Elaboration of pulsed X-ray laser on base of radiation fluxes waveguide-resonance propagation phenomenon

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Abstract. The work presents short characteristics of the radiation fluxes waveguide-resonance propagation phenomenon opened in result of X-ray characteristic radiation transportation peculiarities study by planar extended slit clearance functioned in frame of its total external reflection phenomenon. There are showed that the waveguide-resonance phenomenon must become apparent in frame of the Bragg reflection phenomenon and can be used for elaboration of the Bragg-Laue waveguide-resonance cells (BLWRC). Set of BLWRCs can be used for construction of compact pulsed X-ray laser in form of circular radiation storage. There are presented and discussed its expected parameters.

1. Introduction
Fast processes investigation is possible at existence of high velocity testing procedures. Similar experimental procedures were made accessible in result of pulsed X-ray lasers appearing, which are able to form short radiation pulses with very great X-ray photons concentration and adjustable filling factor [1]. Experimental experience showed that the X-ray free-electron laser is the best approach for pulse radiation beams facility preparation [2]. The European XFEL is a sample of such construction [3]. It can generate femtosecond X-ray pulses with filling factor near 27 kHz. At the same time, the similar facility exploitation is very expensive and its experimental accessibility is limited. So, there are good grounds for search of simple cheap constructions of pulsed X-ray laser system, which can be used in any laboratories studying fast processes. The work presents the principle conception of pulsed X-ray laser elaboration on base of radiation fluxes waveguide-resonance propagation phenomenon consequences.

2. Phenomenon of radiation fluxes waveguide-resonance propagation
The phenomenon of radiation fluxes waveguide-resonance propagation (or the phenomenon of radiation fluxes superfluidity) was discovered in systematic investigation result of X-ray quasimonochromatic radiation fluxes transportation peculiarities by planar extended slit clearances [4]. This phenomenon is the consequence other phenomenon – the X-ray flux total external reflection on a material interface (TER) [5]. The interference field area arising of X-ray standing waves in result of incident and reflected fluxes interaction is the notable feature of TER phenomenon. The interference field appearing was fixed the first by group of prof. Bedzyk [6]. But it is the need to
notice that the fact of the optical standing waves interference fields appearing at the optical fluxes reflection was revealed more early [7]. The theoretical base of X-ray standing waves appearing is connected with name of prof. Laue [8]. Relying on this conception he explained the anomalous transmission effect of X-ray fluxes through thick monocrystal objects known as the Bormann effect [9]. After these publications the conception became a ground for description of the Bragg diffraction [10]. But it was disregarded at interpretation of the X-ray flux transportation effect by X-ray slitless collimator [11]. Authors of this work explained the device function on base of the multiple total external reflection effect. Such approach failure was proved in process of systematic experimental investigation of planar extended air slit clearance width influence on parameters of X-ray beam formed by the clearance [4]. The systematic experimental data allowed to elaborate the model of radiation fluxes waveguide-resonance propagation. Main feature of the model is X-ray standing wave uniform interference field arising in all space of the planar slit clearance. The uniform interference field appears when the width of the slit clearance will be smaller as the radiation half coherence length transported by the clearance. (Radiation coherence length is defined by expression $L=\lambda_0^2/\Delta\lambda$, where $\lambda_0$ is the average wavelength of radiation and $\Delta\lambda$ is the monochromatism degree of it. When the slit clearance width will be larger of the radiation half coherence length X-ray flux will be transported by the multiple total external reflection mechanism (figure 1a). When the slit clearance width decrease up to smaller as the critical size $s=\lambda/2$ local interference areas combine and form the radiation standing wave uniform interference field (figure 1b).

Figure 1. Schemes of quasimonochromatic X-ray fluxes propagation through wide extended slit clearance by the multiple external total reflection manner (a) and through nanosize one accordingly to the waveguide-resonance propagation mechanism (b).

Analogical picture can be expected for the Bragg reflection realization. But it is a need to bear in mind that the total external reflection of X-ray fluxes takes place on the material interface regardless of its structure and phase states. High effective Bragg reflection can be realized by use perfect monocrystals in its specific orientation, only. The effect of multiple consecutive Bragg reflection was demonstrated in experiment in the work of Bonse and Hart [12]. They elaborated the X-ray high effective monochromator on base of Si low dislocation monocrystal. The monochromator was prepared as the planar extended slit clearance with width $s=8$ nm formed by Si surface crystallography orientation [220]. Experimental testing of the monochromator showed that its emergent beam was characterized by angular divergence near $0.0025^\circ$ and preserved near 30% from CuK$\alpha$ initial beam integral intensity.
after 10 Bragg reflections in the clearance of Si monocrystal. Because of the CuKα radiation coherence length is equal to 430 nm we can maintain that the Bonse-Hart monochromator functions in frame of the multiple Bragg reflection mechanism. In our preliminary investigations we built the Bonse-Hart monochromator on base of NaCl monocrystal reflectors with mutual orientation [200] and channel width s=1 mm. In the result of many times Bragg reflections (n=10) in the channel we got CuKα emergent beam with angular divergence δϕ=0.001° and integral intensity I=0.9I₀. Owing to strong hydroscopicity of NaCl crystals and difficulties of reflectors mutual orientation we could not realize the waveguide-resonance regime in Bragg reflection conditions with this materials. Today we have the waveguide-resonance cell functioned in frame of Bragg reflections conditions built on base of Si reflectors with mutual orientation [110] and distance between them s=0.1 µm. It characterized by very small angular divergence near 0.0005° but and very small integral intensity of CuKα emergent beam (I~0.05I₀). It is very difficult to prepare distortionless surface of Si reflectors and to execute the procedure of its precise mutual orientation. But we continue to work on enhancement of the cell properties with Si, Ge, LiF, Al₂O₃, SiO₂ and Al crystals. Name of the new device is Bragg-Laue waveguide-resonance cell (BLWRC). As we expect that BLWRC will display better properties in comparison with Bonse-Hart monochromators because of the planar X-ray waveguide-resonator (PXWR) shows better characteristics in comparison with X-ray capillary structures [13]. Main distinction of Bragg-Laue cells from PXWR is connected with its ability to change of X-ray beam propagation direction on the double Bragg angle almost without its integral intensity attenuation. For example, BLWRC devices built on LiF monocrystal reflectors with mutual orientation [200] and Ge crystal reflectors with mutual orientation [220] will turn CuKα radiation flux on 45° almost without it intensity decreasing. In the result, similar cells set application contained 8 devices can to build the circular X-ray storage. Figure 2 presents the principle scheme of the circular storage oriented on BLWRC set been able to turn of X-ray beam on 45°. The scheme contains two additional devices intended for induce of X-ray radiation (M₁) and for the pulsed discharge of radiation bunch (M₂). M₁ radiation indenter introduces the pumping flux into the storage by use the modified Bormann structure. Moreover, this device has additional function as the total external reflection mirror. M₂ device is used as the total external reflection mirror placed on fast pulsed goniometer. Radiation pumping of the storage can be accomplished by any source of X-ray radiation. In storage construction presumed to building in our laboratory the radiation pumping will be executed by standard X-ray tube BSW-24 (Cu) in combination with planar X-ray waveguide-resonator, which is able to form nanosize small-divergence radiation fluxes.

3. Evaluation of storage emergent beam parameters
Bunch duration of the storage emergent beam will be defined by total length of its circle. If it would appear reasonable the circle radius is equal to 1 meter the duration of radiation bunch will be near 10⁻⁸ sec. In principle, time size of the bunch can be decreased on 1÷2 orders but in the any case the X-ray
Free Electron Laser will win in this parameter in comparison with the circular radiation laser. For evaluation of the bunch photon quantity one can suppose that the flux total attenuation in the storage is 10%. Initial experiments will be executed with BSW-24 (Cu) X-ray source in regime \( U=20 \) keV, \( I=10 \) mA together with PXWR. Size of the CuK\( \alpha \) radiation beam formed by this device will be \( h=10 \) mm, \( s=100 \) nm and its integral intensity is near \( 2 \times 10^6 \) photon/sec [14]. Taking into account of CuK\( \alpha \) radiation coherence length one can calculate that the bunch will contain \( 1.5 \times 10^{12} \) photons. Magnitude of this parameter is competitiveness with one of emergent beams characteristic for best XFELs. Owing to the coherence length parameter of CuK\( \alpha \) radiation has nanosize the circular laser emergent beam width will characterize by nanosize too. Angular divergence of the emergent beam will be smaller in comparison with one of the Bonse-Hart monochromator emergent beams.

4. Conclusion
The conception of pulsed X-ray laser elaboration in form of the circular radiation storage built on BLWRC set use was discussed. Similar facility does not present to total alternative to XFEL but its can find an application to study of processes kinetic with time resolution near \( 10^{-8} \) sec.

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