^\circ$ | \
| $\gamma_1$Fe$^{57}$ * | 14.39 | 0.0862 | $2.8\cdot10^{-10}$ | 21 | $6.6\cdot10^7$ | 0.12$^\circ$ | \
| MoK$_{\alpha_1}$ | 17.476 | 0.0709 | $2.9\cdot10^{-4}$ | 21 | 43 | 0.10$^\circ$ | \
| AgK$_{\alpha_1}$ | 22.159 | 0.0559 | $2.8\cdot10^{-4}$ | 21 | 21 | 0.077$^\circ$ | \
| $\gamma_1$Sn$^{119}$ * | 23.80 | 0.0521 | $5.6\cdot10^{-10}$ | 21 | $1.2\cdot10^7$ | 0.072$^\circ$ | \

1 The represented magnitudes are estimated.