X International Symposium

RREPS-13

Radiation from Relativistic Electrons in Periodic Structures

&

III International Conference

Meghri-13

Electron, Positron, Neutron and X-ray Scattering under External Influences

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Section 1

General Properties of Radiation from Relativistic Particles

Spectral Properties of Compton Inverse Radiation

E. Bulyak[1]
NSC KIPT, Kharkov,Ukraine

Compton inverse radiation emitted due to backscattering of laser pulses off the relativistic electrons possesses high spectral density and high energy of photons – in hard x–ray up to gamma–ray energies – because of short wavelength of laser radiation as compared with the classical electromagnetic devices such as undulators.

In this report, the possibility of such radiation to monochromatization by means of collimation is studied. Two approaches have been considered for the description of the spectral–angular density of Compton radiation based on the classical field theory and on the quantum electrodynamics. As is shown, both descriptions produce similar total spectra. On the contrary, angular distribution of the radiation is different: the classical approach predicted a more narrow radiation cone.

Also proposed and estimated is a method of the "electronic" monochromatization based on the electronic subtraction of the two images produced by the electron beams with slightly different energies. A "proof–of–principle" experiment of this method is proposed for the LUXC facility of KEK (Japan).

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Compact Gamma-beam Source Based on Compton Storage Ring for Nuclear Waste Management

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[b] *KEK, Tsukuba, Japan*

A compact storage ring dedicated to the nuclear waste management by use of the nuclear resonance fluorescence is described. Gamma-beam with the quanta energies from 0.3 MeV to 7.2 MeV is generated in the Compton scattering of the "green" laser photons on the electron beam with energies from 90 MeV to 430 MeV. The characteristic property of the proposed gamma-beam source is a narrow spectrum (of 1%) at high average gamma-yield (of $10^{13}\gamma/s$) due to special operation mode.

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New Source of High-energy Gamma Radiation in Atmosphere

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Rapidly expanding field of energetic particle and radiation physics in terrestrial atmosphere, namely, High-Energy Atmospheric Physics, impacts traditional atmospheric electricity and lightning physics, study of cosmic-ray extensive air showers, discharge physics, space physics, plasma physics, and aviation safety. One of the most exciting manifestations of the new field is so called Thunderstorm Ground Enhancement (TGE): abrupt enhancements of surface particle detector count rates correlated with thunderstorm activity. Facilities of the Aragats Space Environment Center (ASEC) observe charged and neutral fluxes of secondary cosmic rays by the variety of particle detectors located in Yerevan and on slopes of Mount Aragats at altitudes 1000, 2000 and 3200 m. ASEC detectors measure particle fluxes with different energy thresholds as well as Extensive Air Shower (EAS) initiated by primary proton or stripped nuclei with energies greater than 50-100 TeV and Extensive Cloud Showers (ECS) initiated by the electron-gamma ray avalanches in the thunderstorm atmosphere. TGEs detected during 2008-2013 allow the detailed analyses and taxonomy of the new high-energy phenomena in the atmosphere.

Ambient population of secondary cosmic ray electrons in the electric fields with strength greater than critical value unleash the electron-gamma ray avalanches and total number of particles on the exit from cloud can be multiplied by several orders of magnitude. Proceeding from the measurements of the charged and neutral fluxes as well as from the energy deposit of particles in thick scintillators we recover the energy spectra of TGE electrons and gamma rays. The energy spectrum of the electrons and gamma rays born in Thunderstorm ground enhancements (TGEs) shed light on the origin of TGE, on RREA development in thundercloud, on the nature of the seed particles and on strength and elongation of atmospheric electric field. For the first time we present differential energy spectra of gamma rays in wide energy range 4-100 MeV for 5 TGE events detected in 2012-2013 at Aragats. We use special technique of electron/gamma ray fraction determination to select TGE events with very small contamination of electrons.

The power law indexes of "small" TGEs are very close to the background cosmic gamma ray spectrum ($\gamma \sim -2$ at altitude 3000 m above sea level); thus we can deduce that these small events are due to modification of the energy spectra (MOS) of cosmic ray electrons in electric field of thundercloud. Larger TGEs measured by NaI network and 2 largest TGE events earlier recovered from energy releases in 60 cm thick scintillator have much more harder energy spectra, which can arise in the avalanche process, thus proving existence of the Relativistic Runaway Electron Avalanches (RREA) unleashed in the strong electric fields of the thundercloud. The shape of measured differential energy spectra and classification of TGE according to intensity and spectral index pointed on 2 main mechanisms of the TGE gamma ray origin Ц runaway process and modification of electron energy spectra in the thunderstorm atmospheres.

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Radiation of Laser-channeled Electrons

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Nowadays channeling has wide applications including beam manipulation, deflection and transportation. And the very term "channeling" is getting wider today absorbing new phenomena that could be successfully described with the help of channeling methodology, from X-ray quanta channeling in nanostructures [1] and propagation of electrons in plasma channels [2] to a controlled particles movement in the fields of different nature.

The possibility of trapping electrons in channels formed by standing electromagnetic waves was shown before [3, 4]. Standing electromagnetic waves can be created in waveguiding structures (either planar or axial) and could present a new technique for beam reflection and steering. Propagation of electrons in such systems is to be considered as channeling, since they perform oscillations in periodic potential channels and since such oscillations are orientation-dependent with the critical angle

$$\phi_{cr} = \frac{\sqrt{2mU_{eff}}}{p}, \quad (1)$$

where $U_{eff} \sim (\lambda E_0)^2$ is the efficient potential barrier height [4].

This work is devoted to the description of radiation spectrum of electron channeling in the field formed by standing electromagnetic waves. The analytical expression for electron radiation spectrum derived and computer experiments conducted will be presented.

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Feasibility of X-ray Cherenkov Radiation for Beam Diagnostics of Linear Accelerators

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Recent progress in development of accelerator technology for future linear colliders and X-ray free electron lasers has generated an interest in developing novel diagnostics equipment with resolution overpassing the unique beam parameters. Vavilov-Cherenkov radiation (CR) in X-ray region is one of the promising sources for beam diagnostics of linear accelerators, because the CR is only generated in the frequency region in the vicinity of the atomic absorption edges, where the well-known Cherenkov condition is work.

In this work we used the method of "polarization currents" [1] to determine the CR characteristics generated by a charged particle at oblique incidence and passing by a rectangular screen and through a plate of finite dimensions and finite conductivity in the vicinity of the atomic absorption edges. In the limiting cases of normal incidence the expressions obtained for the radiation intensity coincide with the results of paper [2] for ultrarelativistic energies and paper [3] for moderately relativistic electrons.

In particular we have demonstrated CR characteristics in X-ray region significantly depend on the energy of the emitted photons. This peculiarity can be explained by resonance behaviour of the permittivity in the frequency range. It will result in the fact that the CR will stand out of any other types of polarisation radiation both on intensity and shape of angular distribution giving a unique opportunity to apply this phenomenon for charged particle beam diagnostics.

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On Electromagnetic Radiation in the Atmosphere of the Excess Negative Charge in the Nuclear - Electromagnetic Cascade

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To analyze the dynamics of the negative charge excess in the secondary cosmic rays flux [1] the simulation of the nuclear-electromagnetic cascade in the Earth's atmosphere have been done using a software package Geant-4 (Planetocosmic) [2] and the analytical model PARMA [3]. The module "Planetocosmic" allows one to simulate a nuclear-electromagnetic cascades induced by cosmic rays in the Earth's atmosphere, taking into account the Earth's magnetic field and calculate the particles fluxes at a given height. A set of realized processes of interaction includes electromagnetic and hadronic processes, the processes of decay and the evolution of short-lived particles in the energy range from 250 eV to several TeV. The PARMA analytical model allows one to calculate the fluxes of secondary particles using selected empirical formulas with sufficient accuracy (Fig. 1). The results of the simulation are used for analyzing the

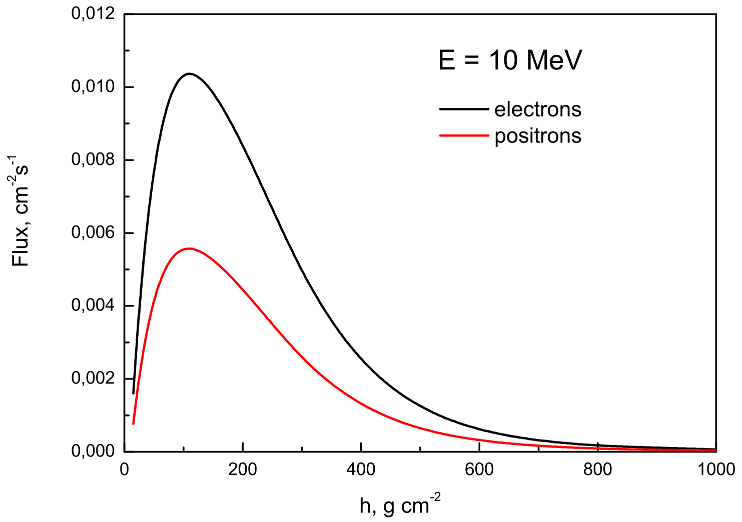

Figure 1. The electrons and positrons fluxes with energies of 10 MeV via the depth of the atmosphere.

excitation of longitudinal and transverse electromagnetic waves in the atmosphere caused by the excess of negative charge in the electromagnetic cascade.

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Polarization Radiation in a Teflon Target

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Geometry of Cherekov (ChR) radiation when an electron moves close to a dielectric target is in analogy to diffraction radiation (DR) geometry. In this case we may expect DR generation from the upstream surface of the target besides that ChR. The joint observation of these booth types of radiation is very interesting from the pseudo-photon viewpoint, which is applicable for relativistic electrons. Unexpected results obtained in our experiment insist on reflection about nature both DR and ChR. The experiment was performed on the relativistic electron beam with energy 6.2 MeV in Tomsk Polytechnic University.

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Ray-Optical Analysis of Radiation of a Charge Flying nearby a Dielectric Object

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Calculation of radiation of charged particles and bunches in the presence of dielectric objects is an actual problem for the accelerator and beam physics [1]. As a rule, dielectric target has a complex form, so obtaining an exact analytical solution is impossible. At the same time, direct computation of electromagnetic field is very laborious. Therefore development of approximate methods for calculation of bunch radiation in the presence of complex dielectric objects is now of a great interest [2, 3, 4, 5, 6]. The method developed by us [6] can be used when typical wavelengths are small in comparison with size of the object. This technique allows taking into account the influence of "neighbouring" boundaries of the object, as well as effect of "external" boundaries (using the ray optics laws).

In this report, we consider, in particular, two cases of charge movement in the presence of dielectric prism. In the first case, the charge moves in the vacuum channel inside the prism. In the second case, the charge moves along the prism boundary. The problem solution includes two steps. At first, the field of the charge in an infinite medium without "external" borders is calculated. The second step is the approximate calculation of the radiation exiting the object on the basis of ray optics laws. The results obtained show typical dependences of the radiation field on the observation point displacement and the problem parameters.

As well, we discuss prospect of applying the method under consideration to other problems. In particular, we consider the case of a charge which flies out of a waveguide loaded with a dielectric layer and having an oblique end. This situation is of interest for some accelerator applications. In the case of high waveguide modes, the technique under consideration can be used for analysis of such problems as well.

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Multiple Filamentation of the UV Supercritical Laser Beam

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lthough filamentation of high-power Ti:Sa laser pulses in air due to Kerr effect is under extensive studies since 1995 [1], a multiple filamentation regime which arises at supercritical powers $P >> P_{cr}$ stays the most unknown [2]. It is easier to obtain it for UV light, as the critical power $P_{cr} \approx 100$ MW for $\lambda_0 = 248$ nm (KrF laser) is less in 30 times than for $\lambda_0 = 800$ nm (Ti:Sa laser). Multiple filamentation of UV picosecond pulses with $P \sim 0.3$ TW ($P/P_{cr} \sim 3000$) being produced at GARPUN-MTW Ti:Sapphire/KrF laser facility was investigated for the first time under propagation along an extended air distance of $\sim$ 100 m in various focusing geometries ($NA = 1.5 \cdot 10^{-2} - 1.5 \cdot 10^{-3}$). Beam filamentation was compared for a single laser pulse and a train of few pulses with time interval $\sim$ 5 , being less than electrons relaxation time in plasma. Multiple bright spots of typical diameter $\sim$ 0.1 mm are evidently seen over the beam cross section, which point up a multiple filamentation arising immediately at the output of the laser (**Fig. 1 a**). A density of filaments increases with beam focusing (**b**) and near the focus they are indistinguishable because of overlapping (**c**). Behind the focus in the expanding beam filamentation structure reappears again. In spite of a multiple filamentation, UV laser beam demonstrates linear focusing, which is in contrast to the filamentation of IR radiation where nonlinear Kerr self-focusing compensates the beam divergence. For measured UV energy attenuation $\sim$ 1 mJ/m parameters of filaments were found to be quite different of IR filaments.

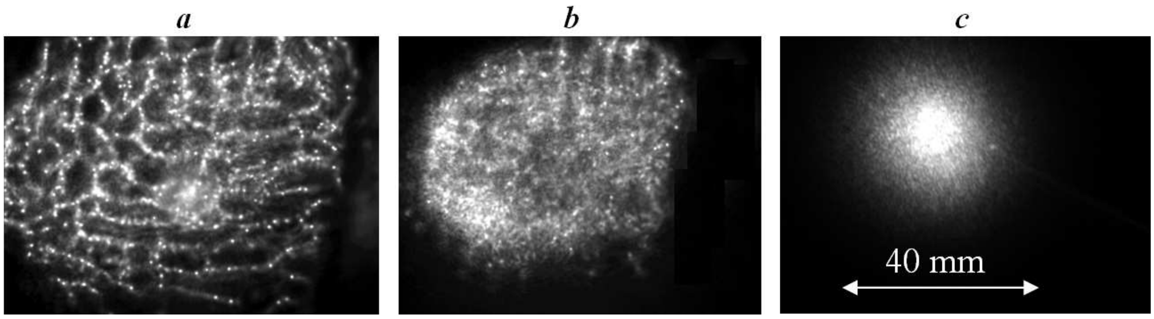

Figure 1. Distribution of UV radiation over laser beam cross section at distances (**a**) 75 m and (**b**) 50 m in front of the focus $F = 100$ m, (**c**) in the focal plane.

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Total Field Generated Inside a Relativistic Electron Beam Propagating in a Rectangular Dielectric Waveguide

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Dielectric waveguidesare extensively researched as wakefield accelerating structure, where Cherenkov radiation is used for accelerating of charge particles [1,2].These structures can be excited by electron beams (Cerenkov radiation) or by an external X band power source. Rectangular structures are more simple in terms of manufacturing technology and can be used in THz range, in test experiments for developing new accelerating schemes and for studying the materials properties. Calculation of the total field of relativistic electron bunch in a dielectric rectangular waveguide was carried out with the help of the expansion in eigenfunctions of the transverse operators Helmholtz equations. This study presents an expression for the Green function of the total field, which is expressed in terms of a superposition of LSM and LSE modes. The resulting expression is incorporated in the calculation module for transverse dynamics of electron beams in original BBU code [3]. The transverse dynamics of the relativistic electronic beam is analyzed. Parameters ranges of essential influence of far-field (Cherenkov radiafion) and near-field on beam dynamics are determined.

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Reconstruction Procedure for Single-photon Radiation Spectra from Multi-photon Ones

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In coherent radiation processes with moderate photon multiplicities, the measured multi-photon spectrum deviates from the classically calculable single-photon one. There are two ways of taking multi-photon effects into account: either evaluate the multi-photon spectrum issuing from the single-photon one, or vice versa, if the spectrum does not significantly depend on impact parameters of the radiating electron to be averaged over, a single-photon spectrum can be reconstructed from the measured multi-photon one. We describe the corresponding reconstruction procedure, and apply it to the case of recently measured radiation at volume reflection.

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Electromagnetic Radiation of Electron Bunches Channeled in Ion-channels

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As known during the process of powerful ultrashort laser impulse interaction with a plasma almost spherical ionic cavity [1] is formed behind the impulse. The cavity is capable of trapping the plasma electrons previously accelerated by the laser impulse. Neglecting the acceleration of trapped electrons by the field of ionic cavity, the cavity can be considered as an infinite ion-channel (in reality the cavity develops down together with the laser). Plasma electrons having rather large transverse momentum perpendicular to the direction of the ion cavity spread can be strongly attracted by the moving ion cavity that can be described as electrons channeling in a plasma-ion channel [2]. Such electrons emit strongly radiation becoming a source of powerful x-ray radiation similar to synchrotron radiation (betatron radiation). Recently it was shown [3] that at certain transverse momentum values, electrons moving in the ion-channel could undergo the bunch modulation that strongly influences the processes of both coherent and incoherent radiations. And till now, the radiation by free electrons injected into the cavity, with smaller (with respect to trapped plasma electrons) transverse momenta, is under intense studying.

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Polarization Properties of the Cherenkov Radiation from Relativistic Heavy Ions in a Solid Radiator

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Since Tamm and Frank (1937), it is well-known that Cherenkov radiation (ChR) is linearly polarized in a plane formed by the particle velocity vector and the vector of radiation direction. Until now polarization properties of ChR were not studied in detail except first experiments made by P.A. Cherenkov with 70 keV electrons. The detector physicists utilize mainly two well-known properties of ChR: its threshold character and fixed emission direction.

Recently, in [1] it was suggested that the linear polarization of ChR can be used for studies of the earlier stages of the broad air showers development. The physical reason for that is connected with the fact that ChR from earlier parts of the shower has definite polarization direction while latter directions become more or less stochastic. So, the usage of polarizing filters with corresponding orientation allows studying of earlier stages of the broad atmospheric showers formation.

In the case of relativistic heavy ions (RHI), as showed in Ref. [2-8], the RHI slowing-down in a solid radiator may change sufficiently both angular and spectral properties of ChR. Here we study in detail the polarization properties of ChR from RHI taking account of the influence of the slowing-down in a solid radiator. Due to RHI velocity decrease in a solid radiator, the direction of linear polarization of ChR from RHI changes (it is not connected with the change of velocity direction, as in the case of Ref. [1] - since only multiple scattering can change it - but for RHI one can neglect it) and one can suggest the new experimental schemes utilizing the polarizing filters, as in Ref. [1], to study fundamental properties of ChR from RHI.

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Microwave Radiation from a Charged Particle Revolving along a Shifted Equatorial Orbit about a Dielectric Ball

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The radiation from a charged particle uniformly revolving along a shifted equatorial orbit about a dielectric ball has been investigated. The results of numerical calculations based on exact solutions of Maxwell equations with due regard for dielectric losses of energy within the ball material testify that (a) for definite "resonant" values of the particle revolution frequency relativistic electron may generate microwave Cherenkov radiation tens of times more intense as that generated at the revolution in a continuous, infinite and transparent medium with the same permittivity as that of the real part of the permittivity of ball material and (b) in case of large values of permittivity of ball material (strontium titanite) the "resonant" radiation is generated by the revolving electron with energy of the order of 20keV.

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On the Influence of a Dielectric Ball on Electromagnetic Processes

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The influence of a dielectric ball on the radiation from a charge moving along an assigned path (a straight line or a circle) has been studied based on exact solutions of Maxwell equations. It was shown that optimal from the point of view of emissive power is a) the circular trajectory of the particle and the case when b) the ball is within the particle orbit, in the event of which the particle may generate anomalous Cherenkov radiation power at the "resonance" rotating frequency.

The novel source of laser radiation demonstrated in the USA in 2009 had dimensions several times as less as the wavelength of emitted light [1]. The novelty of source (”nanolaser”) consists in the use of plasma electromagnetic waves localized at the surface of nanoparticle. For practical applications of such a ”nanolaser” it is urgent to identify the generation mechanisms of surface electromagnetic waves, the extrinsic laser pumping for which is not required. As was shown in the present work, in case of revolution at the "resonant" frequency about the ”nano ball” the electron may generate anomalously strong electromagnetic oscillations in the ball bulk, strong electromagnetic oscillations being also generated closely at the surface of the ”nano ball”. It is proposed to use this effect as an alternative mechanism for ”nanolaser” pumping.

Metamaterials composed of magnetodielectric spheres have attracted much attention because of their almost-isotropic and low-loss properties, which make them candidates for many potential applications. Multi-layer concentric spheres give us more flexibility in search for geometrical and material configurations exhibiting a negative index of refraction [2]. Even though these metamaterials have been analyzed by a number of authors, it is still not clear how accurate their solutions are since each of them made different approximations in their analyses. For solution of this important (for practical applications) problem, in the present work it is proposed to use an exact, visual and numerously approved method for solution of Maxwell equations for a medium consisting of spherically symmetric concentric layers.

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Optics of Gyrotropic Crystals in the Field of Two Counter-running Ultrasound Waves

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An oblique light transmission through a gyrotropic crystal layer in the field of two counter-running ultrasound waves is considered. The problem is solved by Hambartsumian's layer addition method. The results of investigation of the obtained amplitude and polarization characteristics on the wavelength for various parameters of the problem are presented. The reflection spectra evolution is investigated for the wavelength changes and the difference of the amplitudes of the counter-running acoustic waves. The application possibilities of such systems are discussed.

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Photons Scattering on Planar Channeled Positron and Electron

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When a relativistic charged particle enters into a crystal at small angle with respect to a crystal plane or axis its interaction with crystal can be described by continuous (averaged) potential of the crystal plane or axis [1]. The relativistic charged particle can be captured into channeling state [1, 2, 3]. The channeled particle has the discrete transverse energy levels. Therefore the ordinary perturbation theory for quantum electrodynamics does not work and Feynman rules should be changed (see for example [4]).

In the present report we investigate photon scattering on the channeled electron and positron. For the simplicity we use co-moving (with channeled particle) coordinate system when non relativistic description can be used. During scattering process the channeled particle can change its transverse energy level. Analysis shows that it is possible transitions as with increasing so with decreasing the transverse energy. The calculations have been done for two cases: single crystal potential well and periodic crystal potential. On the Fig.1 it is shown cross-section of photon on channeled positron as a function of photon scattered angles for positron transition $i \to f$ ($i = 1$, $f = 1$ and $i = 3$, $f = 2$) in single potential well.

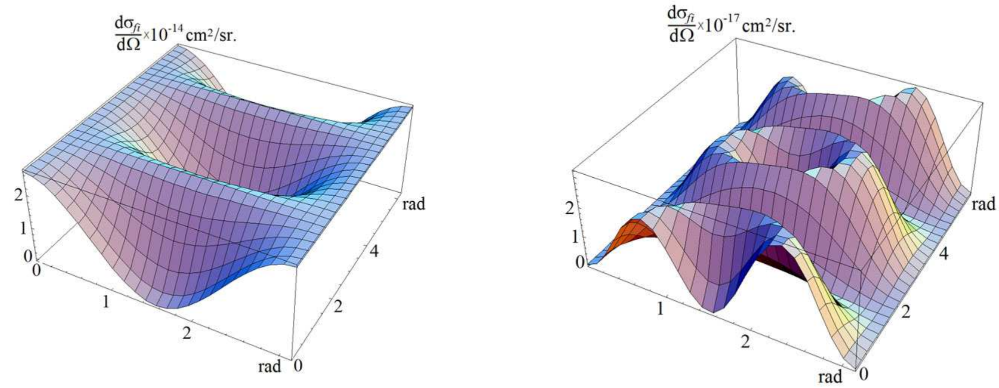

Figure 1. cross-section of photon on channeled positron as a function of photon scattered angles for positron transition $i \to f$: a) $i = 1$, $f = 1$; b) $i = 3$, $f = 2$

Early in the literature it has been discussed using the Compton Effect for creation of the intensive γ – ray beam (see [5] and references therein).

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Monochromaticity of Compton Backscattering Radiation Source for High Intensity of a Laser Beam

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The main purpose of the ELI-NP project [1] is to construct the bright monochromatic Compton backscattering source with energy bandwidth better than 0.3% by hard collimation of a resulting gamma beam. Many authors investigated a worsening of a monochromaticity due to divergences of electron and laser beams, relation between transverse size of laser beam and collimation aperture, energy distribution of initial electron beam and so on (see, for instance, [2,3]).

In this report we show there is the additional effect which leads to a broadening of gamma beam bandwidth – the multiple interaction of an initial electron with laser photons (both in linear and nonlinear modes). Using Monte-Carlo technique we have simulated shape of spectral line for collimated radiation for different concentrations of laser photons in the interaction region and obtained dependence of rms deviation of spectral lines on this characteristic.

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Propagation of the Transverse Waves in Plasma Interacting With Laser Beat Waves

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The self consistent kinetic equation, describing the state of the collisionless plasma with the initial Maxwell distribution and interacting with laser beat waves is considered. Expressions for dielectric permittivity and the dispersion equation are obtained to investigate the spectra of the transverse electromagnetic waves. An analysis of the dispersion equation for travelling in plasma low and high frequency electromagnetic waves has been carried out.

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Section 2

Transition Radiation

Gamma Cherenkov-Transition Radiation of High Energy Electrons and Methods for the Measurement of the Refractive Index of MeV

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The famous experimental and theoretical results [1] showing and explaining that the refractive index of some materials for MeV photons can be greater than 1 as well as proposing important applications of these results in gamma optics and nuclear physics are discussed briefly. Since there are some published doubts [2] on the corresponding theoretical results, and taking into account the difficulties for repeating the experiment [1] it is proposed easier experimental methods which can be used to confirm or decline the results [1]. It is given a review of the theoretical works on gamma ray Cherenkov transition radiation and methods proposed for the measurement of refractive index of MeV photons in some materials.

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Coherent X-Ray Cherenkov Radiation Produced by Microbunched Beams

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Analytical and numerical results on the coherent X-ray Cherenkov radiation (CXCR) produced by microbunched beams in the region near the K-edge of some materials are obtained. The results show that CXCR can serve as a suitable mechanism for production intense beams of photons in the "water window" region as well as for studying the important for XFELs microbunching process at FLASH TESLA, LCLS and other FELs.

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Electromagnetic Field of a Charge Intersecting Boundary Surfaces in a Waveguide

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Radiation of a charged particle (or a small bunch) crossing a boundary between two homogenous media in a metal cylindrical waveguide has been analyzed in series of papers including our previous works [1, 2, 3]. In particular, an interesting effect of Cherenkov-transition radiation (CTR) at the dielectric-vacuum boundary [3] was investigated. It was shown that the CTR can be dominant in the vacuum area. Recently, the idea of self-amplified Cherenkov radiation (CR) in the waveguide filled with a periodic dielectric structure was discussed [4]. In view of this, it is of significance to consider an intermediate case when a charge intersects two or several boundaries in the waveguide.

We analyze the electromagnetic field (EMF) of the charge moving uniformly and traversing a waveguide discontinuity: a dielectric plate in a vacuum or a vacuum cavity in a dielectric. It should be noted that the case of dielectric plate situated in a waveguide was considered before [5]. However, the main attention was only paid to the investigation of the energetic characteristics, and the EMF structure was not analyzed. We obtain exact expressions for total field including the so-called "forced" EMF (the field of the charge in the regular waveguide) and the "free" one connected with the influence of the boundary. The small losses in media are taken into account. The main attention is focused on the most interesting case when CR is generated in a dielectric. We perform an analysis of the field components of each mode with methods of the complex variable function theory. An algorithm of computation using exact expressions for the EMF is presented also. Consideration of the EMF structure is given for different velocities of the charge motion and for different time moments. The results obtained in this work can be the basis for analysis of the bunch radiation in the waveguide with finite series of dielectric plates.

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Radiation from Varying Velocity Charge in Flight through a Plate

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General expressions for the electromagnetic field of a charged particle arbitrarily moving in a medium in the presence of two plane-parallel interfaces are given in [1]. In the present work the electromagnetic field of a particle rectilinearly traversing a plate at variable velocity normal to the surface was determined by means of an accurate and illustrative method (other than that used in [1]). The expressions obtained are simpler than those following from general formulae in [1].

It was shown that the slowing-down of particle may essentially influence (a) the spectral-angular distribution of Cherenkov radiation from the particle and (b) the interference of transition radiation generated by the particle at the flight in and out of the plate (these phenomena have not been studied in [1]). The results of appropriate numerical calculations and their visual explanations are given. Possible practical application of the obtained results is discussed.

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Sub-micrometer Transverse Beam Size Diagnostics Using Optical Transition Radiation

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Transverse electron beam diagnostics is crucial for stable and reliable operation of the future electron-positron linear colliders such as CLIC or Higgs Factory. A sub-micrometer resolution beam profile monitors are required to measure high-energy particle emittance. The-state-of-the-art in transverse beam diagnostics is based on the laser-wire technology, i.e. when a high power laser is focused in the interaction region down to a micrometer dimension and is scanned across the electron (positron) beam generating intense inverse Compton scattered photon beam. The photon intensity is proportional to the number of particles in the beam and to the laser position with respect to the beam center. By measuring the Compton photon yield versus laser position one can directly measure the transverse beam profile. The use of high power laser significantly increases the cost of the laser-wire system. In linear colliders over 70 such stations are required. Moreover, the laser maintenance will require a team of highly qualified experts, which will increase its operation cost. Therefore, a simpler and relatively inexpensive method is required. A beam profile monitor based on Optical Transition Radiation (OTR) is very promising. The resolution of conventional OTR monitor is defined by a root-mean-square of the so-called Point Spread Function (PSF). In optical wavelength range the resolution is diffraction limited down to a few micrometers. However, in [1] we demonstrated that the OTR PSF differs from a conventional PSF of an optical system. The vertical polarization component of the OTR PSF has a two-lobe structure which visibility can be used to monitor vertical beam size with sub-micrometer resolution. On the other hand if the beam is flat, which is true for linear colliders, the horizontal projection of the distribution represents a direct measurement of the horizontal beam size. It gives an opportunity to diagnose an electron beam size in two directions in a single shot. In this report we shall represent the recent experimental results of a micron-scale beam size measurements. We shall describe the entire method including calibration procedure, new analysis, and calculation of uncertainties. We shall discuss the hardware status and future plans.

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Investigation of EUV Backward Transition Radiation Characteristics generated by 5.7 MeV Electrons in Mono- and Multilayer Targets

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Transverse beam profile imaging based on backward transition radiation (BTR) in the visible region is widely used in modern linear accelerators. However, recent results from linac based light sources such as LCLS (USA), FLASH (Germany) and SACLA (Japan) show that BTR based imaging in the visible region might fail due to the microbunching instability which leads to coherent BTR emission from some regions inside the bunch, thus making their use as a standard beam diagnostics impossible. In order to overcome this problem it was proposed to use BTR in the EUV region [1]. One of the problems that appear for EUV BTR is a rather low light output that comes from the low reflection coefficients of the mono substance layer (monolayer) targets. Due to this fact, a large target tilt angle of about 60-70 degrees is required between beam trajectory and target normal. While for conventional diagnostics based on optical BTR the target tilt angles amount typically 22.5 or 45 degrees, such grazing incidence geometry has the disadvantage of a large image distortion because of the depth of field effect. One possibility to achieve smaller tilt angles for EUV radiation is to use a multilayer structure with appropriate spatial period that has better reflection coefficients at the geometry of interest instead of a monolayer target.

In this report we present results of an experimental investigation of VUV and EUV BTR generation with a 5.7 MeV electron beam in monolayer and multilayer targets. The monolayer targets consisted of a molybdenum layer evaporated onto a silicon substrate and a polished pure silicon target. The multilayer target was a Mo/Si structure with 11.3 nm period. During the experiment, orientation and angular characteristics of BTR were investigated. The experimental results were compared with the theory of BTR for oblique incidence of electrons on the front surface of the monolayer [2] and multilayer [3] target.

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Gamma Cherenkov-Transition Radiation Produced by Charged Particles in Stratified Radiators

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The spectral distribution and total number of photons of gamma-ray Cherenkovtransition radiation (GCTR) produced by charged particles in the photon energy region (1-10) MeV passing through a stratified radiator consisting of M plates with thickness l1 and distances l2 between the plates are calculated using the formulae of resonance transition radiation.

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Coherent Effects in the Transition Radiation of Electron Bunches on Acoustic Superlattices

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We investigate the spectral-angular distribution of the forward transition radiation from an electron bunch interacting with an acoustic superlattice generated in a finite thickness plate. In the quasiclassical approximation, a formula for the radiation intensity is provided for a general distribution function of electrons in the bunch. Various examples of the longitudinal distribution are considered. In particular, we investigate coherence effects in the case of modulated electron distribution. The features of the radiation intensity are described in dependence of the ratio of the acoustic wavelength to the period of the modulation of the bunch.

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Overview of Experimental Investigation of X-ray Transition Radiation Generated by 300-900 MeV Electrons in Periodic Multifoil Radiators

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An overview of the results of experimental studies at the Tomsk synchrotron of the resonant x-ray transition radiation (RTR), generated by relativistic electrons in periodic multifoil radiators is presented [1-5]. The experiments were made with the use of both the internal beam of the Tomsk synchrotron and the external beam of secondary electrons of a magnetic pair γ-spectrometer in the range of electron energy of 300-900 MeV. The multifoil radiators consist of the sets of thin amorphous foils of different materials. It was also investigated that the generation of X-rays in a compound radiator consisted of the multifoil radiator and a crystal. In this case, the resonant X-ray transition radiation generated in the multifoil radiator was then diffracted in the crystal and emitted at Bragg angles together with parametric X-ray radiation (PXR) generated in the crystal. The spectral and angular properties of the resonant X-ray transition radiation and the diffracted resonant X-ray transition radiation (DRTR) were investigated. The ratio of the contributions of the diffracted resonant X-ray transition radiation and other types of radiation in the total flux of coherent X-rays generated by electrons in multifoil radiators and crystals was also estimated.

The key outcomes of this research cycle are as follows:

- The effect of resonant X-ray transition radiation diffraction on the PG crystal was recorded experimentally. The spectra of RTR, PXR, DRTR were estimated in the same experimental conditions using coherent X-rays generated by electrons in multifoil radiators and crystals, and obtained results were compared with theoretical findings.
- Placing a multilayer resonant structure even with a small number of layers in front of the PG crystal (M = 9) results in significant increase in X-ray radiation over pure transition radiation. In this case, angular spectral radiation density remains high. It is obvious that use of multifoil radiators consisting of hundreds of thin foils makes it possible to create intense, monochromatic X-ray source rather attractive to many applications.

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Section 3

Parametric X- Radiation

X-ray Imaging Based on Small-angle X-ray Scattering Using Spatial Coherence of Parametric X-ray Radiation

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An X-ray imaging based on small-angle X-ray scattering (SAXS) was carried out using the parametric X-ray radiation (PXR) source at the Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University. The experimental setup employed in the novel imaging is the same as which employed in the diffraction-enhanced imaging (DEI) [1], the kind of X-ray phase-contrast imaging methods. In the SAXS-based imaging, the image contrast is correlated with the rocking curve peak broadening due to the scattering from sub-micron grains in the sample material [2]. Figure 3 shows a result of the SAXS-based imaging for the samples shown in Fig. 1, which was obtained with the X-ray beam of 25.5 keV. In comparison with the absorption-contrast image shown in Fig. 2, the visibility of the styrene-foam rod has drastically improved. The result suggests that the PXR beam has a high spatial coherence that makes it possible to detect small scattering angles in the range of micro-radian. In the experiment the SAXS-based imaging combined with the PXR beam method has demonstrated a possibility to be a powerful tool to obtain information on micro structures of sample materials smaller than the spatial resolution of a detector.

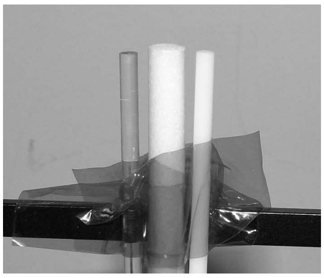

Figure 1. The picture of the samples. From left to right, an acrylic rod 3 mm in diameter, a styrene-foam rod 6 mm in diameter, and a polystyrene rod 3 mm in diameter.

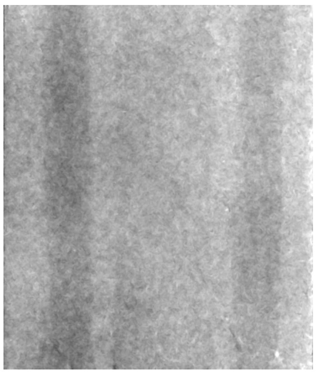

Figure 2. The result of absorption-contrast imaging at the X-ray energy of 25.5 keV.

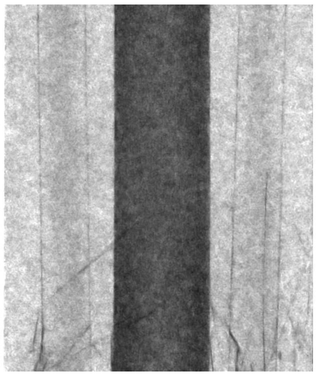

Figure 3. The result of SAXS-based imaging at the X-ray energy of 25.5 keV.

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Increase of Parametric X-ray Intensity due to the Borrmann Effect

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Parametric X-ray radiation (PXR) from relativistic electrons in a crystal with a thickness larger than the X-ray absorption length is considered. The characteristics of this radiation are analysed in detail taking into account the dynamical diffraction theory. It is shown that the PXR intensity increases and its dependence on the electron energy changes when the X-ray quanta are emitted under conditions of anomalous absorption (the Borrmann effect). The details of the PXR angular distribution and its comparison with the experimental data are also discussed.

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Quantum Jumps in PXRC Angular Distributions from Relativistic Channeled Electrons in a Crystal

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Recent experiments [1, 2] on studies of angular distributions of parametric X-radiation from 255 MeV channeled electrons (PXRC) in a Si crystal showed some differences between of that distribution and standard (without channeling) angular distribution of parametric X-radiation (PXR) [3]. According to Ref. [1], this difference is connected with manifestation of two quantum effects: a) transverse form-factors of quantum states of channeled electrons; b) initial population of these quantum states.

Based on these ideas, in a present work we investigate in more detail the difference between PXR and PXRC angular distributions in dependence of electron beam energy. We predicted qualitatively (separate plane approximation) and confirmed by detailed numerical calculations (true periodic channeling potential) appearance of "quantum jumps" in PXRC intensity when one increases the relativistic factor of channeled electrons (electron beam energy).The band structure of transverse quantum states sufficiently influences the form-factors and initial population of these states [4, 5]. As a result, the angular distribution of PXRC undergoes "quantum jumps", connected with appearance of every new quantum channeling state with increase of the electron beam energy. At these values of the beam energy the magnitude of these jumps can be sufficiently greater than observed in an experiment [1, 2] with 255 MeV electrons.

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Parametric X-Rays and Background Radiation at 50 Gev Proton Beam

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The experimental layout designed to study properties of focused parametric X-ray radiation generated by relativistic protons in a bent crystal and parametric X-ray radiation generated by relativistic ions and positrons at accelerator U70 is described [1]. Preliminary results of measurements of spectra of characteristic and parametric X-rays observed at 50 GeV proton beam are shown and discussed. The origin of the background radiation that obstacles for detail research of the PXR properties at proton beam is identified. The distribution of the ionization losses of relativistic charged particles in the X-ray detector similar to Landau distribution is measured and discussed. The joint research is supported by the directorates of the IHEP and KIPT, and grants by the RFBR ϵ 13-02-90434 (Russia), by the SFFR ϵ F53.2/107 (Ukraine), by the MES ϵ 14.B37.21.0912 (Russia).

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Influence of Real Photons Diffraction Contribution on Parametric X-ray Observed Characteristics

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Problem of the diffracted bremsstrahlung (DB) contribution into parametric X-ray radiation (PXR) characteristics observed is not decided jet. Conclusion about this contribution absence [1],[2] contradicts with some experimental results. A simple model for calculation of fast electron DB yield in perfect crystals with arbitrary thickness is suggested and realized. The model was experimentally confirmed in the measurements of bremsstrahlung yield in forward direction from thick tungsten crystal [3],[4] and in the measurements of PXR angular distribution in a silicon crystal [5]. It is shown that in the dependence of the experimental condition the DB and the parametric X-ray radiation contributions may be comparable. An influence of real photon diffraction contribution on the results of the PXR polarization measurements [6], [7] is discussed. It is shown that taking into account real photons diffraction leads to better agrement between experimental and calculation results for the experiment [6]. Possible influence of the crystal mosaicity effect [4] on the work cited results is discussed.

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Fresnel Coefficients for Parametric X-Ray Radiation

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Formulae for amplitude Fresnel coefficients of the parametric X-ray radiation (PXR) arising due to diffraction in a crystal of virtual photons accompanying a relativistic charged particle moving through the crystal are derived in kinematical approach. The expressions for PXR frequency, spectral peak width, and yield are obtained and compared to the Ter-Mikaelian theory and the available experimental data on PXR. Properties of the PXR Fresnel coefficients are discussed.

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Section 4

Diffraction Radiation, Smith-Purcell Effect

Status Report on UV and X-ray Diffraction Radiation for Non-invasive Micron-scale Beam Size Measurement

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Diffraction radiation (DR) is produced when a relativistic charged particle moves in the vicinity of a medium. The electric field of the charged particle polarizes the target atoms which then oscillate, emitting radiation with a very broad spectrum. The spatial-spectral properties of DR are sensitive to a range of electron beam parameters. Furthermore, the energy loss due to DR is so small that the electron beam parameters are unchanged. Therefore DR can be used to develop non-invasive diagnostic tools. The aim of this project is to measure the transverse (vertical) beam size using incoherent DR.

For future accelerators such as the Compact Linear Collider (CLIC) there are two main requirements for transverse beam size measurements: the instrumentation should be non-invasive and measurements must have micron-scale resolution. DR monitors could be foreseen for the Ring To Main Linac (RTML) or for the Drive Beam (DB) accelerator where the beam size is considerably larger. The sensitivity to beam size improves at shorter wavelengths. Therefore to achieve the micron-scale resolution, DR in the UV and soft X-ray spectral-range must be investigated.

Currently the experimental validation of such a scheme is being conducted on the CesrTA at Cornell University, USA. Here we present a status report for the project including the design of the targets and vacuum hardware, optical and data acquisition systems as well as reporting on our most recent test.

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Coherent Diffraction and Cherenkov Radiation in Dielectric Fibers

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The ability to use a radiation of relativistic electrons in optical fibers in beam diagnostics was proposed by X. Artu at symposium RREPS-11 (see also [1]). In this work the properties of different types of radiation induced in fibers by electromagnetic field of relativistic electron were considered. We present in this report the results of experimental investigation of this phenomenon in millimeter wavelength region in coherent condition. The nature and properties of radiation in fibers was analyzed experimentally for different geometry of fiber position in respect to the electron beam.

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Smith-Purcell Radiation from Surface Waves

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Radiation generated by the passage of charged particles above the surface wave excited in plane interface between homogeneous media with different dielectric constants is investigated. For the surface wave of general profile the radiation intensity is expressed via the radiated power from a single charge and bunch form factor. Various types of transverse and longitudinal distributions of electrons in the bunch have been considered. In the case of a scalar field, we consider also the quantum radiation due to the dynamical Casimir effect induced by surface waves.

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Coherent Diffraction Radiation as a Source of Electromagnetic Radiation

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Various radiation sources based on accelerators (from THz up to gamma range) are widely used around the world. One of the promising source is the source based on polarization radiation which appears when electromagnetic (EM) field of a charged particle interacts with a medium (Cherenkov radiation, Smith-Purcell radiation, diffraction radiation and so on). For diffraction radiation (DR) case charged particles moves in vacuum in the vicinity of the target. In the report we present the results of absolute measurements of the diffraction radiation yield.

The experiment was carried out at the SINAP fs linear accelerator facility [1]. The DR target was consisted of 2 μm aluminum foil covered on 0.3 mm polyamide film fixed by a holder with 46×20 mm^2 of the target dimensions. Other parameters of our scheme are the followings: 23 MeV electron beam, number of electrons per bunch is about $\sim$ 109, number of bunches per train is about $\sim$ 104, average train duration is 3 μs. The measurements of DR with Michelson interferometer and without it were done.

The simulation of absolute DR yield for SINAP facility was also presented which show us a good agreement in comparison with the measurement. In our simulation model we took into account the near-field zone effect and the target finite size as well as detector and chamber output glass window properties such as spectral sensitivity and window transmission respectively. As a result we can conclude that the coherent diffraction radiation from a few MeV energy electron beam may be considered as an effective radiation source if the length of short electron bunch is less than required wavelength of source.

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Section 5

Coherent Bremsstrahlung and Channeling Radiation

Wave Packets in Electromagnetic Processes at High Energy in Matter (Problem of Half-bare Electron)

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Evolution in space and time of high energy wave packets is considered. It is shown that such packets arise in a natural way in various electromagnetic processes at high energies in matter. They lead to different coherent and interference effects in interaction of particles with crystal and amorphous media. Particular attention is paid to the problem of "half-bare" electron in matter. The processes of bremsstrahlung, transition radiation and ionization energy losses by ultrarelativistic "half-bare" electrons are considered for thin targets.

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Multiphoton Effects in Coherent Radiation Spectra

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In calorimetric measurements of gamma-radiation spectra from ultra-relativistic electrons, the pileup of events at high radiation intensity causes significant departure of the detector signal from the classically evaluated spectrum. We describe the corresponding resummation procedure for the photon spectral intensity, and apply it to the study of spectra of coherent radiation with an admixture of incoherent component. The effects of the finite photon non-emission probability on the spectrum shape are discussed. The limit of high photon multiplicity for coherent radiation is explored, wherein the resummed spectral density generally tends to a Gaussian, but corrections to the Gaussian form may be significant.

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Energy Loss of Channeled Positron in Crystalline Wiggler

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Due to the curvature of the crystal planes, channeled positron except oscillations in the channel with high frequency, and oscillates at a lower frequency. The case where the oscillation parameters with less frequency much greater than unity is considered. Then the amplitudes of the higher harmonics in the radiation process partially overlap. And occurs constructive interference. It is shown that the total spectrum of photons does not depend on the harmonic number. Radiation occurs in a narrow angular sector in the plane of positron motion. The energy loss by radiation may be the order of the positron energy.

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Coherent Bremsstrahlung from Planar Channeled Positron

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It is well known that when the charged relativistic particle penetrates into an aligned crystal, there are coherent effects [1] or channeling effect [2]. But one can imagine more complicated situation when the relativistic particle simultaneously involved in a coherent process and is moving under channeling conditions. This means that combine effect takes place.

For example, the coherent bremsstrahlung (CB) from relativistic electrons pass through the crustal in axial channeling regime differs from ordinary CB. In this case energy spectrum of the emitted radiation is split [3] due to contributions of electron transitions from one transverse energy level to another during photon emission.

In the present report we investigate the combine effect in CB from relativistic positrons moving in a planar channeling regime. To study this combine effect we modified method of virtual photons, taking into account the channeling of radiating particles. The cross -Ц section of photon scattering on channeled positron was derived in [4].

The dependencies of the CB cross-section on the positron energies and emitted photon energies have been studied. The numerical calculations show that the combine effect in CB result in small corrections to the CB cross-section and to splitting of the coherent peaks.

The work is partially supported by Russian Education Federal Agency program "Support of Scientific Schools", contract 224.2012.2.

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Scattering of 255 MeV Electrons at (220) Channeling in Silicon Crystal

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The properties of both angular and spatial distribution of 255 MeV electrons at <100> axial channeling in thin silicon crystal have been investigated experimentally at SAGA light source [1]–[2] and by computer simulations [3]. The simulation of trajectories, angular and spatial distributions of electrons on the screen monitor has been performed taking into account initial spatial as well as angular divergence of electron beam using computer code BCM-1 [4]. Comparison of the experimental and simulation results shows a good agreement [3]. Both experimental data and simulations show the brilliant effect of so-called "doughnut scattering" (DS) that can be used for the diagnostics of the incident beam angular divergence.

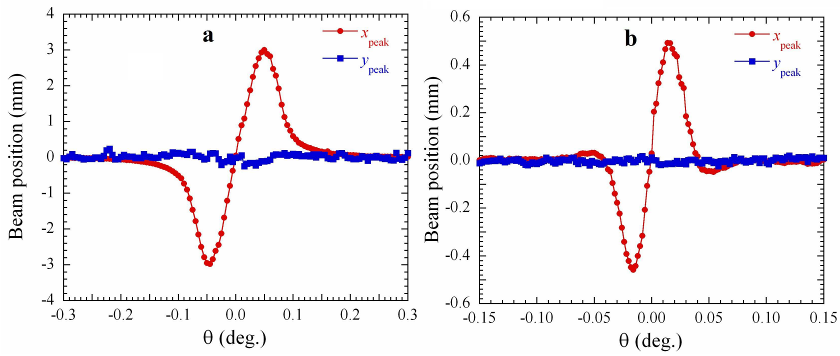

Figure 1. The experimental results for 255 MeV electrons penetration through 20 μm Si crystal. a – <100> alignment, b – (220) alignment. θ is the the angle of incidence of the electrons on the crystal.

Recently, a new experiment on 255 MeV electron scattering at (220) planar channeling in 20 μm Si crystal was carried out at SAGA LS. In this work we studied (both experimentally and by means of computer simulations) the spatial and angular distributions of electrons penetrating through the thin Si crystal at (220) alignment. Comparison of axial and planar channeling results shows that for axial channeling effect significantly brighter than for the case of planar channeling (see Figure 1.).

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Coherent Bremsstrahlung of Relativistic Electrons Under the External Acoustic Field

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Investigated the process of coherent bremsstrahlung of relativistic electrons with the energy of 20 MeV in a single crystal of quartz in the presence of external acoustic field. For the spectral analysis of coherent bremsstrahlung used reflecting atomic planes $(10\bar{1}1)$ of Quartz crystal - analyzer of X-cut, in which excited acoustic oscillations providing conditions of "full transfer" and "the effect of transparency". In the experiments investigated the coherent bremsstrahlung depending on the amplitude of the acoustic field. At first observed the intensity of the line increases with the increase of the amplitude of the acoustic field, and starting from a certain value - are decreases. In the spectral distribution new bands and peaks are observed, and individual peaks are suppressed according to the operating parameters of acoustics. Theory is constructed for the intensity of spectral components and for the spectral distribution in dependence of the acoustic field parameters. The calculations qualitatively agree with the experimental results.

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Total Yield of Channeling Radiation from Relativistic Electrons and Positrons in Thin Si and C Crystals

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Radiation energy loss of the ultra-relativistic 150 GeV electrons and positrons was estimated by semiclassical Baier-Katkov method in [1] and for 1 GeV electrons in the framework of classical electrodynamics in [2]. Angle-of-incidence dependence of the total yield of channeling radiation (CR) from 155-855 MeV electrons in Si and W was considered in [3] using developed code [4]. Also the possibility to use angle-of-incidence dependence of the total yield of CR for the alignment of thin Si and W crystals and initial angular divergence of the particle beam was suggested in [4]. Dechanneling effects were neglected.

Here we consider in detail the angle-of-incidence dependence of the total yield of CR from 255 MeV electrons and positrons at <100> axial, (100) and (111) planar channeling in 20 μm silicon and 50 μm diamond crystals in the framework of classical electrodynamics. Calculations were carrying out taking into account the angular divergence of the initial electron and positron beams. Dechanneling length of the electrons and positrons in the diamond crystal is assumed to be greater than 50 μm [1], so in this case dechanneling effects were taken into account. As the dechanneling length for electrons and positrons exceeds 20 μm in silicon crystal [5] we neglected dechanneling effects in this case.

Simulation are performed in connection with the experimental program on the interaction of electrons with crystals at linear accelerator of SAGA Light Source (Tosu, Saga, Japan) [6].

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Above-Barrier Reflection and Degenerate States of Energy Band Spectrum in Planar Channeling of Electrons and Positrons in Crystals

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The motion of a charged particle in a one-dimensional periodic potential of the Krnig-Penney type is considered. The energy band structure, Bloch wave functions in coordinate and momentum representation are investigated in detail. Two sharply distinguished groups of states, i.e. below-barrier and above-barrier, are extracted and the role of both of them in the channeling of positively and negatively charged particles is explained. It is shown that only using a dispersion equation form one is able to obtain information on the symmetry properties of the Bloch wave functions at the edges of energy bands. An estimate of the corresponding regions of the edge coherence in the Brillouin zone is given. In the above-barrier case a nontrivial effect is found of parity interchange violation of the Bloch wave functions at the edges of energy bands, connected with the nullification of the reflection coefficient either from the single barrier or well. An oscillatory behavior of both allowed and forbidden band widths is revealed. The analytical results for different values of the parameters are illustrated by computer calculations.

The behavior of Bloch wave reflection coefficients from potential barriers and wells for the nearest above-barrier energy band as a function of quasi-momentum in the Brillouin zone is investigated for different energies of channeled electrons and positrons. The variation of above-barrier reflection coefficients for the whole energy spectrum at transition from one energy band to another for each fixed energy value of incident particles is also studied.

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Radiation of the Positron Bunch at Channeling in Nanotubes

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The trajectories of the channeled in nanotube positrons are obtained on the bases of a model potential which agrees very well with the real one. The spectral density of the positrons' dipole radiation intensity is obtained from the unit length of path taking into account the medium polarization. An averaging of the radiation intensity over all possible trajectories of the transverse motion of the positrons assuming uniform distribution over the polar coordinates in the bunch has been carried out. A large value of the intensity is maintained due to long dechanneling length.

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Spectral-Angular Distribution and Polarization of Non-Dipole Radiation by Relativistic Electrons in a Thin Crystal

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The multiple scattering of ultra relativistic electron on atoms of matter conduces to violation of the dipole regime of radiation process. It occurs when the mean-square angle of electron scattering within the coherence length of radiation θ_{ms} exceeds the characteristic angle of radiation of relativistic particle $\theta_k \sim \gamma^{-1}$, where γ is the Lorentz factor of an electron. One of the well-known examples of the non-dipole regime is the Landau-Pomeranchuk-Migdal effect of suppression of radiation in an amorphous medium [1]. Another manifestation of the non-dipole regime of radiation is the effect of radiation suppression in a thin layer of matter, which was predicted and theoretically studied in [2,3] and recently discovered experimentally in SLAC E-146 [4] and CERN NA63 [5].

One of the most unusual features of non-dipole radiation in a thin target is the logarithmic dependence of radiation yield in the soft part of the spectral density from the target thickness [3,5,6]. In crystals, the condition of non-dipole regime of radiation, namely $\theta_{ms} > \gamma^{-1}$, can be fulfilled at less thickness than in amorphous target due to the coherent electron scattering on atomic rows, known as the Ydoughnut scatteringY effect (see, e.g. [7]). In a thin crystal, when the coherence length of radiation process is bigger than the crystal thickness, there are some interesting features of angular distributions and polarisation characteristics of radiation at the non-dipole regime [6,8], which may be used for polarized gamma-quanta beam production.

We present here a brief review of theoretical and experimental studies of the features of the non-dipole regime of radiation in amorphous and crystalline targets and our propositions for new experimental investigations in this field, especially concerning the angular distributions and polarization characteristics of the non-dipole radiation in a thin crystal.

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Simulation of Coherent Radiation of Relativistic Electrons and Positrons in the Field of Periodically Bent Crystal Planes

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The coherent and interference effects in radiation are manifested at relativistic electron motion in a crystal at a small angle to one of the crystallographic planes of atoms. Due to this effects the spectral density of radiation contains sharp maxima with high intensity in them [1, 2]. Similar effects are possible at particle motion in the field of periodically bent crystal atomic planes.

In the present work a method for simulating coherent radiation of relativistic electrons and positrons in the field of periodically bent crystal atomic planes are developed. This method allows us to take into account the contribution to the radiation of both above-barrier and channeled particles in a crystal. Moreover, incoherent scattering effects in the crystal particles scattering in this simulation may be taken into account. Peculiarities of the coherent radiation of relativistic electrons and positrons in this case at different particle energies and different bending parameters of the crystal planes are considered.

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Quantum Chaos Manifestation in the Axial Channeling

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Quantum chaos means the study of semiclassical behavior characteristics of systems whose classical motion exhibits chaos. The most prominent of such characteristics is the statistics of energy levels. It was demonstrated in many cases [1] that the spacing s between neighboring levels satisfies Wigner distribution

$$p(s) = (\pi s/2D^2)\exp(-\pi s^2/4D^2) \quad (1)$$

(where D is the mean level spacing) for chaotic systems, while exponential distribution

$$p(s) = (1/D)\exp(-s/D) \quad (2)$$

(sometimes referred to as Poisson distribution) for regular ones.

In the present report we have found the transverse energy levels for the axial channeling electrons in the uniform potential of [110] atomic string of silicon crystal as well as the potential of two parallel neighboring strings using the numerical method [2]. The motion is classically chaotic in the last case if the transverse energy exceeds the saddle point of the potential well [3]. The level spacing distributions obtained in the semiclassical domain (close to the top of the potential well) demonstrate quite good agreement with the prediction (1), see Figure 1 for example. Small discrepancy could be caused by the lack of statistics (the massives of ~ 200 energy levels have been analyzed whereas the typical massives in [1] contain some thousands of levels).

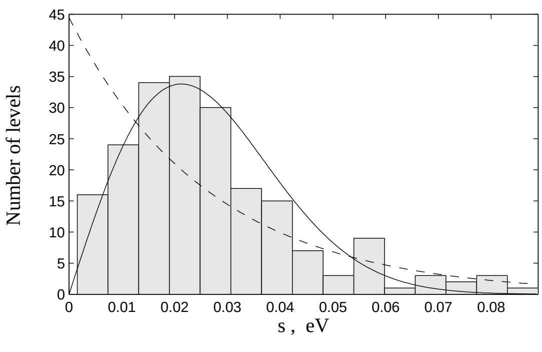

Figure 1. Transverse energy levels spacing distribution in the range $-8 \leq E_\perp \leq -2.6$ eV for $E_\parallel = 400$ MeV electrons channeled in the field of two parallel [110] strings of silicon crystal (histogram) as well as theoretical predictions (1) for chaotic motion (solid line) and (2) for regular motion (dashed line).

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Flux Dynamics, Angular Distributions and Radiation of Relativistic Electrons and Positrons in a Half-wave Crystals

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Recent studies of nonrelativistic protons planar channeling in an ultra thin crystal - "half wavelength crystal" (below - HWC) - reveals very interesting features of both flux dynamics inside a crystal and angular distributions after a crystal [1]. The thickness of HWC is connected with initial energy of the particle. Similar effect should manifest itself in the case of relativistic electrons and positrons. For example, if the HWC thickness $l = 1$ micrometer, the electron/positron energy should exceed at least 1000 MeV in the case of Si crystal. In fact, similar effect may occur even if electron/positron makes several oscillations during penetration through an ultra-thin crystal, at the beam energy below 1000 MeV.

We confirmed this by detailed computer simulations using our computer code BCM–1.0 [2], which was successfully applied to explain (describe) recent experimental data on doughnut scattering (DS) and PCS (planar channeling scattering) of 255 MeV electrons in a 20 micrometer Si crystal obtained at SAGA Light Source [3]–[4]. We inwestigated the flux dynamics of 255 MeV electrons and positrons in a 1 micrometer Si crystal at (220) alignment. The simulation of trajectories and angular distributions of electrons have been performed taking into account initial spatial as well as angular divergence of electron beam.

The specifics of trajectories as well as very small crystal thickness should effect on the channeling radiation spectra. There are several points of interest. First, we expect strong influence of trajectories "tails" first considered in [5]. Second, it is the just the case when during calculations of channeling radiation spectrum one can try the approach suggested in Ref. [6] for calculation of BS spectrum in the thin amorphous target which simplifies the calculations. Third, this problem is closely connected with radiation spectrum from a particle moving in an arc [7] (never studied experimentally). In connection with above, we present channeling radiation spectra calculated using obtained trajectories in a HWC and discuss their specific properties to stimulate future experiments.

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Governing of the Channeling Radiation by Ultrashort Laser Pulses

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Using numerical methods it is investigated the interaction between 10-100 MeV electron channeled in a crystal and laser pulses in the framework of the semi-classical theory. It is shown that for the given laser shape the output of the electron radiation depends on the carrier frequency phase in the peak of the laser pulse (carrier envelope phase) and on the difference between of the electron entering time into a crystal and the initial time when laser pulse acts onto electron. The dependence of the populations and the channeling radiation densities upon the electron transit time in a crystal as well as the corresponding channeling radiation spectra under the influence of the laser pulses with various parameters on the channeled electron is calculated. The possibility of the increase of the channeled electron radiation output by relevant choice of the ultrashort laser pulse parameters is shown.

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High-frequency Corrections to the Trajectories of Relativistic Electons and Positrons at Axial Channeling in Si and W Crystals

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Usually, the channelling is determined by so-called continues potential of crystallographic planes or axes. In fact, this potential is only a part of the complex periodic potential of the plane (axis). In this case we can consider the motion of an electron subject to a time independent field of potential $V(\vec{\rho})$ and to a force $f = f_n \cos\omega_n t$ which varies in time with a high frequency $\omega_n \approx \frac{2\pi nc}{d} \gg 1/T$, where T is period of motion in the field $V(\vec{\rho})$, d – is the distance between atoms in the axis. For such field electron will transverse a smooth path and at the same time execute small oscillation of frequency ω_n about that path. Accordingly the trajectory of electron may be represented as a sum of "smooth" trajectory $\vec{\rho}(t)$ and small ascillation with frequency ω_n – $\vec{\zeta}(t)$ [1]. Equations for calculation $\vec{\rho}(t)$ and $\vec{\zeta}(t)$ can be derived using the method of P. L. Kapitza [1]. For the simulation of "smooth" trajectories $\vec{\rho}(t)$ we used the averaged potential of atomic axes in the Doyle-Turner approximation for atomic form factors and computer code BCM-1.0 [2]. It

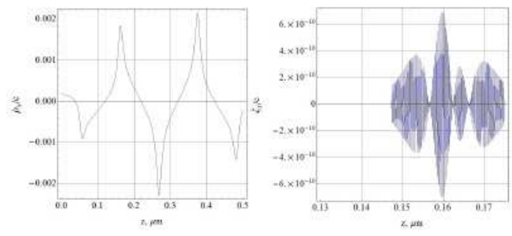

Figure 1. The result of simulation of <100> electrons channeling in W crystal. a – velostity of electron motion along "smooth" trajectory , b – velostity of small oscillation.

is well known that spectrum of particles radiation is determined its velocity, so the appearance of high frequency oscillation of velocity (Fig. 1.) will lead to arise of high frequency split harmonics in the spectrum of channeling radiation compared with the usual spectrum [3]–[5].

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Section 6

X-Ray Scattering without and by Acoustic Superlattices

Influence of Radiation on the Nanoelectrical Structure and Scheme

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The effect of individual particles on the functioning of nanoelectrical devices and schemes. This includes questions of stability and the connection between the new principles of response.

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X-ray Diffraction Microscopy Based on Refractive Optics

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Effect of the Thermal Heating of a Crystal on the Diffraction of Powerful Pulses of a Free-Electron X-Ray Laser

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Spatiotemporal dependences of the distribution of the crystal temperature under the effect of pulses of a free-electron X-ray laser are found using the solution of a thermal conductivity equation. The effect of temperature, its gradient, and the deformation of the crystal lattice on the diffraction reflection and the transmission of pulses in crystals of synthetic diamond is considered.

Emissions of a free-electron X-ray laser (XFEL) consist of pulses with wavelength $\approx 0.05-0.16\ nm$, duration $\approx 10-100\ fs$, and an angular divergence of $\sim 1-3\ \mu rad$ [1]. The pulses are characterized by an almost complete spatial coherence and a very moderate temporal coherence, leading to a spectral width of pulses of $\Delta E/E \approx 10^{-3}$. The authors of [2] suggested various four-chip and single-chip circuits to reduce the spectrum width to $\Delta E/E \approx 10^{-5}$, allowing us to attain a self-seeding mode and better laser generation with the crystal placed between two undulators. The diffraction reflection of femtosecond pulses from crystals and multilayered structures with the aim of their monochromatization and raising the degree of temporal coherence was considered in [3-5].

Pulse energies of the European XFEL in channels SASE1 and SASE2 are $20-2500\ \mu J$ [1], leading to average energy flows of 60 W/cm^2 to 80 kW/cm^2 in the region of the first elements of X-ray optics at distances of $500-800\ m$ from the undulators. Allowance for and prevention of the strong thermal heating of the crystals and multilayered mirrors is one of our most serious problems.

In this work, we consider the effect of such factors as the pulse energy; the temporal structure of the FEL radiation; the distance from the undulators; the initial and maximum temperatures of the crystal; the temperature dependences of the coefficients of specific heat capacity; the heat conductivity; and the linear thermal expansion coefficient on the diffraction reflection and transmission [6].

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Peculiarities of Parameter Control of the Electromagnetic Radiation of Angstrom Range

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The study of the real structures of single crystals, as well as, their inner distortions, conditioned by the defects within them and external influences, is one of the actual problems of Solid state physics. For such studies, the X-ray diffractometery has its important role. The purpose of the submitted work is to conduct the research using new methods that enable, emanated from the scheme geometry and the parameters of the used sample, to beforehand estimate the parameters of the obtained monochromatic X-ray beam (integral intensity, angular aperture, energetic dispersion, etc.) It was experimentally studied the behavior of the X-ray beams pumped from the quartz single crystals depending upon the thermal gradient values. The scrupulous study and analysis of the obtained dependencies will allow us to determine, beginning form what values of the thermal gradient, the beams out of the diffraction condition with bigger angular aperture than the Darwin's table width start participating in the dynamic diffraction processes inside the second crystal as well as for what values of the thermal gradient the angular intensity redistribution for the pumped beam. The obtained results will allow us, emanating from the experimental scheme geometry and the parameters of the used single crystals, to beforehand estimate the parameters of the obtained X-ray beam.

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Study of Functional Properties of Diamond Elements and their Use Under Extreme Radiation Conditions

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Diamond is very promising as a material, on which basis several devices such as detectors of nuclear radiation, highly sensitive temperature gages, dosimeters, heat sinks, thermal resistors could be designed for semi-conductor techniques. Physical, chemical and optical characteristics of diamond are superior to analogous properties of other materials. Its unique hardness, heat stability, radiation resistance, break-down strength, chemical inertness, low friction coefficient, transparency from UV to IR make it a promising material for various applications. The aim of this study is to obtain new functional elements on the basis of diamonds (synthesis of high quality polycrystals), complex study of their physical properties and possible applications in high-radiation areas. To ensure the needed quality and enable variation of sintering parameters (temperature, pressure, rate of their changes) in a wide range of sintering parameters (temperature, pressure, rate of their increase), the devices capable of achieving pressures up to 10 GPa ("toroid" type) and temperature 1500 - 2000 K were used. The samples were made as 2 mm thick tablets 8 mm in diameter. The average size of diamond particles in the samples was about 10 microns. Absorption spectra of ASM and ASN synthetic diamonds were taken in UV-VIS -NIR regions. It has been determined that in the chosen conditions of thermobaric treatment, annealing of Me-X centers and aggregation of single nitrogen atoms in pairs (A-defects) takes place. The degree of aggregation for C-defects is higher than 90% in all investigated diamonds. Measurements of frequency dependence for dielectric parameters were carried out in the range from 200 Hz to 1 MHz with the electric field amplitude of 100 mV. With increasing frequency a significant non-monotonic decrease of dielectric loss has been revealed (non-monotonic decrease of loss tangent). At the Armenian NPP experimental measurements carried out to determine the effect of ionizing radiation on diamond ceramics elements (heat sinks, thermo-resistors) have shown that in gamma (Co^{60} source, gamma ray energy of 660 KeV) and 1.2 MeV fast neutron source fields, resistance of the elements on the basis of diamond ceramics did not change within the whole measurement range.

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Focusing of Hard X-rays in Crystals Under External Influences

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In the works [1,2] was first observed the phenomenon of the full pumping of X-rays from the direction of the reflection in the direction of single crystals of quartz, under the influences of the temperature gradient or acoustic vibrations in the Laue geometry. In work [3] is experimentally investigated the angular width of a full pumping around the X-ray emission as a function of the thickness of the single crystal. It is shown that the angular width of the full pumping radiation is directly proportional to the thickness of the sample. One of the important processes in the control of X-rays in space and time is its focus. The papers [4,5] experimentally and theoretically shown that with the help of acoustic field and temperature gradient it is possible control the location of the focus of the diffracted beam in space and time, as well as convert a spherical wave into a plane wave. In order to obtain controlled lenses in the range of hard X-rays carried out detailed studies of focusing of white beams hard X-rays considering the above-mentioned results obtained earlier.

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Application of Three Beam Diffraction for Determination of Structural Parameters of the Epitaxial Layers

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Three beam diffraction combines more the one diffraction geometry, corresponding peaks contain information on different strain components and displacement fields that provides a possibility to obtain the structural parameters using the simplest symmetrical Bragg geometry. On basis of the experimental study of the three beam diffraction (the Renninger schema was used) for different epitaxial structures, following opportunities are shown: simultaneous precise measurement of the lattice parameters in directions normal and parallel to surface; estimation of the type of a dislocation structure in highly distorted systems; determination of parameters of epitaxial superlattices; detecting of a presence of crystalline blocks rotating about the surface normal; revealing an ordering in crystalline solid alloys (such as AlGaN, SiGe). Three beam diffraction can be used for determination of precise positions of the in-plane crystallographic directions and employed also as an element in diffraction optical schemas for decreasing of vertical divergence. Interpretation of the experimental observations is presented from the point of view of intensity distribution in the reciprocal space.

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X-Ray Diffraction by the Triangular Model of Superlattice with a Stacking Fault

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The dynamic theory of X-ray diffraction by the triangular model of the superlattice with a stacking fault between the layers has been developed.

Heteroepitaxial superlattices are artificially grown one-dimensional superlattice crystals of GaAs-AlAs type, which have a wide application in microelectronics and computer engineering. The stacking fault between the layers impairs superlattice parameters.

If the superlattice layers are thin, owing to the interdiffusion of superlattice components, different materials will be overlapped throughout the layer. One may describe such a superlattice by the symmetrical triangular model.

Expressions for reflection and transmission amplitudes depending on the shift vector and depth of the stacking fault for triangular model of superlattice have been developed. For comparison with ideal superlattice the relative modification of reflectivity is calculated.

Comparison of results with the square-wave model which describes the superlattice if the interdiffusion is negligible is also considered. X-Ray diffraction by the square-wave model superlattice with a stacking fault between the layers is developed in [1].

It is shown that the existence of interdiffusion of heteromaterials is reducing satellite intensity. The change of satellite intensities during the interdiffusion is being discussed. The obtained results show that while the intensity of the principal maximum during the interdiffusion decreases the magnitude of the oscillations increases.

The results obtained may be used to interpret the X-ray diffraction patterns produced by superlattices.

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High-resolution X-ray Spectrometer Based on Acoustic Monochromator

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Operating principle of the spectrometer is based on attenuation the intensity of X-rays passing through the sample. The degree of attenuation depends on the energy of the radiation and the chemical composition of the absorbent material. Based on the X-ray tube and acoustic monochromator assembled an intense source of monochromatic X-rays without harmonics compared with the existing analogues. Such spectrometers more focused on obtaining the monochromatic line without harmonics, unlike similar devices using acoustic monochromator in the spectrum of reflection practically no harmonics and at the same time obtained maximum intensity at the expense of the effects of full pumping and transparency. In this case, using acoustic monochromator can refuse difficult mechanics thereby highly lowering the cost and the final cost of the device.

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Advanced Piezoelectric Crystals of $La_3Ga_5SiO_{14}$ Family

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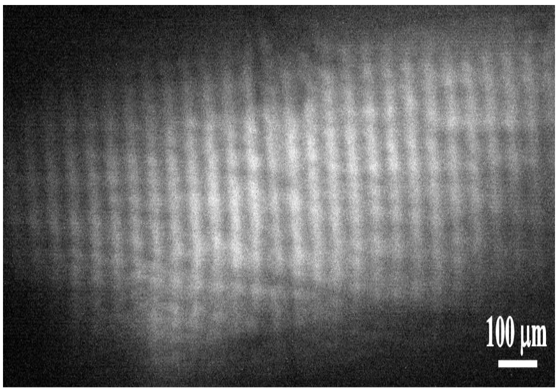
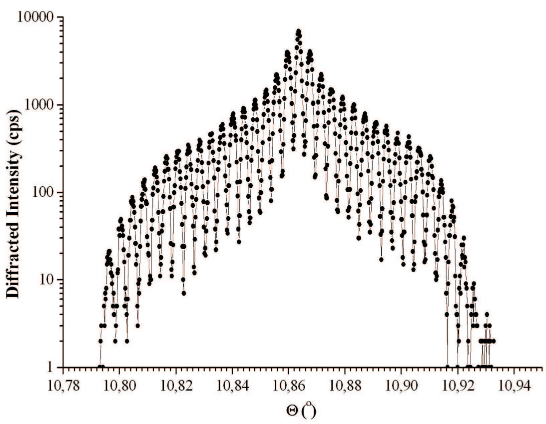
The development of modern acoustoelectronics urges the search for new promising piezoelectric crystals with high piezoelectric constants and good thermal properties. To this end, lanthanum-gallium silicates were extensive studied in the last ten years. Crystals of lanthanum-gallium silicate group belong to the 32 symmetry class, like the piezoquartz SiO_2 crystal. Materials of this group have good thermal stability. Although the coefficients of electromechanical coupling of this crystal group are not as high as those $LiNbO_3$, they are nevertheless several times higher than the corresponding values of quartz crystals. Note also that the interest to crystals of the langasite group is due to that these crystals undergo no phase transition up to melting temperature. The aim of this work is to investigation of piezoelectric and acoustic properties of non-ordering crystals ($La_3Ga_5SiO_{14}, La_3Ga_{5.5}Ta_{0.5}O_{14}$) and ordering crystals ($Ca_3TaGa_3Si_2O_{14}$) of langasite family. Both high-resolution X-ray diffraction and topography techniques were used for investigation of surface and pseudo-surface acoustic wave propagation in crystals. Furthermore high-resolution X-ray diffraction was used to measure the independent piezoelectric strain coefficients in the condition of an external electric field applying to the crystal, which leads to the change of interplanar spacing due to the reverse piezoelectric effect.



Talbot imaging of the SAW ($\Lambda = 50\mu m$, $f = 46.373MHz$) propagation in the Y-cut of $Ca_3TaGa_3Si_2O_{14}$ crystal along axis X with velocity of V=2320 m/s.



Rocking curve of the X-cut of a $Ca_3TaGa_3Si_2O_{14}$ crystal modulated by SAW with wavelength of $\Lambda = 6\mu m$

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Integrated Intensity for the Dynamic Diffraction of Thermal Neutrons in Weakly Deformed Crystals

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The integrated intensity determined as the ration of total energy recorded in the counter with the rocked crystal near the Bragg condition. On the other hand, the same intensity can be defined as the integral of the intensity distribution along the base of Bormann's triangle, when crystal wave field is created from point source of thermal neutrons near the entrance surface of crystal, which follows directly from Parseval's theorem for the Fourier transform [1]. Based on the second determination and derived point source function for the diffraction of thermal neutrons in weakly deformed crystals integrated intensity has been formulated, taking into account, that linear coefficient of absorption is negligible small $\mu \simeq 0$ for the thermal neutrons. The integrated reflectivities data calculated are compared with previously derived experimental results [2, 3] sufficient agreement have been recorded.

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Study Small Structural Changes in Doped on-Liner Optic Crystals by X-ray Sychrotron Renninger Scanning

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Controlling materials properties is one of the most fundamental goals in the science and engineering of materials. In terms of current trends in designing technological materials, quantifying correlations between variations of physical properties and very small changes of crystal structure can be the key to acquiring knowledge of the physics involved and to allow the efficient design of new materials with improved properties. Methods for monitoring small structural changes are therefore important. Although there are well established methods for probing crystal structures, mostly X-ray diffraction methods, the scope of conditions in which these methods can be applied is limited.

Synchrotron X-ray multiple diffraction (XMD) and X-ray powder diffraction have been applied to study the incorporation of Mg^{+2} ions into Nickel sulfate hexahydrate (NSH) crystals. Rietveld refinement of the powder diffraction data indicates expansion of the tetragonal unit cell, as well as small changes in direction and angle of the chemical bonds between nickel and oxygen atoms. These structural changes could explain why dehydration temperatures of Mg^{+2} doped NSH crystals (NSH:Mg) are greater than in pure NSH crystals. Moreover, in analyzing single crystals by XMD, remarkable differences regarding doped and pure crystals are observed in the line profile of diffracted intensities. The observed differences imply in phase shifts of the invariant triplet phases the triplet phases are invariant regarding the origin choice of the unit cell, they carry important structural information, and are physically measurable quantities. By increasing the atomic disorder only of O^{+2} sites in doped NSH crystals, the sense and magnitude of induced phase shifts in the model structure match the ones that would be necessary to justify the observed differences in the diffracted intensities. The amount of extra disorder of the oxygen sites is very small and beyond the resolution power achievable by analyzing diffracted intensities from powder samples.

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Focusing of Hard X-rays at Quartz Single Crystals in the Presence of Temperature Gradient

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The research of the focusing and defocusing of the diffracted X-rays with different wave fronts in crystals under temperature gradient and ultrasonic vibrations is given in work [1]. In work [2] the Laue diffraction of narrow collimated no monochromatic X-ray radiation in quartz and the KDP single crystals under the influence of the temperature gradient is researched and it is shown that a certain threshold of the temperature gradient simultaneously reflects K_{α_1} and K_{α_2} lines and there is a focusing of the reflected beams, and focus continuously closes to the crystal with increasing value of the temperature gradient. The threshold of the temperature gradient becomes as small, as the greater are the angle of collimation and the thickness of the single crystal. Based on the above stated in this paper we consider the Laue diffraction white spectrum of X-rays in crystals of high thickness under the influence of the temperature gradient with the aim of focusing and defocusing the hard X-ray radiation range.

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Some Optical Properties of a Stack of Layers of Cholesteric Liquid Crystal and an Anisotropic Medium

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Optical properties of a stack consisting of layers of a cholesteric liquid crystal (CLC) and an anisotropic medium are investigated. The problem is solved using the modified Ambartsumyan layer addition method. Particular features of reflectance spectra of this system are studied. It is shown that, in contrast to a single CLC layer, this system exhibits multiple photonic band gaps. There are two types of photonic band gaps: selective and nonselective with respect to polarization of the incident light. It is shown that eigen-polarizations in the system generally coincide with quasi orthogonal quasi circular polarizations, except for regions that are selective with respect to polarization of the diffractive reflection. It is shown that, for an even number of layers, the system under consideration is nonreciprocal and can function as an optical diode. The influence of thickness of CLC sublayers, angle of incidence, local dielectric anisotropy of CLC layers, refractive indices and thicknesses of layers of an anisotropic media on reflectance spectra and other optical characteristics of the system is investigated.

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Study of Ionization Effects in Wide-band Gap Insulators Under the External Influences

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Corundum (αAl_2O_3) is of great scientific and practical importance due to its exceptional properties: high hardness, refractoriness, chemical and radiation resistance, low electrical conductivity and high optical transparency in a broad spectral range. The aim of this work is to study the manifestation of "radiation memory effect" in corundum crystals. The objects of study were some samples of nominally pure (undoped) single crystals of corundum (αAl_2O_3) grown by different methods: horizontal unidirectional crystallization (HUC), Verneuil technique. The concentration of uncontrolled impurities in the fusion mixture were as follows (in percent by weight): $Cr_2O_3 - 3 \cdot 10^{-3}; Ti_2O_3 - 10^{-4}; Ca, Fe, Ni - 10^{-3}$. Corundum single crystals were irradiated using 50 MeV linear accelerator, 2 MeV reactor neutrons, X-ray beam of synchrotron radiation ($h \sim 12KeV$). The samples were annealed in the air at various temperatures. Irradiation of the samples with high-energy electrons (50MeV at a dose of $10^{17} e/cm^2$) increases the absorption coefficient in the whole spectrum. The revealed band at 6.05 eV (205 nm) is the most intense and observed in the spectrum of induced polarization of the corundum crystals grown by other methods. The revealed bands are anionic centers: F-center (6.05 eV - anion vacancy with two localized electrons) and F^+ -center (5.4 eV, 4.86 eV - anion vacancy with one localized electron). To clarify the nature of the color centers (CC) induced by fast electrons, the corundum samples irradiated by 2 MeV reactor neutrons at a dose of $10^{17} n/cm^2$ and annealed at 700°C were analyzed. It is revealed that real crystals also have a number of uncontrolled metal impurities that stimulate the formation of growth defects to maintain the composition of charges, which do not disappear after high temperature annealing. Such defects are potential traps for the radiation point defects in the form of interstitial ions and vacancies. Some of these defects can become color centers (F, F^+,F^{2+}). In addition, there are inelastic interactions that change the charge state of pre-irradiation defects according to the following reaction: $F^2 + e \rightarrow F^+$; $F^2 + 2e \rightarrow F$, which just leads to the formation of F- and F^+-centers as well as other CC types. Due to the radiation-induced processes, the interstitial ions can partially migrate to the surface of the crystal thanks to their high mobility. Irradiation by of X-ray photons ($h \sim$ 12KeV synchrotron radiation at various time exposures) has shown that there are changes in the intensity of absorption bands. A new absorption band at 302nm (4.1 eV) is detected, which plays a significant role in the "radiation memory" of corundum. It follows from the experimental results that the existence of F-center and CC with 302nm band gives the right to present it as a $[Al_i^+ F]$ center. A mechanism of manifestation of "radiation memory" in corundum single crystals is presented, and the frequency content of the absorption spectra caused by F, F^+, $[Al_i^+ F]$ color centers is determined.

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Program of Model Calculations of X-ray Diffraction With Outside Influences

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The process of coherent scattering of X-rays on single crystals is modeled in the presence of temperature gradient or ultrasonic vibrations for the incident beam with spectral-angular distribution of intensity $I(\lambda;\theta)$ In the condition of full pumping of X-rays, the integral intensity of the reflected beam increases more than 20 times, when the incident beam has relative angular and spectral width of more than 10^{-4}, the increase from 3 to 20 times is seen when the relative angular and spectral width changes from 10^{-5} to 10^{-4}, and increase in 2^{-3} times when the relative angular and spectral width is less than 10^{-5} (the case of plane monochromatic radiation, but the increase in 3 times can be achieved with the effect of the transparency). The angular and spectral width of the pumping X-rays depends on the thicknesses of the tested crystal and the maximal integral intensity of the reflected beam is reached when the thickness of the single crystal is $\mu t = 1$.

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Imaging of Defects in $ZnGeP_2$ Crystals by X-Ray Topography on Base of Borrmann Effect

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Single crystals of ternary semiconductor compound $ZnGeP_2$ with chalcopyrite structure are used as a high-performance medium for conversion of laser frequency radiation in the middle IR, what allows to solve a lot of problems of high-resolution spectroscopy. In present contribution an analysis of structural defects in $ZnGeP_2$ crystals by X-Ray transmission topography has been carried out. $ZnGeP_2$ single crystals were grown by seeded Vertical Bridgman method from melt in Institute of Monitoring of Climatic and Ecological Systems SB RAS (Tomsk, Russia).

The state-of-the-art results in $ZnGeP_2$ growth with sufficiently perfect structure allow to register a presence of Borrmann effect and to apply X-Ray topography method based on this effect (XRBT method) [1]. The method has a high sensitivity to defects of crystal lattice and it has already shown its high effectiveness for a wide group of semiconducting materials such as Ge, Si, GaAs, SiC and monocrystalline alloys of Bi-Sb [2]. Additional methods were method of X-Ray topography in back reflection geometry and the method of photoelasticity (birefringence contrast method).

By XRBT method images of all the main types of defects of crystal lattice - three-dimensional, or volume (large inclusions, dislocation networks, the elastic stress fields), two-dimensional, or planar (twins and stacking faults), one-dimensional (dislocations of different slip systems), quasi-point defects (micro-inclusions of various types and small dislocation loops) were found and identified in $ZnGeP_2$ crystals.

Under certain conditions, in the XRBT method defect produces an image in form of contrast rosette with multiple petals. For example, the rosette is formed, if the line of the dislocation lies in the reflection plane of the crystal along the direction of propagation of energy of the X-Ray wave field. Identification of defects is carried out by comparing of their images on the experimental topographs with simulation ones or with already decoded images of defects. For the computer simulation a semi-phenomenological theory of contrast on the basis of Indenbom-Chamrov's equations modified by L.N. Danil'chuk may be used. Recently the possibility of direct simulation of image of dislocations in thick absorbing crystals by solving of Takagi equations was shown [3]. These results show great possibilities of the "rosette" technique of topography in registration and study of structural defects in $ZnGeP_2$ crystals.

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Dynamical Diffraction of X-ray on ADP Single Crystals Under the Influence of Thermal Gradient

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The relation between integer intensity of the diffracted X-ray radiation from ADP (ammonium dihydrophosphate) single crystal was studied in Laue geometry, under the existence of thermal gradient . It is stated that lineardependence between the integer intensity of radiation refracted from single crystal, and the thermal gradient, which was applied perpendicularly to the reflecting atomic planes, takes place. This is true till the saturation. When the value of thermal gradient is small, and the vectors of refraction and gradient are antiparallel to each other, the integer intensity of refracted radiation decreases for 10%, and then increases monotonically, with increasing of the thermal gradient. Depending on theoretical analysis the observed phenomena are explained.

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The Energy Resolutions and Fano Factors of Si(Li) and CdTe X-Ray Detectors

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Results of the experimental research of the energy resolutions of the X-ray spectrometers with cooled Si(Li) and CdTe detectors are presented. The source of soft characteristic X-rays excited by tritium is described. The experimental data on the energy resolution are compared to calculations. The Fano factors of the detectors are determined. Analytical expressions for description of the energy resolution of the spectrometers in the energy range 1-100 keV are found.

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Features of Digital Processing of Topography Contrast in Single Crystal Materials

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X-Ray topography method based on the Borrmann effect (XRBT method) is effective at the study of single crystals with low dislocation density and dislocation-free materials [1]. Contrasts formed by structural defects, have the form of intensity rosettes, shape and number of petals of which depend from the type of defect and its location in the volume of a single crystal, and the size depends from the type of material. Identification of structural defects is performed visually and it is based on a comparison of experimental contrast with the earlier studied and decrypted contrast or with the theoretically simulated from the modified Indenbom-Chamrov's equations images. "Noise" factors: background inhomogeneity and graininess of photographic emulsion having a negative impact on this process. Against the background granularity it is impossible to identify structural defects with dimensions comparable to or less than the grain size, and is difficult to detect defects of structure and to determine features of their contrast in highly illuminated and shaded areas. Effective elimination of these factors may be done by digital image processing, based on the analysis of brightness or frequency characteristics of the contrast (Fourier and wavelet analysis) [2]. The best results were obtained at digital processing using discrete wavelet analysis. Successive elimination of background inhomogeneity and graininess reveals on topographs previously non-detected images of microdefects of various types in the form of one-, two- and threefold intensity rosettes with sizes of 25 microns. At use of the digital processing it is possible to avoid errors at interpretation of contrast, clearly separate images of closely spaced structural defects and distinguish defects of emulsion from them. Descriptiveness of topography methods and digital processing techniques at identification of "fine" features of contrast formed by structural defects may be greatly enhanced by the obtaining and subsequent digital processing of images with High Dynamic Range (HDR-images).

Analysis of the received results indicates that the digital processing for the effective elimination of the main noise factors can reliably identify defects and does not introduce distortions into the experimental contrast.

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Quantitative Criteria for Quality Evaluation of Single Crystal Topography Images

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In this contribution we compare the effectiveness of different methods of digital processing and quantitative evaluation of quality of X-Ray topographs, containing images of various types of structural defects in single crystals.

Identification of structural defects usually carried out visually by analyzing of topographs and photos, and the result depends from the experience, skills and visual acuity of the researcher. Analyzing the same contrast, various experts may interpret it differently and identify defects in different ways too. Compared contrasts may be qualitatively indistinguishable at visual study, but actually have differences - the "fine" features the detection of which may be carried out using digital processing, based both on the analysis of brightness and frequency characteristics. Reducing of subjectivity at the analysis of experimental contrast is achieved by selecting of simple quantitative criteria, in which we can take the Mean Squared Error (MSE), Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM).

The most simple, express and technically easy to implement is approach based on using as quantitative criteria for evaluating the quality of digital processing of brightness characteristics (BC), profiles of intensity (IP) and the difference of contrast (DC) [1]. DC is obtained by subtracting one image from another, and if the images are perfectly identical, we get zero DC. BC demonstrates the relative number of points N, which have a definite intensity value I in grayscale colors: on the horizontal axis the intensity in grayscale is indicates, and the vertical axis reveals the number of points having a given intensity. IP demonstrates the change of intensity in the selected direction: on the ordinate axis intensity I in grayscale is specified, and on the horizontal axis the size of the image in pixels is given. This approach has been applied by us at evaluating the effectiveness of different methods of digital processing of simulated theoretical topographs of defects obtained from the modified Indenbom-Chamrov's equations and experimental images of various types of structural defects, at choice of the most efficient wavelet basis and at assessing the distortions introduced by digital processing.

Analysis of experimental and theoretical results showed that the most promising method for digital processing is a discrete wavelet analysis [1].

This work was performed in joint with Ioffe Physical Technical Institute RAS Laboratories "Computer technologies in diffraction diagnostics of materials" of Novgorod branch of SPbGEU and "X-Ray topography methods at research of materials for electronic engineering" of Yaroslav-the-Wise NovSU with the support of RFBR grant No **12-02-00201**.

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Integral Reflection Coefficients for the Dynamic Scattering of X-ray in Weakly Deformed Crystals

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Integrated intensity of the reflection is one of the main characteristics of the diffraction of the short wavelength radiation in crystals. Based on previously derived point source image function for the diffraction in weakly deformed crystals [1] the integral intensity of reflection for X-rays has been formulated and discussed. The integrated intensities of the diffraction of monochromatized X-rays has been registered for the crystals KDP, ADP and quartz [2] under the influence of temperature gradient. A comparative analysis shows good agreement between theoretical and experimental results.

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Rationale for a New Principle of Calculating the Intensity of Dynamically Diffracted X-ray Beam in Single crystals with Defects

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By analyzing the dynamic theory of Bragg diffraction of X-rays in perfect single crystals satisfying the small-angle scattering theory, has proposed and proved a new principle of computation of the intensities of dynamically scattered X-rays in single crystals with defects. The analytical form of the corresponding coefficient obtained by the comparison of the relevant formulae with a particular solution of integral-differential equations of dynamically scattered X-ray waves in weakly deformed single crystal. Further development of the theory of dynamical scattering of X-rays in deformed crystals and crystals with defects is of critical importance in structural studies of condensed matter from the point of view of solving the phase problem of x-ray scattering. This will lead to an unambiguous interpretation and explanation of x-ray diffraction and interference patterns, in order to accurately determine the structural distortion of the materials.

This theory is well developed and integral-differential equation is obtained for the direct study of the problem [1]. However, the integration of this equation - not an easy task, and formulation and solution of the inverse problem, determining the exact structure of the materials based on these equations is an unsolved problem. Usually, the problem can not be solved analytically. The numerical integration of the equations greatly limits the ability of a developed, of strictly dynamical theory of scattering of X-rays in distorted crystals, in terms of new predictions for the development of the experiment in this area. Uncertainty of unambiguous theoretical interpretation of the experimental results, to some extent, is easier when a crystal is distorted by certain external influences (temperature gradient, the ultrasonic field). In order to overcome the above mentioned problems in, we proposed a new principle of computation of the intensities of X-rays (or thermal neutrons), dynamically scattered in single crystals with defects.

Confirmation of the new principle is carried out by comparing the corresponding formulae with a particular solution of integro-differential equations of dynamically scattered X-ray waves in weakly deformed single crystal. The amplitude of the diffracted wave will be considered as the result of a two-step diffraction. At the first stage, a beam of x-rays dynamically scattered on perfect single crystal (Bragg diffraction). In the second stage the diffracted at the first stage waves undergo small angle scattering on defect. At the first stage, the dynamic Bragg diffraction of x-ray beam on a perfect single crystal, for which the amplitudes of the diffracted waves are known. In the second stage, diffracted at the first stage waves undergo Fresnel or Fraunhofer diffraction on a defect, depending on the defect size and geometry parameters of the recorded intensity of diffracted radiation. The essence of the new principle consists in that the amplitude of the diffracted X-ray wave on a crystal with defect can be calculated by adding the scattered amplitude of two stages.

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Two Schemes of Diffraction of X-ray Radiation Widely Divergent Beam

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We have developed a new technique for realization of the X-ray diffraction of widely divergent beam (WDB). The basic constituent part of this technique is a chamber containing the crystal under examination, diaphragm (funnel-like hole with diameter of $30-40\ \mu m$ in the $\approx 1\ mm$ thick tantalum plate), and photographic plate. During the exposure time, the chamber rotates about the diaphragm axis. In one diffraction scheme, the crystal is placed behind the diaphragm (scheme c-d), in other scheme, the crystal is placed in front of the diaphragm (scheme d-c). The diffraction images, which are formed at schemes c-d and d-c, essentially differ from each other in many relations. Particularly, in the case of application of the scheme c-d, there is a mutual correlation between the object and its image: each point in the image corresponds to a certain point at the crystal surface. In other words, the recorded diffraction image is a topographic map of the points on the crystal. In the case of application of the diffraction scheme d-c, there is no such a type one-to-one correspondence between the points of the object and its diffraction image. Except of above indicated schemes c-d and d-c, the WDB diffraction may be realized by placing the crystal in the very proximity to the diaphragm (in front or behind it). Such a type diffraction scheme is equivalent to Kossel's scheme. The scheme d-c is equivalent to all the possible pseudo-Kossel schemes. The scheme c-d is the most informative, and there is no any scheme that could be qualified as being equivalent to it.

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Section 7

Interaction of Particle Beams with Artificial Structures (Acoustic Superlattices, Metamaterials, etc.)

Polarization Bremsstrahlung on Metallic Nanospheres in Liquids

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The presentation is devoted to the theoretical investigation of Polarization Bremsstrahlung (PB) produced by fast electron scattering on metallic nanospheres in liquid. Actuality of this process stems from the possible PB applications in biomedical investigations with the use of nanoparticle technologies.

The main feature which discriminate our consideration from previous work is the account for the molecular Brownian movement. The influence of this movement on PB depends upon the size of the nanoparticle and liquid properties. So in principle it is possible to evaluate the nanosphere radius with the help of the PB angular and spectral distribution. Our work aims to estimate the quantitative degree of above mention dependence and to determine the optimal condition of the manifestation of this effect. From the mathematical point of view the account for molecular Brownian movement come to the following replacement in the formula for PB spectral and angular distribution:

$$\delta(q^0) \to \frac{1}{\pi}\frac{D\mathbf{q}^2}{(q^0)^2 + D^2\mathbf{q}^4} \tag{1}$$

here $\delta(x)$ is Dirac delta function, $q = (q^0, \mathbf{q})$ is four-dimensional wave vector transferred from the incident electron to the nanosphere solution, D is diffusion coefficient of nanosphere in the liquid which is given by well-known Stokes-Einstein formula

$$D = \frac{k_B T}{6\pi\eta R} \tag{2}$$

where R is the radius of nanosphere, T and η are temperature and viscosity of the liquid, k_B Boltzmann constant. The physical essence of the relation (1) is connected with the energy transfer from the nanosphere to the liquid via Brownian movement of liquid molecules during PB process.

The calculation of PB characteristics is made in the spectral range corresponding to the excitation of the dipole plasmon on the nanosphere surface where the PB intensity has a maximum.

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Experimental and Theoretical Spectroscopical Data of Radiation Channeling Inside μ-capillary Holed Glass Plates

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Grazing-incidence X-ray methods based on the analysis of secondary radiation, i.e., reflection and fluorescence, emitted from a solid surface as a result of interaction with a primary beam have a great number of scientific and technological applications. Ultra long-wavelength spectroscopy is an effective method for analyzing the state of solids surface. Experimental and theoretical studies were carried out and X-ray reflection spectra were collected at grazing incidence on a flat surface and the channel walls of microchannel plates. In particular, we present experimental and theoretical calculated feature of fine structures of spectra at the energy of the Si L-edges detected under the condition of the total X-ray reflection. Theoretical calculations were made using a model taking into account the transition layer on the sample surface.

Capillary optics is a fundamental X-ray technology capable to generate a high flux density with a sub μm spot size. The physical basis of capillary optics refers to the mechanism of X-ray total external reflection although radiation transport experiments inside these structures are really limited. X-ray transmission through micro-capillaries is challenging research aimed at the development of new optimized focusing devices. Advancements may lead to novel applications and in many disciplines.

We present here experimental data and theoretical calculations of fine structures were carried out on the base of the transition layer model were permittivity varies in the depth from the surface. The radiation spatial distribution at the exit of microcapillary structures was calculated and the properties of soft X-ray fluorescence radiation at the exit of these multichannel structures have been studied.

On the base of both experimental and theoretical analysis important results can be pointed out for various applications of soft X-ray optics, in particular, to achieve extreme focusing with a polycapillary system.

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The Transverse Dynamics of the Azimuthally Inhomogeneous Electron Bunch in a Multilayer Dielectric Waveguide of Circular Cross-section

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Recently, methods of wakefield acceleration of charged particles are extensively researched [1]. These methods are expected the energy transfer from the driver bunch to the witness bunch passing throw the accelerating structure with speed of light. Dielectric waveguides most widely used as wakefield accelerators where driver bunch generate Cherenkov radiation for acceleration of the beams entered to structure with delay. The efficiency of wakefield acceleration schemes is related with transformation ratio, defined as the ratio of maximum accelerating field behind driver bunch maximum decelerating field inside one. For collinear single-layer dielectric waveguide transformer ratio does not exceed 2. With using of ring beam in a multi-layer waveguide can significantly increase the transformation ratio by separating the areas of driver and witness bunch propagation [2,3]. The main problem of this scheme is the transverse dynamics of the driver bunch due to the high charge and low energy. It is important to keep inner dielectric tube inside the waveguide by titanium thread for passage of accelerated bunch. This causes segmentation of driver bunch to prevent his ingress on threads. In this paper we research the transverse dynamics of the annular beam with different types of azimuthally asymmetries that depend on the specific of beam generation and structure of multilayer waveguide. We considers continuous charge and segmented charge distribution. It is shown dependence between the different types of beam asymmetry and hybrid modes which are excited. With help of original code BBU we presents an analysis of wakefield structure of and the results of the transverse dynamics.

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The Device for X-ray Absorption Spectral Analysis with Using of Acoustic Monochromator

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Nowadays, XRF is the most common method of X-ray elemental analysis. This method has some incontestable advantages, such as an ease and high level of acquaintance. There are some problems, though, which is still impossible to solve by XRF method. One of them is ultrapure elemental analysis, during which radiated fluorescence is almost completely absorbed by investigated object. Variety special methods of sampling, such as grinding or evaporation, are used now for solving this problem. Nevertheless this way has some significant disadvantages: it is quite difficult, requires extra time and the main one - leads to destruction an object.

Another solution, which has no previous drawbacks, can be obtained by analyzing of different wavelength X-ray absorption degree instead of XRF analysis for determination of elemental composition.

In the paper, the device for ultrapure elemental analysis based on X-ray absorption spectroscopy principles is proposed. The device has in its structure the following parts: X-ray tube as an X-ray source; collimator; acoustic monochromator, which is crystal one with an acoustic supper lattice, set in the first holder of $\theta - 2\theta$ type goniometer; the holder for investigated sample; and a detector, set in the second holder of goniometer.

Working principle is described below. X-ray goes through collimator and falls on monochromator. Certain monochromatic energy line goes through a sample and after that is registered by the detector. Consistently changing orientation of monochromator and detector it is possible to register the dependence of unabsorbed X-ray intensity on energy and coefficient of X-ray absorption accordingly. Presence of one or another element is determined by presence of corresponding absorption edge.

Preliminary simulated by GEANT4 programming package results shows that sensitiveness of this method not less than 10^{-4} by Cr admixture in the SiO_2 matrix.

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Modeling of Refraction Indexes of some Types of Dielectrics under Influence of External Electromagnetic Fields

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Formation and control of periodic nanostructures in various media (medium with periodically modulated refractive index) are now among the most important problems in applied physics and material science. First of all, it is related to the possibility of creating compact UV or X-ray Free-Electron Lasers (FEL) based on the emission of transition radiation (TR) (see, for example, [1]). Recently we have investigated the problem of creation of dielectric constant's superlattice in SiO_2 type mediums under the influence of external electromagnetic fields. In particular we have developed quantum and classical representations for description of properties of spin glass medium under influence external standing electromagnetic fields [2, 3]. We have shown that $3D$ medium can be considered as an non-ideal ensemble of finite lengths $1D$ spin-chains. The complex-classical Hamiltonian was a first used for investigation of statistical properties of spin system in external fields with taking into account relaxation effects. The distribution functions of different parameters of spin glass system are calculated from first principles of complex-classical mechanics. It is shown that behaviors of different distributions parameters are quite different even at weak external fields. Critical properties of medium such as catastrophes in Clausius-Mossotti equation depending on value of an external fields are studied. It is shown that the complex-classical approach excludes catastrophes, which allows organize continuous parallel computing on the whole region of values of an external field including critical points. By way of calculation it is proved that under the influence of weak external fields' creation of dielectric constant superlattice is possible. Last circumstance is very important for finding new effective radiators of transition and Cherenkov radiations.

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Channeling of Protons in Radially Compressed Carbon Nanotubes

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Channeling of 10 MeV protons in compressed chiral carbon nanotubes is considered. Monte Carlo simulation program is used for the calculation of the trajectories, energy losses and angular distributions of protons in nanotubes of various lengths, where the potential in Doyle-Turner approximation is used to describe the interaction between a proton and a nanotube. Calculations were carried out for different angles between incident proton beam and the nanotube axis, and for different initial proton beam divergence. The results show that a decreased angular distribution of the beam is observed, compared with propagation through a straight nanotube, in case when it enters from the compresed end of the nanotube and for larger beam divergence. This collimation of the beam also depends on the type of the nanotube. Furthermore, focusing of protons in smaller area is achieved, in case when beam enters from the uncompressed end. The energy distribution of channeled protons in nanotubes present a series of small peaks besides a main one, the number of which depends on the nanotube length and the angle of incidence. It is shown that each peak seems to be correlated with a zone of the corresponding angular distribution, hence with the point of incidence. It must be noticed, that this peaks appear with different degree in all three cases, proton beam entering straight nanotube, compressed and uncompressed end of nanotube.

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Section 8

Control of Parameters of Plasma by Acoustic Superlattices and Monochromatic Optical Radiation

Selective Amplification of Separate Spectral Emission Lines in the Low-pressure Acoustoplasma Discharge

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The spectra of radiation for nitrogen acoustoplasma by low and ultra-low pressure in the discharge tube with water cooling is obtained. The experimentally obtained conditions significantly increase the intensity and decrease the width of the separate emission line of nitrogen acoustoplasma in the visible range (0,65 mkm). An attempt is made to describe theoretically the obtained results. It is shown the possibility of the separate spectral lines by changing the regime of operation of the acoustoplasma discharge (depth and frequency modulation, a values of the direct components of the discharge current). To obtain the spectra employed a modified spectrograph ISP-51 (ИСП-51), was made the a new output tube, in the focus of which was established reception CMOS matrix, the image of the spectrum is displayed. For the mathematical processing of the spectra was used specially developed software.

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Electrical and Optical Spectroscopic Studies of the Parameters of the Diffusely Cooled Acoustoplasmic Glow Discharge in the CO_2-laser

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In the laser gas mixtures $CO_2/N_2/He$ of the diffusely cooled glow discharge has been studied. Using electro-physical and optical-spectroscopy techniques have been studied the effect a small modulation of discharge current on the regime of burning and plasma parameters. It is found that the modulation of the current causes the excitation in the discharge pulsation of sound pressure, discharge current, and intensity of the laser radiation. There were observed the following frequencies: modulation current, its harmonics, as well as frequencies of spontaneously arising of the resonant standing acoustic waves in the discharge tube, and combinations of these frequencies with a frequency of the ripple current source. It is shown that the excitation of spontaneous resonance oscillations of the discharge current, or the performance of its modulation changes the intensity of infrared luminescence of the upper laser level of the CO_2 molecule and the laser power. This is due to the heating of the plasma in the positive column due to its contraction in the field of acoustic wave, initiated by the ripple current. It is shown the possibility of controlling the power of the radiation by the creation of the active medium of the laser the acoustoplasma instabilities excited by the small modulation of the discharge current.

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The Influence of the Acoustoplasma Discharge Regime on the Parameters of the Gas-discharge CO_2-laser

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We consider the influence of parameter changes on the parameters of the acoustoplasma discharge in a gas-discharge CO_2-laser. For the experiments we used a standard laser LG-23 with a discharge tube GL-502, designed for DC power. For measurements in acoustoplasma regime included the following changes: using a vacuum system has the ability to change the working medium in the discharge tube; the standard output mirror in the resonator of LG-23 laser was replaced by a plane-parallel germanium plate; for use in acoustoplasma regime used a specially designed power supply. It is presents the data for optimizing the optical power of the laser at a wavelength 10.6 microns depending on the pressure, gas mixture and discharge parameters. It was shown experimentally that the optimal mixture in acoustoplasma regime is different from the classical case ($CO_2 : N_2 : He = 1 : 1 : 8$).

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Changing the Emission Spectrum of the Acoustoplasma Discharge at Change of Parameters of the Discharge in a CO_2-laser

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There are presented the emission spectra in the visible range (0.35-1 mkm) for the CO_2 - laser mixture in a water-cooled discharge tube. It was shown experimentally the increase in the intensity of radiation of various spectral lines by the transition to a acoustoplasma regime, obtained the dependence of the spectrum intensity on the gas pressure and the discharge parameters. We estimate the influence on the emission spectrum of the separate components of the laser mixture. To measure the spectrum was used computer spectrograph "Ocean Optics PC2000" and modified spectrograph ISP-51, for which you have made a new outlet tube and at its focus was fixed reception CMOS matrix. The spectrum image is displayed. For mathematical processing of the spectra was used specially developed software.

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Determination of Parameters of the Acoustoplasma Discharge using a Method for Solving of Inverse Problems

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We propose a method of "treatment of experiments", to simplify calculations. On the basis of experimental data by the method of solving noncorrect-posed inverse problems are obtained changing the charge and RCL-parameters in the discharge tube during the period of the modulation current. Using electrical and optical parameters of the discharge plasma for CO_2 -laser using the method of inverse problems is not determined by the integrand, as usual, and the transformation operator of energy invest into the discharge of the spectral energy distribution of the density of the optical spectrum. The experiment was carried out for the part of the visible region (wavelength 0.6-0.7 mkm). For nitrogen acoustoplasma acoustic parameters defined by the electrical and optical characteristics.

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Section 9

Application of Radiation Beams

On the Radiation Generated through Multiple Volume Reflection in a Single Bent Crystal

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The radiation emitted by 120 GeV/c electrons traversing a single bent crystal under multiple volume reflection condition has been measured. Multiple volume reflection (MVROC) effect was experimentally discovered at CERN for both positive and negative particles, with the purpose to increase the deflection angle achievable by a single volume reflection (VR). Indeed, MVROC occurs as the beam trajectory is nearly parallel to a crystalline axis because repeated VRs onto the planes sharing the same axis take place, leading to a multi-reflection process within a short distance. The experimental radiation spectrum resulted to be very intense over the full energy range up to the nominal energy of the beam. As compared to radiation emission by an individual volume reflection, the spectrum is more intense and peaked at a photon energy three times larger as shown in Fig. 1. Experimental results were compared to a theoretical approach based on the quasi-classical operators method of Baier and Katkov. An investigation about the features of MVROC radiation has been done, showing that such type of radiation takes place over a broad angular range and weakly depends on the beam divergence. Such features, together with the high-intense, wide spectrum and high deflecting power, renders MVROC radiation attractive for some applications, such as a crystal-assisted collimation devices and beam-dump at future linear electron-positron colliders.

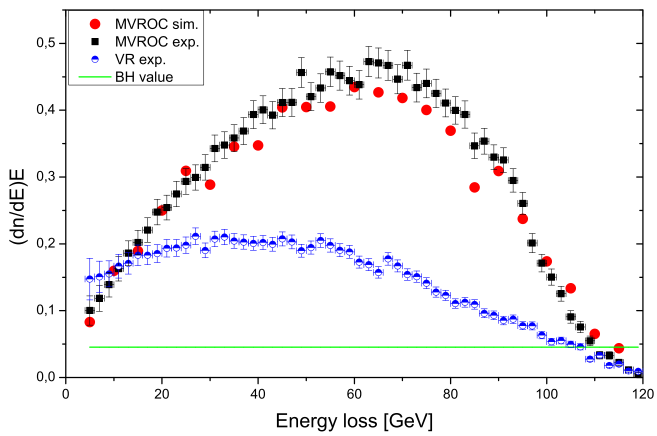

Figure 1. Energy loss spectra for 120 GeV/c electrons in the StR3 crystal; VR experimental results (circles with bars); amorphous estimation (solid-line); MVROC experimental results (squares with bars) and simulations (circles).

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Simulation of Positron Energy Spectra Generated by Channeling Radiation of GeV Electrons in a Tungsten Single Crystal

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Intense gamma-radiation generated during channeling of high-energy (GeV) electrons through a single crystal may be applied for the creation of positron beams. As suggested in [1], a non-conventional positron source consists of a separate radiator crystal used for the production of channeling radiation (CR) and a consecutively arranged amorphous converter where the radiation is materialized into e^+e^- pairs. In contrast to the single-target assembly applied in [2], at a hybrid positron source the heat load into radiator and convertor due to beam interactions should be minimized. In a first work, we simulated positron energy spectra produced in a tungsten (W) convertor by CR and coherent bremsstrahlung (CB) generated in a thin W radiator crystal [3], where the CR/CB spectra were calculated in the framework of classical mechanics and electrodynamics for realistic continuous potentials of the W (110) and $< 100 >$ crystallographic plane and axis, respectively (see *e.g.* [4, 5, 6]). Optimization of the thickness of the crystalline target, however, requires consideration of dechanneling. Applying the method recently described in [7], we evaluated dechanneling in the W radiator crystal by solving the Fokker-Planck equation numerically. The CR/CB spectra obtained are used as input data for the simulation of pair creation by means of the GEANT4 package. Simulation results and relevant conclusions will be presented.

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The Possibility of Obtaining Intense Neutron Source on the Base of Proton Cyclotron C18

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The possibility of obtaining the quasi monoenergetic beams of neutron on the external proton beam of the Cyclotron C18 was investigated. The intensity and neutron spectra in dependence of the matter and thickness of target was studied. The quasimonoenergetic neutron beams and scattering of neutrons on periodic structure will be used for fundamental investigation, applied physic in the field of nuclear medicine and astrophysical research.

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Study of Coherent Interactions Between a Sub-GeV Electron Beam and a Thin Bent Silicon Crystal

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We report the observation of efficient steering of a sub-GeV electron beam by means of planar channeling and volume reflection in a bent silicon crystal. A 30.5 μm thick plate of silicon (211)-oriented was bent to cause quasi-mosaic deformation along the (111) crystallographic planes, which were used to steer the 855 MeV electron beam of MAMI accelerator. Experimental results resemble very much the achievements obtained in the hundreds-GeV energy range, which to date is the only comparison term (see Fig. 1). The rechanneling mechanism seems to play a crucial role in particles dynamics, as studied through Monte Carlo simulations, and hinders the spoiling of channeled particles. Obtained results allows a deep understanding of the dynamics of sub-GeV electrons subject to coherent interactions in a bent silicon crystal. Morevoer, we investigated also the emission of electromagnetic radiation by 855 MeV electrons through coherent interactions in bent crystals. In more detail, we studied the influence of bending to radiation spectrum and investigated the e.m. radiation generation in volume reflection conditions. The information extracted from this experiment, regarding both dynamics and radiation generation, can be exploited to investigate the possibility to use bent crystals to manipulate GeV particle beams or taken into account to properly design periodically bent crystals to be used as innovative and powerful sources of high-intensity electromagnetic radiation.

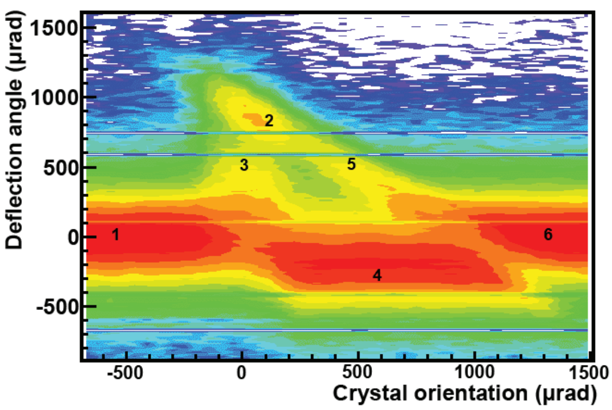

Figure 1. Deflected beam profile as a function of the misalignment angle between the electron beam and the crystal. Six different regions, corresponding to different interaction regimes, can be distinguished: (1) and (6) non-channeling; (2) channeling; (3) dechanneling; (4) volume reflection; (5) volume capture.

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To the Problem of Coherent Electron Cooling

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In [1] the authors proposed a method of coherent electron cooling (CEC) of ion beams in a storage ring of the Large Hadron Collider (LHC). They estimated that theirs method, in contrast to the other traditional methods of cooling, is an efficient cooling procedure for the proton beam at high energy. As the subject of beam cooling is very interesting, we decided to compare the method described in [1] with the one described in [2].

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Crystal Devices for Beam Steering in the IHEP Accelerator

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Different crystal devices are described, which provide an extraction and splitting of beams for a long period of time at the U-70 accelerator of IHEP. The modes of channeling and volume reflections in the bent crystals are used for these tasks. In regular accelerator runs crystals produce the particle beams in a wide range of intensity, from 10^{+6} up to 10^{+12} particles in a cycle. Novel crystal techniques suitable for charged particle beams deflection and focus as well as photon generation are presented also.

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Study of Surface Reflection of High Energy Protons from Solids at PNPI

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In experiment at PNPI with 1 GeV proton beam, we have studied a surface reflection of high energy protons from solids. The layout of the experiment was similar to the case of volume reflection study in bent silicon crystals [1]. As samples, the deep polished plates from fused quartz of ~ 100 mm length were used. The flatness and roughness of the quartz surfaces were about 100 nm and 10 nm, respectively. An amorphous material was chosen to exclude any effects from crystalline structure. Surface reflection effects from quartz faces were measured under different angles respect to the proton beam.

Analysis showed that under small gliding angles the surface scattering reveals an essential reflection from an average potential step arising from a density gradient on the body boundary. Thus, for the incident angle of 130 μrad, the deflection angle of reflected protons was found to be ~ 260 μrad with the efficiency of reflection (which is a ratio of number of reflected protons to the number of protons incident onto the surface) near 70% [2].

The value of the surface potential step was estimated from the experimental data and found to be ~ 12 eV. Assuming the thickness of the surface layer being about roughness parameter (10 nm), the effective electrical field in such a layer is estimated on the level of 12 MV (megavolts).

The meaning of obtained result is that a first passage of the high energy proton under certain gliding angles and surface conditions through any material (amorphous or crystalline) used as beam collimator should result in the kick of the order of potential step on the solid boundary that may essentially exceed effect induced by a multiple Coulomb scattering and influence on particle behavior on the next turns in collider. Also the obtained result gives perspective to develop a new type of charged particle deflector for beam extraction.

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On High-Energy Charged Particle Beam Diffusion in Crystal

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If a high-energy charged particle moves in a crystal with a small angle between its momentum and direction of one of the main crystallographic axes, the movement of the particle is determined mainly by continuous atomic string potential [1]. The longitudinal component of the particle momentum parallel to the crystallographic axis in such field preserves. Thus, the problem of motion of such particle in the crystal is a two-dimensional problem of motion in the transverse plane. In the report we consider high-energy charged particle beam diffusion in crystal in the plane orthogonal to one of the main crystal axes. Analysis of such diffusion in coordinate space helps to understand orientation effects in particle scattering. For different initial conditions such diffusion can exhibit properties of both subdiffusion and superdiffusion [2]. On the other hand, analysis of diffusion in angular space gives an opportunity to measure the speed and law of formation of angular distributions typical for charged particles scattering in the crystal. Also we consider conditions of applicability of random string approximation for the description of high-energy charged particles motion in a crystal.

This work was partly supported by the National Academy of Sciences of Ukraine in the framework of the project CO-3-1.

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Diagnostics of Nanodispersive Polycrystals using Polarization Bremsstrahlung from Relativistic Electrons

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Polarization bremsstrahlung (PB) appears as a result of scattering of a relativistic particle Coulomb field on atoms. The PB spectrum contains Bragg coherent peaks when the particle moves in a structured medium. The position of the peaks is determined by the distance between crystallographic planes, which makes it possible to determine the parameters of the lattice similarly to XRD methods. The spectral width of the peak is determined by the angle between the particle propagation direction and the direction of PB observation. The width of the peak has a minimal value at about 1-10 eV in the case of backscattering geometry, when the PB signal is detected in the opposite direction to the direction of particles velocity. This circumstance allows measuring the parameters of the lattice with accuracy better than 0.1%.

The results of the presented work consist of measurements of PB in backscattering geometry under interaction of a 7 MeV electron beam with Ni polycrystalline foils. The PB peaks were detected in conditions when the average grain size of the target was of order 100 nm. The PB signal was measured from two targets. The first target was without texture and all peaks were detected at the same time. The second target was textured and the orientation dependence of the yield for crystallographic planes (111) and (220) was measured. The measured orientation dependence was compared with analogous dependence for broadband X-Ray scattering on the same target.

The results show the possibility to use PB to develop a new energy dispersive method for diagnostics of the atomic structure of the medium.

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Undulator-based and Crystal-based Gamma Radiation Sources for Positron Generation

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Conventional positron sources are based on producing of electromagnetic shower by a few GeV electron beam in a thick amorphous target and separation and acceleration of positrons. Such a scheme meets a lot of troubles for a design of positron sources for new facilities (KEKB, SuperB, ILC) where an efficiency of electron/positron conversion should be higher than one. In this case a huge energy deposition in a thick target leads to a significant target damage.

The alternative approach allowing to avoid this problem is connected with a design of two stage positron source - at the first one an initial electron beam generates intense gamma radiation which produces positrons at the second one (in a thin amorphous converter). In order to achieve the required electron/positron conversion efficiency an intensity of gamma quanta downstream the first stage has to be well above ten photons per electron.

Yield of gamma quanta from different mechanisms (undulator radiation, channeling radiation and coherent bremsstrahlung) and feasibility of its using for positron production are considered.

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New X-ray Source for Medical Applications Based on Channeling Radiation and Polycapillary Optics

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Many important medical imaging technologies require a high brightness and quasi-monochromatic X-ray source. These are phase contrast imaging, coherent X-ray diffraction imaging, digital subtractive angiography, dichromography, time-of-flight imaging, mammography. Monochromatic radiation source results in better imaging, and, what is even more important, lower irradiation dose for patients, doctors or nurses.

In this work channeling radiation source is discussed as possible alternative for another quasi-monochromatic X-ray sources based on Synchrotron radiation, Compton scattering, K-capture.

The second key solution is the idea to use policapillary optics to select narrow band energy portions of radiation free from the hard X-ray radiation tail. X-ray channeling in policapillary optics can be used to deflect selectively defined portion of radiation emitted by the beam of electrons in a crystal (near 33 keV) through rather large angles of 10-15 degrees that would allow the radiation to be delivered to the patients. Hard tail of the radiation spectrum remains undeflected and the irradiation dose for a patient and personal becomes much lower.

The design of proposed medical facility, first results of our studies on electron and photon beams dynamics in linac, crystal and polycapillary optics, as well as on the dose distribution simulations will be discussed in our presentation.

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Deviations from Garibian Effect for Ionization Losses of High-energy Electrons in Thin Plates

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The evolution of electromagnetic field of high-energy electron after its emission from solid into vacuum is studied. It is shown that during long period of time after emission the electron can exist in the state with significantly nonequilibrium field ('half-bare' state) in which considerable part of Fourier-components of the field around the electron is suppressed comparing to equilibrium Coulomb field. The ionization energy losses of such 'half-bare' electron in thin plate situated on different distances from the solid are investigated. It is shown that their value should differ from the results of Garibian [1] and Sorensen [2] for ionization energy losses of relativistic electron with equilibrium field in thin plates (according to which the density effect is absent in such plates) and considerably depend on distance between the plate and the solid. The conditions for manifestation of such effect are discussed.

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Electron-Positron Pair Production by Channeling Radiation in Radiator-Converter Approach: Computer Modeling

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The axially aligned tungsten crystals are known to be reasonably effective positron source when it is hit by a high energy (up to 10 GeV) electron beam. However, alternative approach is to use electron beam for production of channeling radiation (CR) in a tungsten crystal (radiator) and subsequent electron-positron pair production in amorphous tungsten (converter), so called a "hybrid" solution [1]. Planar channeling and CR of electrons in silicon-tungsten radiator-converter [2], as well as the polarization properties of produced positrons at axial channeling and CR of electrons in tungsten-tungsten radiator-converter [3] were earlier described. At present the studies on possibility to increase the positron yield is in progress. The Mathematica [4] code developed by the authors enables calculating the trajectories and CR spectra of both planar and axial channeled electrons as well as positrons in crystals. The code was used to calculate the angle-of-incidence dependence of the CR total yield [5]. In order to obtain maximal total yield of CR the channeling in radiator is certain to be axial, however, the planar case has been studied as well. Here we analyze the radiator-converter approach at 150-200 MeV channeled electrons (the SPARC facility energies) to determine optimal parameters of both radiator and converter such as the materials and their thicknesses. Computer modeling is carried out taking into account electron dechanneling at planar channeling in the radiator and positron stopping in the converter. The comparison of simulated results within the model [6] with those obtained by GEANT4 is given.

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Methods for the Measurement of the Refractive Index of MeV Photons Using Total Internal and External Reflections

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Recently it has been theoretically and experimentally shown that for 1-10 MeV and 1-2 MeV photons, respectively, the refractive index of Si is or. Though the measured and predicted values are small, nevertheless, these are important results since they open new possibilities for experimental gamma optics and nuclear physics. Taking into account the difficulties of the carried out experiments it is proposed to measure directly the refractive index of Si and other materials detecting the total internal and external reflections and using capillaries.

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Lepton Pair Production in Peripheral Collisions of Relativistic Ions

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The long-standing problem of multiple photons exchanges in the process of lepton pair production in the Coulomb field of two highly relativistic nuclei is considered. It is shown that the probability to produce lepton pairs is completely determined by the Feynman scattering matrix in the presence of two nuclei. This matrix can be expressed through the scattering matrices associated with individual nuclei in the form of infinite Watson series.

We investigate the problem of infrared divergencies of separate terms of these series and show that for the certain sums of these terms the numerous cancelations lead to infrared stability of the scattering matrix. The prescription is proposed permitting to calculate the yield of lepton pairs with any desirable accuracy.

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The Experimental Study of 10 Kev Electron Interactions with Plexiglas Surface

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The possibility to guide electrons by dielectric channels attracts considerable attention because of its potential practical use in different areas of technology and science. All experimental results indicate the formation of the self-consistent charge distribution on the inner walls of that channels providing partially contactless transition of electrons even for non-zero angles of incidence. To investigate the mechanism of the non-contact transmission of electrons through different insulating channels, an experimental study of beam reflection from a single planar surface was undertaken.

The study of sliding a 10 keV electron beam interaction with plane surface of Plexiglas (PMMA) was performed. In addition it was studied the transition of the electrons through the plane channels made of the PMMA.

The experiment results show the existence of the guiding effect however emerge a number of features, such as the deviation of the initial angle of elevation from the negative inclinations of the plate.

The process of the self-consistent charge formation on the Plexiglas surface and its leaking after turning off the current was slower than on the glass surface. This fact may indicate differences in surface conductivity of insulators.

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Coherent Production of Relativistic Ps Atoms by High Energy Photons and Electrons in Aligned Crystals - Revisited

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Here, we reexamine the experimental proposal [1] in connection with current experiments on crystal-assisted physics at SAGA-LS (Japan) and MAMI (Germany) accelerators

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About the Accumulation Regime and the Slow Output of Particles for Synchrotron with Low-energy

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The work is devoted to the study of phenomena of coherent bremsstrahlung of relativistic electrons under the influence of acoustic fields in single-crystal X-cut quartz. For this purpose to increase the number of electrons involved in the processes of scattering without pile-ups the Yerevan synchrotron is given in the operating mode and the slow accumulation of low-energy output.

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Simulation of the Longitudinally Polarization Transfer from Moderately Relativistic Electrons to Positrons

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The method of production the longitudinally polarized positrons using moderately reativistic electrons with longitudinal polarized spins was suggested in [1].

In the report we are considered such a process for hybrid thin converter, consisting of two amorphous parts. Polarized electrons generate circularly polarized γ-beam in the first one and which produce polarized positrons in the second one.

We consider the longitudinal polarization transfer process for different electron energies and different target ticknesses.

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Setups for Tomographic Imaging with Submillimetric Spatial Resolution

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There is a report about development of the setups designed for tomographic images making in the work.

In these work two setups for X-ray imaging is created.

The first one is based on the linear multichannel gas-discharge detector. The detector is a parallel-plate capacitor. The pickup plate consists of 1536 pickup strips, a step of sensitive elements is 250 microns, time of the integration of a signal 2.5 ms, a voltage on the drift electrode is 1 kV. The gas-discharge detector's imaging provides some features. It has low contrast resolution in according to mutual detectors gas volume. On the other hand it is possible to make chip detectors with relatively large size.

The setup based on the linear multichannel gas-discharge detector designed for tomographic images making is made with divergent X-ray beam. The pulsed X-ray apparatus is used as a radiation source in the setup. The sizes of a focal spot are 1.2 x 1.2 mm, anode voltage is selected from 40 to 160 kV, anode current – from 0.4 to 5 mA, and the peak power of a tube is 0.6 kW. The source is synchronized with the detector.

The second setup is based on the linear multichannel semiconductor GaAs detector. It consists of 512 strips; a step of sensing elements is 100 microns. Usage of this detector allows studying smaller objects but it has better spatial resolution. The setup is made with usage of pseudo parallel X-ray beam.

Tomographic images of different objects are obtained via the setups. The value of spatial resolution for both setups is measured.

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Ionization Losses of High-energy Electron-Positron Pair in Thin Targets

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The present paper deals with consideration of high-energy electron-positron pair ionization losses in thin dielectric plate which it traverses after being emitted from solid where it is created. It is shown that in this case the Chudakov effect of reduction of pair energy losses [1] can take place on much larger distance from its creation point than in the case of the pair motion in homogeneous infinite medium. The obtained results are applied for calculation of the ratio of the pair energy losses in two plates situated on different distances from the solid which corresponds to situation at which the Chudakov effect was firstly investigated on accelerator-based beam [2]. It is demonstrated that due to transition radiation which appears during the pair emission from the solid this ratio is noticeably different from the case when the radiation is neglected.

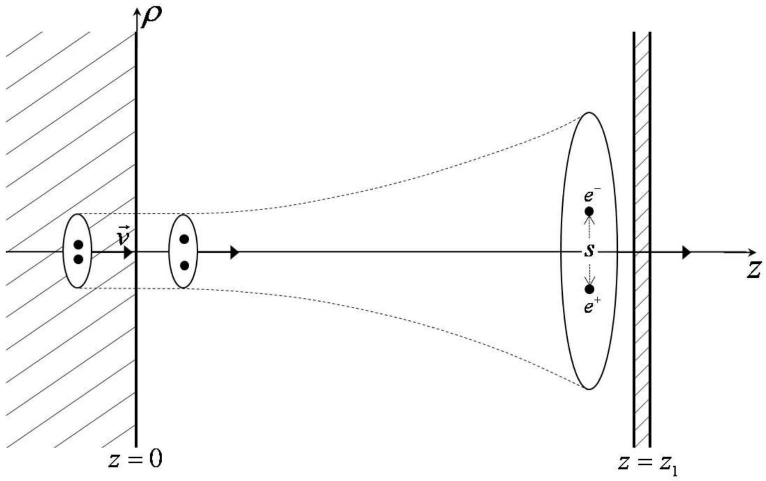

Figure 1. Traversal of thin plate by the pair emitted from substance.

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Influence of Grains Size on Coherent Pair Production Process in Mosaic Crystals

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It is known, see, for example, [1], that coherent bremsstrahlung (CB) intensity in a thin crystal is suppressed when the crystal thickness will be less than coherence length $l_c \sim \gamma^2\lambda$, where λ is photon wave length. This effect is similar to the LPM effect and the so called Ter-Mikaelian suppression of soft component of high energy electron bremsstrahlung in condensed media. The same effect should be observed in a mosaic crystal if the grain size becomes less than a coherence length. This effect was not observed experimentally because in a typical situation for CB generation the coherence length is less then some microns while the grains size is as usual by far larger than this value. Moreover influence of this effect is bordered by channeling effect and coherent scattering of electrons near crystallographic axis or planes because it takes place only for relatively small photon energy and axis or planes misalignments angle [2]. In the experimental works devoted coherent pair production investigation in mosaic crystals of pyrolytic graphite [3], [4]with grain size 1-5 micron [5] the experimental results were about 10% less the theory prediction without grains size taking account. For checking of the analyzed effect manifestation in the works cited simulation of coherent pair production process in mosaic crystals taking into account block size bordering is carried out. The contribution of the analyzed effect in the experimental results cited is discussed.

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Workshop *on THz Radiation Generation*

Zemax Simulations of Diffraction and Transition Radiation

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Diffraction Radiation (DR) and Transition Radiation (TR) are produced when a relativistic charged particle moves in the vicinity of a medium or through a medium respectively. The target atoms are polarised by the electric field of the charged particle, which then oscillate thus emitting radiation with a very broad spectrum. The spatial-spectral properties of DR/TR are sensitive to various electron beam parameters. Several projects aim to measure the transverse (vertical) beam size using DR or TR. This paper reports on how numerical simulations using Zemax can be used to study such a system.

Optical system design is no longer a skill reserved for a few professionals. With readily available commercial optical design software, these tools are accessible to the general optical engineering community. The Zemax Optical Design Program is such a comprehensive software tool. It integrates all the features required to conceptualise, design, optimise, analyse and tolerance virtually any optical system. It is widely used in the optics industry as a standard design tool.

Geometrical ray tracing is an incomplete description of light propagation. Strictly speaking, the propagation of light is a coherent process. As a wavefront travels through free space or optical medium, the wavefront coherently interferes with itself. Modelling this coherent propagation comprises the domain of physical optics. Physical Optics Propagation (POP) is the capability of Zemax which uses diffraction calculations to propagate a wavefront through an optical system surface by surface. The coherent nature of light is fully accounted for by this capability. When using POP, the wavefront is modelled using an array of points. Each point in the array stores complex amplitude information about the beam. The array is user-definable in terms of its dimension, sampling and aspect ratio.

To propagate the beam from one surface to another, either a Fresnel diffraction propagation or an angular spectrum propagation algorithm is used. Zemax automatically chooses the algorithm that yields the highest numerical accuracy. The diffraction propagation algorithms yield correct results for any propagation distance, for any arbitrary beam and can account for any surface aperture, including user defined apertures. When the wavefront reaches an optical surface (e.g. a lens), it is decomposed into rays in order to simulate aberrations and diffraction coming out through the lens, then rays are recomposed into wavefront at the exit of the lens; therefore both, aberrations and diffraction through optical lines, are simulated.

In POP mode, a custom electric field source provided in a C file and compiled as a DLL can be used as an input to Zemax. In this way, the simulation of any source of light is possible (e.g. OTR, ODR, SR)

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Metamaterials on the Basis of Opal Matrixes - Perspective Materials of Radio Electronics of Ultrahigh Frequencies

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Electromagnetic properties 3D-nanocomposites on the basis of the opal matrixes containing particles of one or two transitive metals are investigated. The phase analysis of nanocomposites is carried out. Microwave measurements are executed in a frequency interval 26-38 GHz. Field dependences of factors of passage and reflexion are received. Spectra of a magnetic resonance and an antiresonance are restored. Frequency dependences of amplitude of a resonance and an antiresonance are received. It is established, that in nanocomposites, two transitive metals containing particle, amplitude of a magnetic resonance much more, than in nanocomposite, containing particles of one metal.

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Electromagnetic Field of Charged Particle Bunches Moving in Gyrotropic Media

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In this report, we deal with electromagnetic field generated by uniformly moving charged bunches in gyrotropic media. The main attention is given to the case of an isotropic gyrotropic medium. Such media frequently referred to as chiral or optical active media have been known from the early 1811 [1] and have since been analyzed in many aspects in many papers (see, for example, [2, 3, 4] and references therein). Essential interest to these media is mainly connected with possible applications of artificial chiral materials in different practical areas (see, for example, [5]). The Vavilov-Cherenkov radiation in chiral media has partially investigated in a series of papers [6, 7], but the total field produced by a moving charge in chiral media with frequency dispersion has not been analyzed in detail.

Here we use the Condon dispersion model [2] and analyze in detail the integral representations for field components for the case of weak chirality and ultrarelativistic motion. We develop an effective algorithm for field computation and give representative examples of field behavior. We show that the field of a moving charge contains two low-frequency wave processes with right- and left-hand circular polarizations and a high-frequency wave process with a right-hand polarization. Of most interest is the high-frequency wave arising at an ultra-high velocity and being essential near the plane of charge dislocation for a sufficiently large offset from the trajectory. This wave field oscillates at a frequency that is considerably greater (up to 1-2 orders) than the resonant frequency of the medium. Intriguingly, both of these phenomena exist in the domain in front of the charge, thus producing the low- and high-frequency wave forerunners.

Another case of gyrotropic medium which is briefly discussed in this report, is a cold electron plasma with constant external magnetic field directed along the charge trajectory [8]. Here the external magnetic field, along with gyrotropy, causes an anisotropy of the medium. This problem is particularly relevant in the context of the plasma wakefield acceleration technique [9]. For the case of ultrarelativistic motion, we obtain the approximate formulas for the field of a point charge which predict, in particular, the singular behavior (of the longitudinal components of both electric and magnetic field as well as the transversal electric field) over transversal coordinate near the trajectory. Using formulas for the point charge field as Green function, we develop an effective algorithm for calculation of the bunch wakefield and give a series of representative examples.

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Simulation of Transition Radiation from a Flat Target using CST Particle Studio

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In accelerator physics research various target geometries such as screens and gratings are used for beam diagnostics [1, 2]. Most of these target geometries have well developed analytical models which describe the characteristics of radiations such as Transition, Diffraction and Smith Purcell radiation [3]. However, these models are usually idealised and not always suitable for comparison with experimental data. Advanced electromagnetic simulations provide an opportunity to perform simulations describing a real experiment in a more efficient manner.

Computer Simulation Technology (CST) Particle Studio (PS) is a specialist tool for the fast and accurate analysis of charged particle dynamics in 3D electromagnetic fields [4]. The time domain particle-in-cell (PIC) solver of PS can perform a fully consistent simulation of particles and electromagnetic fields. It is based on the Finite Integration Method which adopts a self-consistent algorithm combining the full Maxwells equations along with the classical and relativistic equations of motion. The code is equipped with a variety of advanced techniques such as approximation of the far-fields [5].

In this report we present initial simulations of Transition Radiation / Diffraction Radiation originating from a at target positioned at 45 degrees with respect to the beam propagation direction. The simulations which are performed for a millimeter wavelength range and a relativistic beam of electrons are compared with the theoretical investigations in the wave and the pre-wave zones [6, 7]. The beam size and target size effects are discussed; the simulation results for a metallic and dielectric target are shown.

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Features of Coherent Edge Radiation Angular Distribution

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The THz coherent edge radiation was investigated in Brookhaven National Laboratory [1] and in Karlsruhe Institute of Technology [2]. However only spectral and polarization properties of radiation were investigated. In this report we present the theoretical and experimental investigation of features of a coherent edge radiation angular distribution in millimeter wavelength region from a short magnet like for instance a steering magnet. It was shown that the coherent edge radiation angular distribution might differ significant from the incoherent one. The correct taking into account the electron bunch form-factor may explain this difference.

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On THz Radiation from Dielectric Tube

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Cherenkov and Smith-Purcell radiation may serve as a good sourses of THz radiation [1-3]. Radiation based on the Cerenkov mechanism arising when particles pass through dielectric tube with the constant radius. In case of variable radius the resulting radiation is based both on the mechanisms of Cerenkov and Smith-Purcell. In our previous work we showed for one electron that using waveguide with periodic radius can give more intensive radiation then waveguide with constant radius [4].

In this work we consider a bunch of electrons moving through dielectric tube with periodic radii. The spectral distributions for the both types of waveguide have been obtained and compared. We also considered different cases of dependences between radii of two waveguides. The radiation from waveguide with periodic radii is compared with Smith-Purcell radiation from flat and inclined gratings.

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Coherent Radiation Spectrum Measurements at LUCX Facility

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In the last decade electromagnetic radiation in the terahertz frequency domain has started playing a key role in different applications ranging from biomedical science to quality control and national security. Recent advances in these studies have encouraged an interest in investigation and development of THz radiation generation methods. One of the research directions in THz science and technology is to generate short and high-brightness THz-frequency coherent radiation pulses using ultra-short electron bunches in a compact accelerator. The intensity of this radiation is proportional to the square of the beam current. For a stable THz emission one should consider generation of electron bunches with the duration smaller than 100 fs (about 30 μm) and the intensity stability of <1% rms. One possibility to obtain such short electron bunches is to illuminate a cathode of an RF-Gun with a femtosecond laser pulse. In this case a well-established on-line diagnostics and control of both the laser and the electron beams are needed. Recent progress in laser technology and ultra-short laser pulse diagnostics gives promising results whereas reliable methods for determination of femtosecond electron bunches still have to be developed. A streak camera can provide about 300 fs resolution which is not applicable in our case. On the other hand deflecting cavity can give required resolution but it makes an inadmissible problem for a "table-top" accelerator based THz source design since the change related to accelerator high power RF distribution system and a significant beamline space allocation are required for the installation.

Another promising technique for longitudinal bunch shape reconstruction is based on the coherent radiation spectral density distribution measurement. Unfortunately this method is likely to have some restrictions and limitations which should be considered in detail to push forward a progress in this direction.

As a potential candidate for spectrometry of the intense broadband radiation in THz and sub-THz frequency range and for bunch shape reconstruction the Michelson interferometer was constructed as a part of a larger THz program launched at KEK: LUCX (Linac Undulator Compton X-ray source) facility. The program aims to investigate various mechanisms for generating EM radiation including stimulated coherent diffraction radiation, undulator radiation, Smith-Purcell radiation and other types of polarization radiation.

In this report we present the detailed design, alignment and initial test of a Michelson interferometer. The first coherent transition radiation spectrum measurement results and ultra-fast broadband room-temperature Schottky barrier diode detector performance are presented. The principles of longitudinal bunch shape reconstruction and future plans are discussed.

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Feasibility of Double Diffraction Radiation Target Interferometry for Compact Linear Accelerator Micro-train Bunch Spacing Diagnostics

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Nowadays there are a few ways to generate intense beams of THz radiation: optically pumped terahertz lasers, photomixing of near-IR lasers, backward-wave oscillators, direct multiplied sources and nonlinear optical processes occurring when an intense laser beam interacts with a material. Another promising candidate is to generate short, high-brightness THz-frequency coherent radiation pulses using a micro-train electron beam (THz sequence of a several fs-length electron bunches) of a compact accelerator. In this case, development of a robust and non-invasive micro-train bunch spacing diagnostics obtains vast importance.

Recent progress in double diffraction radiation target (double DR target) interferometer development [1] gives an excellent basis for such diagnostics implementation. When bunched electron beam passes through the double DR target it emits coherent radiation with intensity being dependent on double target parts relative position (interferogram). This interferogram can be measured when one part of the target moves relative to another one along the beam trajectory.

The LUCX accelerator facility [2] expects to generate a few tens of MeV electron bunches with 100-300 fs duration and variable (0-10 ps) micro-bunch spacing. In this work the interaction between the double DR target and 2-5 micro-bunches per train beam was considered. The pseudophoton diffraction approach but not the far field approximation was used.

The simulation for two energies and bunch lengths corresponding to the beam parameters at the section after the LUCX RF gun and the accelerating section was performed. The obtained result demonstrates a clear dependence of simulated interferograms shape on the bunch spacing in the micro-train. Such a technique can be used for non-invasive determination of submicron bunch spacing.

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Backward Smith-Purcell Radiation

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Smith-Purcell Radiation (SPR) is the special case of Diffraction Radiation (DR). Both DR and SPR were studied experimentally and theoretically in details in the optical and X-Ray ranges in many works [1-5]. SPR and DR are used for noninvasive beam diagnostics.

In the present work the authors deal with SPR from the diffraction grating of N thin strips. The case of the oblique incidence of the single ultrarelativistic particle is considered. It is for the first time predicted that backward SPR exists, i.e. the radiation propagating in the direction of mirror reflection to the particle trajectory. SP dispersion relation is obtained by the polarization currents method [1]. It has the well-known form of Smith-Purcell dispersion relation in case of forward SPR [2]. Characteristics of backward SPR are discussed in optical, THz and X-Ray frequency ranges.

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